# A custom probe station for microstrip detector quality assurance of the CBM

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# Outline

- Sensors for the Silicon Tracking System of CBM
- Strategy for Quality Assurance
- Current status, Results and Experience with sensor prototypes for STS

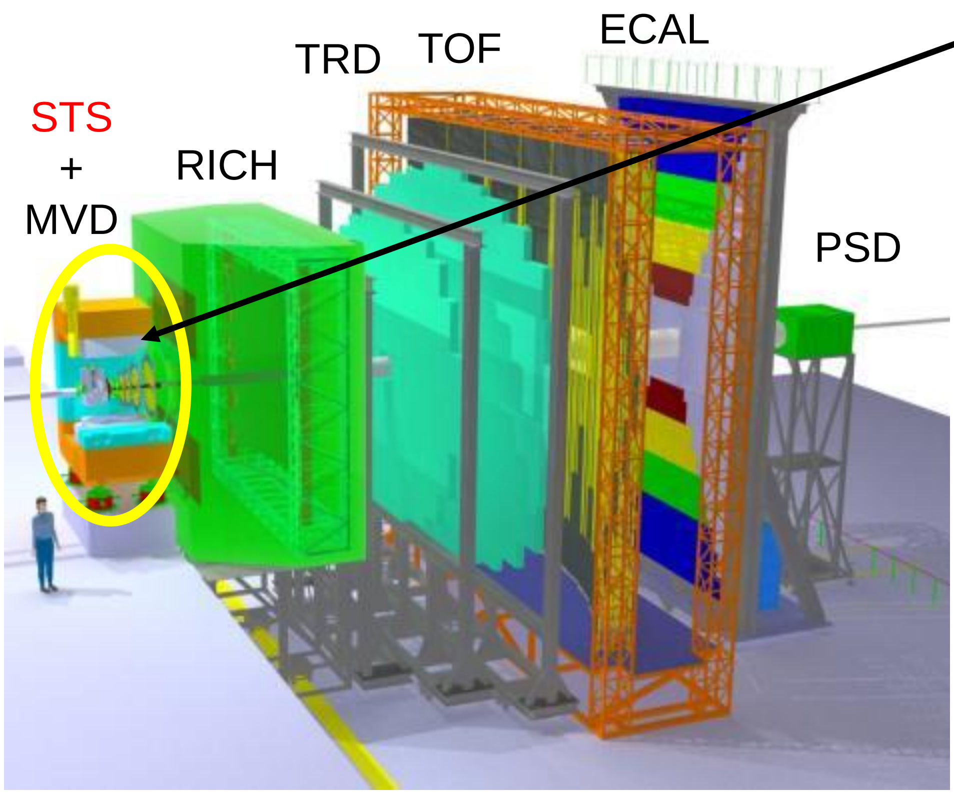
# The CBM Experiment at FAIR

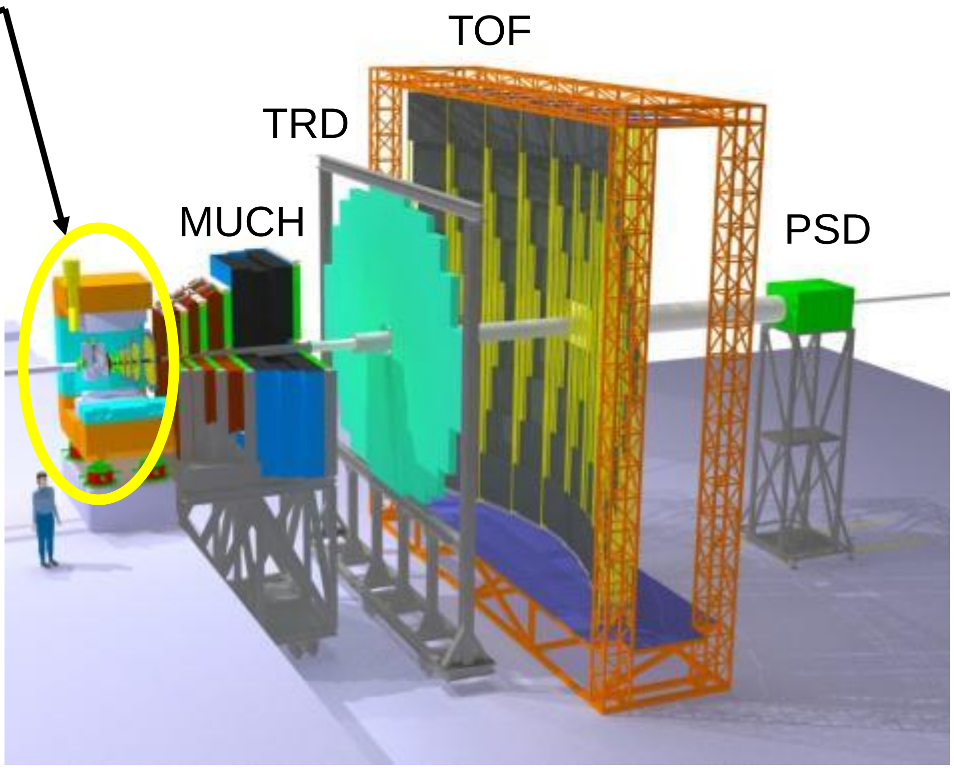
<u>Hadron Configuration</u>
RICH & TRD for electron identification and pion suppression

Silicon Tracking System

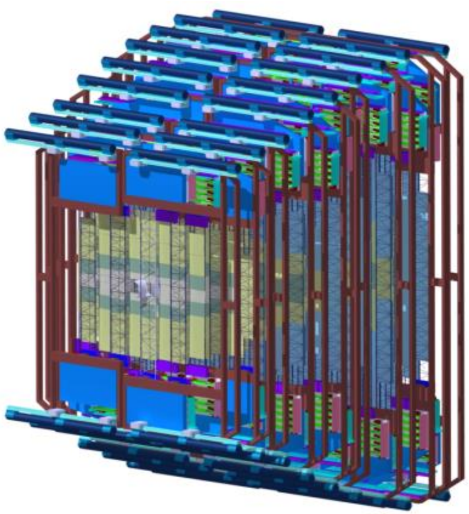
- Track reconstruction of charged particles

<u>Muon Configuration</u>
Absorber and detector layers for muon identification



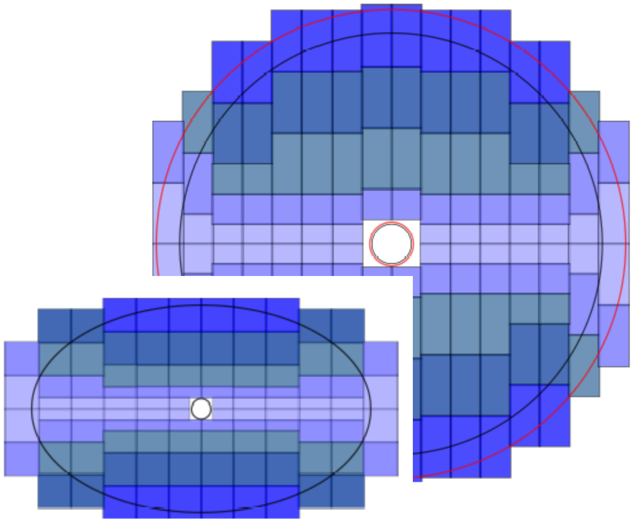



# Silicon Tracking System

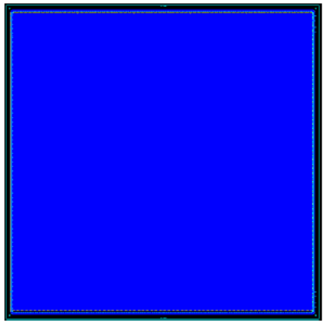


8 tracking stations
Aperture: $2.5^0 < \theta < 25^0$

896 modules



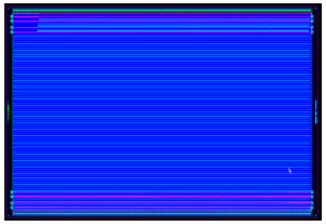
106 ladders



6.2 cm × 6.2 cm

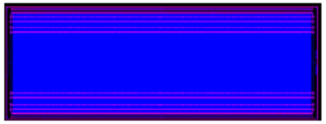
252/900

- 252 single
- 648 in daisy-chains, or 324 “large” sensors →



6.2 cm × 4.2 cm

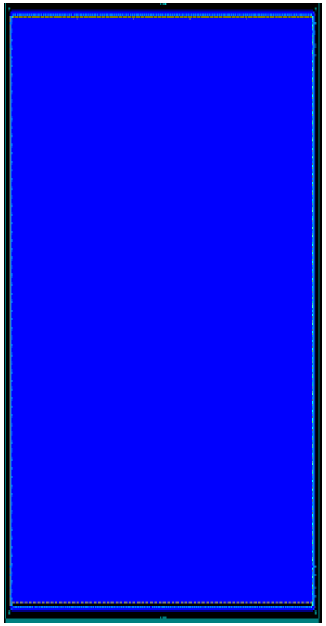
260



6.2 cm × 2.2 cm

60

324

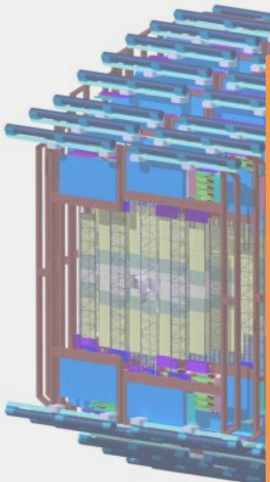


6.2 cm × 12.4 cm

alternative for two daisy-chained sensors:

- less handling (no bonding of inter-strip cable)
- no gap between the two sensors as with daisy-chained pairs

# Silicon Tracking System



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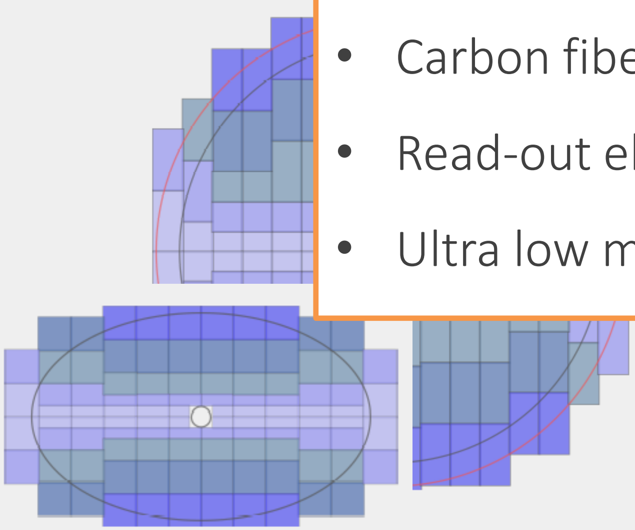
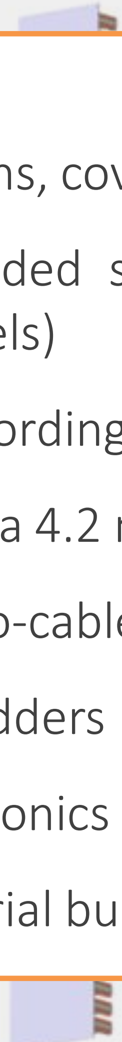
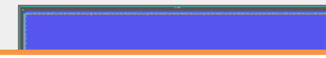




106
ladders



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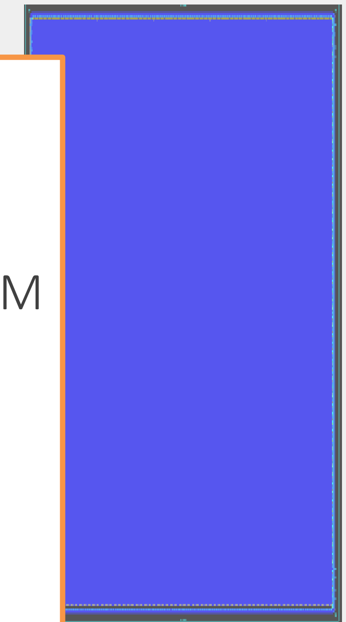

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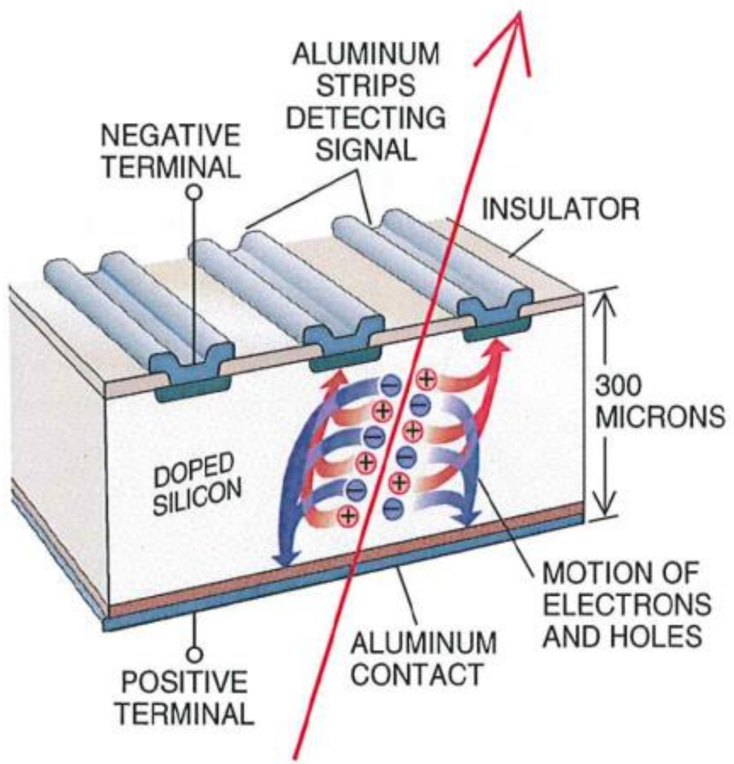
**Summary**

