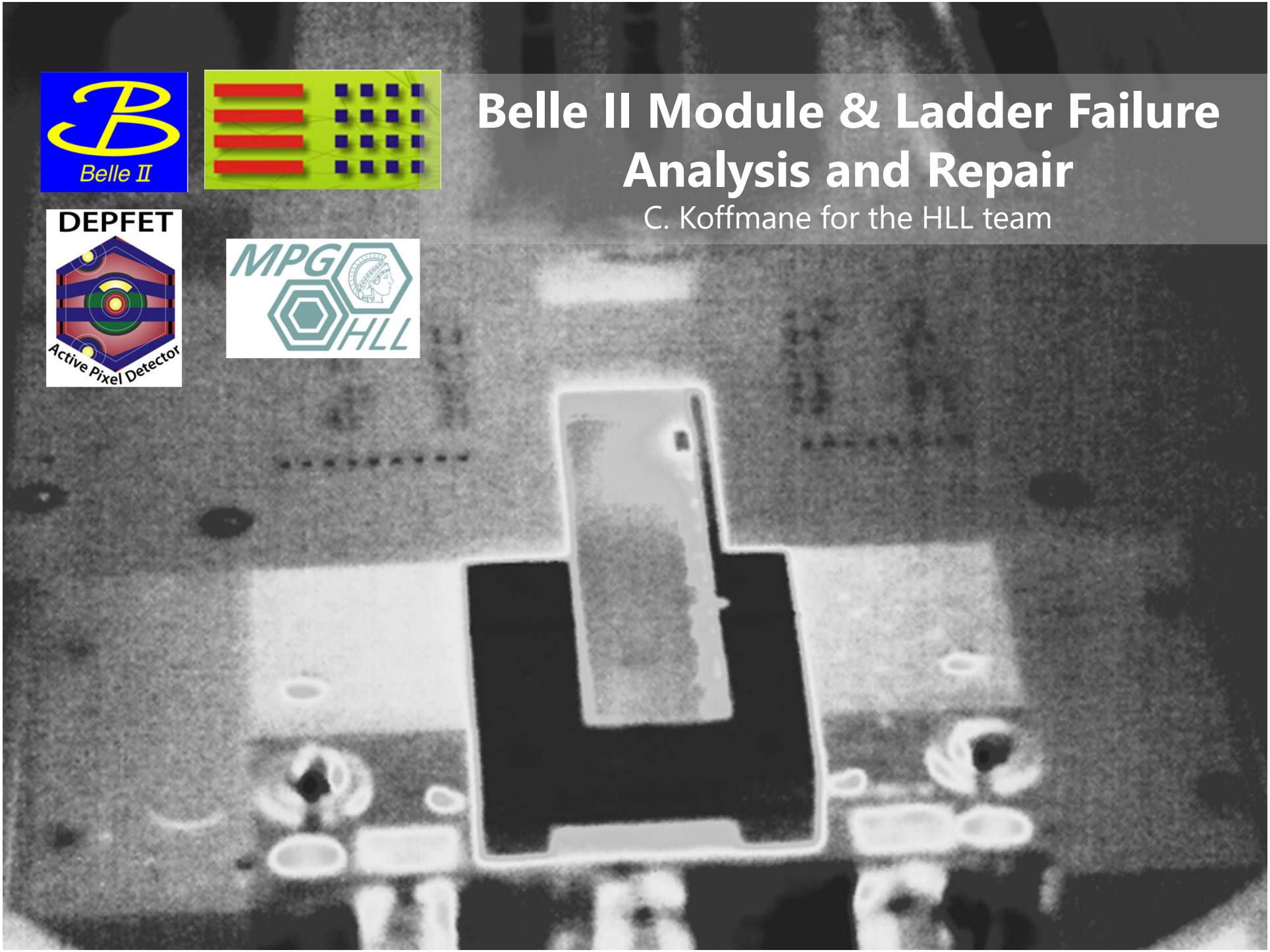


Belle II Module & Ladder Failure Analysis and Repair

C. Koffmane for the HLL team

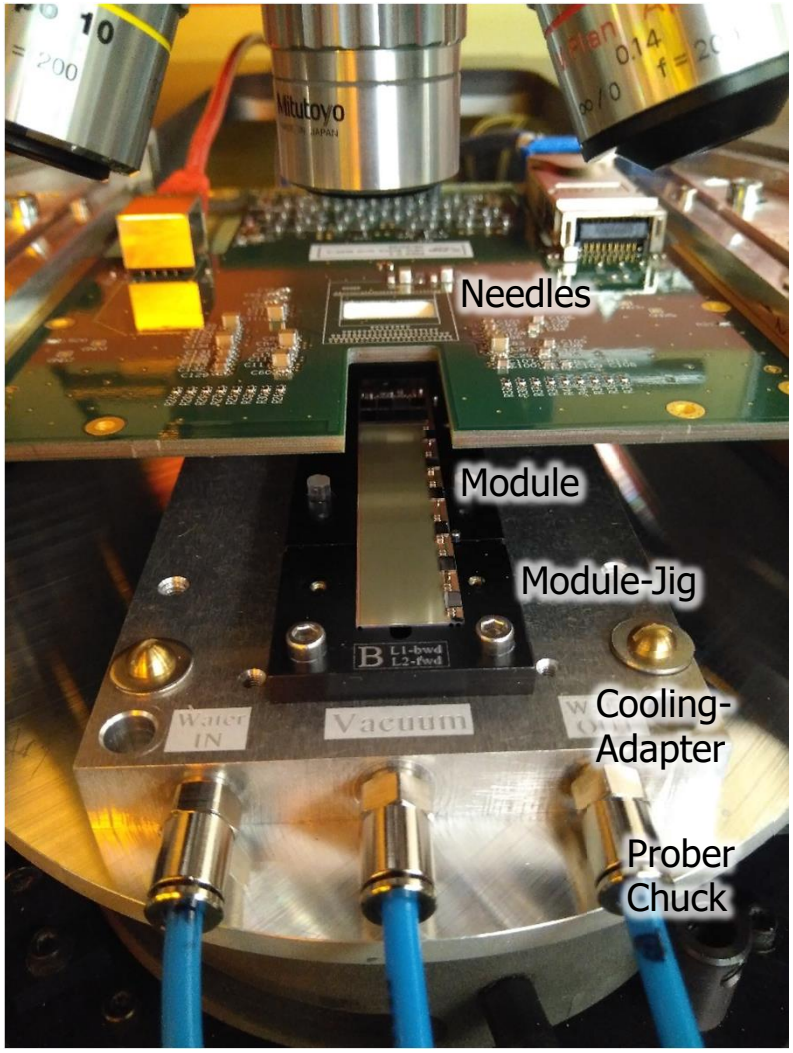
Belle II Module and Ladder Failure Analysis and Repair

Failure analysis was done at three levels

- after **Flip-chip and SMD mounting** (using Probe Card)
- after **Kapton assembly** (using Lab Patch Panels)
- after **Ladder assembly**

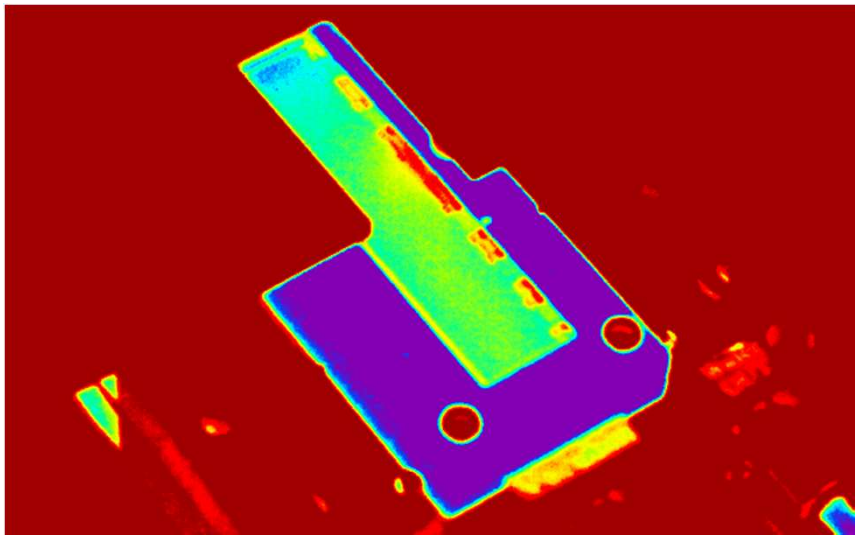
Faults during probe card testing:

- **High SW-DVDD current** (4 times phase 3 + 3 times phase 2/pre-production)
- **DHP-Core/IO short** (once phase 3 + once phase 2)
- **Failed boundary scan** (once)
- **Clear-On/Clear-Off short** (twice)
- **Low DCD-AVDD current** (once, module passed the mass testing)



High SW-DVDD Current

- Caused by faulty switcher
- Switchers could be identified using a thermal camera
- 4 (+2) Switchers successfully replaced



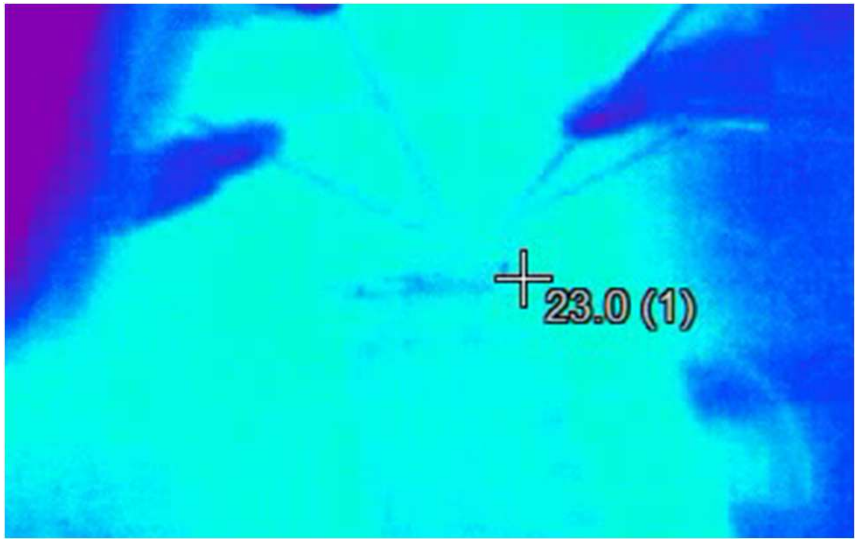
Results

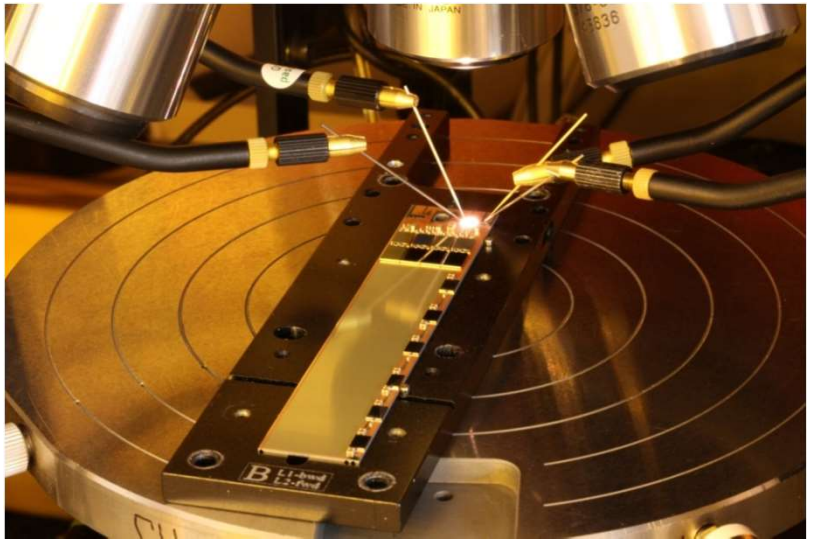
Module	Fault	Action	Result
W31_OB1	SW	SW replaced	ClearOn/Off Used for proto type ladder L2_010
W31_OB2	SW	SW replaced	OK @ KEK
W38_IB	SW rotated	SW replaced	OK Was part of L1_013
W43_OF1	SW4	SW4 replaced	OK, grade A Running in GOE
W44_OF1	SW	Matrix cracked. Module broken.	
W44_OF2	SW6	SW6 replaced	ClearOn/Off in SW3 (Elog ID 7586)
W09_OB1	SW2	SW2 replaced	OK, grade A

Step 01 - DHP and DCD digital supply

			min.	current	max.	actual values	
1	☑	dhp io	0 mA	550 mA	550 mA	1799 mV	140 mA
2	☑	dhp core	0 mA	730 mA	800 mA	1204 mV	377 mA
3	☑	sw dvdd	0 mA	30 mA	30 mA	1041 mV	30 mA

