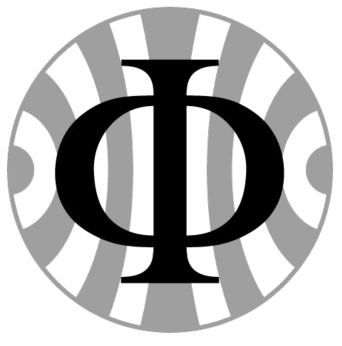
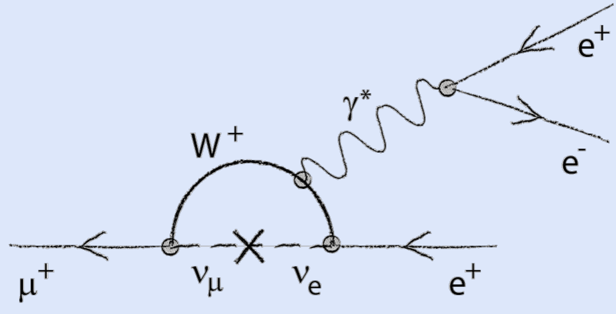


MuPix11 Quality Control

Ensuring Functionality of the Mu3e Pixel Sensors

The Mu3e Experiment

- Search for the cLFV $\mu^+ \to e^+e^-e^+$ decay
- SM Branching fraction <1 x 10^{-54}

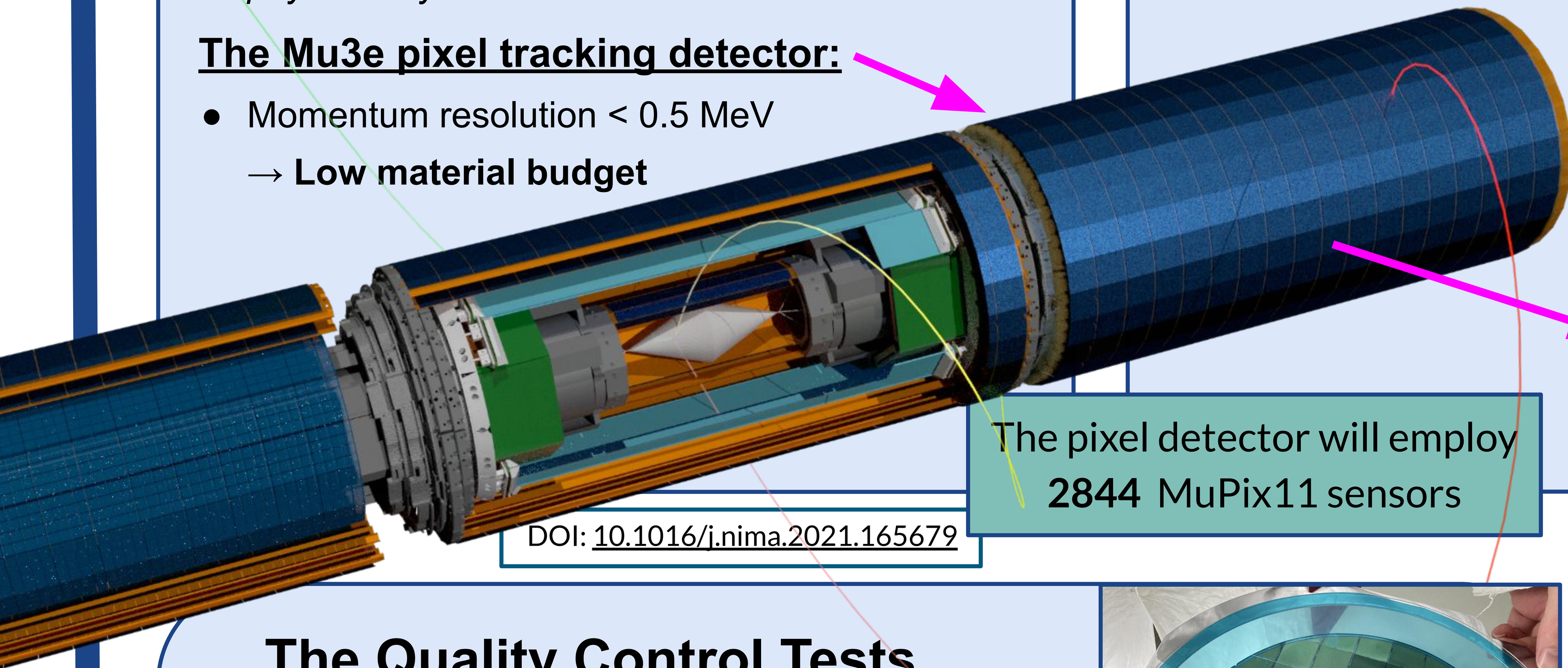


- Observation of cLFV would be evidence of *physics beyond the standard model.*

The Mu3e pixel tracking detector:

