MOSAIX/LAS Wafer Probing

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SVT Working Meeting

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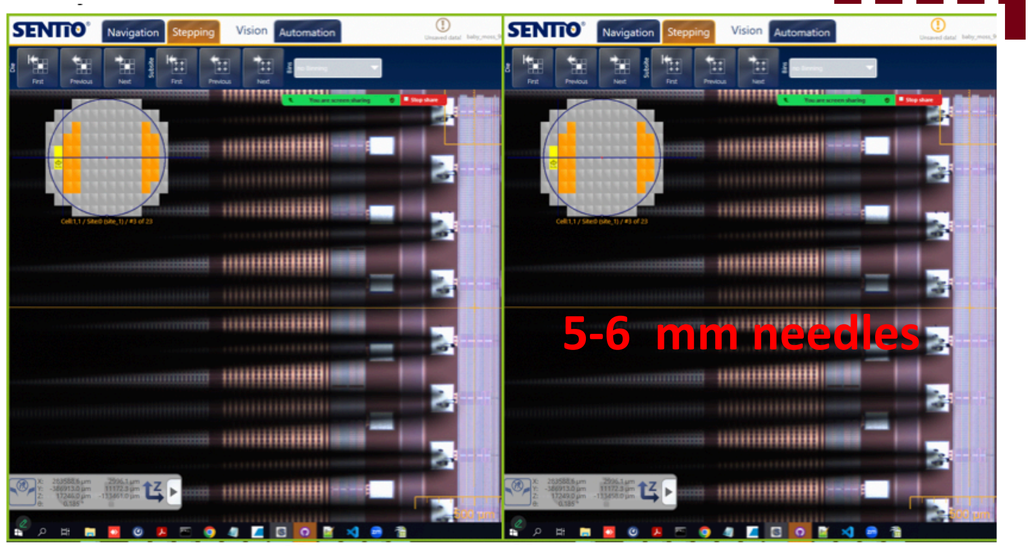
INTRODUCTION

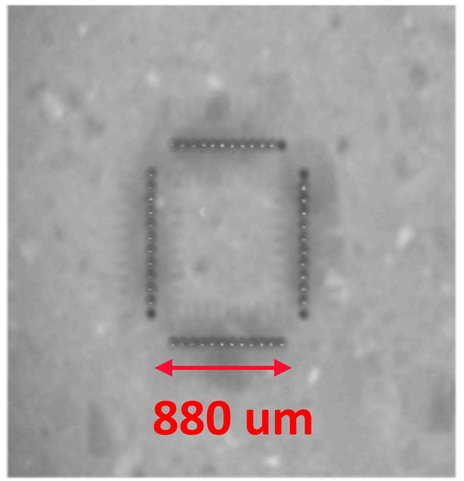
- MOSAIX and LAS will have 10.24 Gbps data links:
  - Standard cantilever probe cards **cannot** be used to **fully characterize** the sensor because limited at few hundred Mbps
  - **Vertical probing** allows operation at > 10 GHz. A prototype probe card was created to validate the technology



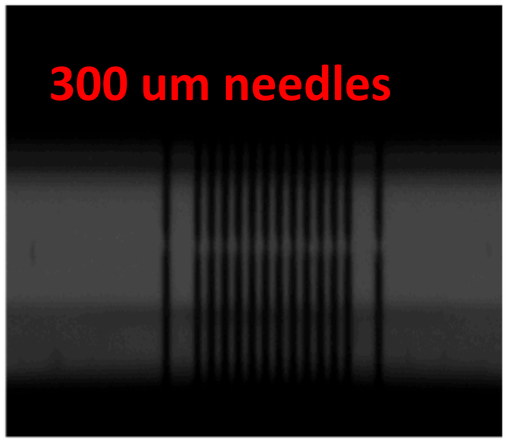
Cantilever needles

- SVT will need 300-400(?) wafers (considering yield and spares). Time needed for characterize 1 MOSAIX/LAS:
  - 12-24h if read out at low speed (160 Mbps)
  - 0.25-1 h if readout at high speed (10 Gbps)

- Automatization and fast readout is critical to the project
- Collective effects studies require parallel readout of multiple MOSAIX



Chuck camera view of the needles

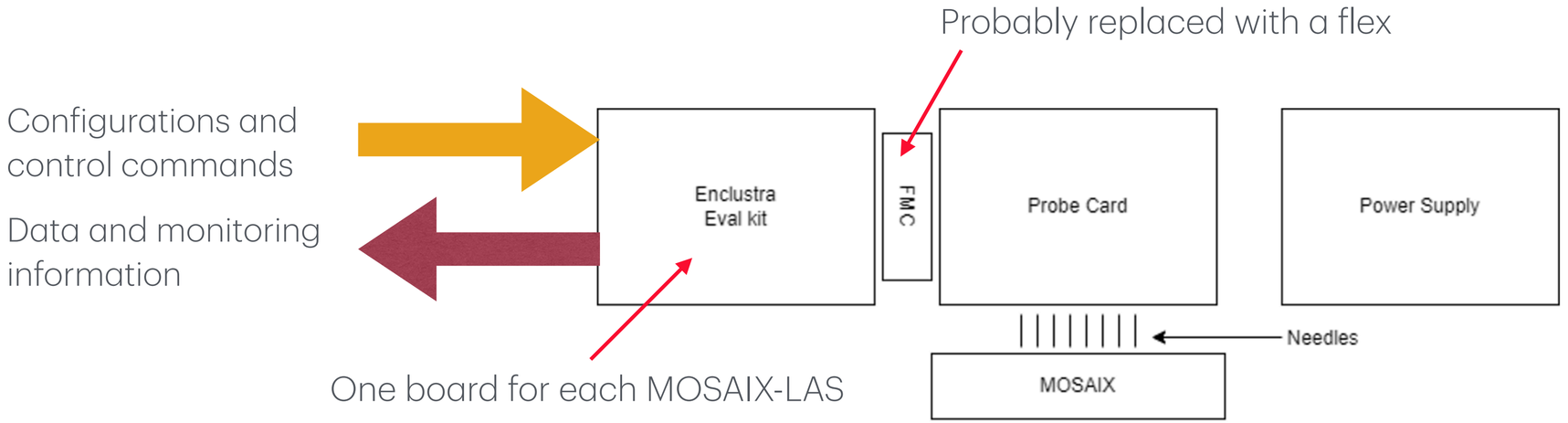


Side camera view of the needles

Cantilever needles

WAFER PROBING GENERAL APPROACH

- Develop general purpose HW that can be used in several wafer probing sites and with different level of performance:
  - **High performance:** RF Vertical probing 300 mm machines
  - **Low performance:** cantilever technology
- ITS3 is developing a probe card with cantilever technology while SVT is developing a probe card with vertical probing technology. SVT will deliver a cantilever probe card if needed.
- General Purpose readout and control hardware and software for MOSAIX
- Dedicated automated software for wafer prober MPI (CERN/MIT, Prague), Formfactor (CERN, ONRL, BNL) and …



WAFER PROBING STATION at CERN

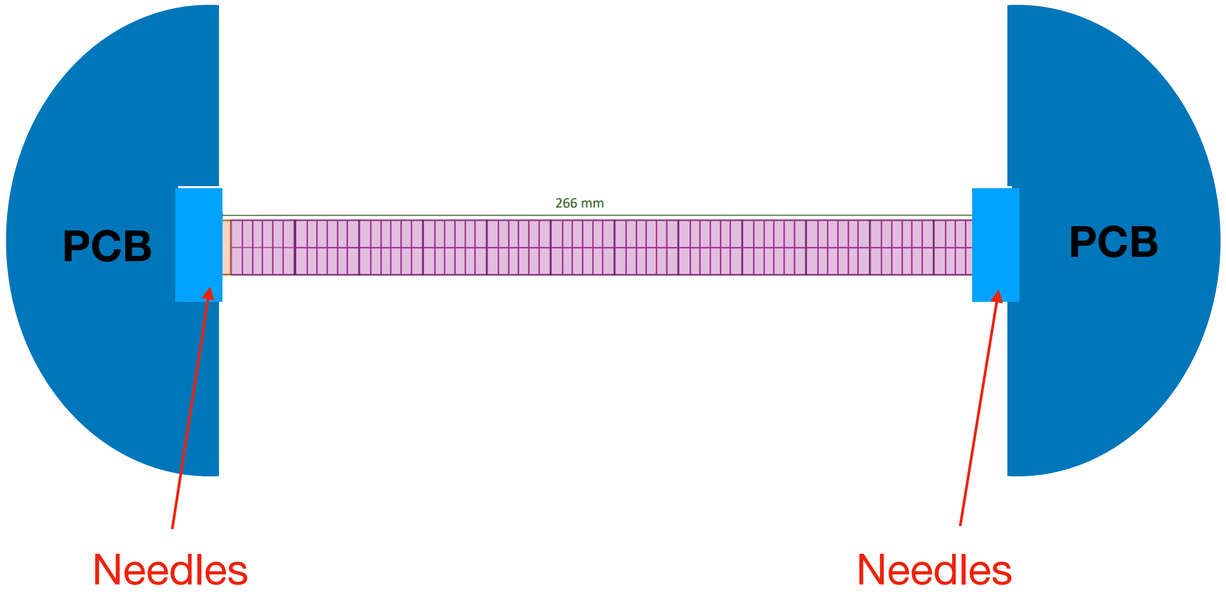
- MPI TS-3500 SE Automated test system
  - Installed at CERN in the DSF (Departmental Silicon Facility) lab

- Main specifications:
  - Designed to be able to load up to 300 mm (12”) wafers
    - **Micro-holes (200 um) chuck for thin wafers handling**
  - RF setup with possibility to test up to 110GHz and beyond
  - Several cameras installed: wide, **chuck, off-axis (vertical probing)**, VCE
    - Automatic Probe To Pad Alignment compensation
  - Extended probe card holder (see later)
  - Wafer wallet could be added for fully automatized process

- Goal:
  - **Commission test setup before being distributed to the institutes**
  - Test all the ITS3 ER2 wafers + (N) SVT ER2 wafers
  - Participate in the SVT production testing

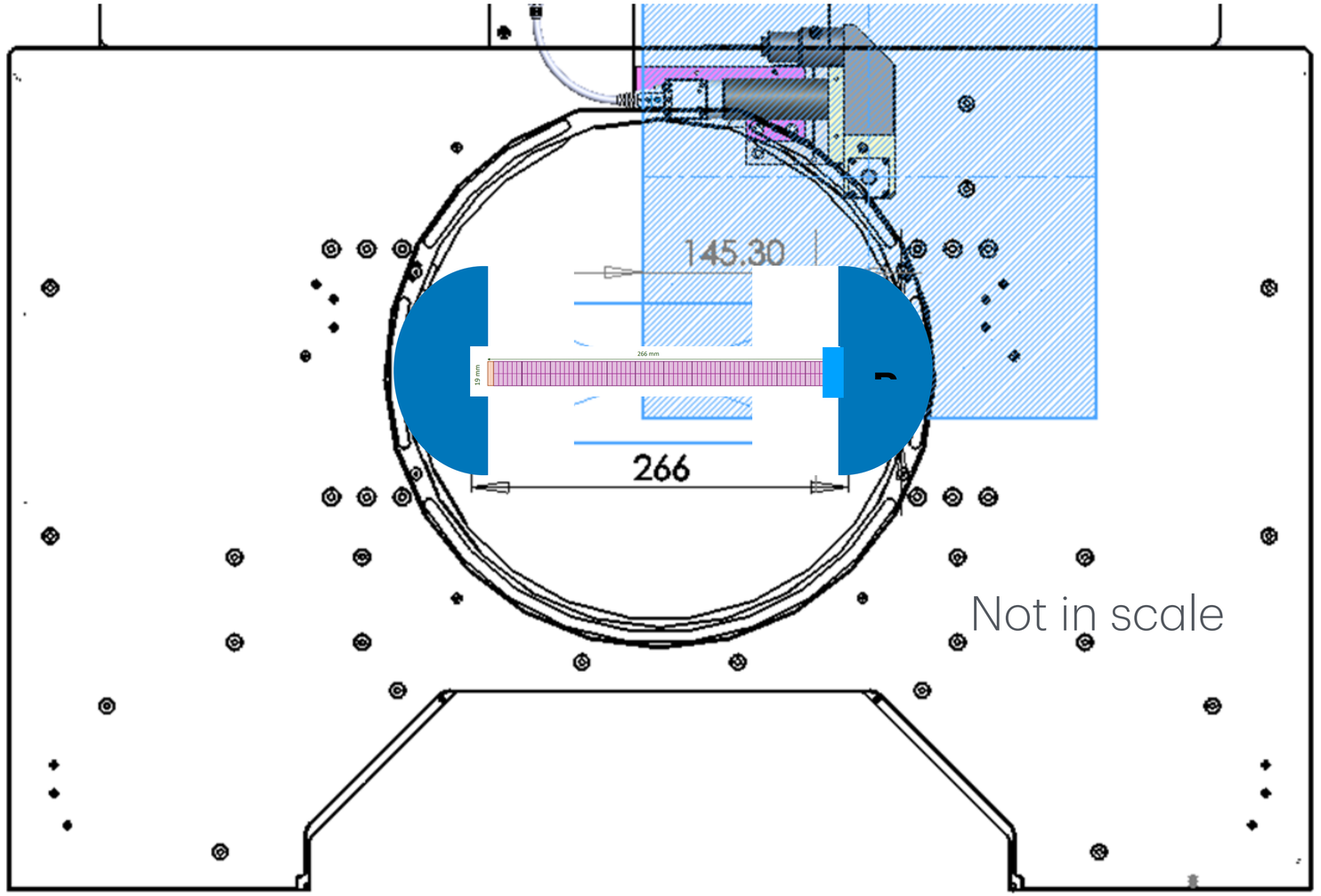
PROBE CARD concept design1

- It allows irradiation, laser and thermal camera studies
- It **can** be easily extended to multipoint only for MOSAIX but not for LAS
- Probe card extend in the space between the sensor and the top wafer prober hole
- Plan B



