# Thin Irradiated Strip and Pixel Detectors

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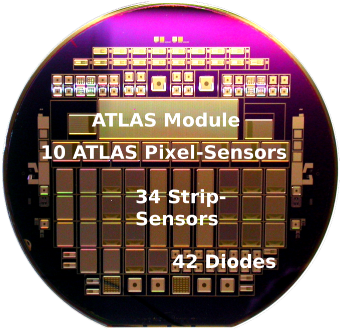
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

In collaboration with
Fraunhofer
EMFT

# Thin Pixel Production at MPP/HLL

$8 \times 6''$ Wafer



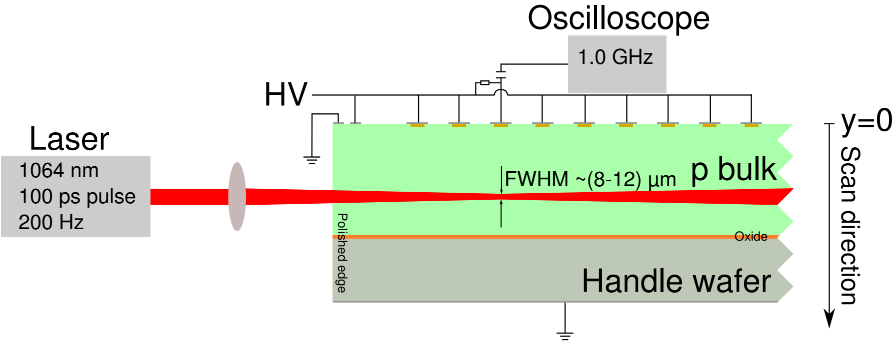

- 4 wafers of 150 µm and 4 wafers of 75 µm active thickness (on handle wafer)
- Proton & neutron irradiations with fluences up to $10^{16}\,n_{eq/cm^2}$ at
  - KIT (25 MeV protons)
  - CERN PS (24 GeV protons)
  - Lubljana (reactor neutrons)


1. Implant backside on sensor
2. Bond sensor wafer to handle wafer
3. Thin sensor side to desired thickness
4. Process on top side
5. Structure resist, etch backside up to oxide

# edgeTCT Measurements

# EdgeTCT Setup & Devices

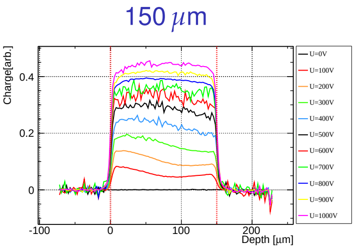
Measurements with edgeTCT setup in Ljubljana were performed.
Aim: Learn more about the charge collection behaviour for these thin devices.

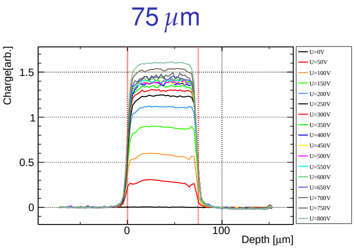


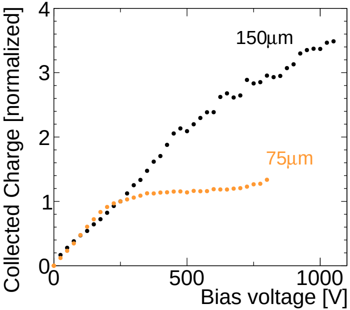

Used Sensors: Strip sensors with 75 $\mu$m & 150 $\mu$m active thickness, irradiated with reactor neutrons to $\Phi = (0, 5, 10) \cdot 10^{15}\, n_{eq}/cm^2$.

– Thanks to: Gregor K. and Marko Milovanovic

# EdgeTCT Measurements (5e15)



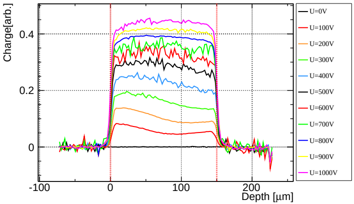



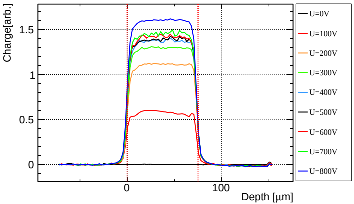

- 150 $\mu$m: Depleting from front side. Above 500 V <Q> almost homogeneous.
- 75 $\mu$m: From start homogeneous ($\rightarrow$ simulation)
- No clear multiplication signal

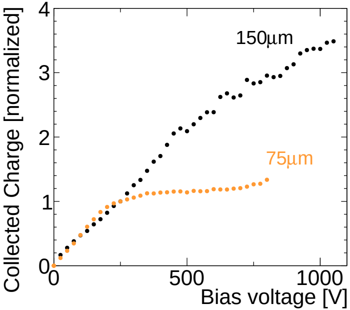
# EdgeTCT Measurements (5e15)