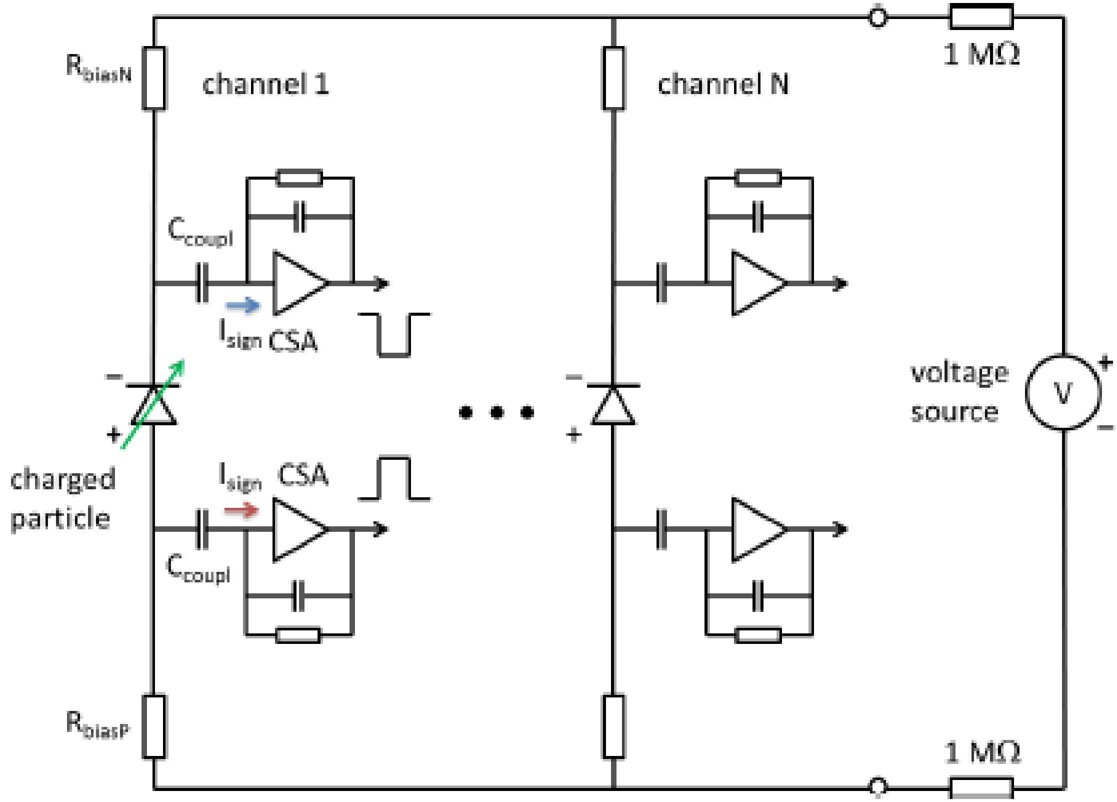
- 8 traking stations, covering aperture: $2.5^0 < \theta < 25^0$
- 1220 double-sided sensors in 3 sizes ≈ **2.5M strips** (1.8M readout channels)
- Granularity according to hit density
- Total silicon area 4.2 $m^2$
- Low mass micro-cables
- Carbon fiber ladders
- Read-out electronics outside of the physics aperture
- Ultra low material budget (~$1\%X_0$/tracking station)

# Silicon Microstrip Detector

Take n- or p-type silicon → create p-n junction → apply reverse bias voltage → operational detector → pattern sides → possibility to get positioning information




Operational principle of double-sided silicon microstrip detector



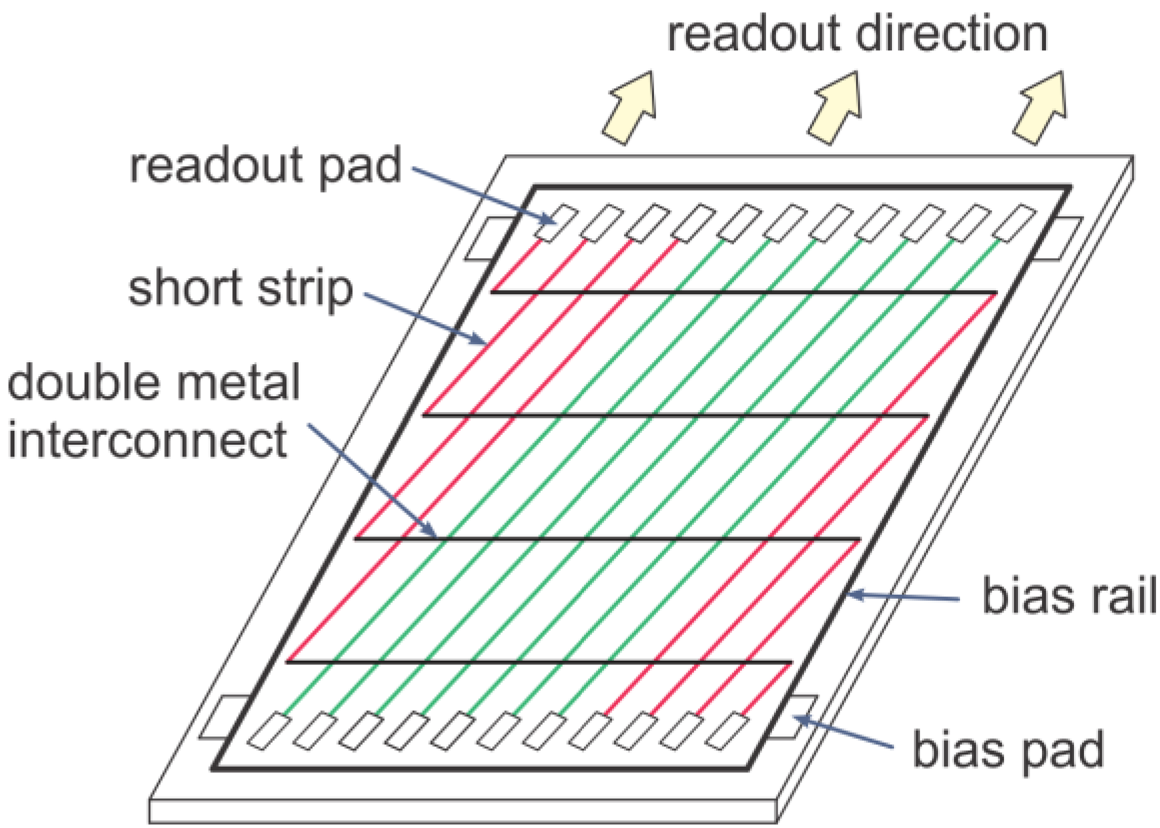

Energy needed to generate an electron-hole pair

$$(E_{\text{e-h}} = 3.6\,\text{eV})$$

Energy loss of a minimum ionizing particle in silicon

$$\left(\frac{dE}{dx}\right)^{Si}_{MPV} = 0.29\,\text{keV}/\mu\text{m}$$

# CBM Sensor Structure




p-side:

- strips under 7.5 deg angle
- AC coupled strips, read-out via 1st metal layer, AC contact pads at top edge
- inter-strip routing lines between side strips on 2nd metal layer

n-side:

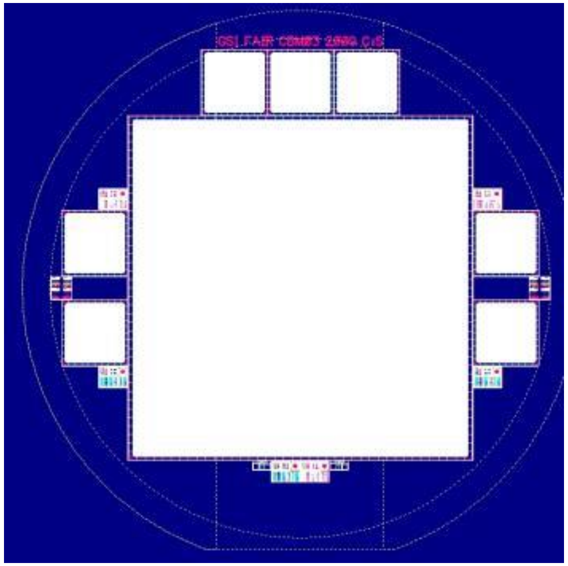
- strips under 0 deg angle
- only 1st metal layer

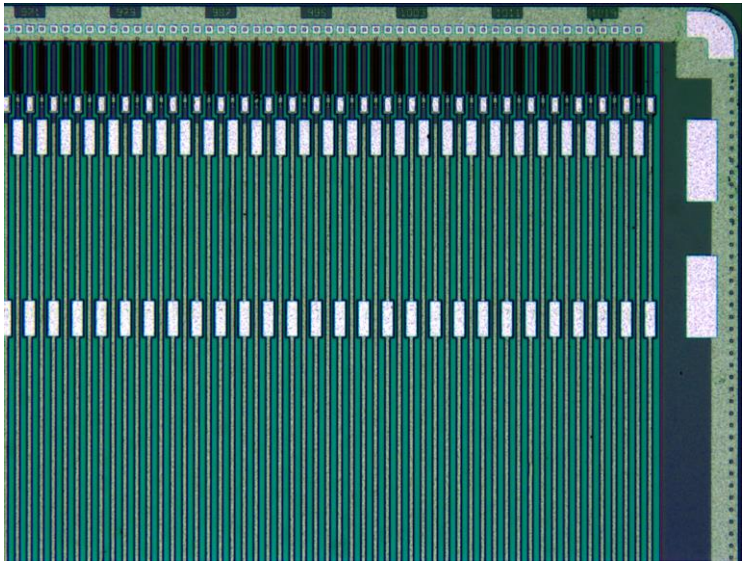
- n-type Si bulk
- thickness 285 μm double-sided, p-n-n structure
- strip pitch 58 μm, 1024 strips per side

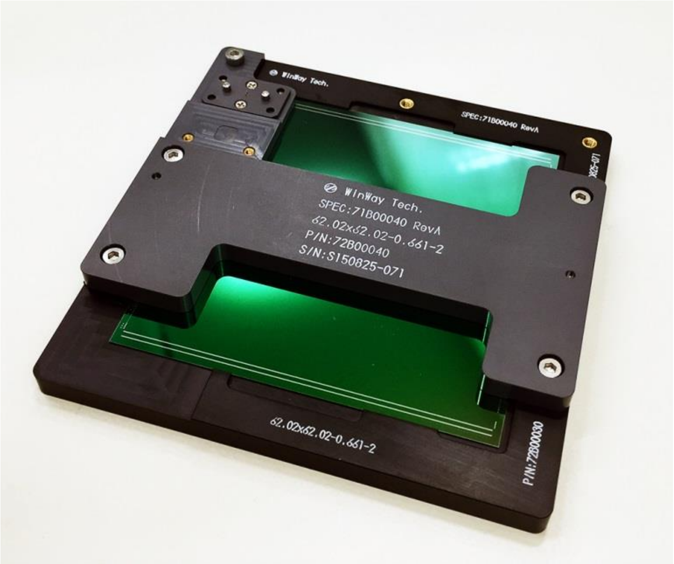
# Silicon Microstrip Sensors for CBM

| Prototype | Year | Size [cm²] |
|---|---|---|
| CBM06C2 | 2015 | 6.2 × 2.2 |
| CBM06C4 | 2015 | 6.2 × 4.2 |
| CBM06C6 | 2015 | 6.2 × 6.2 |
| CBM06H6<br>CBM06H2 | 2015 | 6.2 × 6.2<br>6.2 × 2.2 |
| CBM06C12 | 2015 | 6.2 × 12.4 |
| CBM06H12<br>CBM06H2 | 2015 | 6.2 × 12.4<br>6.2 × 2.2 |