DHPT-Core to DHPT-IO Short



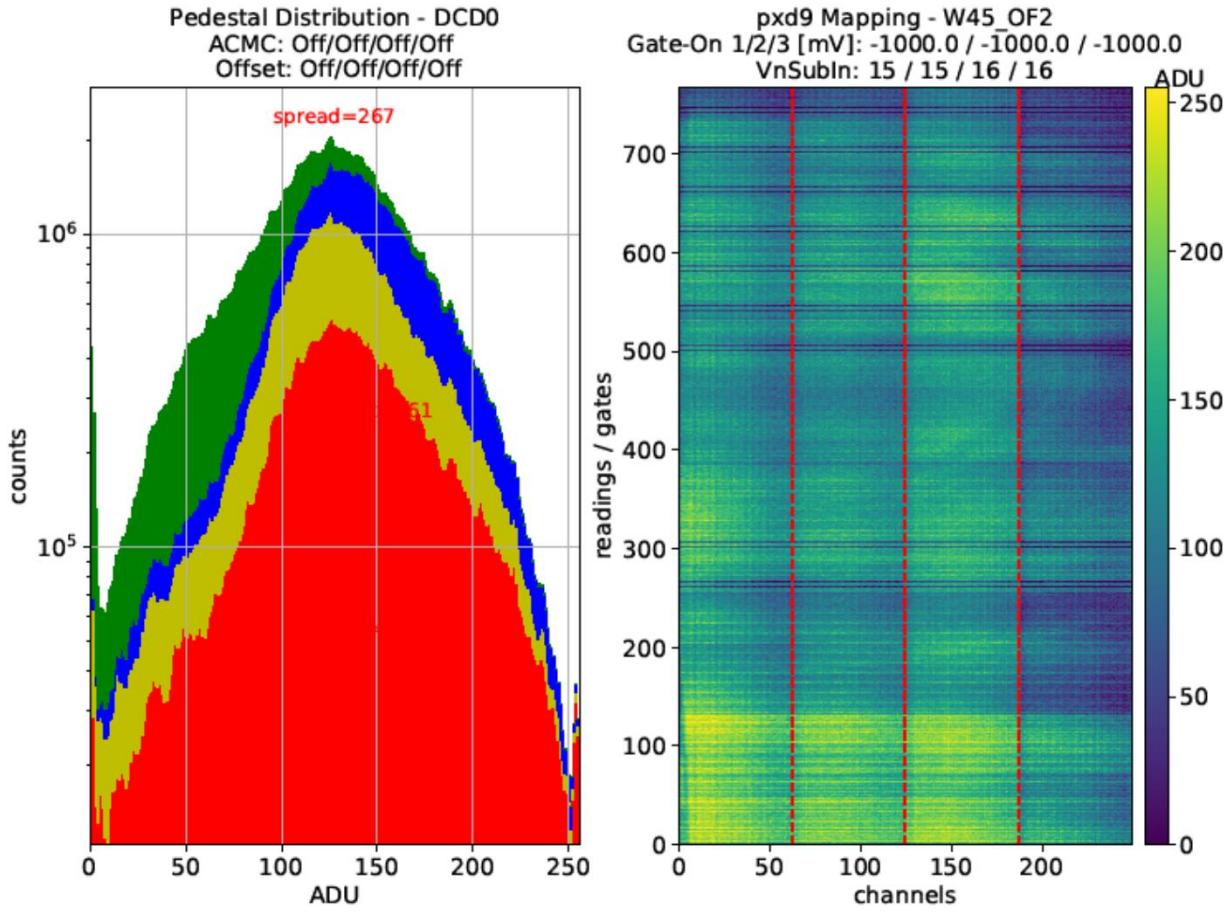


- Module passed the probe card test after DHPT3 was replaced

Module	Fault	Action	Result
W38_OB1	ASIC not identified	None yet.	None yet.
W45_OF2	**DHPT3**	**ASIC replaced with high temp.**	**OK.**

W45_OF2 – after DHPT replacement

Testing ongoing in Bonn, sanity check okay (pedestal)

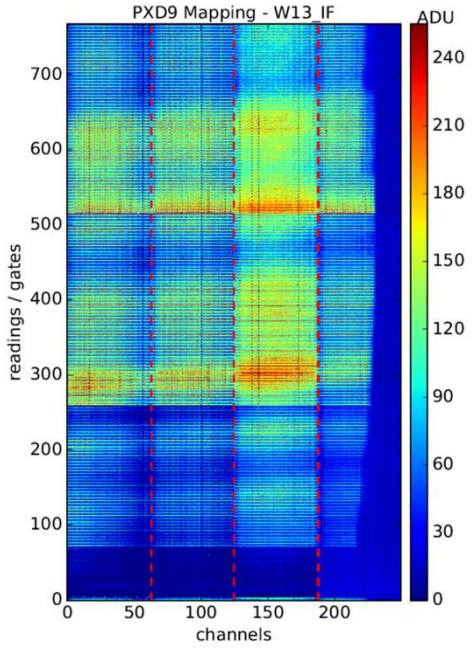


Elog ID: 10766

W13_IF – Fault in Kapton

Failure Description

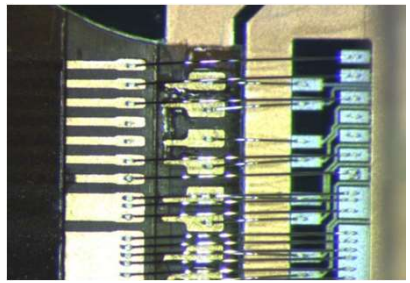
- Module passed the probe card test including taking pedestals
  https://elog.belle2.org/elog/PXD-Mass-Testing/7531
- ASIC digital domains show an increased current consumption at the module test after the Kapton assembly
  - Already after JTAG configuration the current consumption of DHP_core and DCD_DVDD are increased compared to reference modules (by ~ 100mA)
  - When the DCDs analog parts are enabled (via JTAG) the currents of DHP_core and DCD_DVDD are increased dramatically
- DHP control lines (GCK, TRG) are okay (probed on the termination resistors on the module)
- ASIC supply voltages show strong dependence Amplow voltage



Pedestals during probe card testing

Root Cause

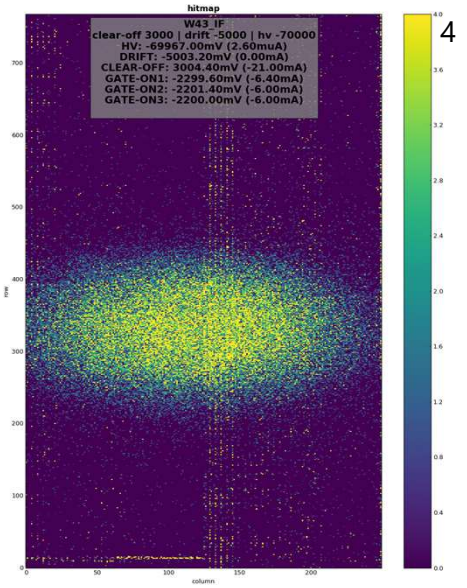
- **Short on the Kapton between DGND_Sense and Amplow_Sense** (6Ohms measured at the pins of the SAMTEC connector after those two wirebonds were removed)
- Output voltages of all the regulators (for the digital nets) were enlarged due to the wrong sensing
- When the DCDs analog part is off, the voltage regulator (current sink) of Amplow is not working in a proper way (the regulator needs some sink current). Therefore the Amplow voltage is not at the set values (but less)

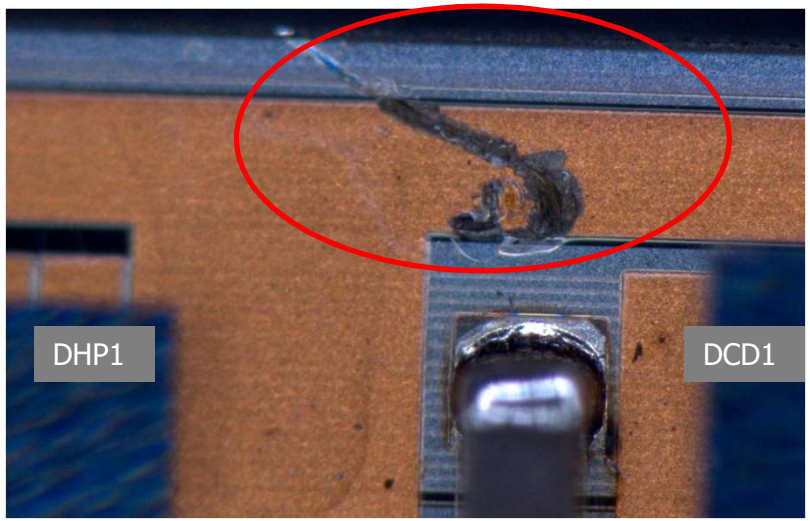


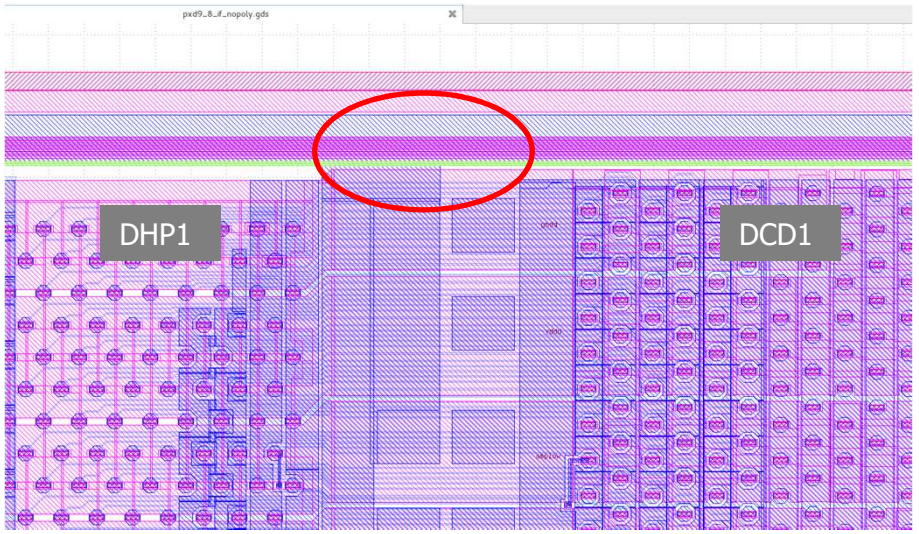
- Passed the testing procedure (grade B) after Kapton was exchanged, part of L1_036

W43_IF – Broken VBP Trace

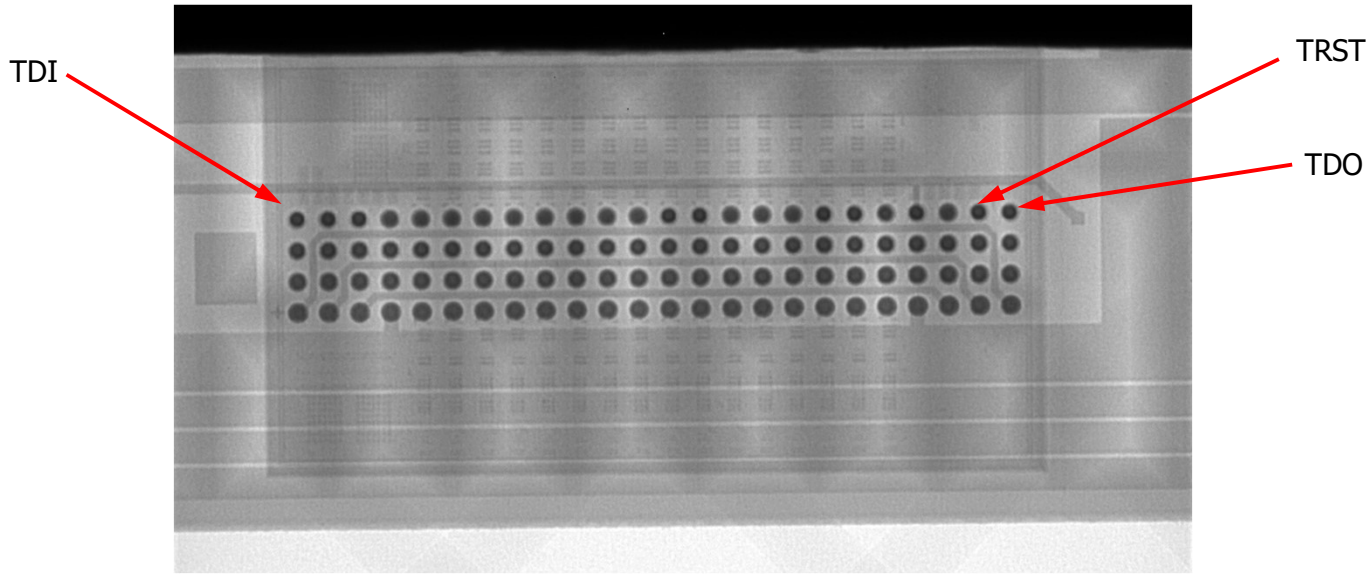
- DCD1 and module damaged after Probe Card testing
- DCD successfully exchanged by IZM
- Operation of the ASICs possible
- Module shows only very few hits in the Sr90 radioactive source measurement
- V_BP was measured correctly on the wirebond pad on the PXD9 module, but there is no current flowing (no current when the matrix is illuminated too)
- The V_BP trace is running below the scratch between DCD1 and DHP1
- Probably the V_BP trace was damaged (cut), neighboring traces Source_Sence, V_Guard, CGG1-3 may be affected too





