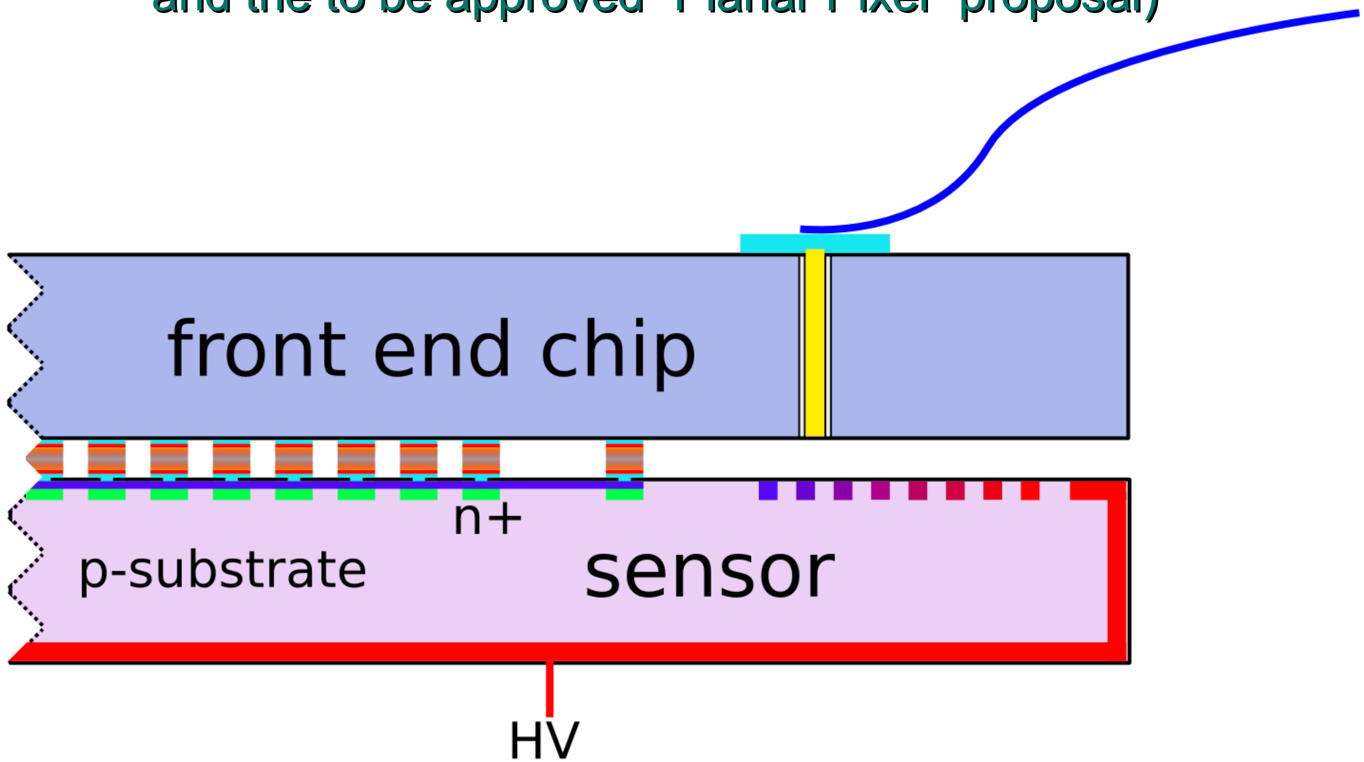
Thin Semiconductor Pixel Detectors for the SLHC

(In the framework of the approved "Thin Sensor" proposal ATL-P-MN-0019 and the to be approved "Planar Pixel" proposal)



GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
FSP 101 ATLAS

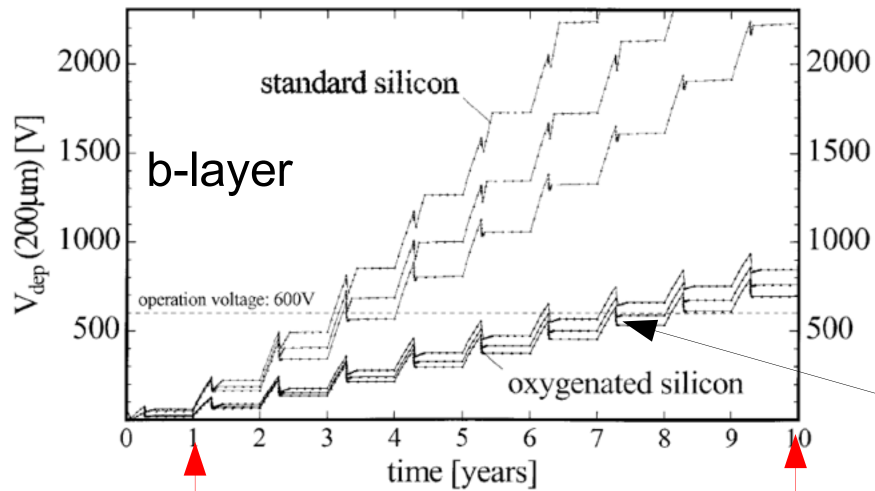
M. Beimforde, ATLAS MPI Meeting, September 15th 2008

Overview

- Motivation
- Concepts
- Ongoing work
- Summary

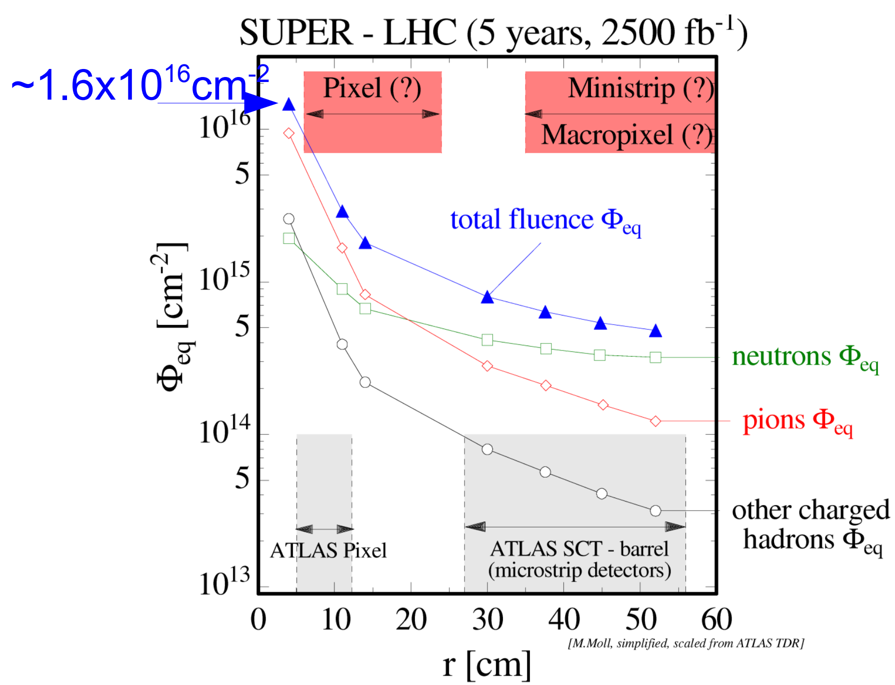
From LHC to SLHC

Voltage needed to get full sensor depletion (full signal):



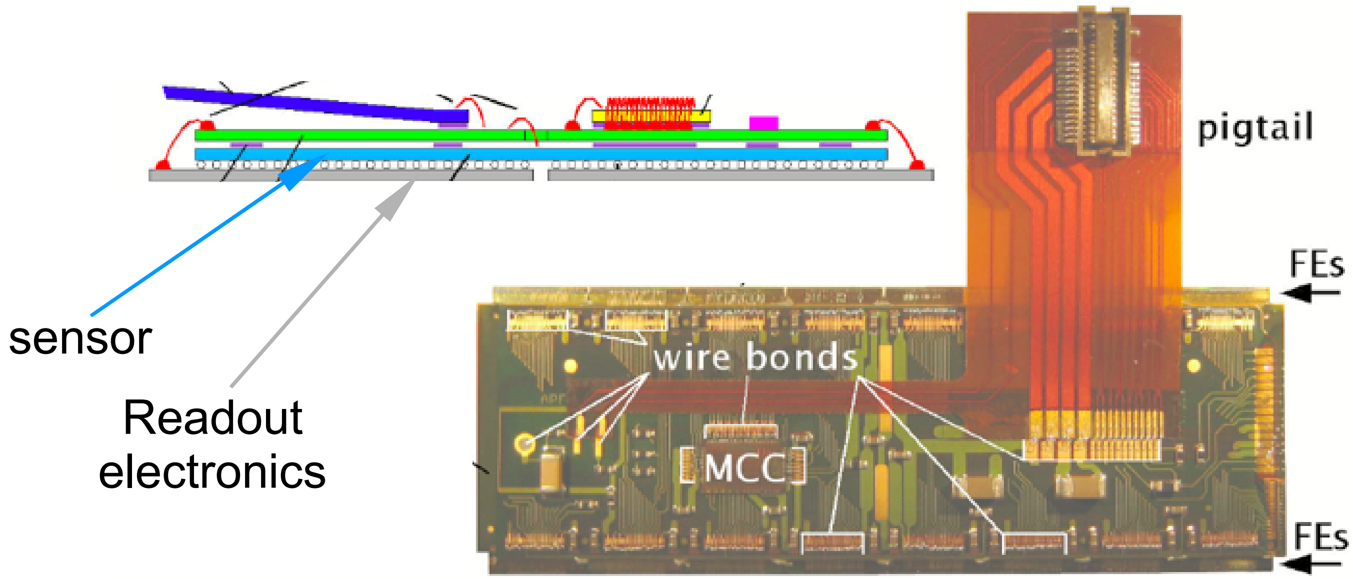
~3x10^{14}cm^{-2} n equiv. fluence ~3x10^{15}cm^{-2}