- Momentum resolution < 0.5 MeV

→ **Low material budget**



The pixel detector will employ **2844** MuPix11 sensors

DOI: 10.1016/j.nima.2021.165679

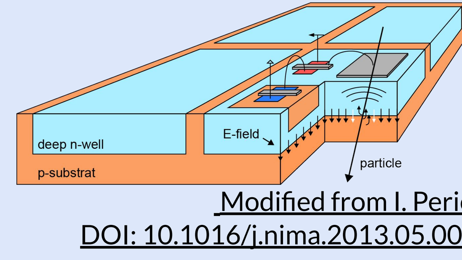
HV-MAPS

HV-MAPS technology is essential for reducing material in the detector

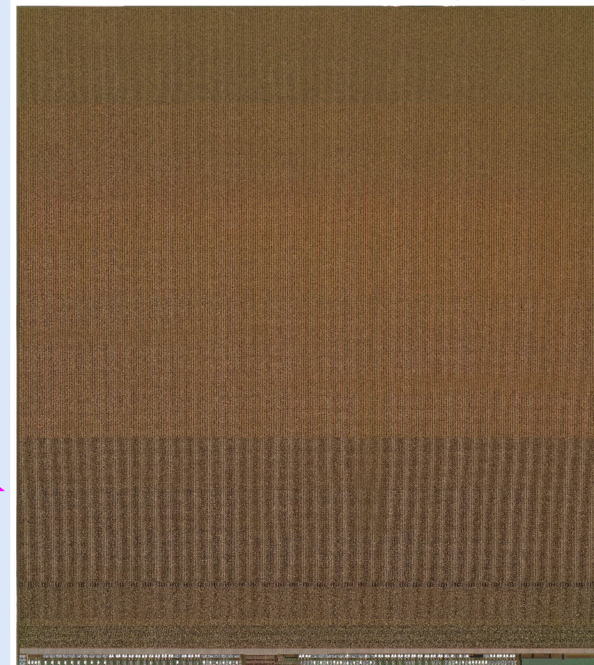
High-**V**oltage **M**onolithic **A**ctive **P**ixel **S**ensor

HV-MAPS:

- Feature high reverse bias voltage
- Integrate readout electronics on the sensor
- Can be thinned to a thickness of 50 µm



Modified from I. Perić, DOI: 10.1016/j.nima.2013.05.006



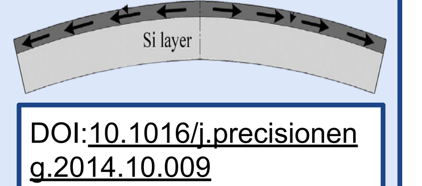
A MuPix11 Sensor

The MuPix11 Sensor:

- 180 nm HV-CMOS process up to -120 V
- Substrate: Low-Ohmic (80 Ωcm & 370 Ωcm)
- Diode: deep, reversed biased n-well
- Thickness: 50 µm or 70 µm (30 µm/50 µm depletion)

Challenges of Thinned Sensors:

- Warping
  - Increases handling damage
- Sub-surface cracks (SSC)
  - Increased leakage current
- Increased handling damage
  - Reduced yield
- Increase in leakage current if the depletion zone reaches the (SSC-) damage layer.