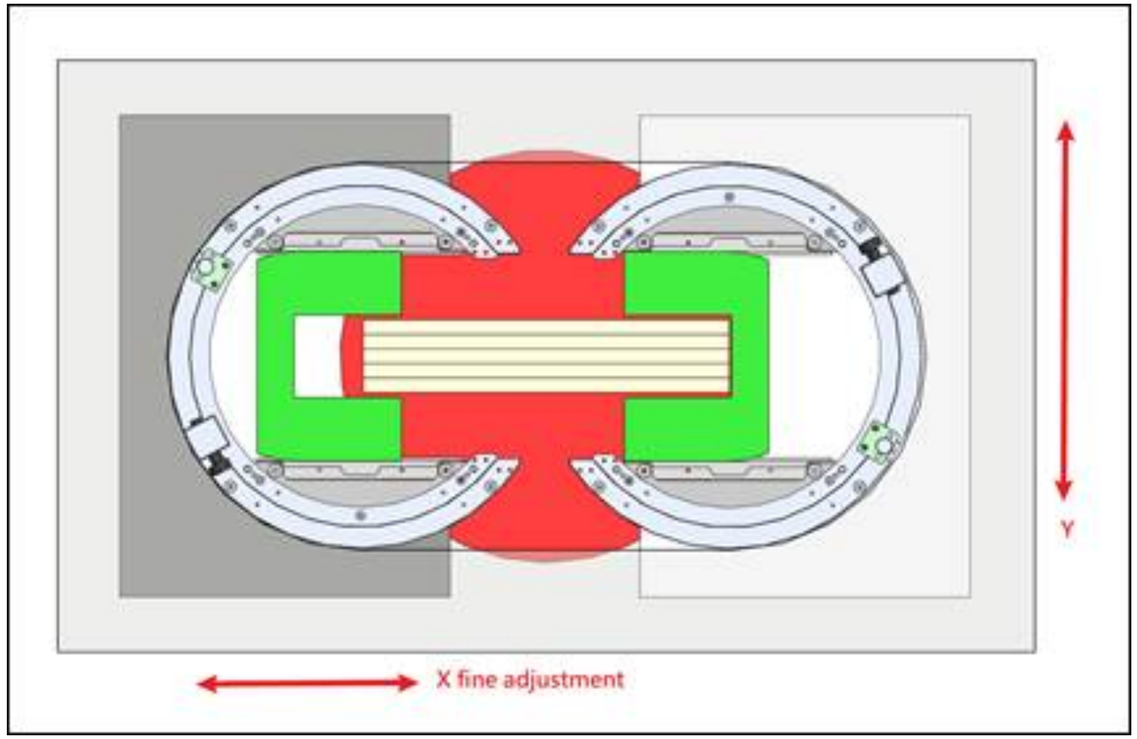
WAFER PROBING STATION at CERN

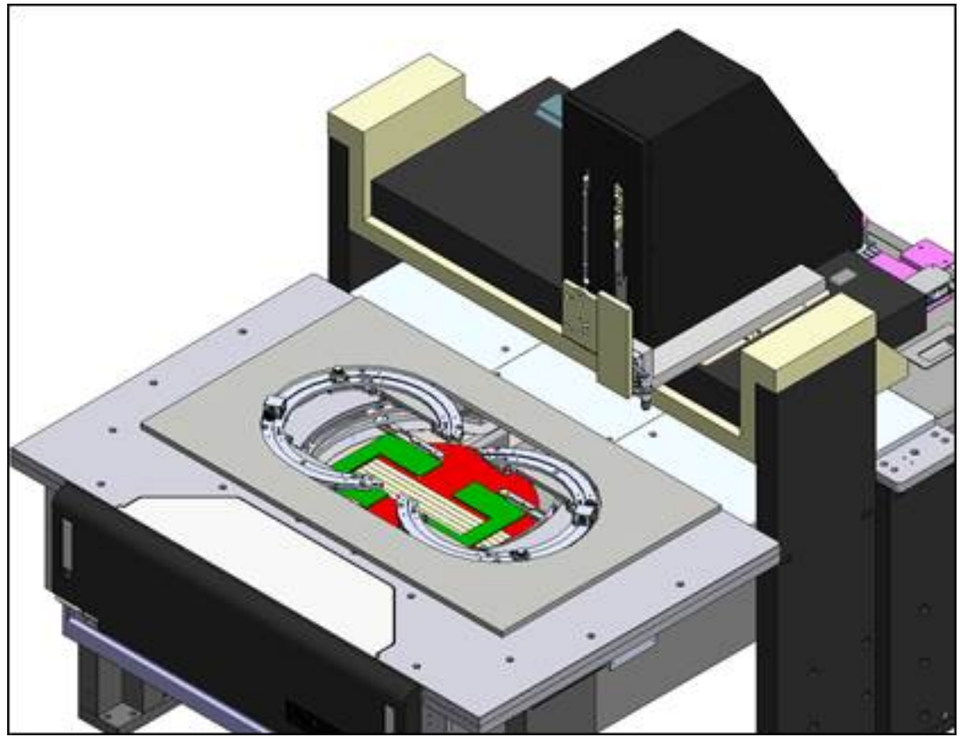
- Extended hole for probe card holder



DESIGN WITH TWO PROBE CARD HOLDER

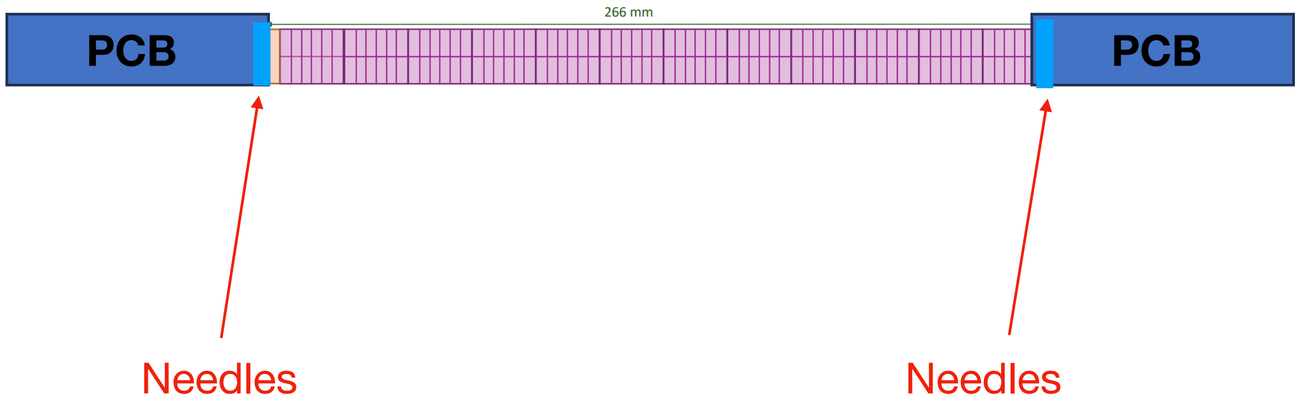
- It allows vertical probing for LEC and cantilever for REC





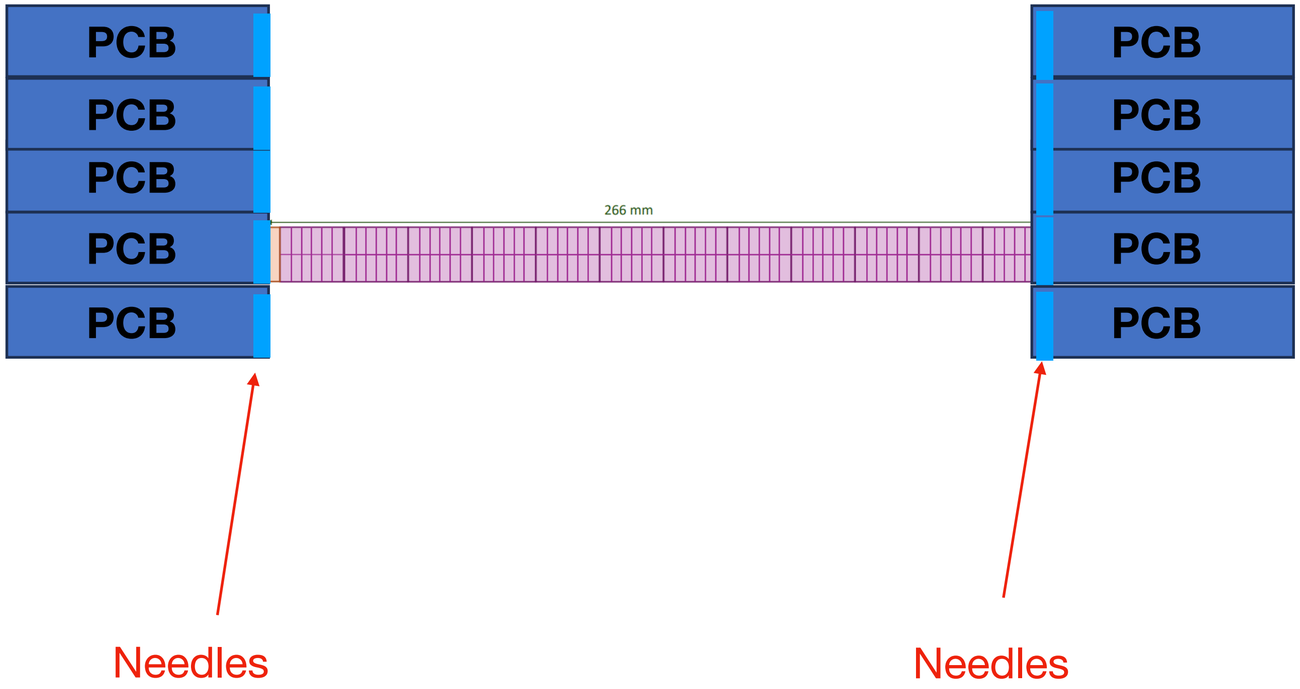
PROBE CARD concept design 2

- It allows irradiation and thermal camera studies
- It can be easily extended to multipoint for MOSAIX and LAS
- Engineering challenge because of low space between the needles and the end of the PCB (400 um)



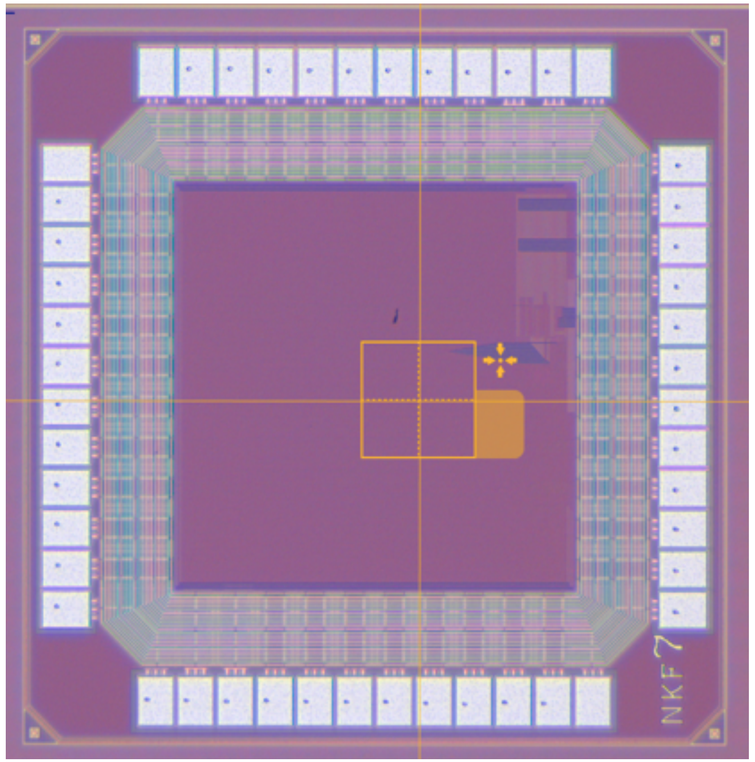
PROBE CARD concept design 2 Multipoint

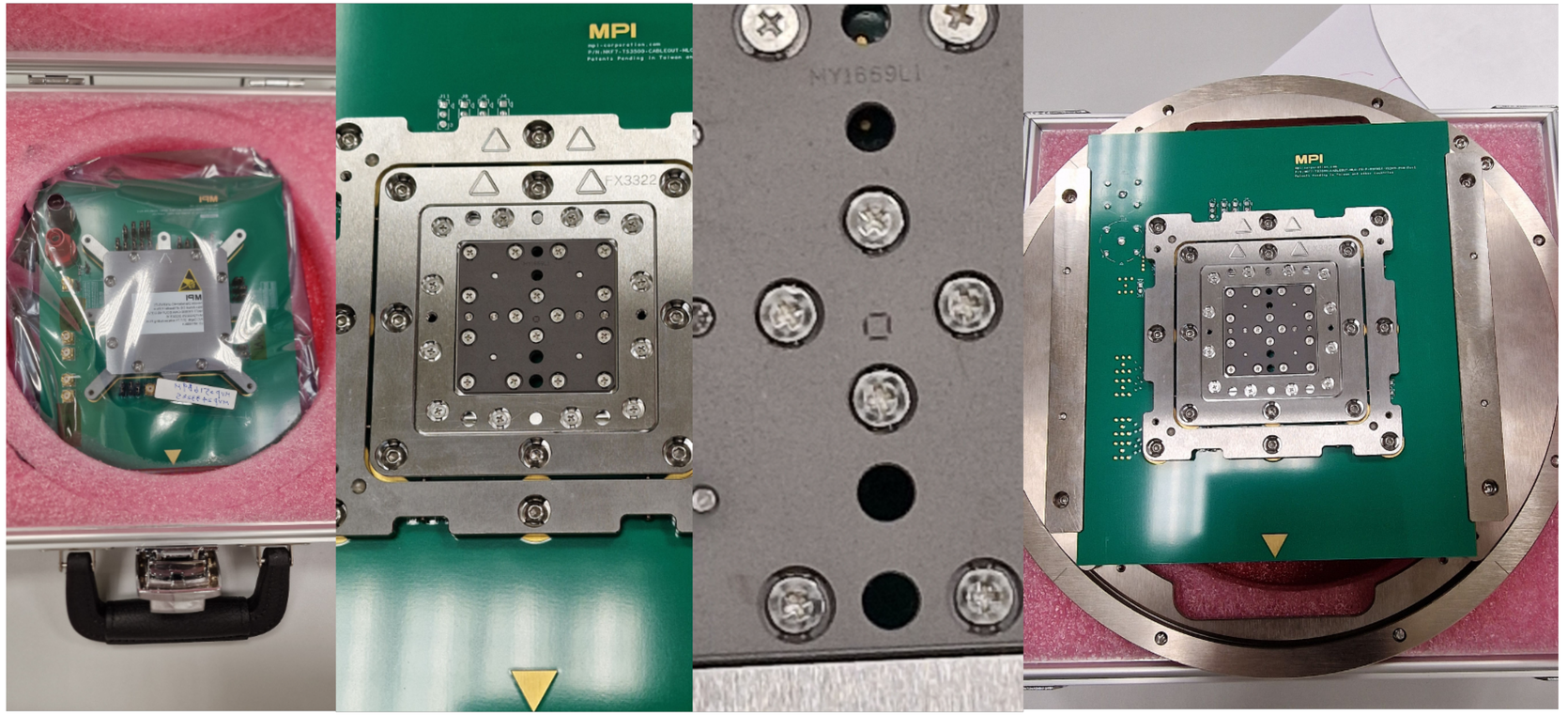
- It allows irradiation and thermal camera studies
- Extended probe card holder below wafer prober top
- Can perform multipoint for both LAS and MOSAIX



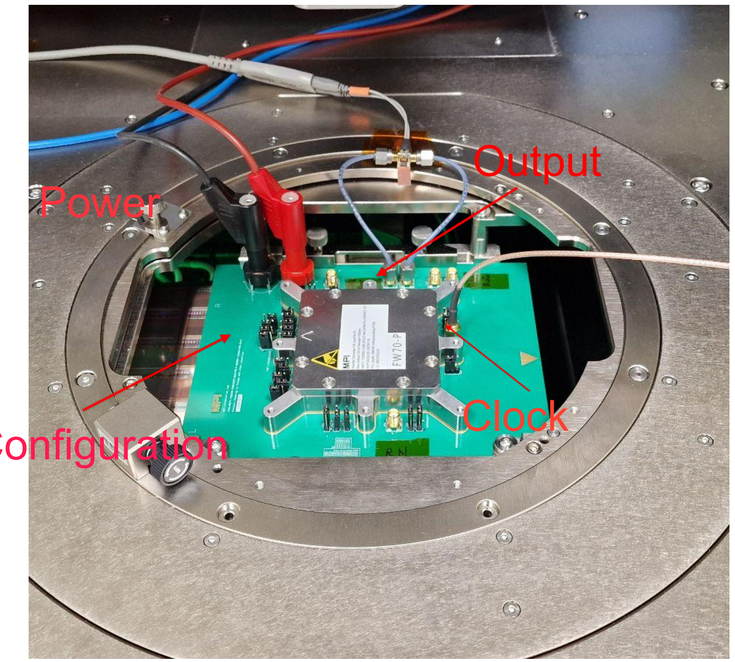
NKF7 PROBE CARD

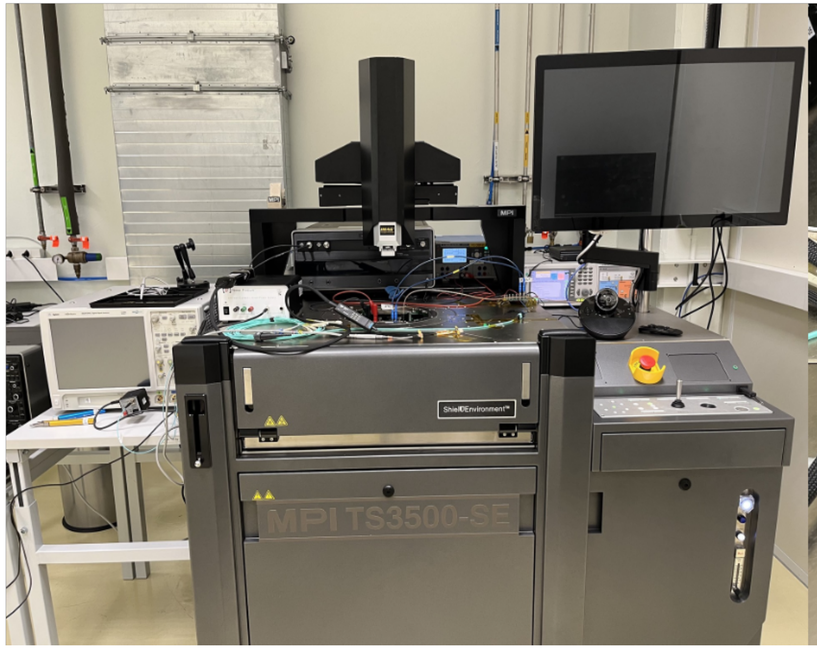
- The NKF7 is the prototype of the 10.24 Gbps link used in MOSAIX
  - It is present on the ER1 wafer as independent ASICs
  - We used it to validate the vertical probing technology and gain experience with the procedure
  - Ref clk: 640 MHz , 16 bits input