- **LHC:**
  - Start: Last Wednesday!!!
  - L=10^{34}cm^{-2}s^{-1} (not yet...)
  - Integrated Lumi. 500fb^{-1} (10 y)
  - ~3x10^{15}cm^{-2} 1MeV n_{eq} @ r=5cm
  - Multiplicity ~ 0.5-1k track / bunch crossing
  - Loss of signal after ~7 years due to crystal defects (therefore the b-layer might be replaced)



- **SLHC:**
  - Start: ca. 2018
  - L=10^{35}cm^{-2}s^{-1}
  - Integrated Lumi. 2500fb^{-1} (5 y)
  - ~1.6x10^{16}cm^{-2} 1MeV n_{eq} @ r=5cm
  - Multiplicity ~ 5-10k track / bunch crossing
- **New detector concepts are needed!**
  - Radiation hardness
  - Cope with high occupancy

The ATLAS Pixel Sensor



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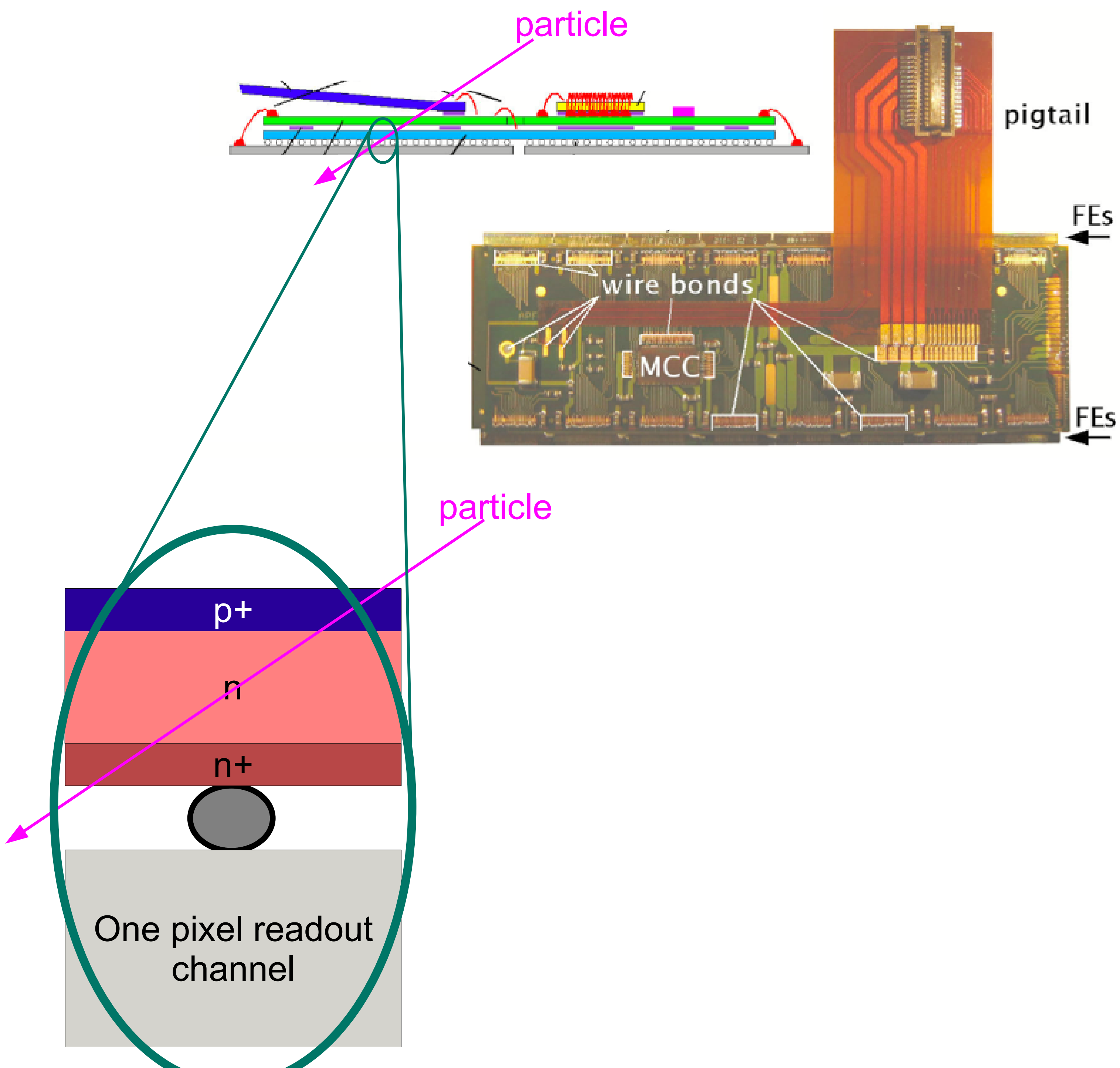

M. Beimforde

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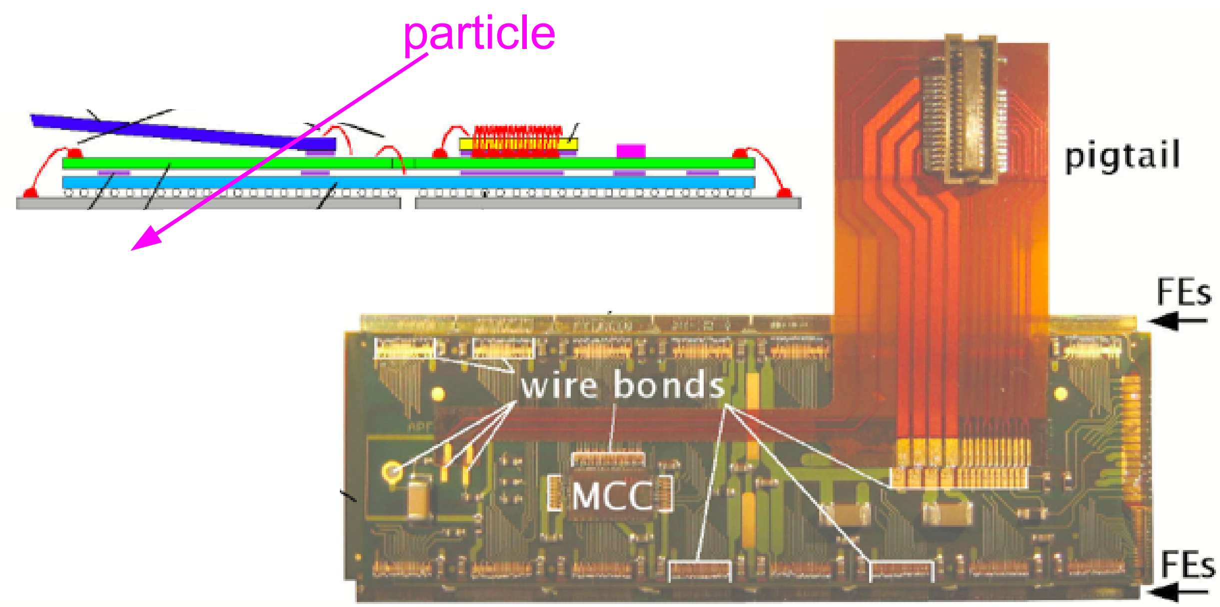
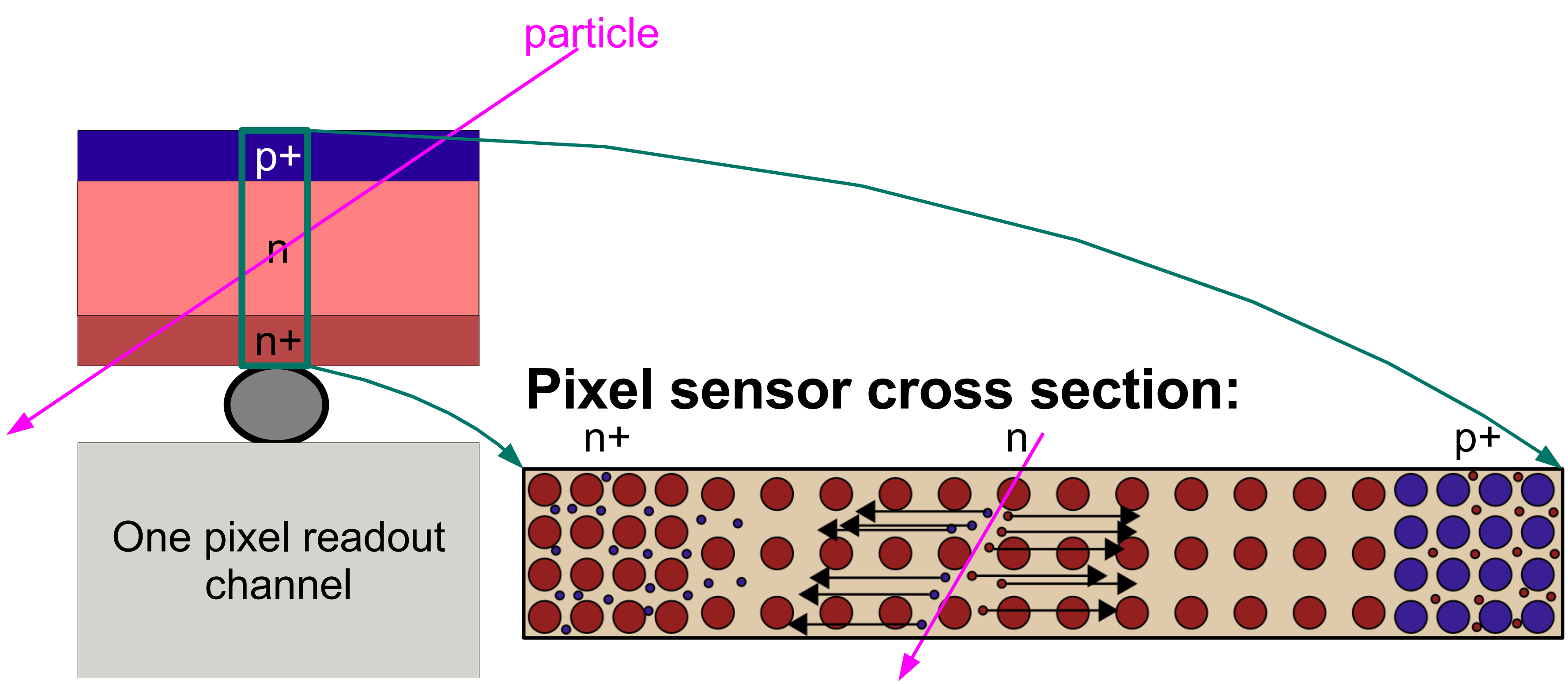
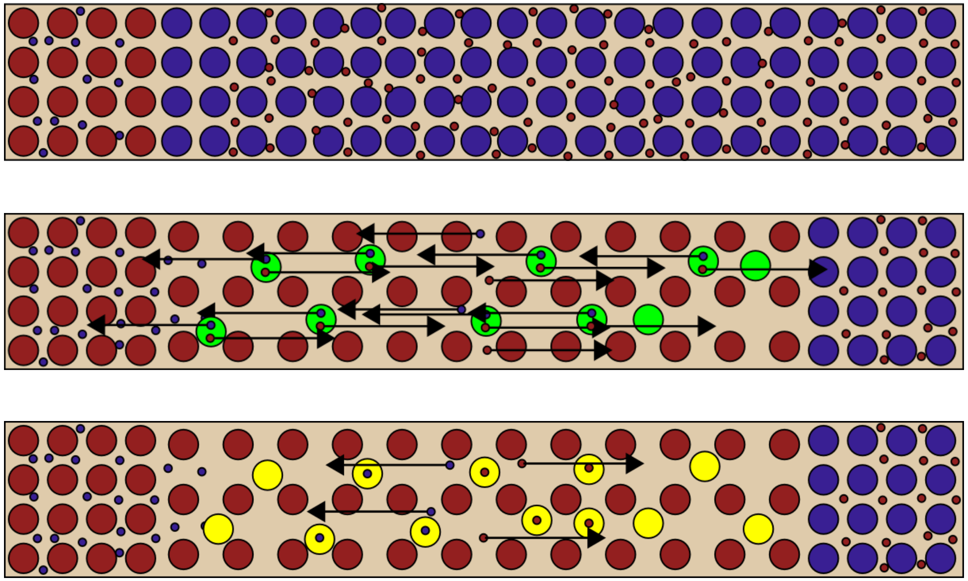