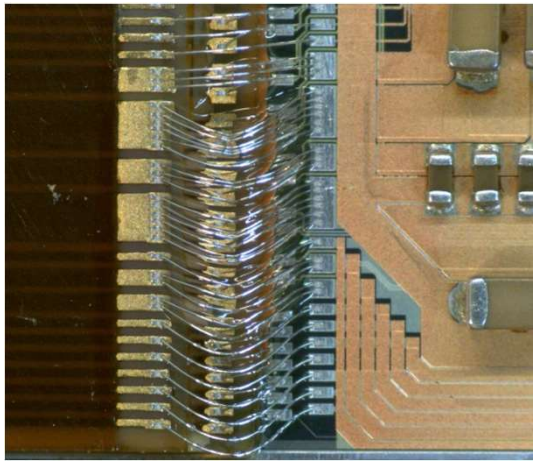


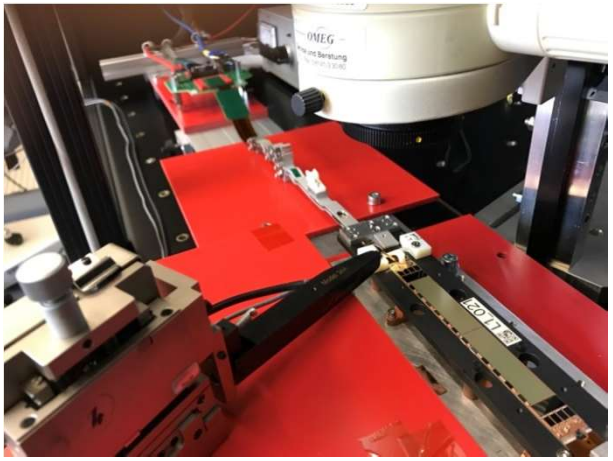
W09_OF2

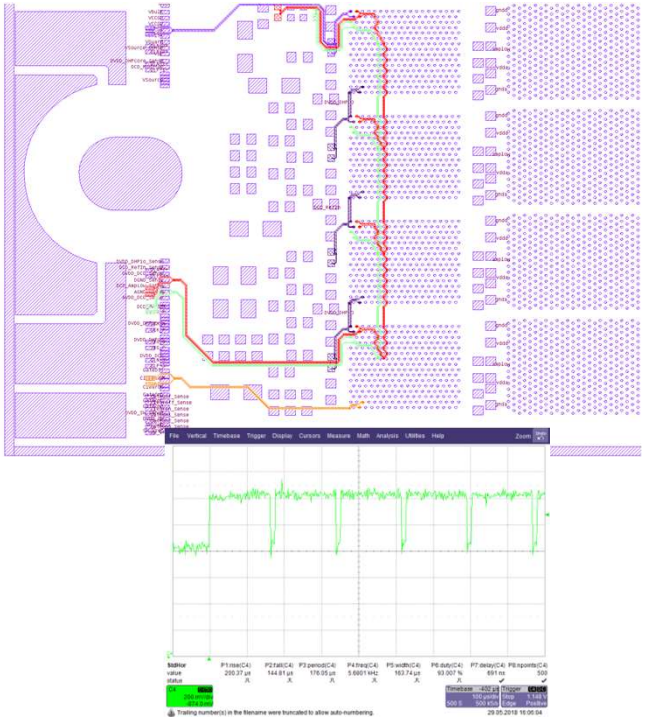


- JTAG configuration fails when Switchers are included into the JTAG chain
  - DCD1 still get's the JTAG commands (e.g. enable analog part or test pattern)
- SW5 showed suspicious bumps in the upper bump row
- Re-solder (exchange) of this Switcher5 was done at HLL (with the Kapton attached)
- Afterwards JTAG configuration works fines with all ASICs
- Sanity check (pedestals) ok, now at MPP for full test

L1_021 (W46_IF)

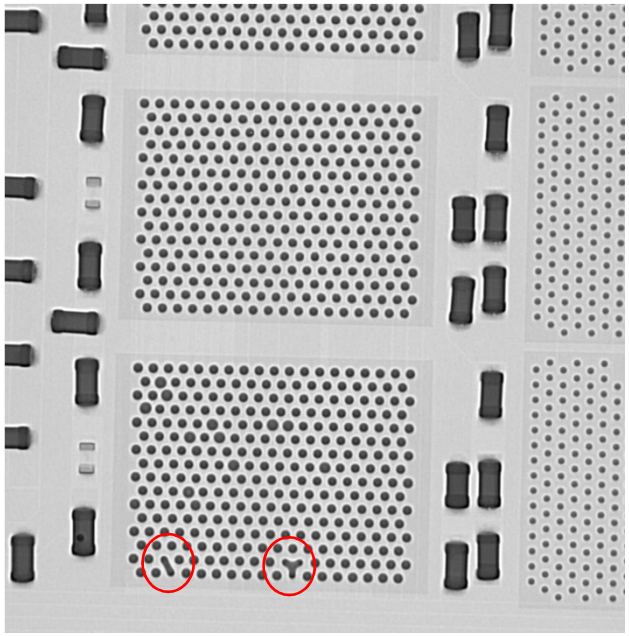


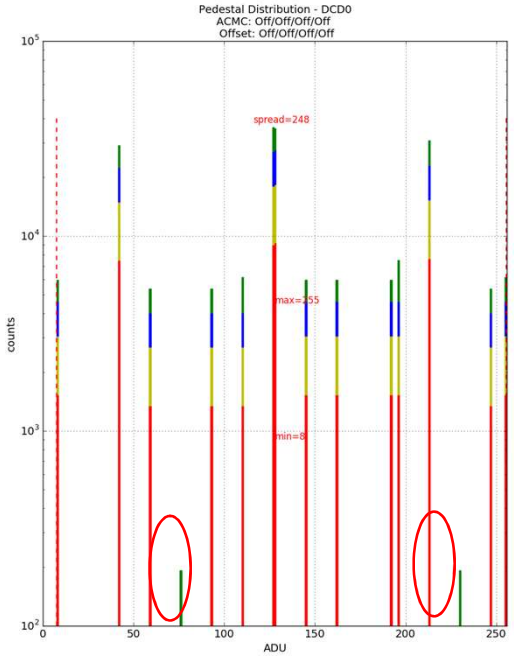


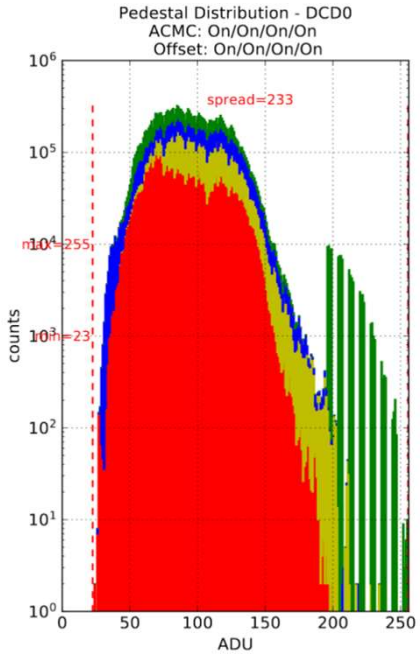


- Ladder was operated without proper thermal contact to the cooling block
- Kapton on the IF side shifted and bent the wirebonds upwards
  - W46_IF electrically okay, but could not be mounted on SCB
- Wirebonds were covered with glob top and bent down at HLL
- After this JTAG initialization failed, nevertheless the first analog voltages (bulk, ClearOn, ClearOff) were applied at MPP
- Since the JTAG initialization failed the ladder was sent back to HLL
  - Optical inspection indicated that TDO and ClearOff wirebonds could touch each other
  - To exclude broken wirebonds all bonds were removed (including the ones below the glob top) and re-bonded
  - All JTAG signals and DHPT control signals were measured on the EOS
    - TDO of DHPT4 does not show any sign of life (no bits toggling, both TDO_N and TDO_P show GND level only)

L1_021 (W46_IF) – after Exchange of DHPT4

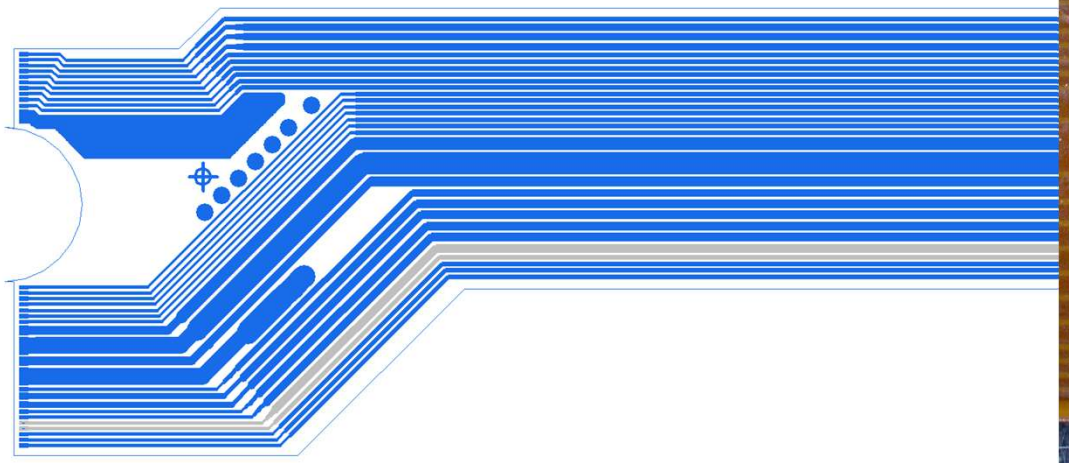


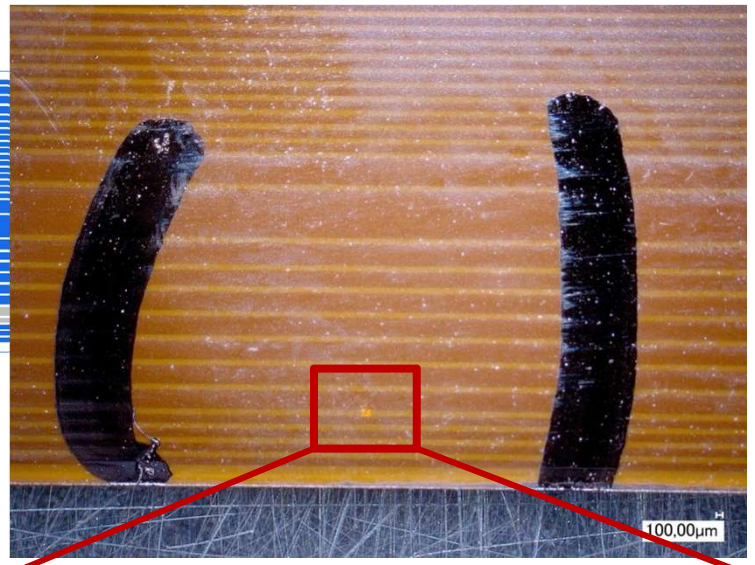


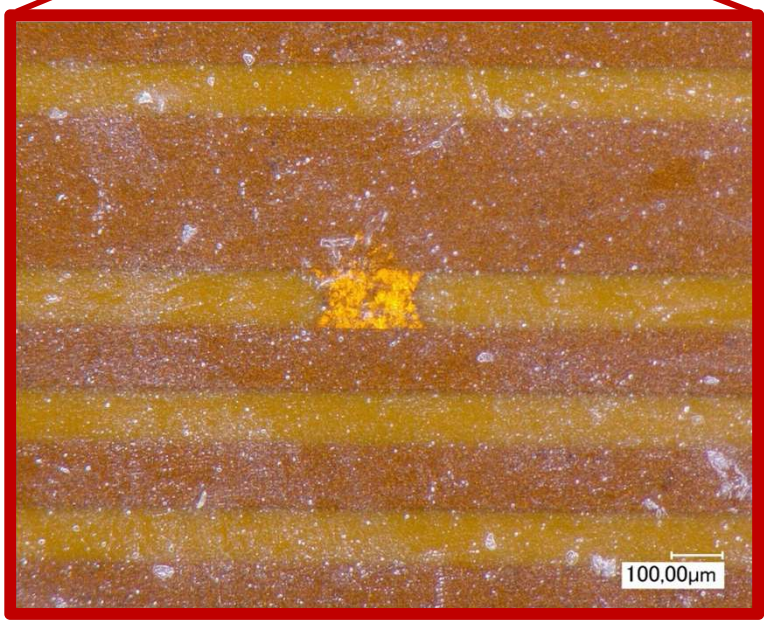


- Shorts after exchange of DHPT4
  - Two DHPT input lines to DHP-IO (stuck bits)
  - TDO_P to SW_StrC_N (two DHPT outputs)
- Basic operation possible (JTAG configuration, pedestals taking), but Source measurement failed due to corrupted data
- Stable operation not possible – 2nd exchange of DHPT4?