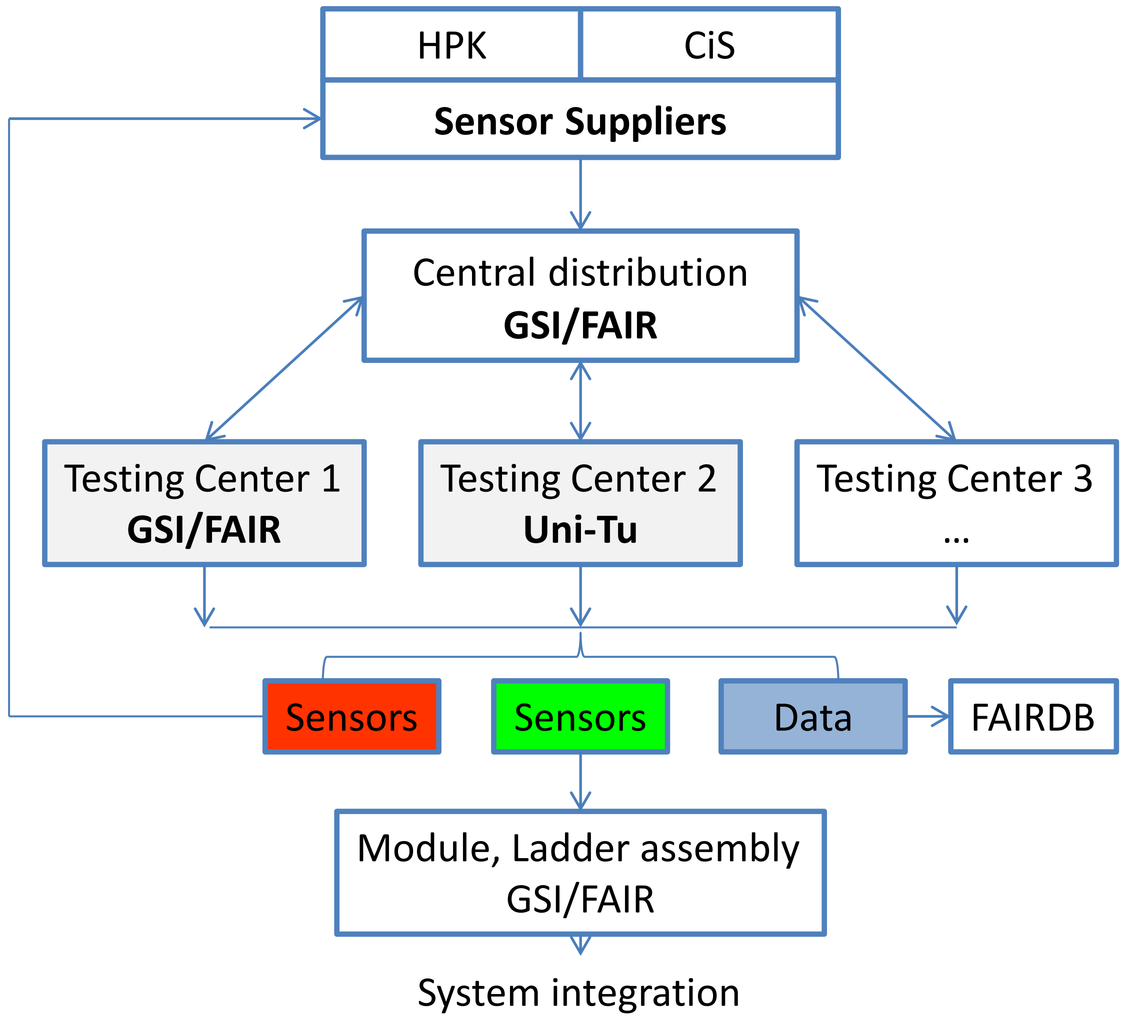
| | |
|---|---|
| Wafer thinckness | 285 ± 15 µm |
| Depletion Voltage | < 100 V |
| Leakage current | < 50 µA @ FVD+20 V |
| Junction breakdown | > 200 V |
| Coupling capacitance | > 10 pF/cm |
| Coupling capacitor breakdown | > 100 V |
| Interstrip capacitance | < 1 pF/cm |
| Polysilicon bias resistor | 1.2 MOhm ± 20% |
| Defective strips | < 1% per sensor |







# QA Organization and Silicon Sensor Flow




Distribution and control Center:

- Initial registration of sensors
- Distribution of sensors
- Monitoring the QA program
- Final acceptance and grading

Testing centers:

- Visual inspection
- IV-CV tests, all sensors
- Strip tests, sensor subsets
- Other tests

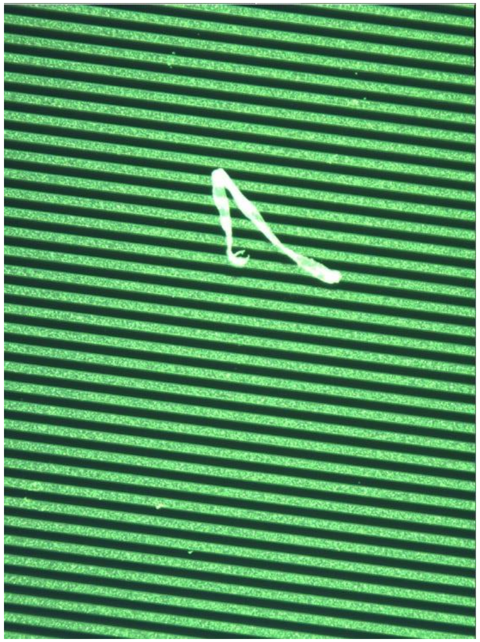
# STS Sensors Quality Assurance

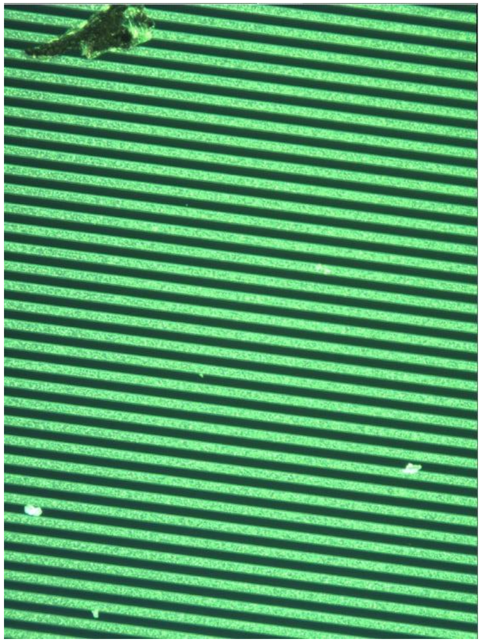
- **Visual Inspection**
  - defects are easily detected
  - to do on **all** sensors
- Metrological measurements
  - Flatness, warp, cutting edge
- **Electrical characterization**
  - Basic tests: IV-CV curves
  - Subset test: Strip tests
  - Specific tests
  - Other tests
- Readout characterization
  - With radioactive source
  - With laser

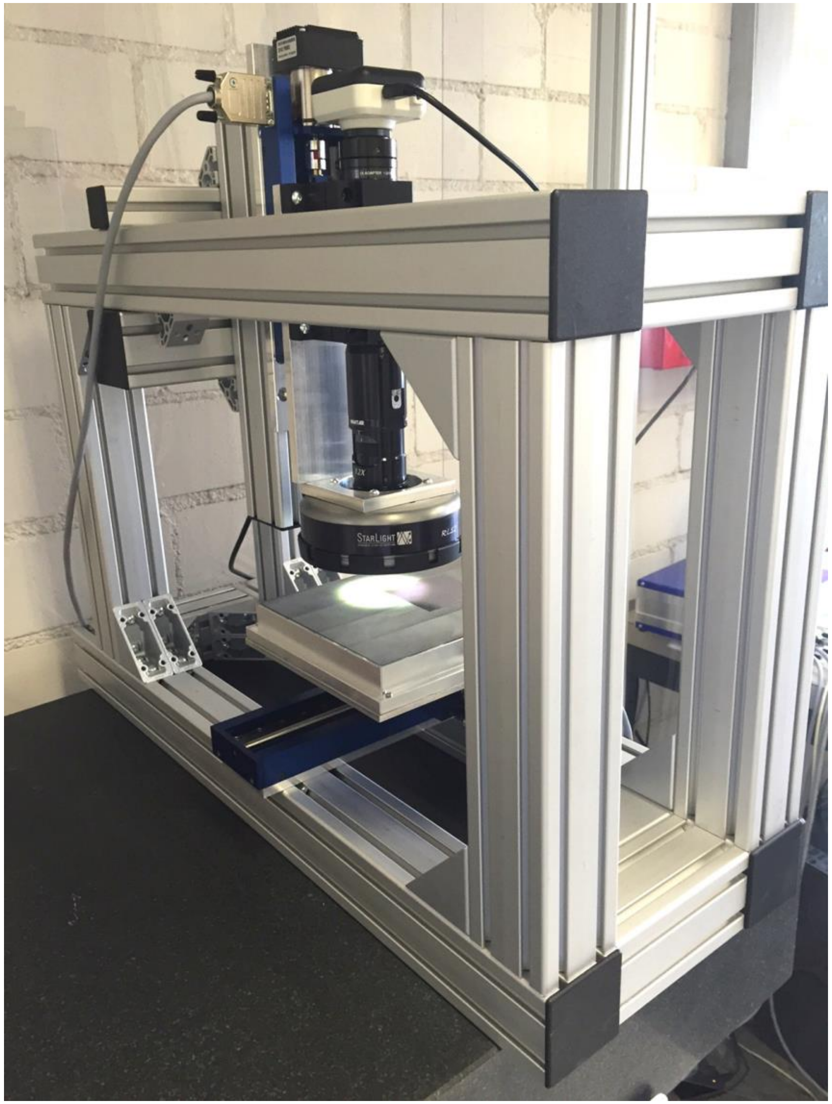
# Optical Inspection

Powerful tool to determine:

- Dust particles and other foreign objects on the sensor surface;
- Scratches;
- Single element integrity (bias resistors, strips, pads, guard ring)
- Sensor edge defects







Optical inspection setup in built-in cleanroom // Evgeny Lavrik

# Electrical Characterization

- **Electrical characterization**
  - **Basic tests**: IV-CV curves
    - $I_{leakage}$@FDV, $V_{FD}$, $C_{bulk}$, $N_{eff}$;
    - To be done for all sensors;
    - Quality criteria: **I@150 < 50 uA**, I@150 / I@100 < 2, **$V_{depl}$ < 100 V**
  - **Subset test**: Strip tests
    - Pinholes in capacitor dielectric, strip metal and implant shorts and opens, single strip leakage current;
    - on ~**10 % of all sensors;**
    - Strip tests for suspicious candidates during visual inspection;
    - **4-5 hours per sensor** for complete testing protocol;
    - Quality criteria: **< 1% of strips fail**
  - **Specific tests**
    - Coupling capacitance of the readout strip, solysilicon resistance, interstrip capacitance, strip capacitors breakdown voltage;
    - Prototyping stage – for all sensors, production – few strips of ~1-2 sensors/batch

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CBM Sensor: **1024** strips on each side.

~1200 Sensors = **2.5M strips**

~ **250k strips** - have to be tested.

For every strip – **3 QA tests**

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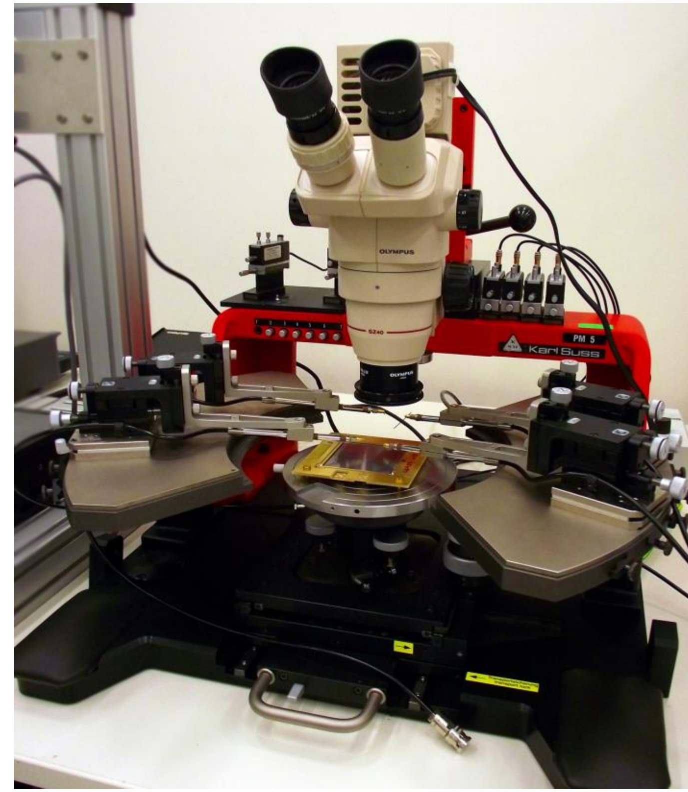
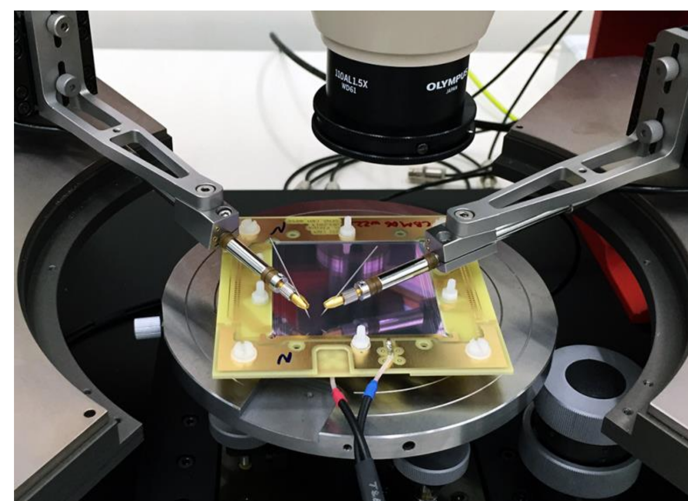
CBM Sensor: **1024** strips on each side.
~1300 Sensors = **2.6M strips**
~ **260k strips** - have to be tested.
For every strip – **3 QA tests**

Manual measurements of each strip take hours of work for a single sensor.