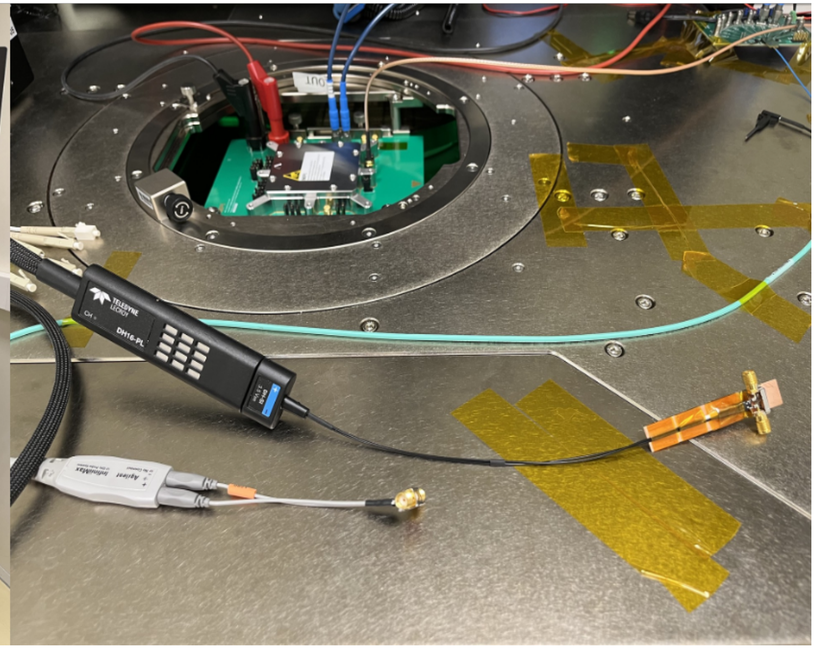




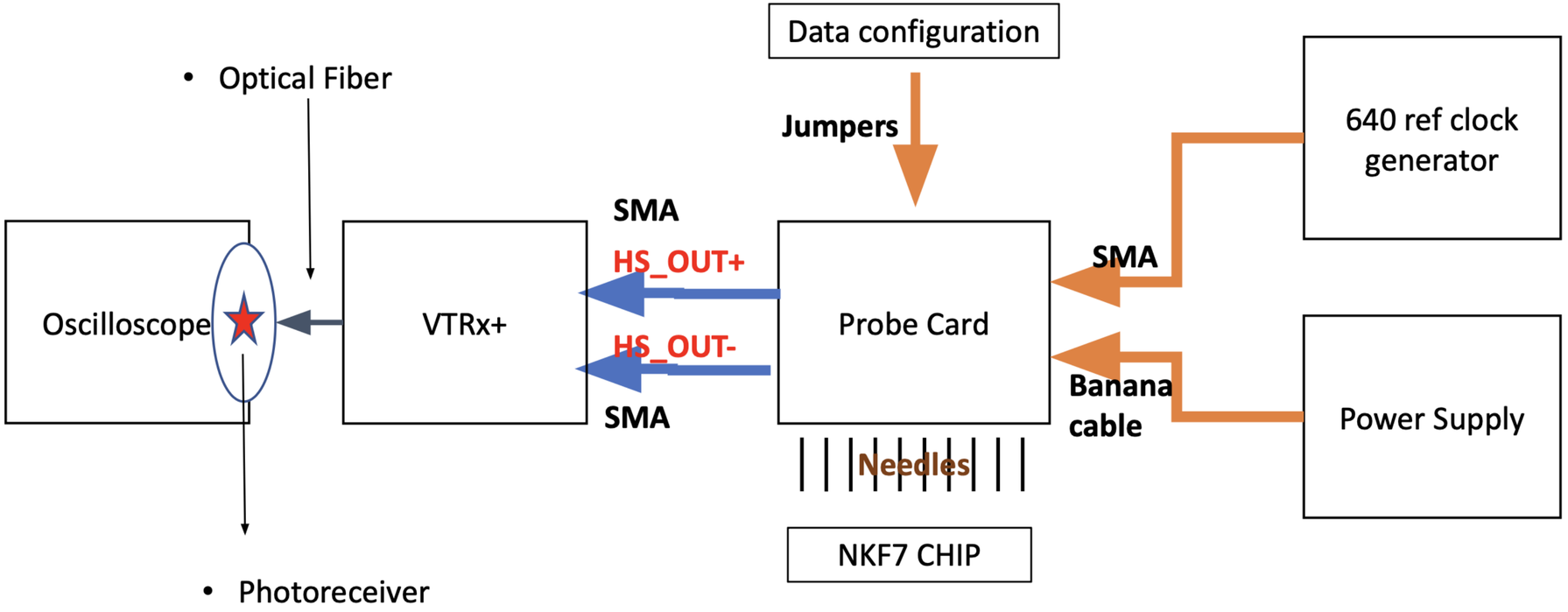
NKF7 ELECTICAL TEST SETUP







NKF7 ELECTRICAL TEST SETUP (one of many)

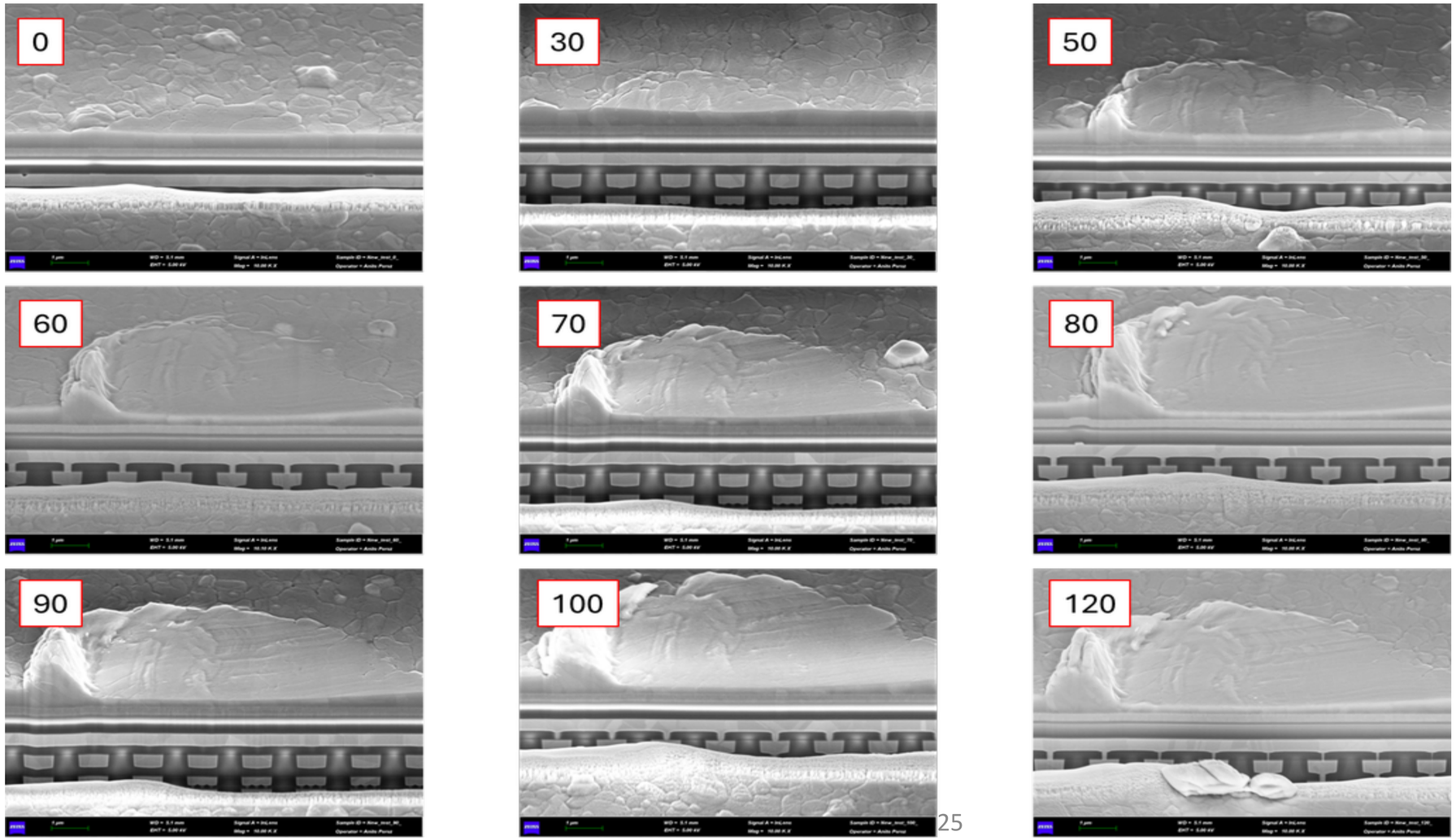


NKF7 ELECTRICAL TEST SETUP (one of many, 1.4 V, 25 mA)

- EXAMPLE measurement!
- AGILENT 12 GHz Scope, VTRx+
- Correct amplitude observed
- Correct frequency
- Low Jitter observed

FIB-SEM IMAGES OF PAD USING EVS_80 NEEDLES

- Measured electrical characteristics at different overdrives (applied force)
  - Perfectly in specs with 70-80 OD
  - No PAD damages deformation/cracks observed

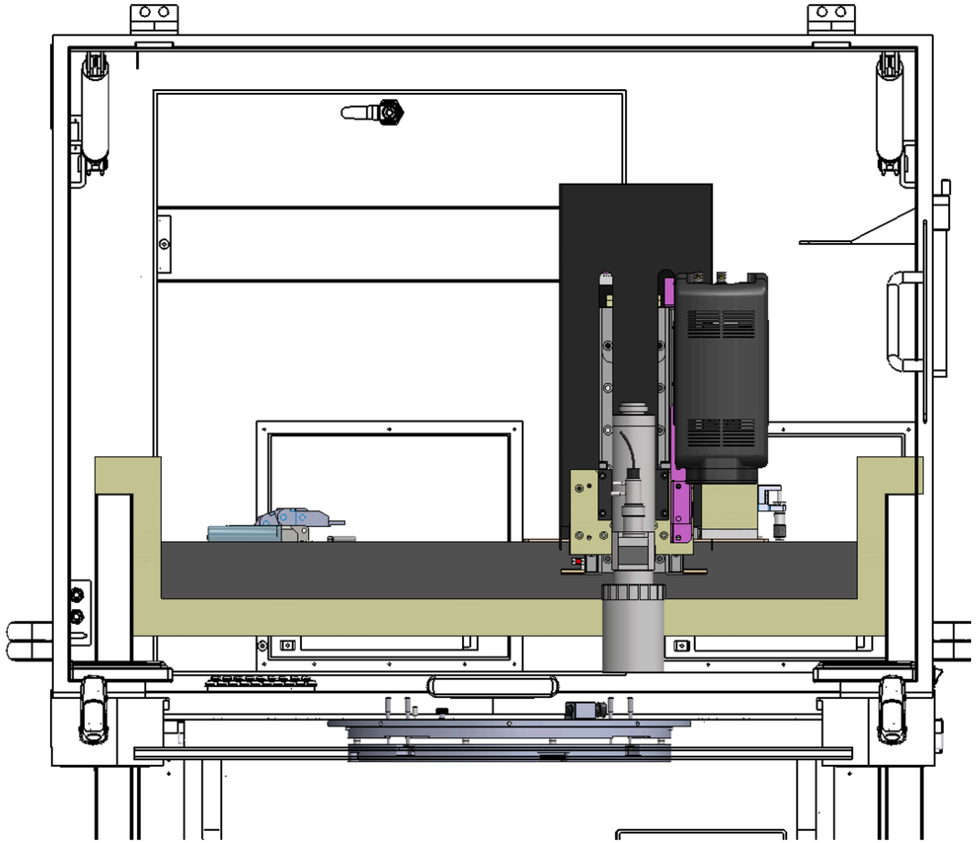


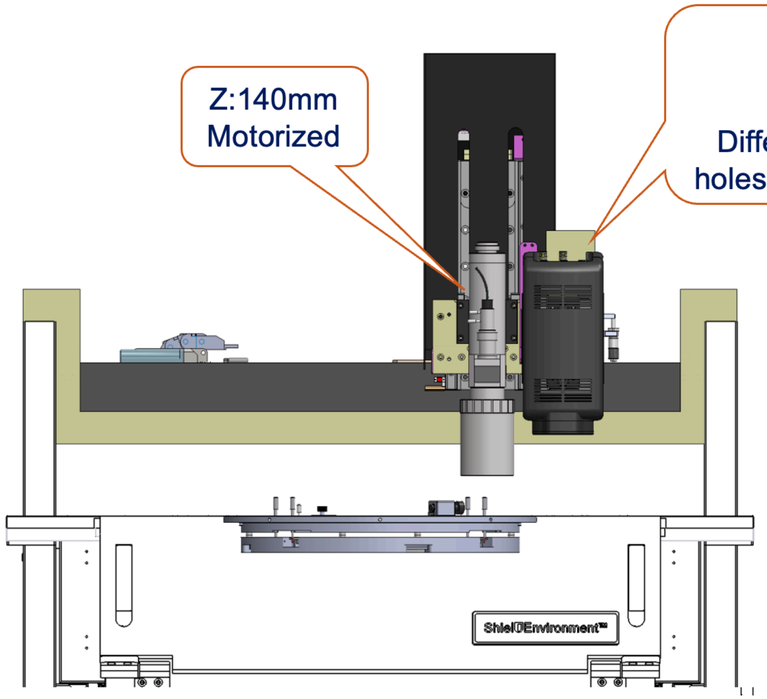
CONCLUSIONS

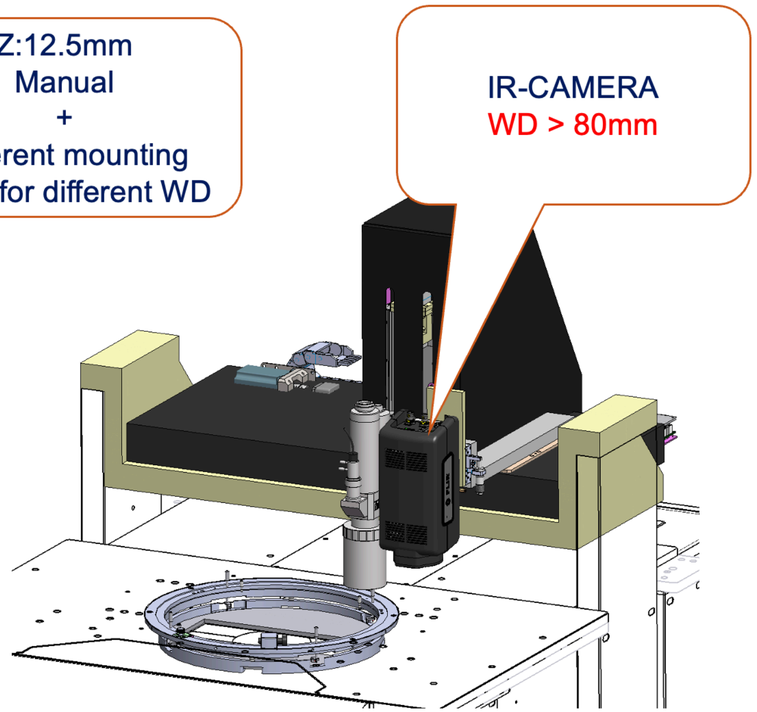
- Prototype probe card with vertical probe technology **fully validated**
- Design of MOSAIX probe card well advanced for single/multi point
- Design of MOSAIX/LAS probe card for multipoint still under discussion
- Probe card holder design for concept design 1 ready

BACKUP

WP UPGRADE FOR LASER/IRRADIATION/THERMAL CAMERA





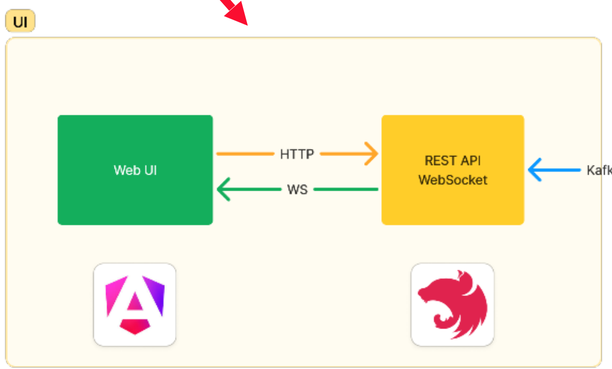


SW Block Diagram

UI produces commands and receives data to visualize. Web Based

Kafka backbone, distributed

SVTSupervisor acts as global brain of the system. On a dedicated server



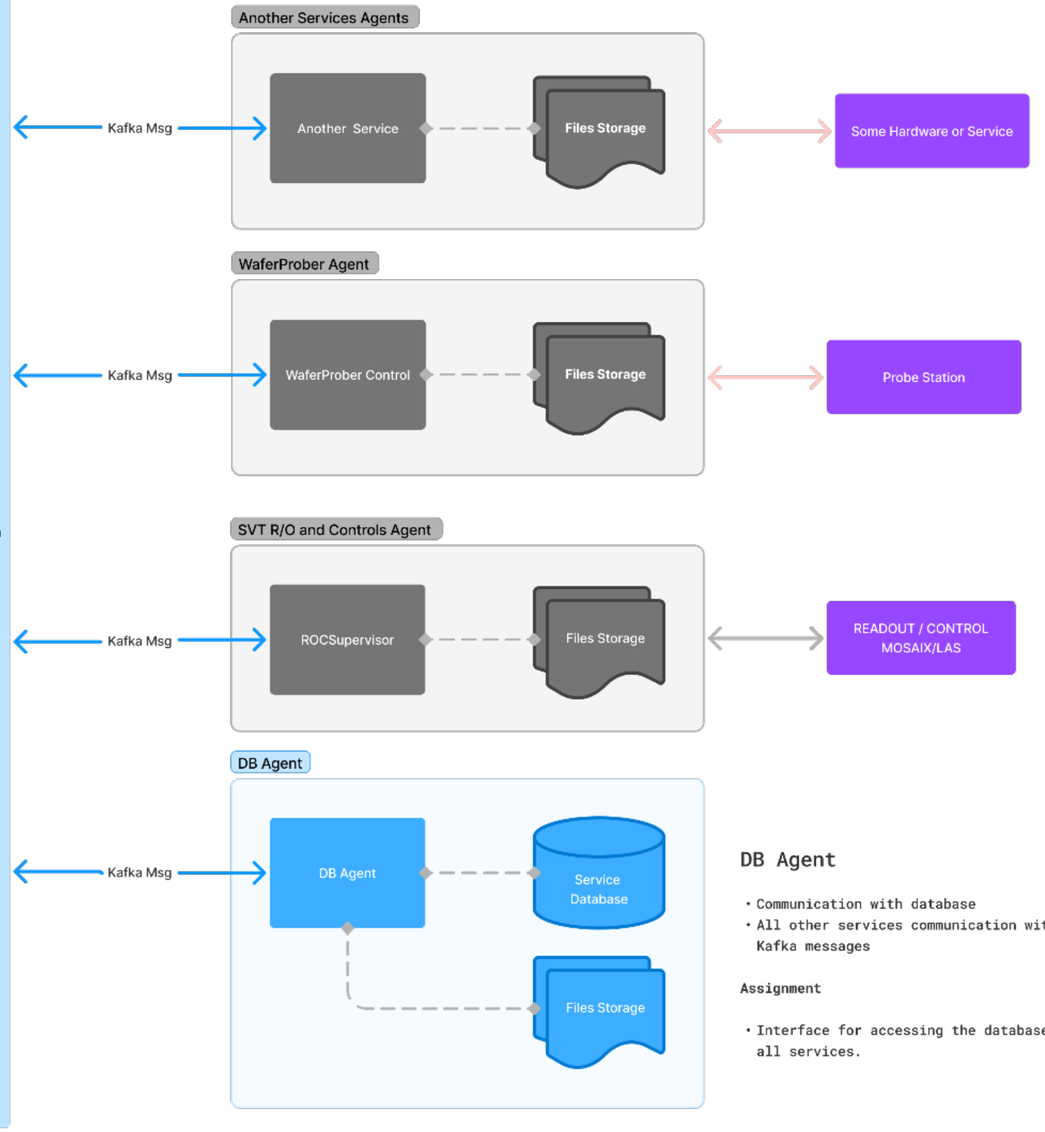
Kafka Msg

SVTSupervisor

Kafka Msg

Kafka

Agents layer, distributed



UI

- Web based service, consist of 2 parts:
  - Front-end
    - running in the browser
  - Back-end
    - ensure communication between other services, provides HTTP, WS, Kafka interfaces for communication
- Assignment
  - UI for start/stop operations
  - UI for data overview/analysis