Radiation damage

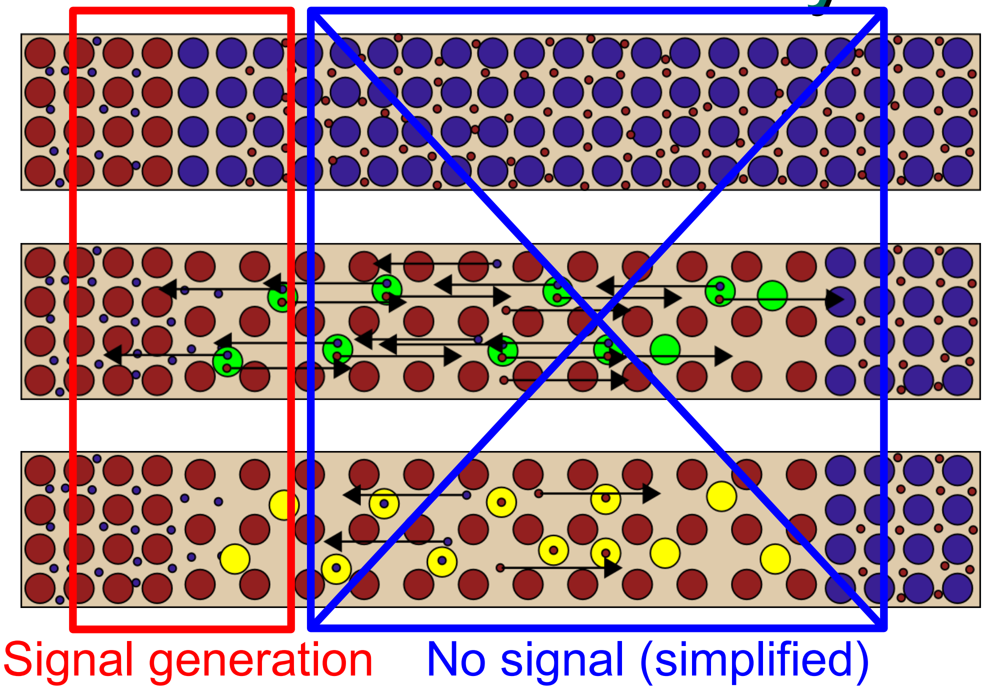
Problems caused by irradiation



- **Small space charge region:**
  - **OR** needs a **much higher voltage** for same depletion depth
  - More power consumption / heat / noise.
- **Generation centers:**
  - Higher leakage current -> noise!
- **Trapping centers:**
  - **Dominating** after SLHC fluences
  - Higher voltage does not help here!

- **How can we beat trapping?**
  - Make drift time shorter than effective trapping time (design for short drift distances!)

Problems caused by irradiation



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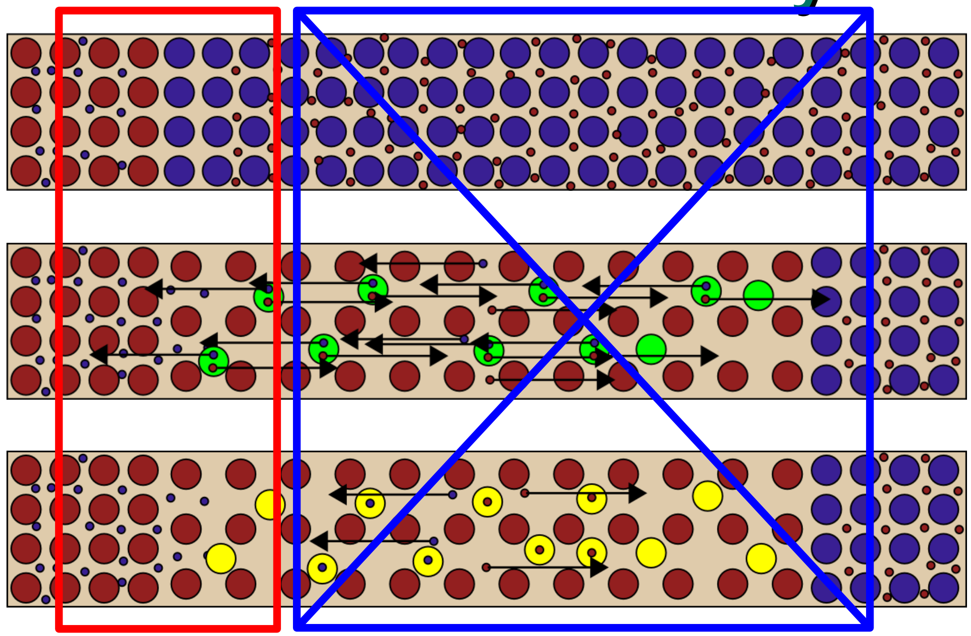

Signal generation   No signal (simplified)

