Identification and Recovery of ATLAS18 Strip Sensors with High Surface Static Charge

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Outline

- Overview of QC test suite
- The general trend of recoveries throughout production
- Summary of the static charge issue
- Association of static charge with specific test failures; IV and Strip test
- Recovery methods and examples of recovery

- A change by the vendor: new packaging material

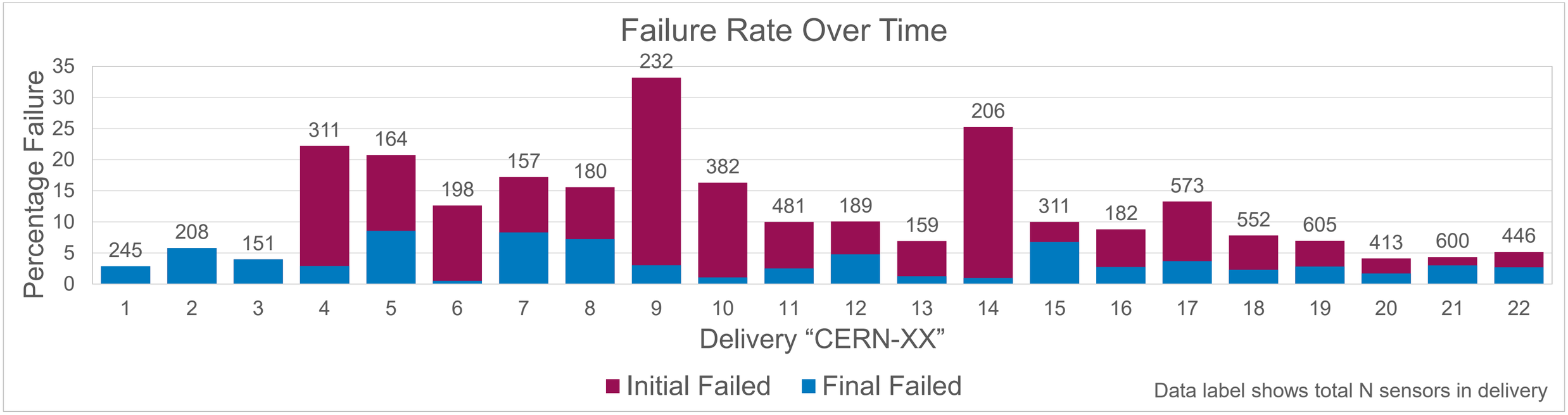
- Additional related information can be found in three posters:
  - *Analysis of the results from Quality Control tests performed on ATLAS18 Strip Sensors during on-going production* – Paul S. Miyagawa
  - *Understanding the Humidity Sensitivity of Sensors with TCAD Simulations* – Ilona Ninca
  - *Long-term humidity exposure of ATLAS18 ITk strip sensors* – Vitaliy Fadeyev

Quality Control (QC) Test Suite

- Mechanical Tests (performed on every sensor):
  - Visual inspection (VI) – Sensor is inspected under microscope for scratches, chips, and other forms of visual damage
  - Metrology – Total sensor bow and thickness is measured across the sensor surface
  - Visual Capture – Total sensor surface is imaged using hi-res camera, images archived in high volume storage area
- Electrical Tests (performed on every sensor):
  - IV – Current-voltage response measured from 0 to -700V bias in 10V steps, 10s delay; short stability measurement “hold steps” at the end ~30s
  - CV – Capacitance-voltage response measured from 0 to -500V in 10V steps, 5s delay
- Electrical Tests (performed on a fraction of sensors):
  - Long Term Stability (LTS) – Sensor is biased to -450V, current is read out every 2 min for a period of 40 hours (~20% batch sample)
  - Strip Test (ST) – Sensor is biased to -150 – -250V. Each individual strip is probed; 10V and then 100V is sourced to the strip while the strip leakage current is measured; Series measurement of the bias resistance and coupling capacitance is performed via LCR meter (>10% batch sample)