Large volume tests require:

- automation of repetitive measurements
- acquirement of several parameters at each step





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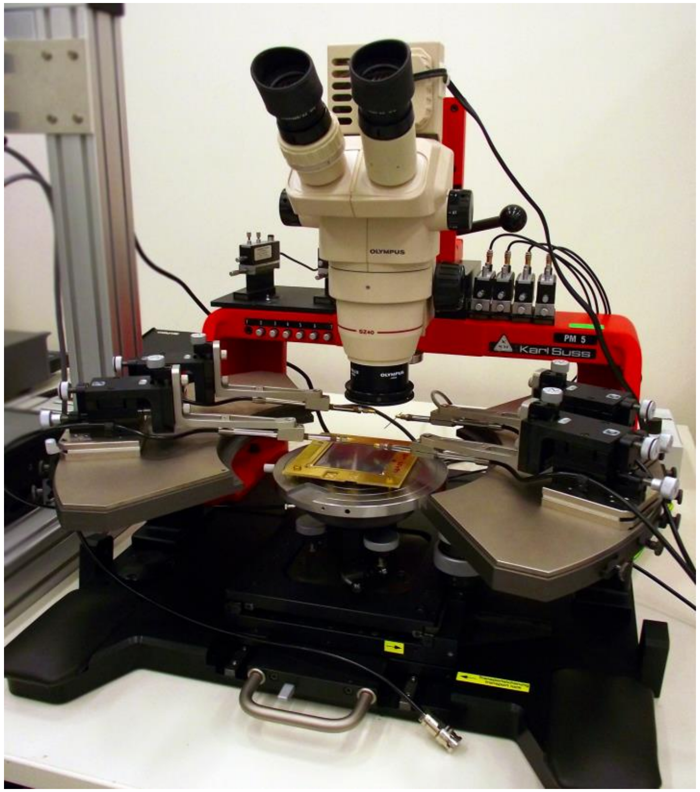
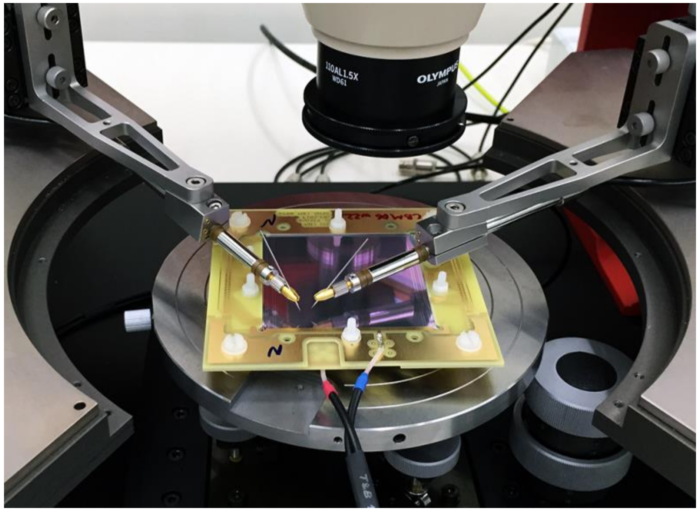
Need a probe station for large scale sensor QA – automation is required for alignment, stepping through channels, measurements





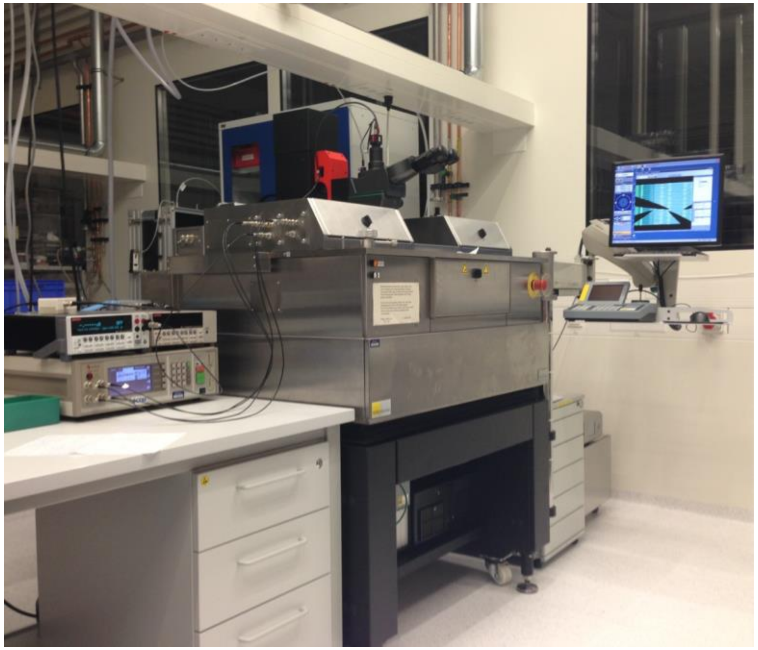
# Custom and Commercial Solutions

**Two solutions**:

- Commercial wafer prober (GSI, Darmstadt)
- Custom-built probe station (Uni-Tubingen)

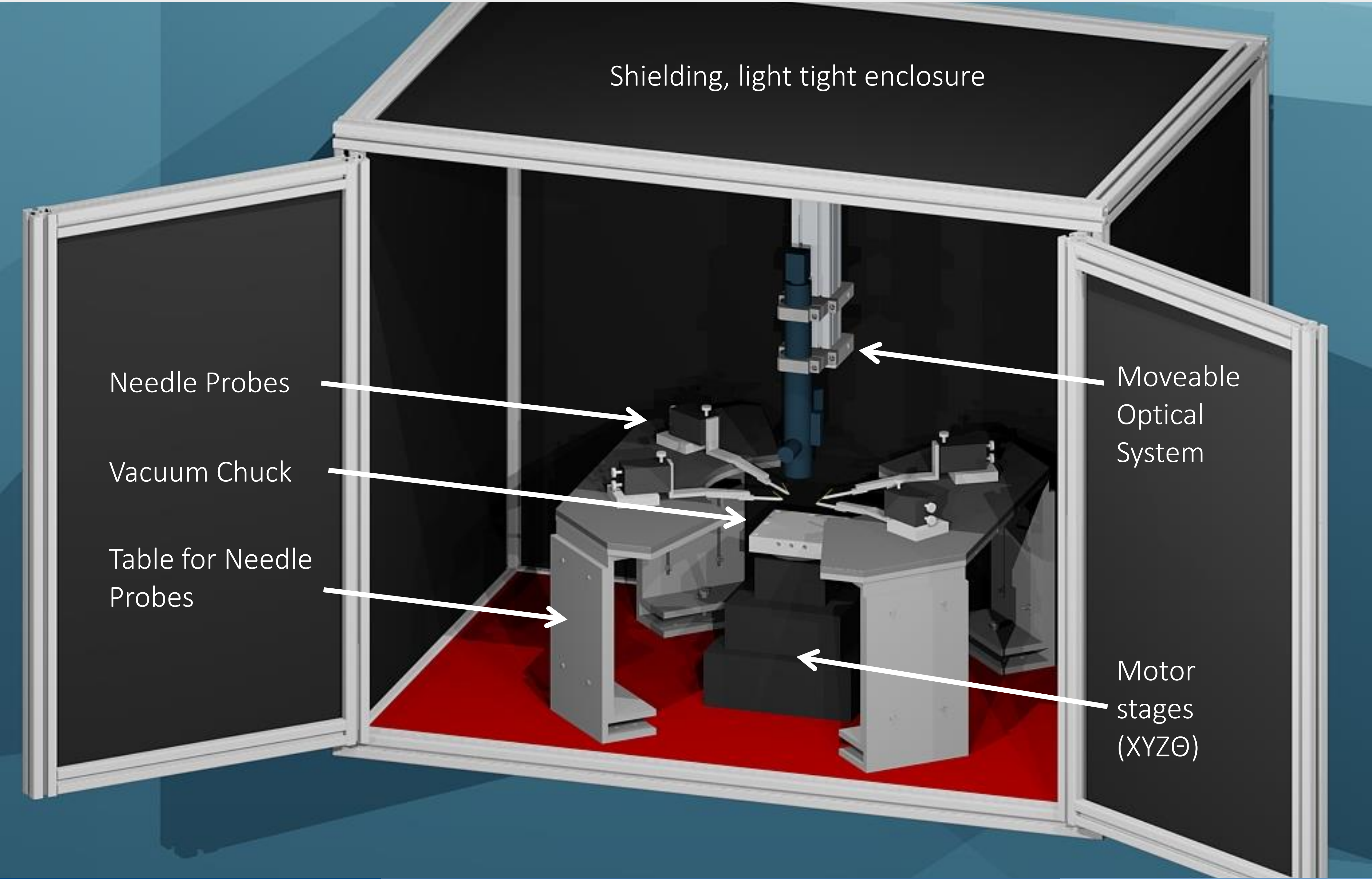
**Why Custom Probe Station?**

- *CBM sensors have 1024 strips with 180x60 um² AC-pads at 58 um pitch* => need a **high accuracy** of positioning and **repeatability** (< 1 μm);
- *CBM sensors are 62x62 and 62x120 mm² in size* => need a large travel range of both positioning and optical systems;
- Custom solution allows to implement features which are really needed (for both hardware and software, e.g. *proper vacuum chuck, auto-alignment of the silicon sensor, repositioning on pads via pattern recognition*, and much more);
- Cost for such commercial device ~300 k€ with many features which are not needed or not implemented;
- Custom (very) high precision device – only ~ 100 k€



Commercial wafer prober **Süss PA300PS** (GSI, Darmstadt)

# Custom Probe Station



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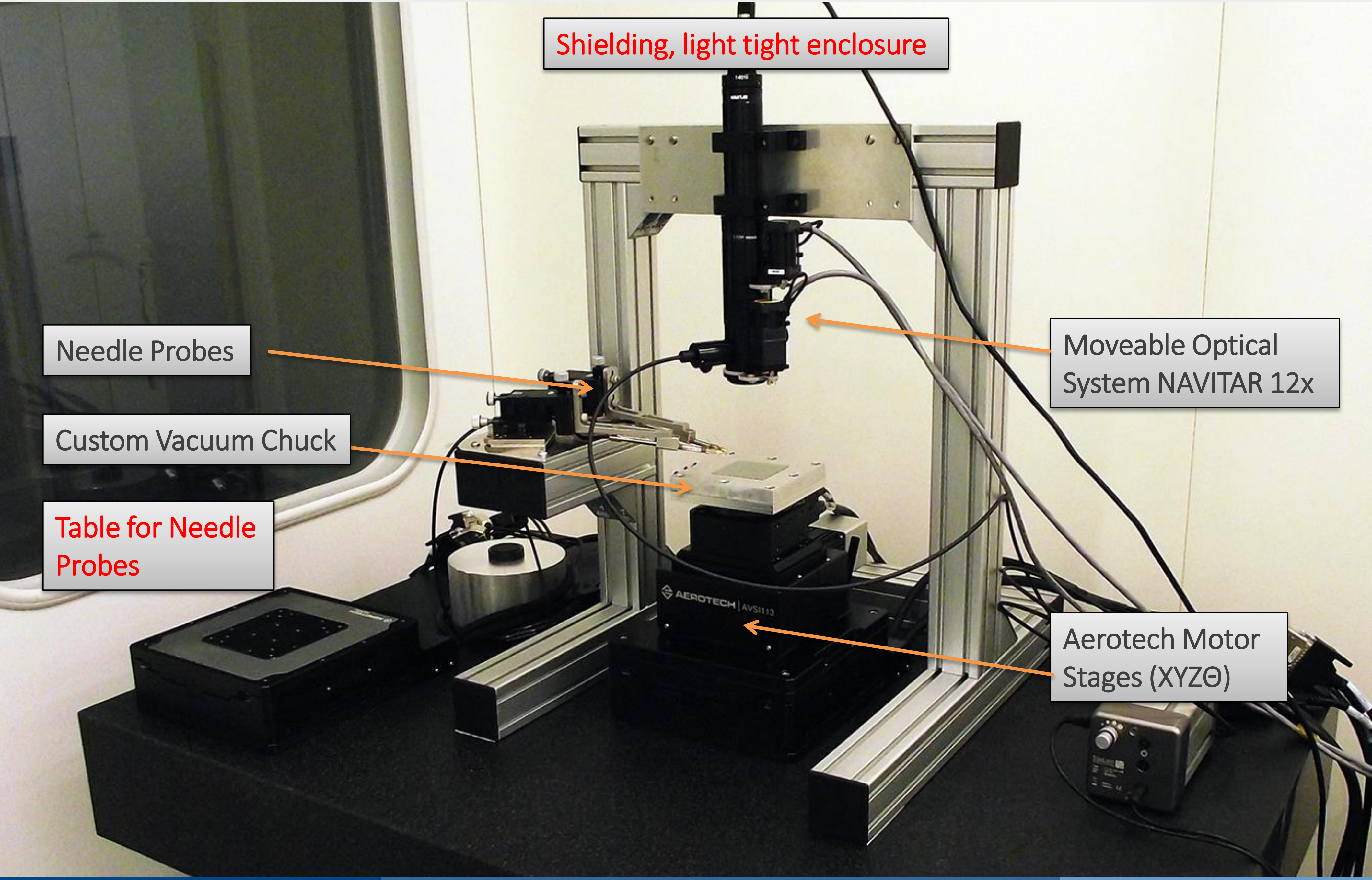
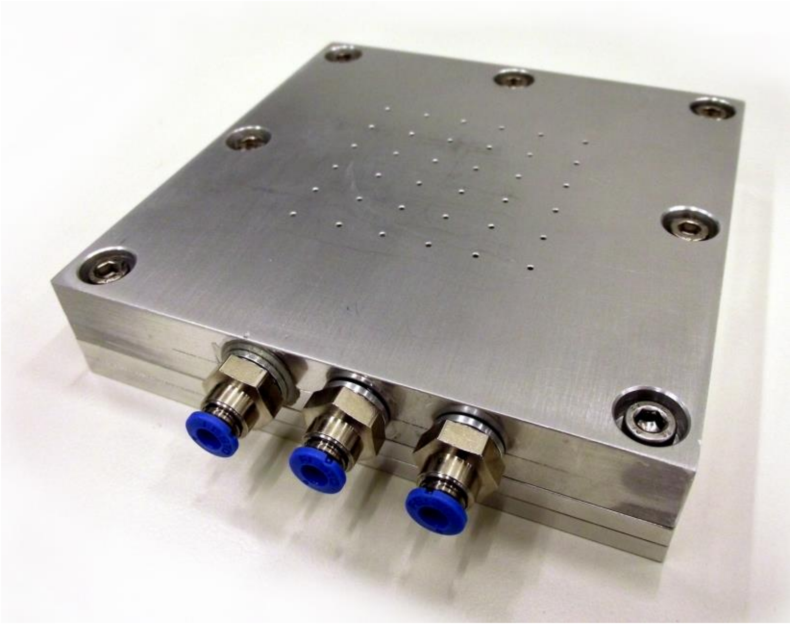


# Vacuum Chuck and Height Measurements



Chuck:

