First Bulk and Surface Results for the ATLAS ITk Stereo Annulus Sensors

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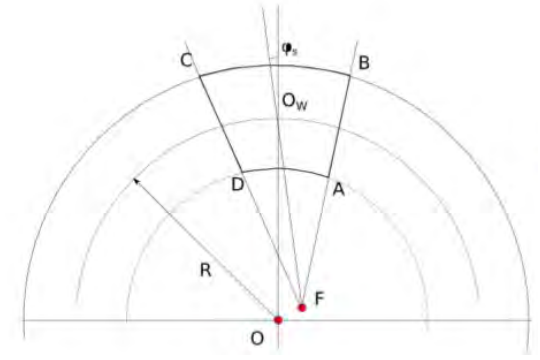
December 12th, 2017
Okinawa, Japan
11th International "Hiroshima" Symposium
On the Development and Application of Semiconductor Tracking Detectors

Outline



- Background

- Stereo Annulus Geometry and Its Advantages

- The R0 Prototype Sensor

See poster by Carlos Lacasta Llacer: "Design of the first full size ATLAS ITk Strip sensor for the endcap region"

- Bulk Sensor Characteristics
  - With comparison to conventionally shaped comparable sensor

See talk by Vladimir Cindro for irradiated bulk performance. Coming up next!

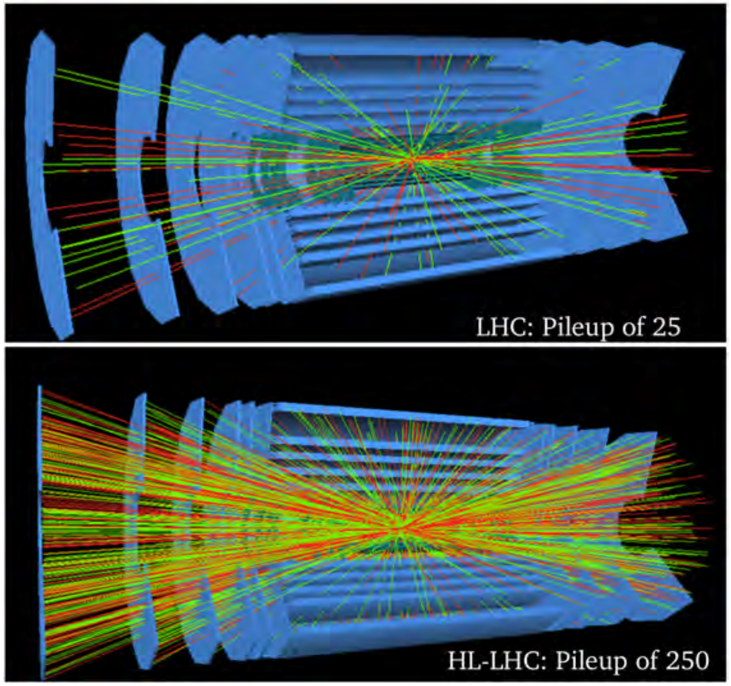
- Surface Property Investigation
  - With evaluation of irradiated performance

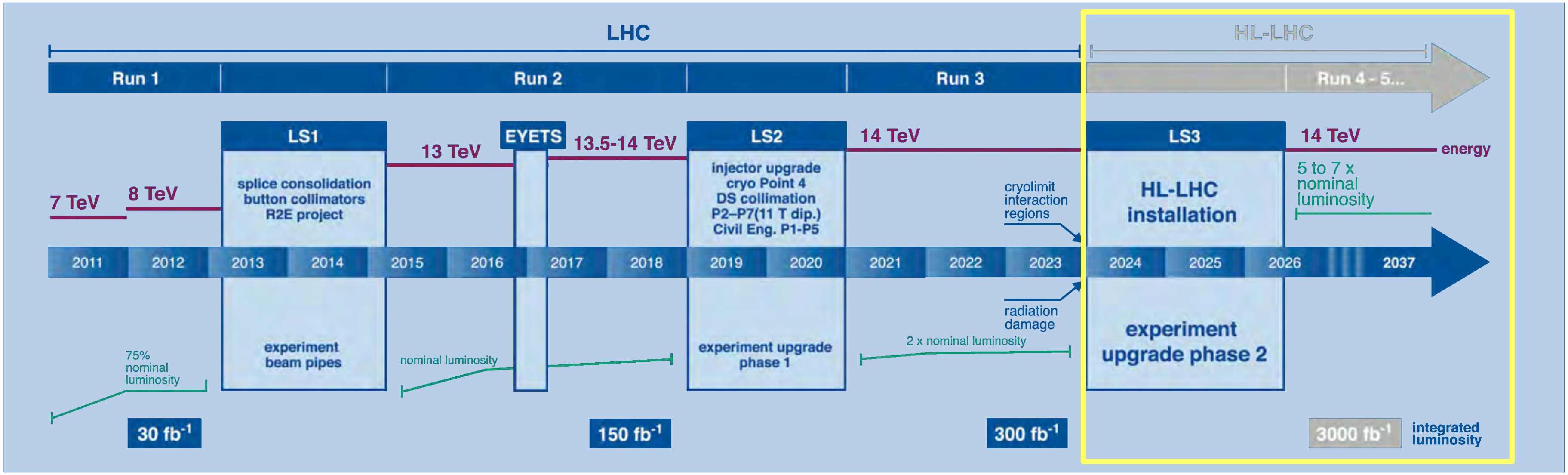
See also, R0 Prototype poster by Carlos Garcia Argos : "Assembly and Electrical Tests of the First Full-size Forward Module for the ATLAS ITk Strip Detector"

The HL-LHC and Challenges Faced

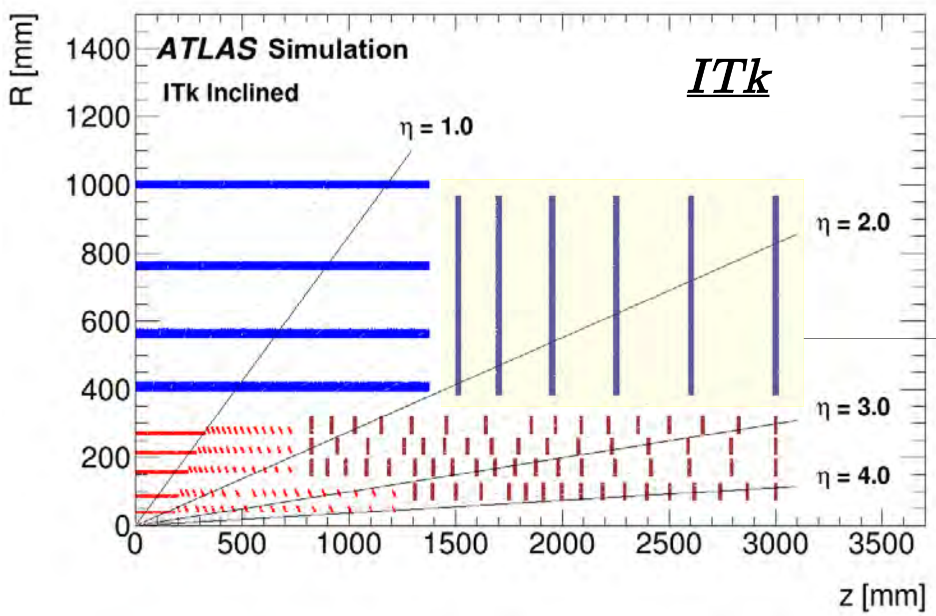
- 10x more premier p^+-p^+ data (3000fb^{-1})
  - ⇒ Higher sensitivity for LHC measurements
    - ⇒ A leading possibility to uncover new physics
- 500-750% increase in instantanous luminosity (levelled 5-7.5x10^{34} cm^{-2} s^{-1})
- 600%-850% increase in number of interactions per 25ns bunch crossing (levelled 140-200 vs. 23/40 avg/peak)
- 170% increase in projected lifetime (27yr vs 10yr)
- 10x more radiation damage (10^{16} n_{eqv}/cm^2 NIEL, 10^7 Gy TID)

⇒ High granularity, reliability, radiation hardness required from detector upgrades

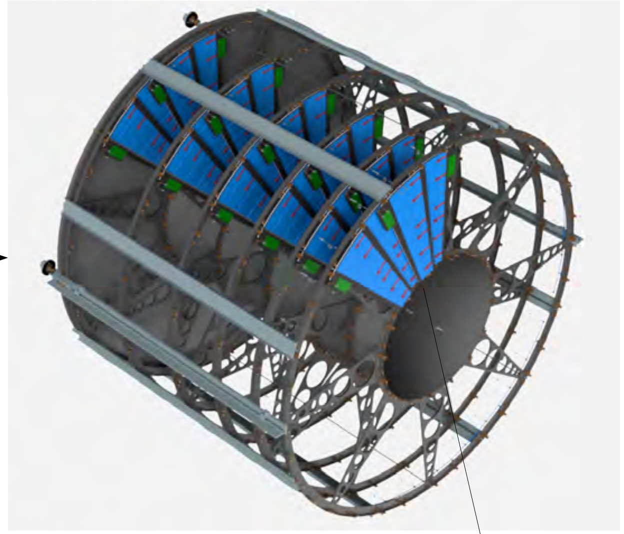


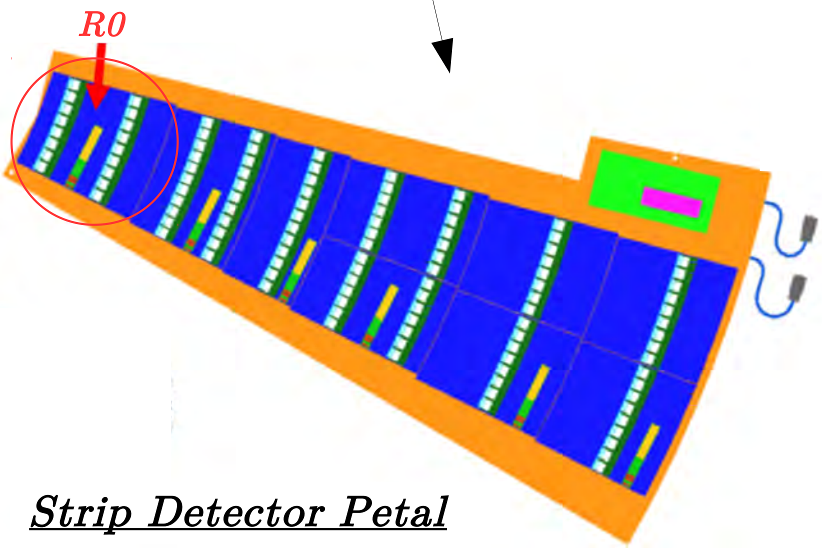


The ITk; Home of the First Stereo Annulus Sensor



Strip Detector Endcap

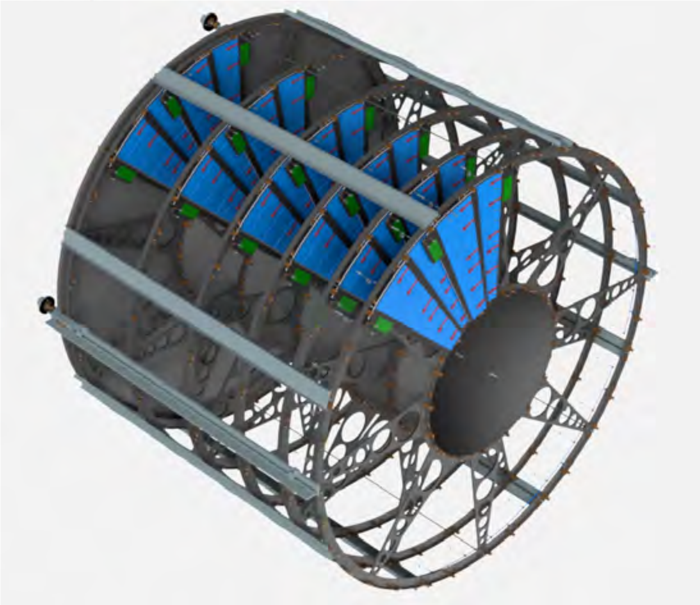




Strip Detector Petal

- *ITk*; all-silicon HL-LHC replacement of ATLAS ID utilizing pixels and strips
- *The Strip Detector*; ~165m² silicon surface area
- *Endcaps*; two each with six disks each with 32 petals
- *Petals*;
  - Double-sided (mirror image)
  - Nine sensors per side in six designs
    - All stereo annulus

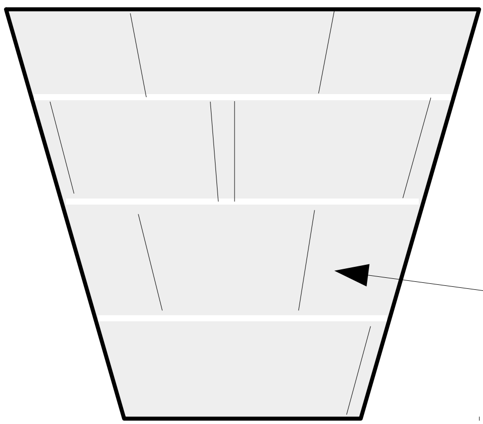
The Stereo Annulus Geometry



- What is the best way to do strip tracking in the restricted endcap geometry?
  - *Primary* dimension to measure is the azimuthal angle (bending dimension)
    - Use the most senstive feature ⇒ strips oriented radially
  - *Secondary* dimension is the radius from the beam-pipe
    - Add a small (20-40mrad) stereo angle to vastly improve resolution
  - (*Tertiary* dimension is the axial distance and is obtained from the disk location)

The Stereo Annulus Design; ‘Reinventing’ the Wheel

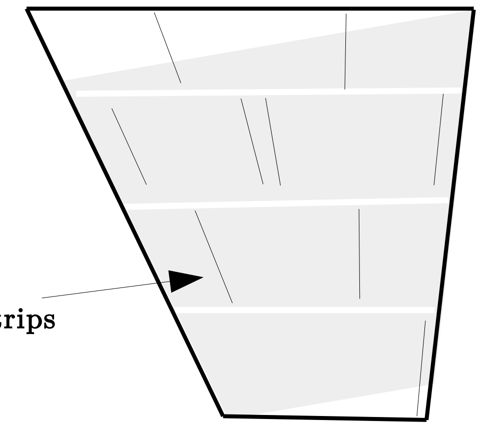
Conventional Geometry:
Symmetric Trapezoidal Wedge
(Sensor itself is rotated by stereo angle)



eg. ATLAS SCT

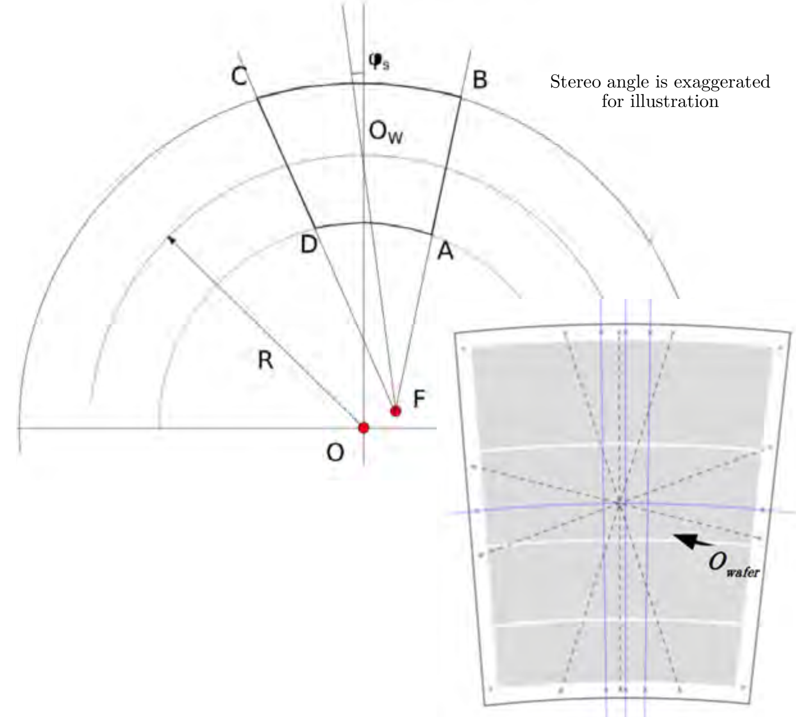
A couple strips drawn for illustration

Upgraded Geometry:
Stereo Trapezoidal Wedge



Stereo angle is Greatly exaggerated for illustration

Optimized Geometry:
Stereo Annulus



Stereo angle is exaggerated for illustration

eg. ATLAS ITk

Stereo strips in symmetric sensor?

- Truncated and orphaned strips

Disadvantages:

- Most difficult interlocking
- Space is limited on petals
- Incomplete coverage at large and small radii
- Uneven strip lengths

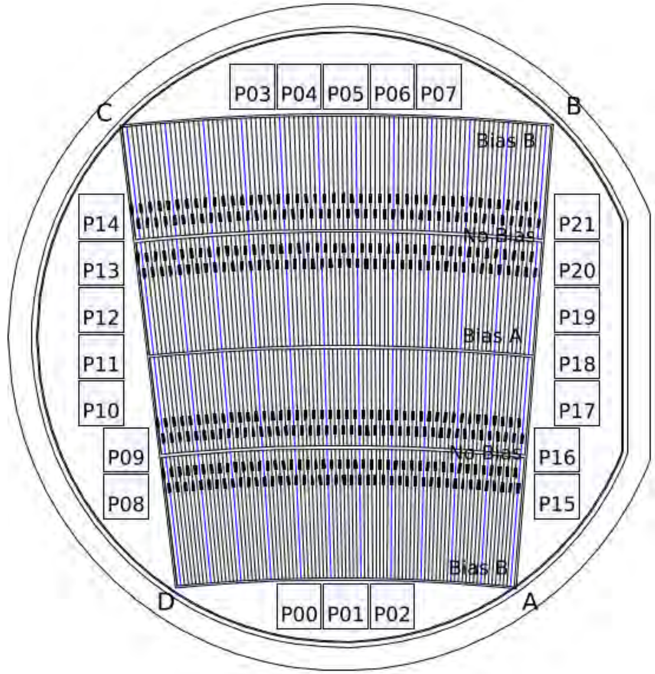
- Interlocking is more managable
- Incomplete coverage at large and small radii
- Uneven strip lengths

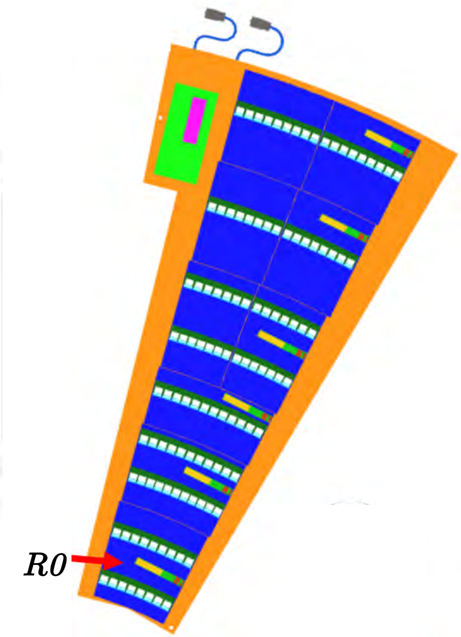
- Inexperience

The R0 Prototype Sensor

See poster by Carlos Lacasta Llacer: "Design of the first full size ATLAS ITk Strip sensor for the endcap region"

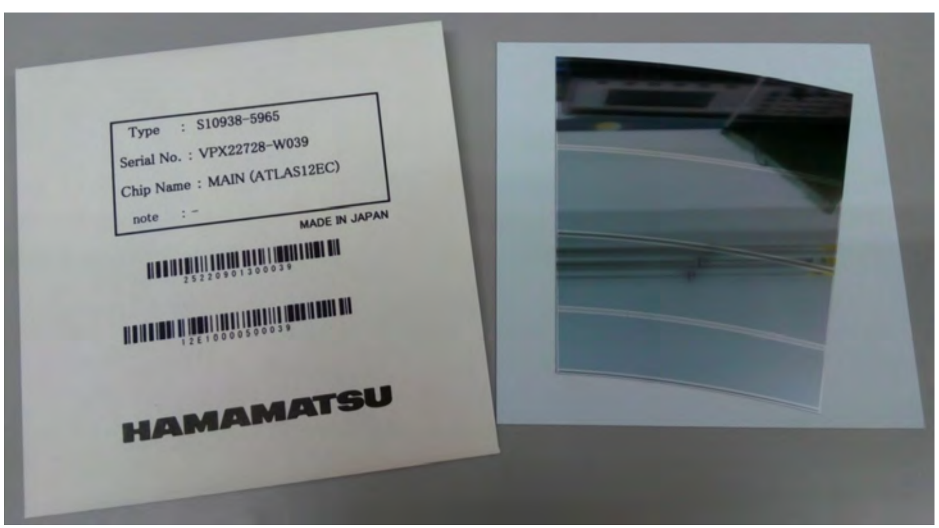
- Prototype of innermost endcap sensor ("the R0"): ***first stereo annulus sensor ever produced***
  - *Annular edges obtained with 16 flat cuts*
- *Large surface:* ***90.0 cm^2*** *bias ring area*
- n^+-in-p, ac-coupled, single-sided, 20 mrad stereo
- 6", FZ-grown, ~325 μm thick, <100> wafer
- Optimized common p-stops, gated PTP
- *Stealth diced slim edge width:* ***450-500 μm***
- SiO_2 and AlN:H passivation
- 4360 strips with constant angular pitch in each of the four segments
- *Hamamatsu Photonics*
- ***72 sensors delivered to ATLAS from two batches***





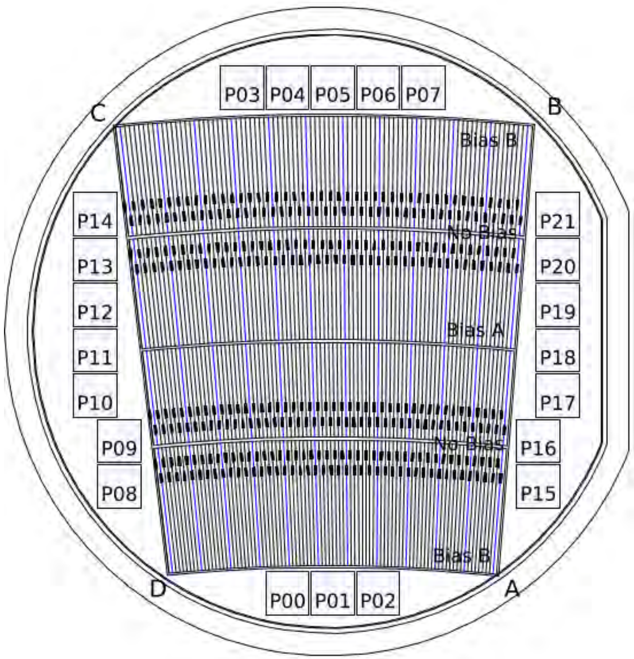
R0 Prototype Sensor Strip Specifications

Row	Length (mm)	I-pitch (μm)	O-pitch (μm)	Pitch (μrad)
0	18.981	74.314	77.983	193.2745
1	23.981	77.983	82.617	193.2745
2	28.981	73.454	78.434	171.8368
3	31.981	78.434	83.929	171.8368

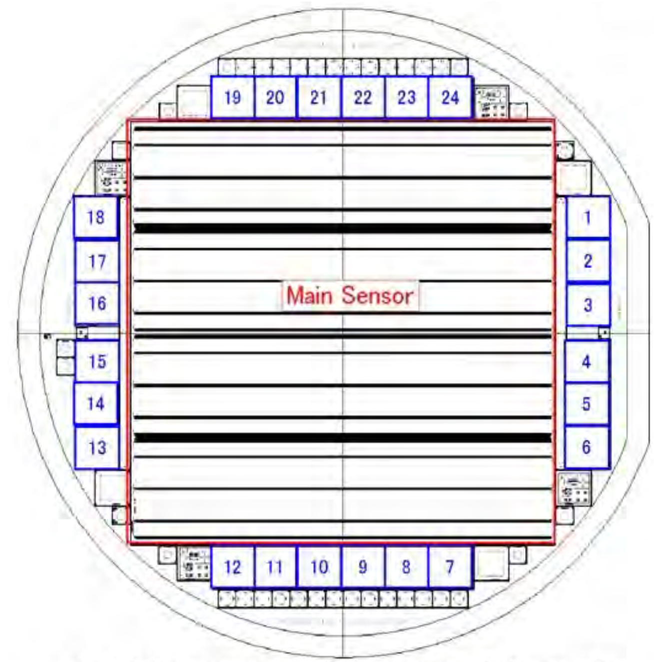


Bulk Character Comparison Samples

R0 Prototype (Stereo Annulus)



ATLAS12 (Conventional Barrel)



- Large surface area: (90.0cm^2,91.8cm^2)
- n^+-in-p, ac-coupled, single-sided
- 6”, FZ-grown, ~325 µm thick, <100> wafer
- Optimized common p-stops, gated PTP
- SiO_2 and AlN:H passivation
- Similar strip and contact pad numbers (4360,5128 strips in 4 segments)
- Hamamatsu Photonics

- Stereo annulus with constant angular pitch in each segment (73.5-83.9 µm) and variant length (19-32 mm)
- Slim edge width for 100% of sensors (450 µm annular edge, 500 µm stereo edge)
- ~60 sensors from 2 batches

- Square with parallel strips of constant pitch (74.5 µm) and length (23.9 mm)
- Slim edge width for 25% of sensors (450 µm with a standard 980 µm)
- ~120 sensors from 4 batches

L.B.A. Hommels *et al.*, *Nucl. Instr. Meth. Phys. Res. A*, vol. 831, pp. 167–173, 2016. (10th International “Hiroshima” Symposium)

See talks by Liv Wiik-Fuchs and Andy Blue for annealing and irradiated testbeam performance of ATLAS12. Coming up soon!

Surface Properties; Irradiated Samples

- 730 $(1cm)^2$ minis
  - ie. square with parallel strips
- 252 minis have already been irradiated up to *2.2×10^{15} n_{eqv}/cm^2* with protons and neutrons
- Minis have ~8 mm long strips and come with variant pitch, coupling, and punch through protection configurations

Narrow / Default / Wide pitch (μm): 70 / 75 / 85

(R0 Prototype pitches range from approximately 73-84μm)

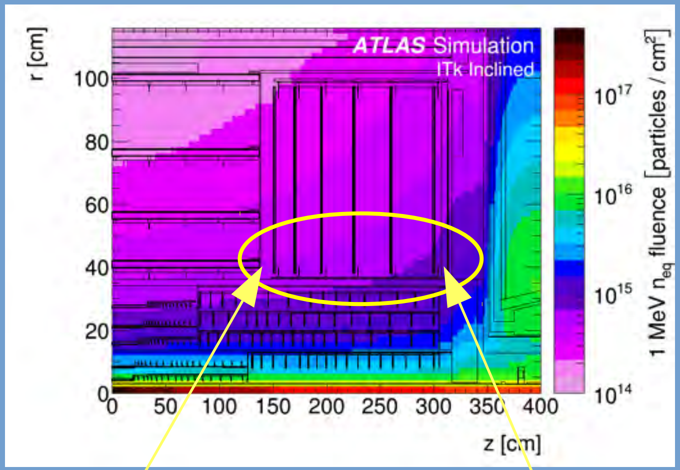
- *Today's results: AC-coupled, PTP minis from one mini test set irradiated with p^+ and annealed 80 minutes at 60°C*

A Mini Test Set:

Fluence unit: *$\times 10^{14}$ n_{eqv}/cm^2*

Pitch	Coupling	PTP	0x	5x	10x	20x	TOTAL
Default	AC	Yes	2	2	2	2	8
	DC	Yes	2	2	2	2	8
	DC	No	2	2	2	2	8
Narrow	AC	Yes	2	1	2	1	6
	DC	Yes		1	1	1	3
	DC	No		1	1	1	3
Wide	AC	Yes	2	1	2	1	6
	DC	Yes					0
	DC	No					0
Total			10	10	12	10	42

Radiation Projections for the R0 Sensor



NIEL Fluence: *3.8×10^{14} n_{eqv}/cm^2*
TID: 9.8 Mrad

NIEL Fluence: *1.2×10^{15} n_{eqv}/cm^2*
TID: 50.4 Mrad

$4500fb^{-1}$ (1.5 safety factor)

The ATLAS Collaboration, "ATLAS Inner Tracker Strip Detector: Technical Design Report," *CERN Tech. Rep. ATL-TDR-025 / LHCC-2017-005*, 2017.

Three mini test sets are *each* irradiated with:

n
reactor neutrons
Ljubljana Reactor
Jožef Stefan Institute, Slovenia

p^+
70MeV protons
CYRIC
Tohoku University, Japan

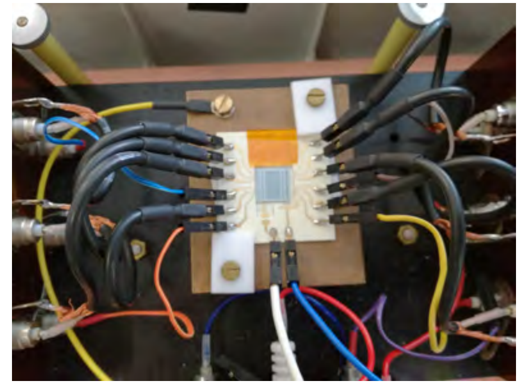
See talk by Vladimir Cindro for irradiated bulk performance including n irradiation. Coming up next!