DB Agent

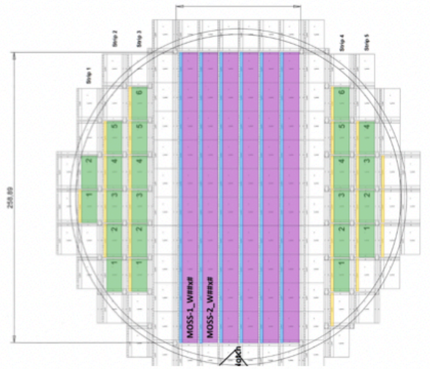
- Communication with database
- All other services communication with Kafka messages

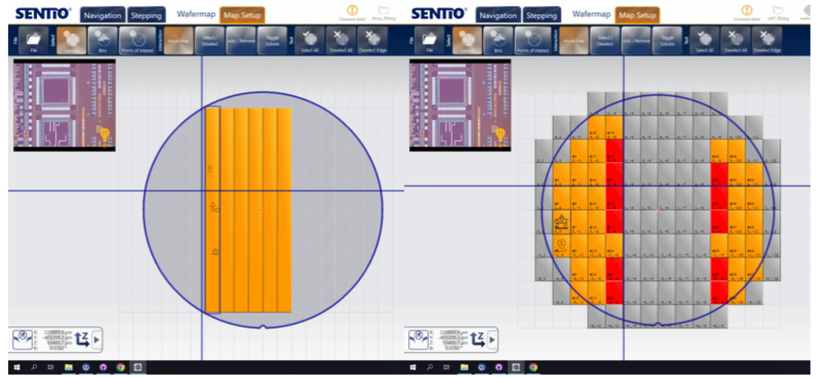
Assignment

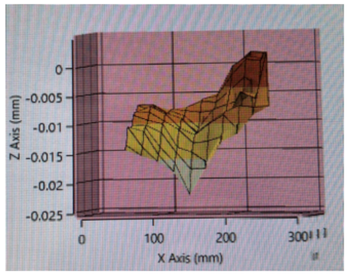
- Interface for accessing the database for all services.

MPI TS-3500 SE

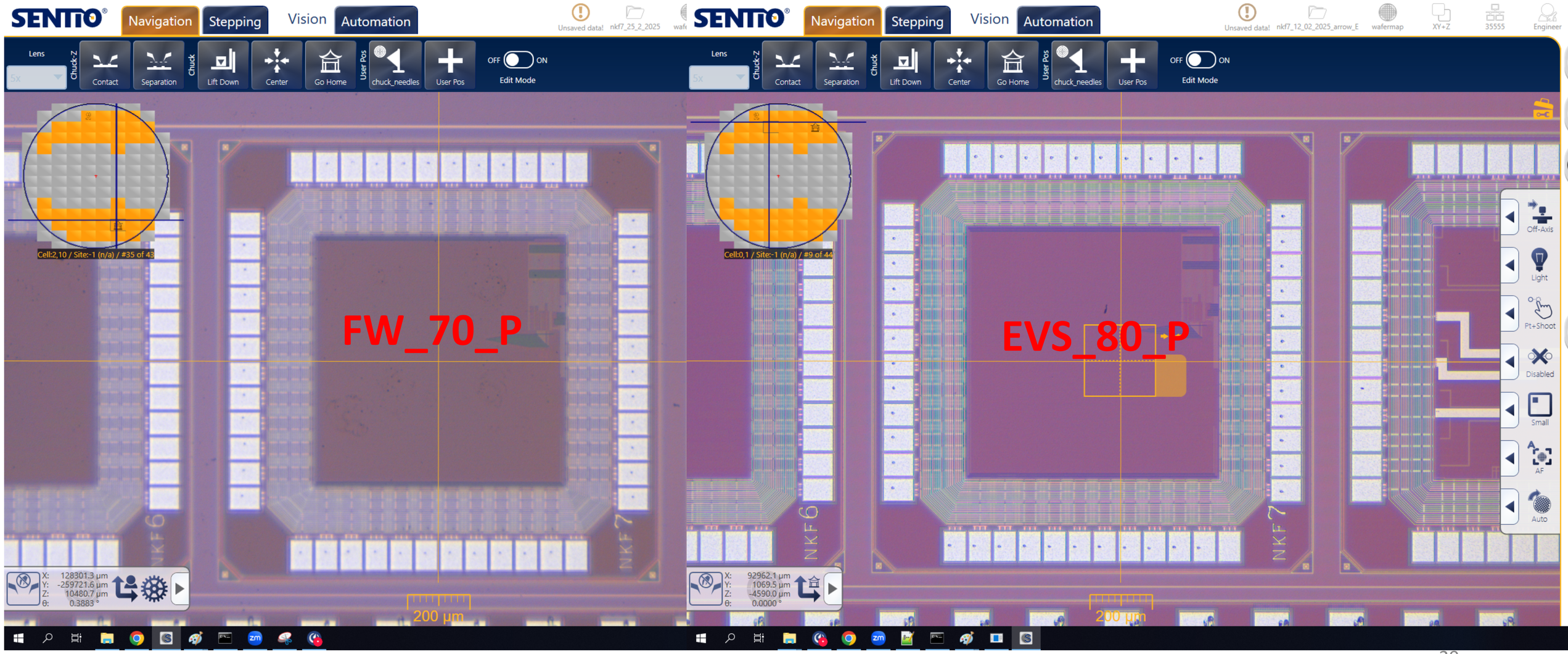
- Probe card alignment:
    - Nikel plated steel probe platen with probe card holder
    - Two adjustments screws for z position at both sides of the r
    - Inclination wheel to add a tilt
- Automatic Probe to Pad Alignment (PTPA) procedure:
    - Corrects for x, y and includes tips (z compensation)
    - Requires training of die alignment marker, pads and tips
    - Aligns needles to pad
- Wafer map automatically generated
- Topography map feature
    - Using the reflection from the light of the cameras it calcula the z differences in the wafer to ~um level







PROBE MARKS


SENTIO
Navigation
Stepping
Vision
Automation
Lens
Chuck-Z
Contact
Separation
Chuck
Lift Down
Center
Go Home
User Pos
chuck_needles
User Pos
OFF
ON
Edit Mode
Cell:2,10 / Site:-1 (n/a) / #35 of 43
FW_70_P
NKF6
NKF7
X: 128301.3 µm
Y: -259721.6 µm
Z: 10480.7 µm
θ: 0.3883 °
200 µm
Cell:0,1 / Site:-1 (n/a) / #9 of 44
EVS_80_P
X: 92962.1 µm
Y: 1069.5 µm
Z: -4590.0 µm
θ: 0.0000 °
Off-Axis
Light
Pt+Shoot
Disabled
Small
AF
Auto

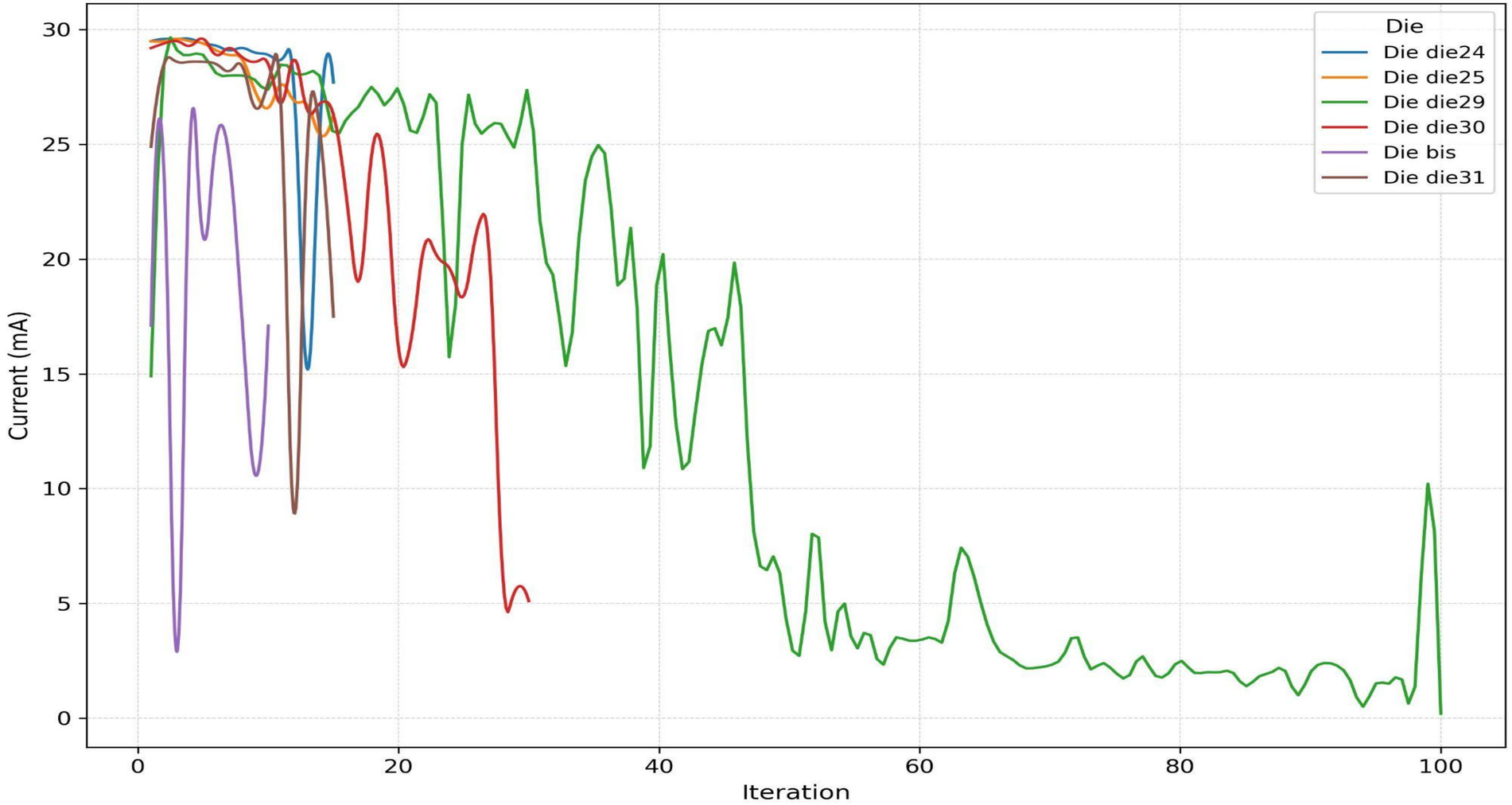
TEST2: TOUCHDOWN PERFORMANCE AT UNIQUE POSITION

- TEST description: Evaluate touchdown performance at a unique position
  - Prepared automatized script that
    1. Goes in contact in a specific die in the center of the pad
    2. Turns on HAMEG PS
    3. Waits for X s in order to get the current stabilized (capacitance ramp-up)
    4. Log of time, current, voltage and contact cycle
    5. Turns off the HAMEG PS

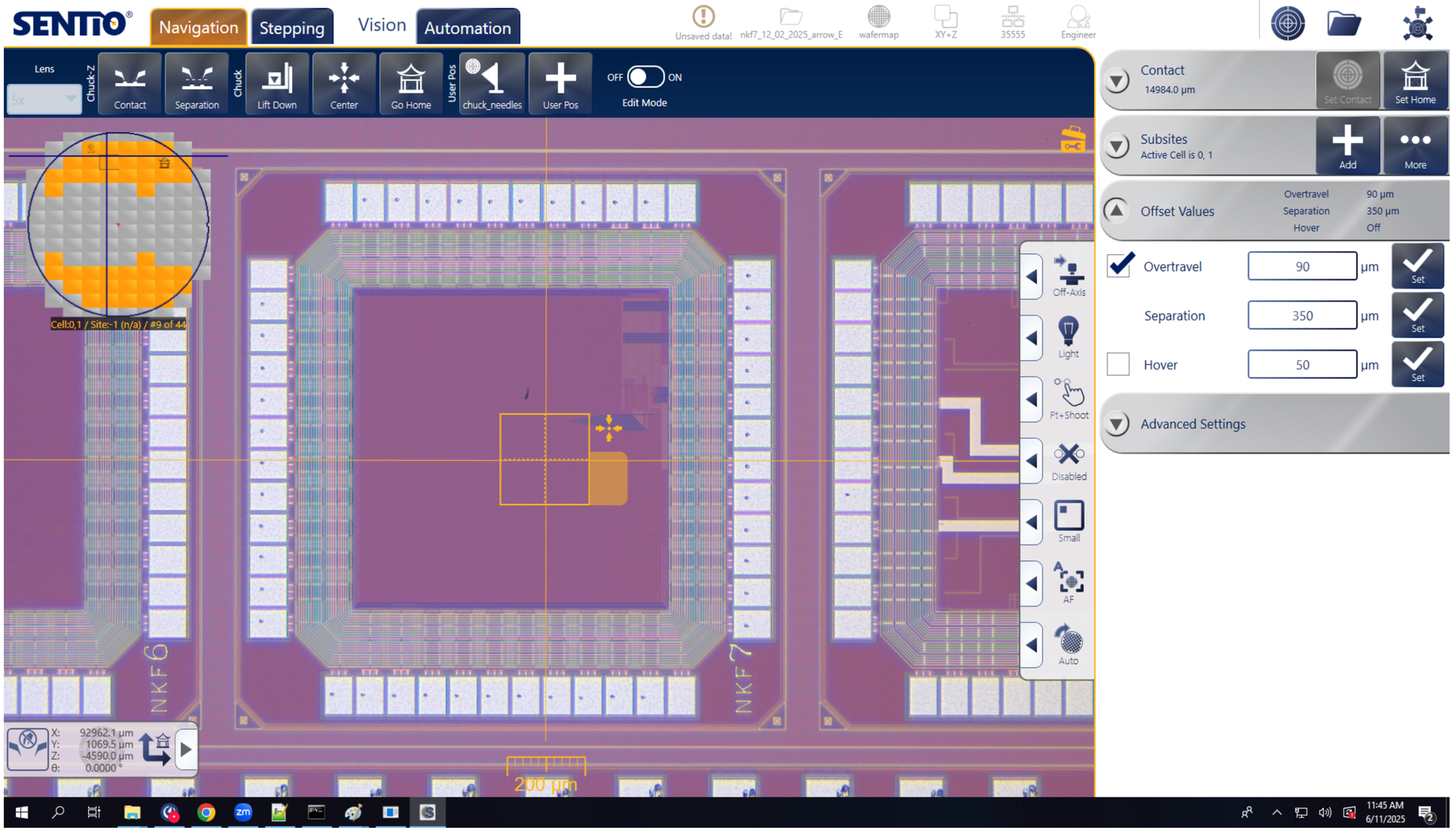
- Performance metric: Current > 25 mA

- Tested 5 dies:
  - Die 29: Number of touchdowns 100, waiting time for stabilization 5s
  - Die 30: Number of touchdowns 30, waiting time for stabilization 10s
    - Repeated tests day after: Number of touchdowns 10, waiting time for stabilization 15s
  - Die 31: Number of touchdowns 15, waiting time for stabilization 15s
  - Die 24: Number of touchdowns 15, waiting time for stabilization 15s
  - Die 25: Number of touchdowns 15, waiting time for stabilization 15s