- push-to-connect vacuum fittings for Ø4 mm tubes
- chuck size 12×12 $cm^2$, vacuum zone size 5×5 $cm^2$;
- 3 vacuum areas for 3 sensor sizes (6.2×6.2, 6.2×4.2, 6.2×2.2 $cm^2$)

- **Chuck flatness, surface quality?**

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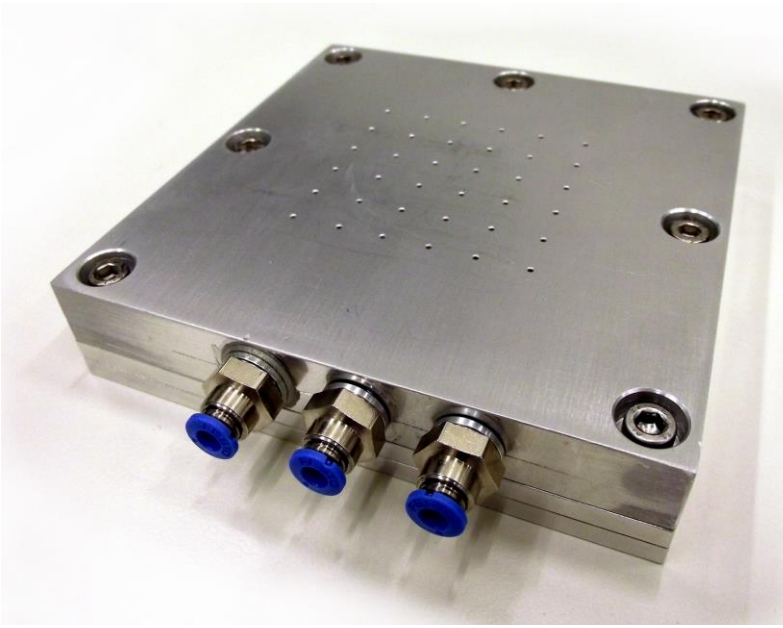

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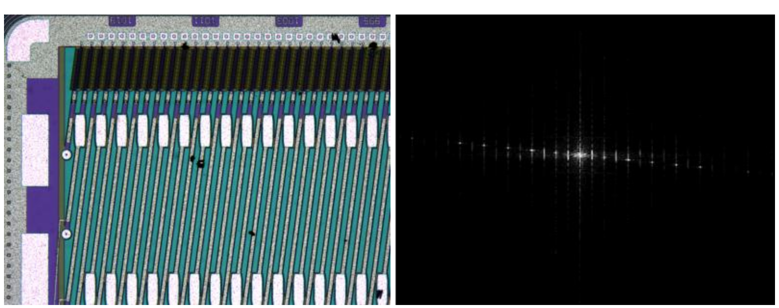
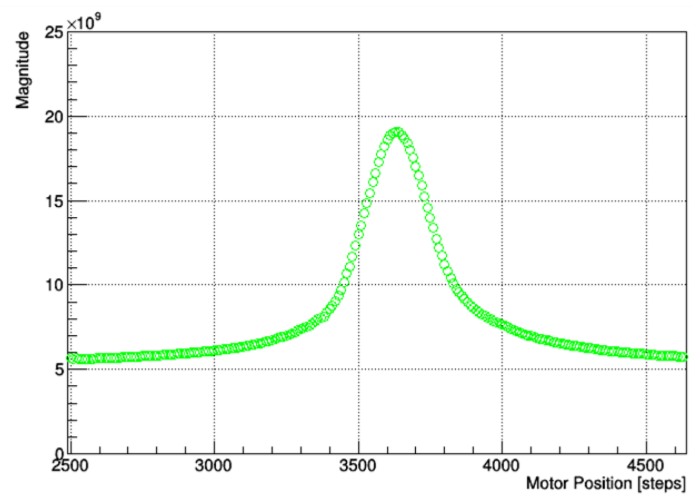
2D Discrete Fourier Transform

$$S(u,v) = \frac{1}{nm} \sum_{x=0}^{n-1} \sum_{y=0}^{m-1} s(x,y)\, \mathrm{e}^{-\mathrm{i}\, 2\pi \left( \frac{ux}{n} + \frac{vy}{m} \right)}$$



FFT complex image




Focus Curve

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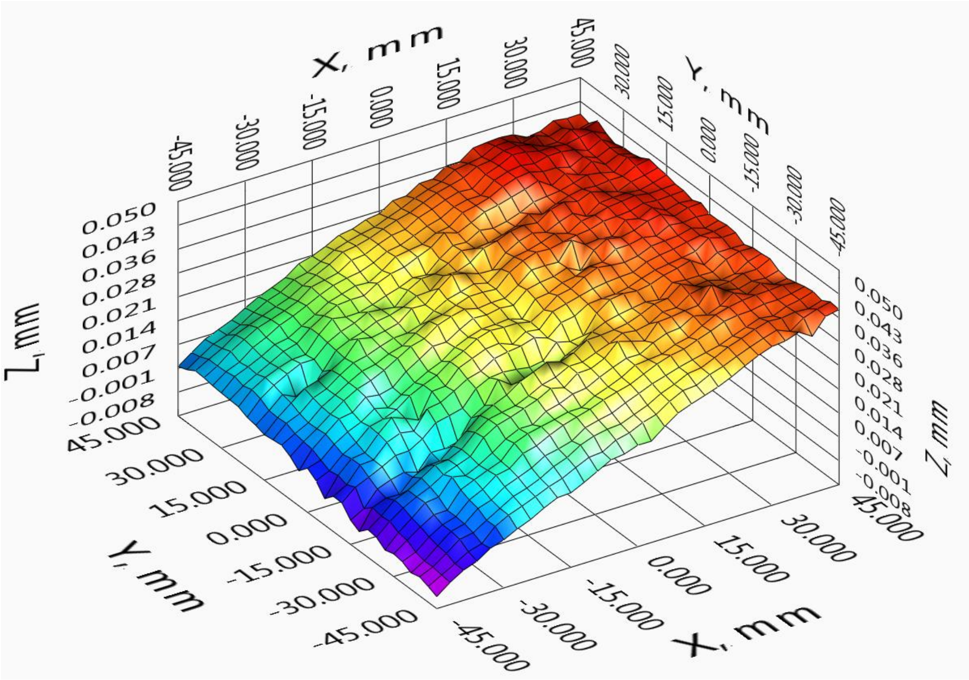


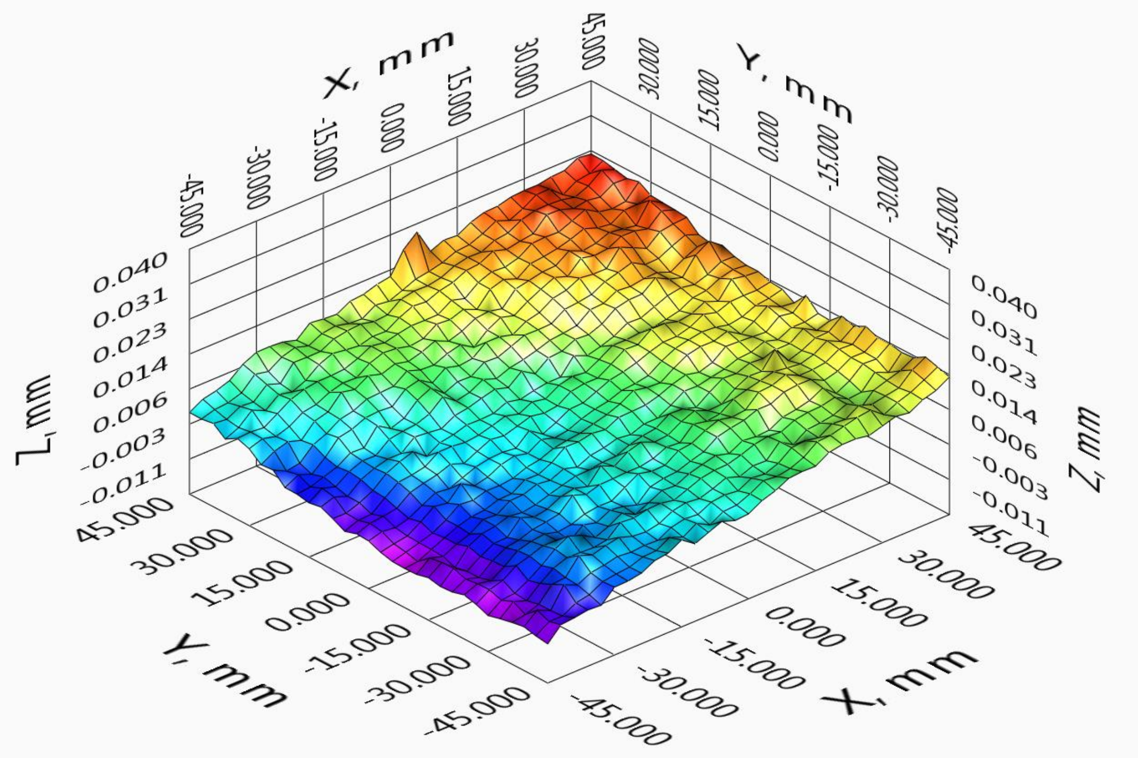

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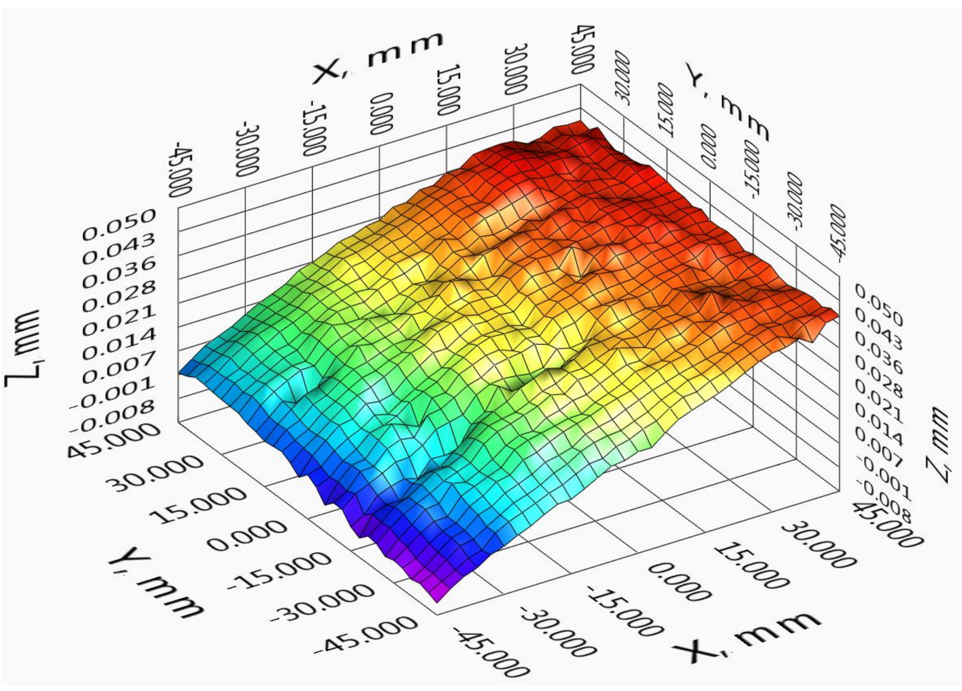


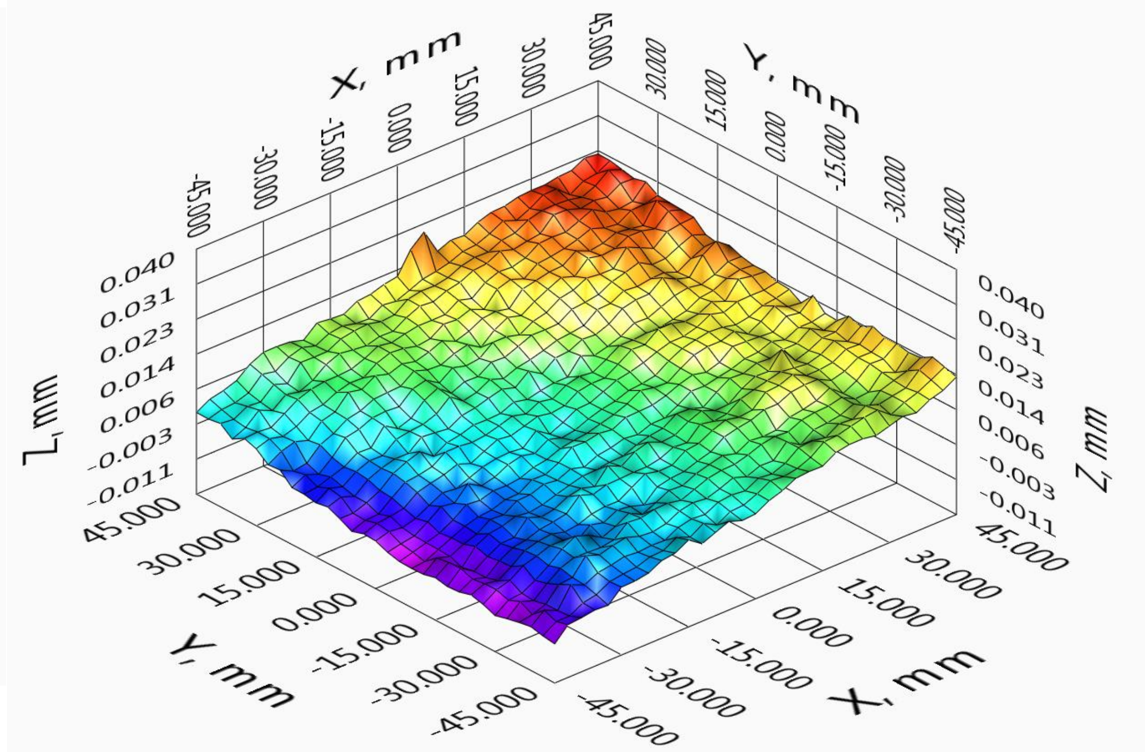


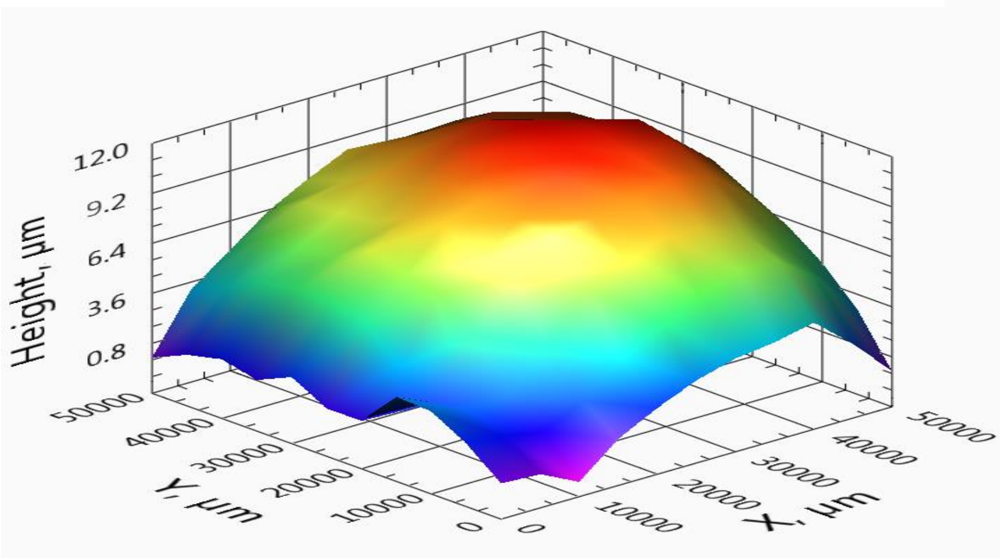


- Metrological measurements
  - Sensor flatness, warp
  - Sensor thickness

Measured Sensor Thickness = 309.6 ± 2.6 µm

(CBM06 sensor thickness = 300 µm)