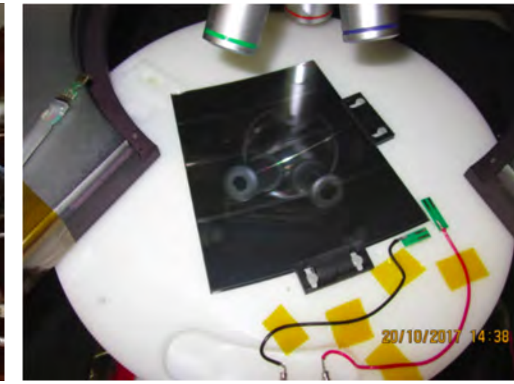
Test Setups

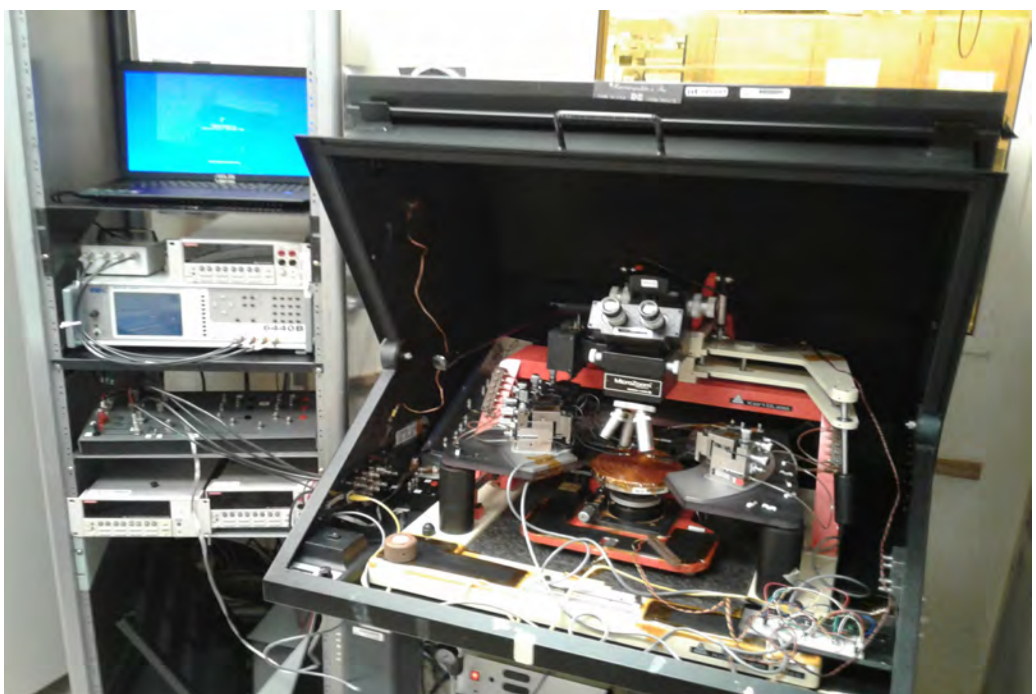
- Tests conducted in probestation or with sensor wirebonded into custom jigs
- Clean environment, dry storage
- Irradiated devices tested cold (in freezer or with a cooled chuck)

Unirradiated Devices +20°C to +30°C

Irradiated Devices -20°C to -30°C







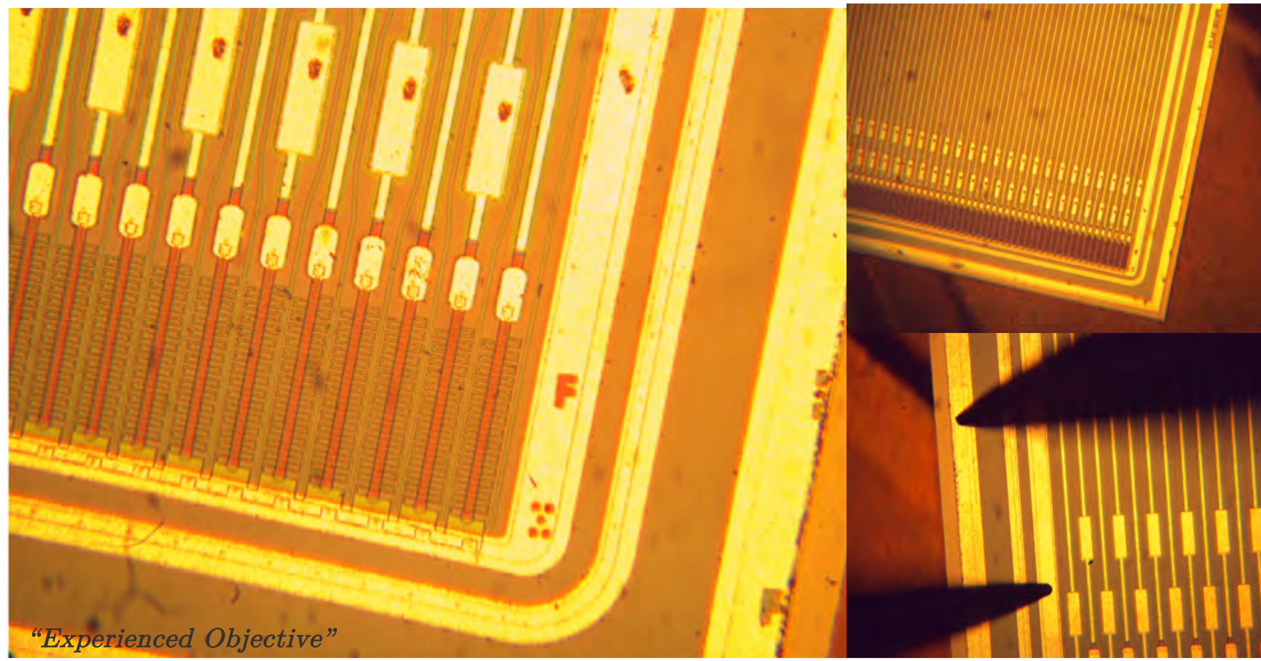
R0 Prototype Test Institutes

FZÚ
Carleton University
Uni Freiburg
Humboldt-Universität zu Berlin
CNM
technische universität dortmund
DESY
Universitat de València
CSIC
IFIC Institut de Física Corpuscular
Excelencia Severo Ochoa
Jožef Stefan Institute
筑波大学 University of Tsukuba
University of Cambridge
University of Toronto

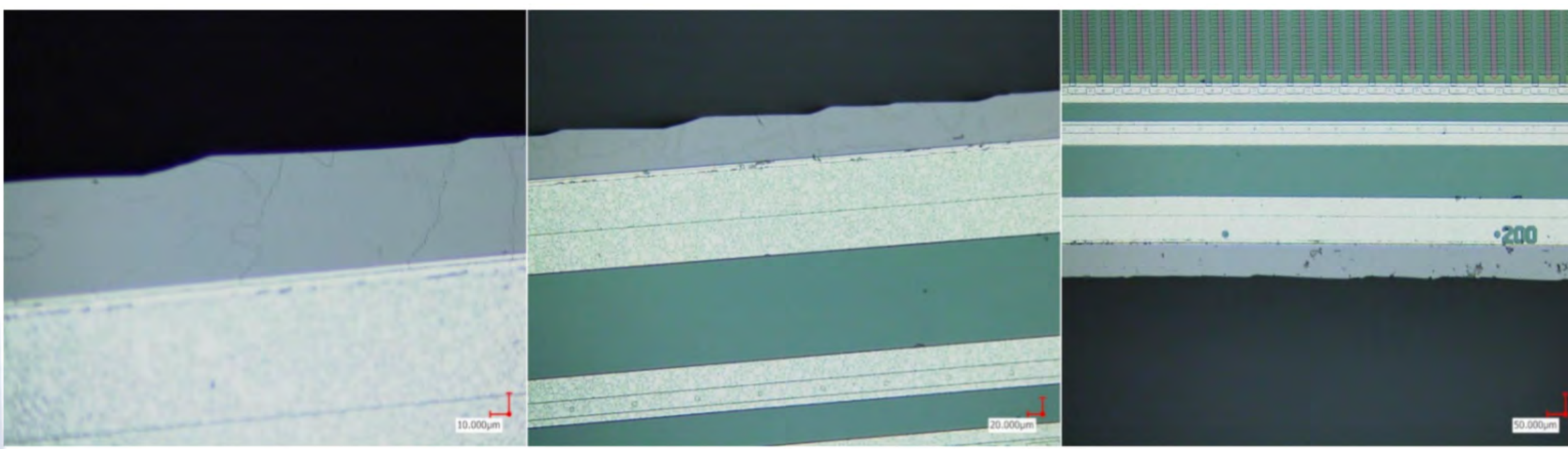
Visual Inspection

- Sensors in good condition
- Observed ~10 μm meander on annular edge flats correlated with crystal orientation

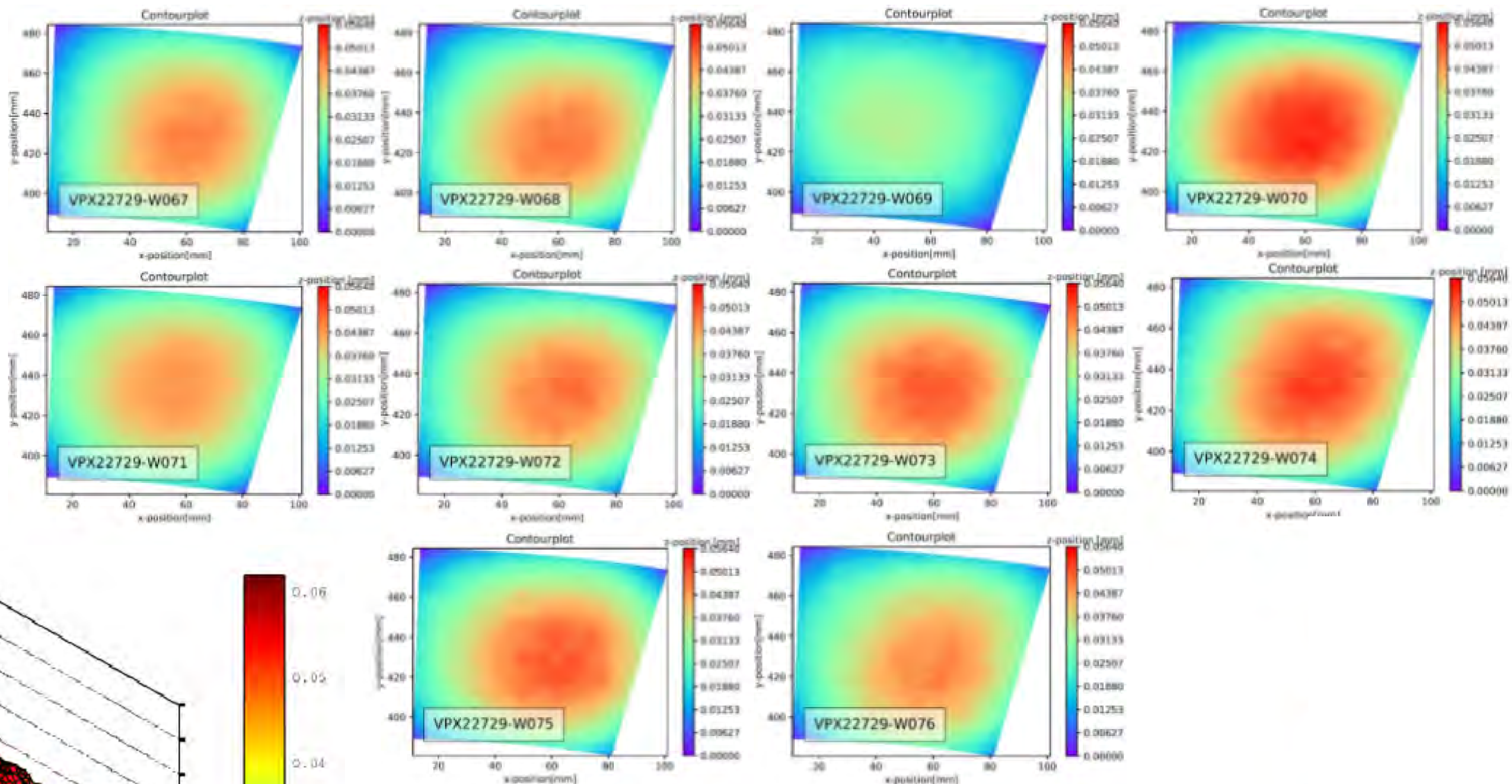
Specification: Devoid of chips or cracks extending 50 μm inward

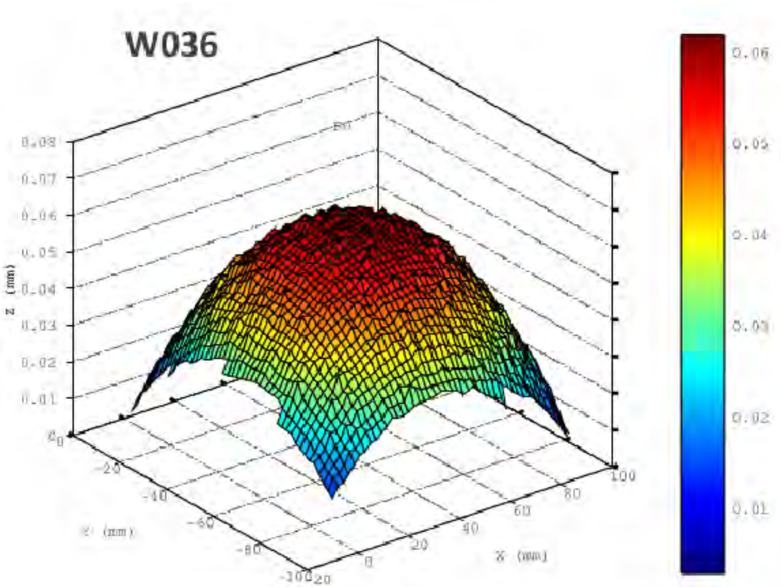


"Experienced Objective"



Metrology; Sensor Bow



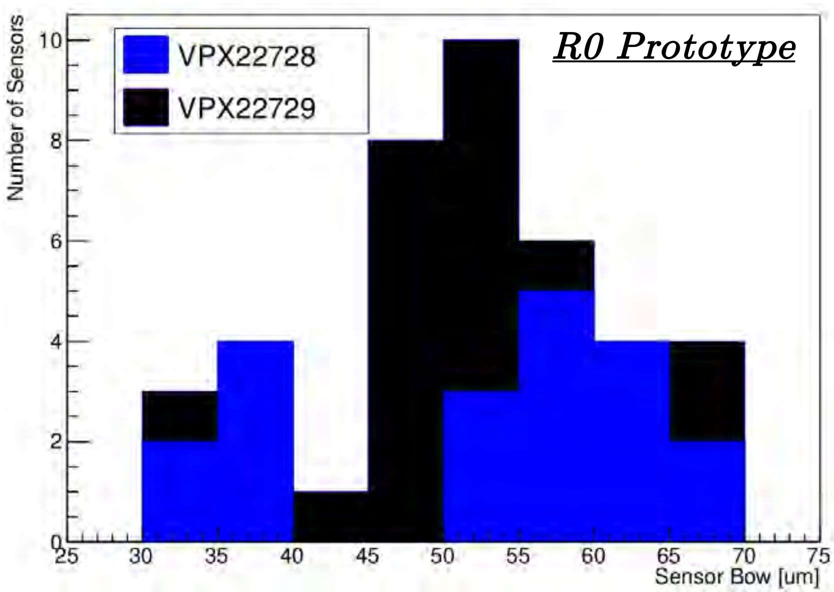


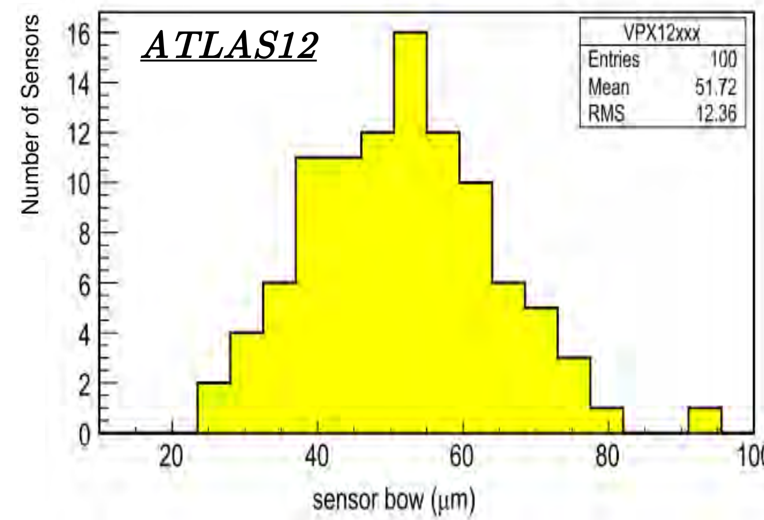
- Considerations for stresses in assembled components restricts the sensor bow

- Sensors had typical dome-like bow profiles well within specification

Specification: < 200μm

Metrology; Sensor Bow





	*Sensor Bow (μm) **	*Number of Sensors (Batches) in Sample*
ATLAS12	*51.72 ± 12.36*	*100 (4)*
R0 Prototype	***51.18 ± 9.30***	***40 (2)***

Specification: < 200μm

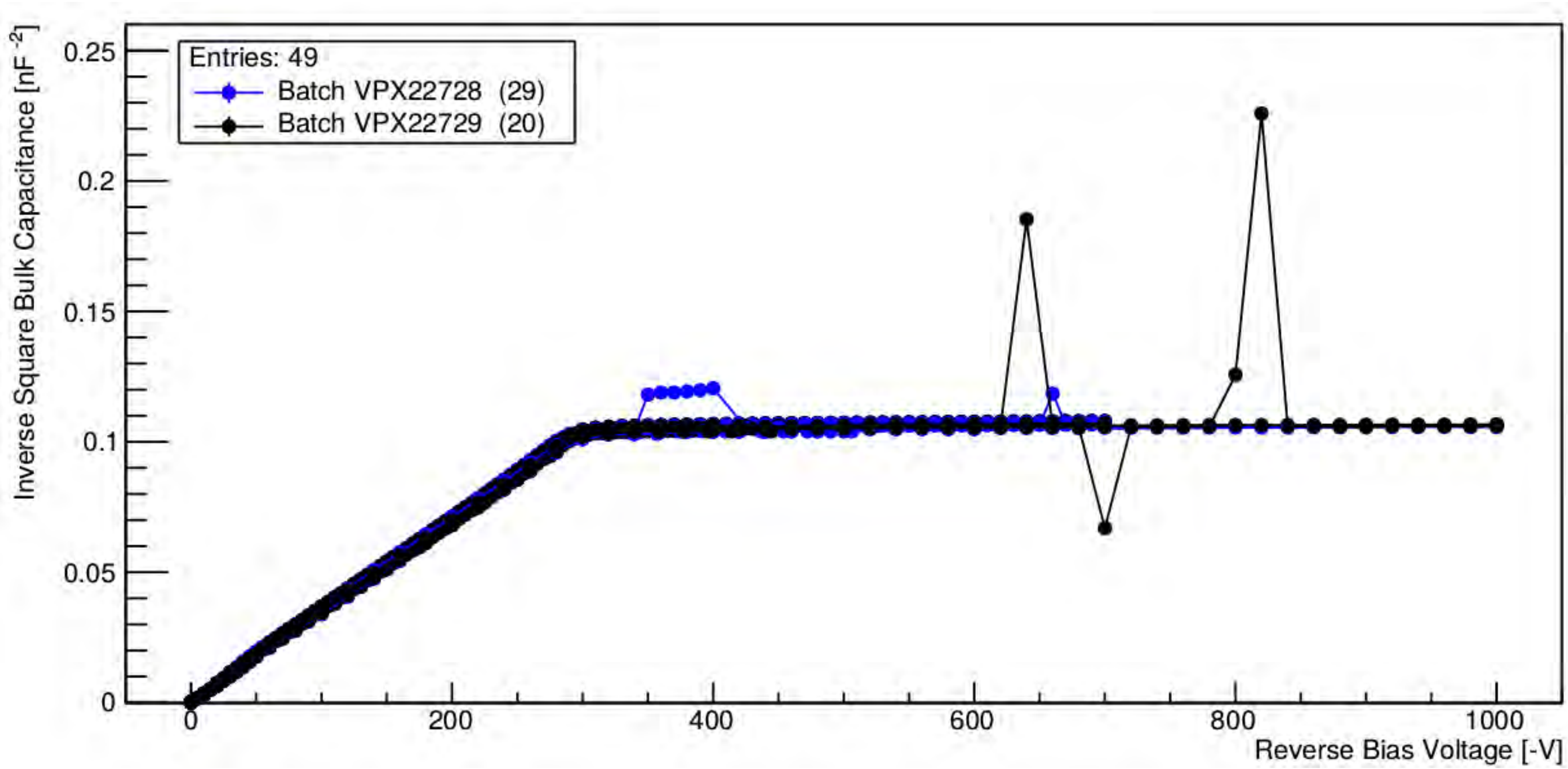
*RMSE against a Gaussian (Default in following tables)

- High consistency across all 40 samples measured
- Well within specification
- Thickness also within specification

Thickness: ~ **320-325 μm**
Specification: 310 ± 25 μm

Depletion Capacitance

- Low full depletion voltage (high resistivity) is especially desired due to the high fluence expectations
- High active depth to full thickness ratio is desired to maximize charge collection

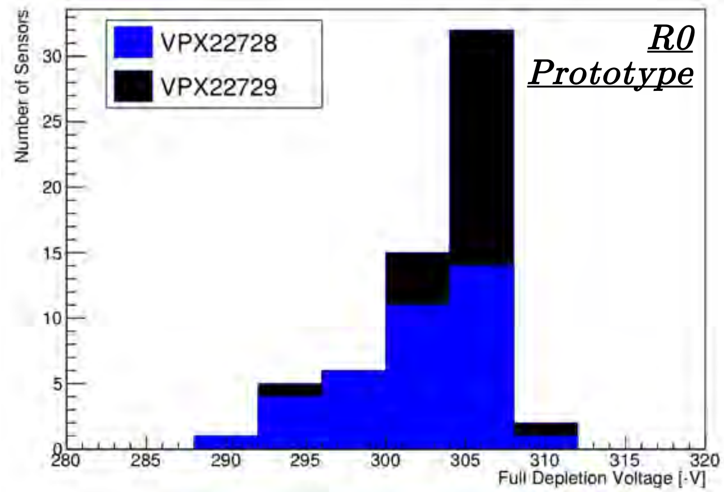


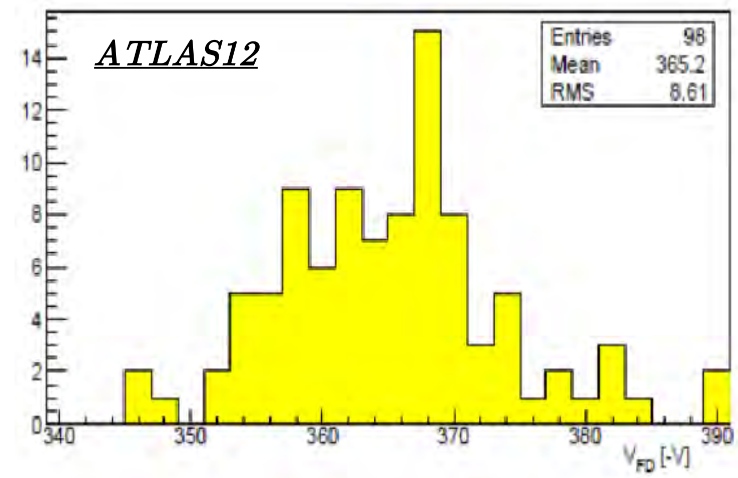
- Excellent consistency in full depletion voltage
- High active depth proportion inferred from active area and depleted capacitance

Depletion Capacitance

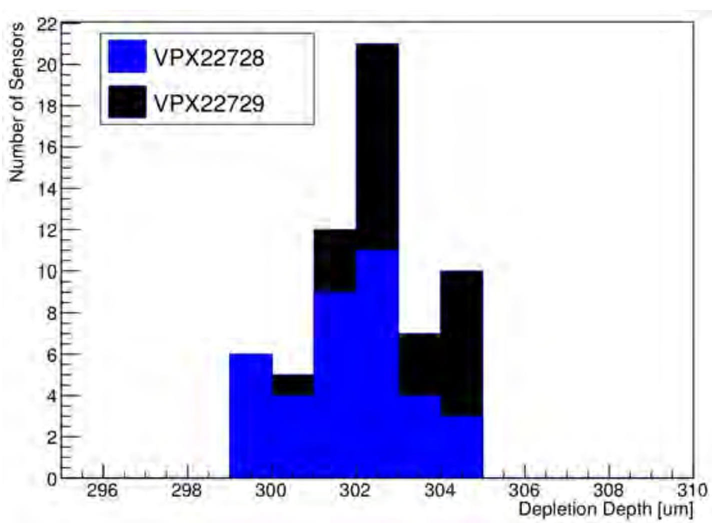
- High consistency in full depletion voltage
- **93%** of full thickness active depths (**$302.3 \pm 1.4\ \mu m$**)
- Resistivity meets specification

Full Depletion Voltage





Active Depletion Depth



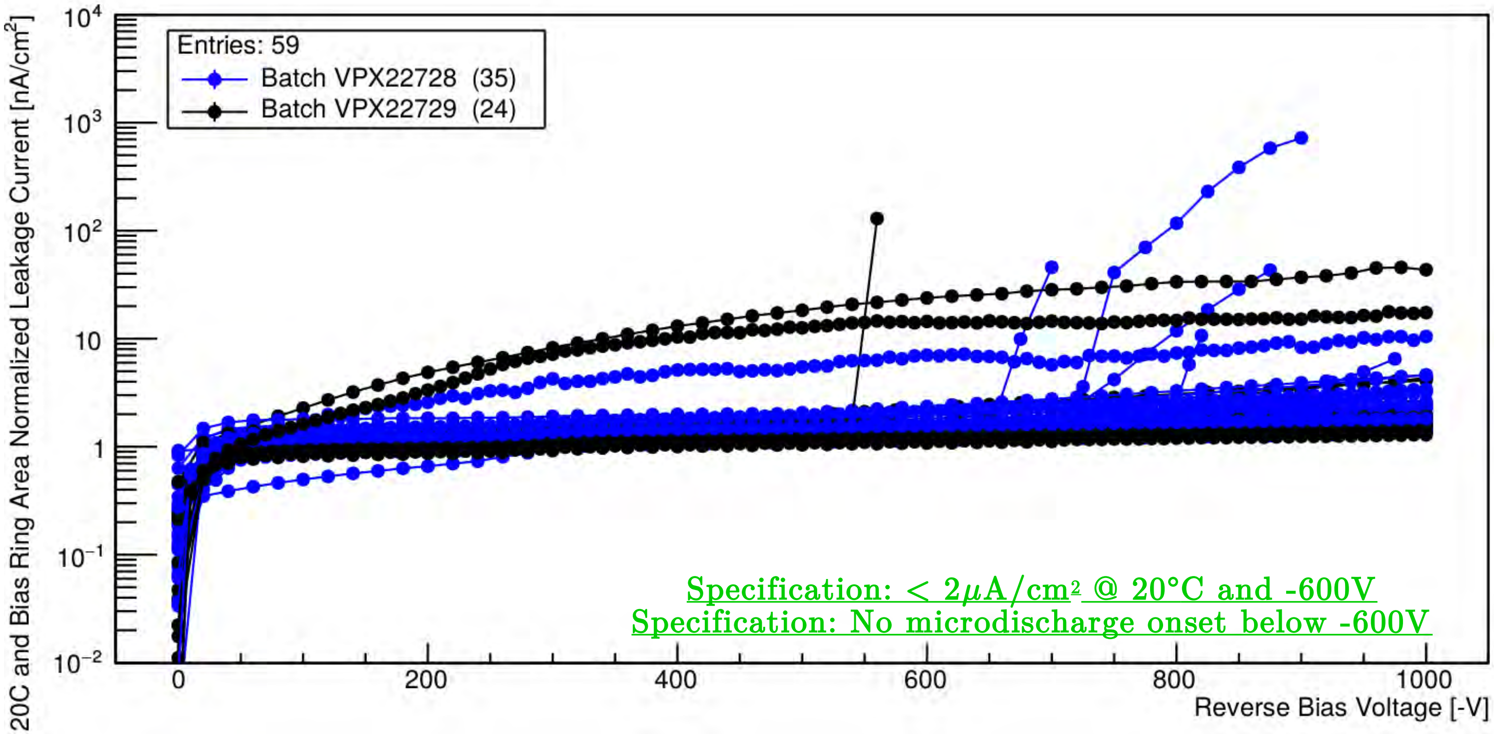
	Full Depletion Voltage [-V]	*Resistivity (kΩ cm)*	*Number of Sensors (Batches) in Sample*
ATLAS12	*365.2 ± 8.61*	*~2.5*	*98 (4)*
R0 Prototype	***303.04 ± 4.17***	***3.24***	***58 (2)***

Calculated resistivity: **3.24 ± 0.03 kΩ cm**

Specification: >= 3 kΩ cm

Leakage Current – IV Curve

- Sensors must have low leakage current to maintain a feasible power budget at end-of-lifetime
- For reliability sensors must be stable up to the voltage of -600V

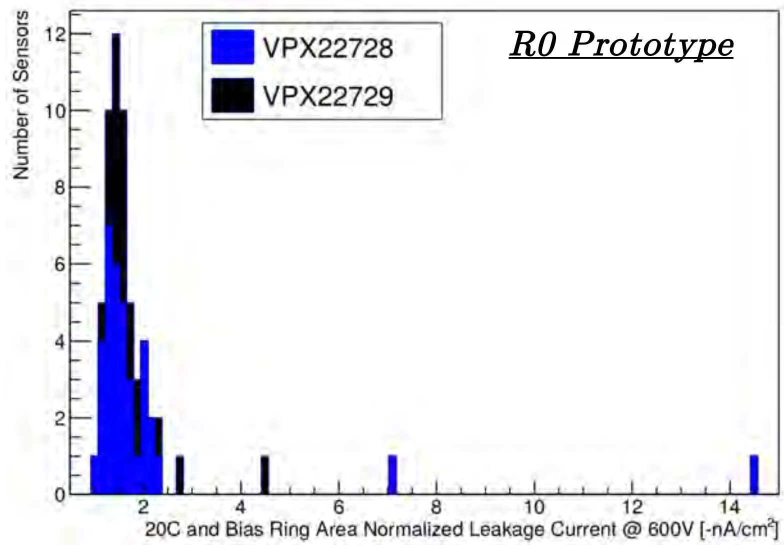


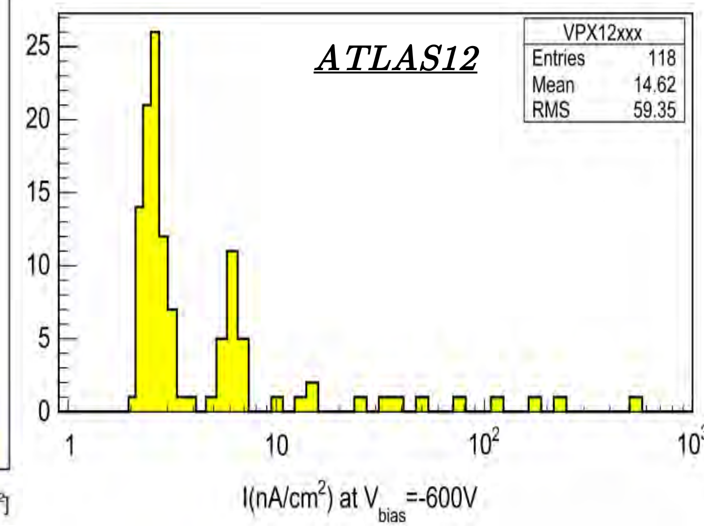
- Orders of magnitude sufficient leakage current obtained
- Levels of instability are very reasonable

Leakage Current – IV Curve

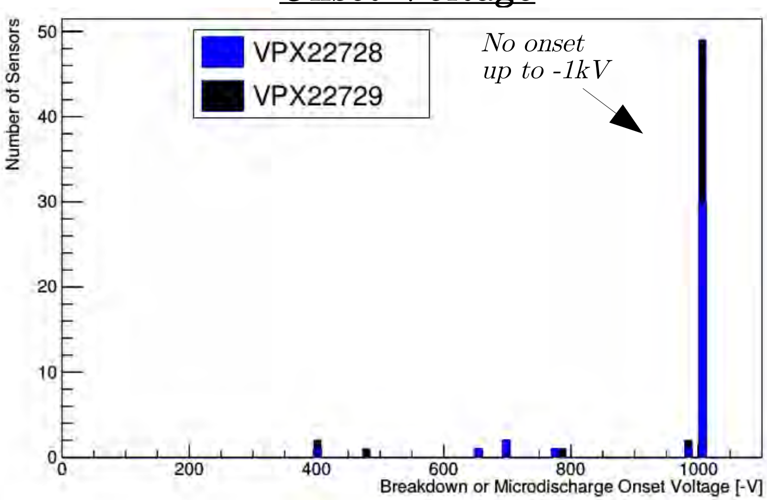
- Vast majority of sensors show very low leakage current [O(1nA/cm²)]
- Orders of magnitude within specification
- Lower level of leakage instability than the conventional sensor shape (ATLAS12)
- Instability attributed to passivation

20°C and Bias Ring Area Normalized Leakage Current at -600V





Breakdown or Microdischarge Onset Voltage



	20°C Leakage Current at -600V [-nA/cm²]	Percentage of Sensors with Increased Leakage below -600V (-1kV)	Number of Sensors (Batches) in Sample
ATLAS12	14.62 ± 59.35	14 (28)	118 (4)
R0 Prototype	1.95 ± 1.87	7 (15)	59 (2)

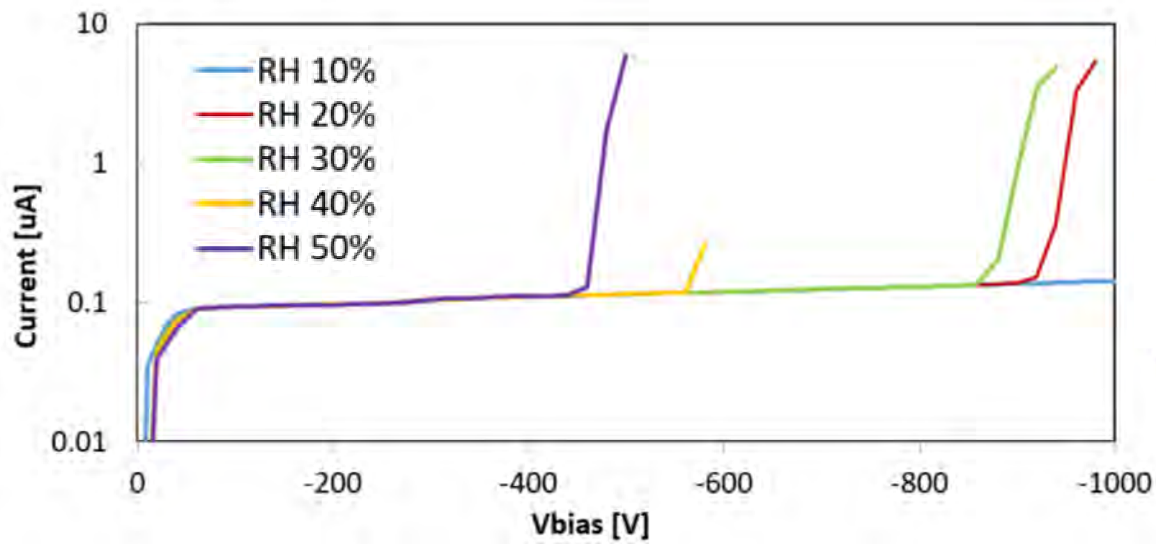
Specification: < 2μA/cm² @ 20°C and -600V
Specification: No microdischarge onset below -600V

Microdischarge Humidity Dependence

- Sensors with early microdischarge onset show a humidity dependency in the onset voltage