W09_IB with Kapton L1bwd_V30_401_104



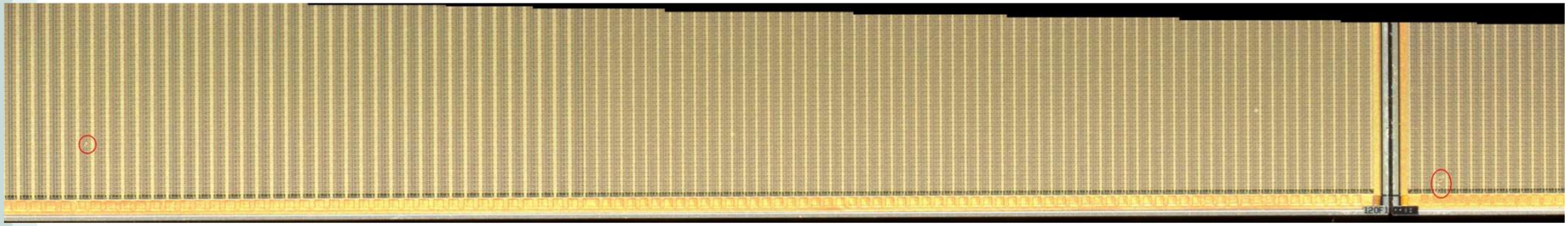


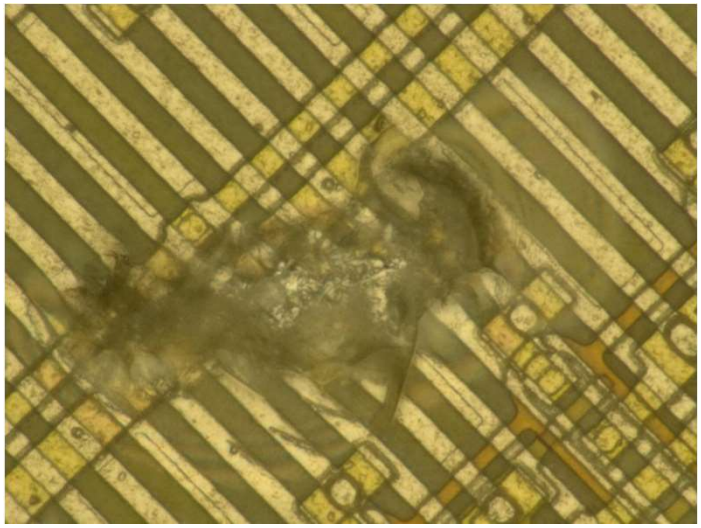


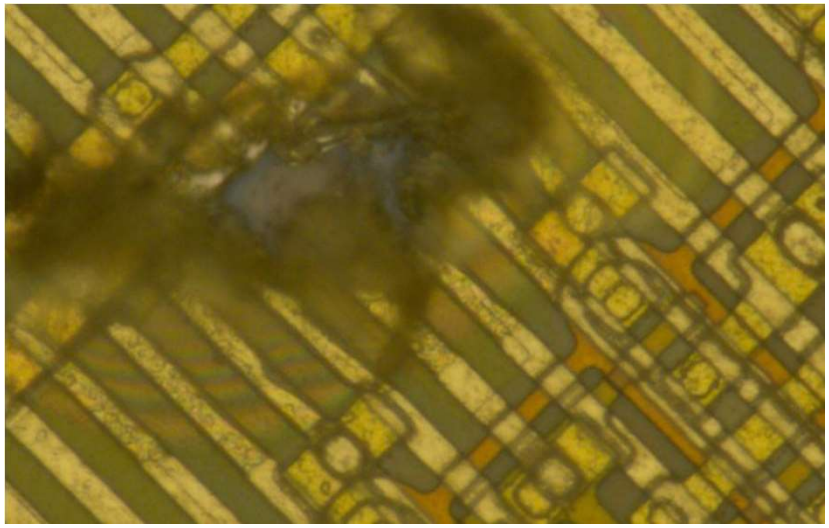
- Short between GateOn3 and SW_DVDD_Sense lines on the kapton L1bwd_V30_401_104
- **Unknown stress to SW1-2 due to overvoltage**
- Kapton exchanged with L1bwd_V30_401_102
- W09_IB passed the testing procedure and is part of L1_030

L2_024

- Short on matrix region after ladder gluing – on OF and OB regions
- First time that the damage due to particles in the ladder gluing procedure was noticed
- Trying to repair the short; it remains a short between Source and V_BP (which is likely due to the mechanical damage of the thin silicon

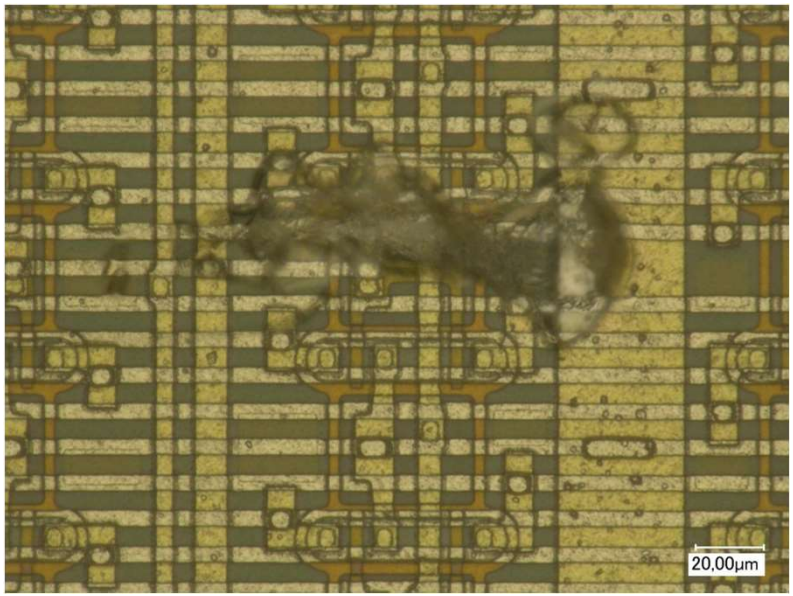


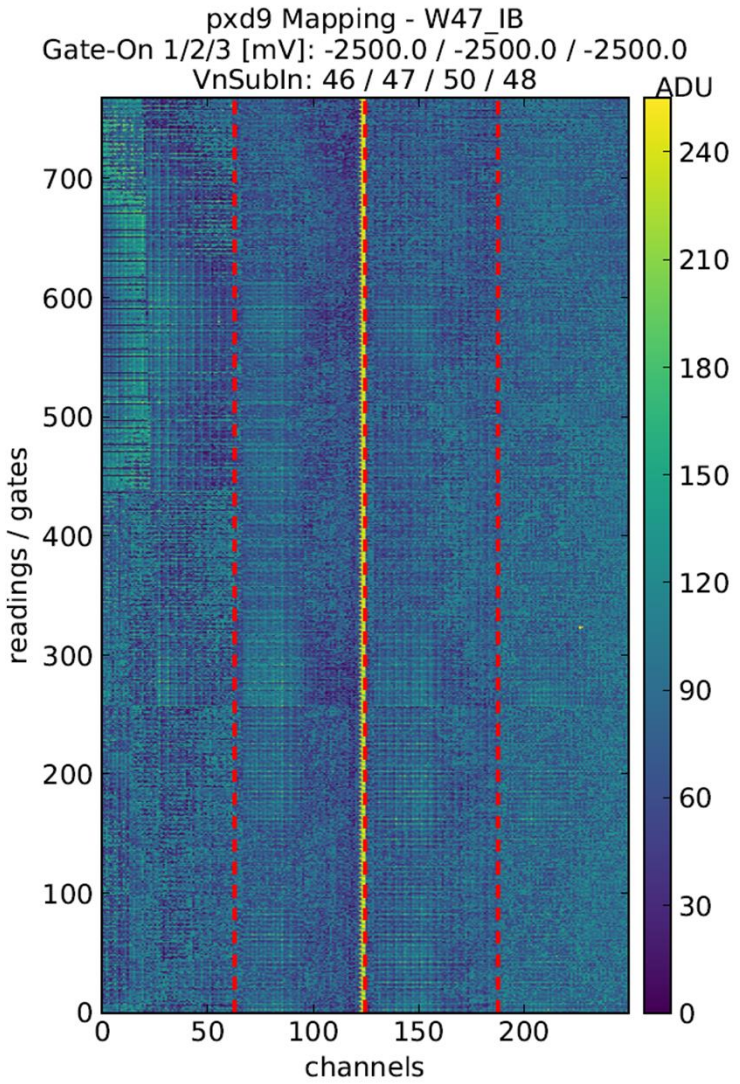




L1_016 – W47_IB

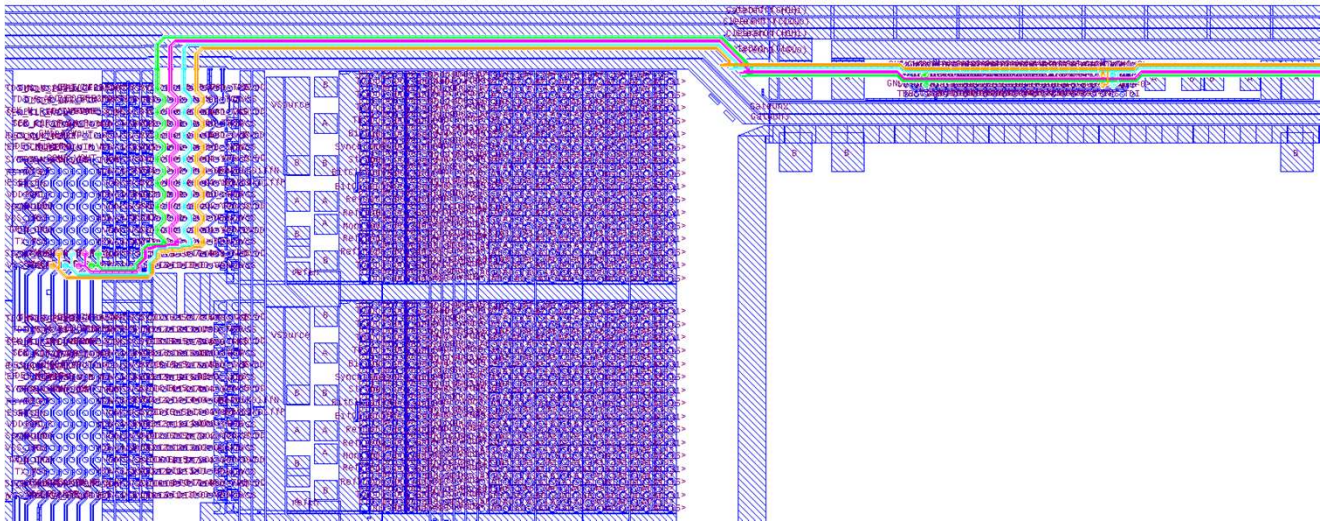
- High value drain lines observed after ladder gluing
- Gluing was done in Oct. 2017 but testing only in March 2018
- Damage of the matrix region visible at the peculiar drain lines
- "long-term" pedestal scan to see if number of effected drain lines increases… seems to be stable