# Switching Scheme


Switching Matrix Keithley 708B

- Keithley switching matrix;
- 8 inputs and 12 outputs;
- Compatible with our measurement devices;
- Adapted for low current, high voltage measurements;
- High command execution speed;
- Low offset of the measured parameters.

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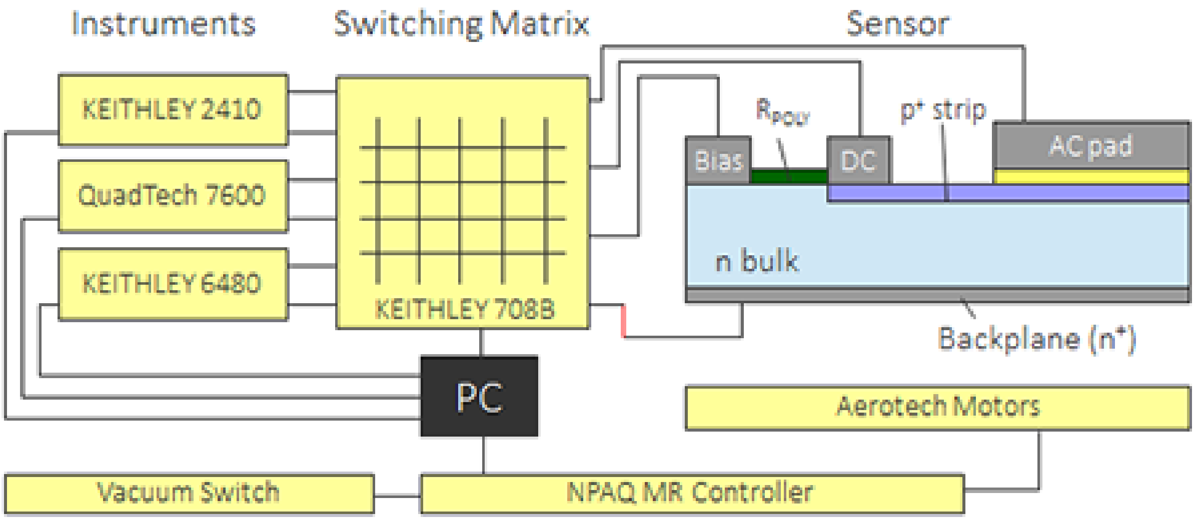
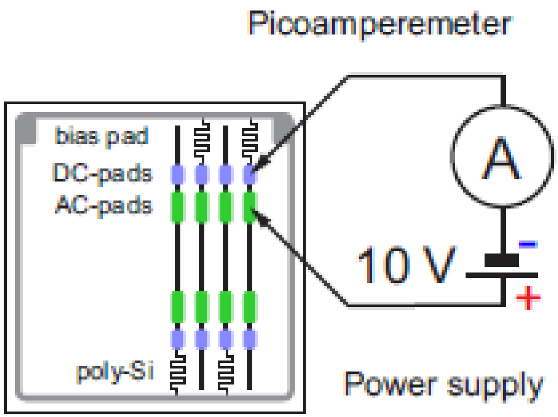



Using the switching matrix allows to realize different measurement configurations without manual interaction.

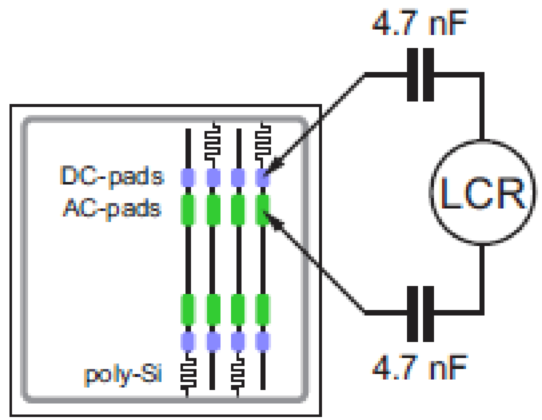
- **All tests can be done in a row**
- **Measurements time can be strongly reduced**

# Measurement Schemes

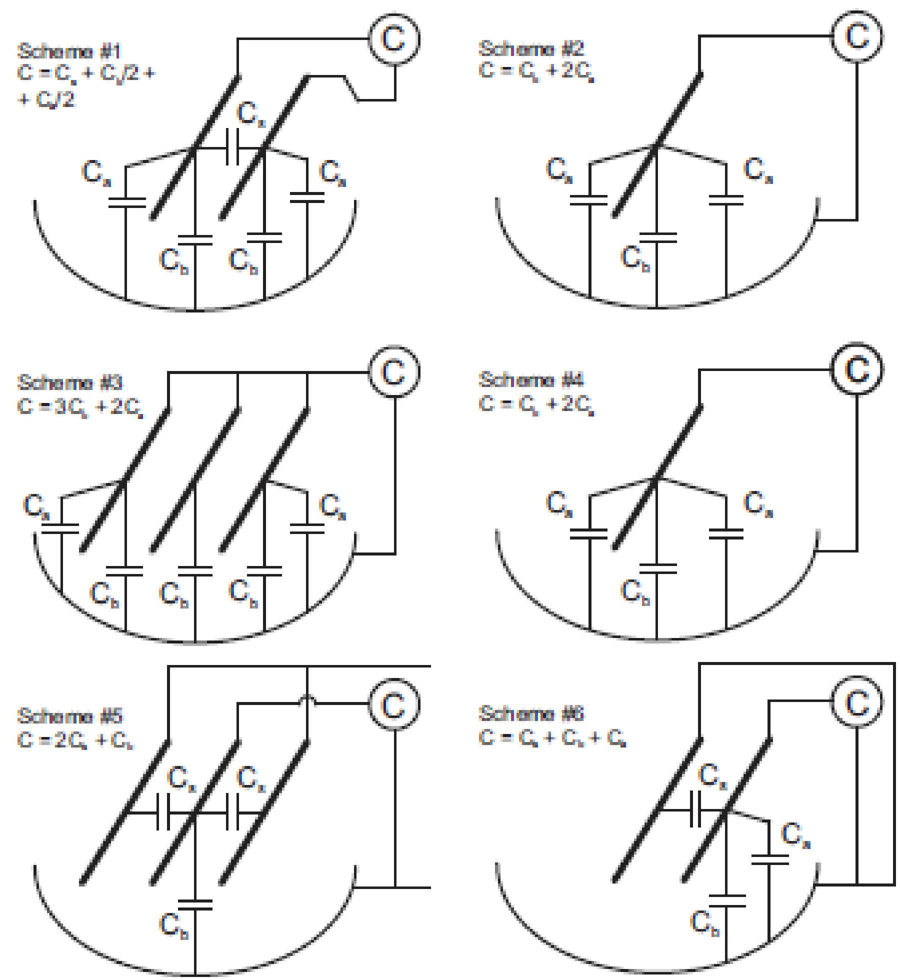
Connection scheme for determination of coupling capacitor pinholes

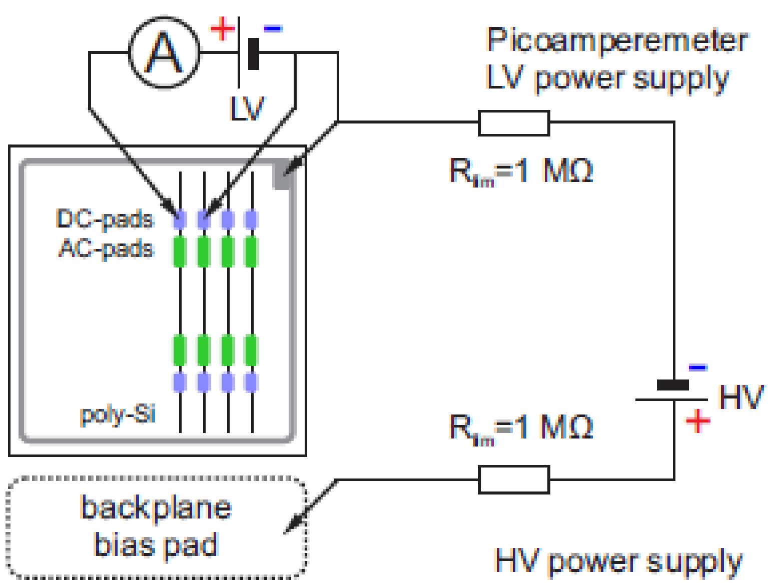



Connection scheme for coupling capacitance measurement



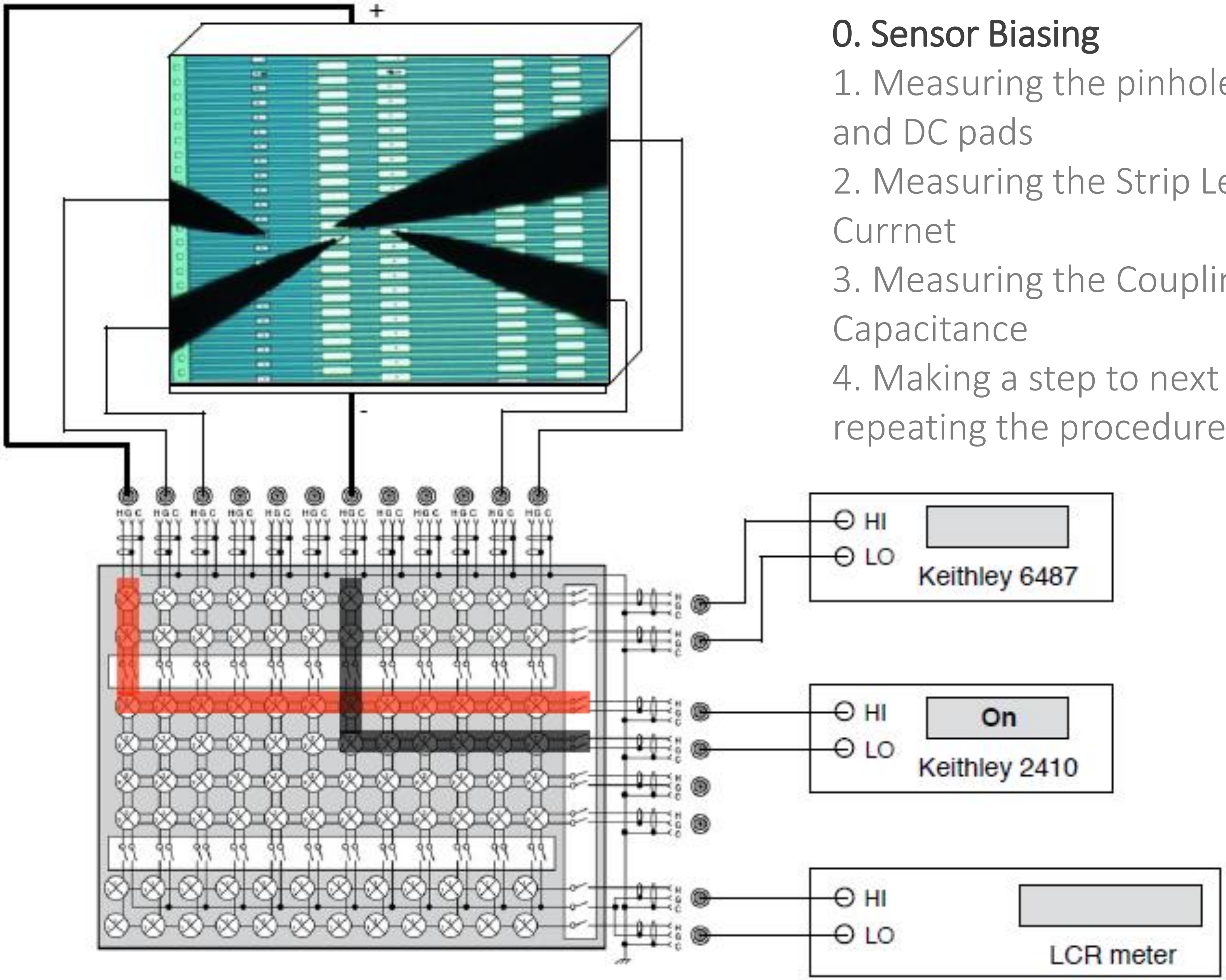

Measurement schemes for determination of interstrip capacitance.