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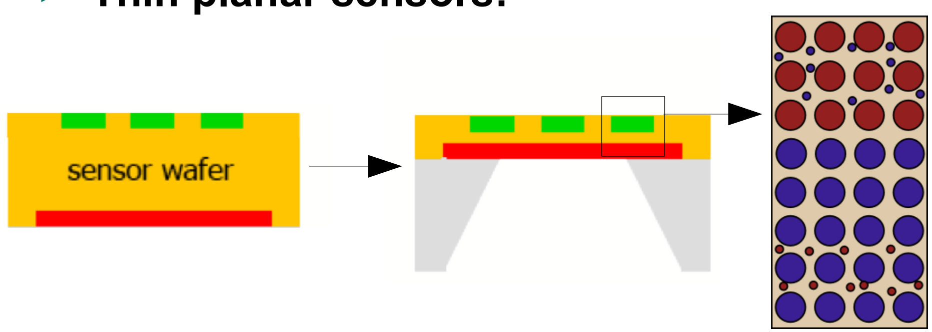
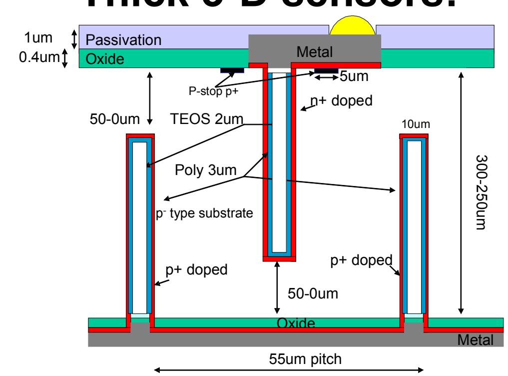
- **How to do this?**
  - **Thin planar sensors:**



- Small signal, relatively easy to build
- A little less multiple scattering

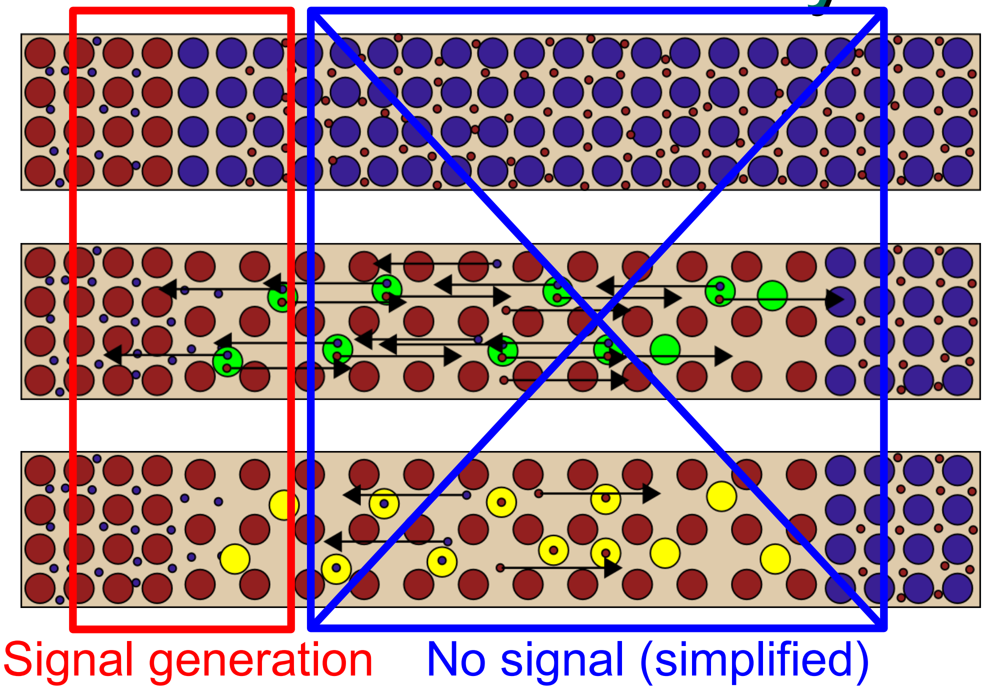
OR

Thick 3-D sensors:



- Large signal, more complicated to manufacture, expensive (only b-layer)

Problems caused by irradiation



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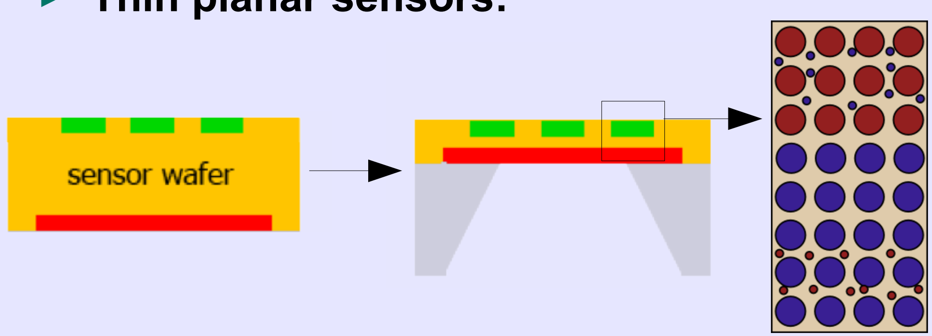
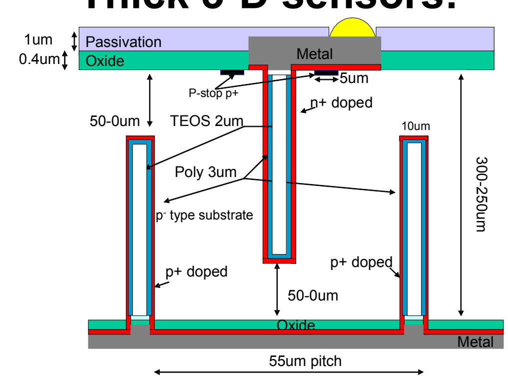


OR **Thick 3-D sensors:**

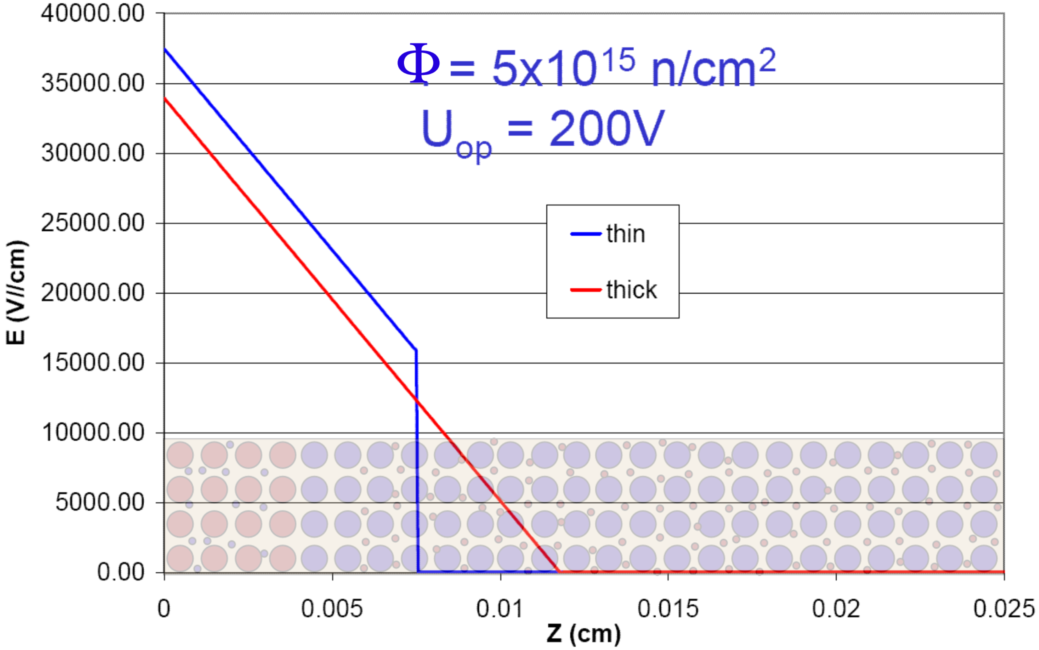


- **Our chosen approach (ATL-P-MN-0019)**
- Large signal, more complicated to manufacture, expensive (only b-layer)

Thin sensor concept

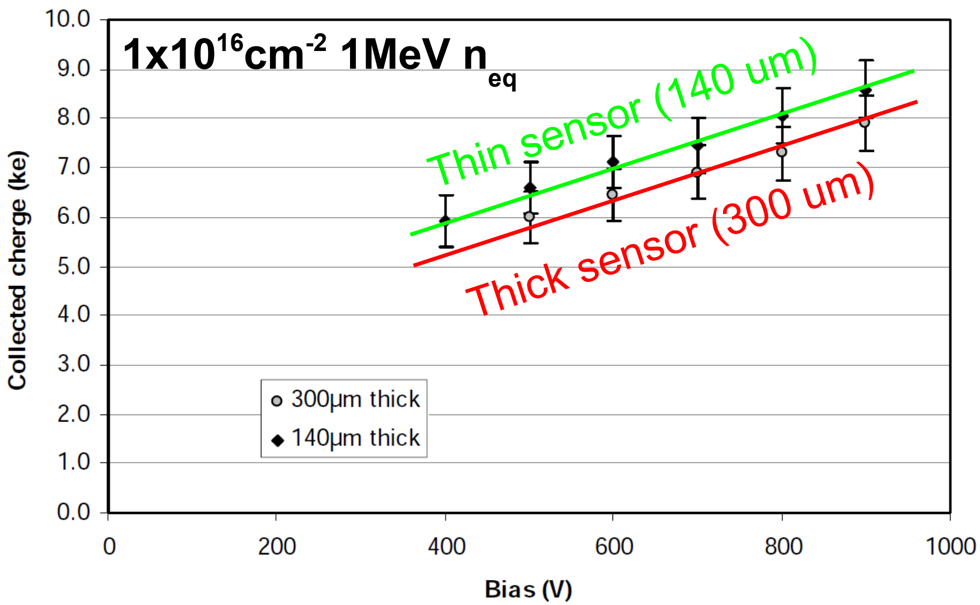
Signals from thin sensors

Calculations by Hans-Guenther Moser (HLL):