  → Lower humidity, higher microdischarge onset voltages

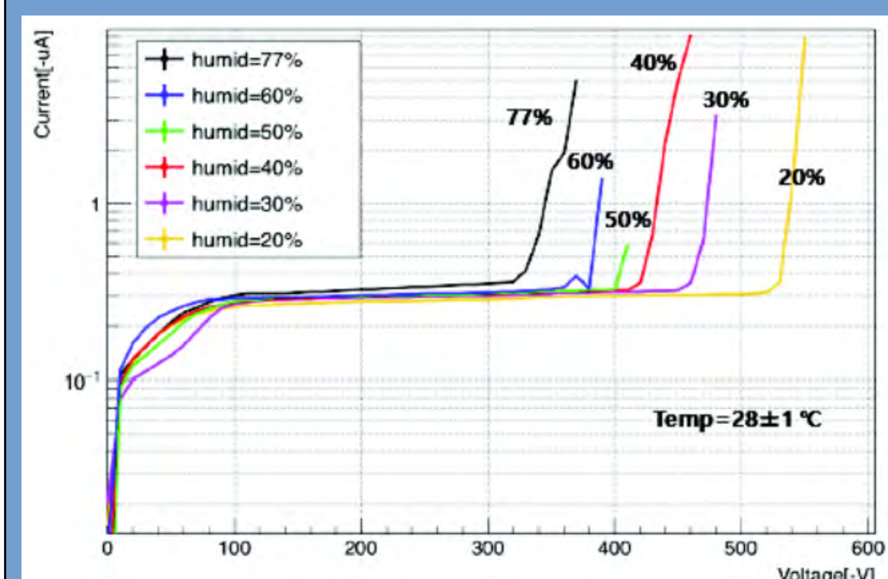
- Similar observations for previous generations

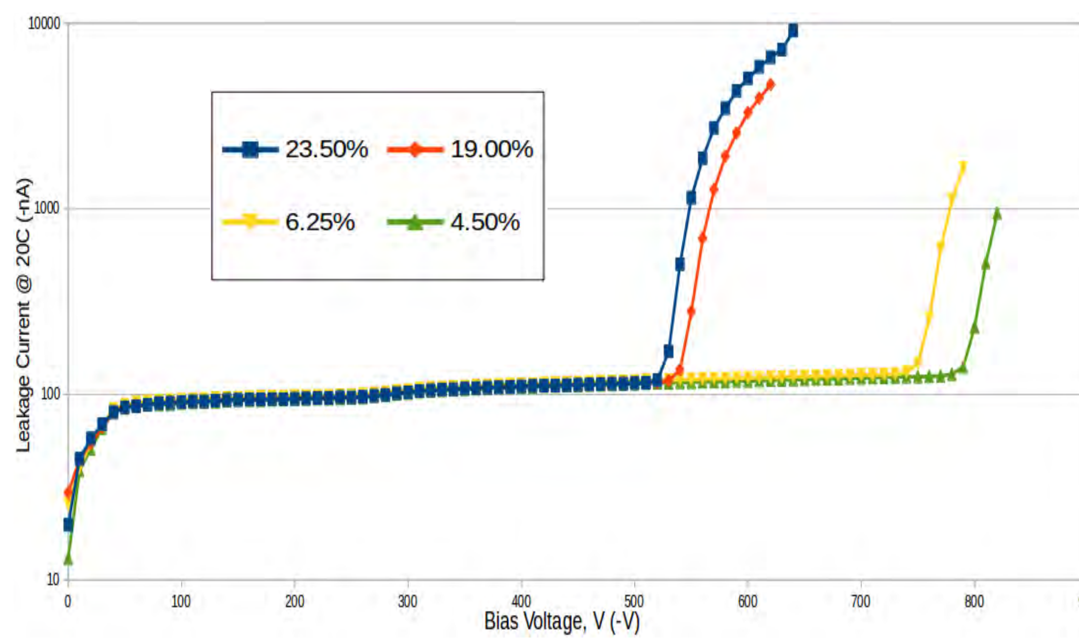


Percentage of R0 sensors with leakage instability below -600V (-1kV): 7 (15)

Specification: No microdischarge onset below -600V

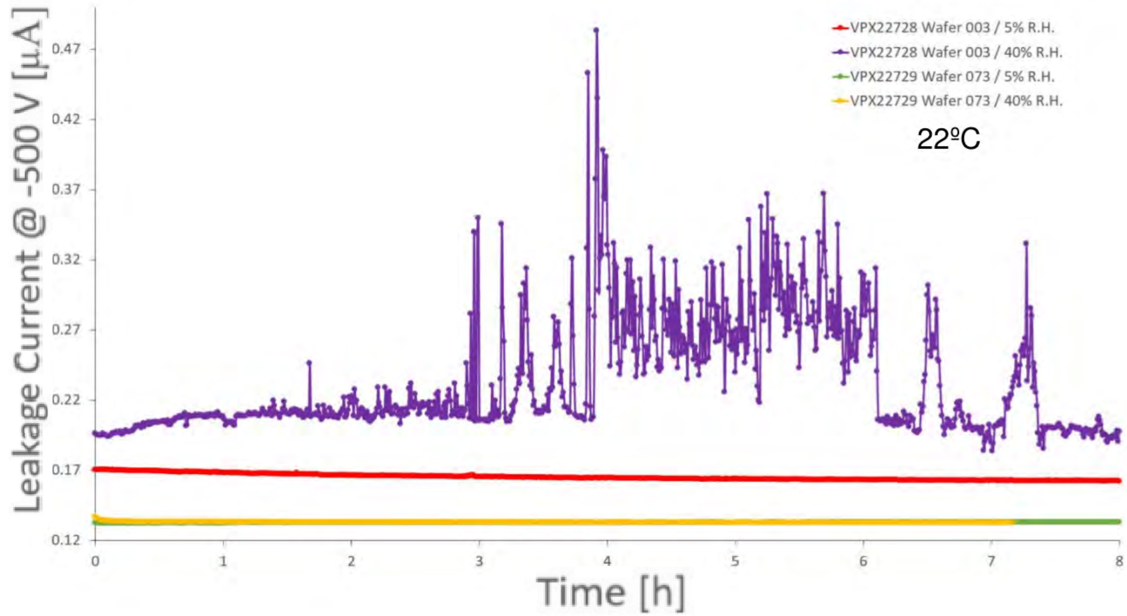
ATLAS12



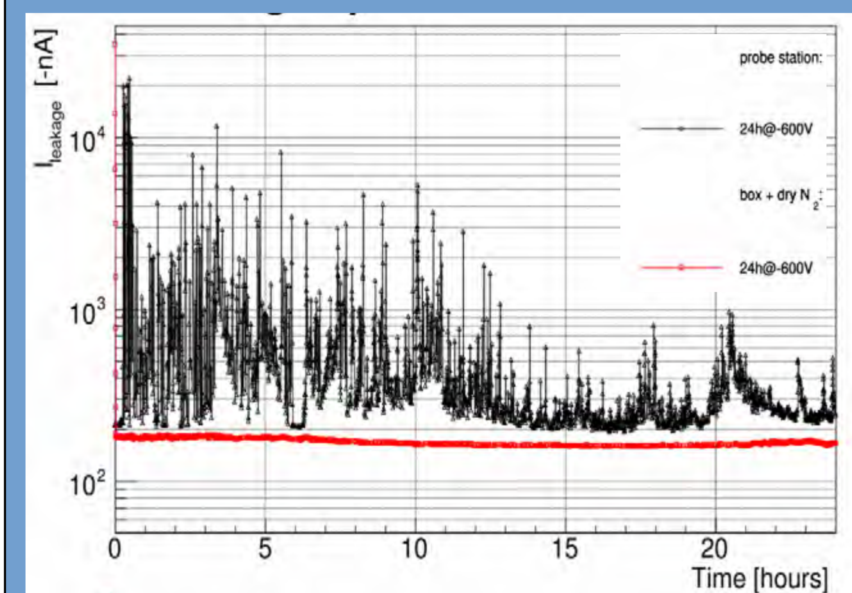


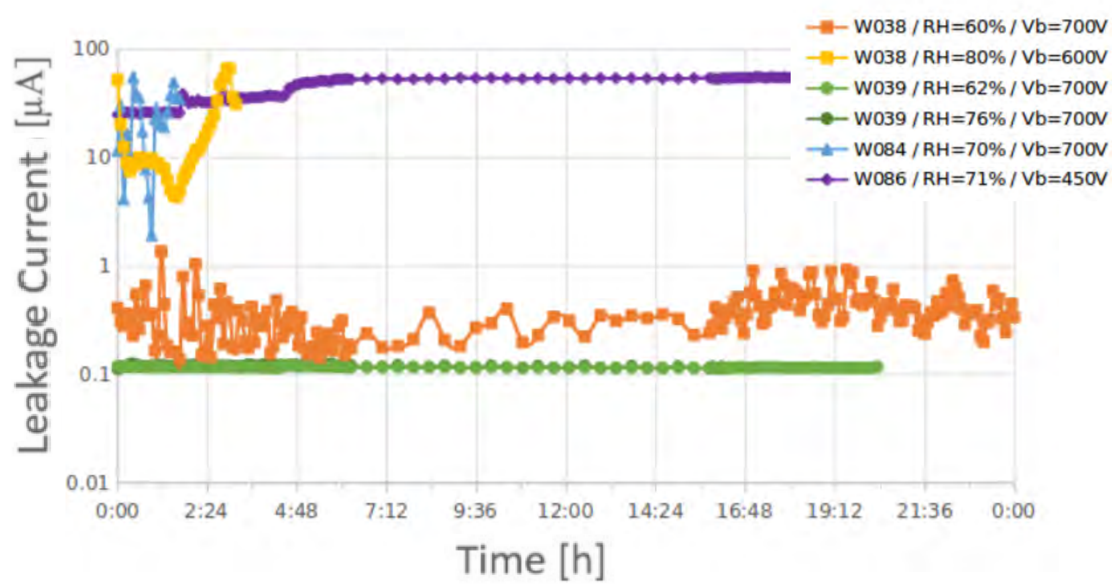
Long Term IV Stability

- Many sensors perform very well; fluctuations O(10nA) over several days even at elevated humidity
- Some sensors show sensistivity to higher humidities
  - Especially prevalent in the sensors with early breakdown/microdischarge
  - Some are recoverable after dry storage and sensor 'training' exercise
- Observations of instability correlated with changes in the rate of humidity change



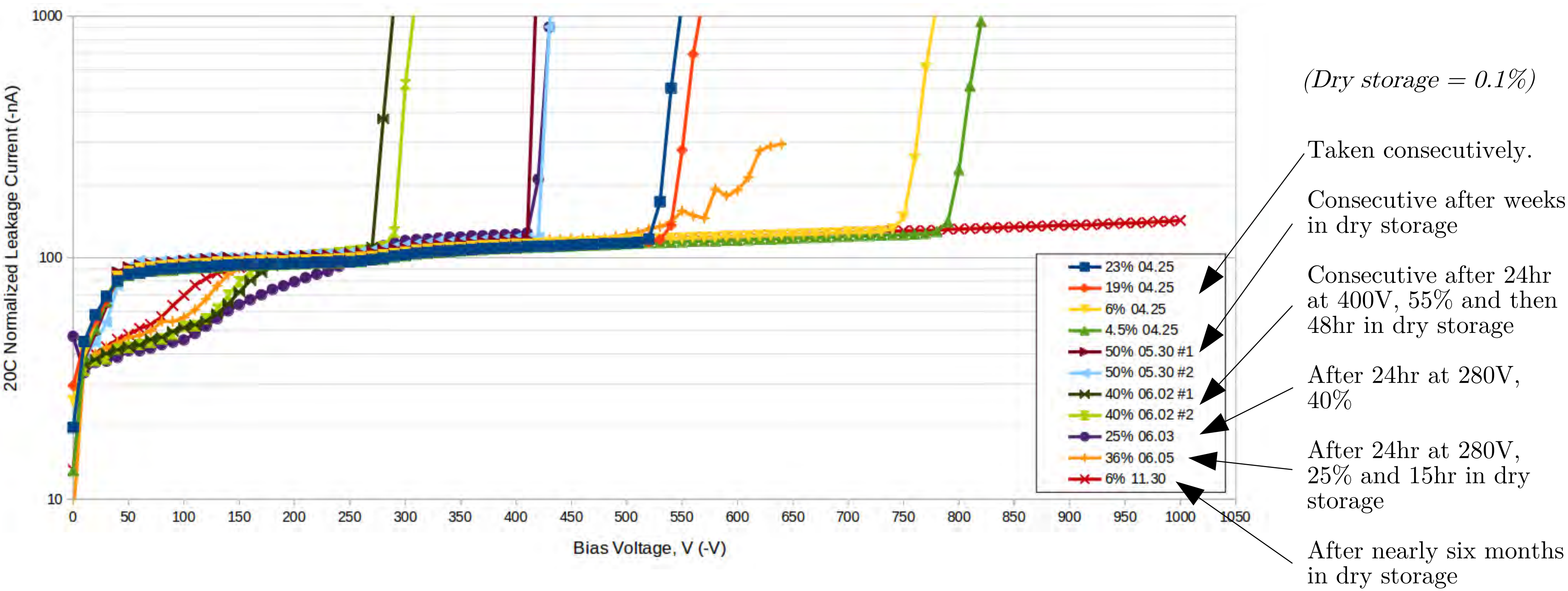
ATLAS12





Instability Conclusions

- Sensors showing early onset leakage instability exhibit much higher humidity sensitivity then their well-behaved counterparts
- Lowered microdischarge breakdown effect is recoverable after long-term dry storage
- Similar observations for conventional sensor shape of comparable size and complexity; not an issue with the stereo annulus geometry
- Evidence for mobile ions and interface trap activation (passivation issues)

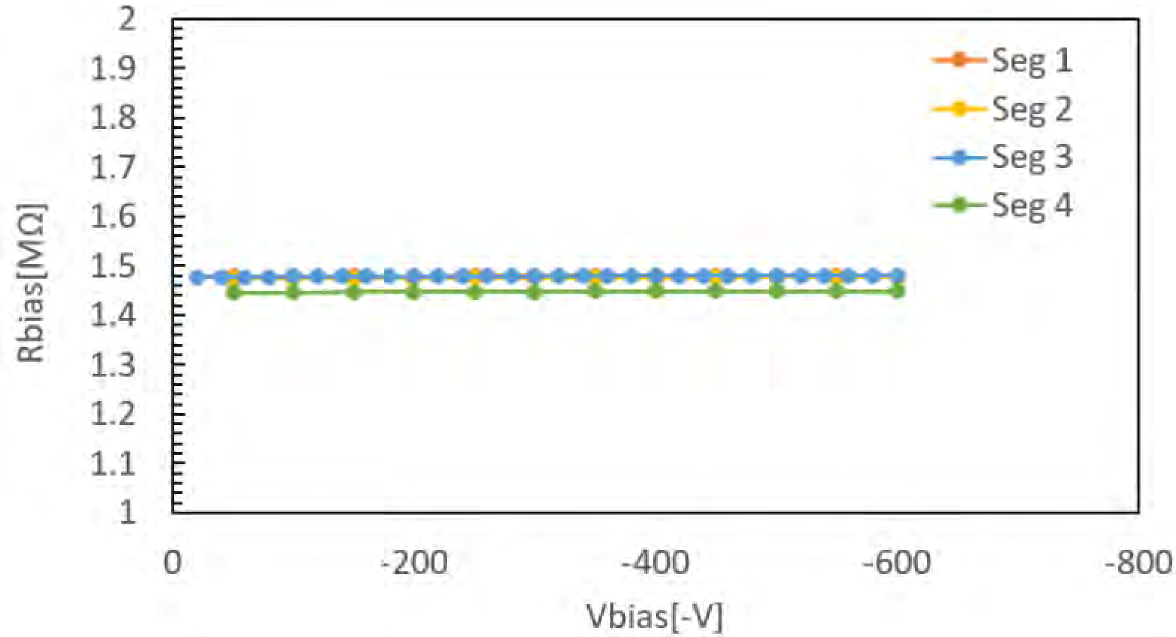


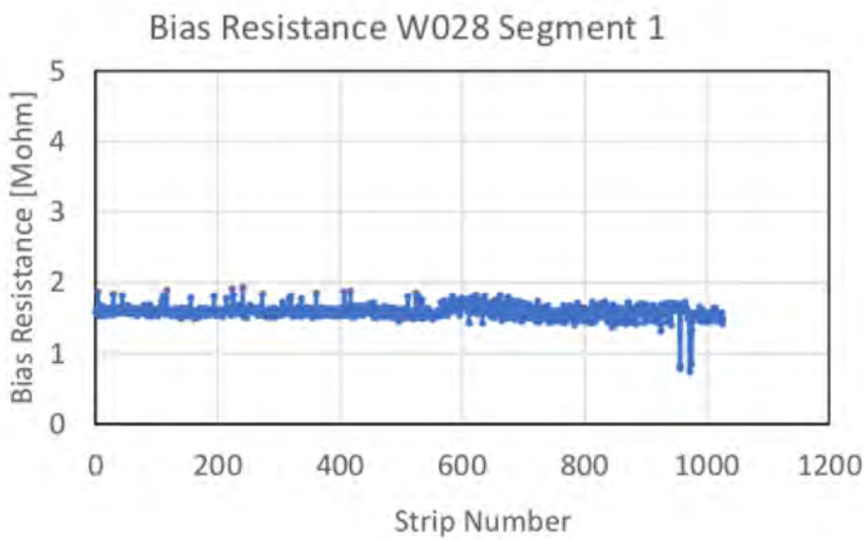
Strip Isolation: Bias and Interstrip Resistances

Full Size Sensors

Bias Resistance

- Must be large to isolate strips
- Must be large and consistent across the sensor to distribute bias effectively
- High consistency, safely within specification observed in all samples measured





Full Segment Average: 1.59 ± 0.01 MΩ*

*No. of Strips Measured: 1026

Other Measurements Range: 1.47-1.52 MΩ**

**No. of Strips (Sensors) Measured: 10 (3)

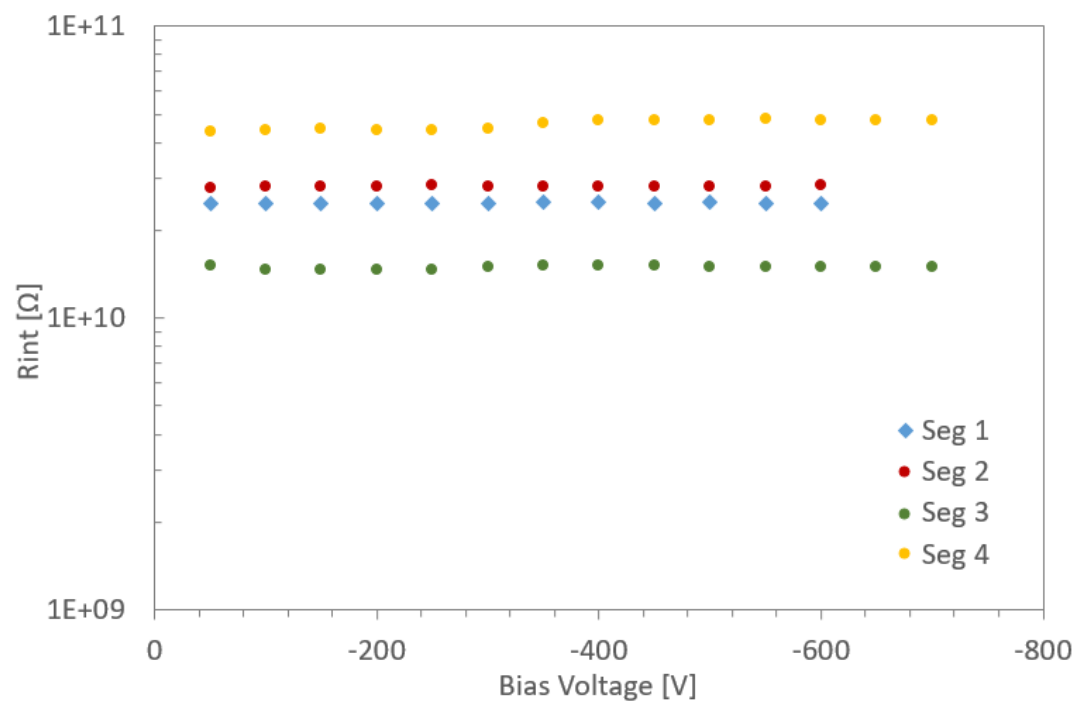
Specification: 1.5 ± 0.5 MΩ

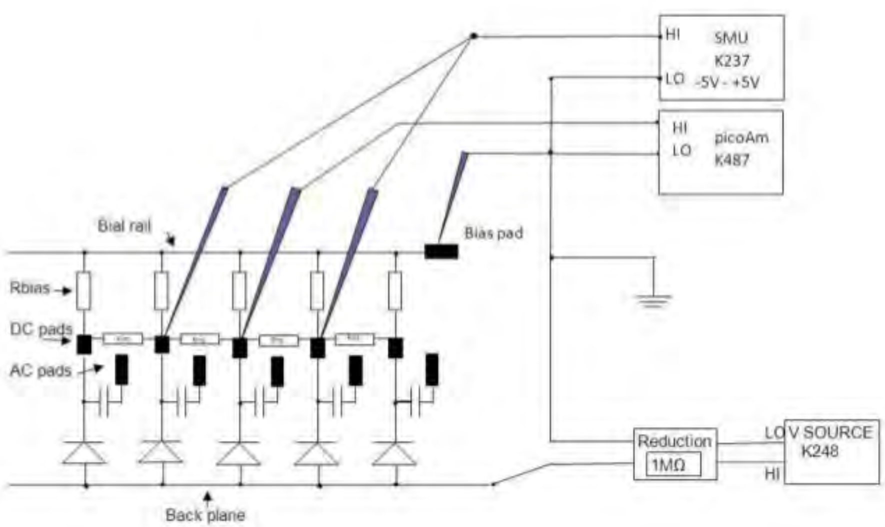
Strip Isolation: Bias and Interstrip Resistances

Interstrip Resistance

Full Size Sensors

- Must be much greater than the bias resistance to maintain channel isolation
- In the ATLAS ITk design the inversion channel inherent in the n+-in-p sensor is overcome with a narrow common p-stop
  - Orders of magnitude within specification





Measurements: *All above 10GΩ**
*No. of Strips Measured: 26

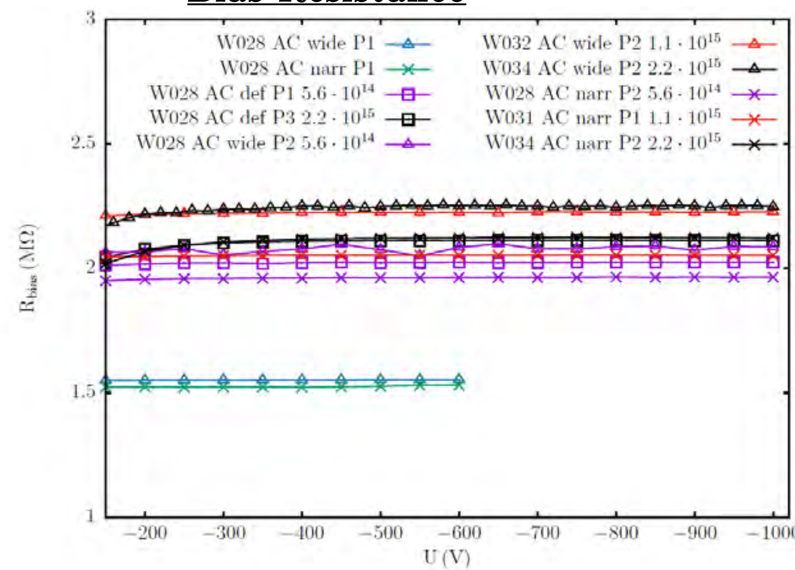
Specification: > 10x R_{bias} at 300V (150MΩ)

Strip Isolation after Proton Irradiation

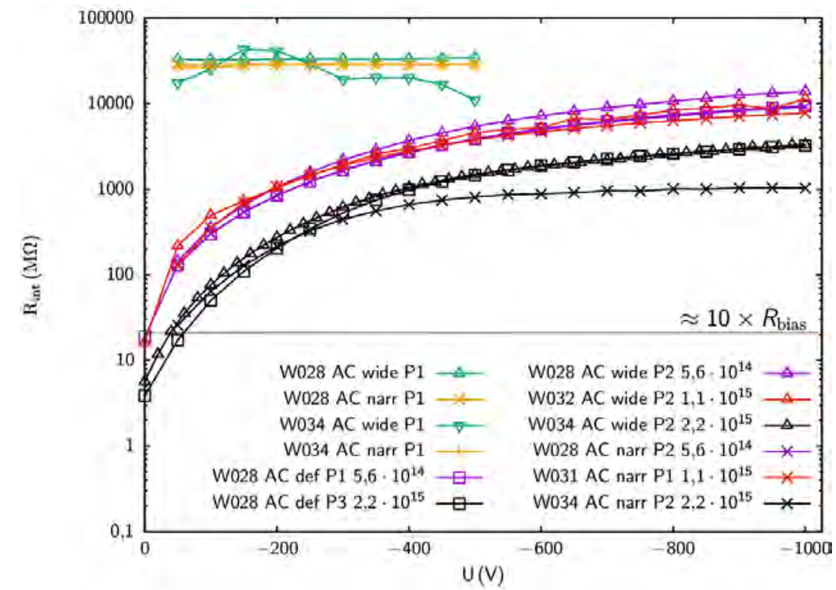
Mini Sensors

- Strip isolation requirements met at 50V for a fluence of $2.2 \times 10^{15}\ n_{eqv}/cm^2$
- Bias Resistance shows very small, positive fluence and negative temperature dependencies
- Interstrip Resistance decreases with fluence and increases smoothly with bias after irradiation
- Measurements very comparable to previous generations

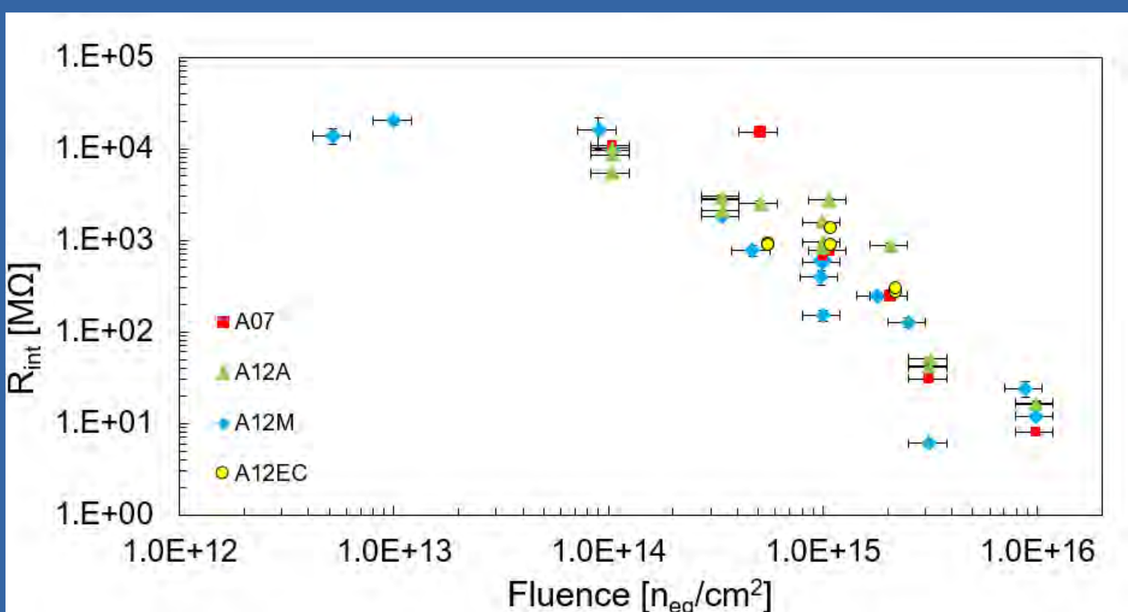
Bias Resistance



Interstrip Resistance

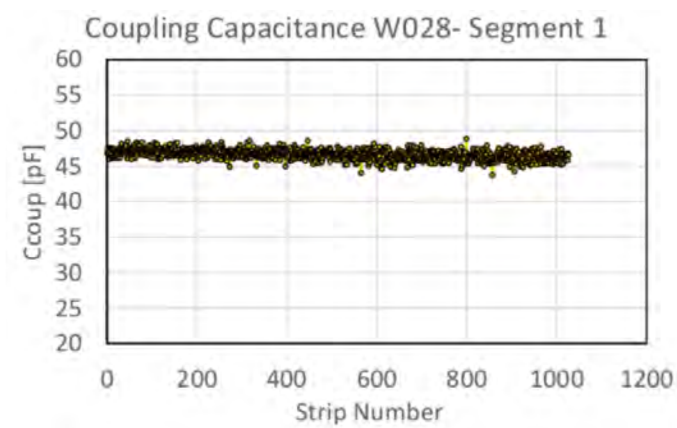


Comparison of Interstrip Resistance vs. Fluence Across the Generations



Coupling Capacitance

- Must be large to maximize signal and its integrity
- Very consistent and within specification
- Follows expected trends in strip length
- No radiation induced change
- Dielectric breakdown voltage is twice the specified value of 100V (~170V for negative voltage on the implants, ~210V for positive)

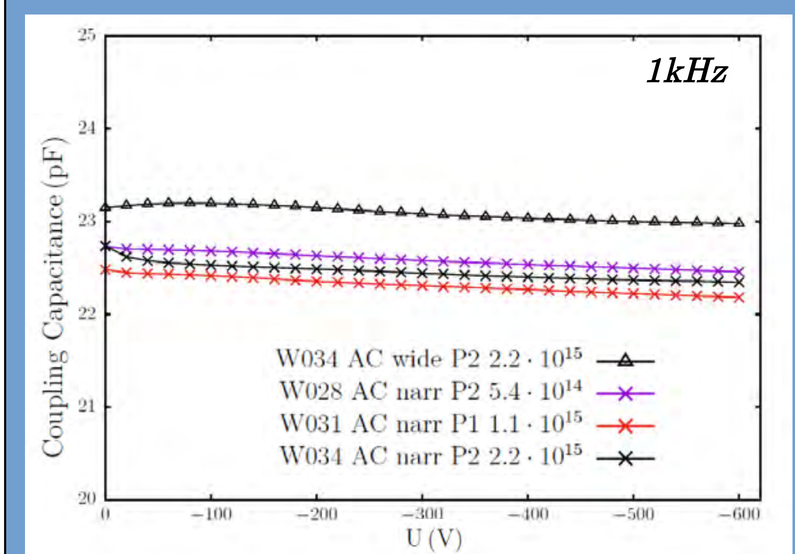


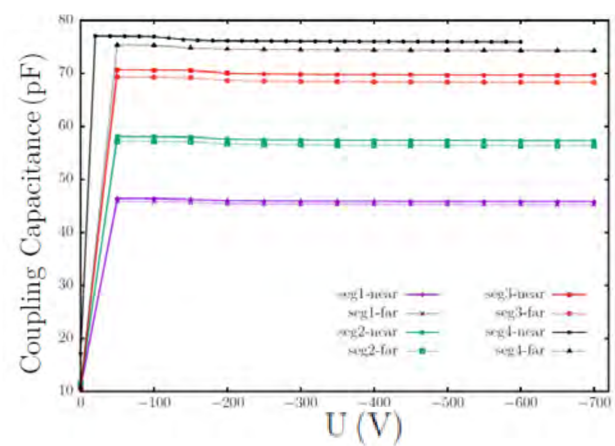
Full Segment Average: 25.21 ± 0.02 pF/cm*
*No. of Strips Measured: 1026

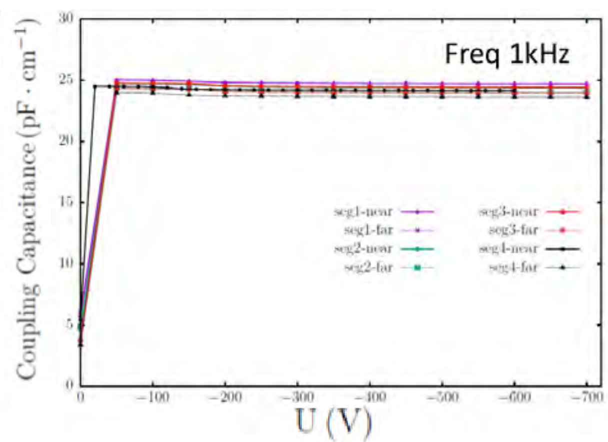
Other Measurements Range: 24.89-28.37 pF/cm**
**No. of Strips Measured: 35