Connection scheme for interstrip resistance measurement

# Measurement Procedure




0. Sensor Biasing

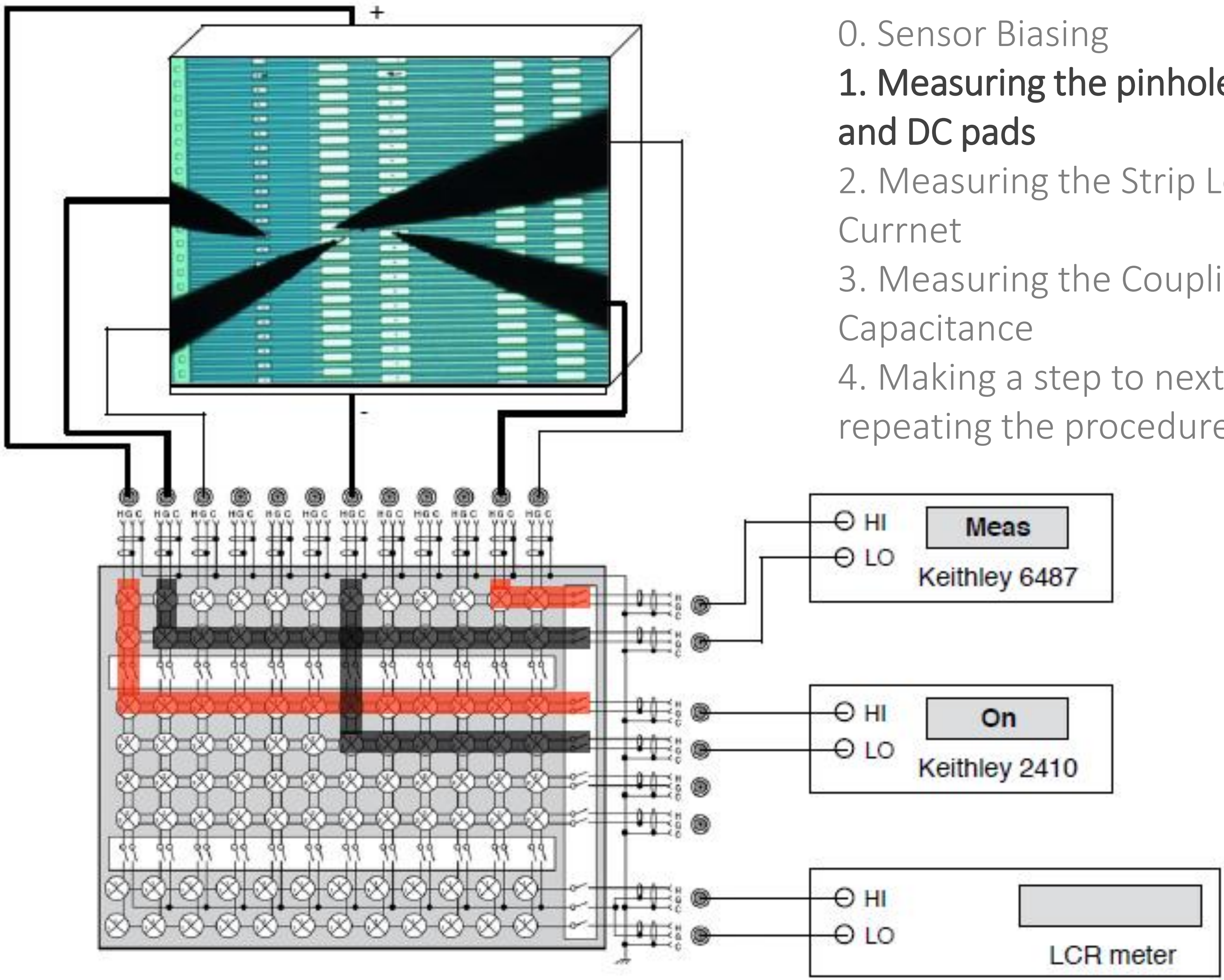
1. Measuring the pinhole between AC and DC pads

2. Measuring the Strip Leakage Currnet

3. Measuring the Coupling Capacitance

4. Making a step to next strip and repeating the procedure

# Measurement Procedure




0. Sensor Biasing

**1. Measuring the pinhole between AC and DC pads**

2. Measuring the Strip Leakage Currnet

3. Measuring the Coupling Capacitance

4. Making a step to next strip and repeating the procedure

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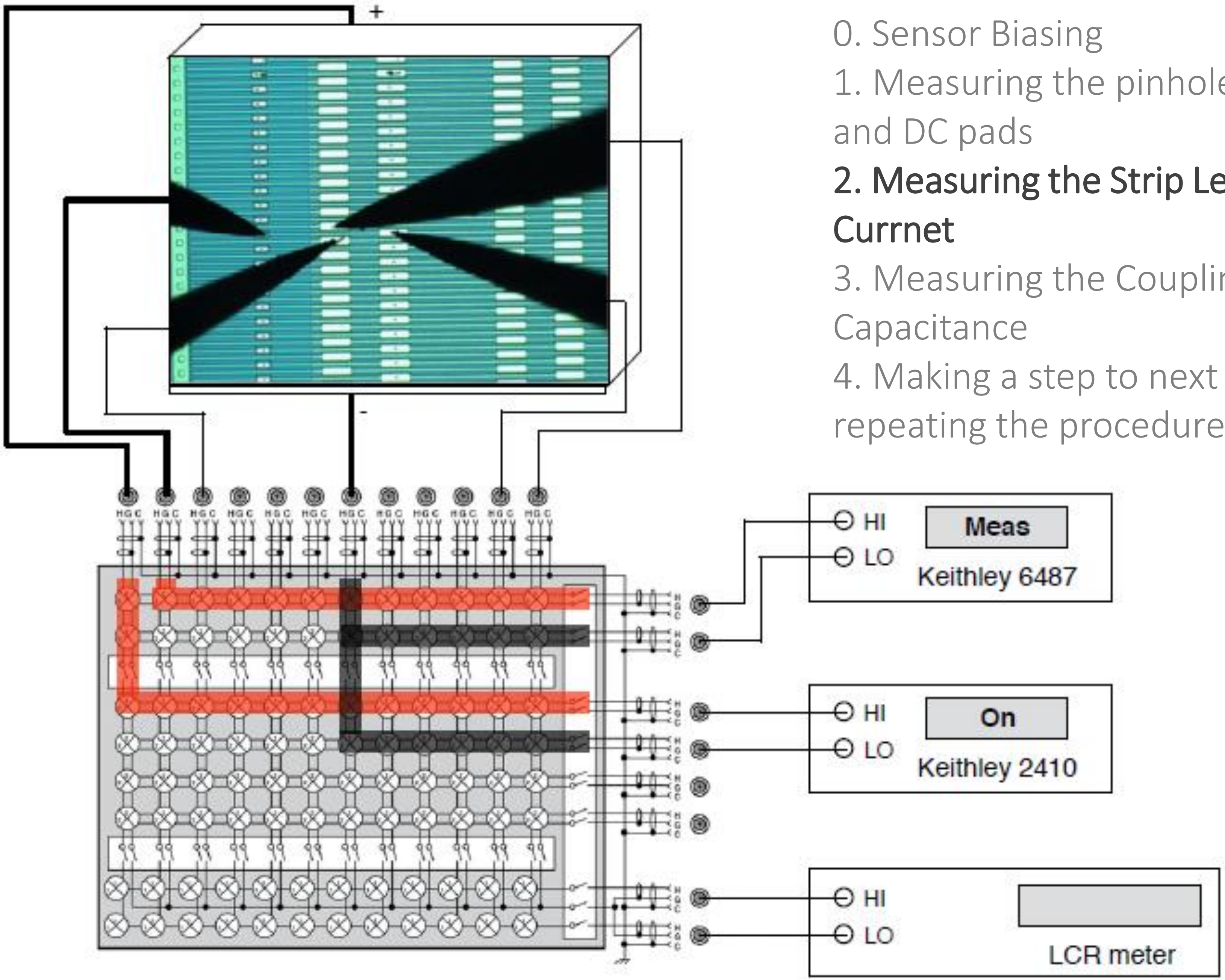


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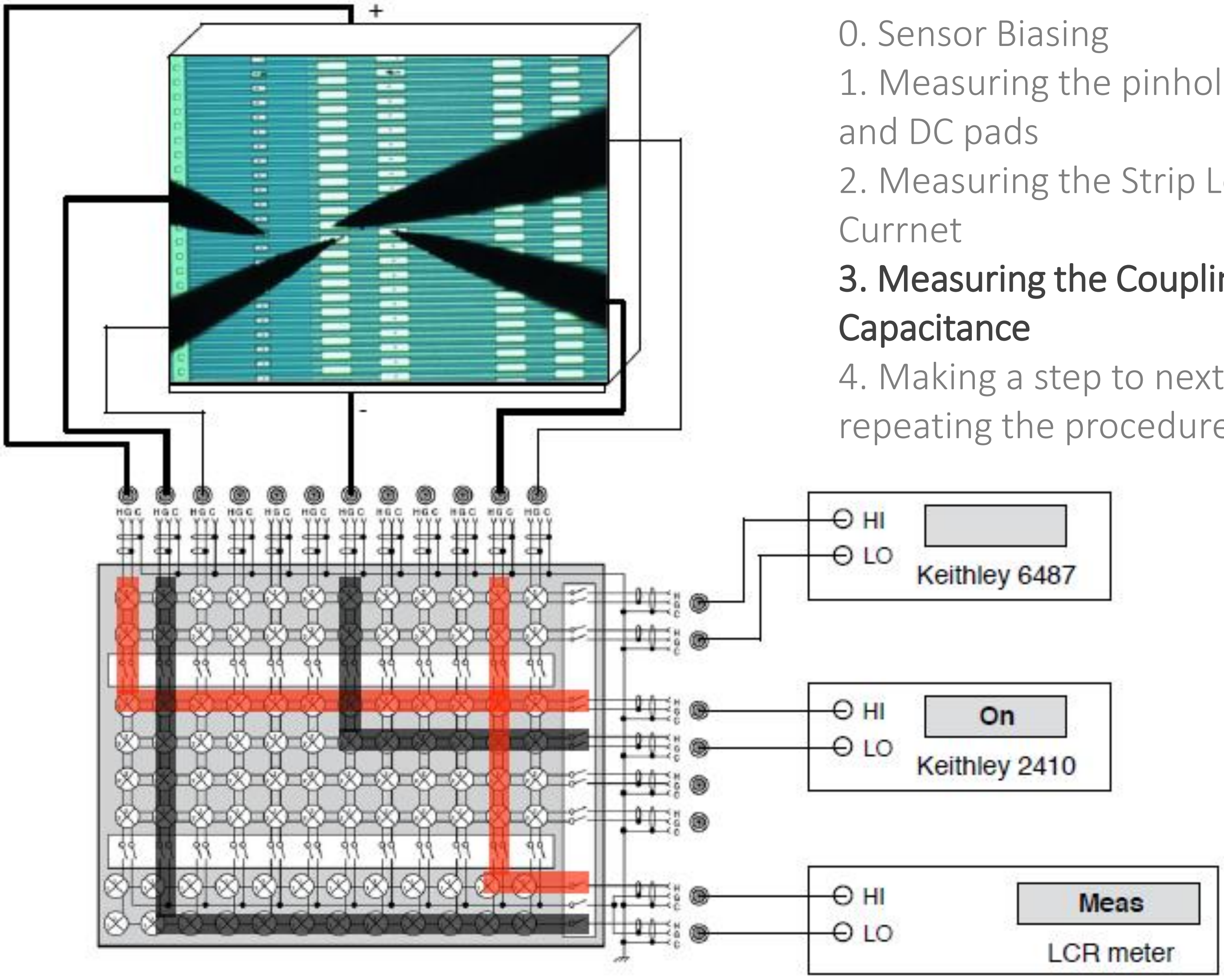