STABILITY OF CONTACT CURRENT OVER REPEATED TOUCHDOWNS



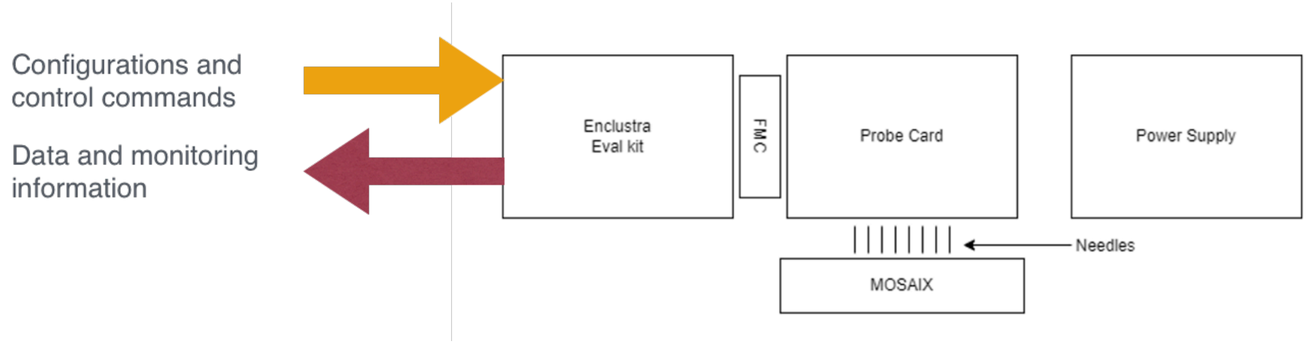
EVS_80_P NEEDLES PROBE MARK



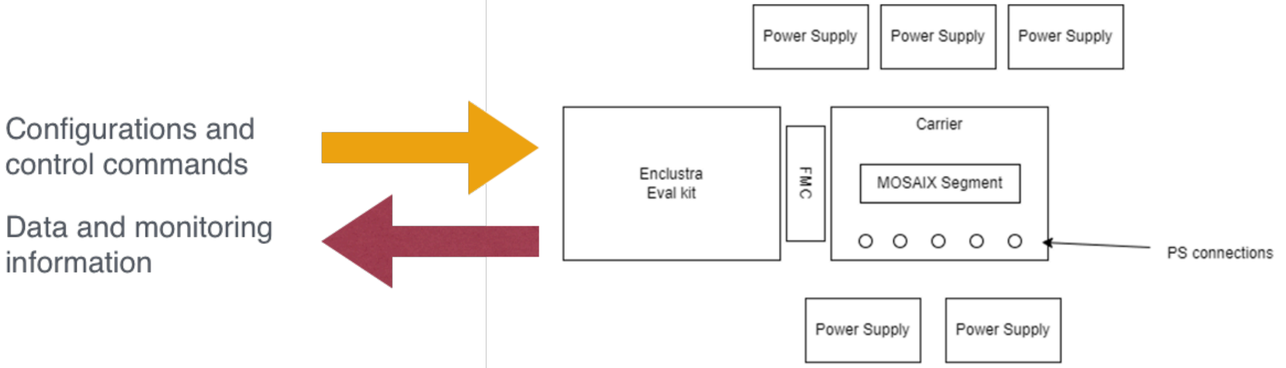
TEST SYSTEM HW CONCEPT ITS3 (MOSAIX ER2)

- System for 1 MOSAIX
- Enclustra Evaluation Kit + FMC and Power supplies are off the shelf commercial components
  - The Enclustra Eval kit acts as control and readout system
  - The Enclustra FW is being developed by the ITS3 team in collaboration with some SVT members
- Probe Card being developed by MIT and Korea University (parallel approach)
- Carrier board is being developed by CERN ITS3 team

WAFER PROBER TEST SYSTEM

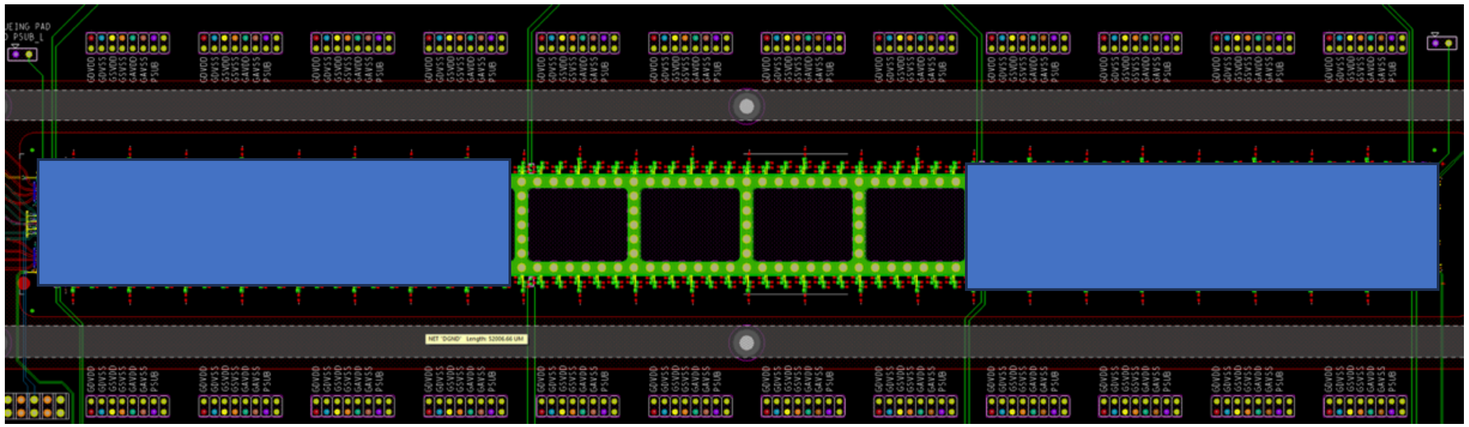


WIRE BONDED TEST SYSTEM



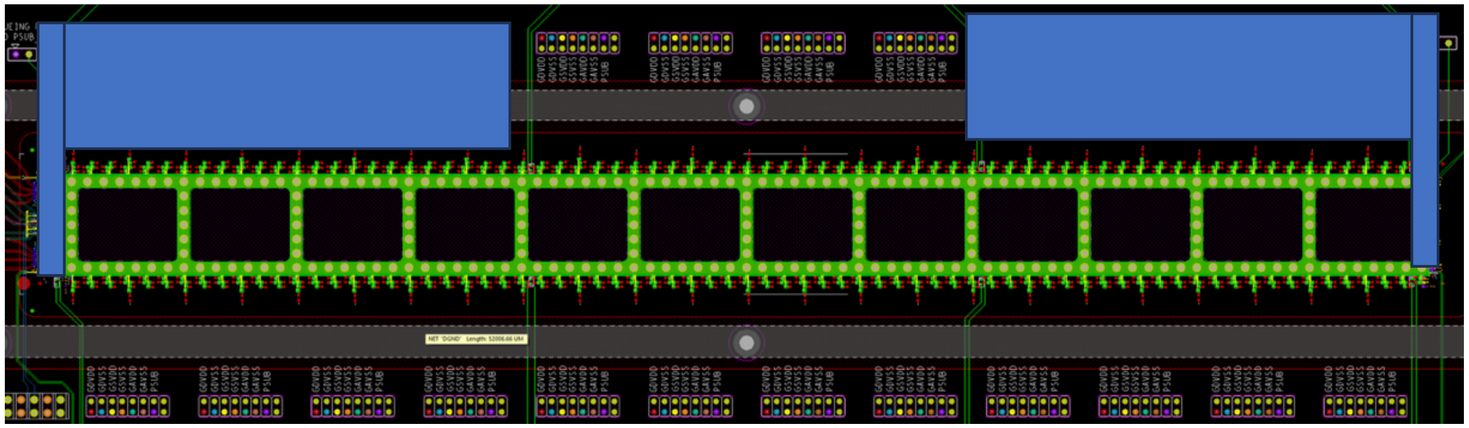
MOSAIX CARRIER BOARD DESIGN

- Compatible with all the WP with standard probe card holder
- Does not allow irradiation with source (needed for ER2 studies)
- It can be easily extended to multipoint



MOSAIX CARRIER BOARD DESIGN

- Compatibility with wafer probers in the collaboration needs to be verified
- It allows irradiation and thermal camera studies
- It limits the re-use of the same modules for multipoint



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- Topography map feature
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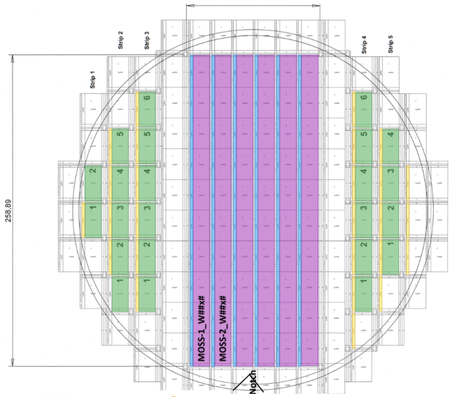
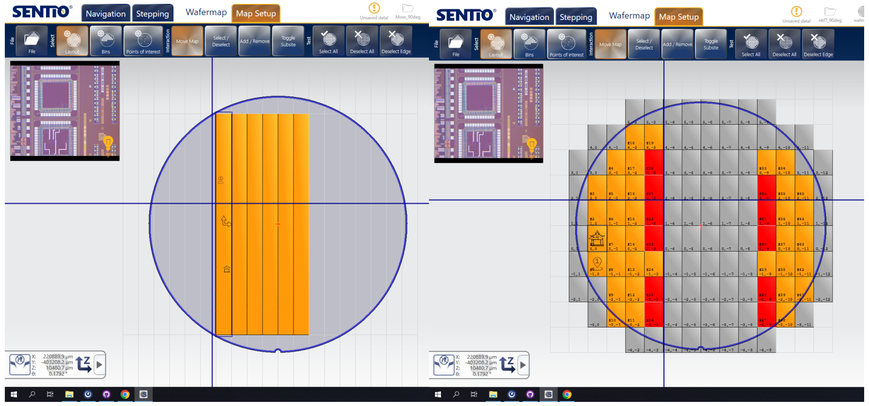
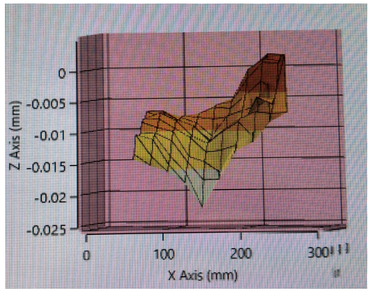






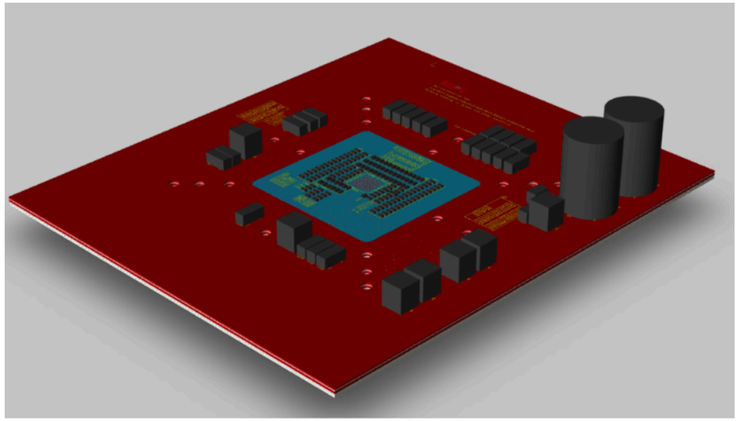
NKF7 VERTICAL PROBE CARD

- First prototype of vertical probe card
  - It will be shipped to CERN before the Chinese NY

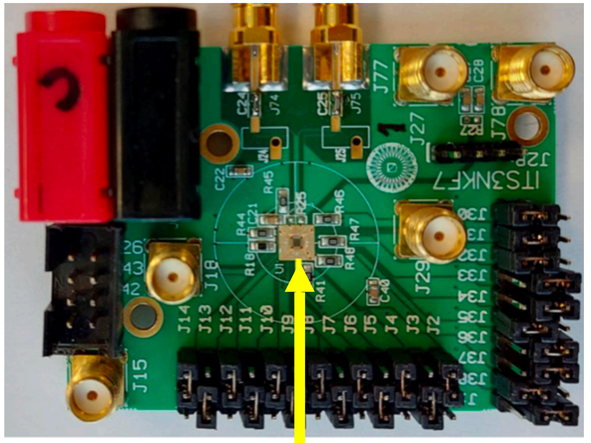
- Design and fabrication being done together with MPI via their European vendors HTT

- Main design specifications:
  - High-speed material laminates: Megtron6
  - Careful layout of high-speed traces
  - Decoupling capacitance network and pull up and pull down resistors
  - Orientation of the MLO and probe card
  - Layer stack-up

- Goal is to use vertical probing probing technique to achieve a data rate of 10 Gbps



PROBE CARD 3D VIEW



NKF7

NKF7 VERTICAL PROBING STATUS RECAP

- Vertical probing technique successfully qualified to test silicon devices operating at 10.24 Gbps
  - NKF7 serialiser chipset characterised
- Original family needles experienced difficulties in achieving reliable electrical contacts on test chips
- ER1 wafer and original vertical probe card sent to MPI in order to check needles matrix
- New needles, EVS_80_P, probe card received 06/06/25 at CERN and retested

FW_70_P

- Force @ OD 90: 3.2 g
- Tip shape: Round

EVS_80_P

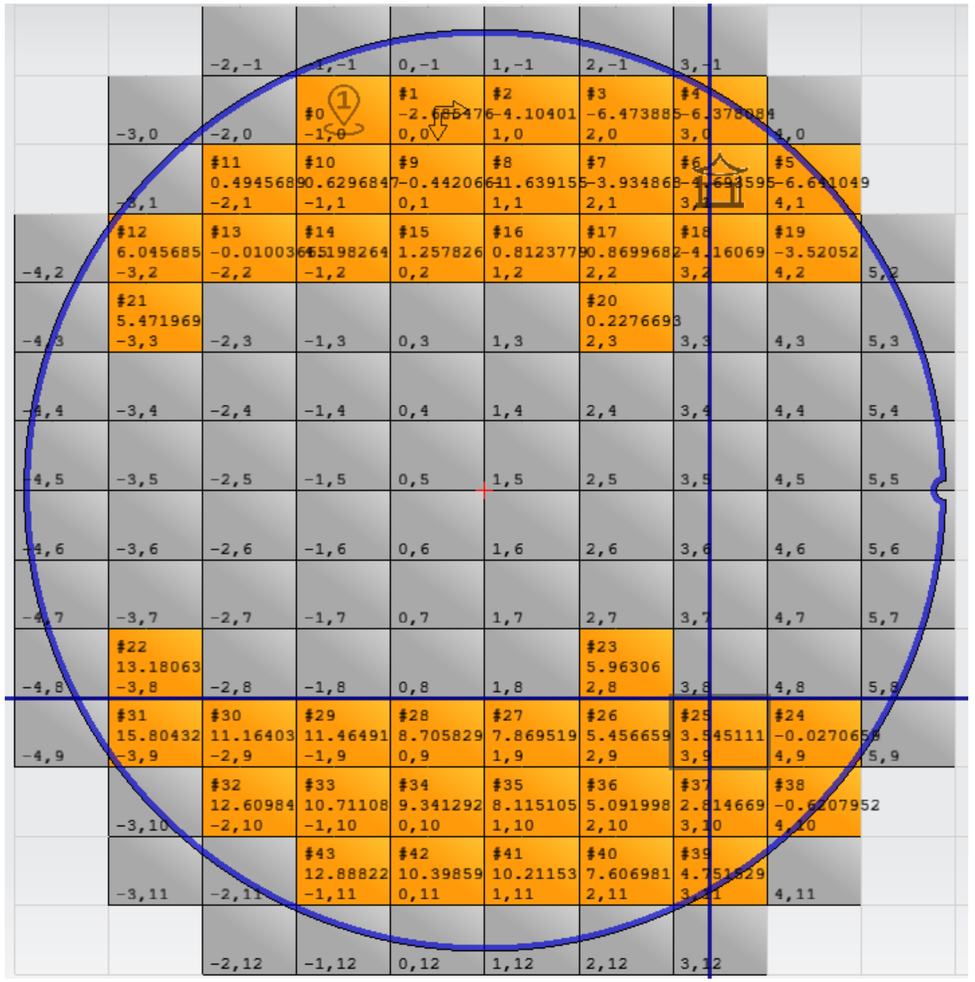
- Force @ OD 90: 4.4 g
- Tip shape: Point