Specification: > 20 pF/cm

p+ IRRADIATED MINIS





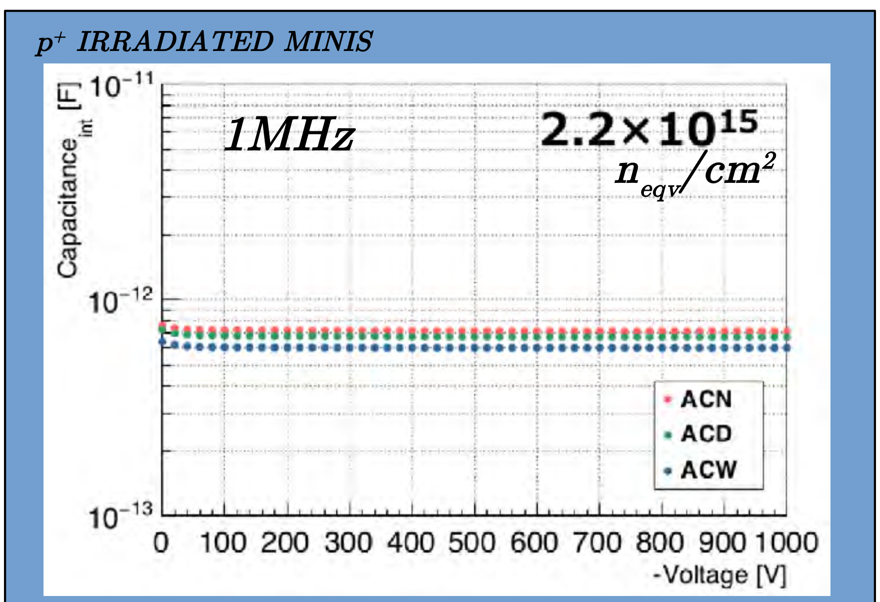


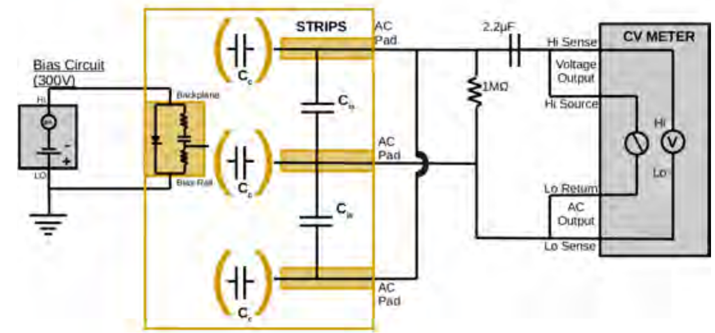
Interstrip Capacitance

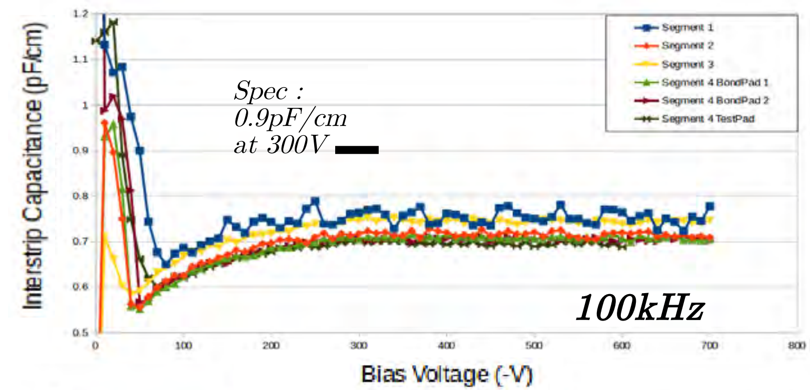
- Needs to be small to minimize noise at the front end and needs to be much smaller than coupling capacitance for isolation of channels
- Capacitance follows expected trends in pitch
- Good consistency
- No change with proton irradiation
- All measurements within specification

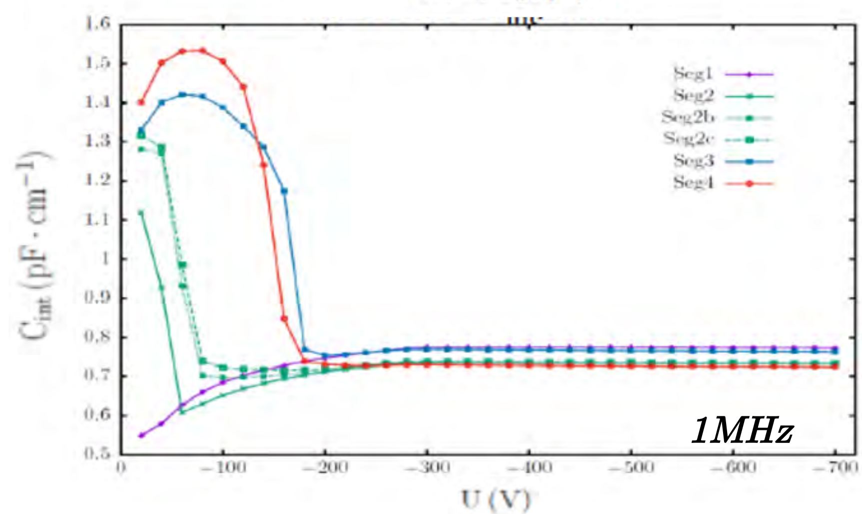
Range: **0.61 – 0.89 pF/cm** (at 700V)*
*No. of Strips Measured: 15

Specification: < 0.9 pF/cm @ 300V, 100kHz





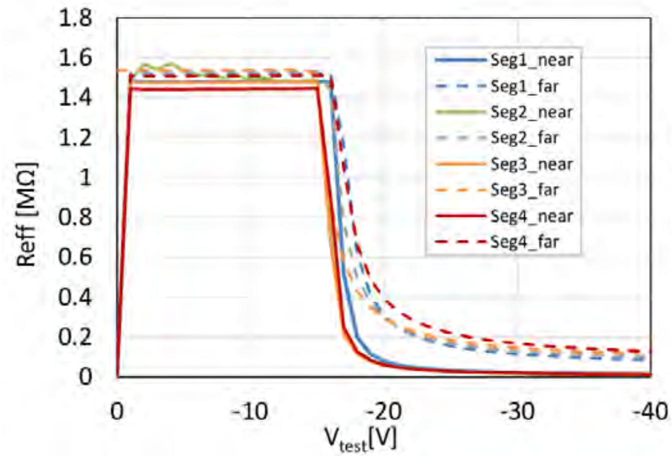


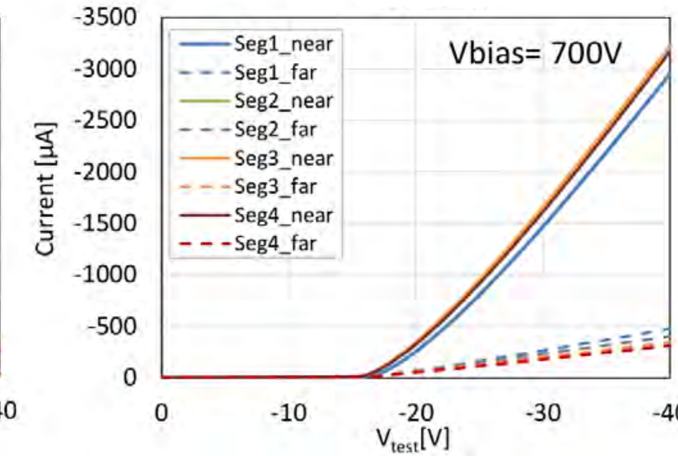


Coupling capacitance range: **24.89-28.37 pF/cm**

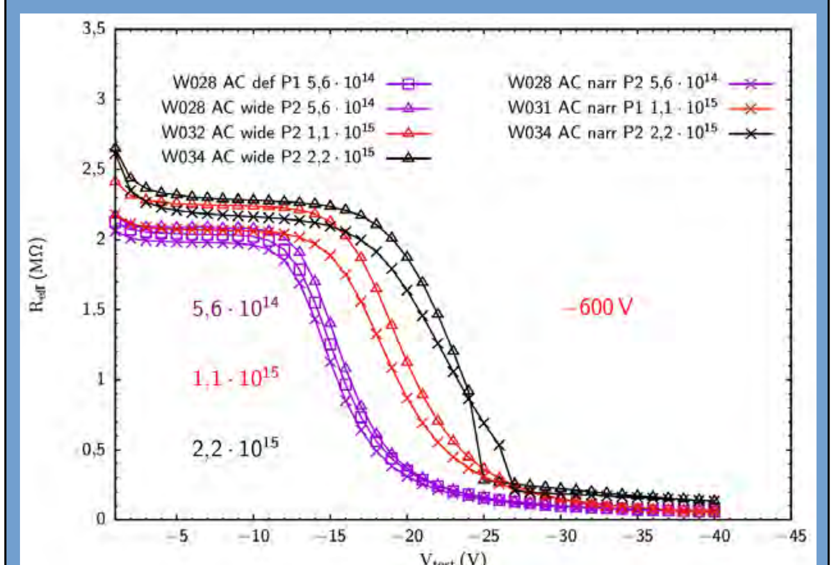
Punch Through Protection (PTP)

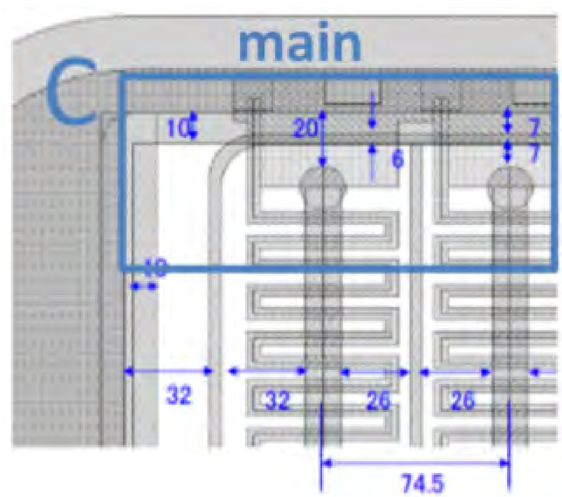
- Protects the coupling capacitor in the event of large charge liberation in the bulk
- Desire early onset voltage and high current flow at -100V
- Onset voltage increases with fluence but is only -30V at $2.2\text{x}10^{15}$ n_{eqv}/cm^2 (at V_{bias}= -600V)
- **Suitable PTP performance**



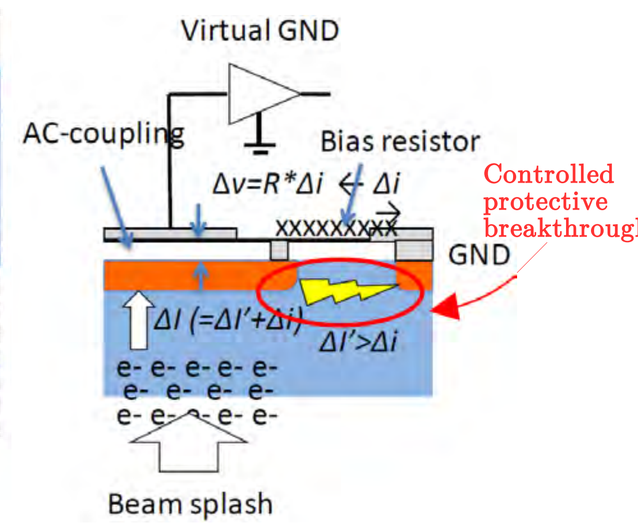


p^+ IRRADIATED MINIS





Y. Unno *et al.*, *Nucl. Instr. Meth. Phys. Res. A*, vol. 765, pp. 80–90, 2014. (ATLAS12 Design)



Summary and Conclusions

- Stereo annulus is an optimized geometry for the restricted space of an endcap strip tracker
  - Stereo angle gains in secondary resolution without negative effects
  - Equal length strips and better annular disk coverage

- The first R0 prototype sensors show excellent results
  - Meets specification in all categories
  - High consistency in bulk character
  - Low leakage and good levels of leakage instability
  - Also high consistency in the surface processing
  - All structures performing as expected

- The stereo annulus geometry is considered to have negligble effect on sensor performance from the comparisons of the R0 prototype to the ATLAS12
  - Instability is not isolated to the R0 prototype and is attributed to passivation
    - The passivation issue will be addressed in the next iteration of R0 prototype sensor

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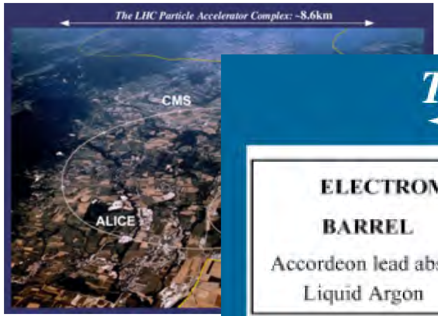
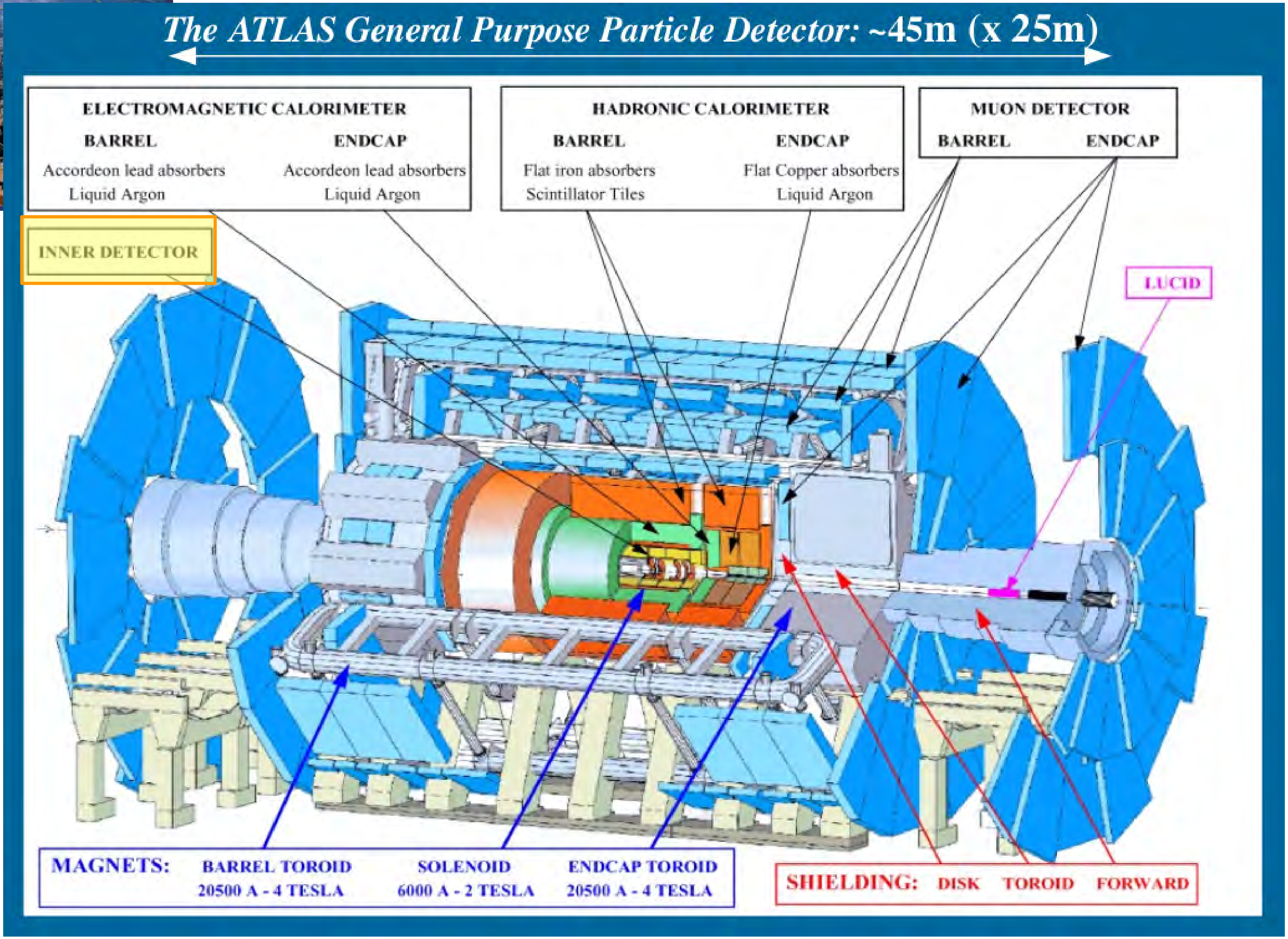
Thank you!

The research was supported and financed in part by Canada Foundation for Innovation, the National Science and
22 Engineering Research Council (NSERC) of Canada under the Research and Technology Instrumentation (RTI) grant
23 SAPEQ-2016-00015; the Ministry of Education, Youth and Sports of the Czech Republic coming from the project
24 LM2015058 - Research infrastructure for experiments at CERN; USA Department of Energy, Grant DE-SC0010107,
the Federal Ministry of Education and Research, BMBF, Germany

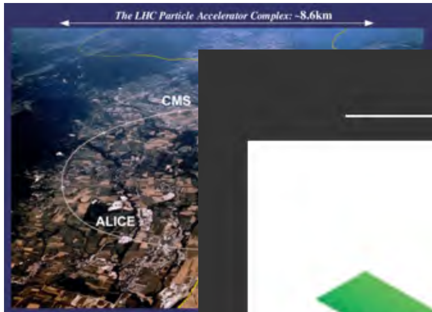
BACKUP

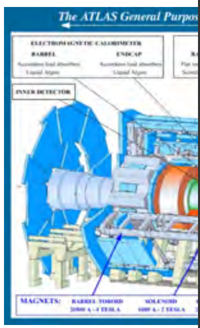
The Itk Strip Detector: Home of the First Stereo Annulus Sensors

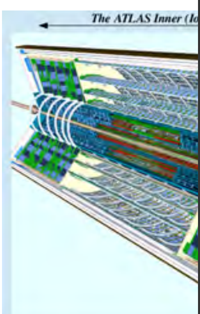


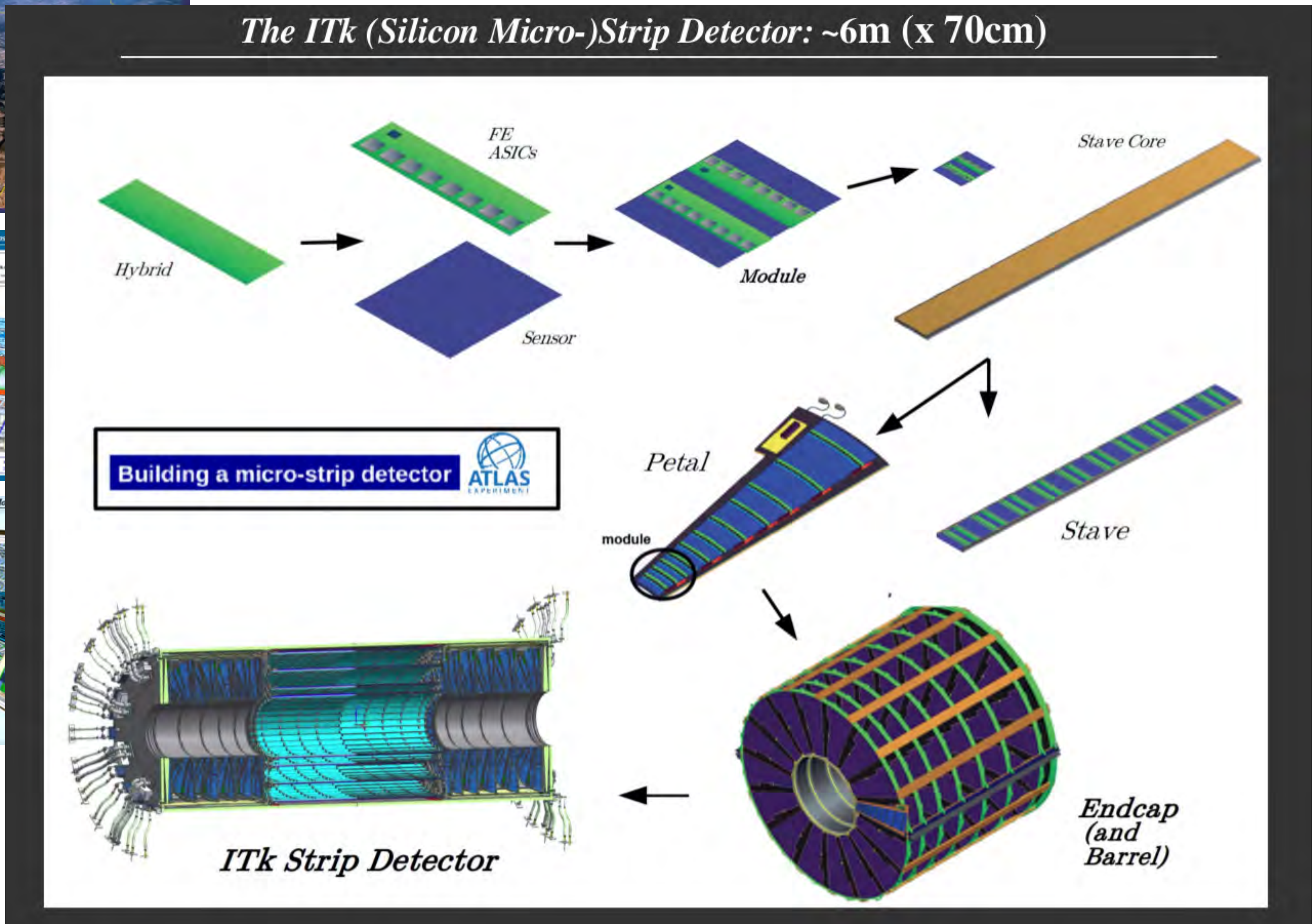


The Itk Strip Detector: Home of the First Stereo Annulus Sensors









Approximately 165m² silicon surface detection area.

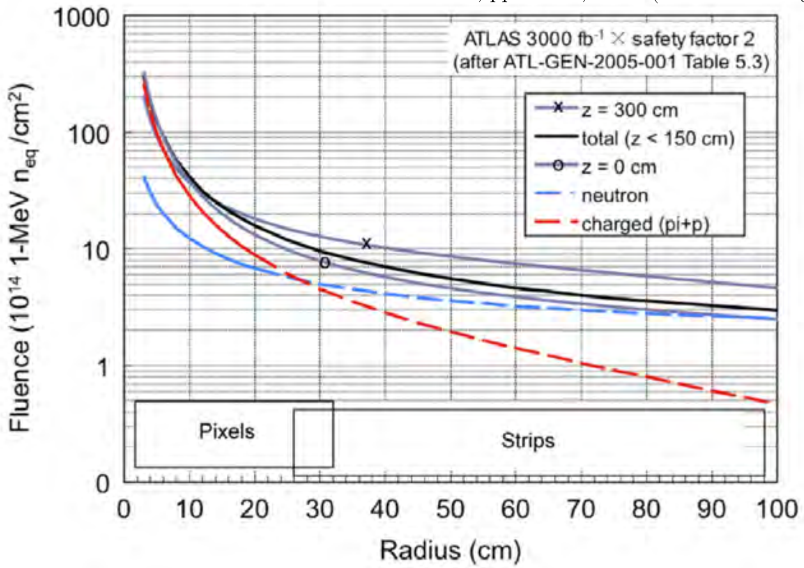
ITk Justifications

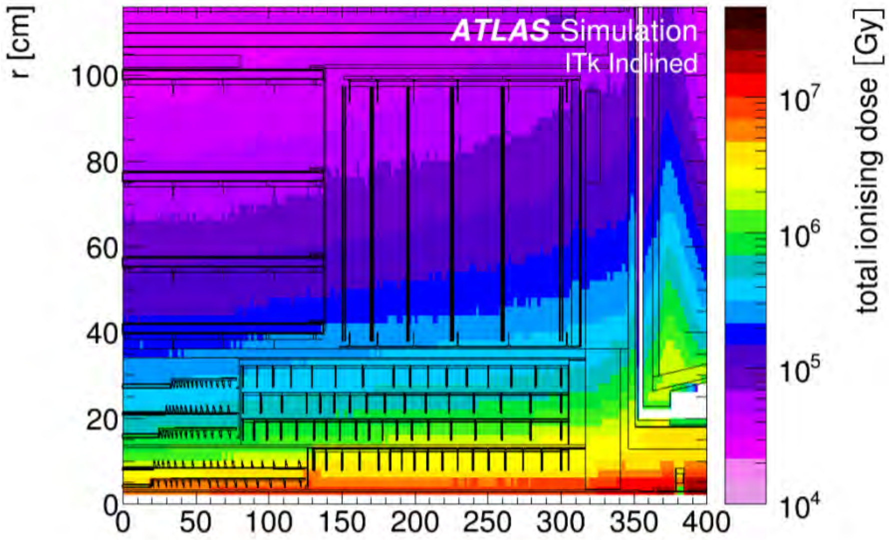
Operational Parameter	ID, LHC, and ATLAS Design Limits	HL-LHC Capabilities and Upgraded ATLAS Requirements
Experiment Lifetime	*10 years*	Current age: ~ *7 years* Age at upgrade: *14 years* Full duration: *27 years*
Peak Instantaneous Luminosity (*x* 10^{34} cm^{-2} s^{-1})	*1.0*	Nominal: *5.0* Ultimate: *7.5* **with leveling*
Pileup (*proton collisions per 25 ns bunch crossing*)	Design: *23* Operational Max: *~40 (peak)* , *~24 (avg.)*	Nominal: *140* Ultimate: *200* **with leveling*
ATLAS Trigger Rate (*kHz*)	Level-1: *100*	Single Mode; Level-0: *1000* Dual Mode; Level-0: *4000* Level-1 (new): *400-600*
Integrated Luminosity (fb^{-1})	Pixels: *400* SCT: *700* Inserted Beam Layer: *850*	Nominal: *3000* Ultimate: *4000*
Maximum High Energy Particle Fluence (*x* 10^{15} *1 MeV* n_{eqv} cm^{-2})	Pixels: *5.0* SCT: *0.2*	ITk Pixel: *18.7* ITk Strip: *1.2*
Maximum Total Ionizing Dose (*MGy*)	Pixels: *3.0*	ITk Pixel: *12.7* ITk Strip: *0.5*

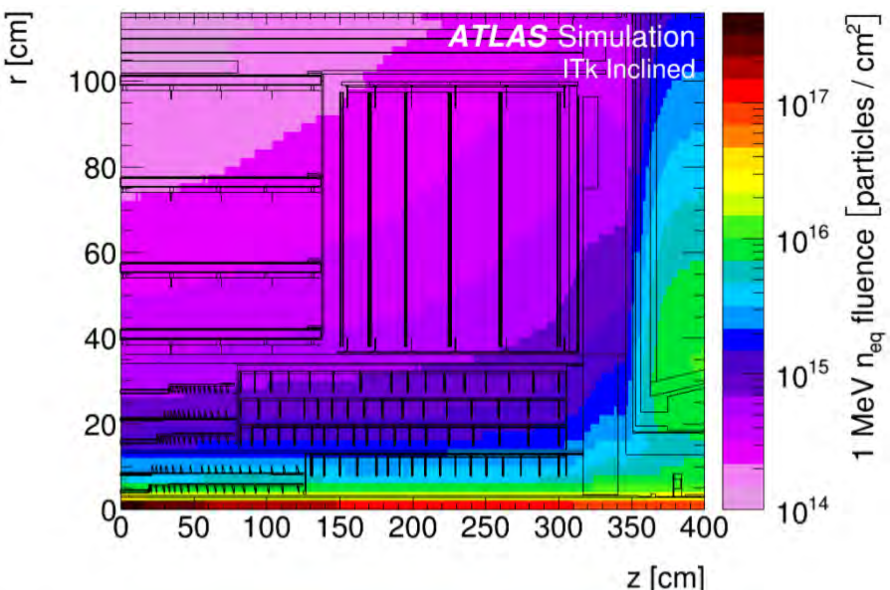
The ID was not designed for the HL-LHC and **will not survive it**.

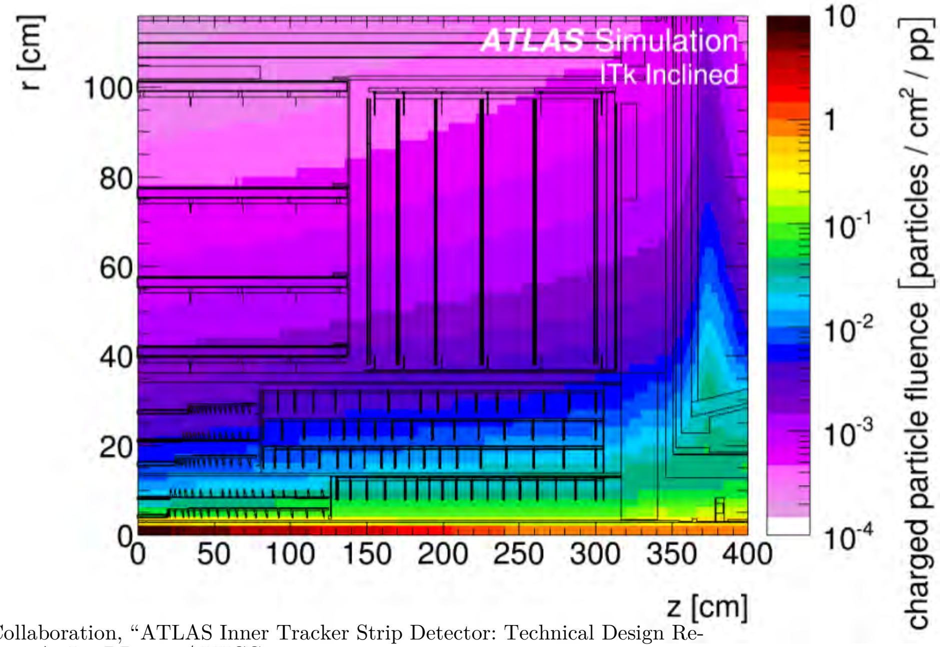
ITk Radiation Environment

Y. Unno *et al.*, *Nucl. Instr. Meth. Phys. Res. A*, vol. 765, pp. 80–90, 2014. (ATLAS12 Design)





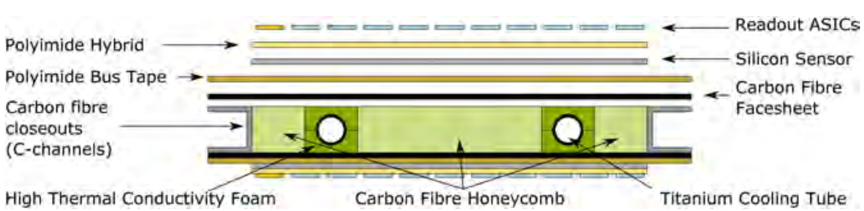


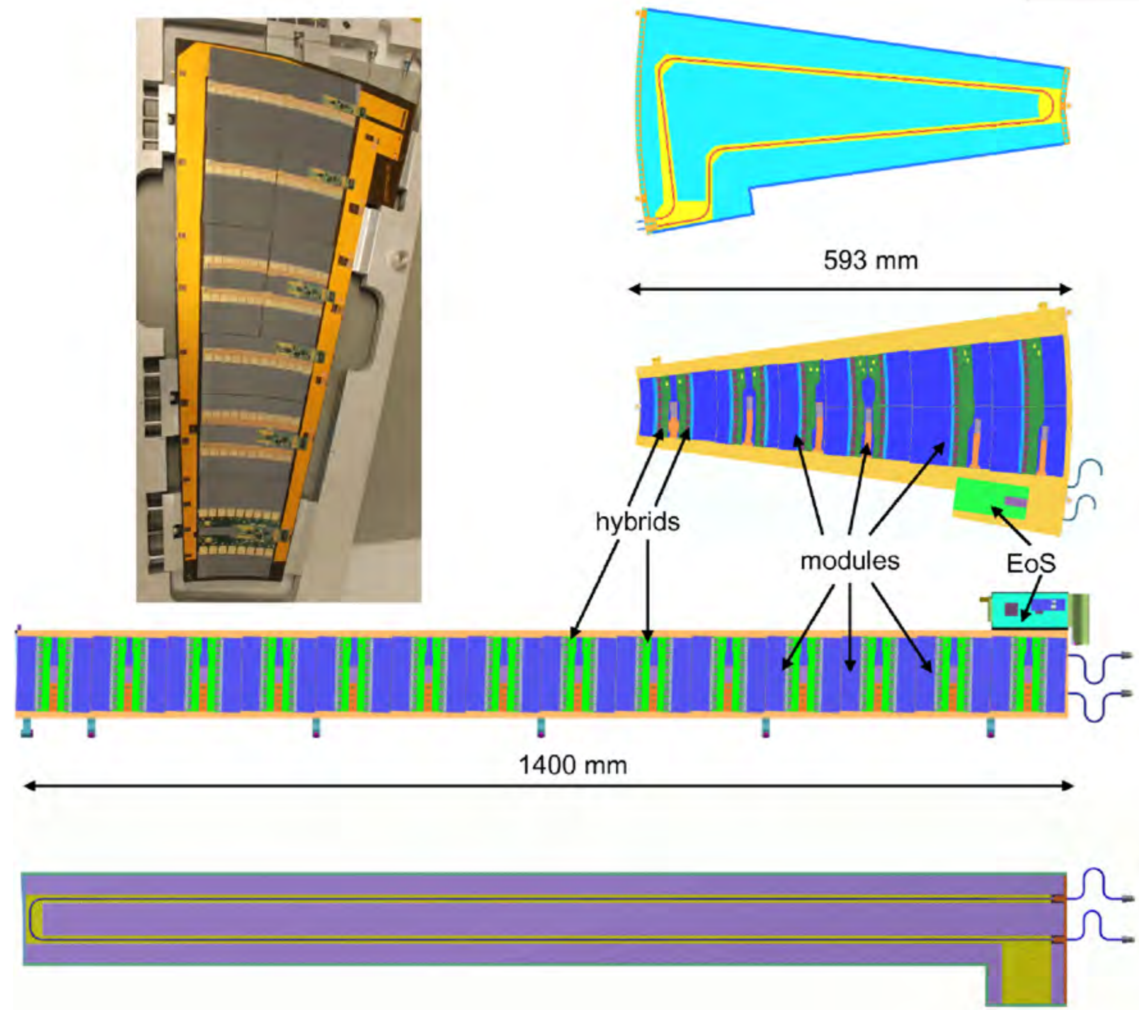


The ATLAS Collaboration, "ATLAS Inner Tracker Strip Detector: Technical Design Report," Tech. Rep. ATL-TDR-025 / LHCC-2017-005, 2017.