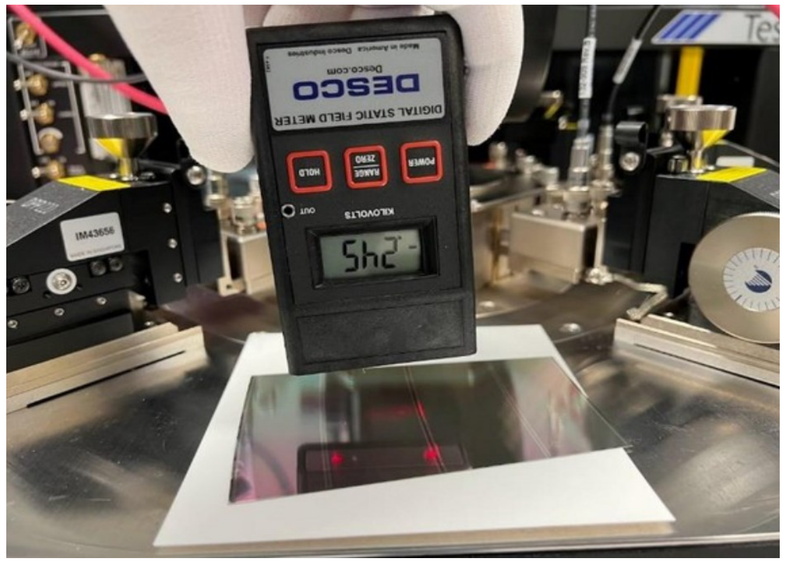
Failures & Recoveries

- At the start of production, failures were low (modulo a rejected batch from second delivery due to bad p-stop doping)
- Need for recovery became apparent around CERN-04 delivery
  - Initially a significant fraction, gradually reduced over time; especially last few deliveries
- Final fraction of failures has been quite consistently low, thanks to recovery efforts
- Decreasing fraction of sensors requiring recovery is still essential:
  - less sensor handling at QC sites,
  - less effort/manpower required for recoveries,
  - higher testing throughput without recoveries



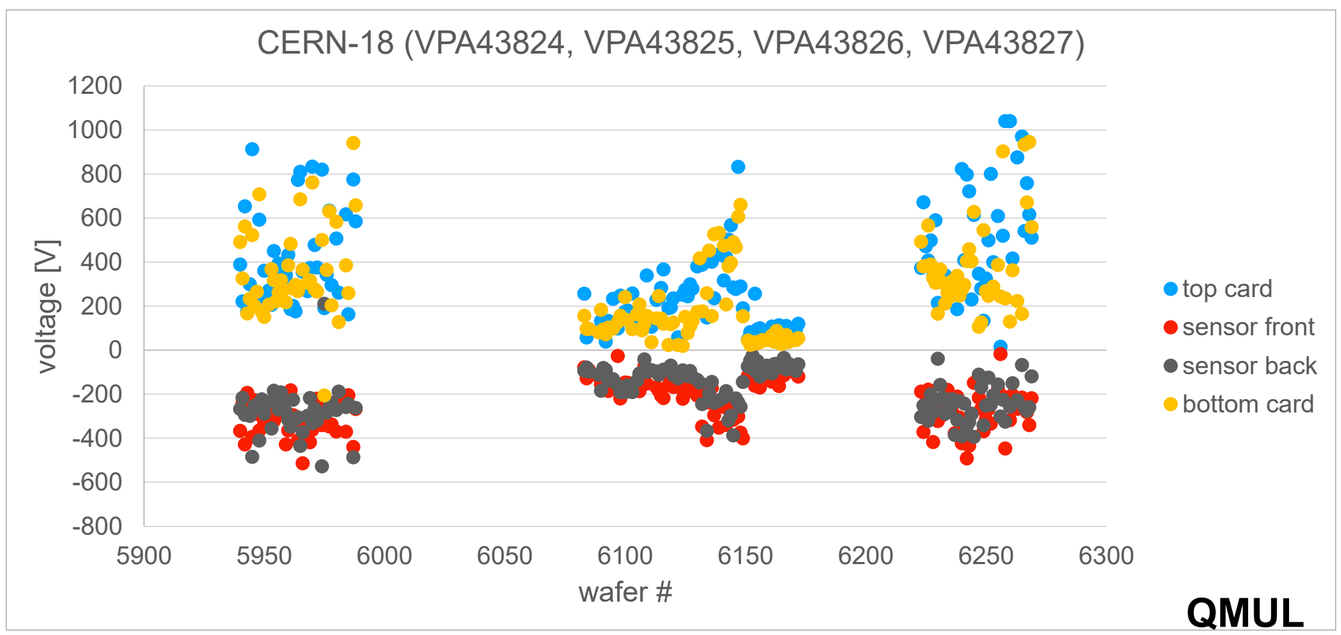
Static Charge Build-up

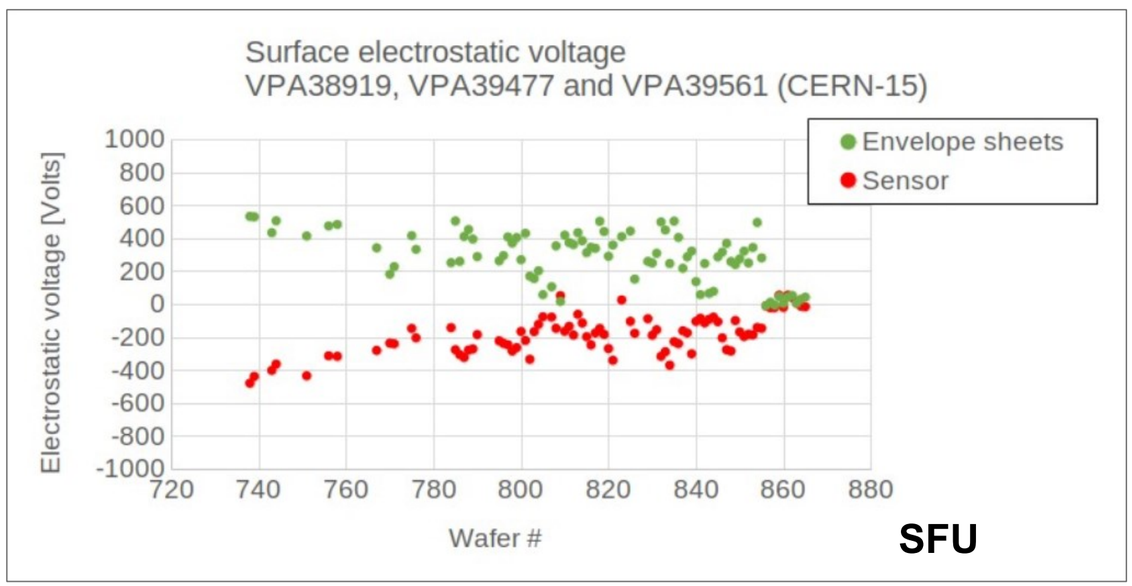
- Almost all QC sites observed a static charge on sensors/sheets
  - Measurement performed with electrostatic field meter upon reception (before any QC)
- Static charge can cause ESD issues (eg. poor strip isolation in strip test and/or lower BD voltage)
- In extreme cases, the static charge built up between the sensors/sheets is enough to “stick” the surfaces together (not seen in pre-production)