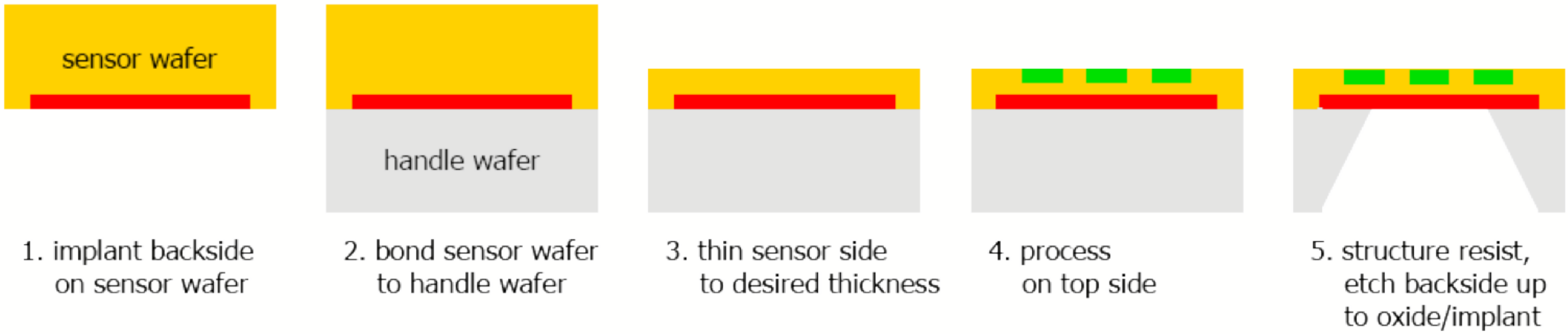
- **E-Fields in thin sensors:**
  - When applying the same bias voltage, a thin sensor shows higher fields over a shorter distance.
  - Charges are a little faster and the chance for trapping is smaller (shorter collection time).

Measurements by G. Casse (Liverpool):

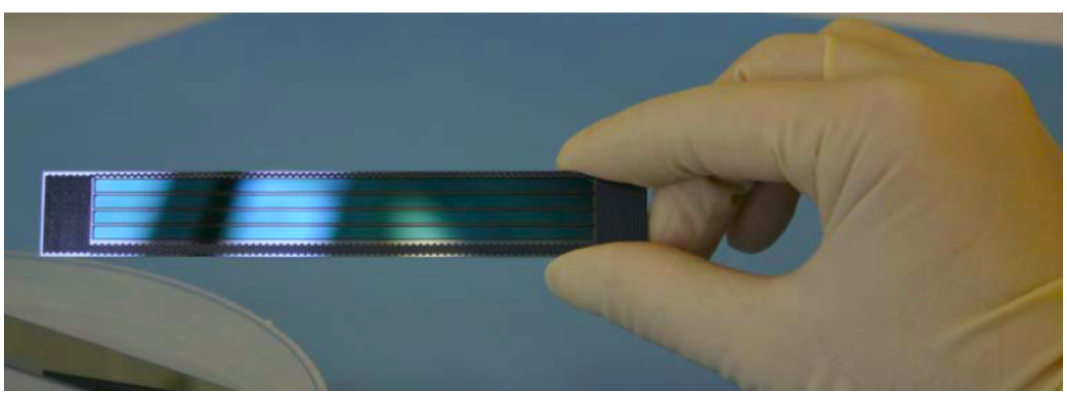


- **First measurements:**
  - Show a slight increase of collected electrons (signal) for thin sensors.
  - This needs to be confirmed with our sensors.
  - It's not much but maybe the best one can do for a reasonable price.

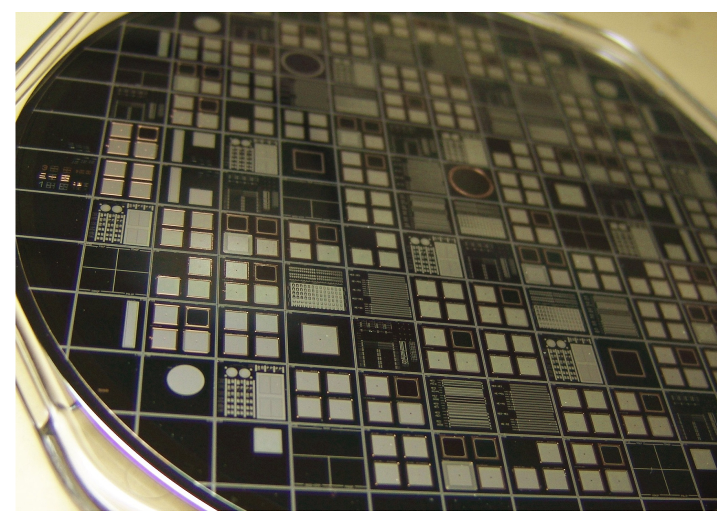
Thin sensor production



- The thinning process is established and prototypes confirmed the mechanical stability
- Thin diodes have been produced on handle wafers and measured



Dummies for mechanical stability tests (d=50 um, l=10cm)

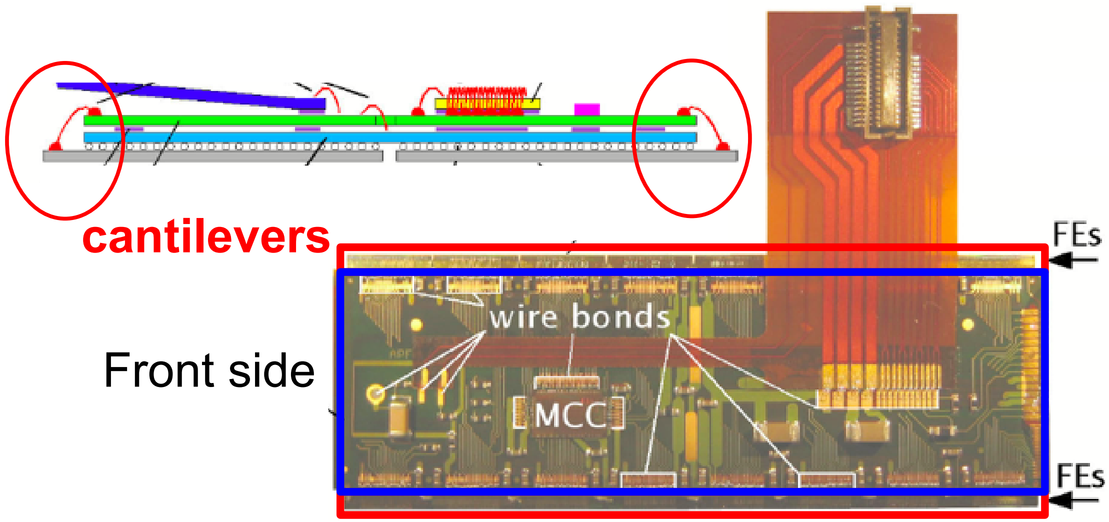


Thin diodes (d=50 um)

ICV-SLID
a new chip-to-sensor interconnection

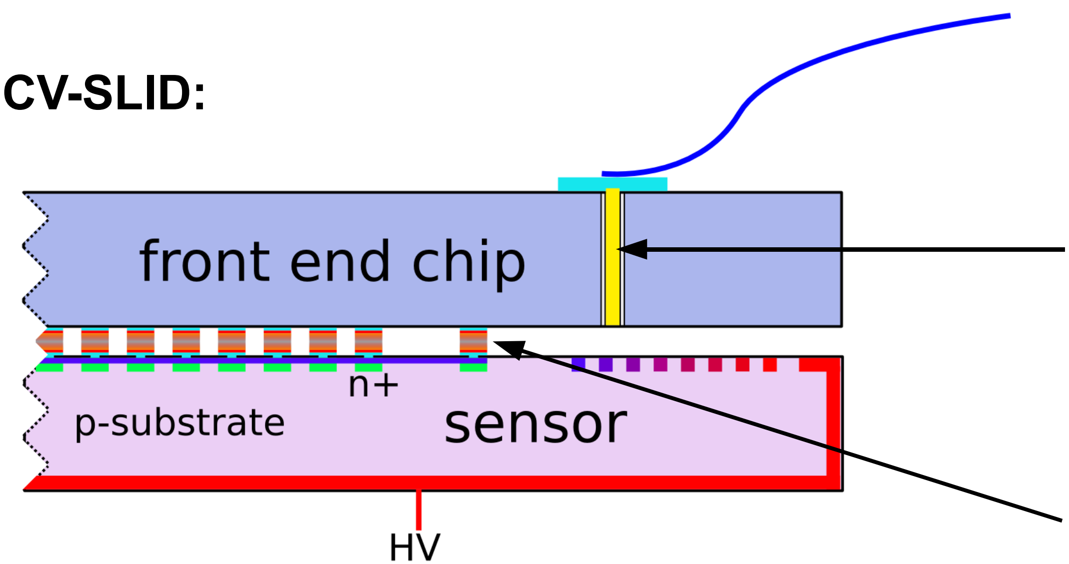
(Fraunhofer IZM Institut Zuverlässigkeit und Mikrointegration)

ICV-SLID – decreasing inactive areas



- Not the whole module area is sensitive.
- "Live fraction" is only 71%.
- A special problem are the wire-bonded FE chips that are larger than the sensors.