Petals and ITk Strip Component Numerology

Barrel Layer:	Radius [mm]	# of staves	# of modules	# of hybrids	# of of ABCStar	# of channels	Area [m^2]
L0	405	28	784	1568	15680	4.01M	7.49
L1	562	40	1120	2240	22400	5.73M	10.7
L2	762	56	1568	1568	15680	4.01M	14.98
L3	1000	72	2016	2016	20160	5.16M	19.26
Total half barrel		196	5488	7392	73920	18.92M	52.43
Total barrel		392	10976	14784	147840	37.85M	104.86
End-cap Disk:	**z-pos. [mm]**	**# of petals**	**# of modules**	**# of hybrids**	**# of of ABCStar**	**# of channels**	**Area [m^2]**
D0	1512	32	576	832	6336	1.62M	5.03
D1	1702	32	576	832	6336	1.62M	5.03
D2	1952	32	576	832	6336	1.62M	5.03
D3	2252	32	576	832	6336	1.62M	5.03
D4	2602	32	576	832	6336	1.62M	5.03
D5	3000	32	576	832	6336	1.62M	5.03
Total one EC		192	3456	4992	43008	11.01M	30.2
Total ECs		384	6912	9984	86016	22.02M	60.4
Total		**776**	**17888**	**24768**	**233856**	**59.87M**	**165.25**

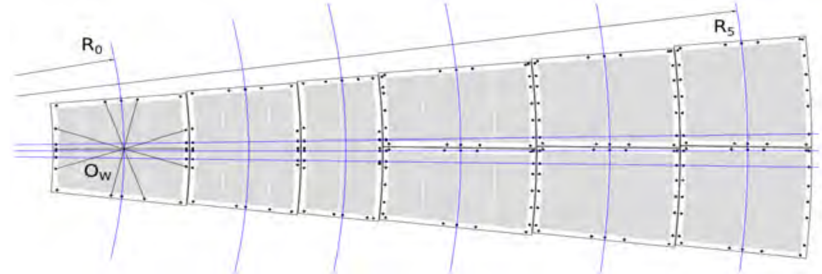




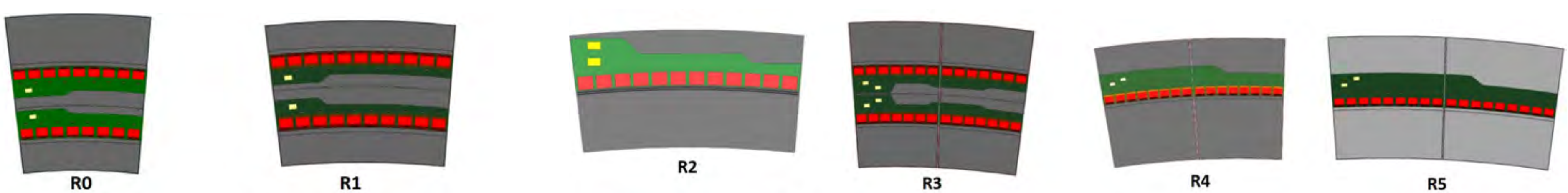
The ATLAS Collaboration, "ATLAS Inner Tracker Strip Detector: Technical Design Report," Tech. Rep. ATL-TDR-025 / LHCC-2017-005, 2017.

Stereo Annulus Sensors of the ITk Endcaps

Sensor type	Number of sensors	Shape	Number of rows	Channels per sensor	Min/max pitch (μm)
Short-strips	3808	Square	4	5128	75.5
Long-strips	7168	Square	2	2564	75.5
EC Ring 0	768		4	4360	73.5/84
EC Ring 1	768		4	5640	69/81
EC Ring 2	768		2	3076	73.5/84
EC Ring 3	1536		4	3592	70.6/83.5
EC Ring 4	1536		2	2052	73.4/83.9
EC Ring 5	1536		2	2308	74.8/83.6

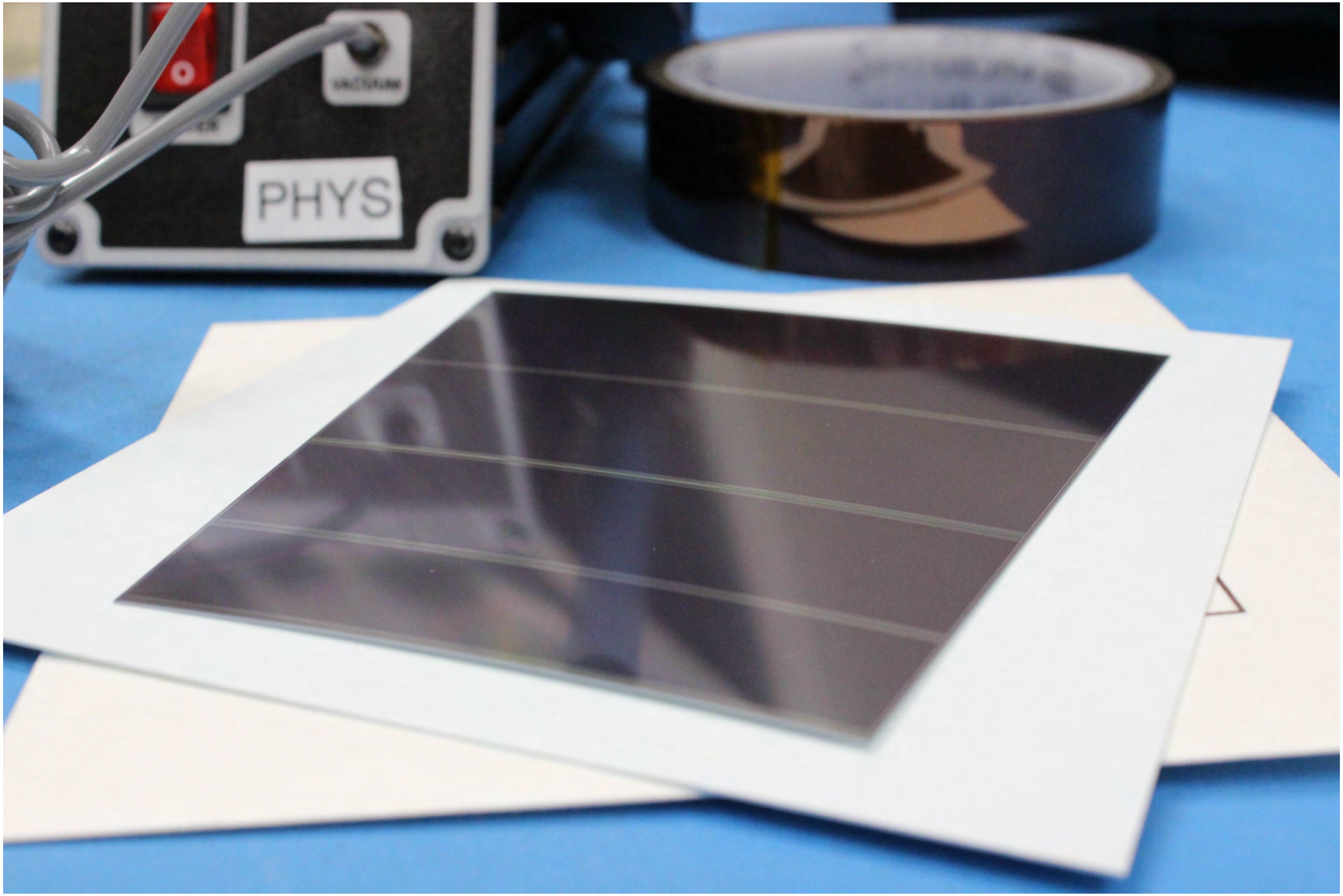


Ring/Row	Inner Radius [mm]	Strip Length [mm]	Strip Pitch [μm]
Ring 0 Row 0	384.5	19	75.0
Ring 0 Row 1	403.5	24	79.2
Ring 0 Row 2	427.5	29	74.9
Ring 0 Row 3	456.4	32	80.2
Ring 1 Row 0	489.8	18.1	69.9
Ring 1 Row 1	507.9	27.1	72.9
Ring 1 Row 2	535	24.1	75.6
Ring 1 Row 3	559.1	15.1	78.6
Ring 2 Row 0	575.6	30.8	75.7
Ring 2 Row 1	606.4	30.8	79.8
Ring 3 Row 0	638.6	32.2	71.1
Ring 3 Row 1	670.8	26.2	74.3
Ring 3 Row 2	697.1	26.2	77.5
Ring 3 Row 3	723.3	32.2	80.7
Ring 4 Row 0	756.9	54.6	75.0
Ring 4 Row 1	811.5	54.6	80.3
Ring 5 Row 0	867.5	40.2	76.2
Ring 5 Row 1	907.6	60.2	80.5



The ATLAS Collaboration, "ATLAS Inner Tracker Strip Detector: Technical Design Report," Tech. Rep. ATL-TDR-025 / LHCC-2017-005, 2017.

An ATLAS12EC Sensor



Sensor Specifications

	ATLAS12EC
Wafer size	150 mm
Thickness	310 +/- 25 µm
Orientation	<100>
Type	P
Ingot	FZ
Resistivity	>3 kΩcm
Strip segments	4
Strip implant	N
Strip implant Width	16 µm
Strip bias resistor	Polysilicon
Strip bias resistance (R_b)	1.5+/-0.5 MΩ
Strip readout coupling	AC
Strip readout metal	Pure Aluminium
Strip readout metal width	20 µm
Strip AC coupling capacitance	>20 pF/cm
Strip isolation	$>10\times R_b$ at 300 V
Strip isolation method	Narrow-common p-stop
Gap between strip segments	56 µm (rail region) 70 µm (no rail region)
Microdischarge onset voltage	>600 V
Maximum operation voltage [*1]	600 V
Leakage current	$<2\ \mu A/cm^2$ at 600 V
Radiation tolerance	1.5×10^{15} 1-MeV n_{eq}/cm^2

[*1] The voltage rating of the external high voltage cable is 500V and tested 1 KV.

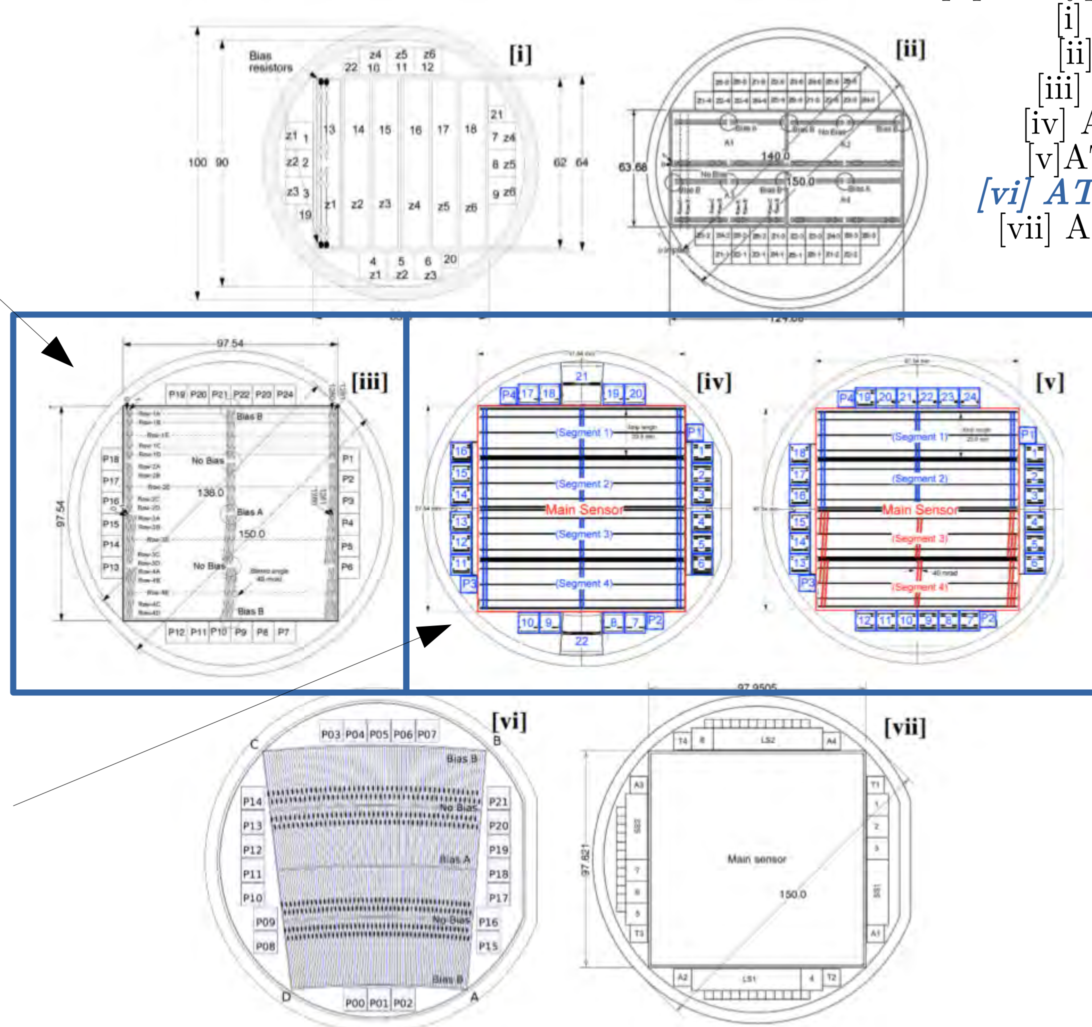
ATLAS ITk Protoype Sensors

Wafer layouts of the ATLAS ITk Strip prototype sensors.
[i] ATLAS05
[ii] ATLAS06
[iii] ATLAS07
[iv] ATLAS12A
[v]ATLAS12M
[vi] ATLAS12EC
[vii] ATLAS17LS

ATLAS07

- First full size sensor (~100cm²)
- Half of strips rotated by 40mrad

J. Bohm. et al., Nucl. Instr. Meth. Phys. Res. A, vol. 636, pp. S104–S110, 2011.



ATLAS12

- Slim edge width for ~30% of sensors (450µm)
- Two variants
  - Same as A07 (half of strips stereo rotated)
  - *All four strip segments unrotated {2}*

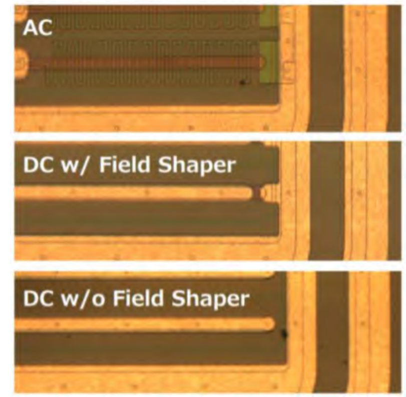
L.B.A. Hommels *et al.*, *Nucl. Instr. Meth. Phys. Res. A*, vol. 831, pp. 167–173, 2016.

See talks by Liv Wiik-Fuchs and Andy Blue for annealing and irradiated testbeam performance of ATLAS12. Coming up soon!

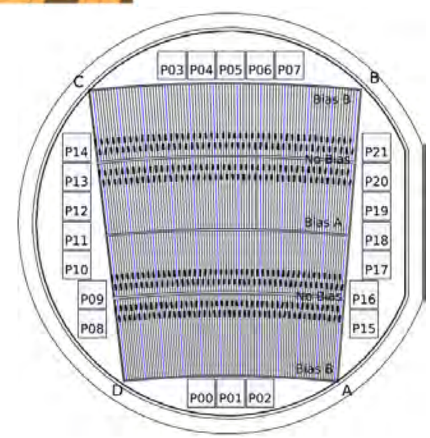
ATLAS12EC Mini Sensors

Mini distribution:

Pitch	Coupling	PTP	Total	Irradiated	Left
Default	AC	Yes	166	48	118
	DC	Yes	166	48	118
	DC	No	166	48	118
Narrow	AC	Yes	58	36	22
	DC	Yes	29	18	11
	DC	No	29	18	11
Wide	AC	Yes	58	36	22
	DC	Yes	29	0	29
	DC	No	29	0	29
			730	252	478



sample	Strips	Width [μm]
Default	103	75
Narrow	111	70
Wide	92	85



Irradiation test set: $(x10^{14}\ n_{eqv}/cm^2)$

Pitch	Coupling	PTP	0x	5x	10x	20x	TOTAL
Default	AC	Yes	2	2	2	2	8
	DC	Yes	2	2	2	2	8
	DC	No	2	2	2	2	8
Narrow	AC	Yes	2	1	2	1	6
	DC	Yes		1	1	1	3
	DC	No		1	1	1	3
Wide	AC	Yes	2	1	2	1	6
	DC	Yes					0
	DC	No					0
Total			10	10	12	10	42

Three mini test sets are *each* irradiated with:

n

reactor neutrons
Ljubljana Reactor
Jožef Stefan Institute, Slovenia

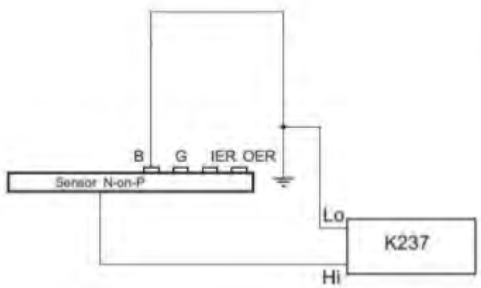
p^+

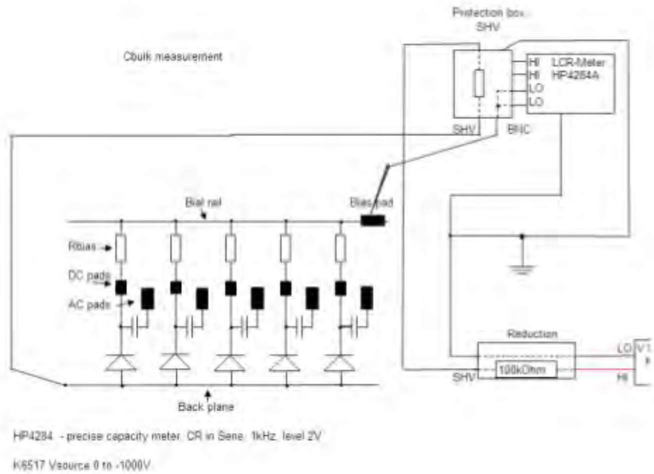
70MeV protons
CYRIC
Tohoku University, Japan

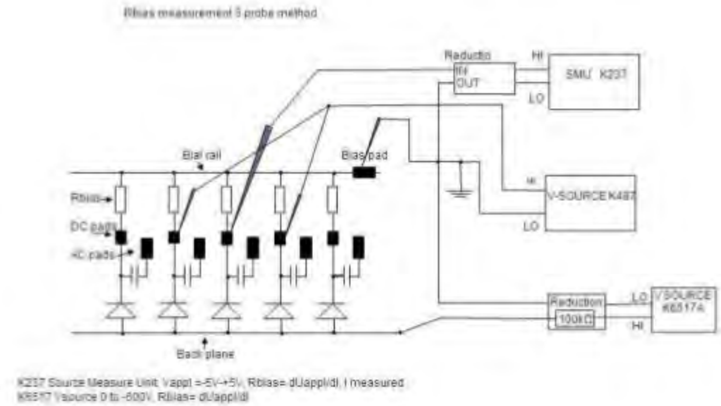
First ATLAS12EC Module

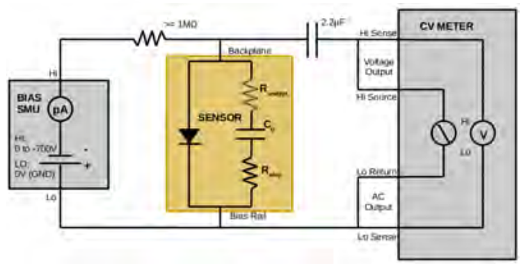
See poster by Carlos Garcia Argos : "Assembly and Electrical Tests of the First Full-size Forward Module for the ATLAS ITk Strip Detector"

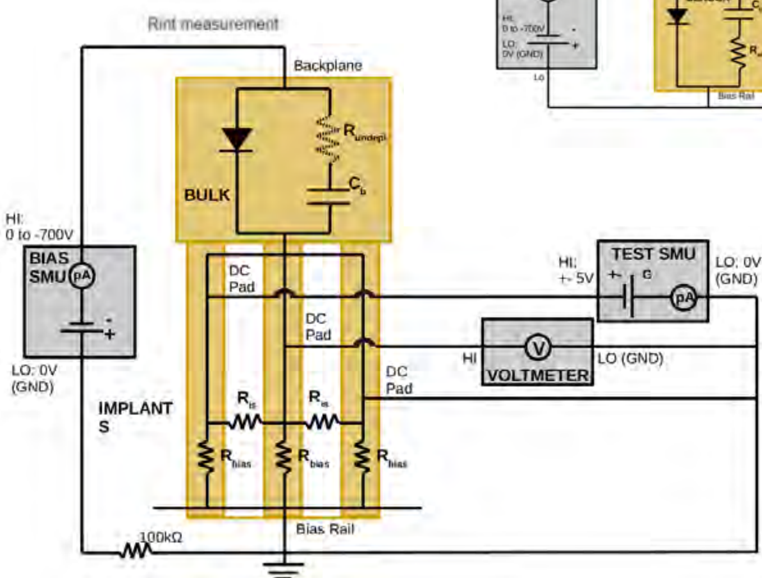
Measurement Techniques

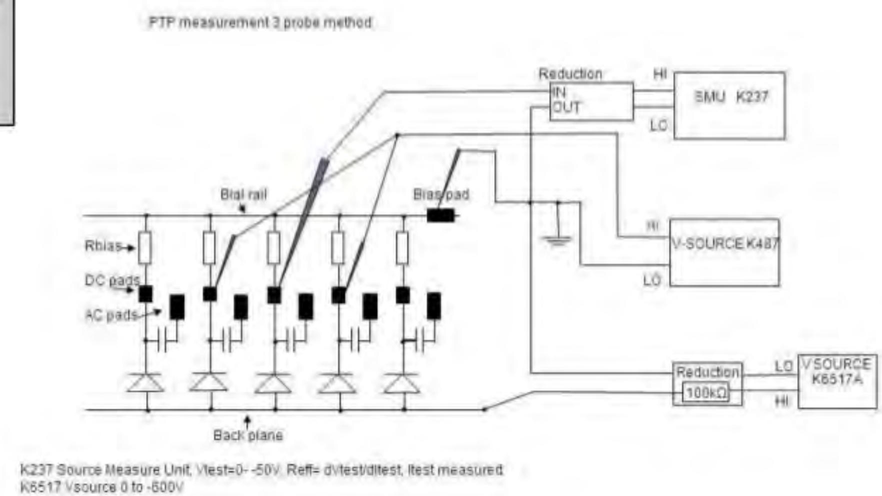




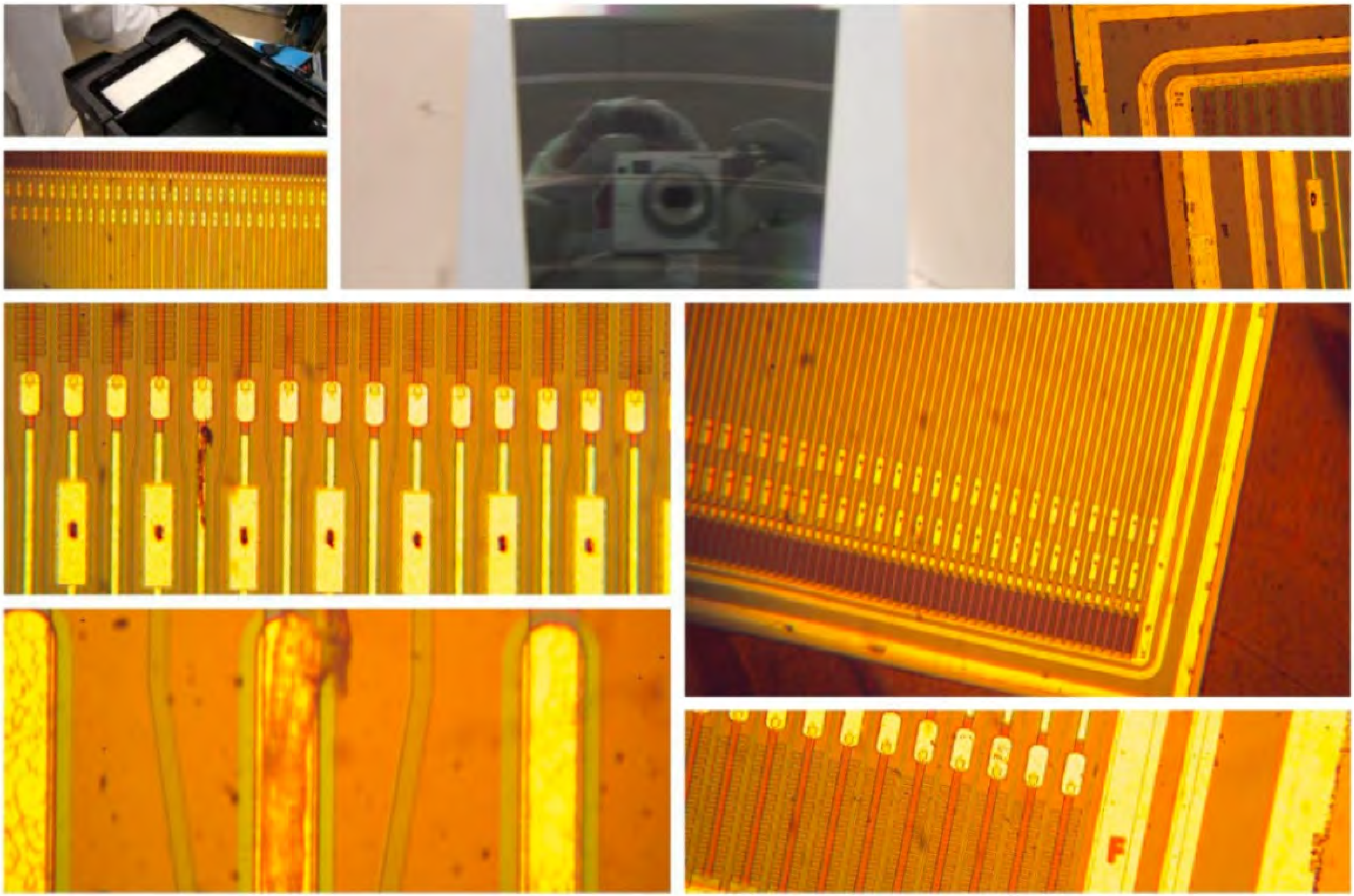






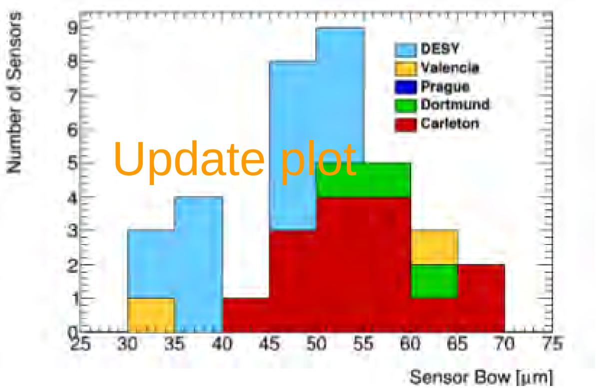


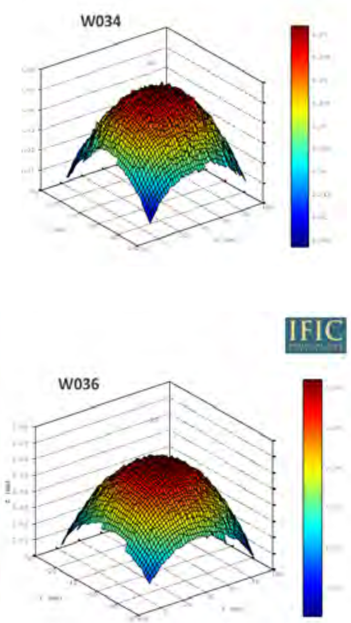
More Visual Inspection Results

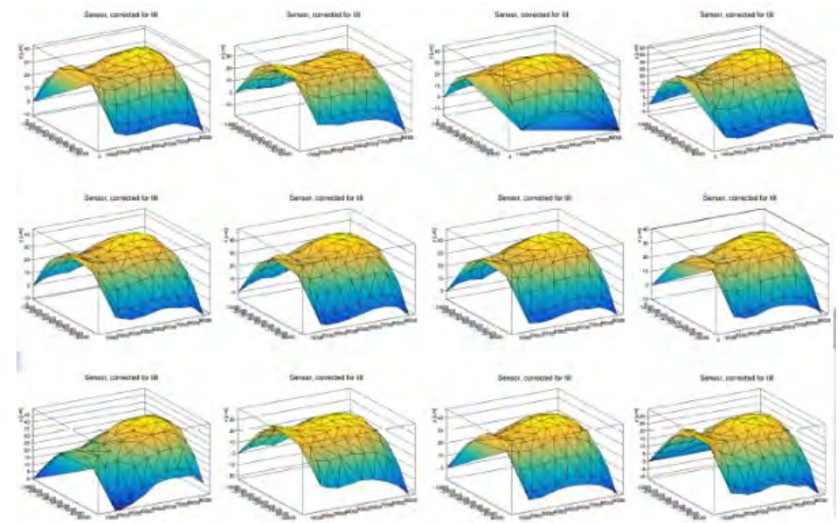


More Metrology Results

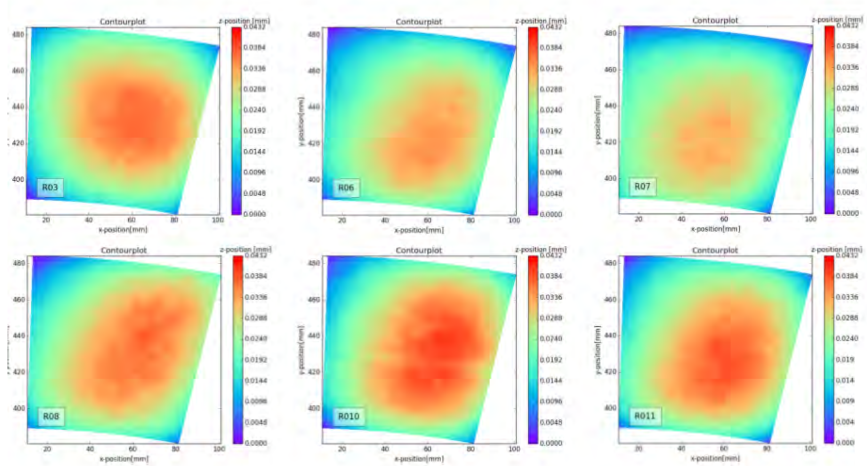
- High consisitency *well* within specification

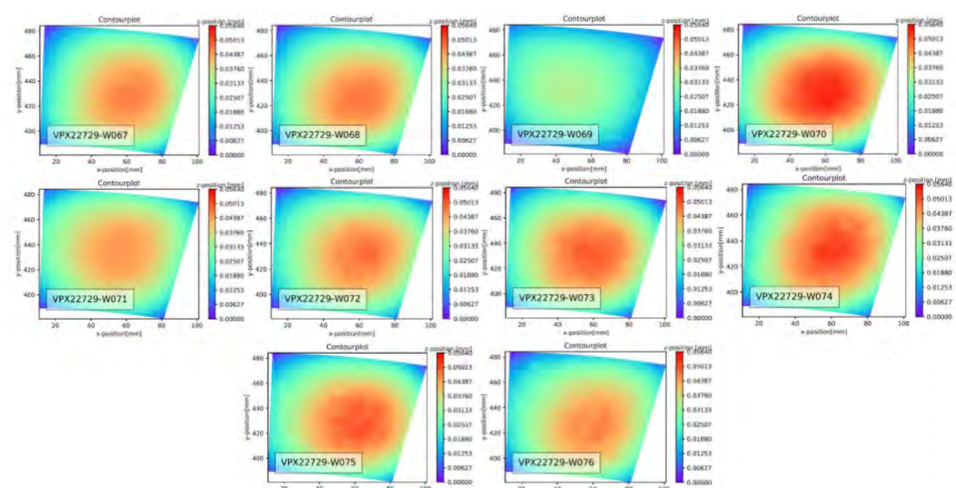






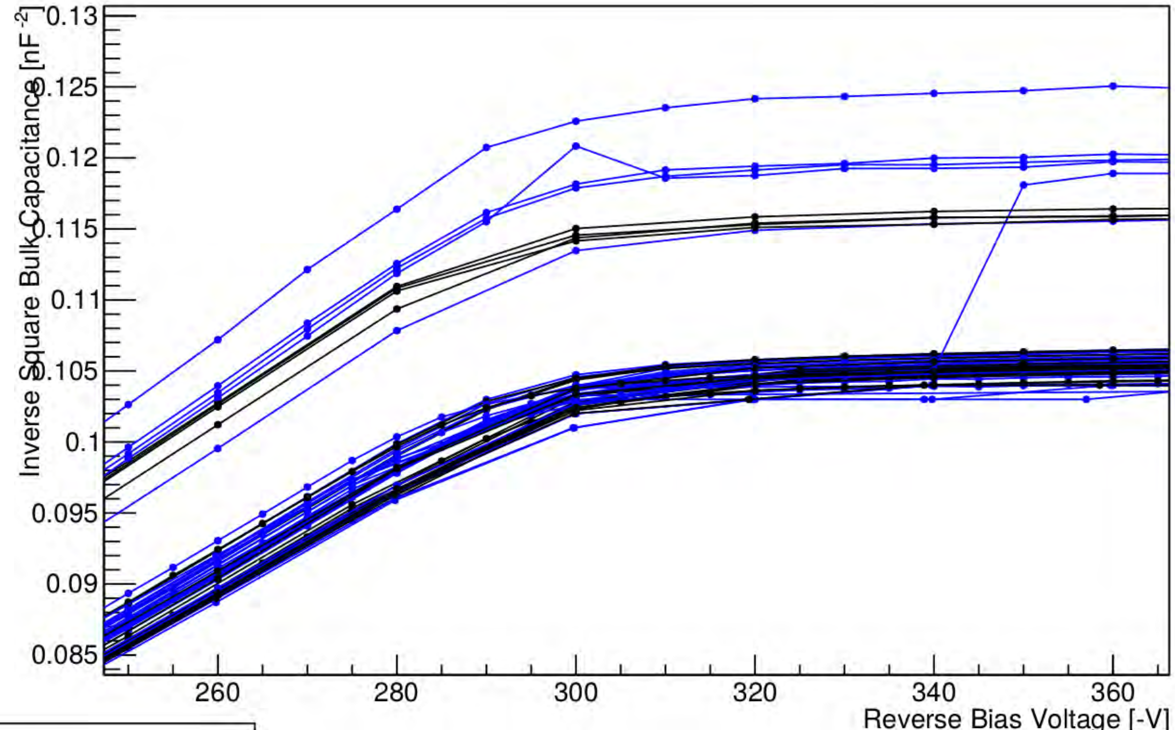
"Turtle-shell" relic believed to be setup related