Static Charge Build-up

- Usually, the packaging sheets are measured to have positive charge, sensor surface has negative charge
- Packaging sheets were noted to have two distinct finishes on either side: “shiny” or “matte”
- Orienting the two cards so the same side faces the sensor (shiny-shiny or matte-matte) reduced the stickiness and partially resolved high static charge





IV Failures

- Sensor with breakdown below 500V is considered a failure
- There is some level of correlation between IV failure and high static charge

CERN-09 Example

Serial Number:	Sheet	Sensor
VPA38913-W00669	142	-386
VPA38913-W00671	222	-214
VPA38913-W00672	287	-372
VPA38913-W00673	296	-274
VPA38913-W00674	96	-376
VPA38913-W00675	221	-440
VPA38913-W00676	224	-562
VPA38913-W00677	256	-342
VPA38913-W00678	373	-421
VPA38913-W00679	220	-342
VPA38913-W00680	124	-306
VPA38913-W00684	144	-347
VPA38913-W00685	261	-463
VPA38913-W00686	250	-314
VPA38913-W00687	446	-480
VPA38913-W00689	473	-470
VPA38913-W00690	247	-360
VPA38913-W00691	241	-376
VPA38913-W00694	213	-394
VPA38913-W00695	318	-513
VPA38913-W00696	373	-396
VPA38913-W00697	251	-379
VPA38913-W00698	231	-424
VPA38913-W00699	491	-532
VPA38913-W00700	264	-392
VPA38913-W00702	482	-413
VPA38913-W00703	283	-378

CERN-10 Example

Serial number:	Sheet	Sensor
VPA38905-W00411	175	-148
VPA38905-W00412	256	-167
VPA38905-W00413	139	-148
VPA38905-W00414	181	-80
VPA38905-W00415	228	-133
VPA38905-W00416	121	-136
VPA38905-W00417	325	-147
VPA38905-W00419	193	-153
VPA38905-W00420	169	-30
VPA38905-W00421	185	-44
VPA38905-W00422	258	-68
VPA38905-W00423	211	-111
VPA38905-W00424	262	-137
VPA38905-W00428	171	-17
VPA38905-W00430	165	-139
VPA38905-W00431	193	-215
VPA38905-W00432	316	-119
VPA38905-W00434	181	-126
VPA38905-W00436	324	-110
VPA38905-W00437	267	-113
VPA38905-W00439	141	-210
VPA38905-W00440	320	-69
VPA38905-W00442	268	-151
VPA38905-W00445	166	-154
VPA38905-W00446	268	-126
VPA38905-W00447	339	-235
VPA38905-W00448	156	-87

Green – IV passed Red – IV Failed
Yellow – soft BD

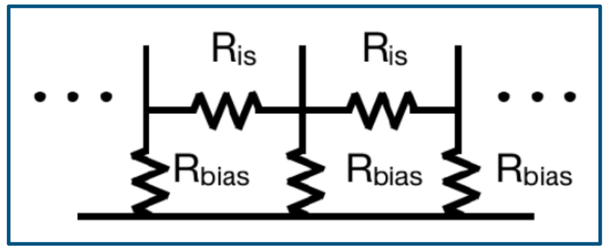
CERN-09 – The sheets are not in the correct orientation (shiny-matte)

CERN-10 – The sheets are in the “correct” orientation (shiny sides inward)

High static charge does not guarantee IV failure, but higher fraction of failures is observed when the overall static charge (measured on the sensor surface) is higher

Strip Test Failures

- Dominant failure mode for strip tests is loss of interstrip isolation
  - Loss of isolation is inferred when measured bias resistance of n consecutive strips is reduced by a factor of n ie. loss of isolation = resistors in parallel $R_{bias}^{meas} \approx \frac{1}{n} R_{bias}^{nom}$



- Often, ST failures have high static charge, but high static charge does not *guarantee* a ST failure
  - Possible mechanism: charges at surface will invert the Si at the interface such that there is a conducting channel between neighbouring strips