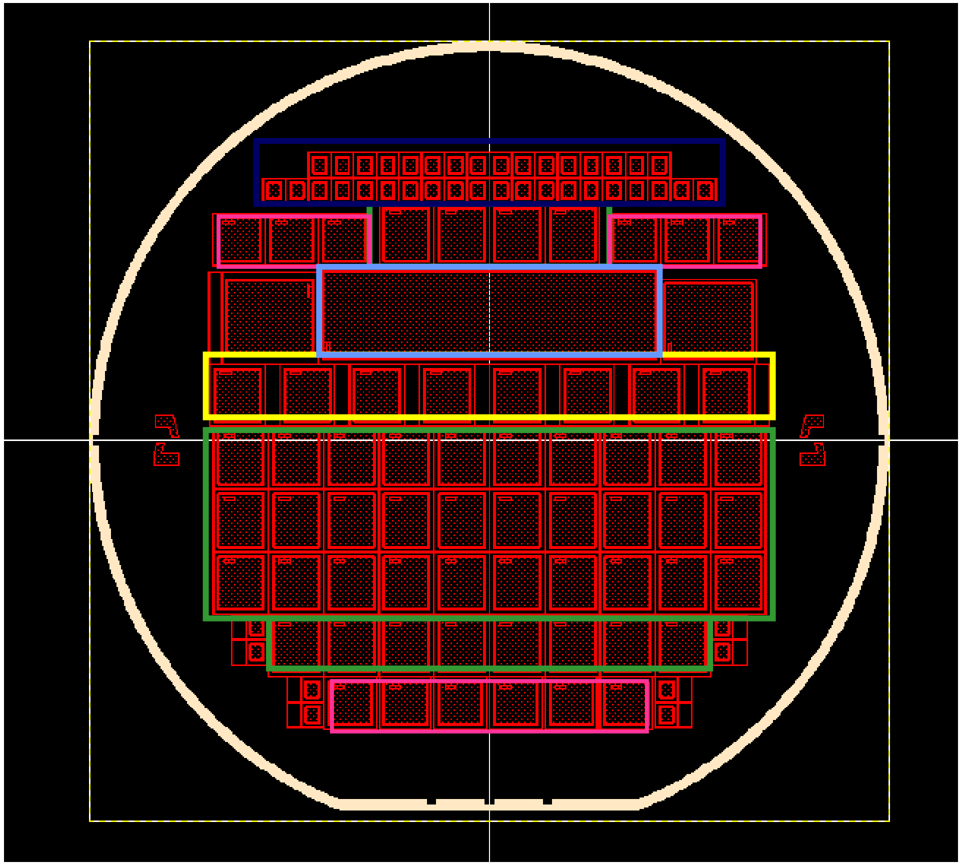
ICV-SLID:



- We try to facilitate a new technique to overcome part of this problem.
- **Inter chip vias (ICV)** allow for signal extraction from the back side.
- No cantilevers are needed!
- Replace the expensive bump balls with a new (cheaper!?) **Solid liquid inter diffusion (SLID)** interconnection.

Ongoing work (sensors)

Production of prototype wafers

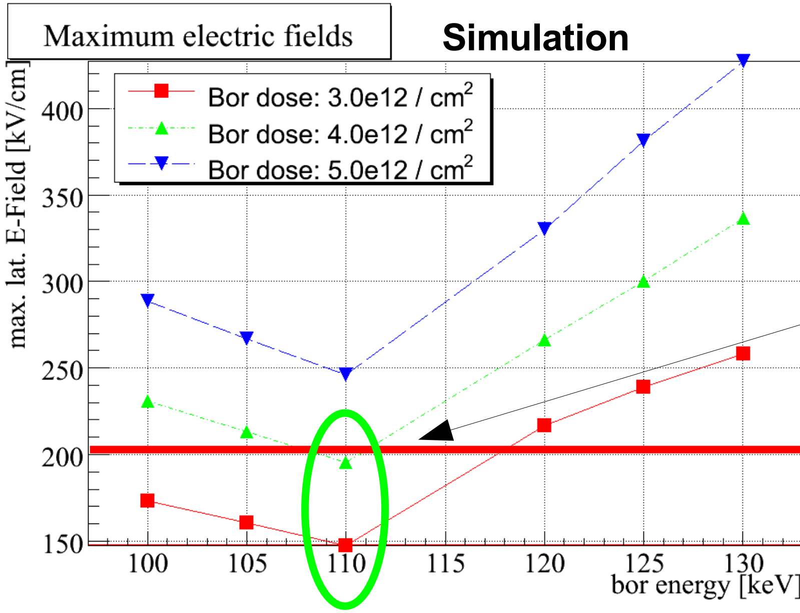


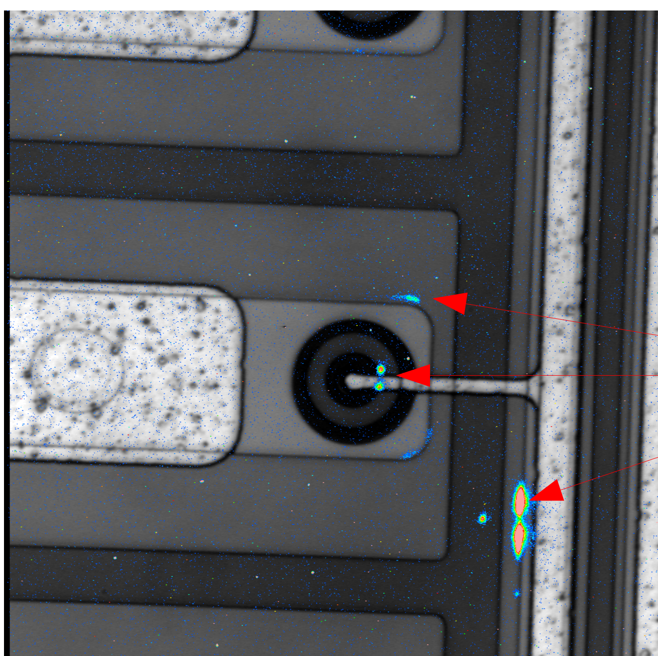
6” wafer

- 42 cells 10.5 x 11.9 mm² — 10 different micro-strips versions + test-structures
- 12 diode cells — 10.0 x 10.0 mm²
- 8 pixel cells – ATLAS geometry to be read out by a single FE chip – designed for SLID interconnection
- ATLAS module, to be connected to the FE with bump-bonding
- Pixel cells to be read out by a FE chip by INTERON (Norway)

- **12 different versions will be produced with different combinations of**
  - Thickness (75 and 150 um)
  - Isolation (good isolation vs. low electric fields)
  - Sensor material (n- and p-type bulk material)
    - P-type bulk allows for one sided processing (cheaper production)
  - Irradiation plans (first interconnect vs. first irradiate)

Inter pixel isolation

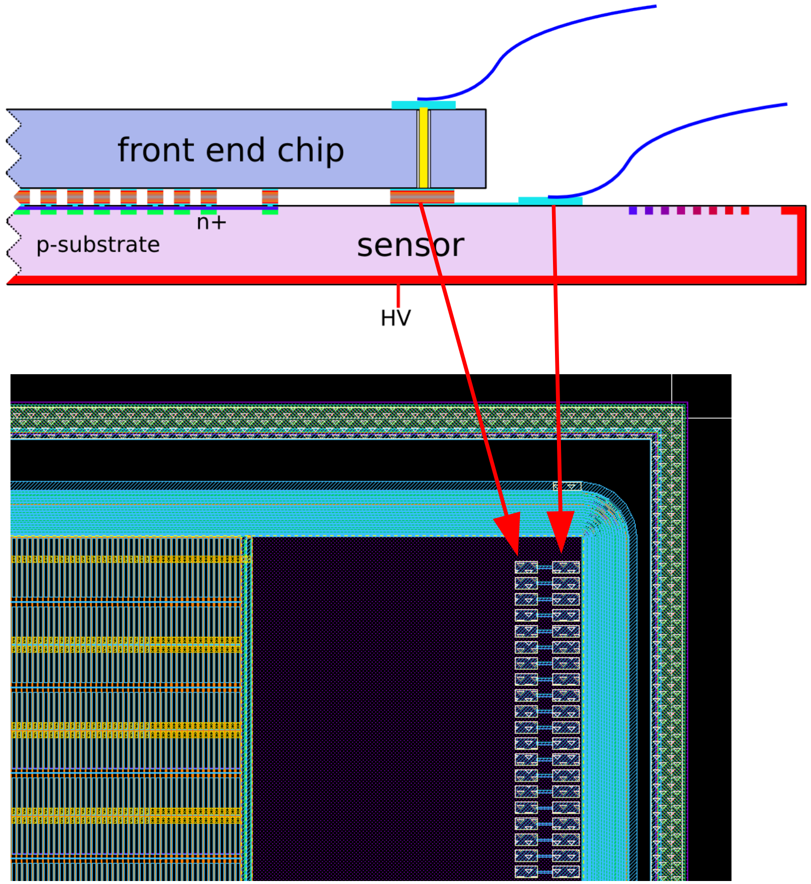




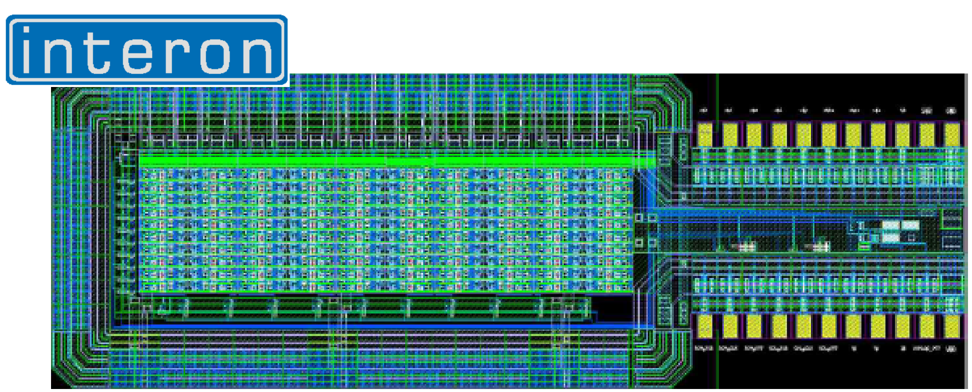
Bremsstrahlung from accelerated electrons show high fields