TEST1: FIND BEST CONTACT OVERDRIVE

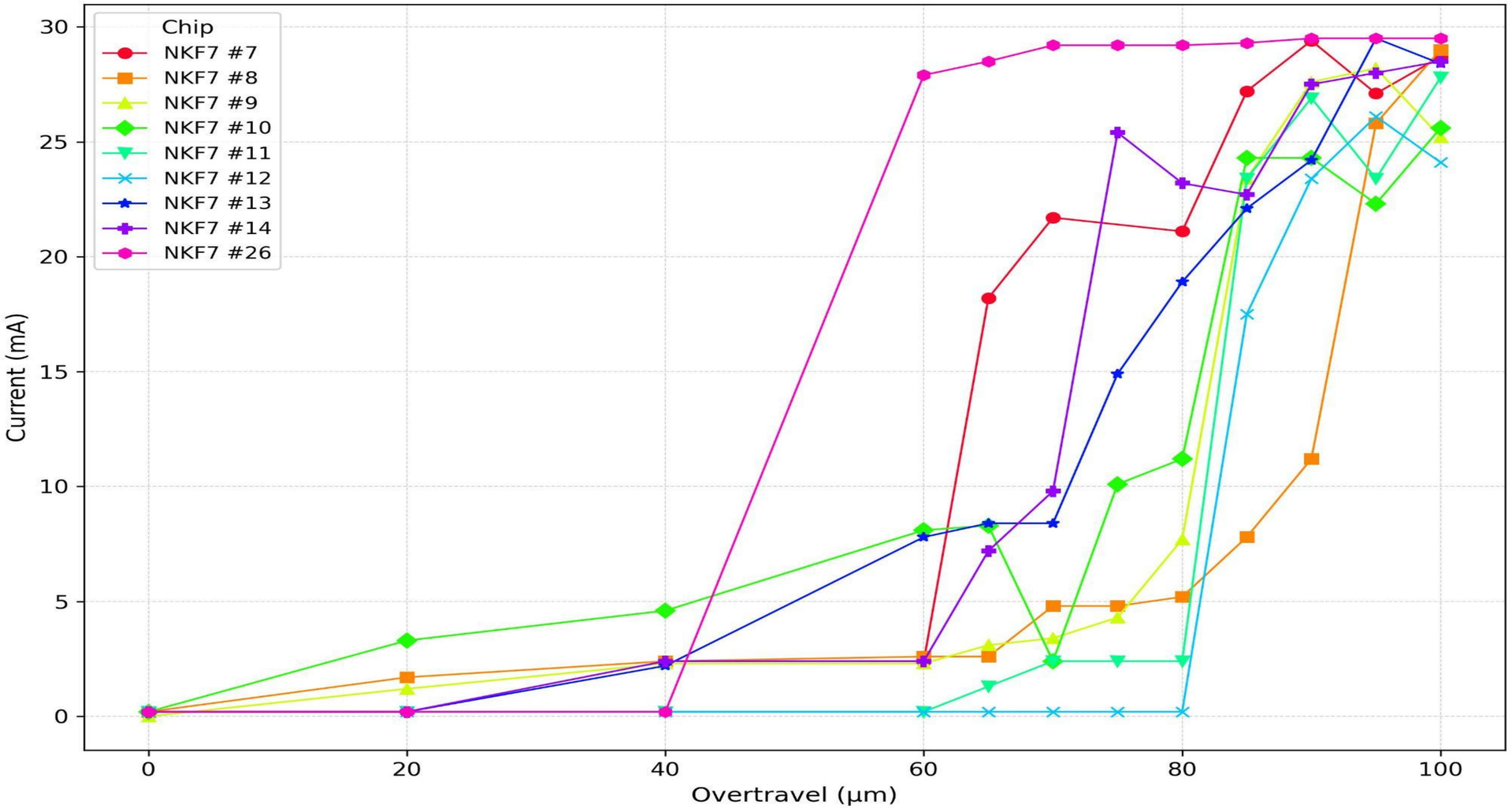
- TEST description: Find the initial position in which a mark starts appearing and slowly increase the over drive to see when the best signal appears

- Currently statistics for 8 dies have been taken
  - Mind that most of these dies are in the top part of the wafer
  - More samples to be measured to increase the reliability of the results

- Company data for reference
  - 100 OD corresponds 4.5 g of force
  - 75 OD corresponds to 3.4 g of force

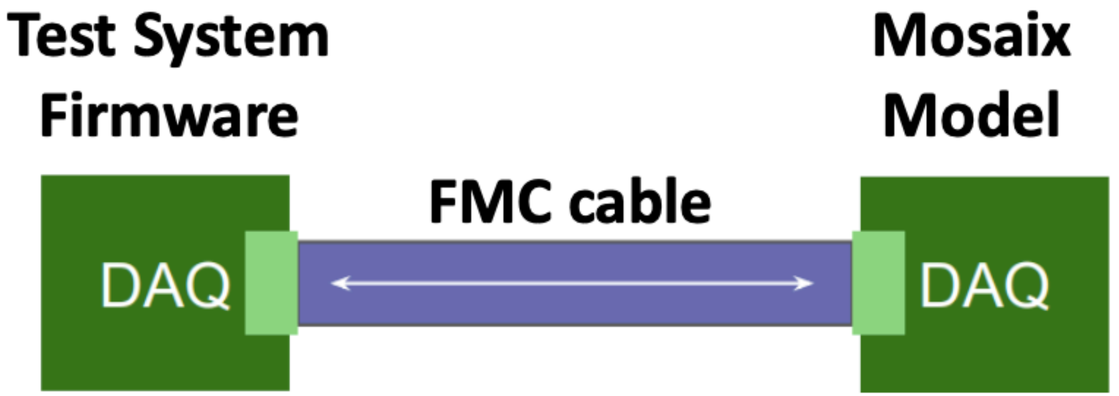


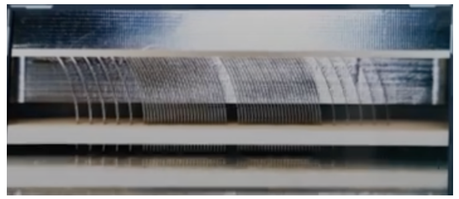
DEPENDENCE OF PROBE OVERTRAVEL ON CURRENT FOR MULTIPLE CHIPS

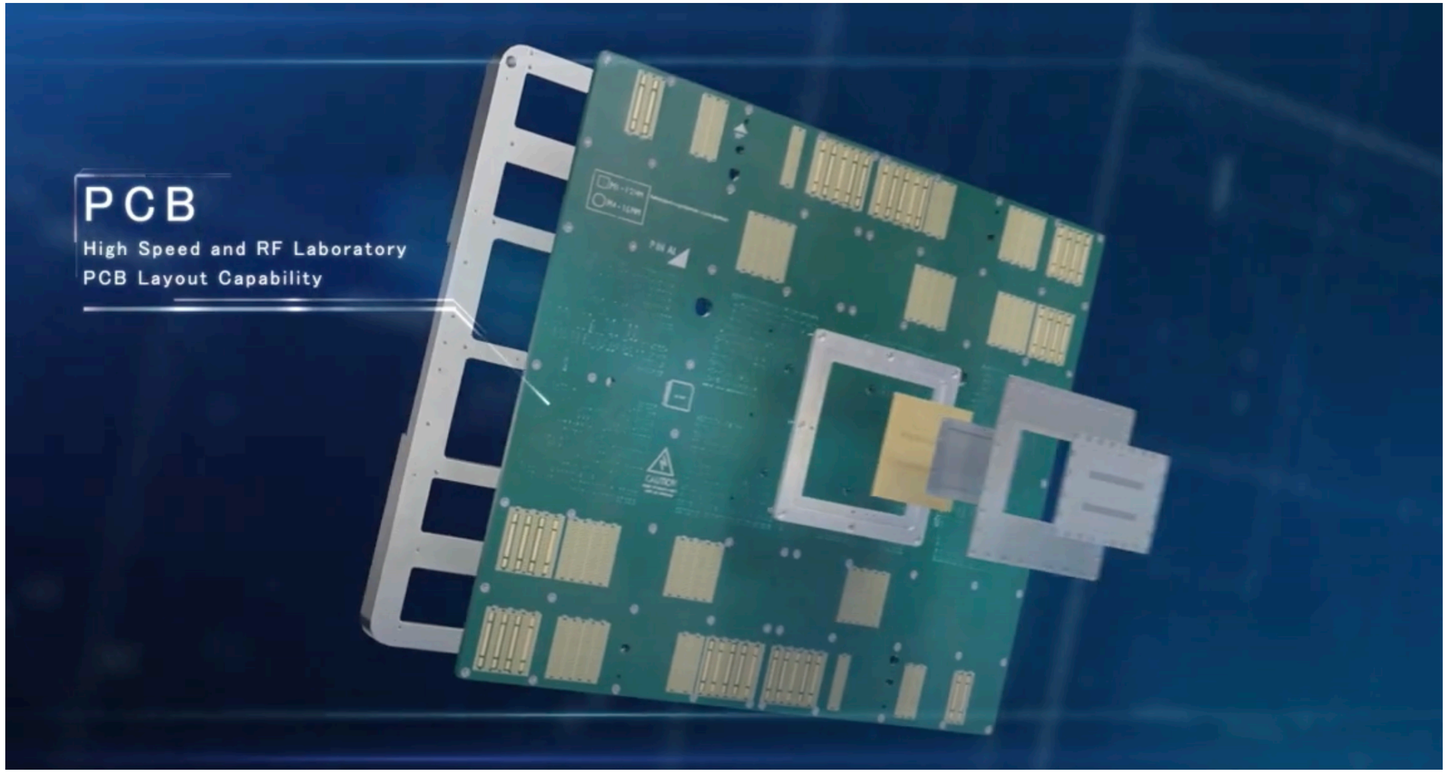


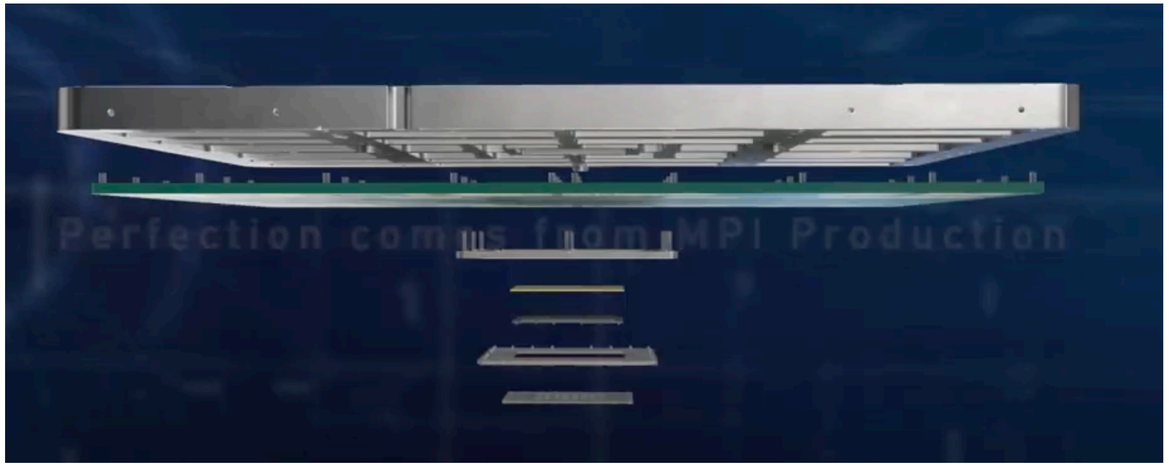
MOSAIX SYSTEM TESTS

- WP2 members currently contributing to the ITS3 system tests
  - Testout readout of tiles at 160 Mbps
- Hardware used: Enclustra boards with Intel Arria 10 FPGA with the ST1+ board
- Firmware development tools
  - Quartus as design suite
  - Altec Riviera Pro used for simulation
  - Cocotb for verification (https://docs.cocotb.org/en/stable/index.html)
- While design is not submitted working on an emulator system that includes MAPS RTL



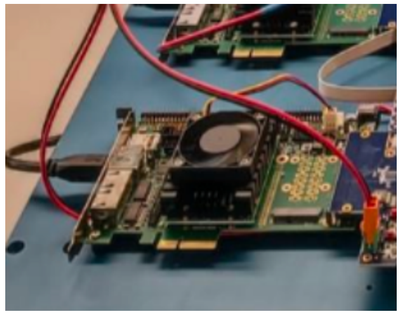



PCB
High Speed and RF Laboratory
PCB Layout Capability


Perfection comes from MPI Production

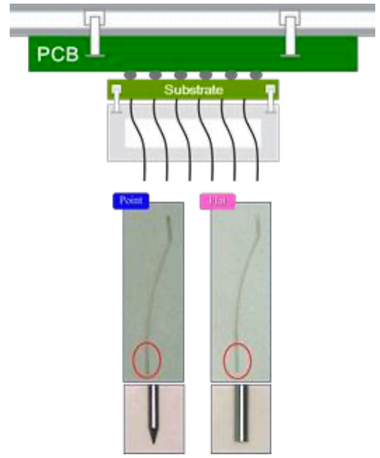
Test System HW (MOSAIX) considerations

- Similar concept/approach may be used also for SVT sensors/modules test and characterization
  - At present there is no agreement between ITS3 and SVT about sharing any HW/SW for the test and characterization system



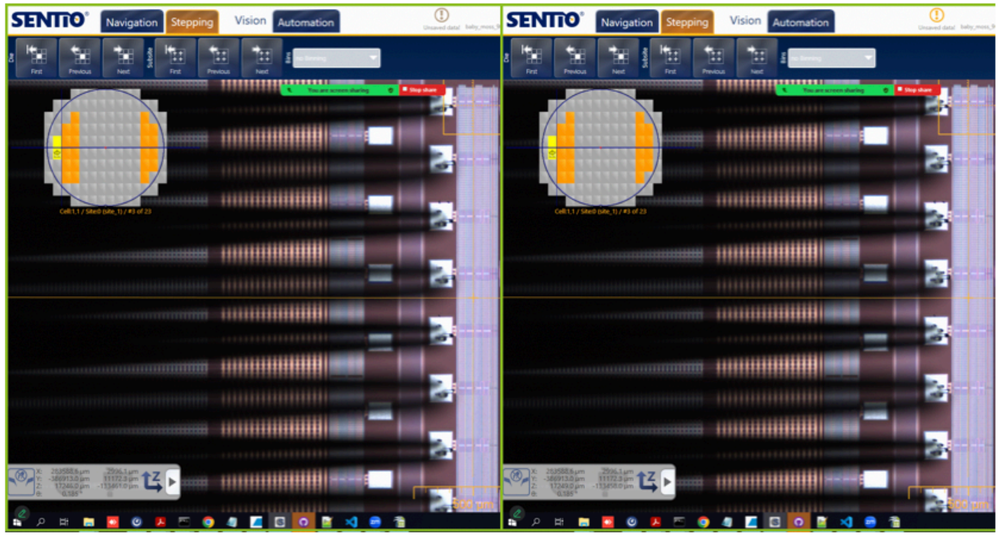
- The HW system designed by ITS3 is mainly focused on a single MOSAIX and it may be too slow for the SVT purpose considering the significant higher number of sensors to be characterized
  - Parallel setups could result on a significantly higher cost and person-power requirements. Studies are needed by the WP2 HW team.

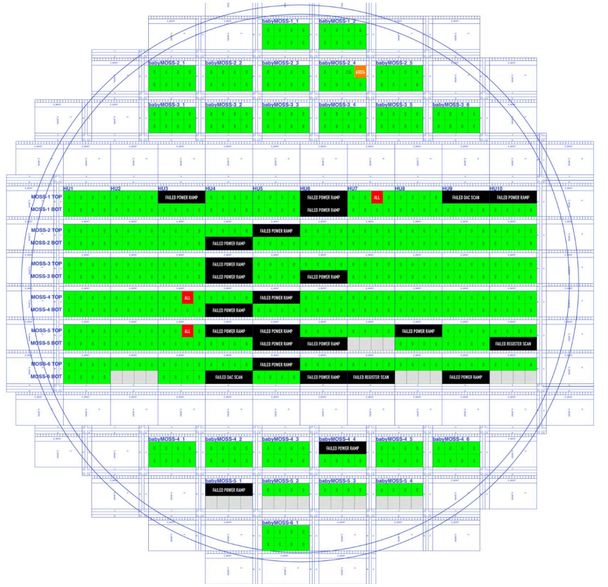
- Probe card status:
  - Probe card technology being identified using Enhanced Vertical Solution (EVS) to allow 10 Gbps link speed usage
  - First prototype is being designed/produced for the serializer NKF7 as a demonstrator and expected immediately after the summer
  - Mixed solution using RF probes and 160 Mbps solution are considered as backup



MACHINE VALIDATION WITH ALICE ITS ER1 WAFERS

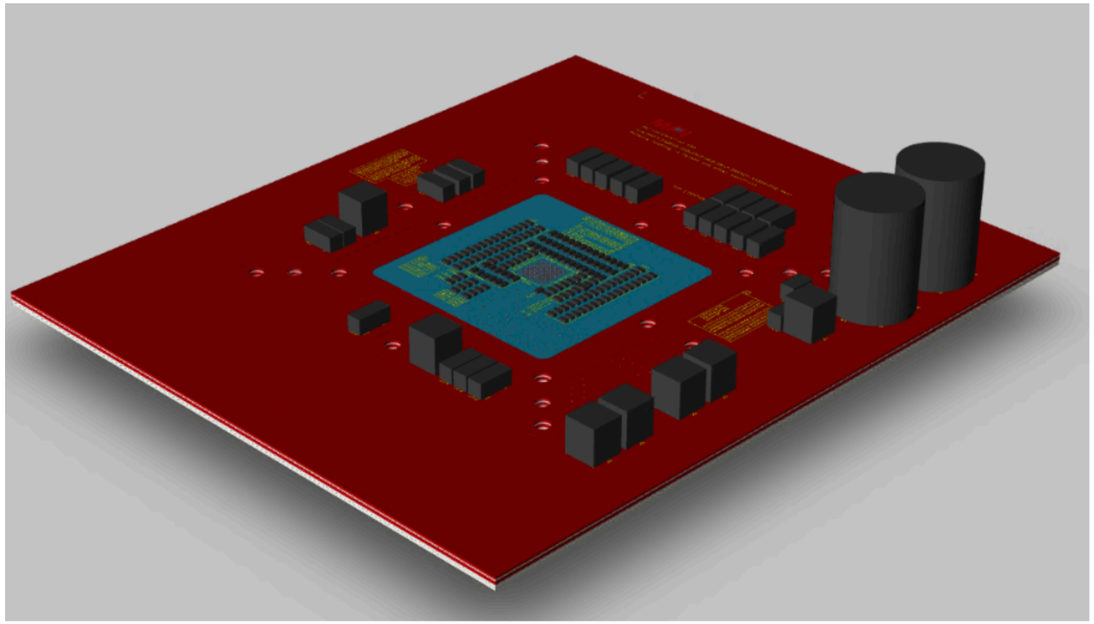
- The machine validation was done following the presented workflow with ALICE ITS ER1 wafers
- Used ER1 readout system as DAQ and HW control
  - Github repo: https://gitlab.cern.ch/alice-its3-wp3/moss-testing/sw
- Tested all 25 babyMOSS top unit in the wafer in 25 minutes with ~identical results to ALICE
- Achieved very nice electrical contact