Initial Strip test pass		Initial Static voltage	Initial Strip test fail		Initial Static voltage
W363-VPA38904	22.7. 2022	+6	W381-VPA38904	3.6.2022	-883
W364-VPA38904	22.7.2022	+11	W395-VPA38904	6.6.2022	-683
W365-VPA38904	22.7.2022	+8	W586-VPA38909	7.6.2022	-694
W380-VPA38904	8 strips low R_{bias} 2.6.	-528	W599-VPA38909	9.6.2022	-601
W385-VPA38904	25.7. 2022	-615			
W594-VPA38909	8.6.2022	-543			
W624-VPA38909	13.6.2022	-649			
W625-VPA38912	13.6.2022	-235			
W639-VPA38912	23.6.2022	-79			
W657-VPA38912	9.6.2022	-338			
W666-VPA38912	13.6.2022	-322			
W635-VPA38916	20.6.2022	-193			
W636-VPA38916	20.6.2022	-124			
W638-VPA38916	20.6.2022	-128			
W639-VPA38916	21.6.2022	-167			
W643-VPA38916	20.05.2022	-104			
W644-VPA38916	23.05.2022	-120			
W646-VPA38916	24.05.2022	-113			

CERN-08: all ST failures had static charge >600V

CERN-09: Many sensors with high static charge do not fail ST

Serial Number: (R4)	Static Charge (V):	Initial Striptest	Low inter-strip isolation	Striptest after 8h curing
VPA38913-W672	-372	Pass		
VPA38913-W675	-440	Pass		
VPA38913-W684	-347	Fail	Large section	Pass
VPA38913-W686	-314	Pass		
VPA38913-W689	-470	Pass		
VPA38913-W695	-513	Pass		
VPA38913-W699	-523	Pass		
(R5)				
VPA38917-W647	-86	Pass		
VPA38917-W652	-157	Pass		
VPA38917-W661	-221	Fail	8 bad strips	Pass
VPA38917-W667	-142	Pass	1 pair bad strips	
VPA38917-W672	-160	Pass	3 pair bad strips	
VPA38917-W678	-135	Pass		

Recovering Failed Sensors

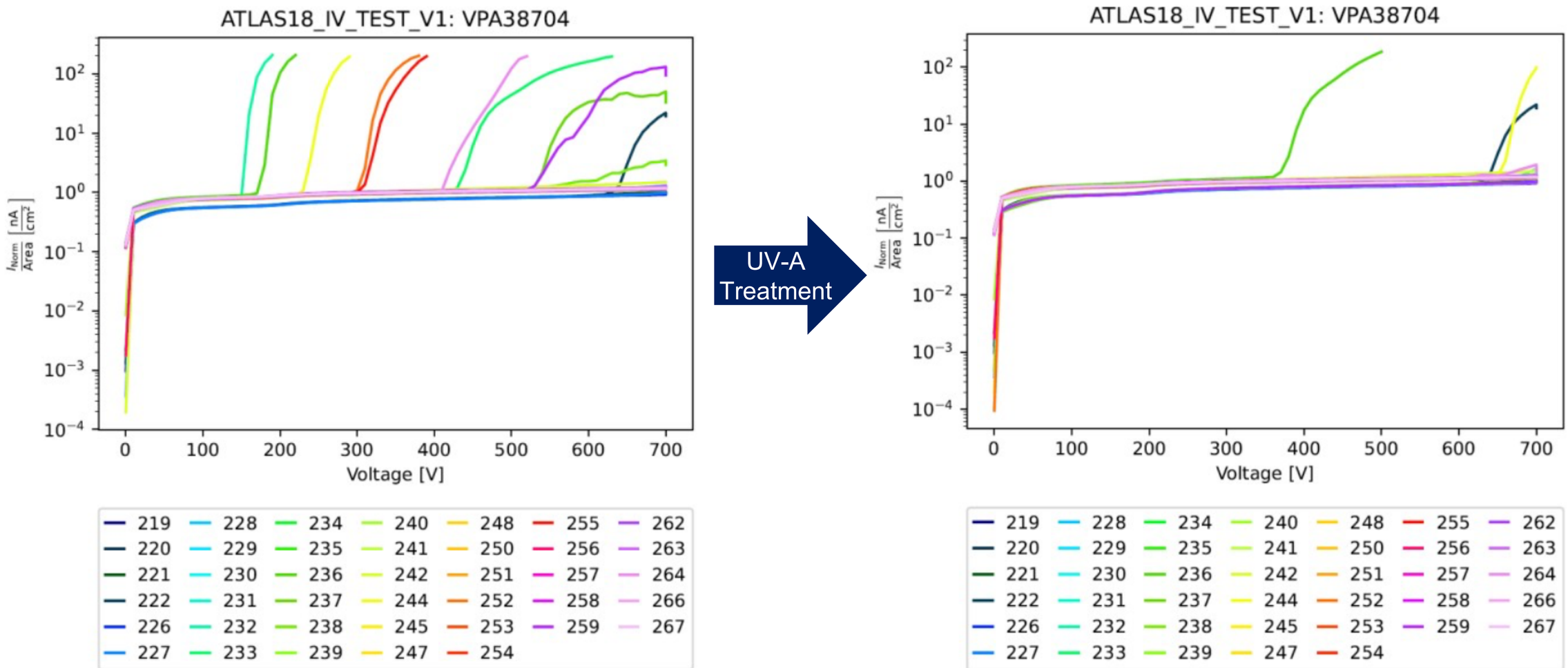
- Long term exposure to UV-A light (370-410nm) has proven to be effective at restoring some sensors' IV and ST performance
- Exposure time varies, but is typically 4-8 hours
- UV-C (~250nm) was also explored (see backup) but has an undesirable side effect of greatly increased (3-50x) leakage current
  - Optionally used in extreme/difficult-to-recover cases