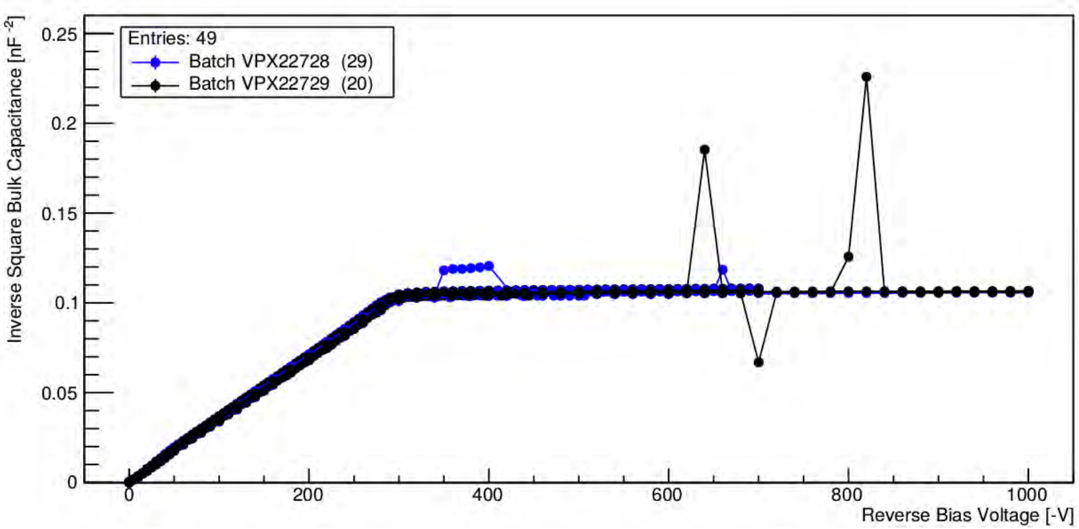


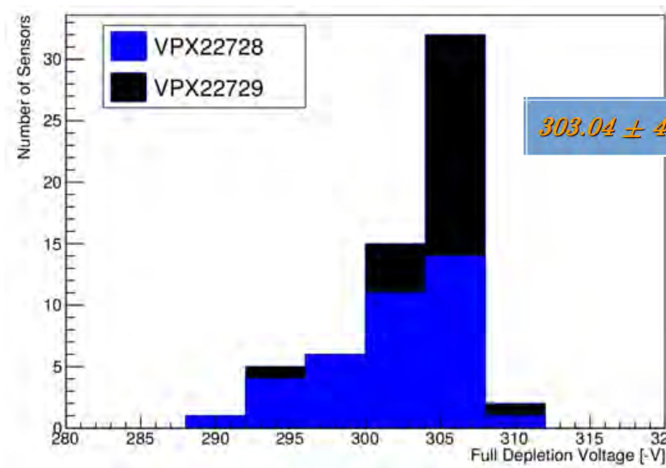


Full Depletion Kink

- Sensors from one institute removed from CV plot due to systematic parasitic capacitance that is not yet fully understood
  - 9 sensors sit above the 49 sensors in the lower curve seen
- This systematic does not affect the full depletion voltage extraction, as seen

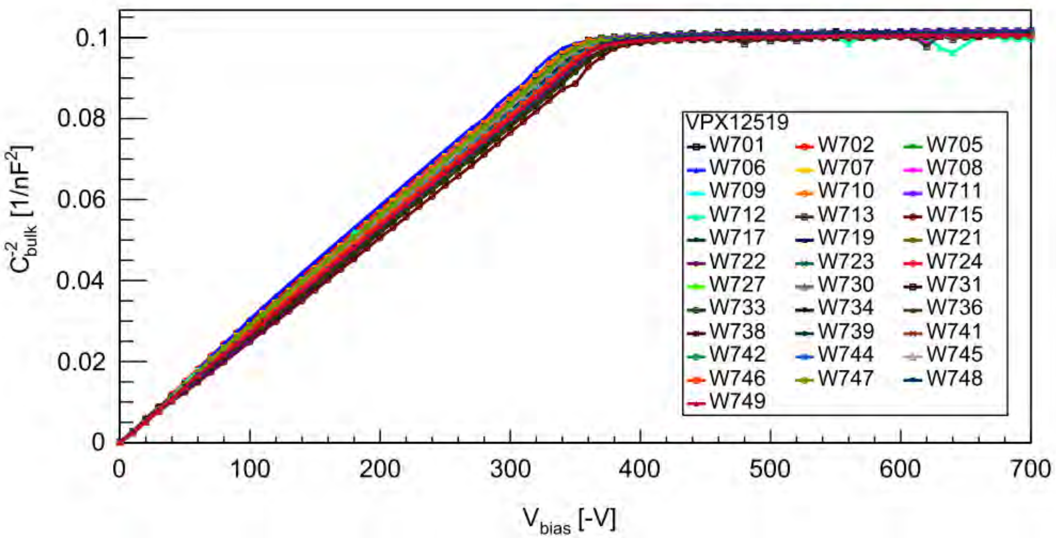




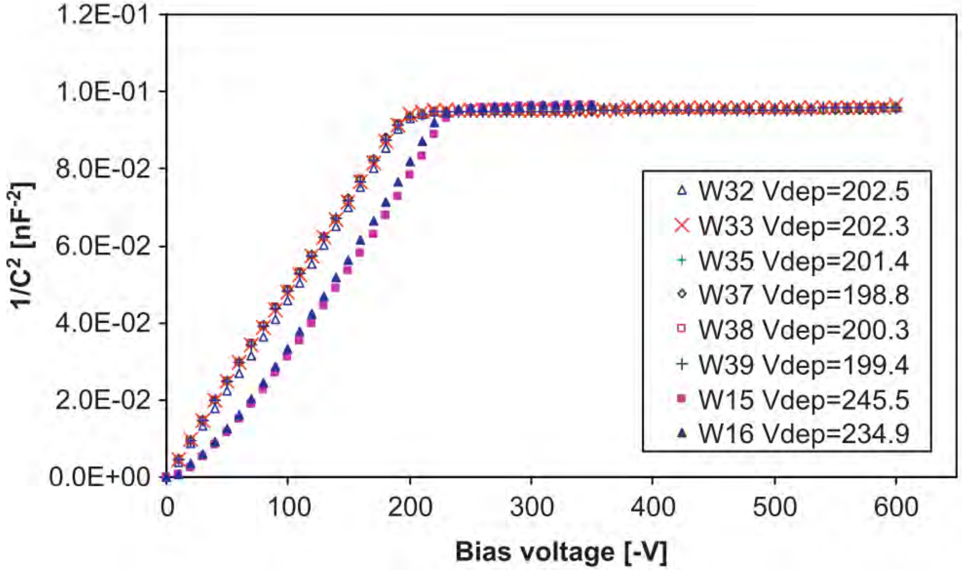


303.04 ± 4.17	~3.0	58 (2)

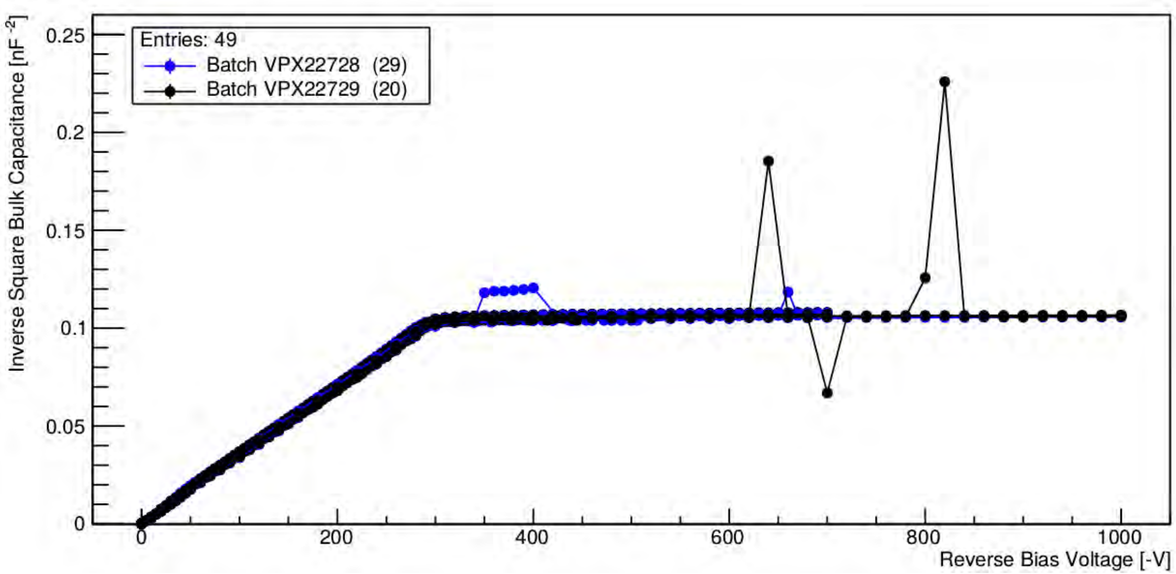
CV Curves (Over the Generations)



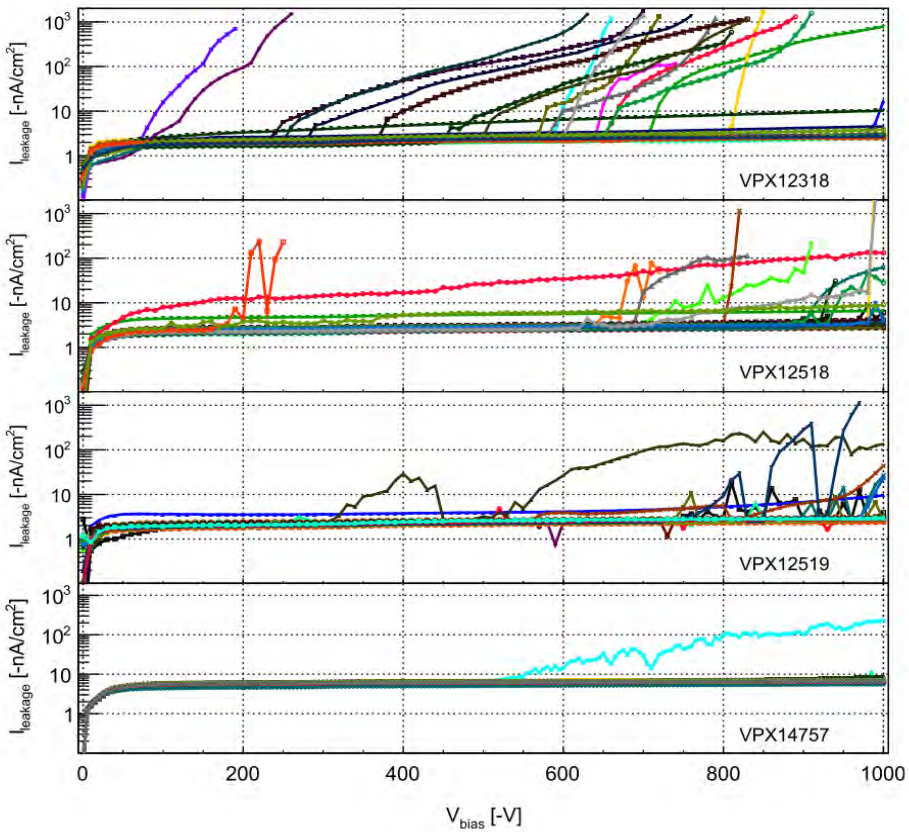
L.B.A. Hommels *et al.*, "Detailed Studies of Full-Size ATLAS12 Sensors". *Nucl. Instr. Meth. Phys. Res. A*, vol. 831, pp. 167–173, 2016.



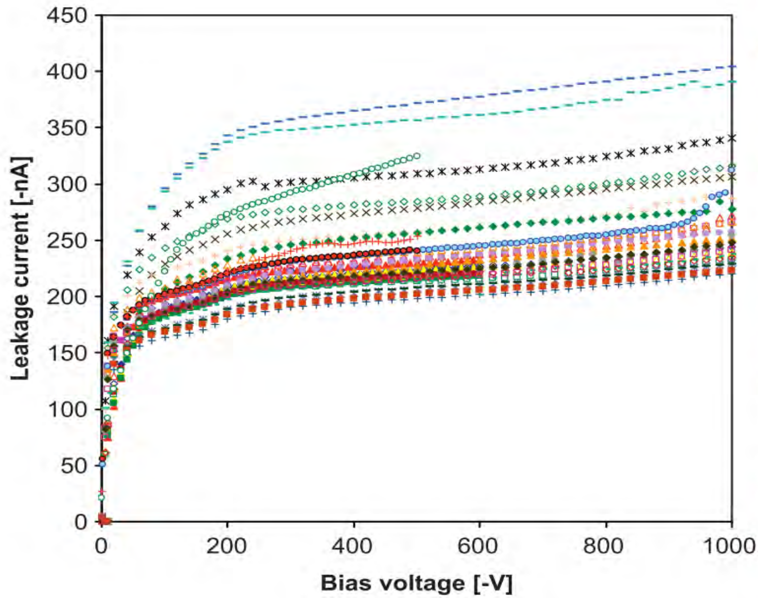
J. Bohm. *et al.*, "Evaluation of the bulk and strip characteristics of lrage area n-in-p silicon sensors intended for a very high radiation environment," *Nucl. Instr. Meth. Phys. Res. A*, vol. 636, pp. S104–S110, 2011.



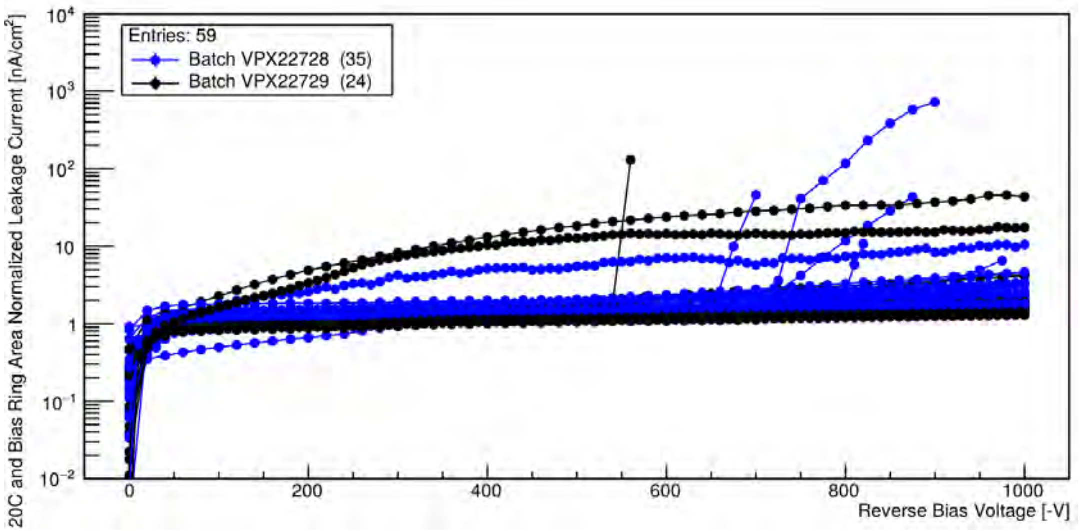
IV Curves (Over the Generations)



L.B.A. Hommels *et al.*, "Detailed Studies of Full-Size ATLAS12 Sensors". *Nucl. Instr. Meth. Phys. Res. A*, vol. 831, pp. 167–173, 2016.



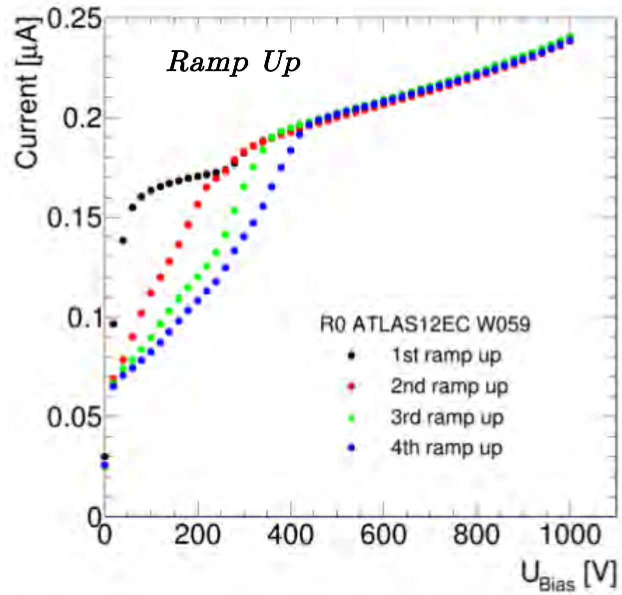
J. Bohm. *et al.*, "Evaluation of the bulk and strip characteristics of lrage area n-in-p silicon sensors intended for a very high radiation environment," *Nucl. Instr. Meth. Phys. Res. A*, vol. 636, pp. S104–S110, 2011.

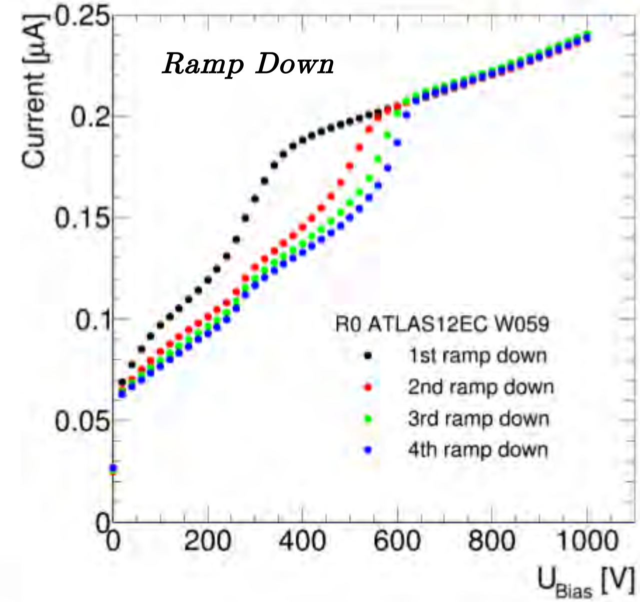


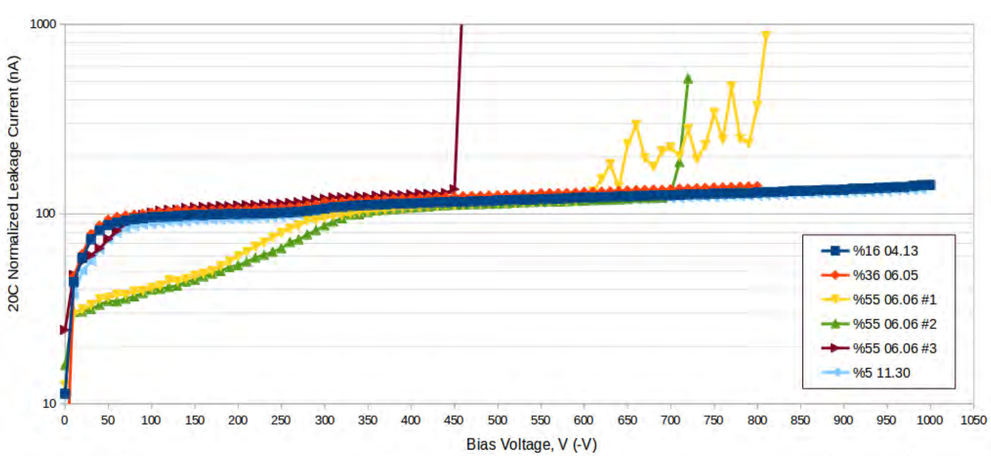
IV Hysteresis

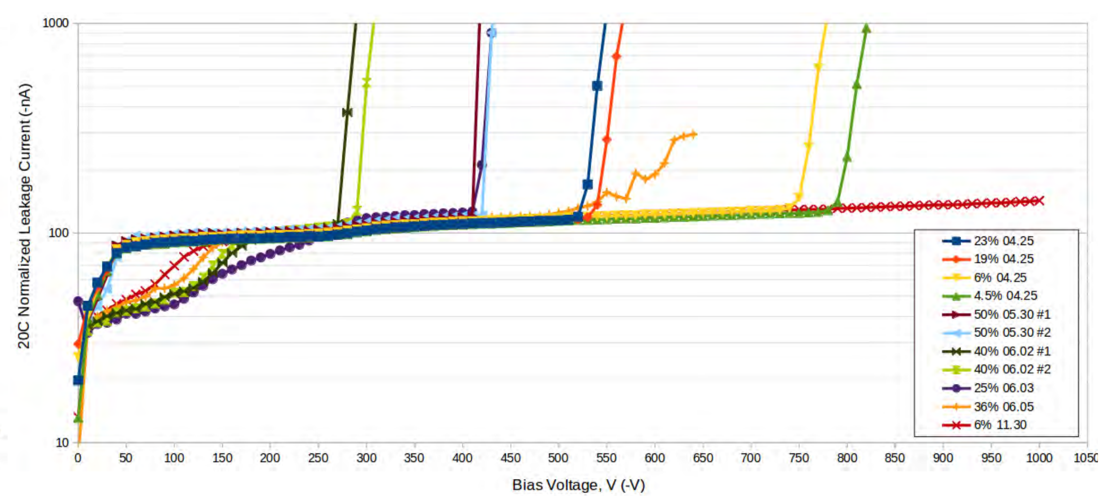
- Observed in sensors with and without strenous humidity history
  - Evidence for bias activated interface states