NKF7 VERTICAL PROBE CARD

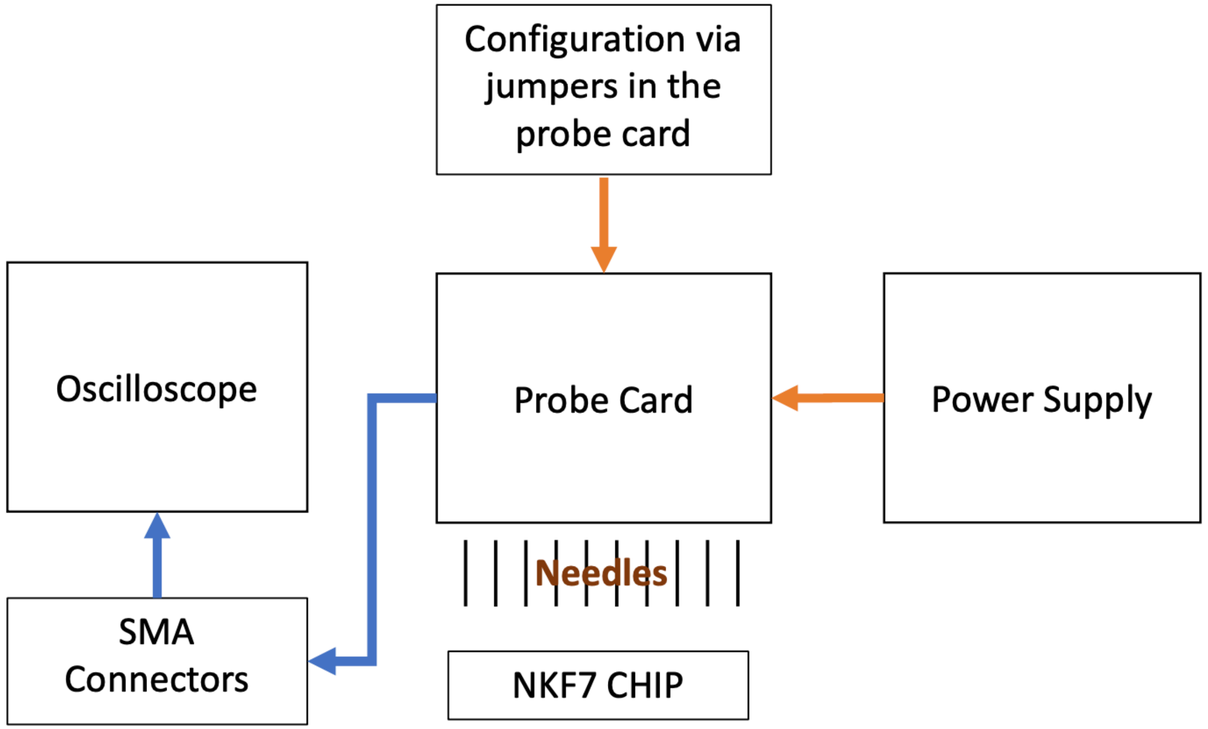
- First prototype of vertical probe card
  - It will be shipped to CERN before the Chinese NY
- Design and fabrication being done together with MPI via their European vendors HTT
- Main design specifications:
  - High-speed material laminates: Megtron6
  - Careful layout of high-speed traces
  - Decoupling capacitance network and pull up and pull down resistors
  - Orientation of the MLO and probe card
  - Layer stack-up
- Goal is to use vertical probing probing technique to achieve a data rate of 10 Gbps



PROBE CARD 3D VIEW

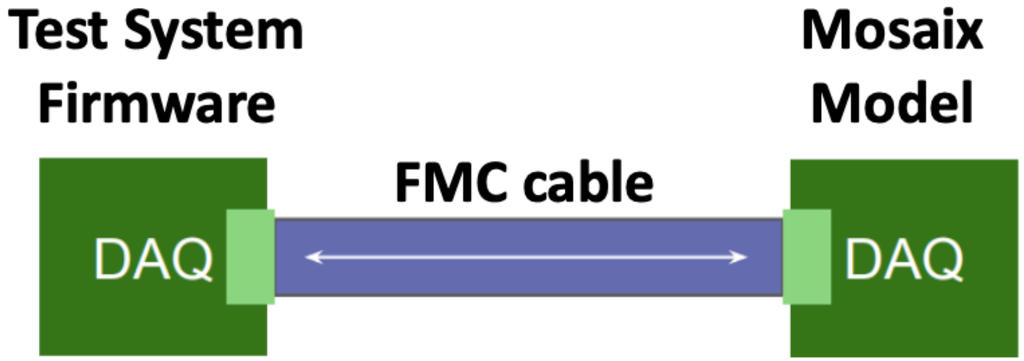
NKF7 TESTING SETUP

- NKF7 testing does not require of an FPGA for the data acquisition system
  - Check that pattern sent via jumpers is received in the scope
- This project will be used to benchmark the system and getting ready to test the Mosaix and LAS in the future
- Vertical probing automatization
  - High-speed data taking from needles



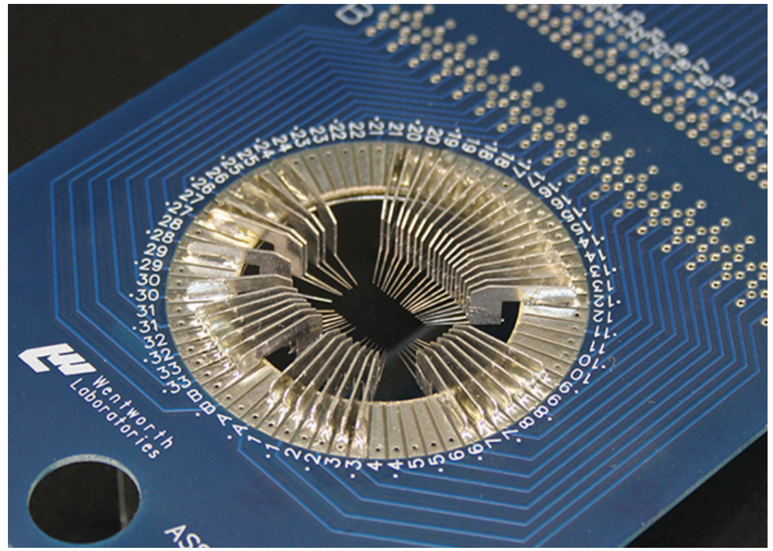
MOSAIX SYSTEM TESTS

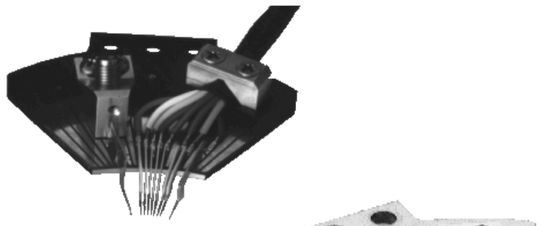
- WP2 member currently contributing to the ITS3 system tests
- Hardware used: Enclustra boards with Intel Arria 10 FPGA with the ST1+ board
- Firmware development tools
  - Quartus as design suite
  - Altec Riviera Pro used for simulation
  - Cocotb for verification (https://docs.cocotb.org/en/stable/index.html)
- While design is not submitted working on an emulator system that includes MAPS RTL

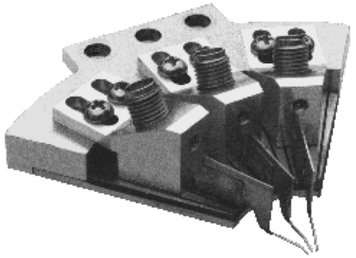


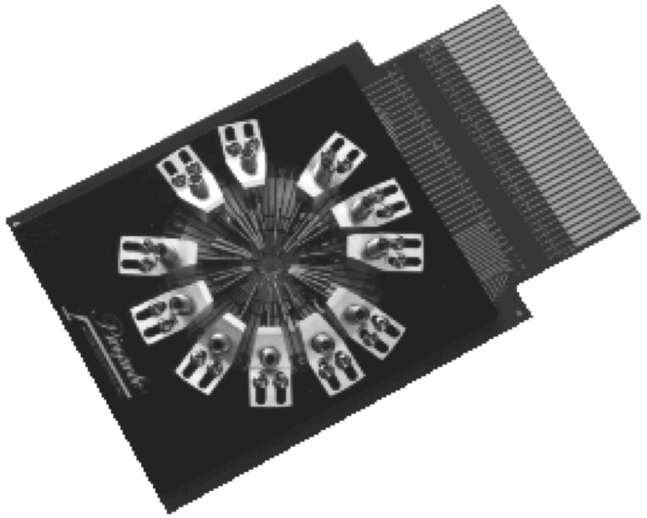
Options for probing

- Standard cantilever probe card are generally designed for ~300 MHz
  - 4-5 GHz with shielded needles
- RF-probes can be used to probe 2-4 pins at very high frequency > 80 GHz



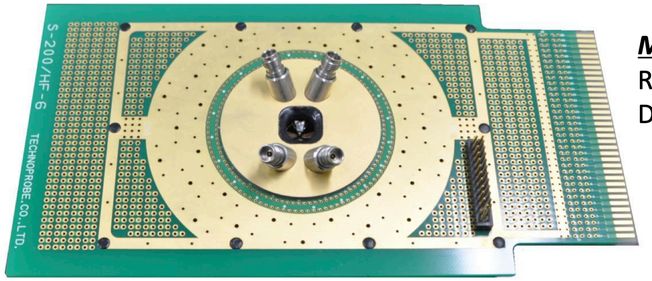




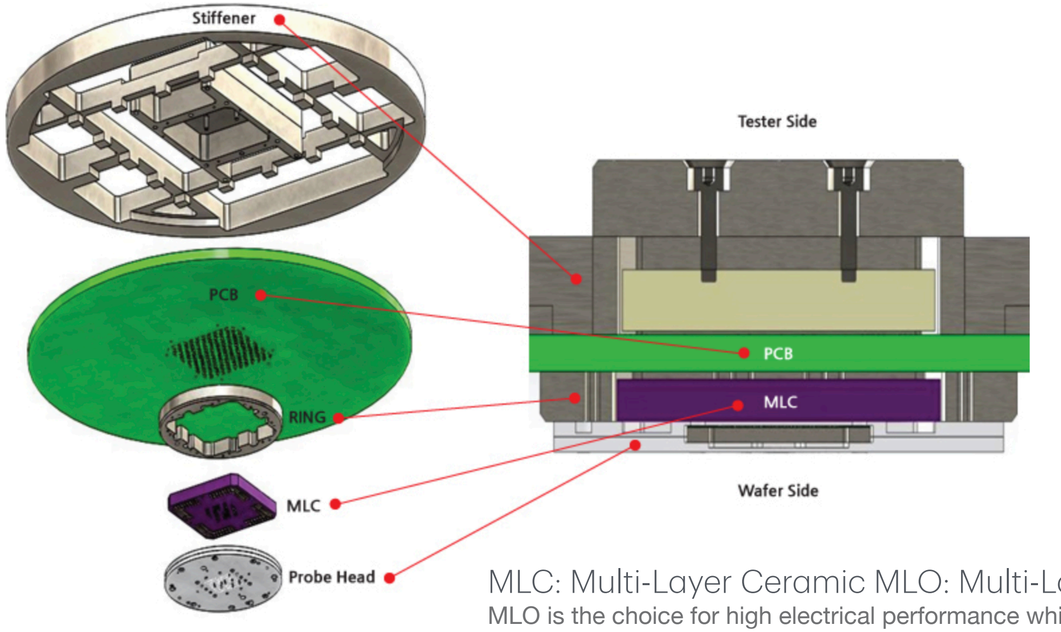


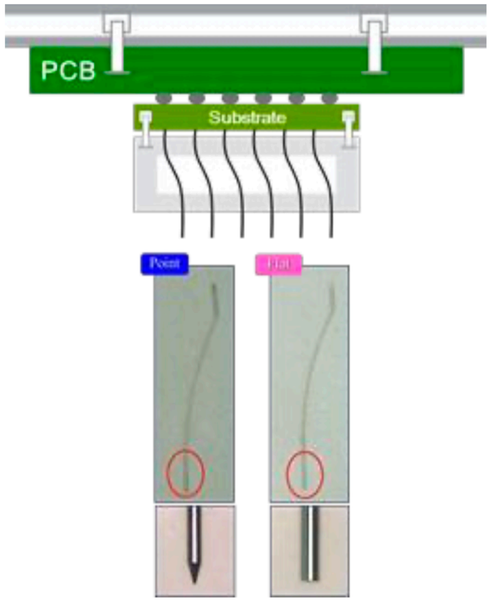
Options for probing

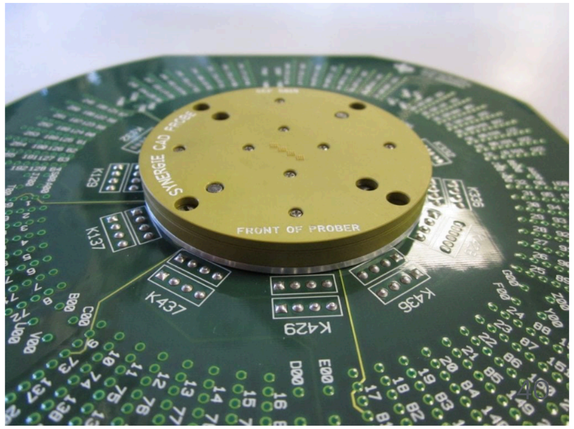
- Mixed cantilever-RF probe technology
- Vertical probing allows construction of probe cards with > 80 GHz range



Maximum Pin Count
RF: 16 (TBD)
DC: 120 (TBD)