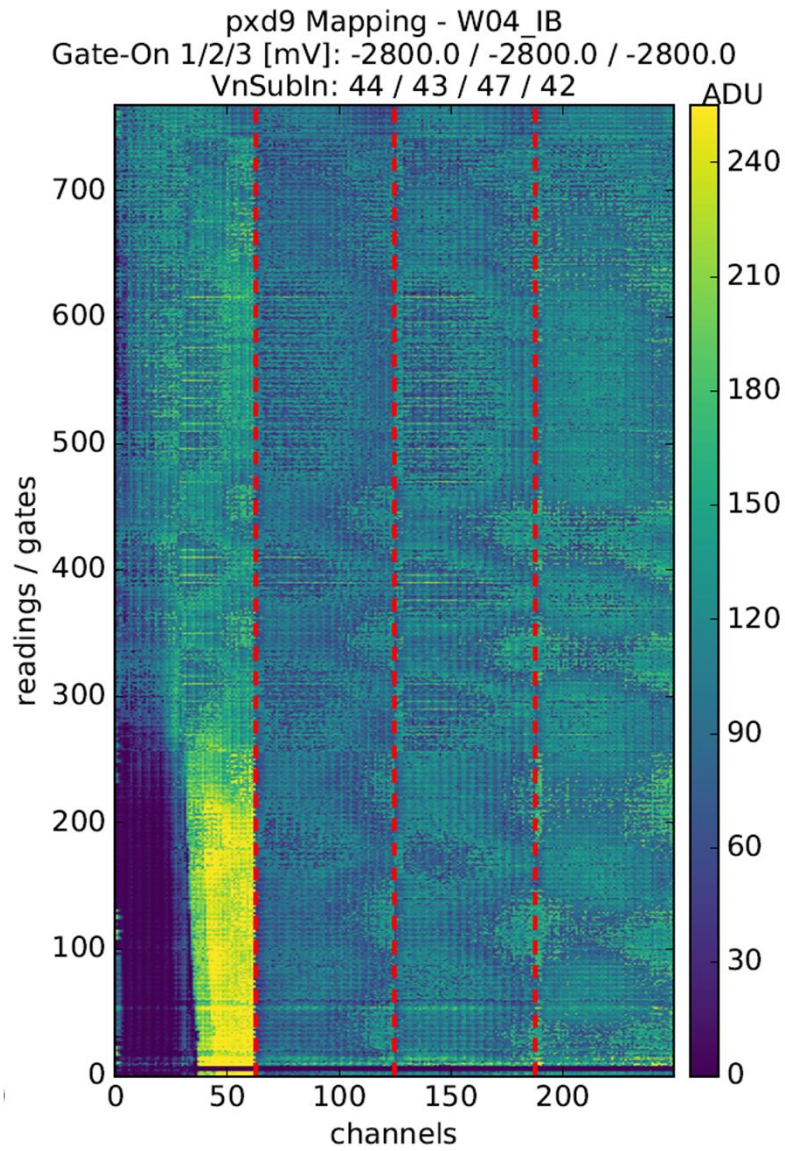


L1_035: W04_IB and W04_IF

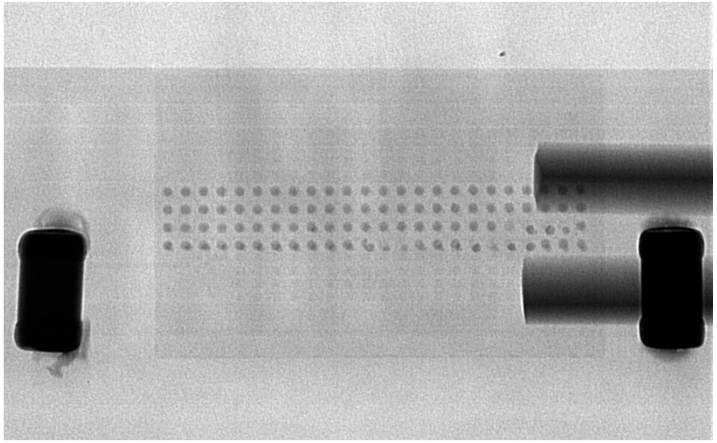
- After ladder gluing the module W04_IB shows an increased, abnormal ClearOn and ClearOff current consumption
- There is no localized ohmic short, but all Switcher channels contribute to the increased current consumption (verified using a dedicated sequences which excludes Switchers)
- Assumption: all Switcher try to switch on all the channels (Clear and Gate) all the time, caused by a broken SW_SerIn line
- Boundary Scan Test fails for all the Switcher control signals (SW_SerIn, SW_CLK, SW_StrG, SW_StrC)
- probing the SW_SerIn signal on the PXD9 module is not possible (generated by DHPT1, no test points)



L1_035: W04_IB and W04_IF



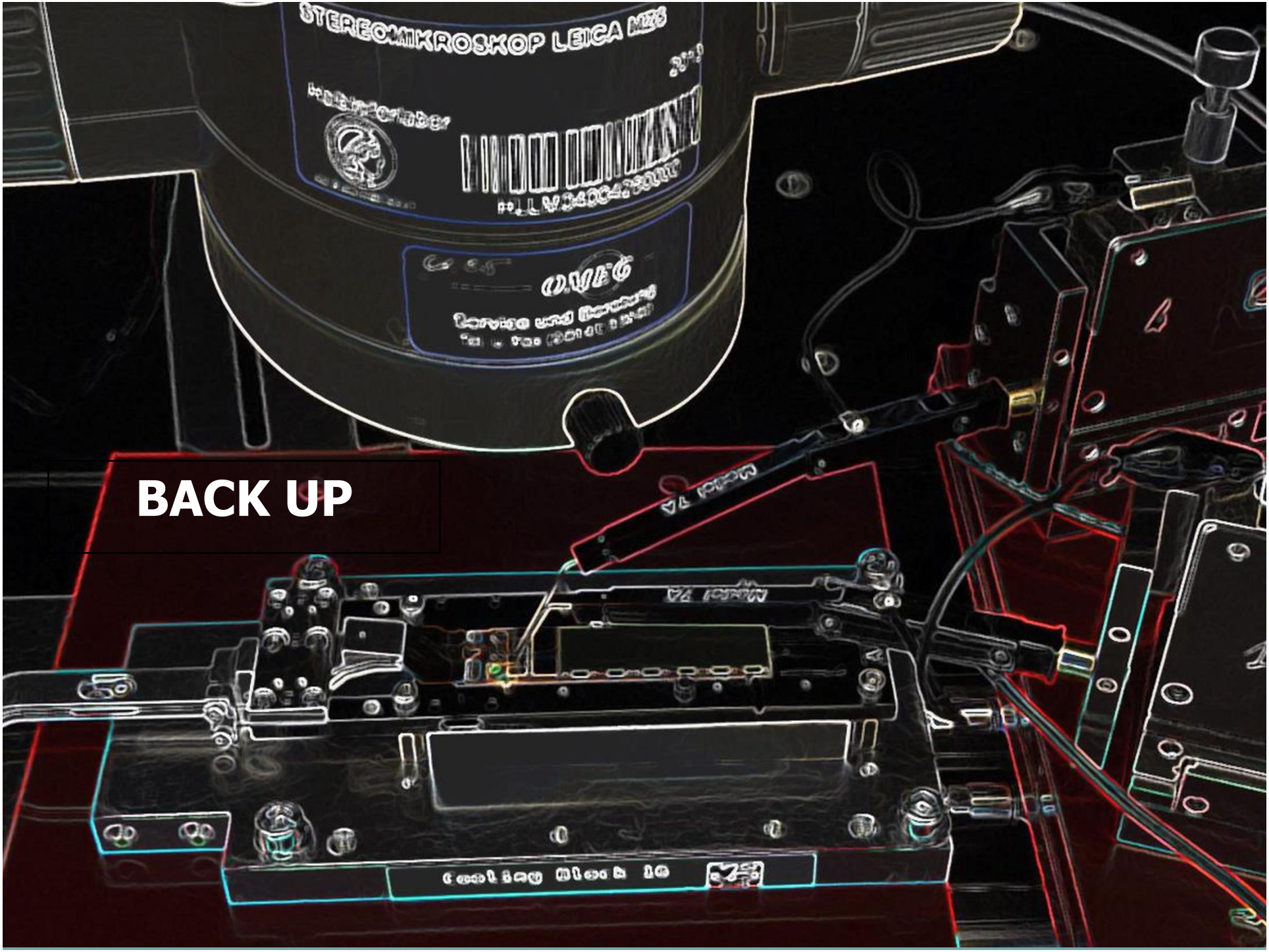
10014 mV	10022 mV	0 mA	bulk
19100 mV	19010 mV	29 mA	clear-on
2867 mV	3000 mV	-22 mA	clear-off
-2869 mV	-2800 mV	-7 mA	gate-on1
-2872 mV	-2800 mV	-7 mA	gate-on2
-2867 mV	-2802 mV	-7 mA	gate-on3
5112 mV	5001 mV	29 mA	gate-off
7296 mV	5991 mV	102 mA	source



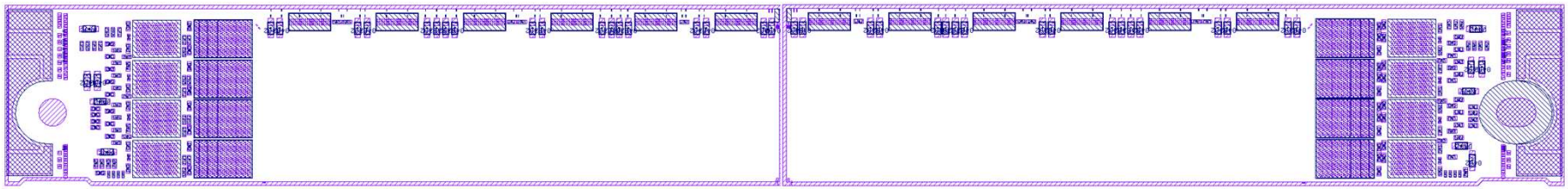
- Replaced SW1 – some bumps not connected
- Configuration okay
- Pedestal change in region of of SW1&2 after re-soldering

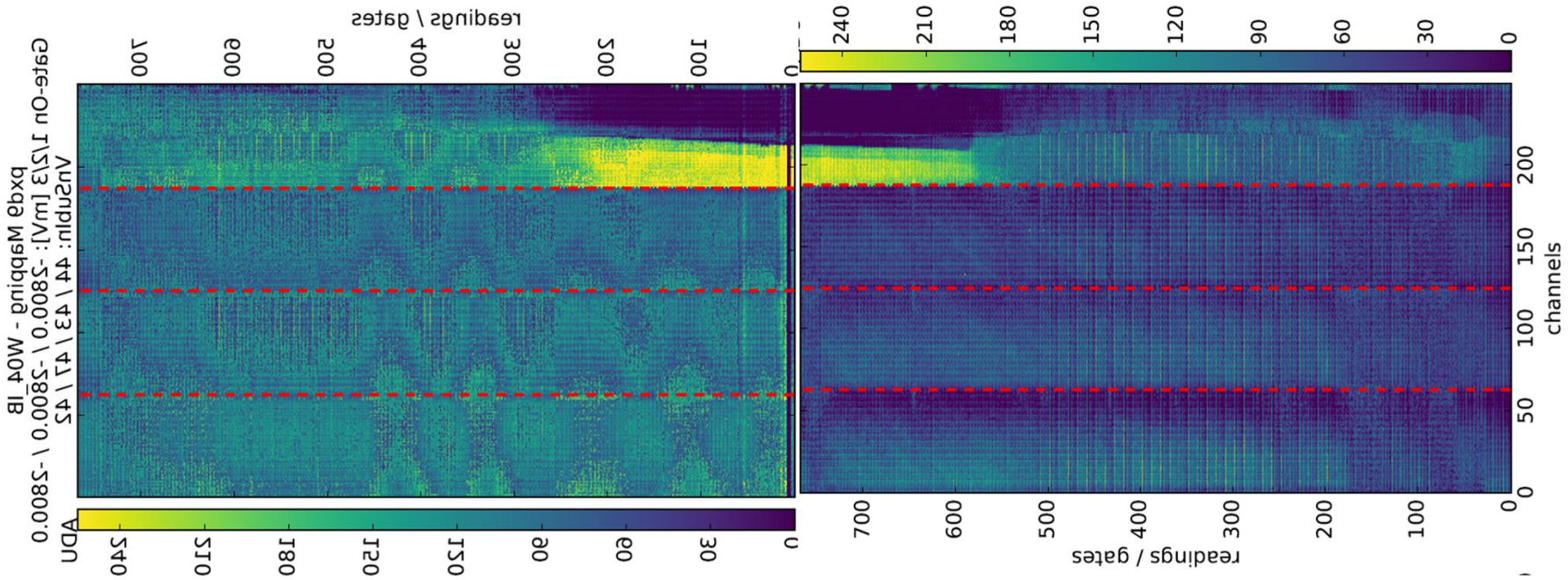
Summary

- Probe card testing helped to rescue seven modules
- Most root causes could be identified (including ASICs, Kapton, mechanical damage)
  - next module W04_OF1 (from Göttingen)
- Open topic: Bulk current
  - 3 out of 4 modules show a high bulk currents (connected to ClearOn ; current in the range of 200µA, W04_IB, W04_IB, W44_IF)