SFU UV-A setup

- Exposing the sensor surface to a constant stream of ionized air is also effective for recovering sensor IV and ST performance
- Exposure time is much less than for UV-A treatment; about 10 min is sufficient
- Some sites now pre-emptively treat all incoming sensors with ion blower

IV Failures and Recoveries

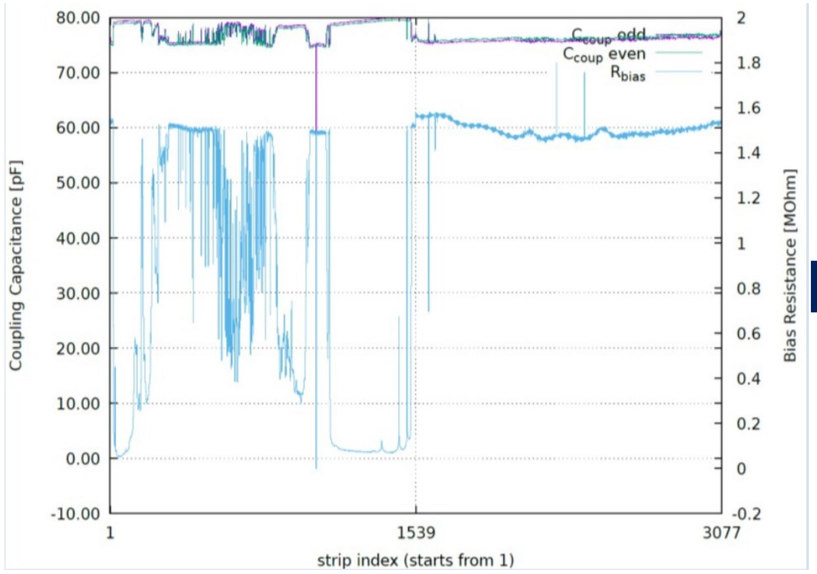
- In below example, all but one sensor is recovered by UV-A exposure

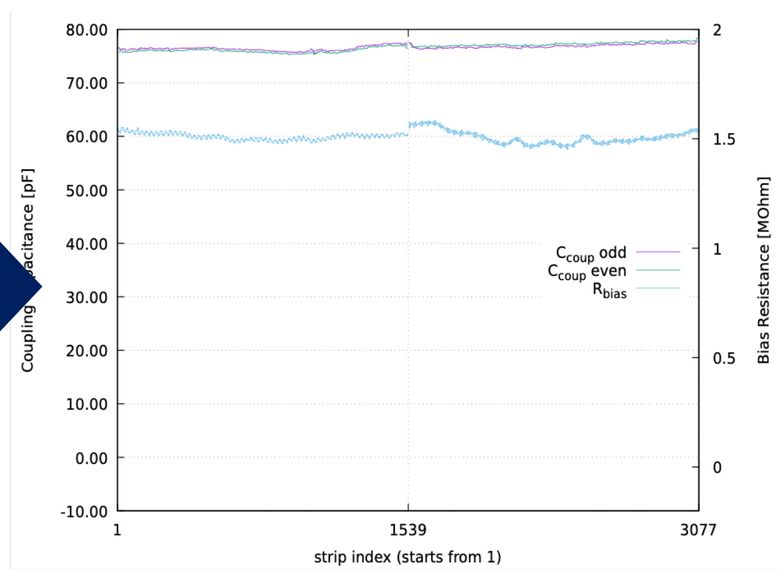


- In addition to ionized air and UV-A treatments, some failed IV can be recovered by prolonged exposure to high voltage (eg. additional LTS testing)
  - In many cases, sensors with “soft-breakdown” are selected for and show improvement after LTS test