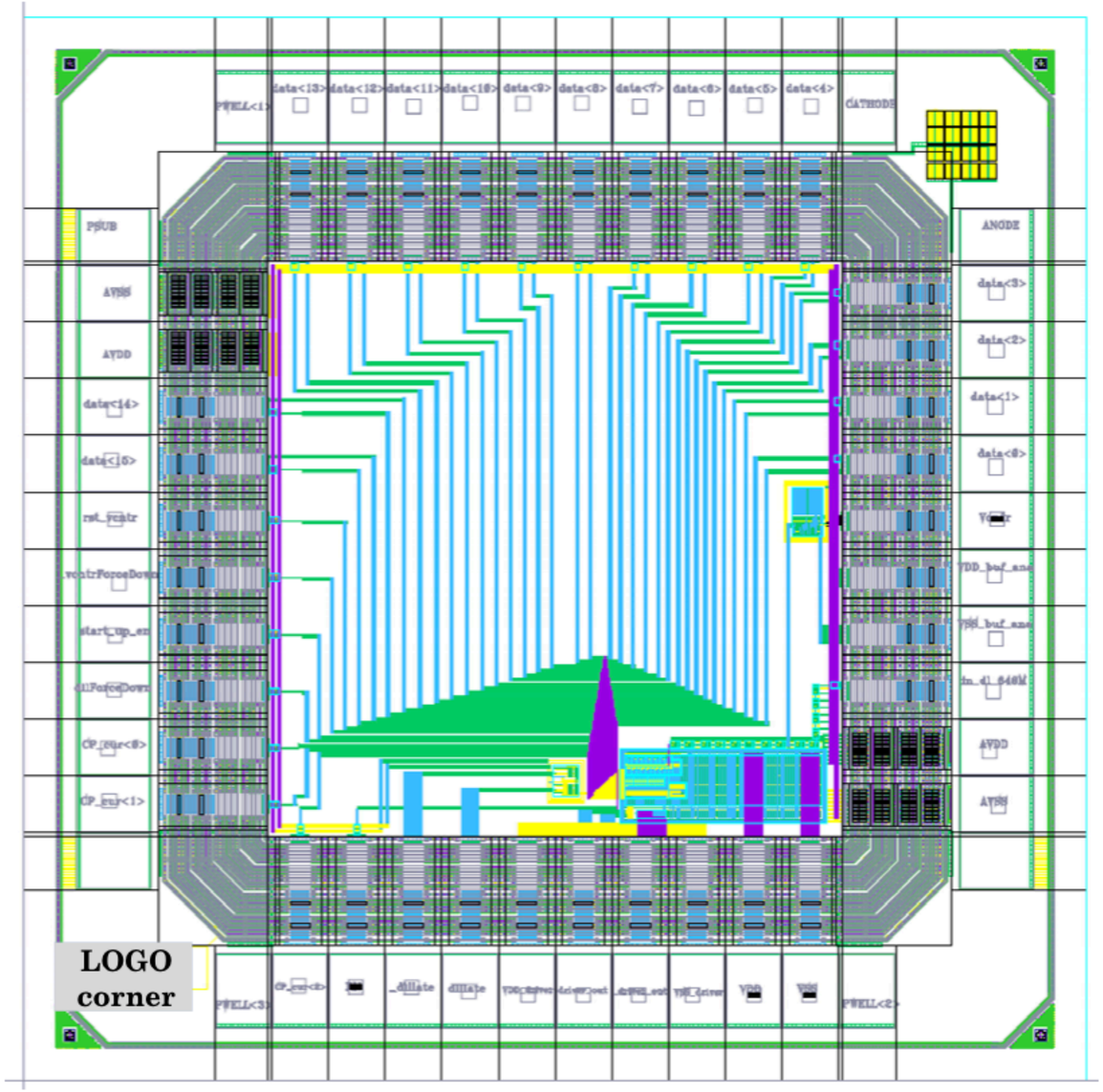


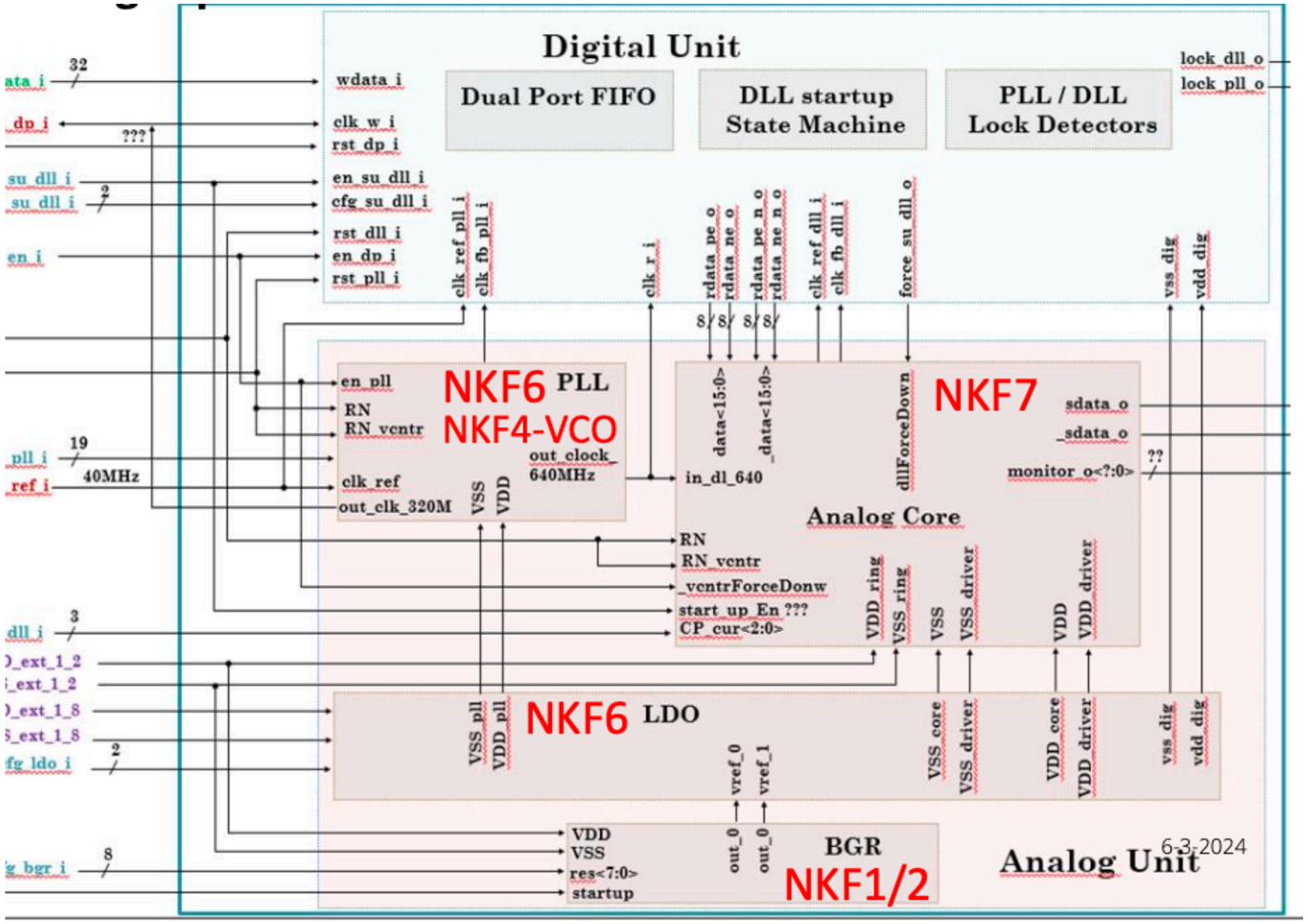


MLC: Multi-Layer Ceramic MLO: Multi-Layer Organic
MLO is the choice for high electrical performance while MLC is classic for precise alignment.

NKF7 serializer

- Ref clk: 642 MHz , 16 bits input, output 10.27 Gbps





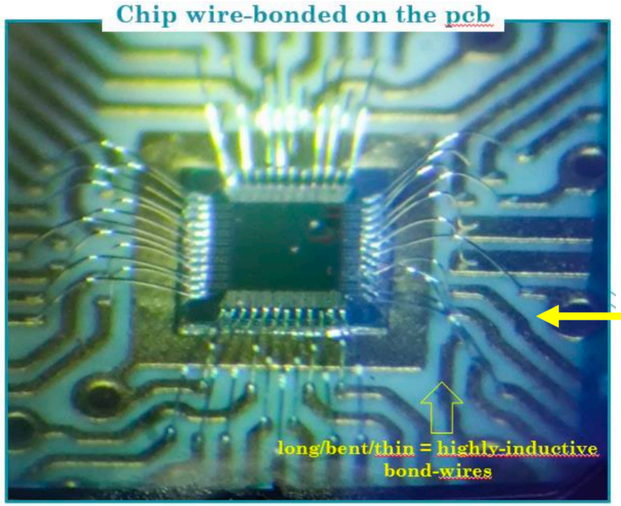
NKF7 serializer

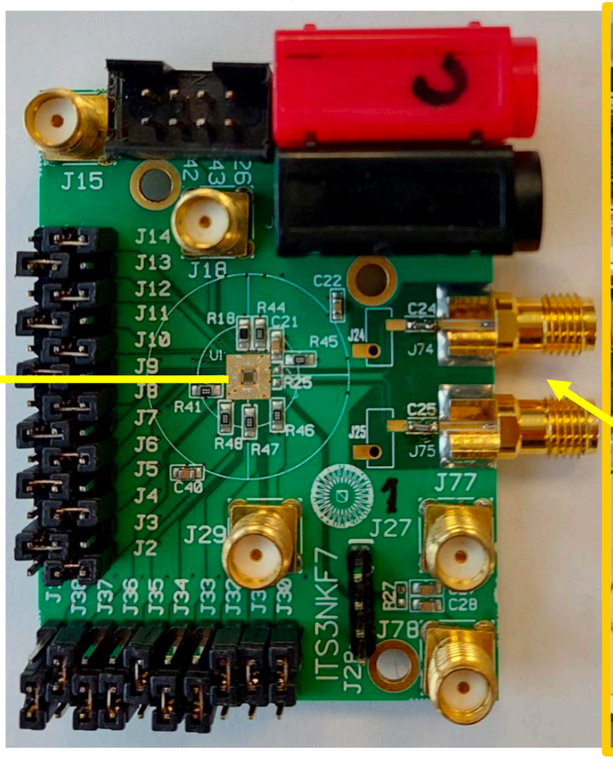
Full presentation: https://www.dropbox.com/scl/fo/v41zz5ib4ghk3xi9tsjrc/h?rlkey=32vxzrr5msu39nudo5n1khg0j&dl=0

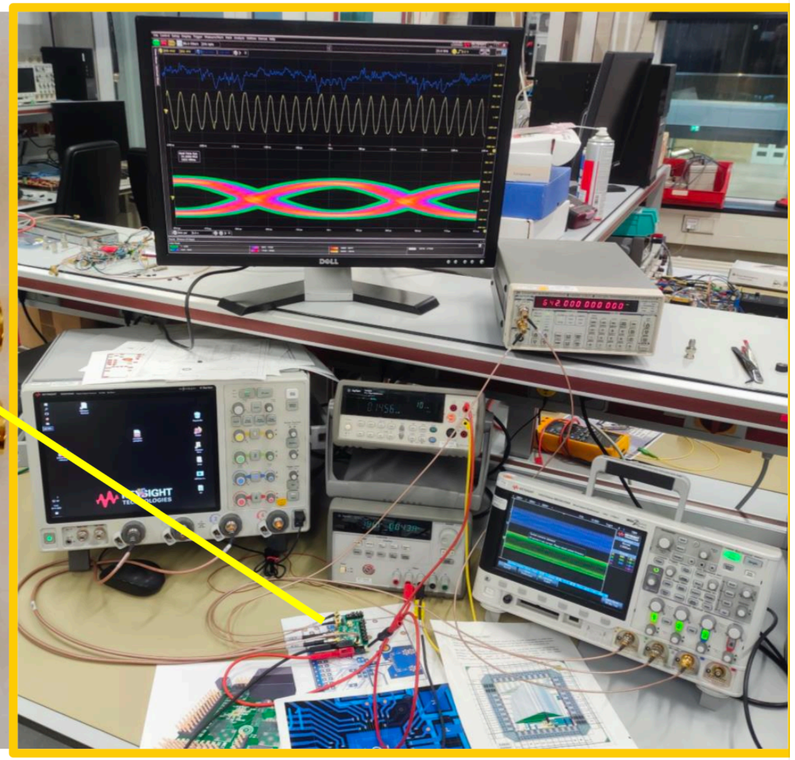
Fixed pattern measurements

Carrier

- Edge mount SMA for high speed links
- Fixed pattern set by jumpers (v2 also has dipswitches)
- 4 layer board, Rogers material



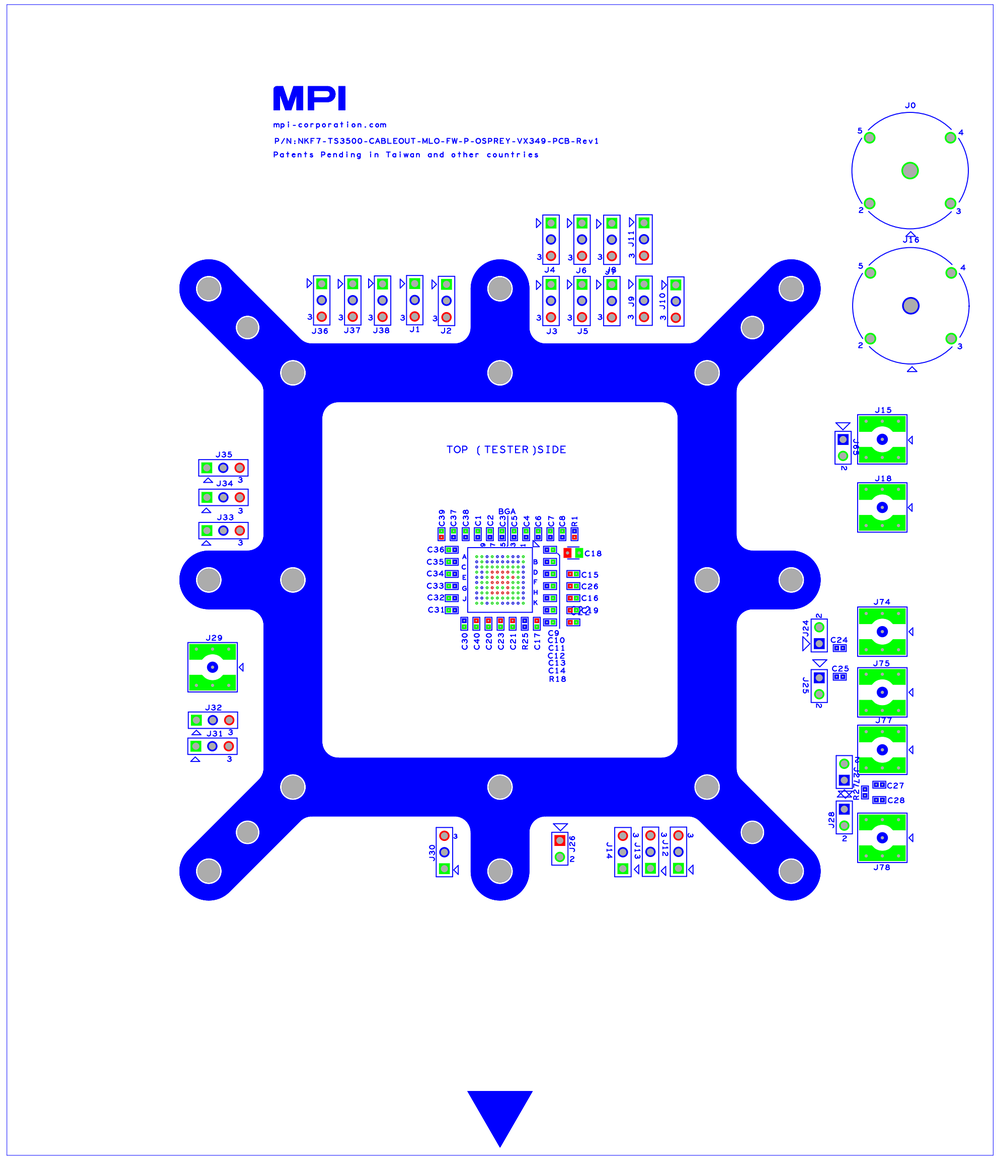


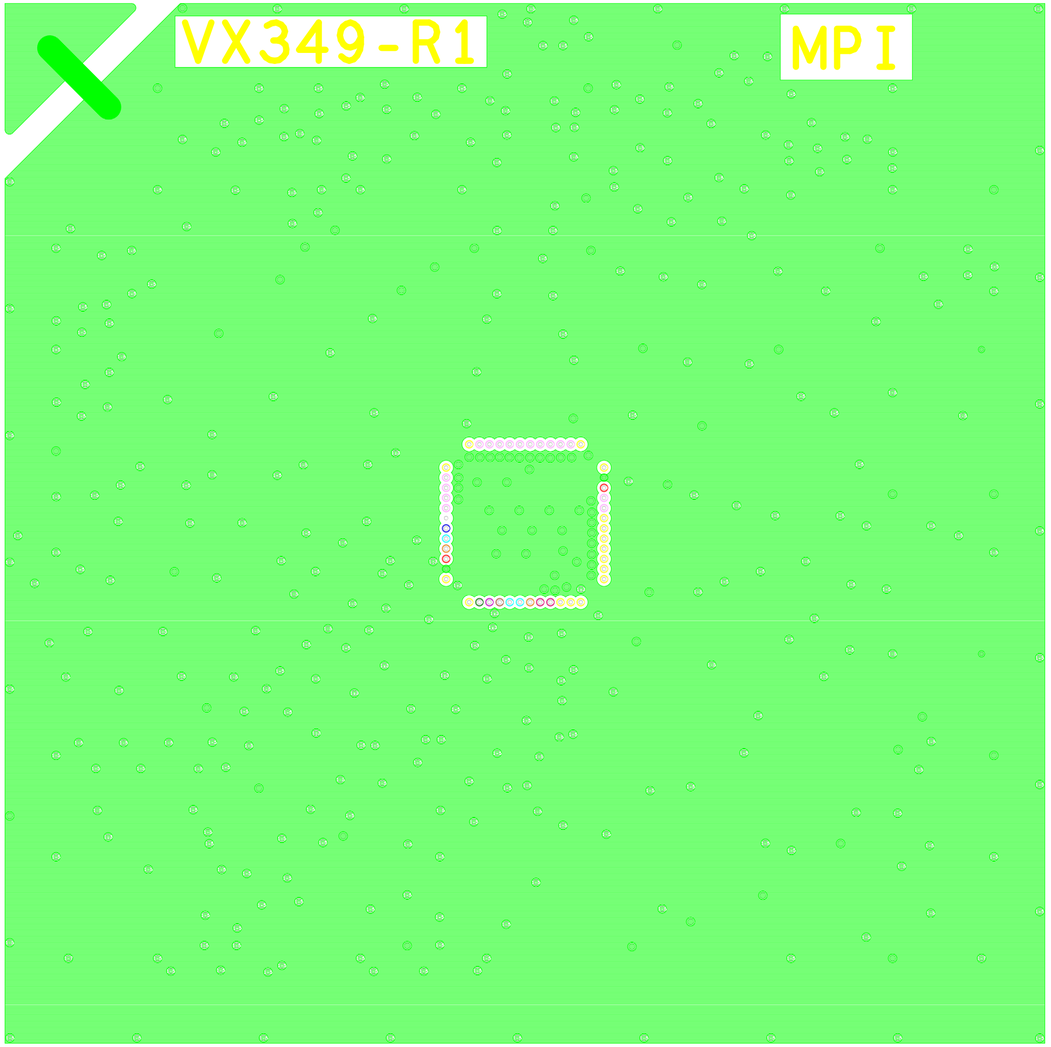


First results reported last TWEPP

- Good output signals at 5Gbps
- At 10 Gbps some distortion
- Simulations suggest distortion from bondwire inductance

NKF7 probe card PCB and MLO





MOSAIX SYSTEM TESTS