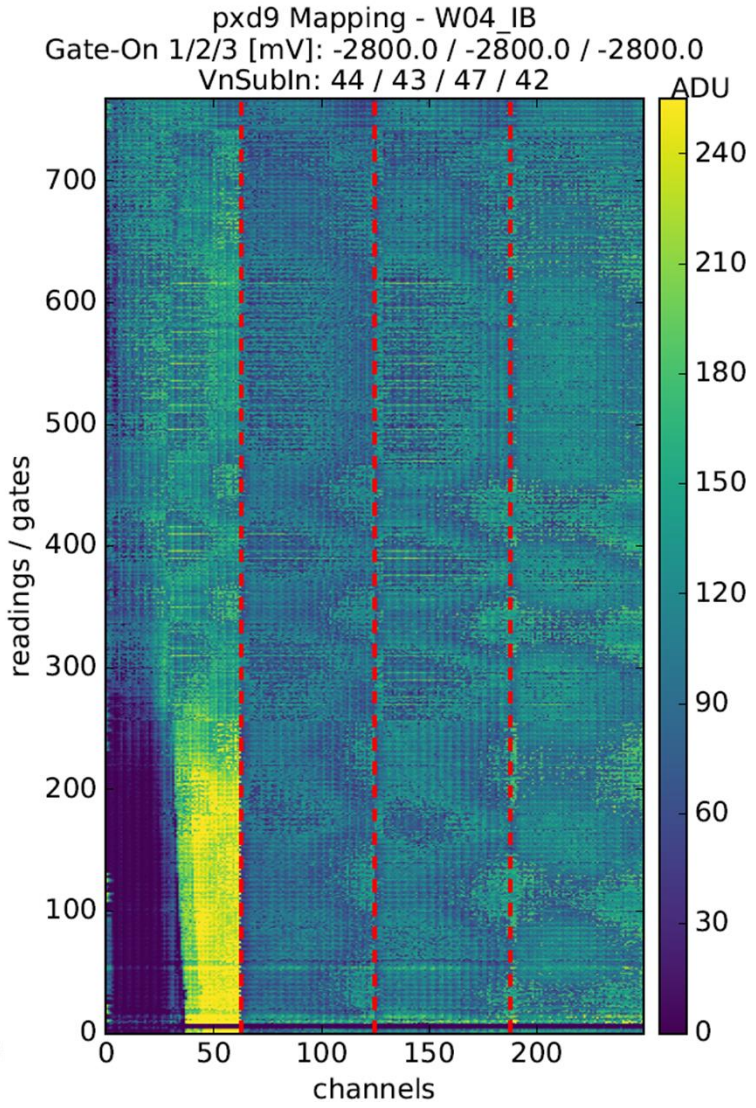

STEREOMIKROSKOP LEICA MZ8
BACK UP

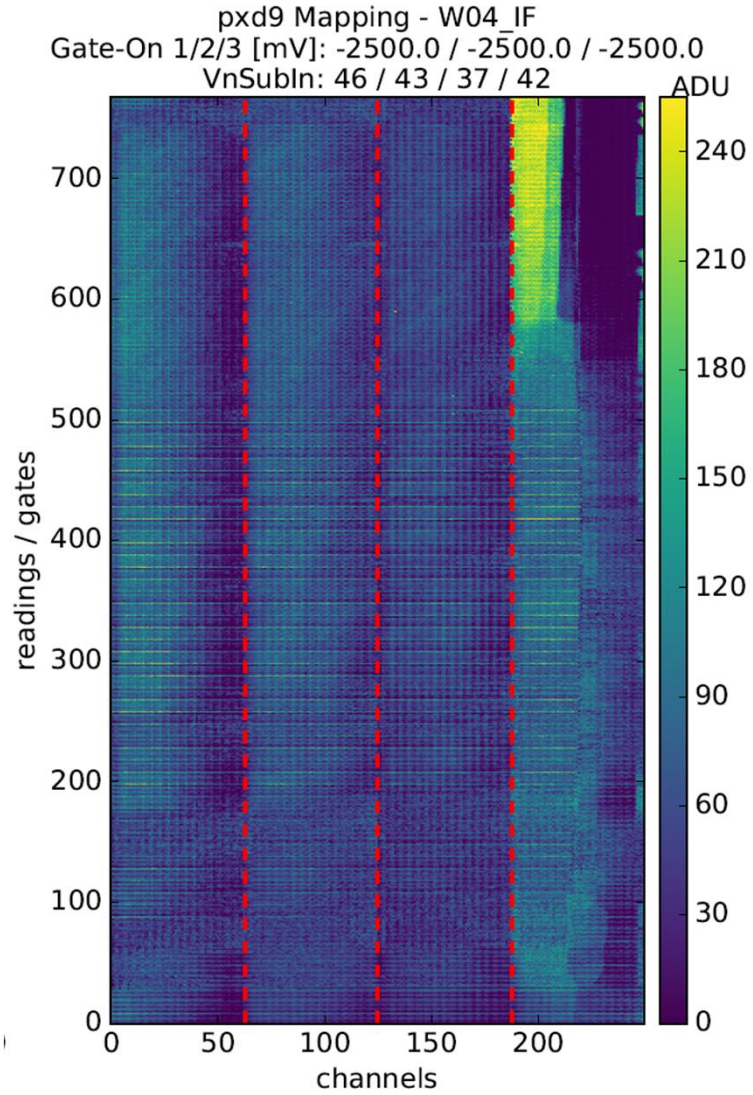
L1_035: W04_IB and W04_IF





L1_035: W04_IB and W04_IF





Ladder Statistics

L1-13 broken during testing (PS malfunction)

L1-14 poor sensor quality

L1-15

L1-16 broken during mounting on cooling block (SCB)

L1-17

L1-18

L1-19 **particle** problem but still ok

L1-20

L1-21 overheated during test → bond height
DHP replacement under study

L1-28

L1-30 accident with screwdriver/**particle**

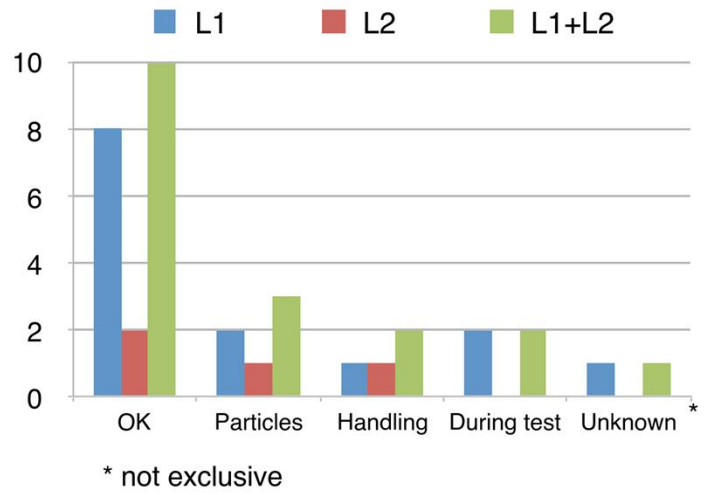
L1-35 short on IB (still under investigation)

L2-22 cracked due to misalignment

L2-24 dead, **particle problem**

L2-29

L2-34



Summary Phase 3 – Module Failure Analysis and Repair

Phase 3 IF/OF			Phase 3 IB/OB			Ladder	Status
ID	Probe Card	w/ Kapton	ID	Probe Card	w/ Kapton		
W05_IF							Drain-Source Short Matrix
W08_IF							SW4: ghost hits
W43_IF							at HLL, not sensitive since VBP is not connected to p+ punch through contact
W13_IF							kapton short between DCD_AMPLOW_SENSE ad DGND_SENSE
W46_IF			W32_IB			L1_021	W46_IF: suffered hot operation → kapton moved and wirebonds lifted up --> TDO of DHPT4 damaged (rework is tested with dummy ladder)
W09_IF			W09_IB (reworked)			L1_030	broken due to particls while ladder glueing and in addition handling acident (screwdriver)
W44_OF1	SW-DVDD						SW-DVDD high current, matrix damaged during manual handling
W44_OF2	SW-DVDD						SW-DVDD high current fixed by replaceing SW6, module broke during 2nd re-work (ClearOn/Off short)
W45_OF2 (reworked)			W03_OB1				W45_OF2: DHPT3 replaced, W03_OB1: garde B
W43_OF1 (reworked)			W05_OB1				W43_OF1: SW4 replaced; W05_OB1: noisy DCD3
W09_OF2			W09_OB1 (reworked)				W09_OF2: broken JTAG module; W09_OB1 SW2 replaced
W04_OF1			W04_OB1				W04_OB1: short between DCD_AVDD and GND (will be sent form GOE to HLL for analysis)
W11_OF2			W06_OB1			L2_022	Visual inspection after ladder gluing showed cracks in W06_OB1
W12_OF1			W44_OB1			L2_024	shorts after glueing, after etching "repair" high source current

Phase 3 L1 Module Overview

Phase 3 IF			Phase 3 IB			Ladder	Status
ID	Probe Card	w/ Kapton	ID	Probe Card	w/ Kapton		
W05_IF							Drain-Source Short Matrix
W08_IF							SW4: ghost hits
W43_IF							at HLL, not sensitive since VBP is not connected to p+ punch through contact
W13_IF							kapton short between DCD_AMPLOW_SENSE ad DGND_SENSE
W04_IF							
			W42_IB				
			W04_IB				
			W13_IB				
			W46_IB				beast phase 2
W45_IF			W01_IB			L1_014	at DESY, IB has very bad pixel yield
W47_IF			W02_IB			L1_015	
W44_IF			W47_IB			L1_016	drain short due to particle during ladder mounting
W32_IF			W44_IB			L1_017	
W41_IF			W41_IB			L1_018	
W03_IF			W43_IB			L1_019	IF suffered power down issue, but still working
W42_IF			W45_IB			L1_020	
W46_IF			W32_IB			L1_021	IF suffered hot operation → kapton moved and wirebonds lifted up --> TDO of DHPT4 damaged (rework is tested with dummy ladder)
W02_IF			W03_IB			L1_028	IF suffered power down issue, but still working
W09_IF			W09_IB (reworked)			L1_030	broken due to particls and screwdriver

Phase 3 L2 Module Overview

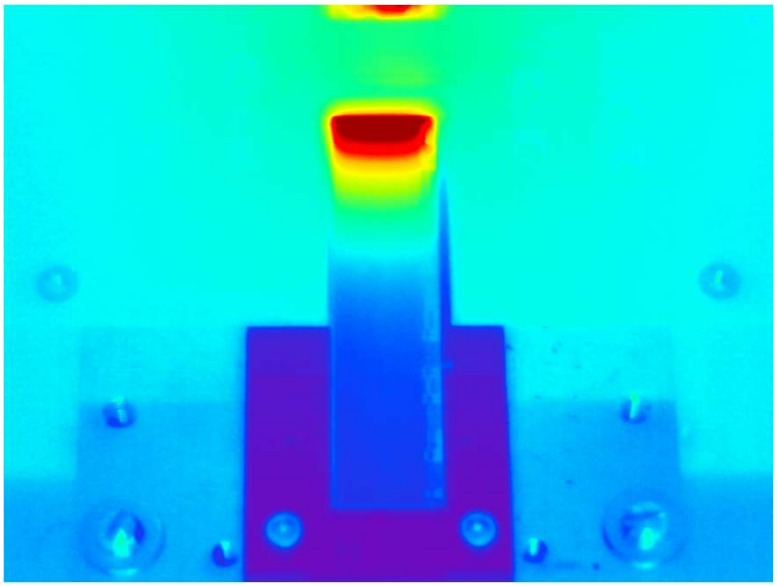
Phase 3 OF			Phase 3 OB			Ladder	Status
ID	Probe Card	w/ Kapton	ID	Probe Card	w/ Kapton		
W44_OF1	SW-DVDD						SW-DVDD high current, matrix damaged during manual handling
W44_OF2	SW-DVDD						SW-DVDD high current fixed by replaceing SW6, module broke during 2nd re-work (ClearOn/Of
W45_OF2 (reworked)			W03_OB1				W03_OB1: garde B
W43_OF1 (reworked)			W05_OB1				W05_OB1: noisy DCD3
W08_OF2			W08_OB1				
W09_OF1 (reworked)			W08_OB2				
W09_OF2			W09_OB1 (reworked)				W09_OF2: broken JTAG module, W09_OB1 reworked (SW2 replaced)
W11_OF1			W12_OB1				W12_OB1: grade B
W32_OF2			W12_OB2				W12_OB2: grade B
W33_OF1			W32_OB2				
W33_OF2			W33_OB1				
W41_OF1			W42_OB1				
W45_OF1			W42_OB2				
W46_OF1			W44_OB2				
W46_OF2			W45_OB2				
W02_OF1			W46_OB1				
W03_OF2			W46_OB2				
W04_OF1			W04_OB1				W04_OB1: short between DCD_AVDD and GND (will be sent form GOE to HLL for analysis)
W05_OF1			W10_OB1				
W11_OF2			W06_OB1			L2_022	Visual inspection after ladder gluing showed cracks in W06_OB1
W12_OF1			W44_OB1			L2_024	shorts after glueing, after etching "repair" high source current
W32_OF1			W09_OB2			L2_029	