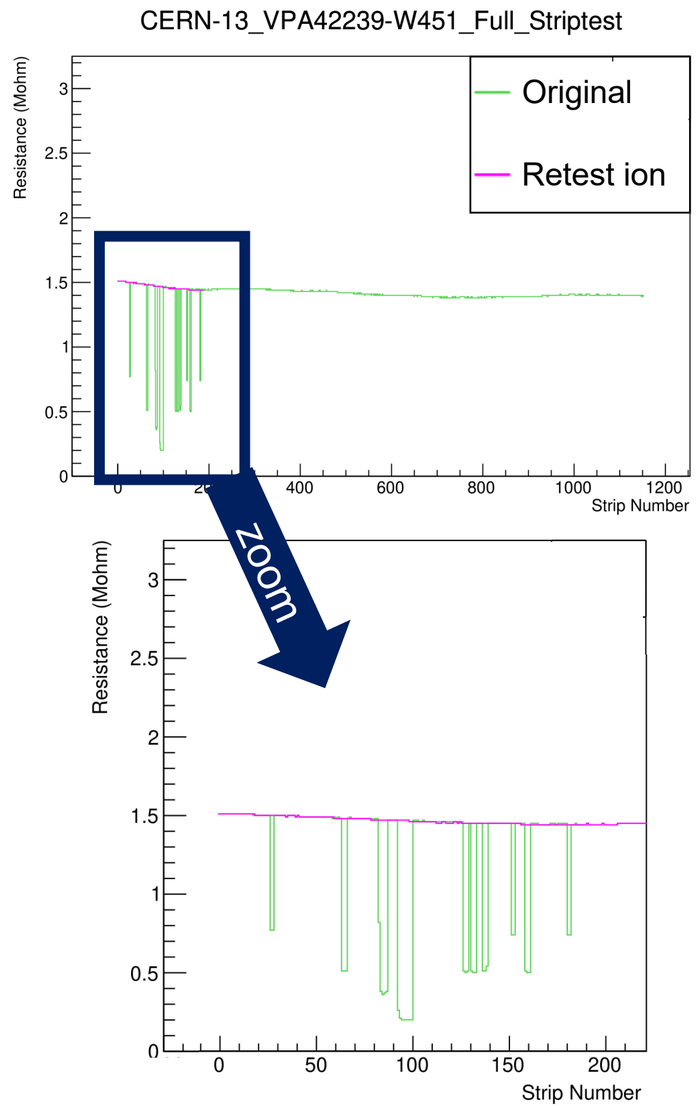
Strip Test Recoveries

- Varying levels of success at each site – At CU and QMUL great success using ionized air; At SFU and FZU, more success with UV-A





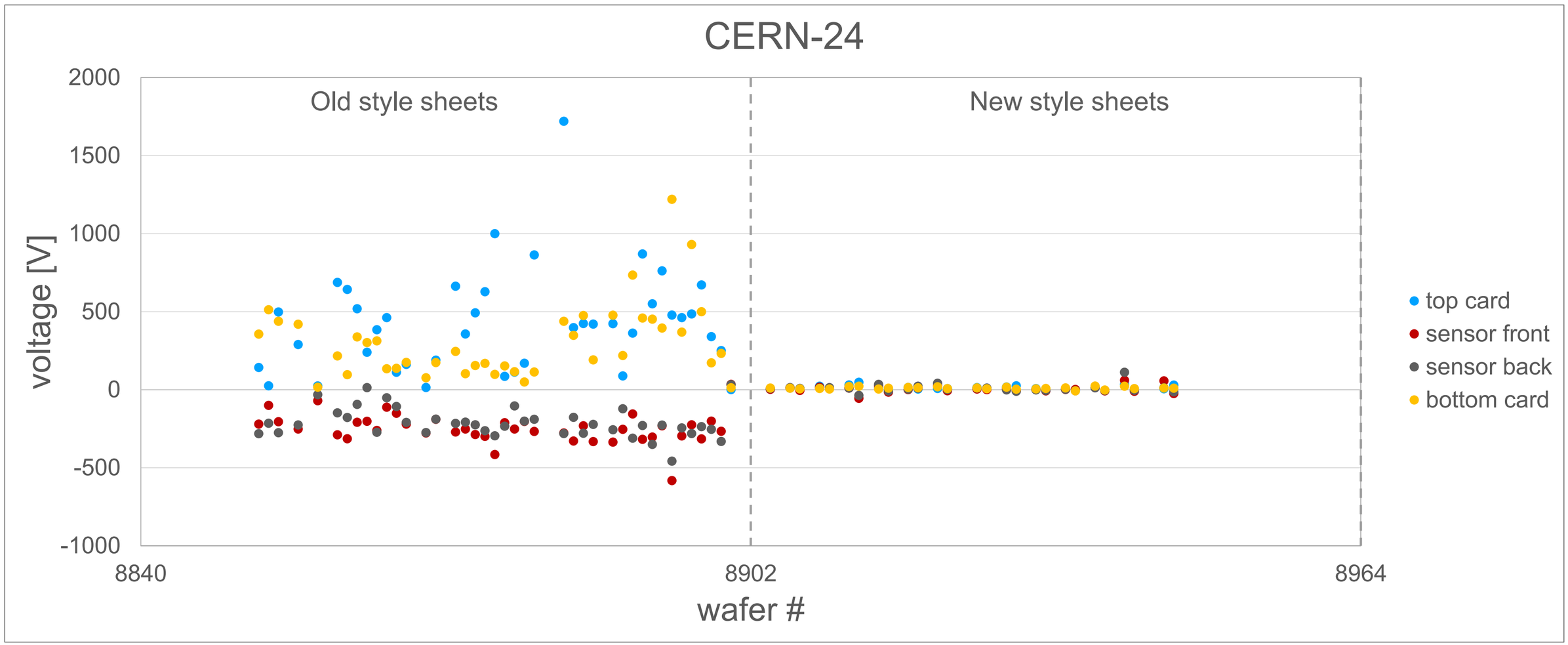
Example: Recovery using UV-A at FZU



Example: Recovery using Ion blower at CU

New Packaging Sheets

- Vendor has updated their packaging materials; now using a different kind of sheet, and with matte-matte orientation
- Has significant effect on the measured static charge
  - Below plot, two back-to-back batches from the same delivery but with different kind of sheets