5-10min Unbiased between Ramps

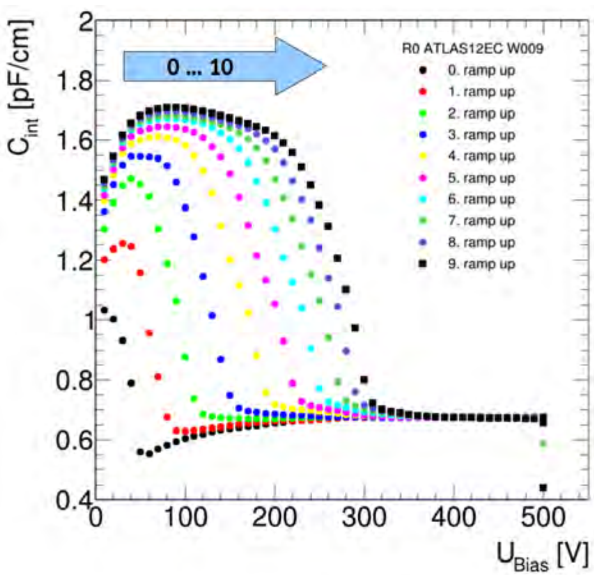


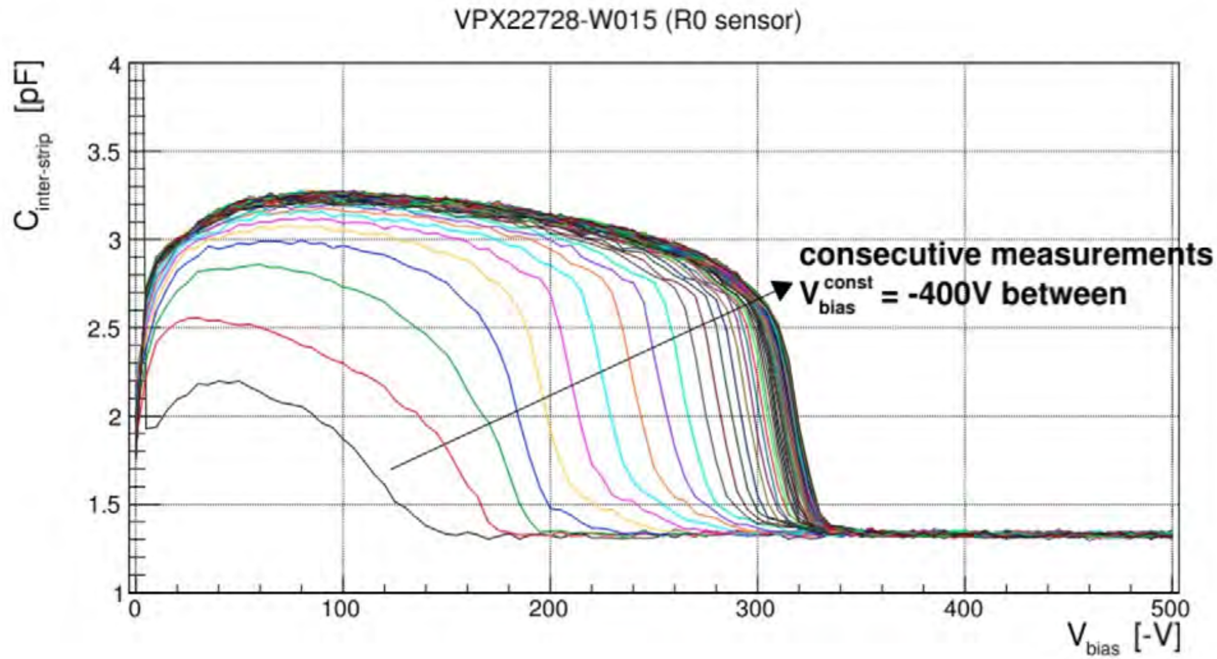


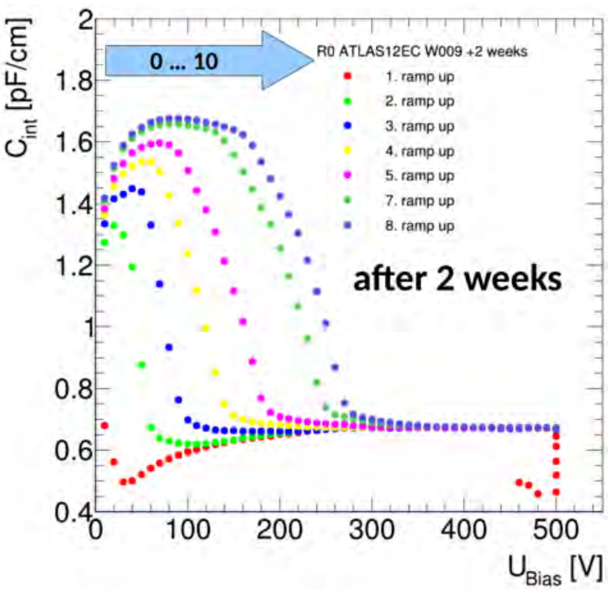


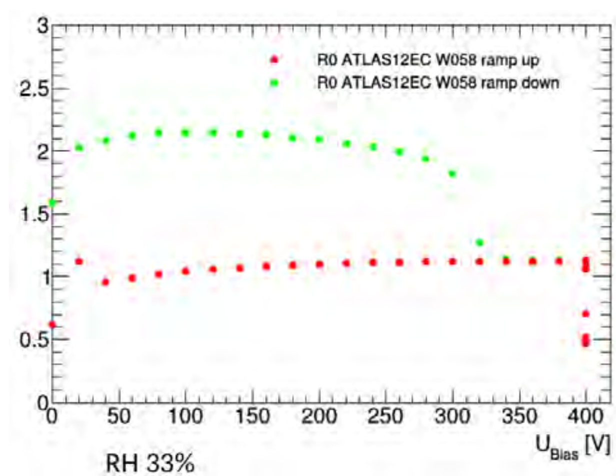


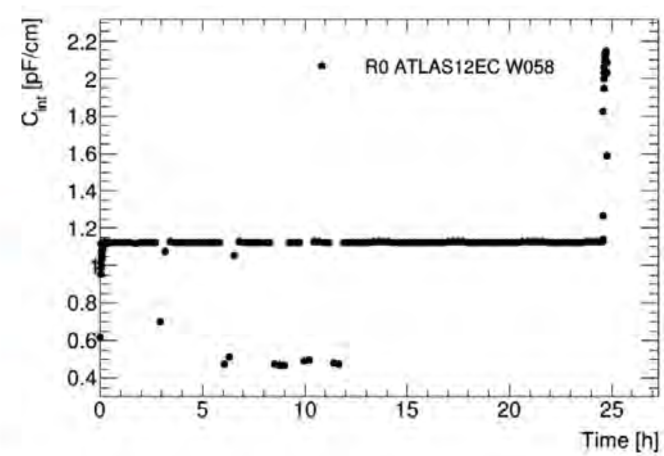
Hysteresis of Interstrip Capacitance





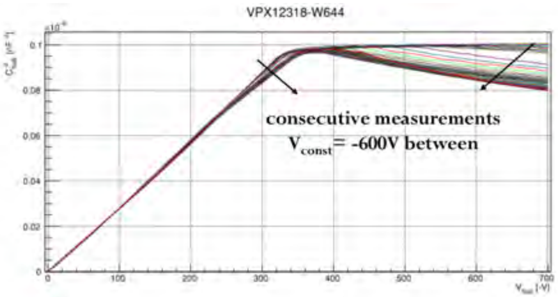


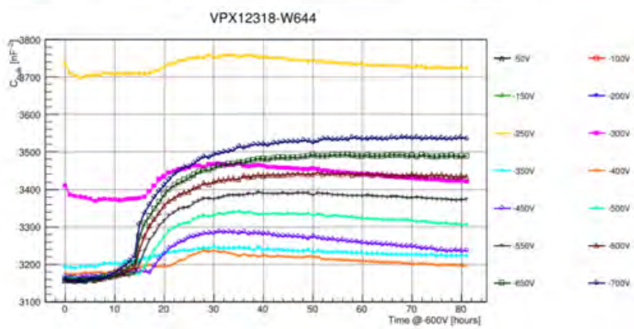


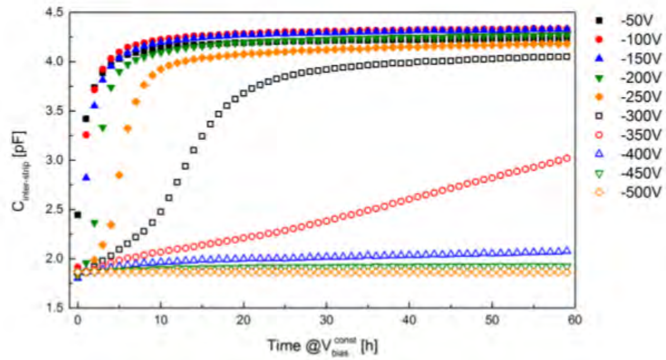


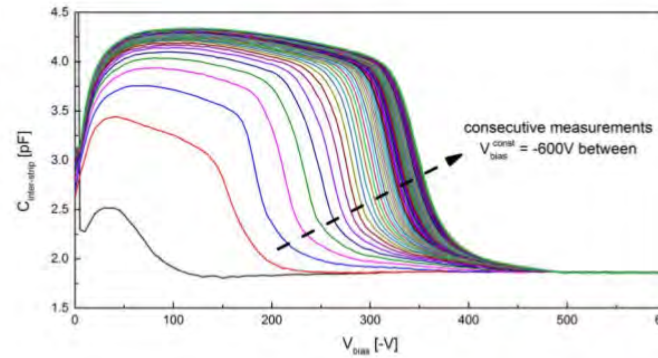
Hysteresis in ATLAS07 and ATLAS12

ATLAS12 Cbulk

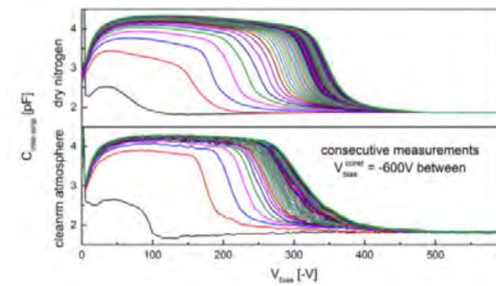






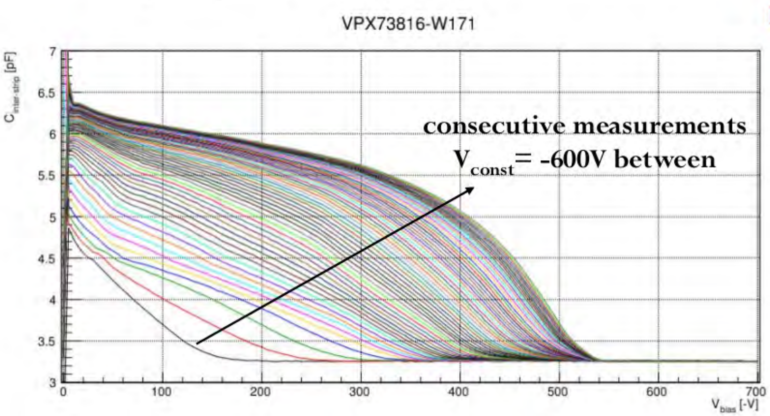


ATLAS12 Cis

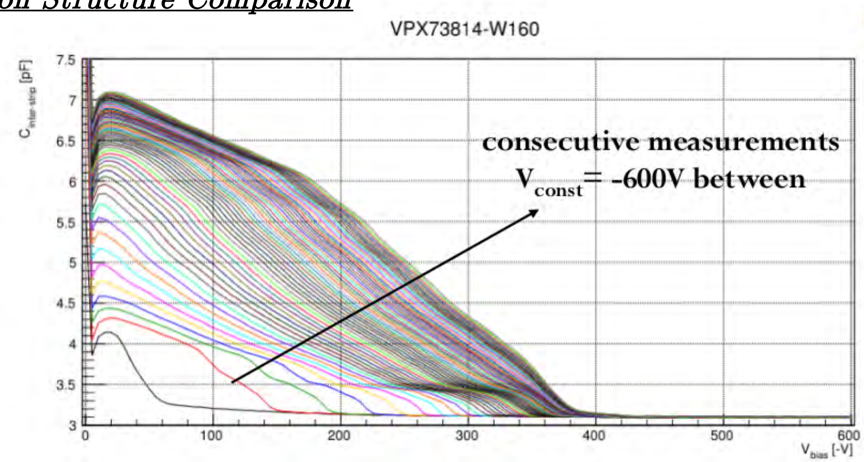


ATLAS07 Cis Strip Isolation Structure Comparison

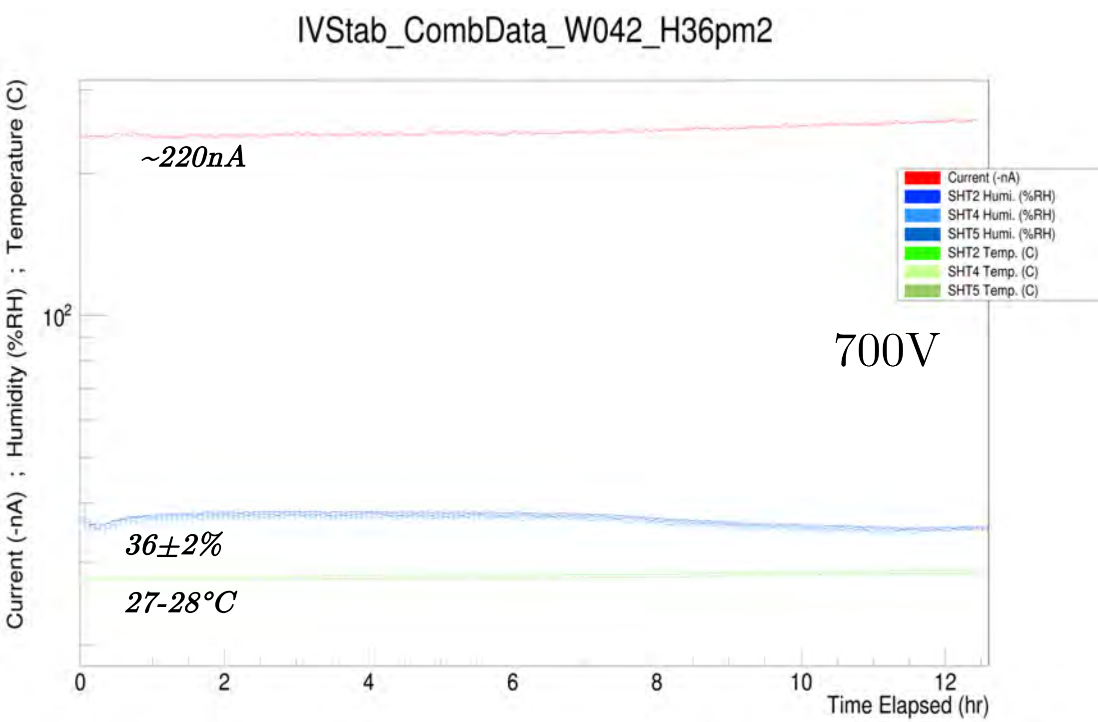
p-stop



p-spray

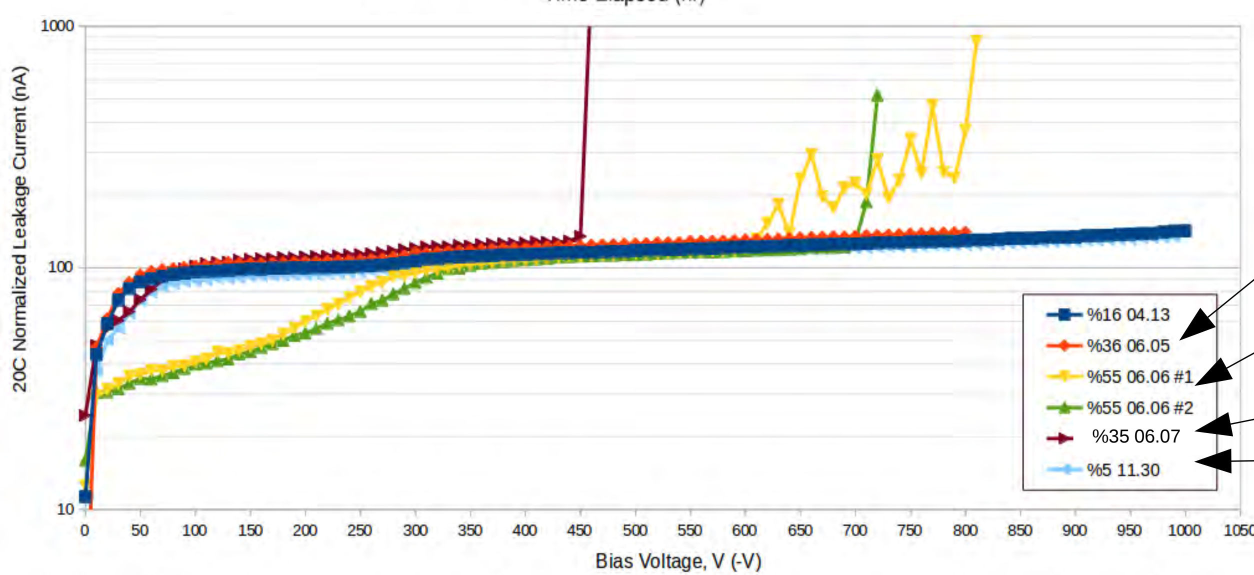


Humidity Sensitivity – A Tale of Two Sensors



- W042 showed good IV character
- Both poor and well behaved sensors (in an IV curve respect) can show humidity sensitivity
- Recovery of sensors after long-term dry storage
  - Complete recovery of microdischarge onset
  - Some hysteresis remains (ion activated interface traps)

(Dry storage = 0.1%)



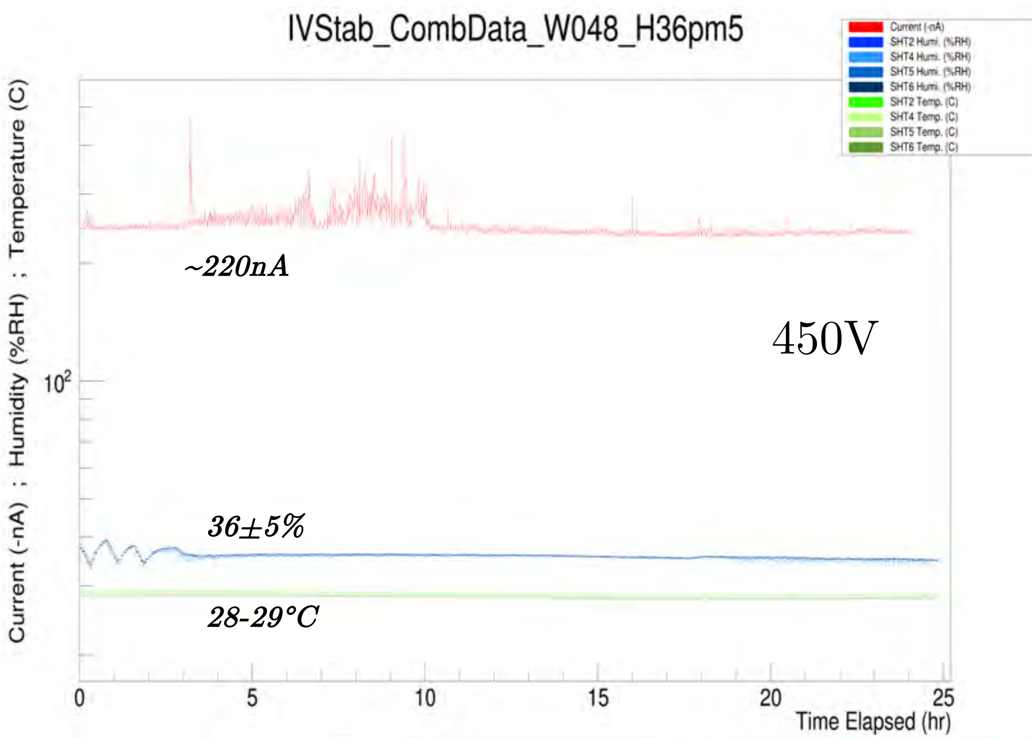
After weeks in dry storage

After 24hr at 700V, 36% and then 26hrs in dry storage.

After 3 hr at 55% and 13hr at 35%

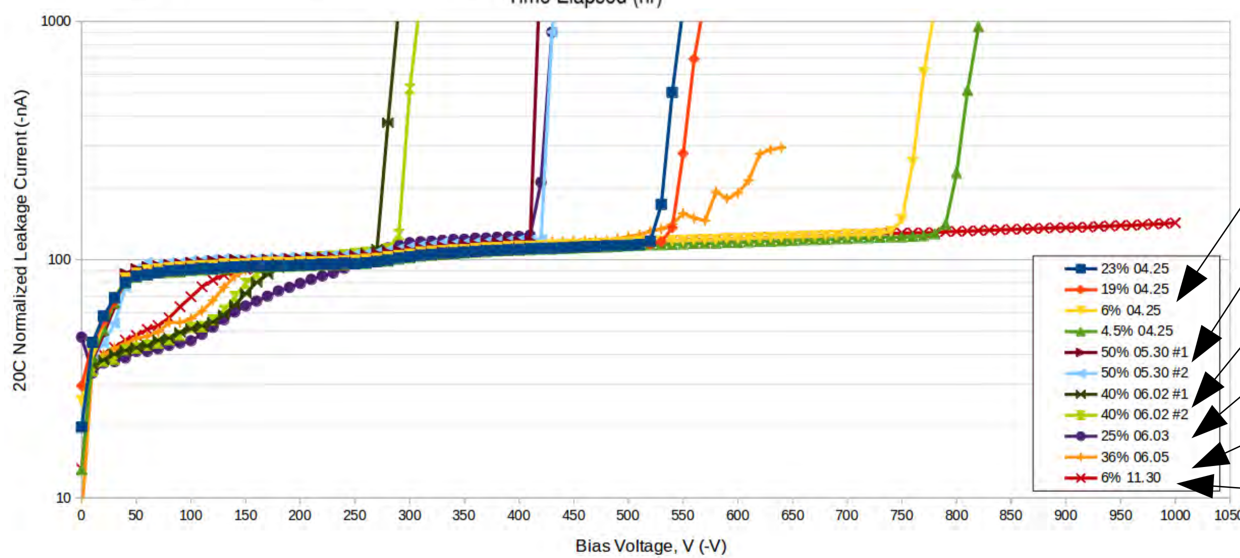
After nearly six months in dry storage

Humidity Sensitivity – A Tale of Two Sensors



- W048 showed early onset microdischarge and a humidity dependency therein
- Both poor and well behaved sensors (in an IV curve respect) can show humidity sensitivity
- Recovery of sensors after long-term dry storage
  - Complete recovery of microdischarge onset
  - Some hysteresis remains (ion activated interface traps)

(Dry storage = 0.1%)



Taken consecutively.

Consecutive after weeks in dry storage

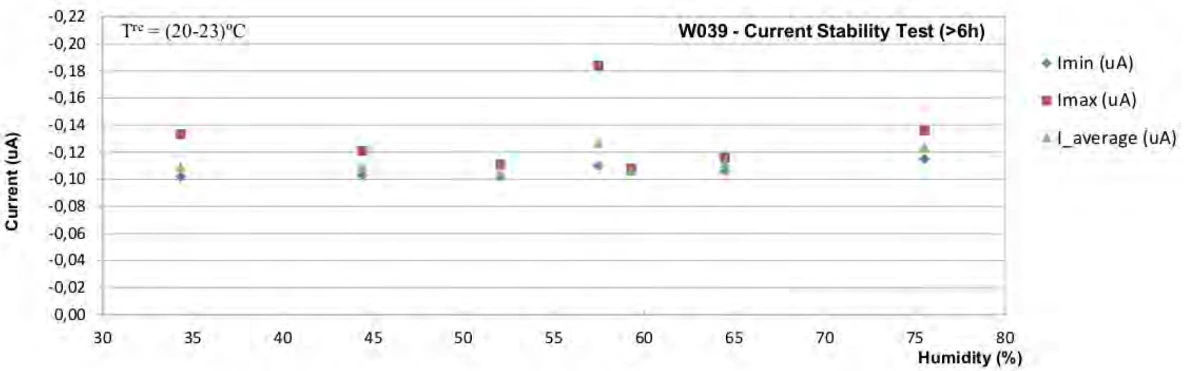
Consecutive after 24hr at 400V, 55% and then 48hr in dry storage

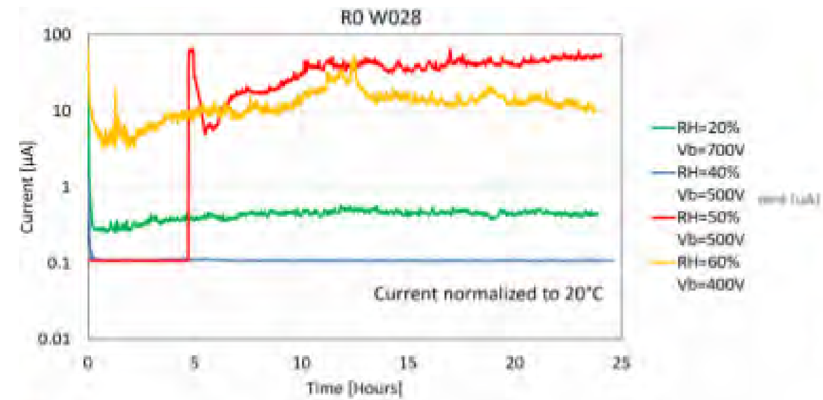
After 24hr at 280V, 40%

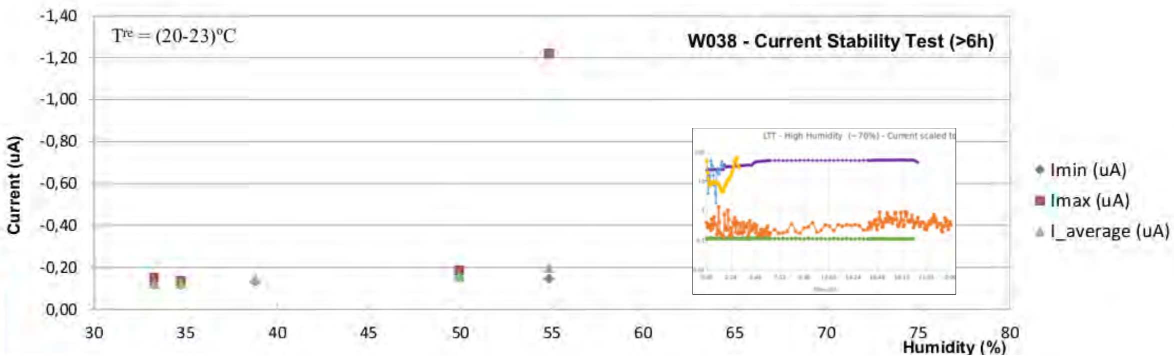
After 24hr at 280V, 25% and 15hr in dry storage

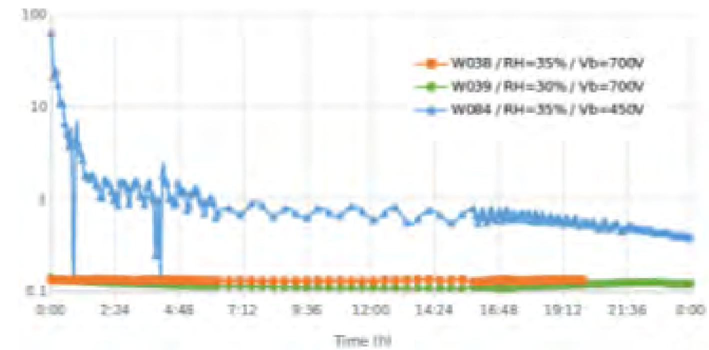
After nearly six months in dry storage

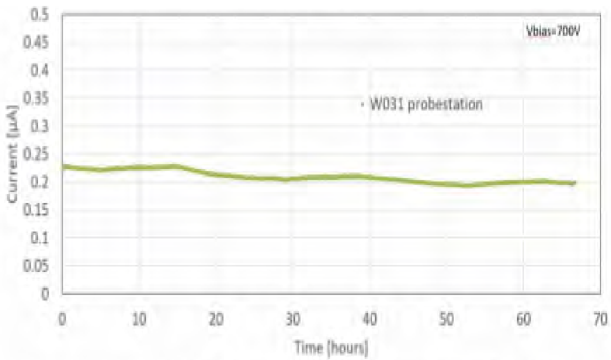
Long Term IV Stability and Humidity

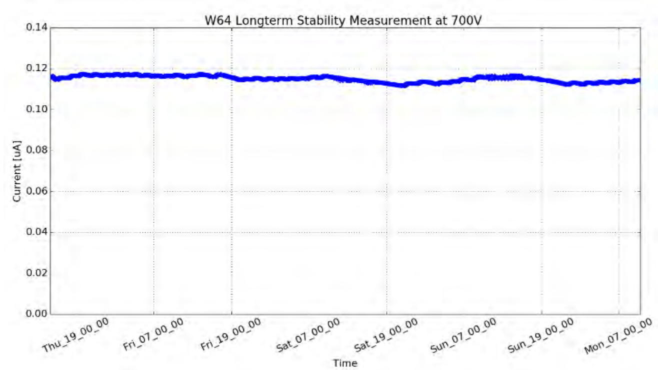


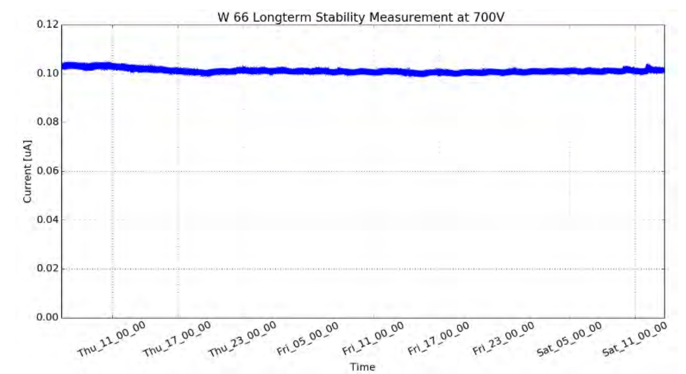






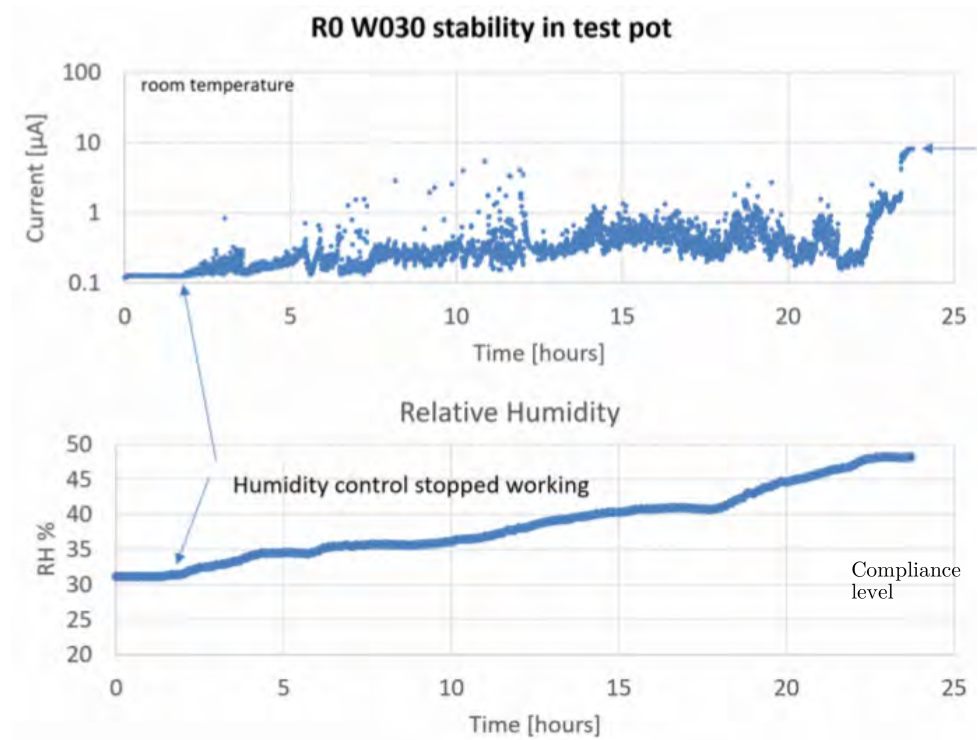


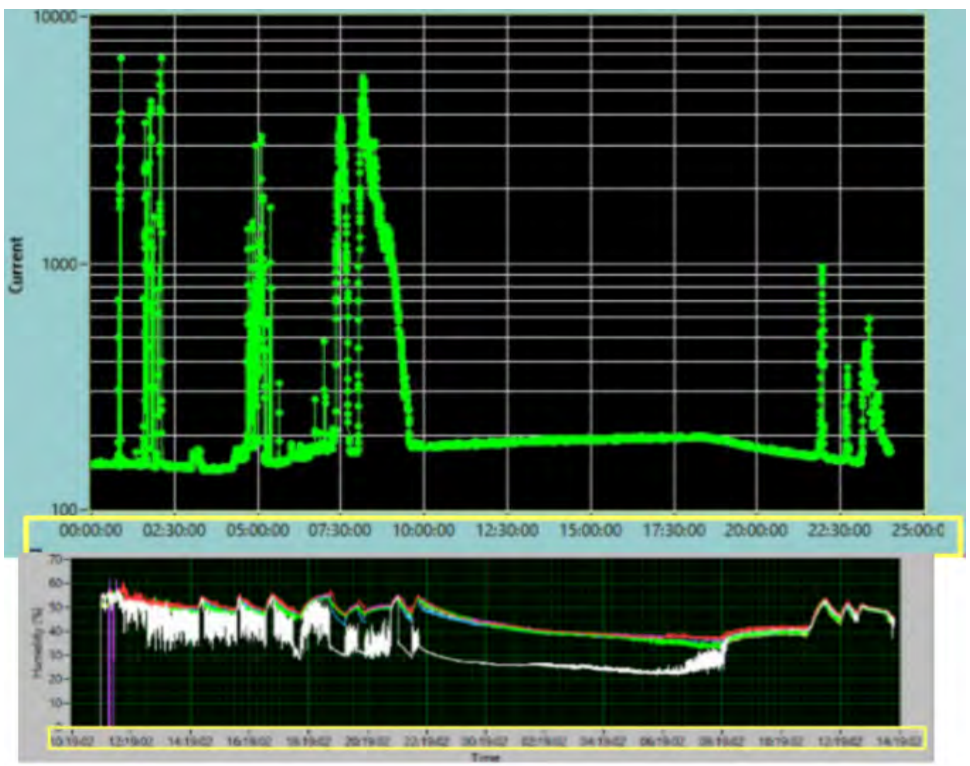




More Evidence for Passivation Issues

- Immediate response to changes in humidity in long term tests





400V

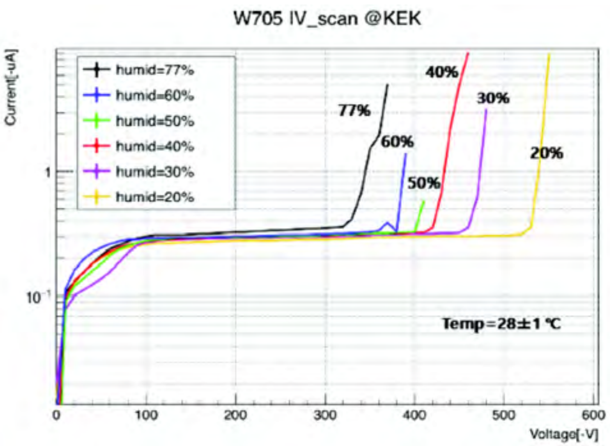
Triple peak at end of run:

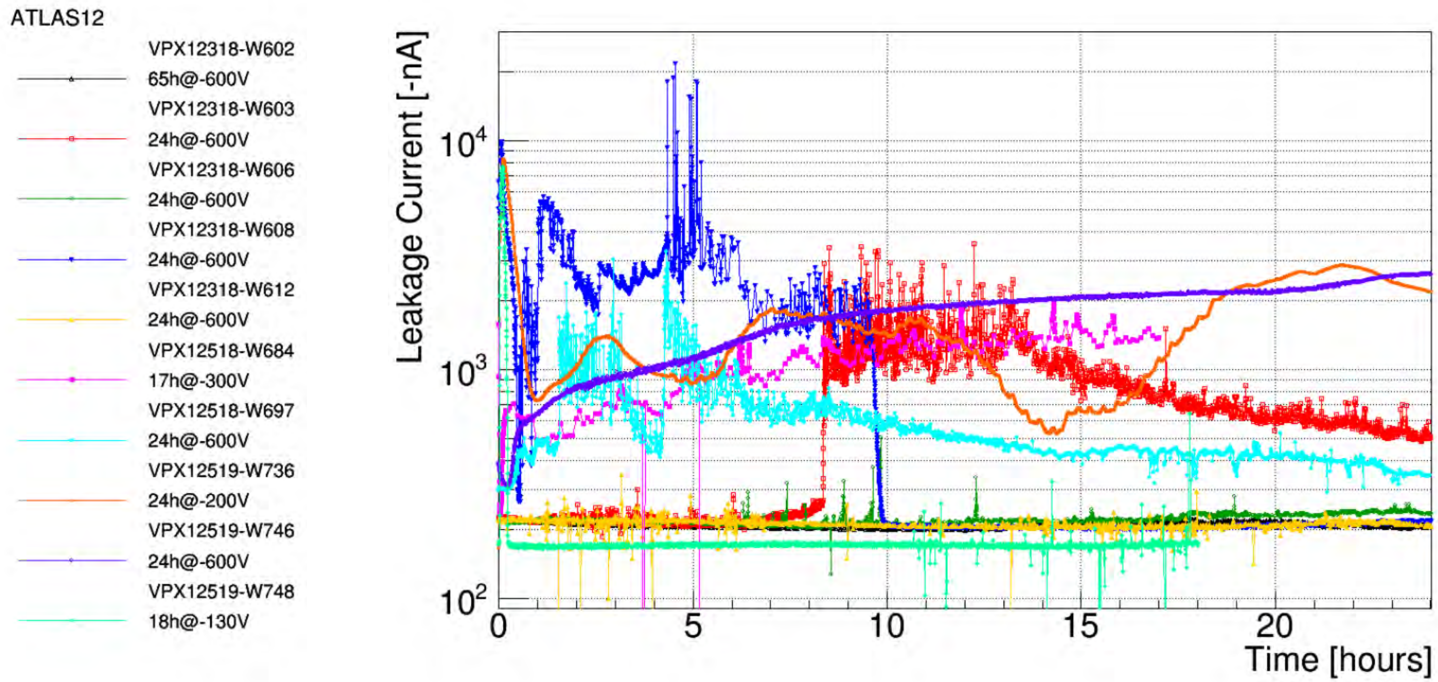
1st peak: ~51.5% up , quick I decrease

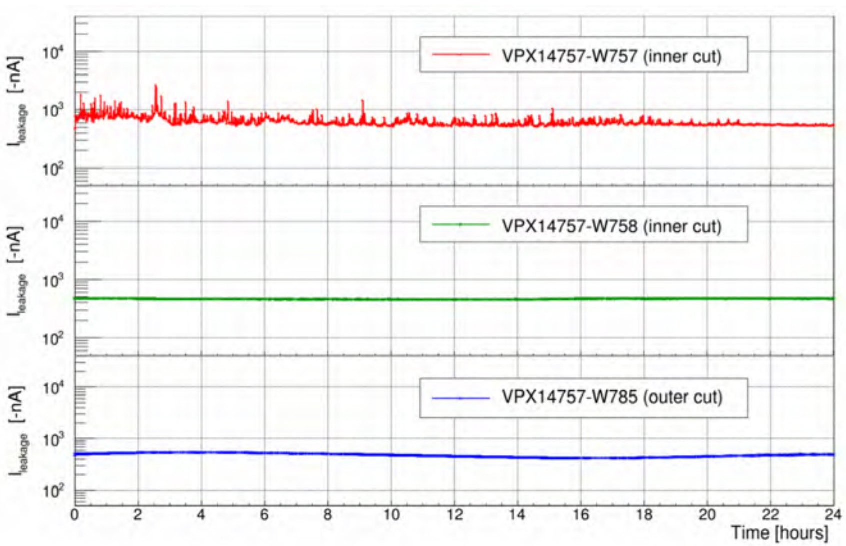
2nd peak: ~50.5% up , quick I decrease

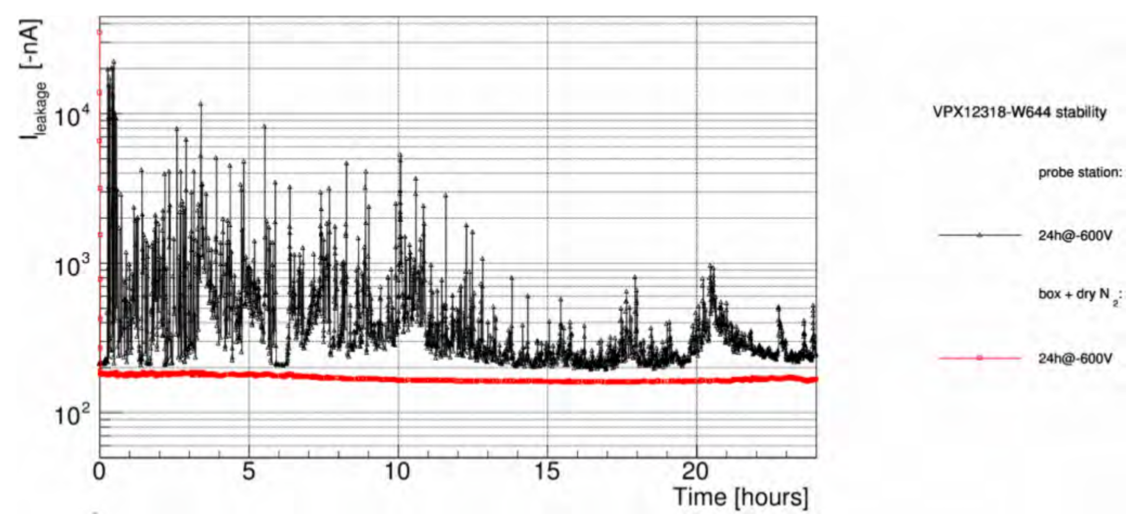
3rd peak: ~49.75% up, leave fan slow to bring down H slow, instability lasts to lower H than with quick fall