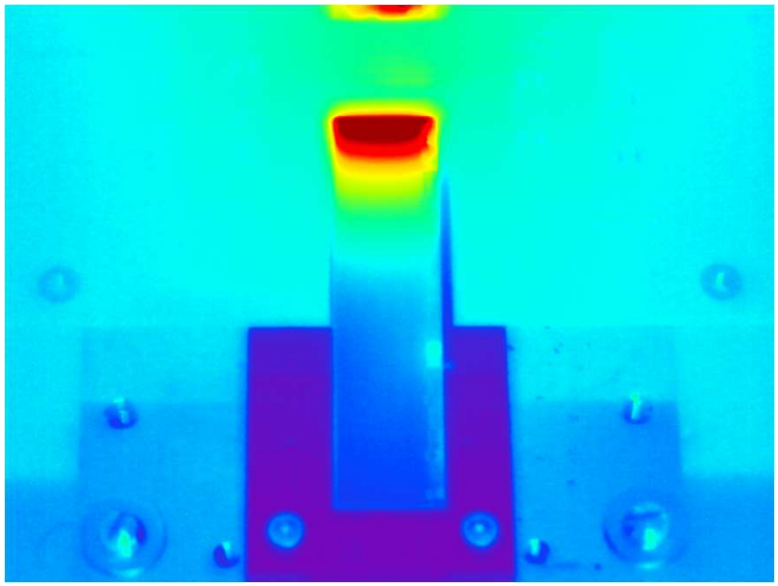
Clear_On/Celar_Off Short

W44_OF2

- Faulty switcher could be identified by thermal imaging
- Module broke during the rework @ IZM

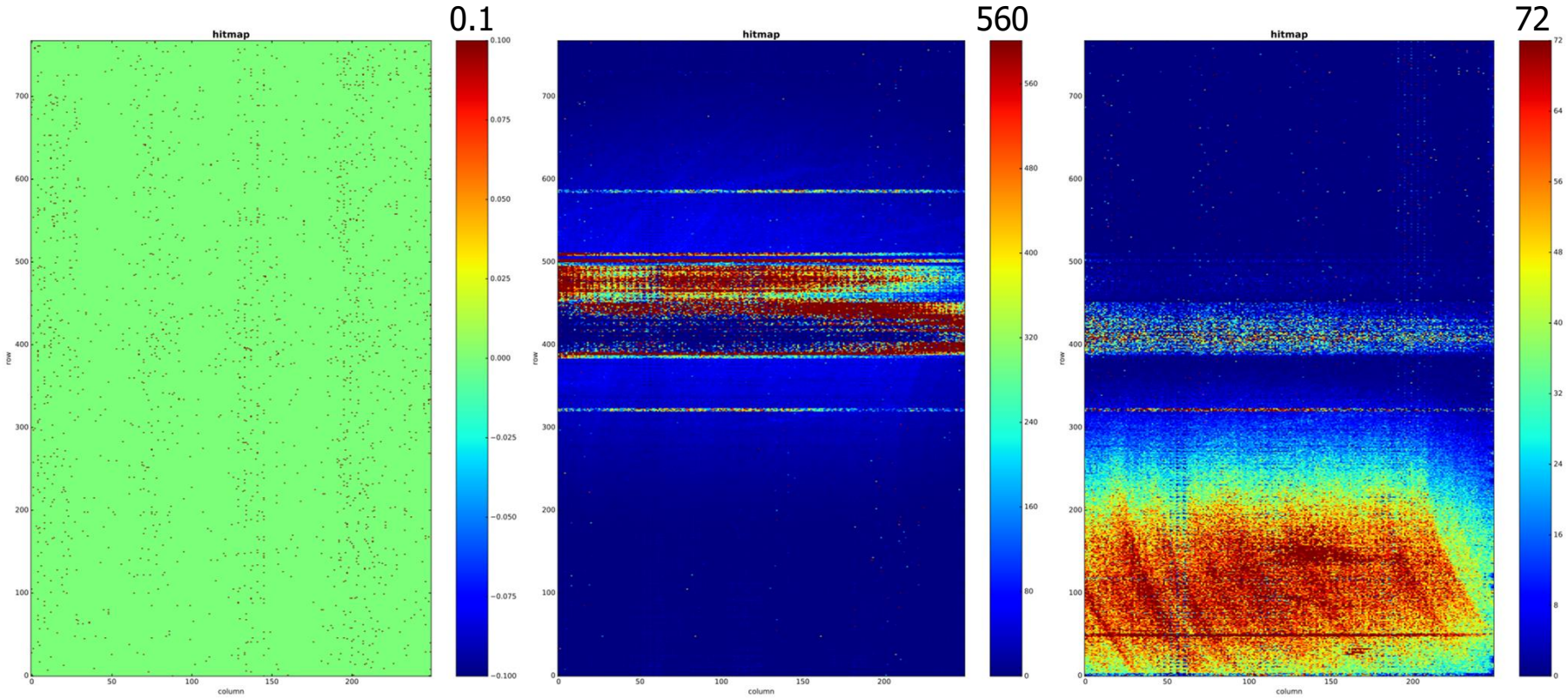
Module	Fault	Action	Result
W31_OB1	Not identified.	None taken.	Module glued to L2_010
W44_OF2	Switcher3	Replace Switcher3.	Module broke during rework.





W08_IF Fails during Source Scan

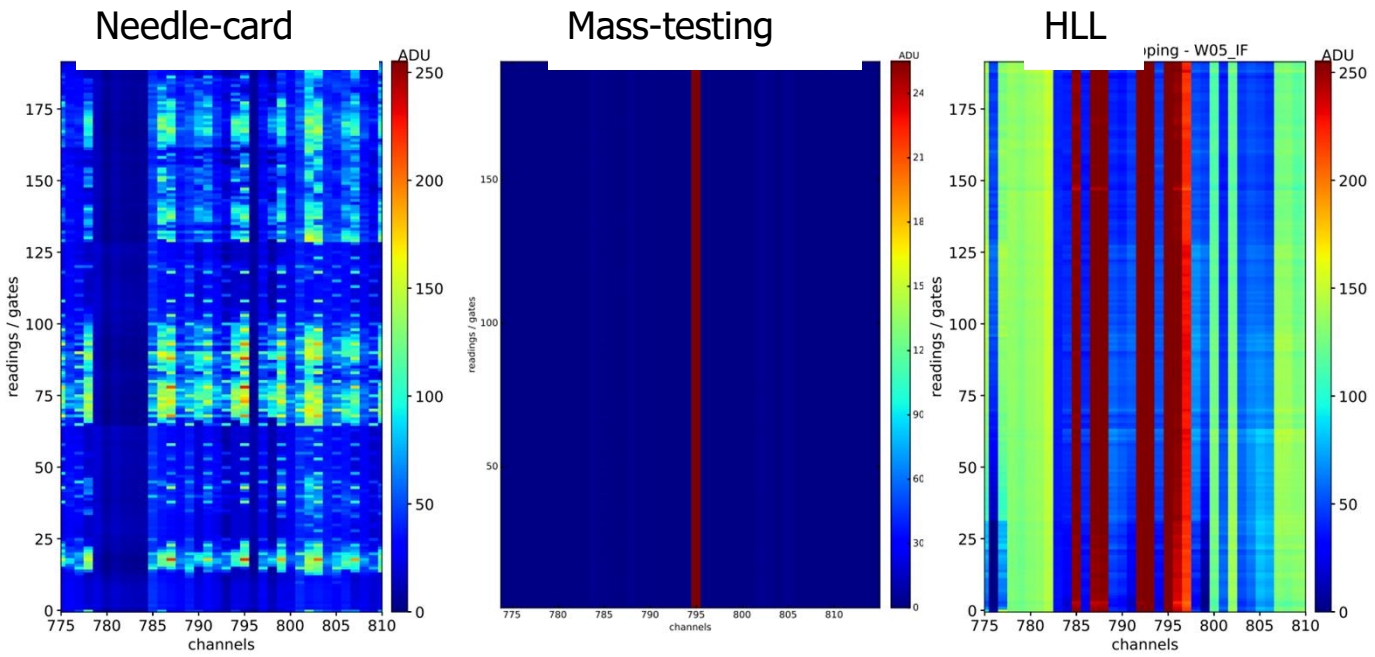
- Without a source over the matrix: no sign of the affected area
- With a source over the affected area: about 10 times as many hits as expected; distribution with no apparent link to the source geometry
- With a source somewhere else over the matrix: about half of the affected area (the part of the region that showed less/no signal before) shows hits



W05_IF (with Kapton)

Module has short between Drain and Source:

- Short was not caught during production QA due to unexpected measurement value (currents O(+10^22A)), was flagged as open instead of short
- Appeared as a single missing electrical column in needle-card test
- First found as single hot line during mass-testing (MPP)
- Damage appears to be growing over time, compromising electrically neighboring lines on DCD4



W05_IF (with Kapton)

Possible solutions:

⇒ Cut drain line between DCD and matrix

- Possible damage on neighboring lines during cutting (very narrow region)

⇒ Removing DCD4 and disconnecting the bump-ball of the affected channel A0<27>

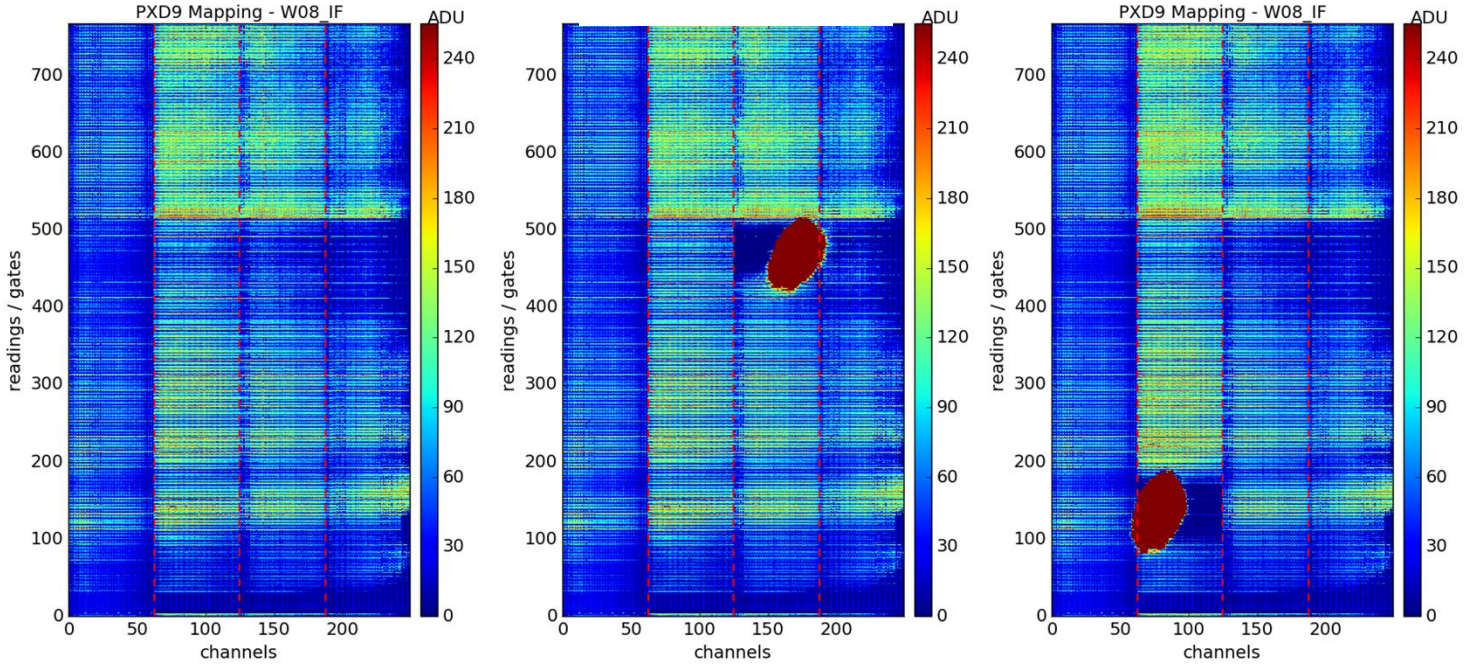
- Replacement of DCD4

- Module used to check power-up/-down sequence at MPP

W08_IF Laser Spot during Probe Card Tests

- No sign of the problem could be seen during needle-card measurements as it is not visible in pedestals (even with laser spot)