Conclusions

- An issue of static charge leading to poor strip isolation and degraded IV have been observed in a minority fraction of sensors during production
- Various recovery methods have been explored for these sensors
  - For poor IV performance: UV-A treatment, ion blower, and/or additional LTS
  - For poor ST performance: UV-A and/or ion blower treatments
- The number of sensors requiring recovery has **decreased** over time; Due to:
  - Updated packaging by vendor
  - Handling procedures and pre-emptive treatments at QC sites

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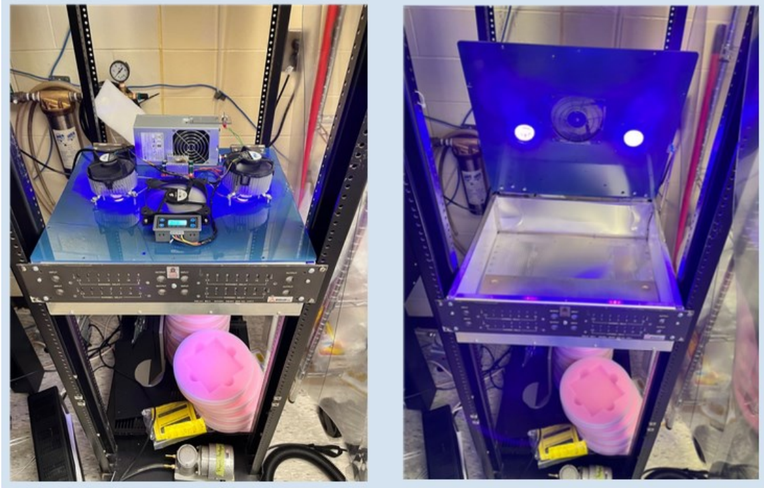
Backup

Recovery Methods — UV-A

- A few examples at various QC sites

SFU UV-A setup

Carleton UV-A setup



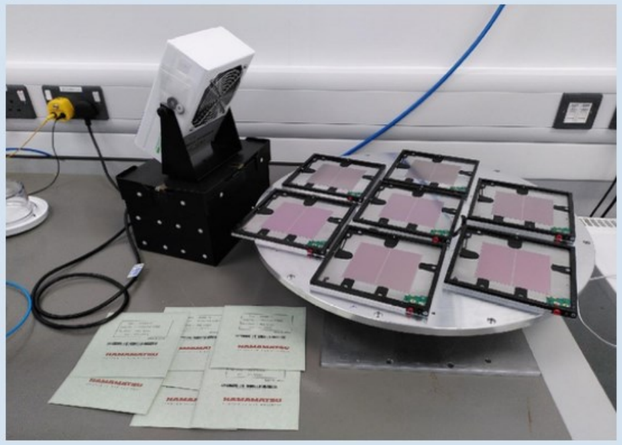
FZU UV-A setup

Recovery Methods — Ionized Air

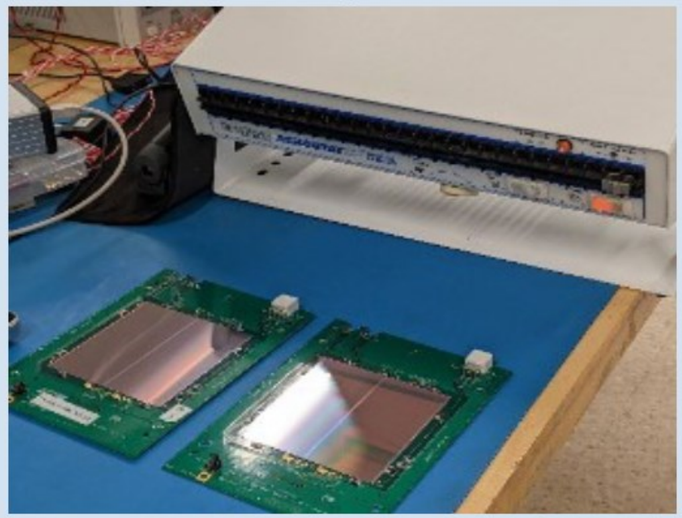
- A few examples of various sites

Carleton - SCS Ion gun. Similar (EMIT) used in FZU.

An example of the Ion Blower setup used in Cambridge (Charlers Watter – now Desco). Similar used also in QMUL (Keyence SJ-F031).