ATLAS12 Humidity Sensitivity

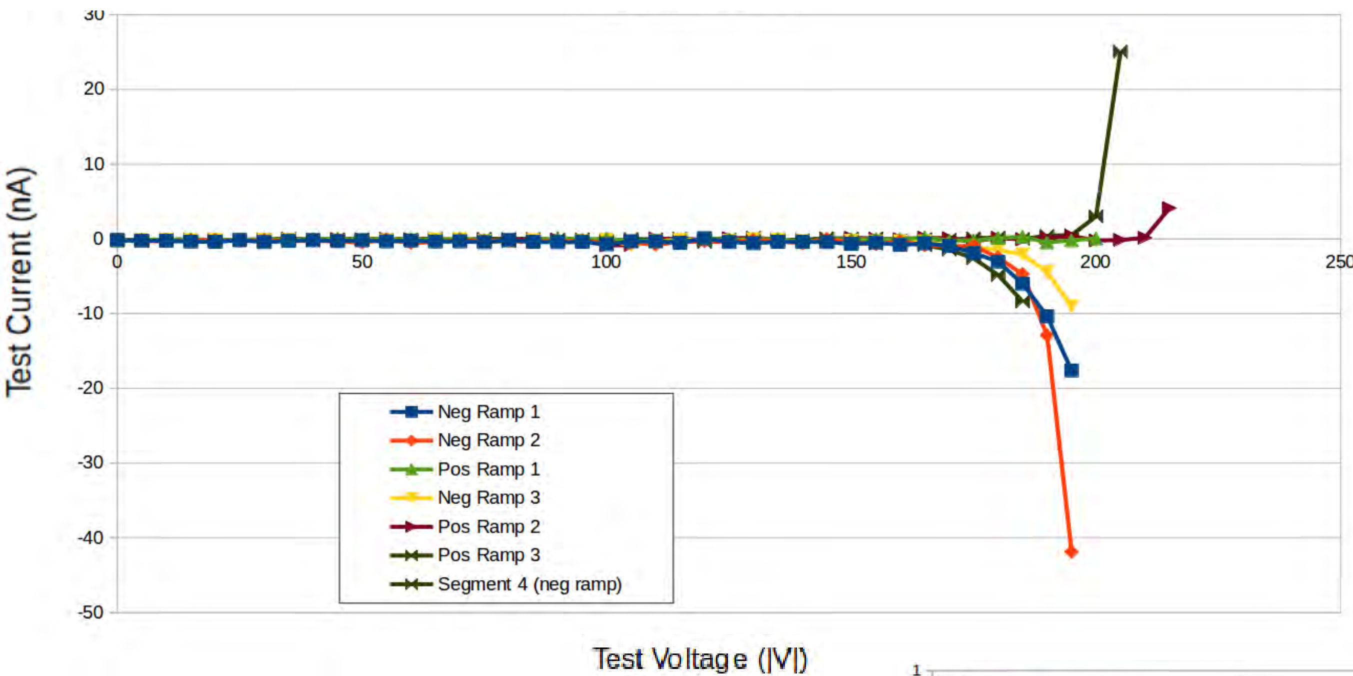








Dielectric Breakdown Voltage

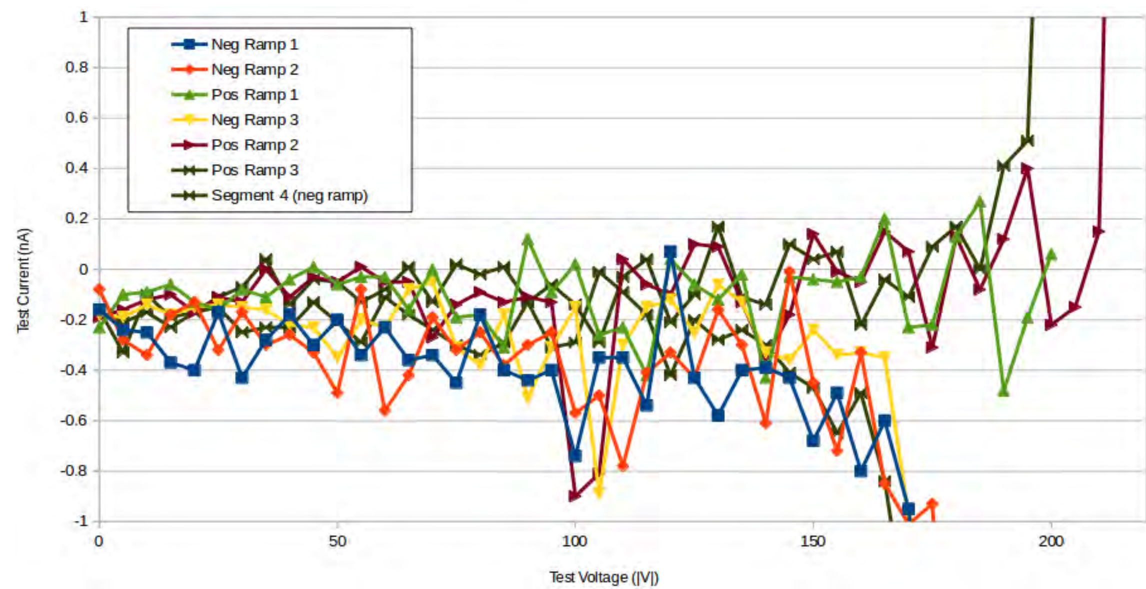


Postive Voltage on Strips:
~200V-210V

Negative Voltage on Strips:
~150V-170V

Specification: > 100V

- Understandable discrepency between negative and positive voltage breakdowns
  - Sensor unbiased, inversion layer opposes the positive strip voltage, reinforces the negative



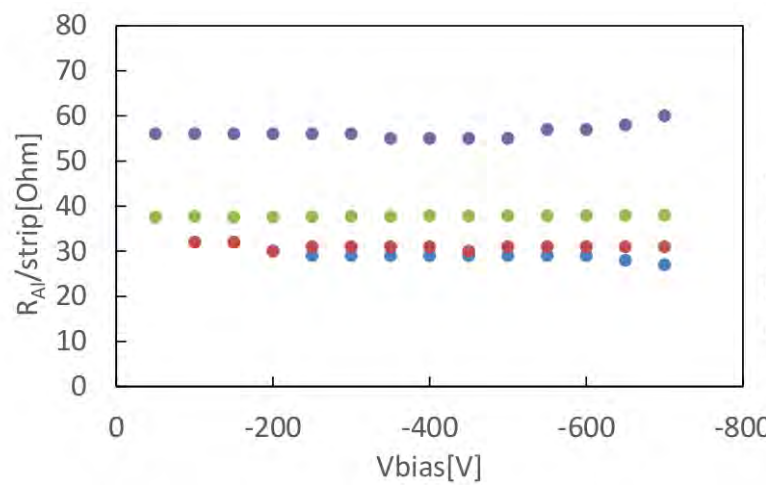
Strip and Implant Resistance

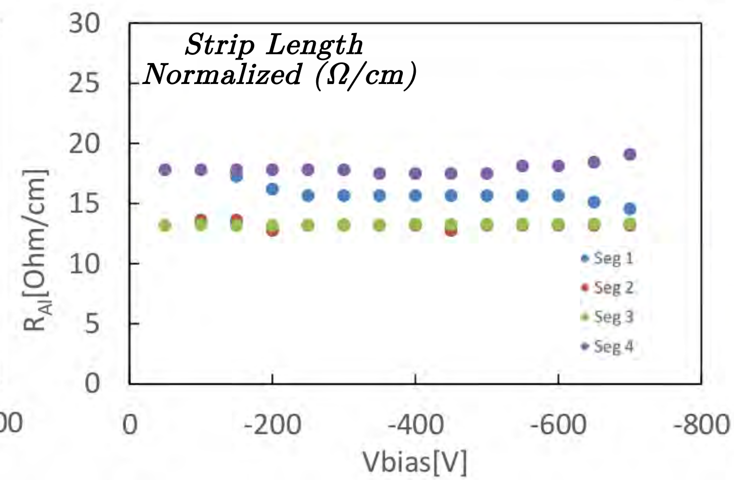
- Must be ‘small’ to maximize signal integrity and consistent for comparable channel response

Aluminum Strip Resistance

Range: 12.1 – 21.05 Ω/cm*
*No. of Strips Measured: 17

Specification: < 30 Ω/cm

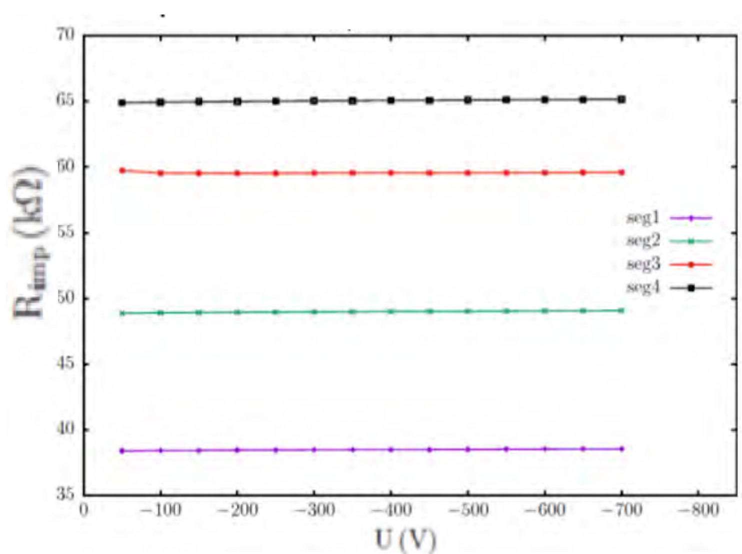


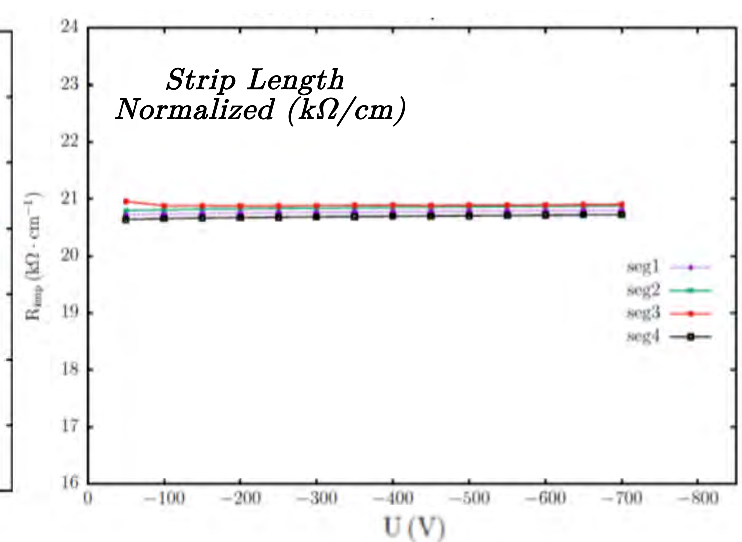


$n^{\pm}$ Implant Resistance

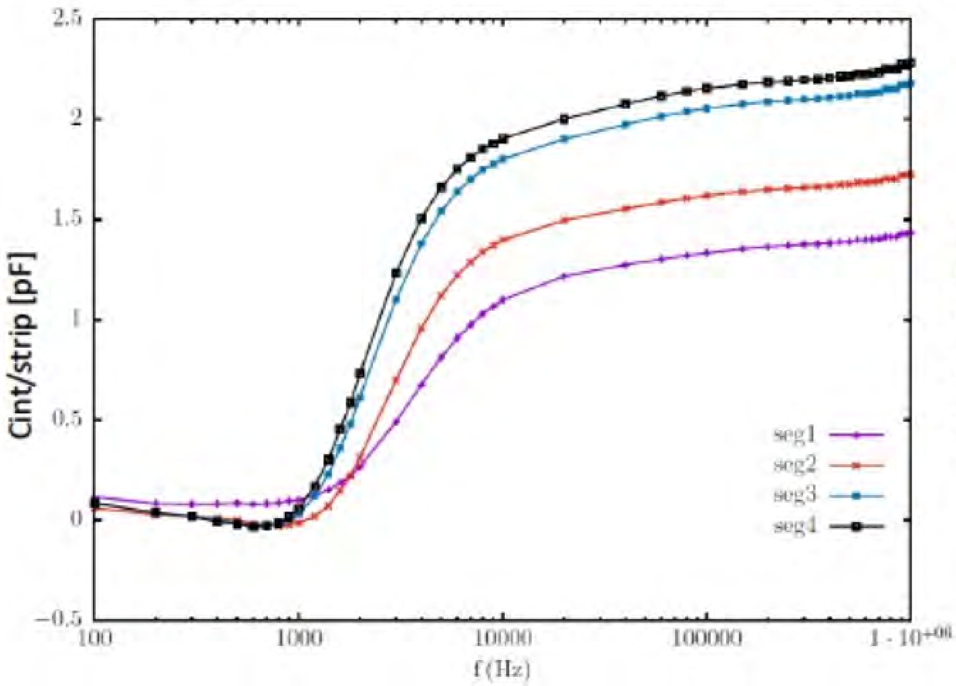
Average: 20.38 ± 0.21 kΩ/cm*
*No. of Strips Measured: 7

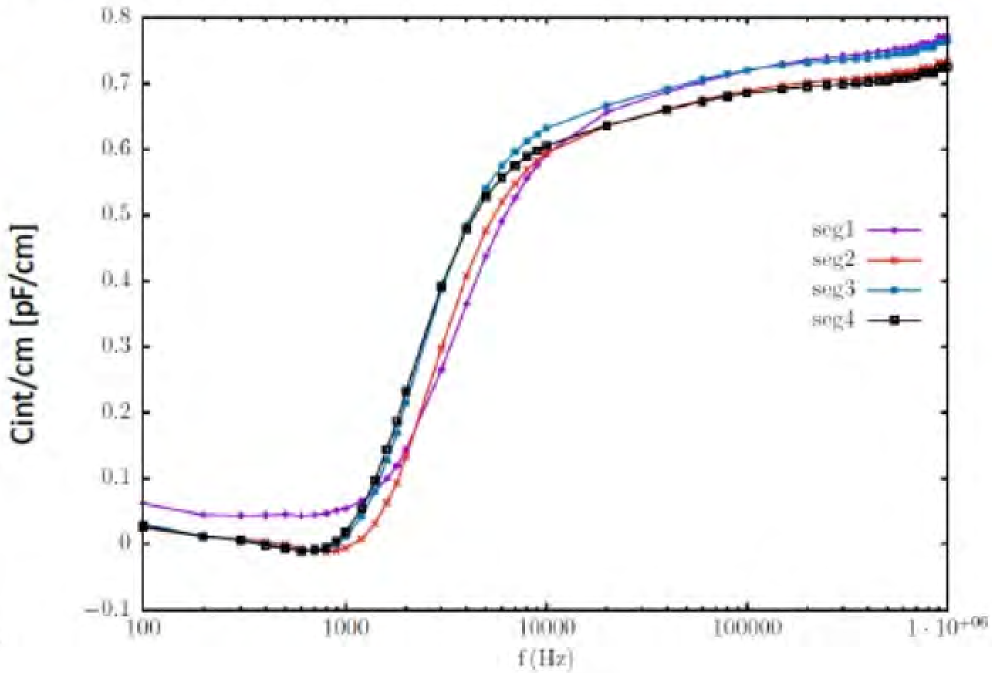
Specification: < 50 kΩ/cm





Frequency Dependence of Interstrip Capacitance





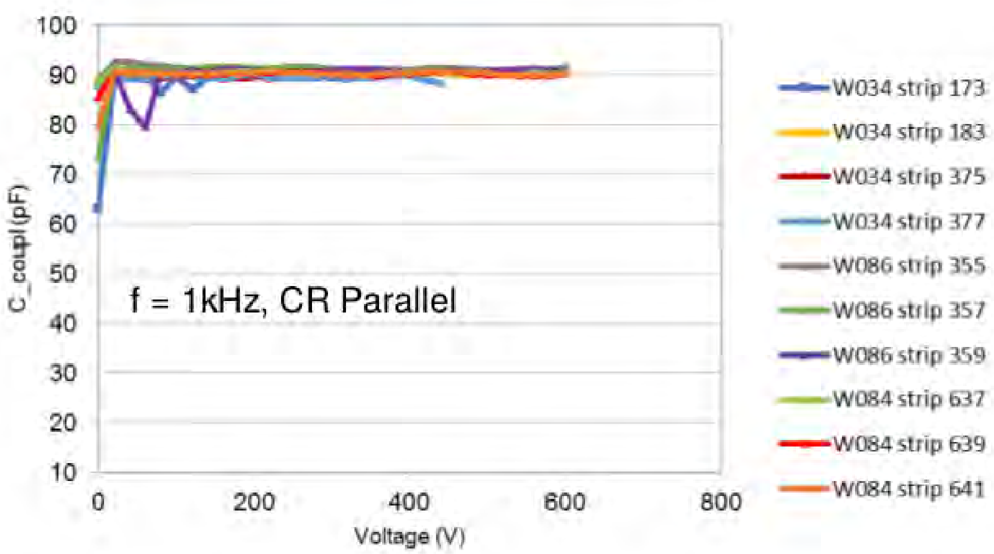
Unirradiated

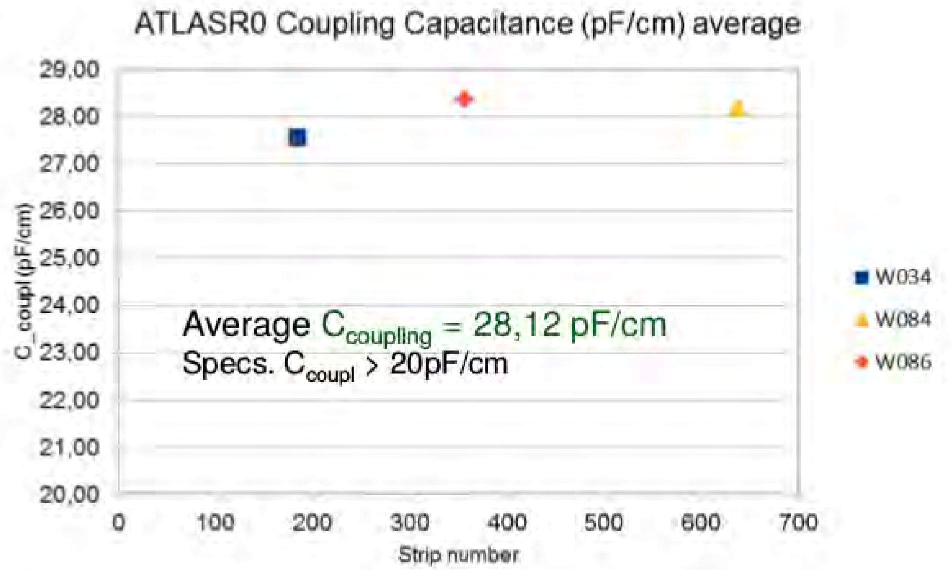
100kHz is chosen as test frequency (sits well into the plateau region)

More Measurements of Coupling Capacitance

Segment	1	2	3	4
Number of Measurements	17	4	3	4
Range (pF)	46.42-46.95	58.21-59.02	69.75-72.28	76.24-77.42
Average (pF)	46.70	58.51	70.90	77.09
Average (pF/cm)	25.24	24.90	24.88	24.55

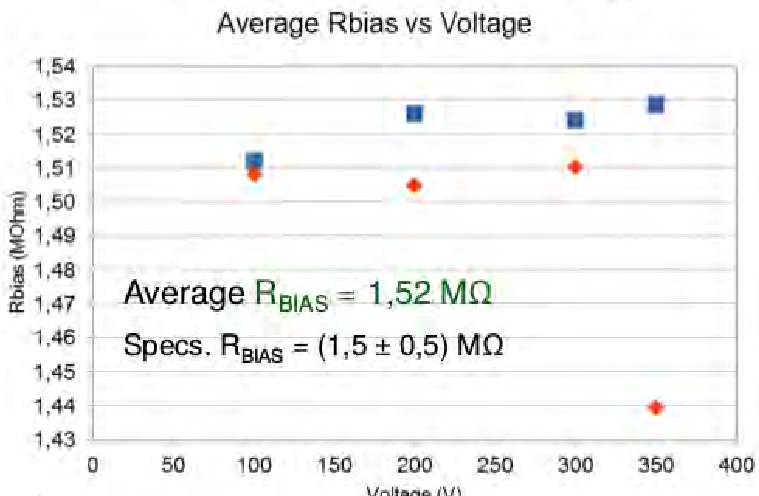
Sensor ID	C_{coup} [pF]
W031	24-25
W034	27.55
W084	28.19
W086	28.37





More Results for Bias and Interstrip Resistance

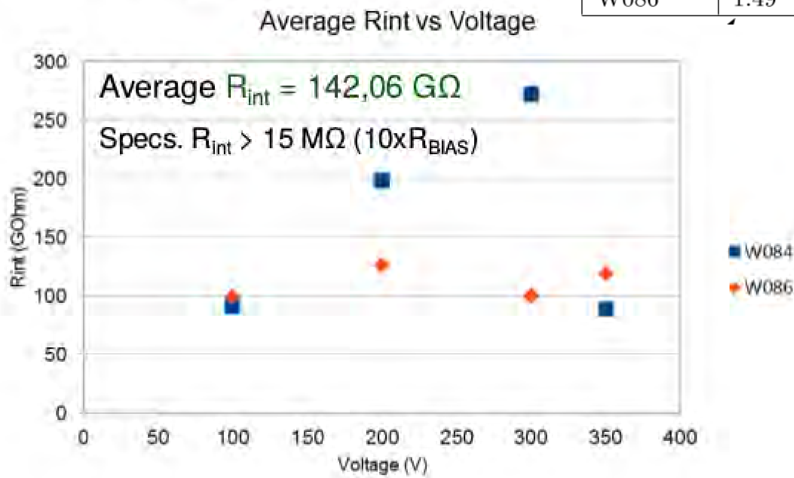
- **Polysilicon Bias Resistor (R_{BIAS})**

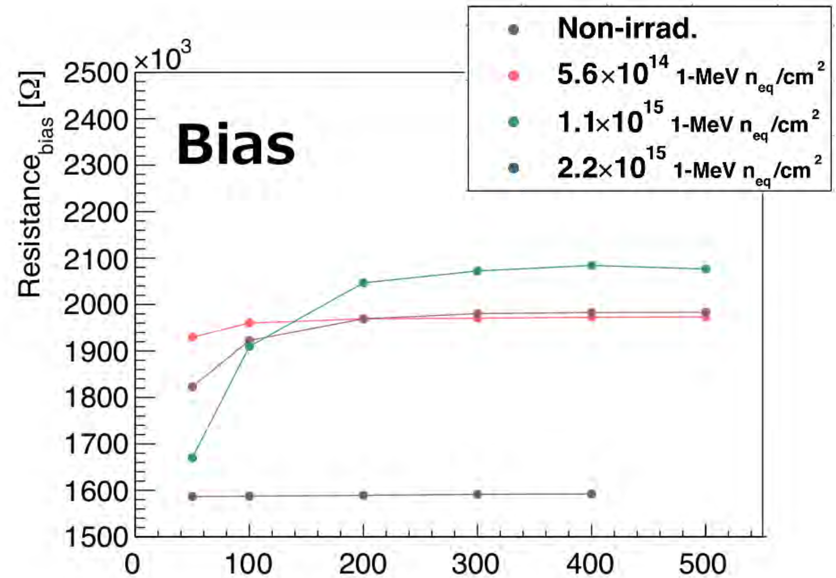


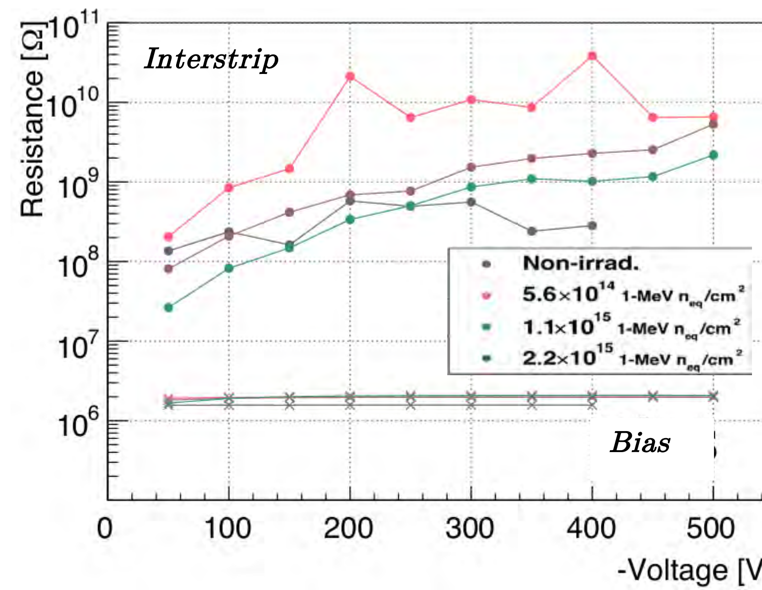
3 random strips per sensor

Sensor ID	R_b [MΩ]	R_{is} [GΩ]
W031	1.47	10-120
W084	1.52	271
W086	1.49	99.8

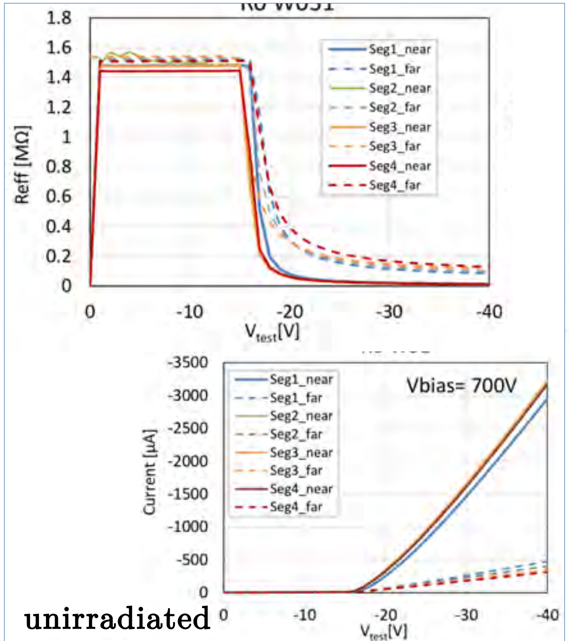
- **Interstrip Resistance (R_{int})**

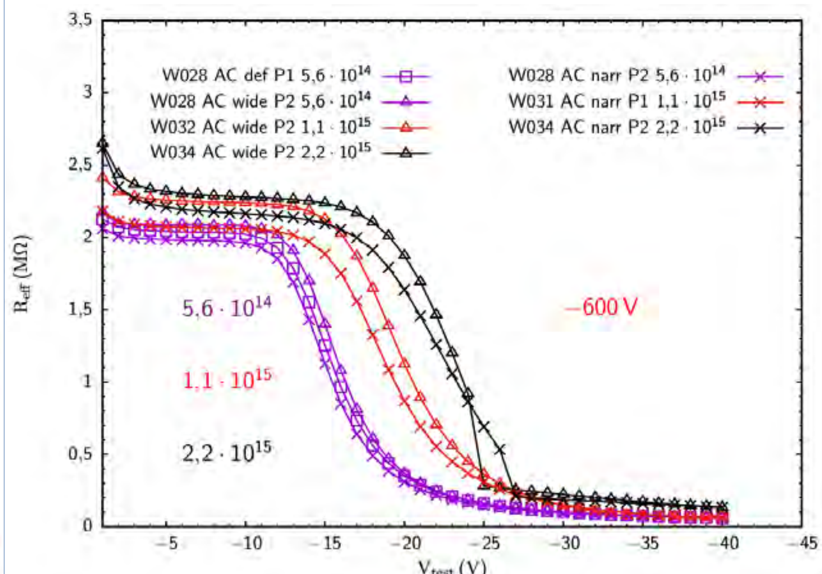


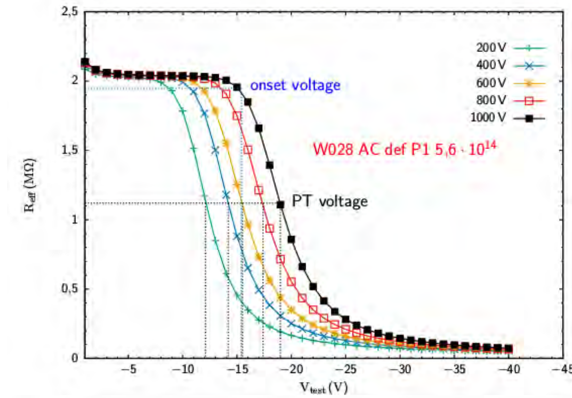


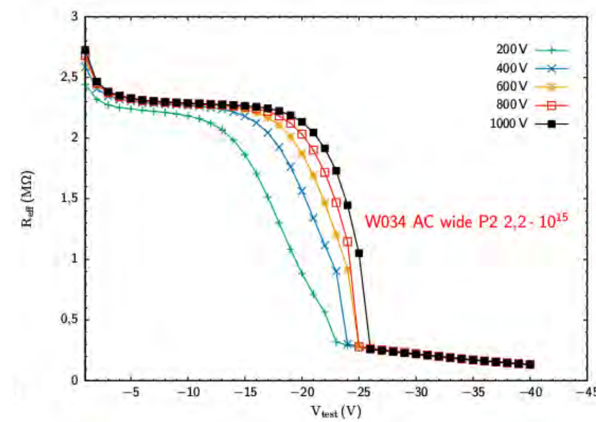


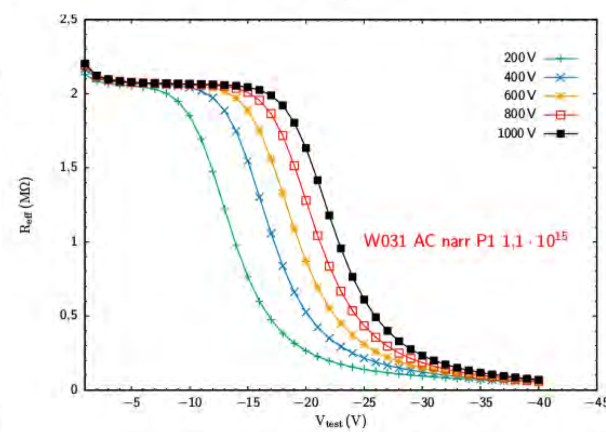
(Irradiated) Performance of the PTP

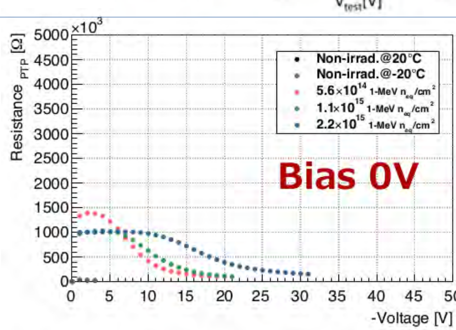


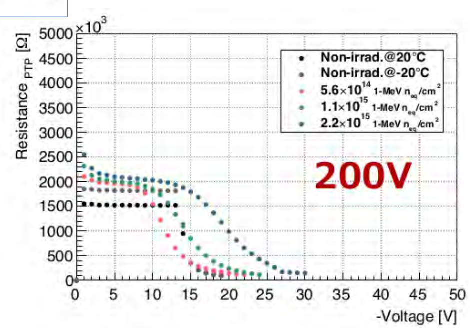


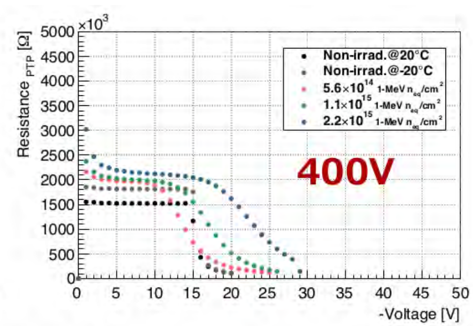


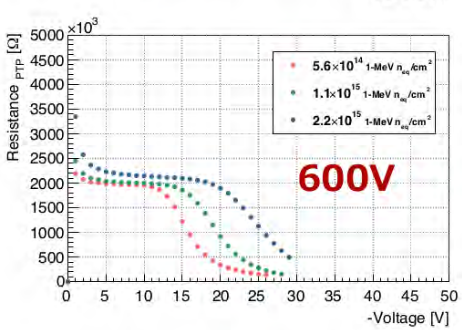


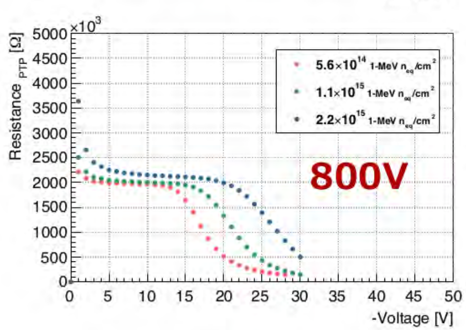


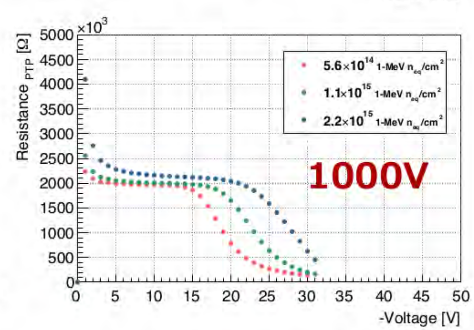












Irradiated Performance of the Interstrip Capacitance