- **Inter pixel isolation:**
  - Is needed to prevent crosstalk between pixel cells.
  - Achieved through (partly moderated) boron implantations.
  - Needs to be balanced between good isolation and low electric fields (high isolation=high fields!).
- **Isolation simulations:**
  - Different isolation possibilities were simulated to derive the most promising parameters.
- **Electric field measurements:**
  - Were performed on p-type micro strip sensors produced by CiS following our design (used for isolation studies).
  - Showed some high fields due processing and design issues (misalignment, over etching, sharp corners).
  - Isolations showed no break throughs.
  - Final design for our production was adopted to these measurements.

Readout of the prototype sensors



ATLAS pixel sensor



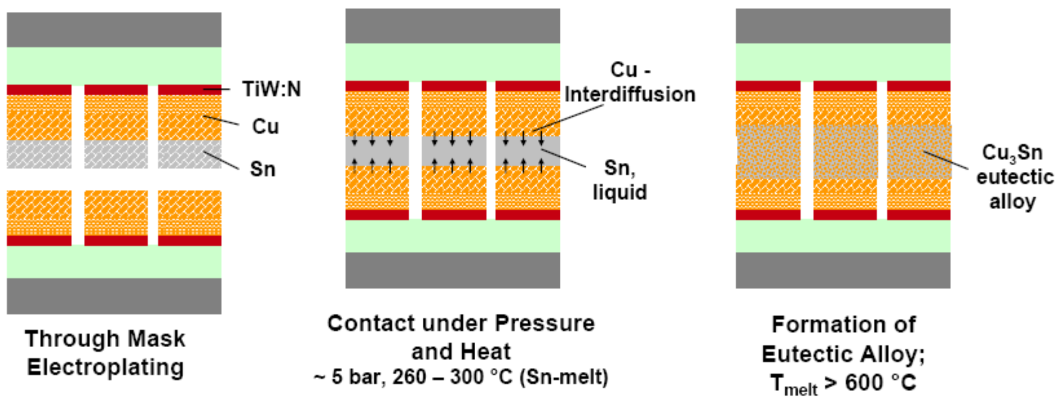
Custom made read out chip

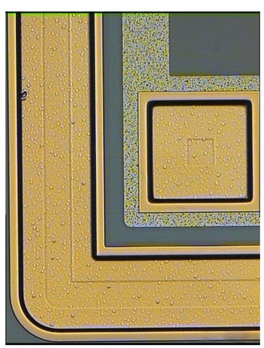
- **ATLAS pixel sensors:**
  - Standard ATLAS pixel sensors (single chip) with fanout structures
  - Possibility for ICV connection or conventional wire bonding
  - Chip-to-wafer SLID connections
  - Minimum feature size limited by the pick an place precision of SLID process
- **Sensors for custom made chips :**
  - Designed to test different pitches in combination with SLID
  - Chips developed together with Interon (Oslo, Norway)
  - Just analog electronics / readout

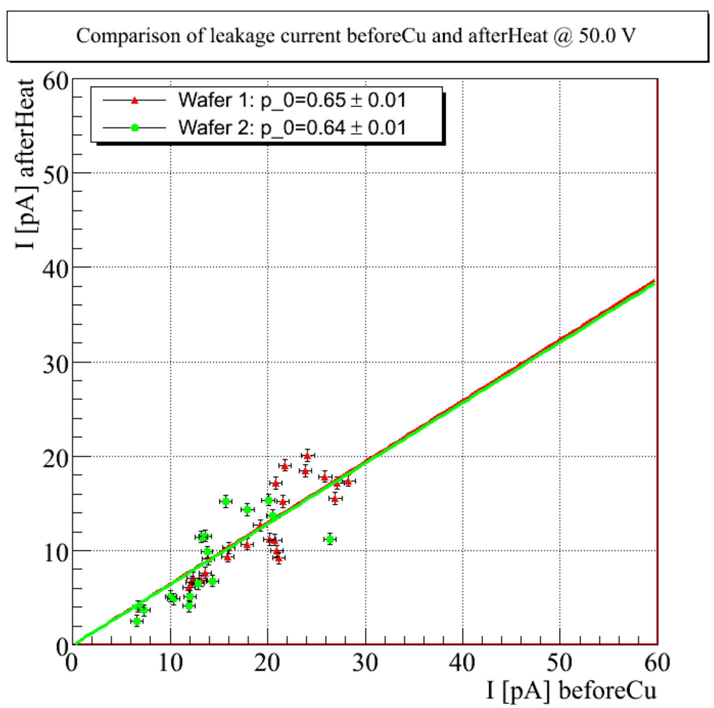
Ongoing work (ICV-SLID)

Testing SLID with thin diodes

Metallization SLID (Solid Liquid Interdiffusion)

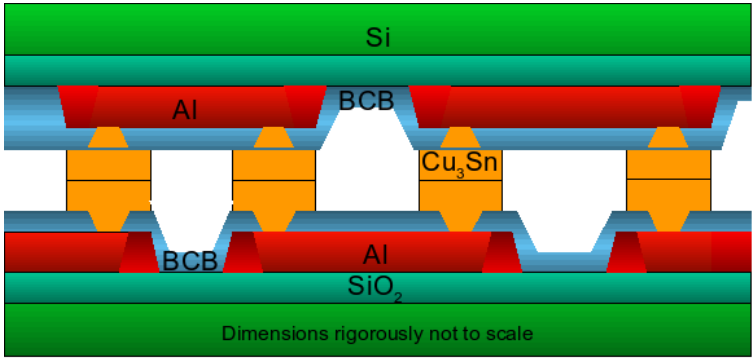






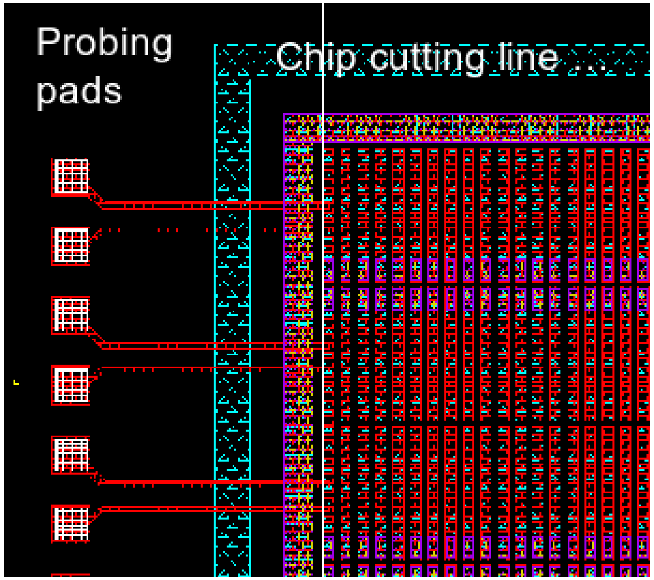
- **SLID processing:**
  - Copper and tin with correct stoichiometric concentrations are sputtered on the contacts
  - Top and bottom structures are aligned and brought in contact
  - Through pressure and heating an eutectic alloy is formed
  - This allows multi layer stacking because $T_{melt,Cu_3Sn} > T_{melt,Sn}$
- **Possible risks:**
  - Copper diffusing into the sensors would cause very high leakage currents which are unacceptable
  - Measurements of thin SLID like treated diodes show low leakage currents before and after heating
  - No copper diffused into the sensors while heating