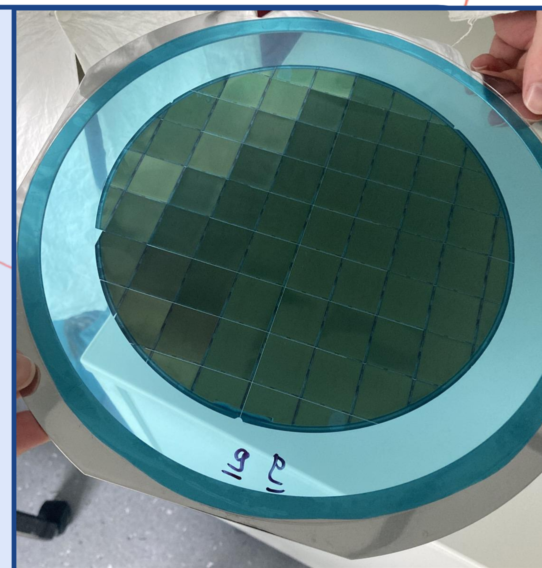
DOI:10.1016/j.precisioneng.2014.10.009

DOI:10.1115/1.4044417

High leakage current ⇒ Reduced SNR

The Quality Control Tests

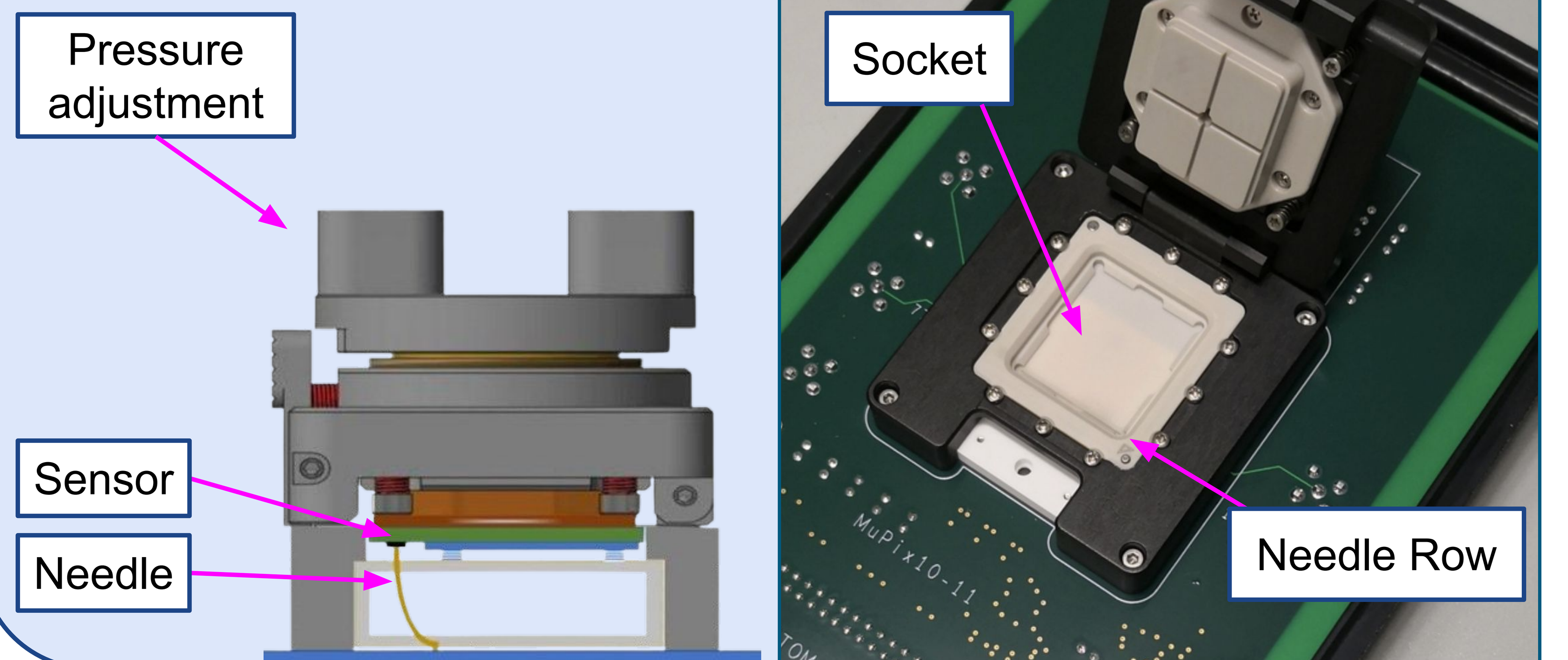
- Pre-installation functionality evaluation
- Five individual chip tests
- Each test evaluates an essential function
- All five tests must be passed for a sensor to qualify for installation



QC Test	Tested Function	Fail Criteria
IV Scan	Pixel biasing for good efficiency and time resolution	High leakage current at low depleted volumes
LV Power- On	Powering of key on-chip circuitries (amplifier, line driver, comparators, clocking, LVDS driver)	LV current not in functional range
Internal Voltages	Optimisation of the voltages supplied to the internal power grid	Incorrect voltages received
VDAC Scans	Ability to set key voltage DACs (amplifier, line driver, comparators, and selected baselines)	Unsuitable voltage or current response
LVDS Links	Data transmission	Errors (8b/10b) in transmitted data

The Quality Control Setup

- Single-chip probe card with a needle contact mechanism
- Fast, temporary and minimally invasive connection
- Light- shielded
- DAQ compatible with the final experiment



Probe card CAD (PTSL) | Probe card for MuPix11 QC (L. Vigani)

Preliminary QC Yield

Preliminary results: More data required!

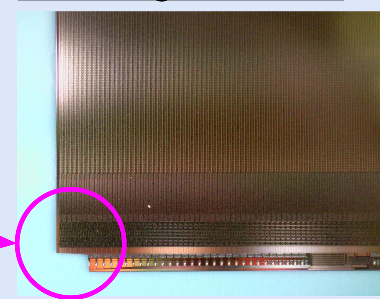
70 µm MuPix11

- **Yield: 66%**
- Most common failures:
  - Physical damage
  - VDACs
- **Differences to 50 µm:**
  - Fewer damaged sensors, fewer failures

    Thicker silicon layer

    ⇒ reduced handling/production damage?