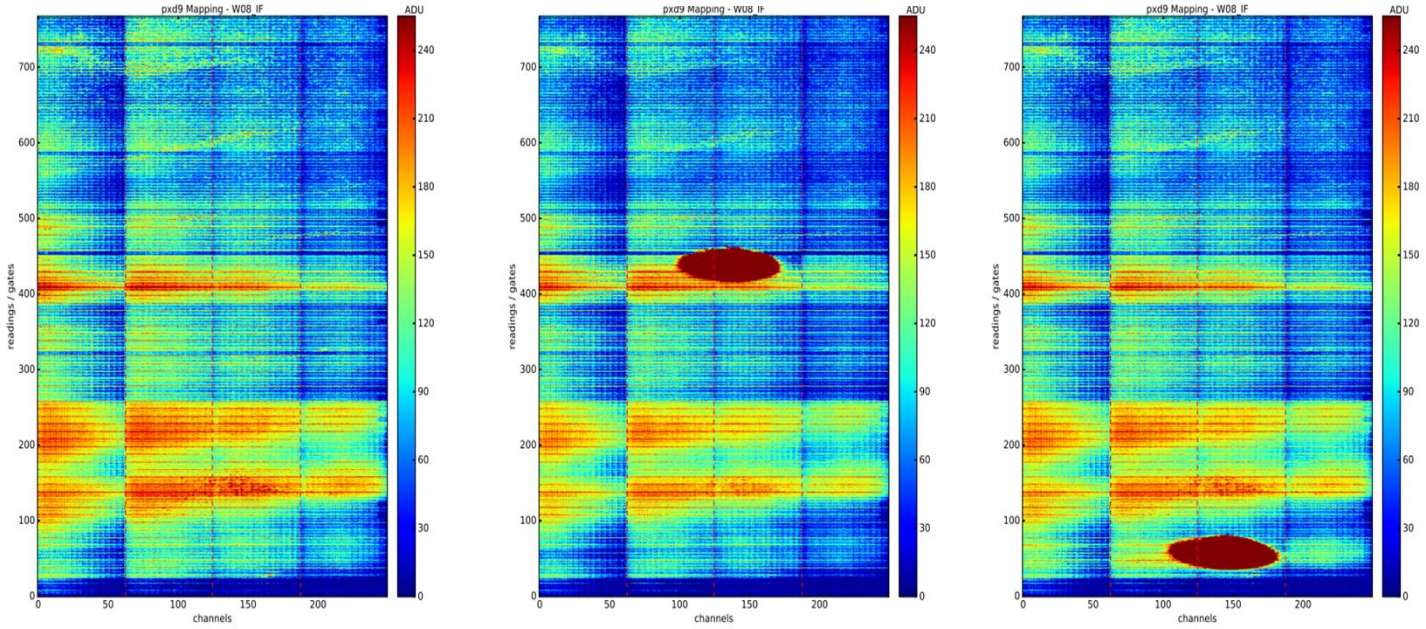
Needle-card:



W08_IF Laser Spot @ pxdtest5 (w/ kapton)

- Nor during pedestals measurements (with laser spot) during with kapton

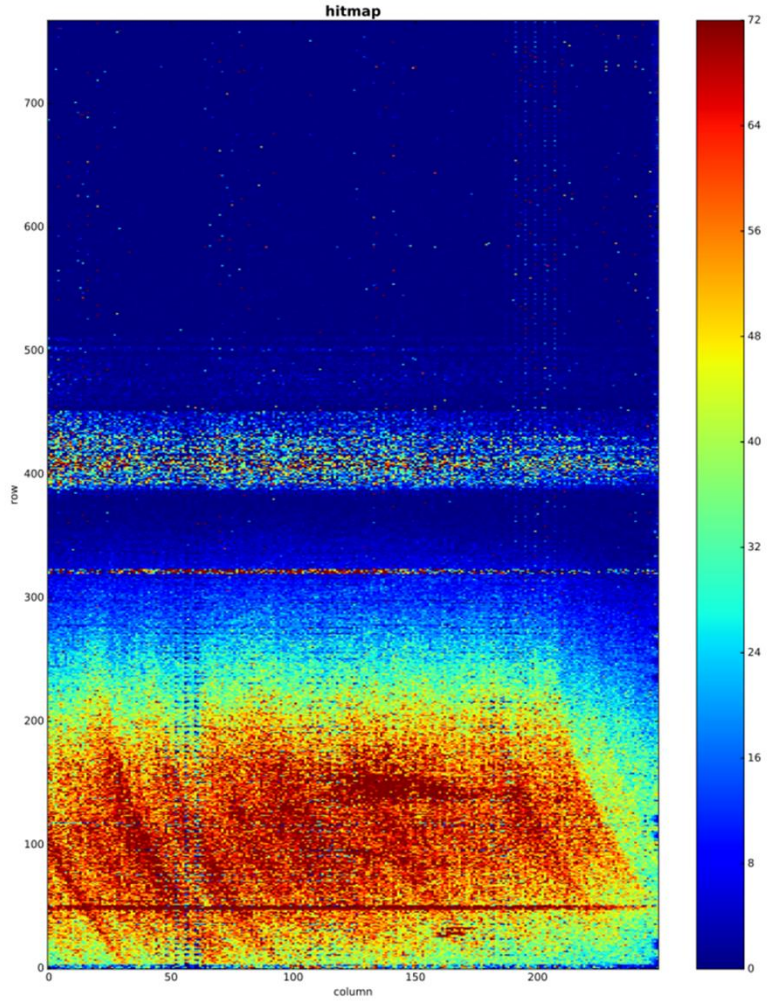
Same with pxdtest5:



W08_IF

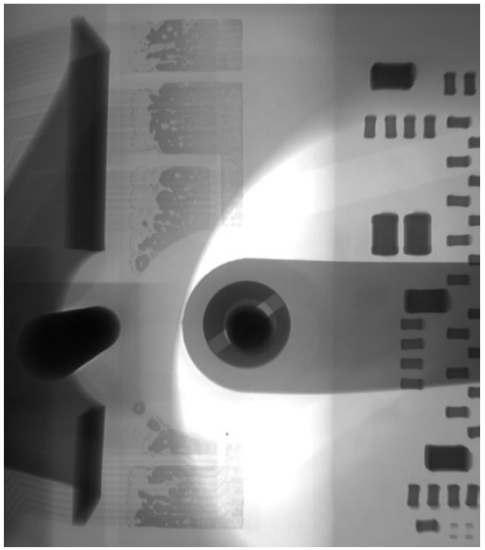
Failure mode is not understood

- Ghost hits only in rows connected to SW4 (exchange of SW4)
- Debugging could be continued using a laser (small spot, controlled timing)

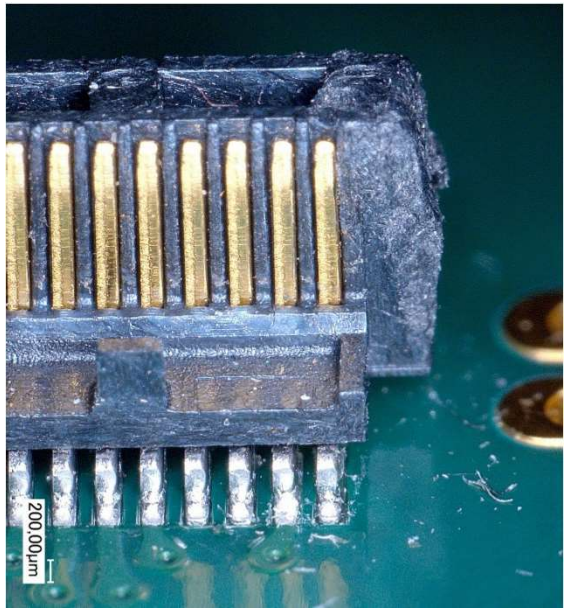


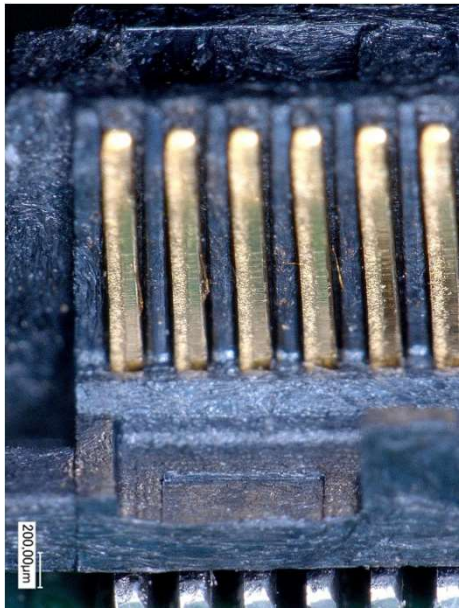
Repaired: **W09_OF1** – with Kapton L2fwd_V30_200_027

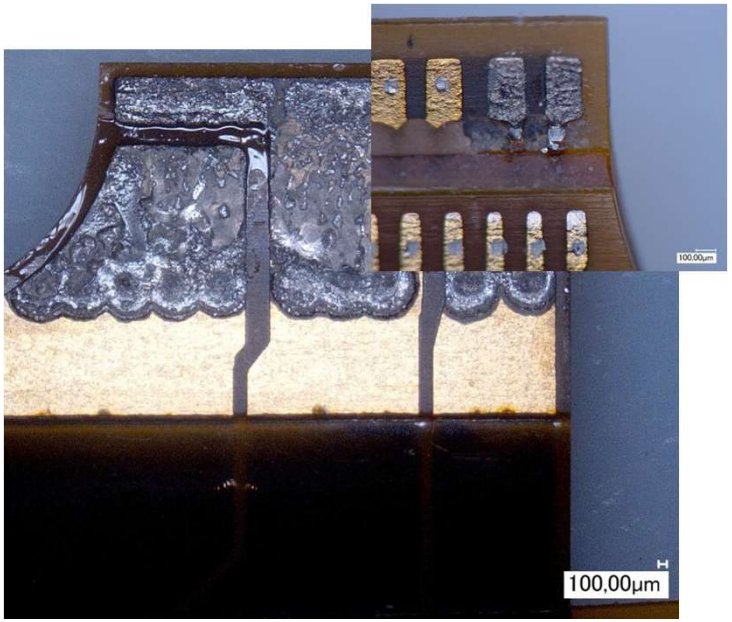
- No clear evidence for the short between GND and DCD_AVDD
- Possible failure mechanism:
  - Connection between the solder pads (AGND and DCD_AVDD are neighboring pads on the bottom of the kapton), x-ray image (on the right side) not suspicious
  - Damaged/misplaced connection of the SAMTEC connector to the Lab Patch Panel
- Kapton was exchanged and module W09_OF1 passed the testing with kapton L2fwd_V30_200_041



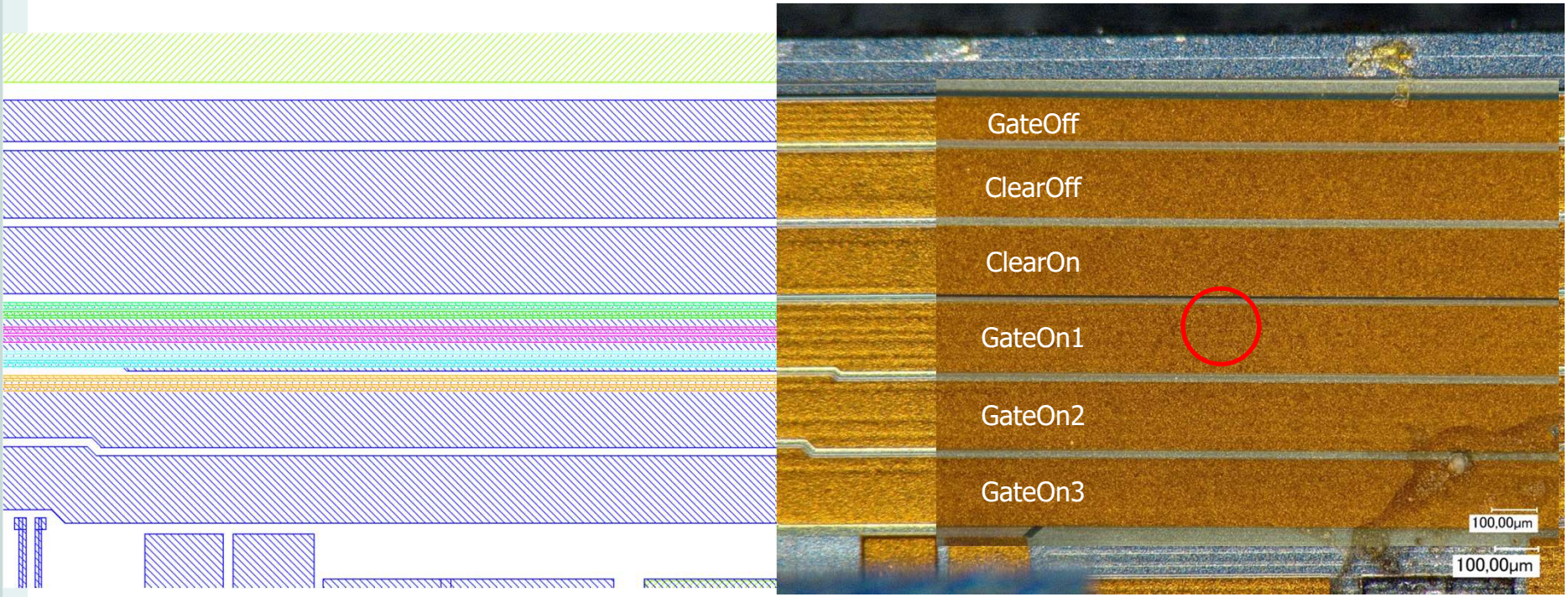
Photos of kapton L2fwd_V30_200_027







L1_035 W04_IB and W04_IF



SW_SERIN (differential line)
SW_CLK