SLID test structures

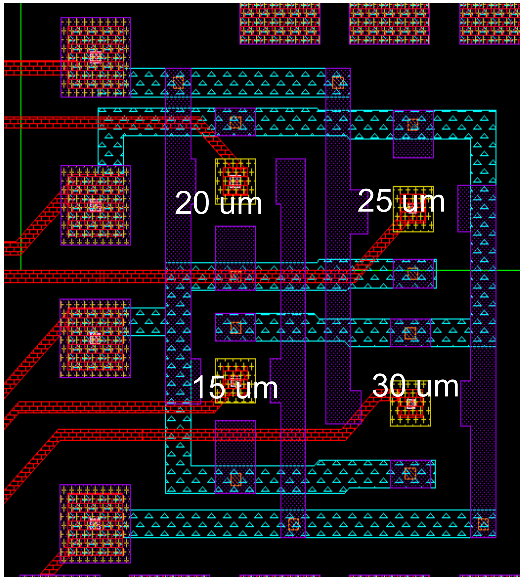


SLID testing w/ daisy chains

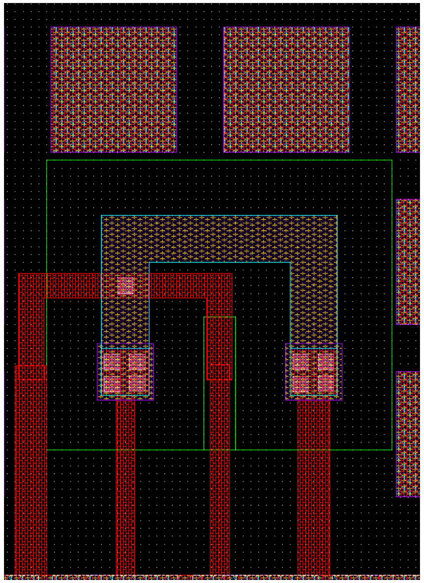
- **SLID test structures :**
  - Separate production
  - Testing of:
    - SLID interconnection (daisy chains)
    - Mechanical stability
    - Pick and place precision
    - Resistance of SLID connections



Daisy chains



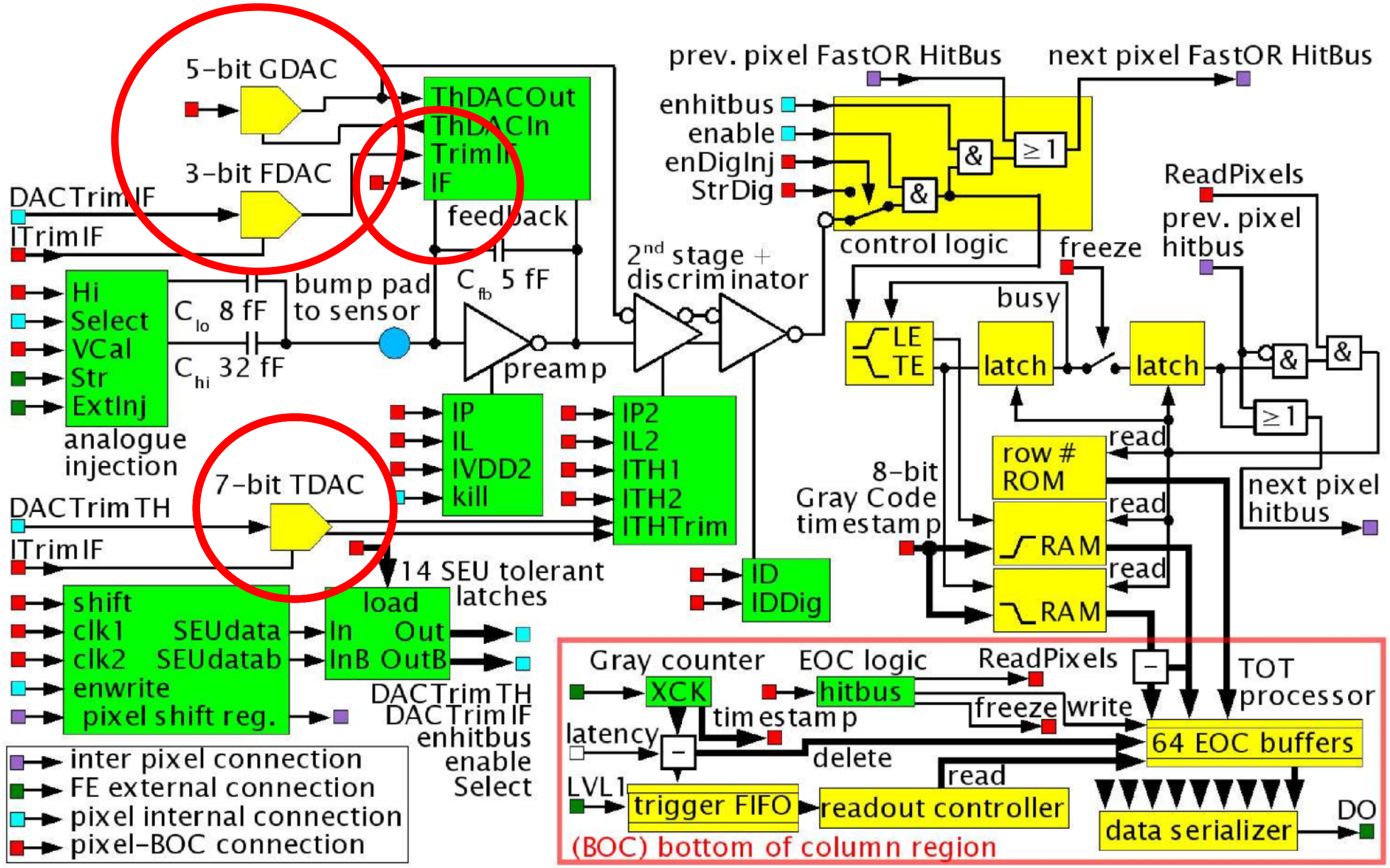
Test pick and place precision



Test resistance of SLID

Ongoing work (electronics)

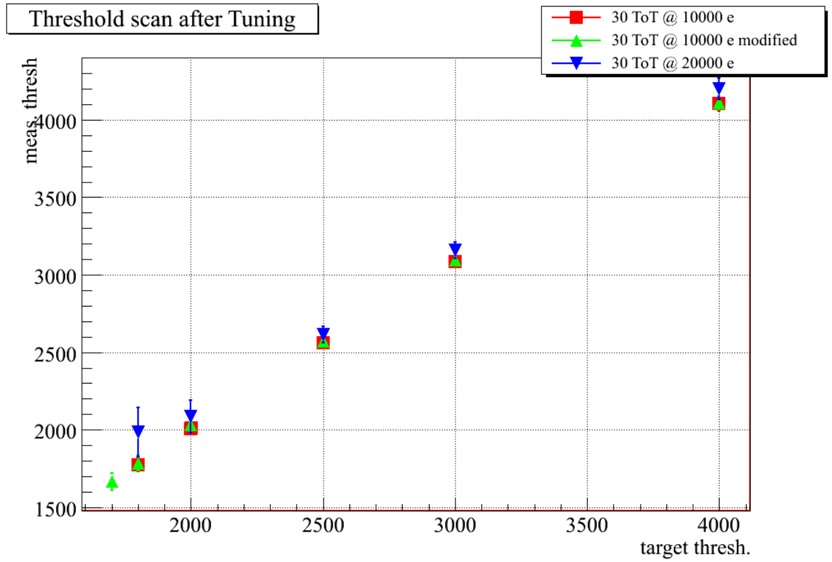
Electronics optimization



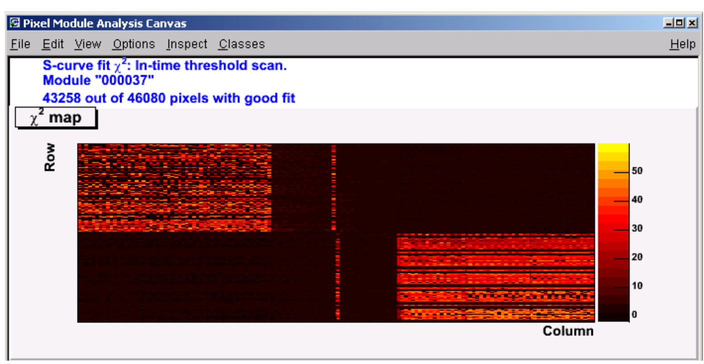
Pixel channel readout scheme

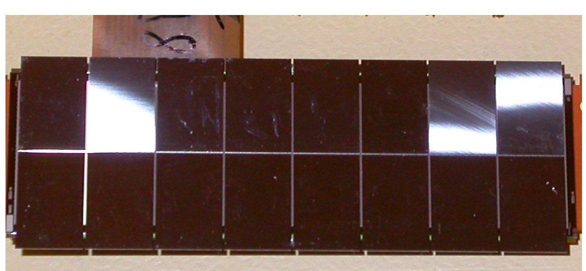
- **Dealing with smaller signals :**
  - The present ATLAS FE-I3 readout chip can be tuned to different working conditions
  - Several DACs allow to lower the threshold to some extend
  - The tuning procedure was optimized for low threshold tunings

Electronics optimization



Tuning to lower thresholds





Fail-pattern observed on three different modules

- **Tuning results:**
  - Tunings from the standard 4000e down to 1800e were performed.
  - At around 2000e noise hits start to dominate and tuning fails.
  - The optimized tuning procedure shows better results for low threshold tunings.
  - A similar “fail-pattern” was seen for all three different modules that were tested.
  - I.e. the FE-I3 seems not to be the most critical component.
  - Either the signal routing or the Module Control Chip (MCC) might cause this pattern.
  - May hint at a good starting point for low threshold hardware optimizations.

Summary

- Developing a pixel detector for the SLHC requires to employ new concepts of semiconductor detectors.
- Radiation damage will decrease the drift distance.
- The sensors thickness can be optimized to maximize the collection efficiency.
- Thin sensors will be interconnected to readout electronics using the new ICV-SLID technology.
- Copper diffusion barriers have been validated to work.
- More ICV-SLID test structures are on their way.
- Electronics are being tuned to smaller signals of thin sensors.