A damaged sensor

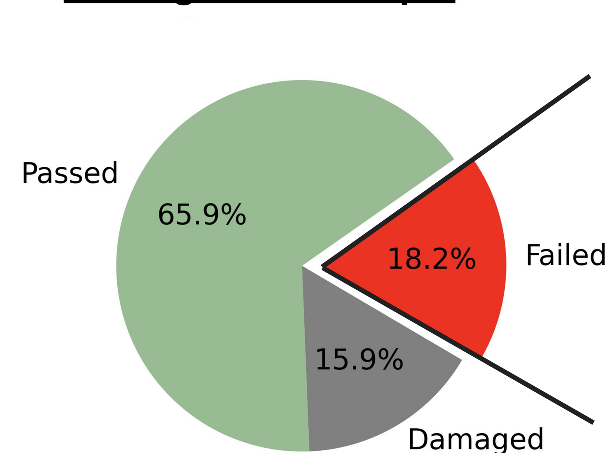


50 µm MuPix11

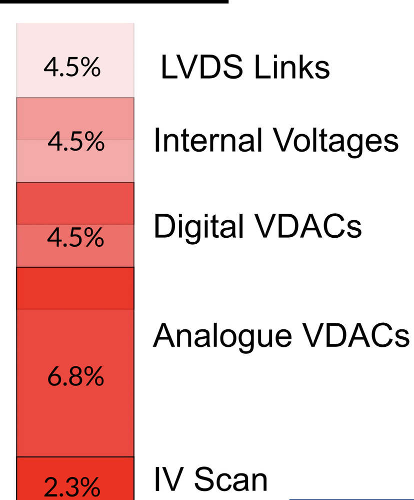
- **Yield: 50%**
- Most common failures:
  - Physical damage, High leakage current, LVDS
- **Differences to 70 µm:**
  - All tests show more failures
  - High increase in IV failures (high leakage currents)

    ⇒ Depletion zone reaches SSC damage region at low depleted volumes

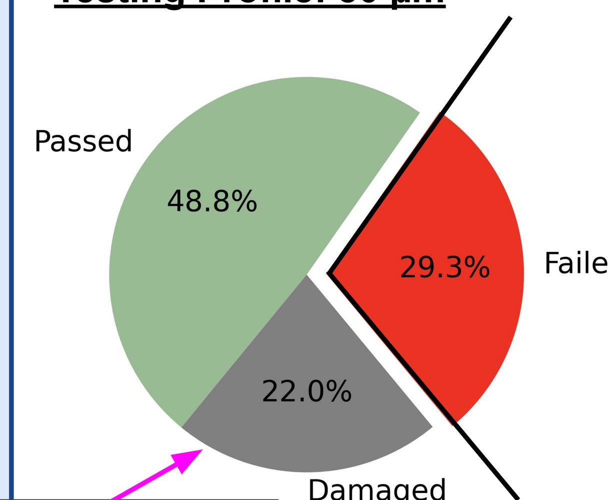
Testing Profile: 70 µm



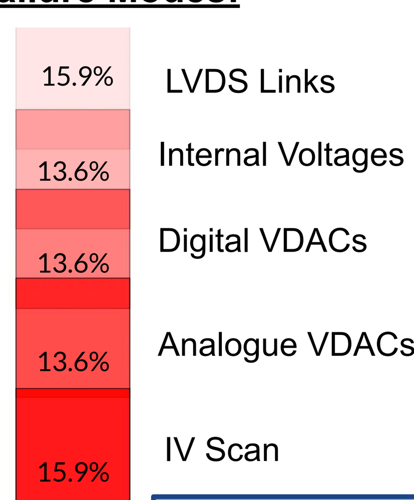
Failure Modes:



Testing Profile: 50 µm



Failure Modes:



Accuracy limited by microscope resolution

Sensors frequently fail multiple tests

Next Steps:

Optimisation of QC to reduce test duration

- ~ 5700 sensors to test (at 50% yield)

Vertex ladder production begins

- Installation of first verified MuPix11 sensors on ladders
- Development of a quality control procedure for ladders

Consider QC yield in production planning:

- 50 µm sensors: material advantage
- 70 µm sensors: higher yield

MuPix11 Ladder Production (T.Rudzki)

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

By Anna Lelia Fuchs,[1)] for the Mu3e Collaboration.

1) Institute of Physics, Heidelberg University, fuchs@physi.uni-heidelberg.de