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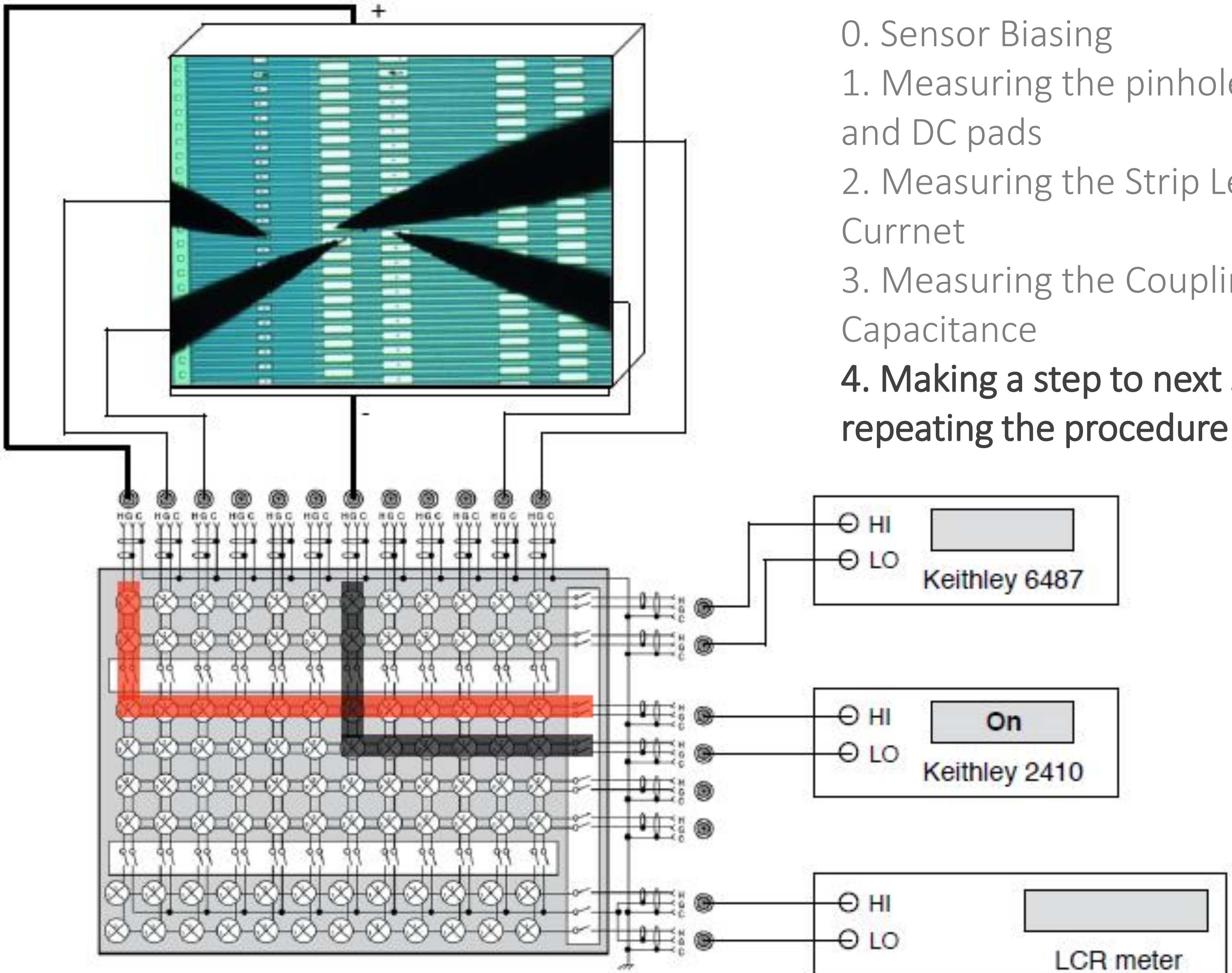


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1. Measuring the pinhole between AC and DC pads
2. Measuring the Strip Leakage Currnet
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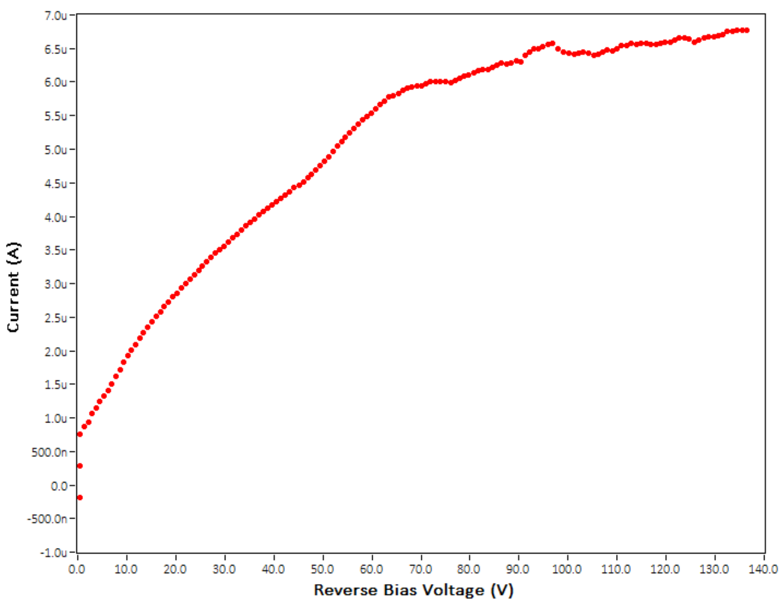
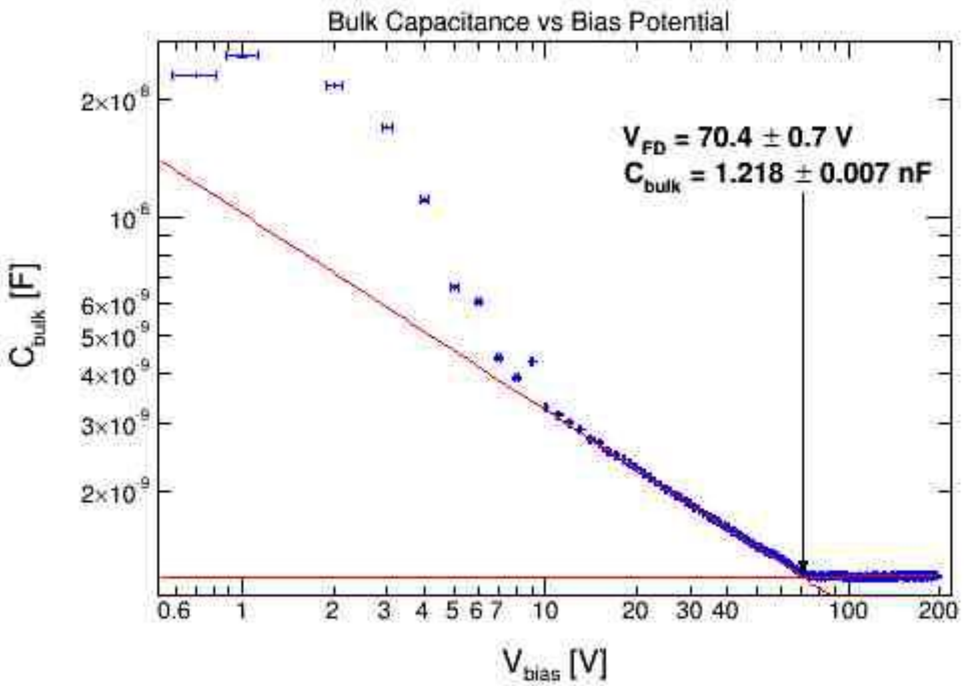
4. **Making a step to next strip and repeating the procedure**

# Results with Prototype Sensors

## IV – CV Characterization

- Performed on 2 prototypes  labeled CBM06 (w18 & w22)
    - **I@100 V < 10 uA @ 20$^0$ C**
    - **$V_{depl}$ ≈ 70 V**
    - **$C_{bulk}$ ≈ 1.21 nF**

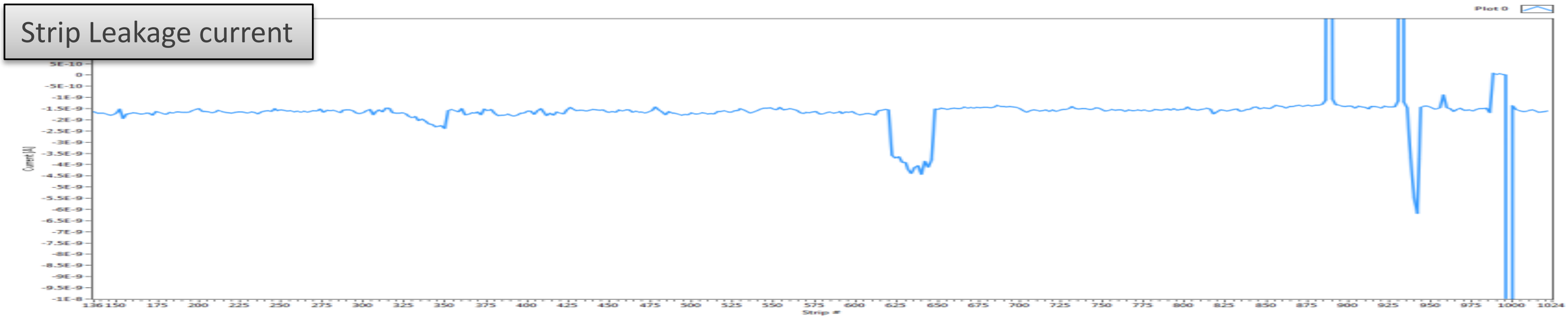


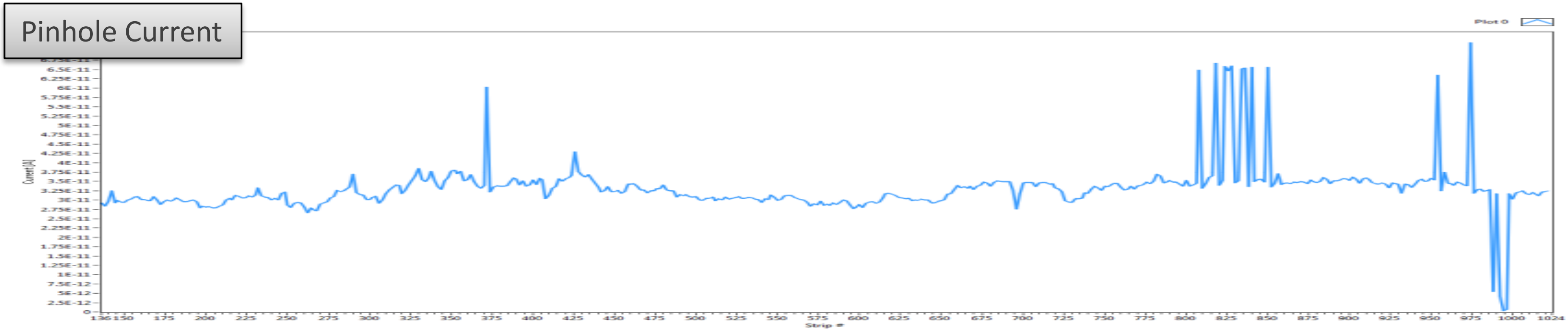
# Results with Prototype Sensors

## Strip-by-Strip Characterization

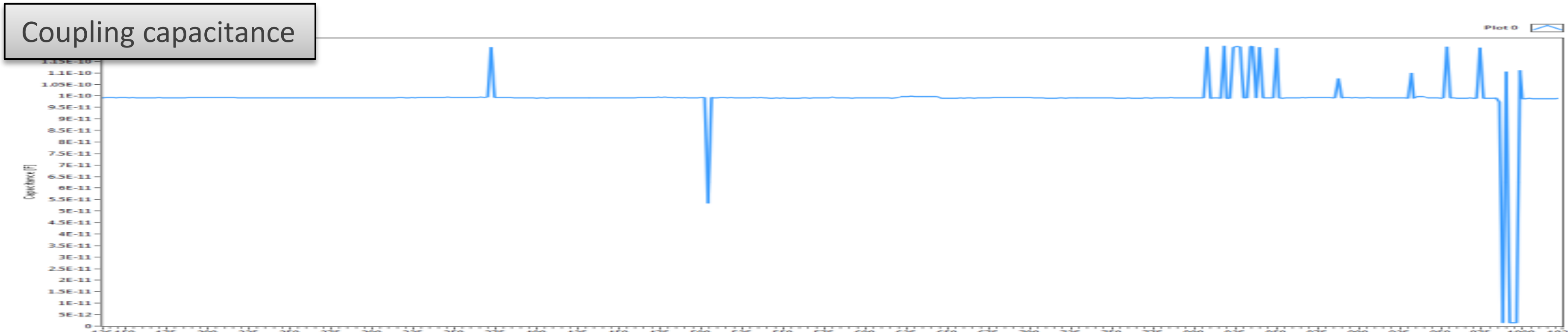
Strip Leakage current



Pinhole Current



Coupling capacitance



# Results with Prototype Sensors

## Strip-by-Strip Characterization

| | |
|---|---|
| • Pinholes in capacitor dielectric | $I_{diel} < 1$ nA @ $V_{op}$ |
| • Strip metal and implant shorts and opens | $0.8\ C_{ac} < C_{ac} < 1.2\ C_{ac}$ |
| • Single strip leakage current | $I_{leak} < 10$ nA @ $V_{op}$ |
| • Coupling capacitance of the readout strip | $C_{ac} > 10$ pF/cm |
| • Polysilicon resistance | $R_{poly} = 1.2$ MOhm ± 20% |
| • Interstrip capacitance | $C_{int} < 1$ pF/cm |
| • Strip capacitors breakdown voltage | $V_{cbd} > 100$ V |

# Results with Prototype Sensors

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**OUTCOME: List of bad channels**

Bad channel = one of the measured parameters is out of required range

# Summary

The *custom probe station has been developed at Tübingen University*:

- Implementing the switching matrix makes possible to perform different measurements by an automated system without manual interaction.
- A dedicated *LabVIEW* based software has been development to automate repetitive measurement steps.
- **QA program with detailed characterization procedures has been developed for CBM-STS sensor QA**.
- First test measurements have been performed on sensor prototypes which allowed to demonstrate  perfect ability of Custom Probe Station to qualify silicon microstrip sensors.

# STS design constraints

**Coverage:** *aperture 2.5° < Θ < 25°*

**Momentum resolution** $\delta p/p \cong 1\%$

*field integral 1 Tm, 8 tracking stations*

*25 µm single-hit spatial resolution*

*material budget per station ~1% $X_0$*

**No event pile-up**

*10 MHz interaction rates*

*self-triggering read-out*

*signal shaping time < 20 ns*

**Efficient hit & track reconstruction** close to 100% hit eff.

> 95% track eff. for momenta > 1GeV/c

**Minimum granularity** @ hit rates < 20 MHz/cm$^2$

*maximum strip length compatible with hit occupancy and S/N performance*

*largest read-out pitch compatible with the required spatial resolution*

**Radiation hard sensors** compatible with the CBM physics program

$1 \times 10^{13}$ $n_{eq}/cm^2$ (SIS100)

$1 \times 10^{14}$ $n_{eq}/cm^2$ (SIS300)

**Integration, operation, maintenance** compatible with the confined space in the dipole magnet