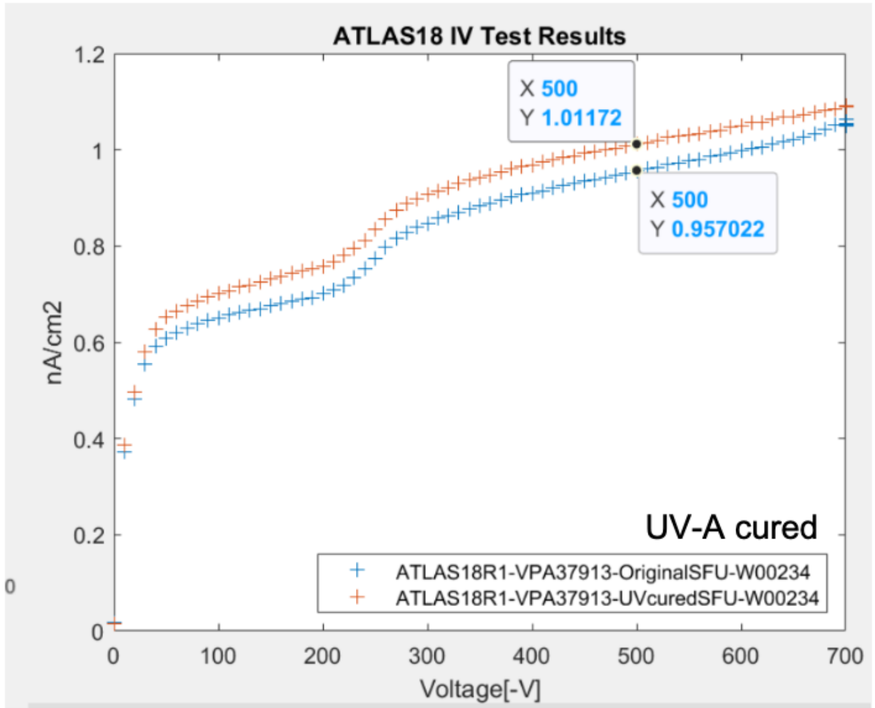
SCIPP - Simco Aerostat XC Ion Blower setup

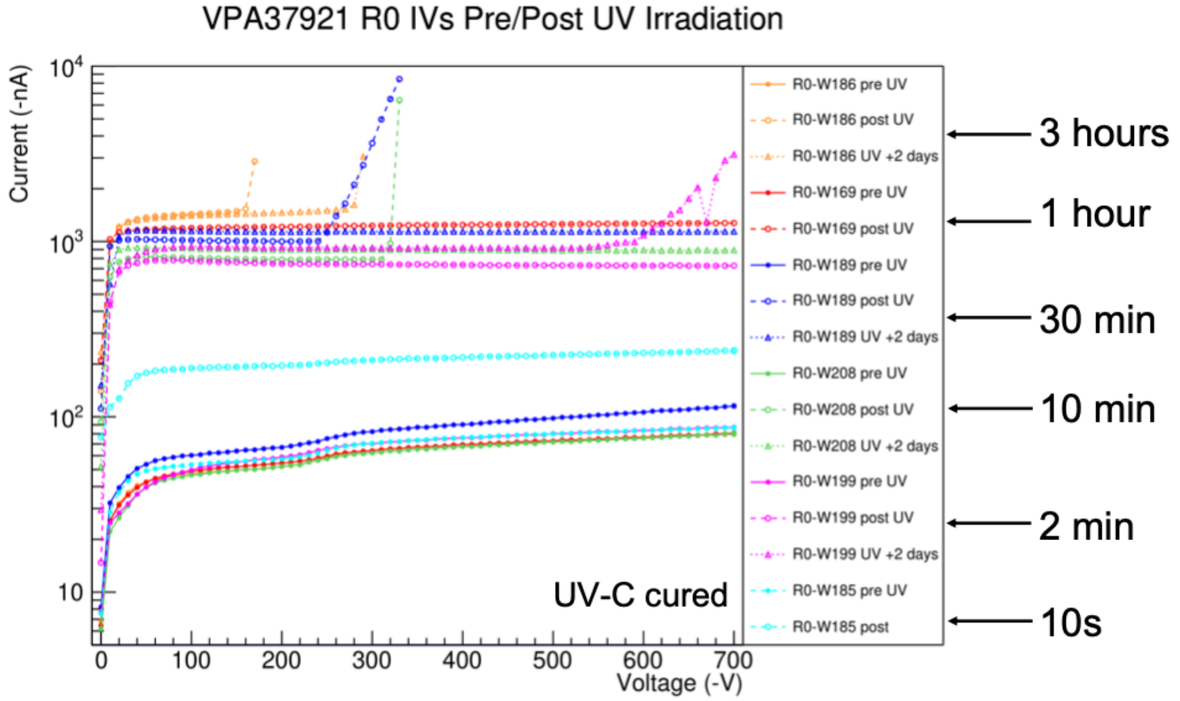


FZU - SCS Ion Blower

Recovery Methods — UV-C

- Example of sensor(s) whose ST performance was recovered by UV-A (left) and UV-C (right)
- Even after a small, 10s, UV-C exposure the leakage current increases ~3x
- UV-C can induce early BD, which sometimes goes away after time in dry storage





New Sheets

- Scale of the plot includes all data points (>1500V)
- Rescaling to better show the charge of the second, low static charge, batch with new sheets
  - Almost all measured static charge is below 100V