150 $\mu$m




75 $\mu$m

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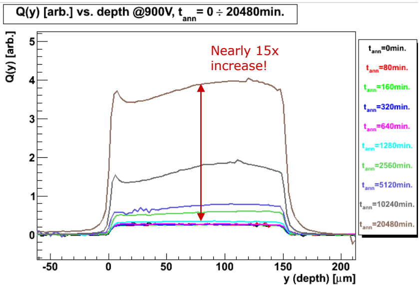
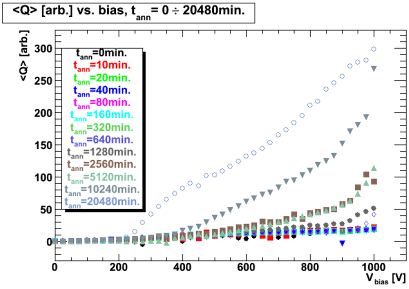
# MPP/HLL – $\Phi_{eq}=5\cdot10^{15}$ n/cm$^2$, $t_{ann}=0 \div 20480$min (150 μm)

Thanks to: Philipp Weigell and A. Macchiolo, MPI




- Initial $V_{fd}\approx$82V.
- Estimated $V_{fd}$ after irradiation and 80min of annealing: ~1500V.
- Charge multiplication contribution to CC ~15x after 20480min! (the detector still under study – currently annealing to 40960min!)
- Charge multiplication noticed even at 250V after the final annealing step!

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(150 μm)

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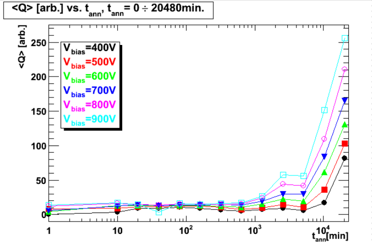
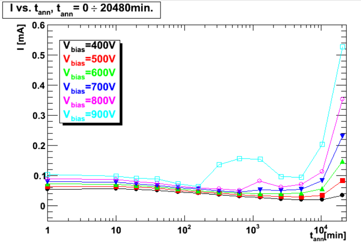
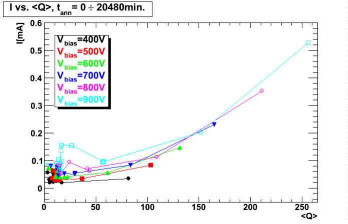
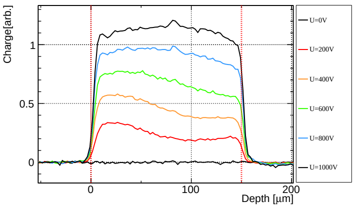


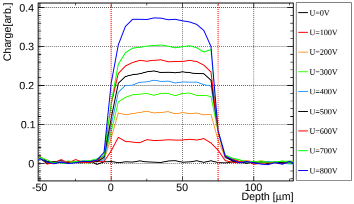



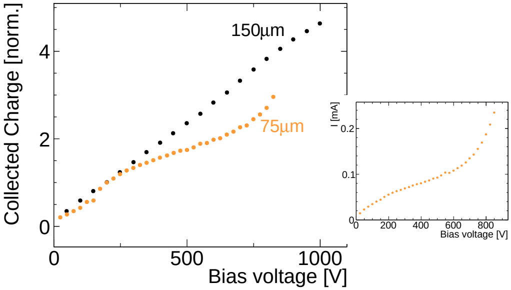
# EdgeTCT Measurements (1e16)

150 $\mu$m




75 $\mu$m



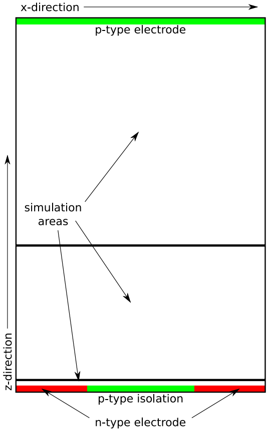




- 150 $\mu$m: Depleting from front side. Above 700 V <Q> almost homogeneous.
- 75 $\mu$m: From start homogeneous ($\rightarrow$ simulation)
- Increase of slope above 700 V for 75 $\mu$m thick sample, reflected in IV

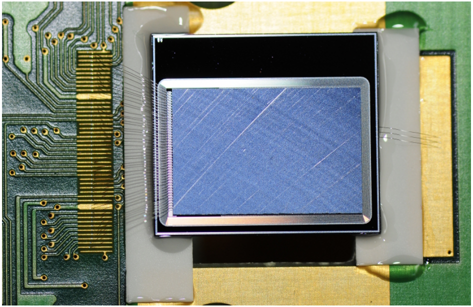
# EdgeTCT Simulation (Plan)

Plan: Simulate the edgeTCT measurements

- Simulation-packet: TOSCA
- 2-Dimensional
- Implantation profile simulated with DIOS
- Solving the coupled differential system of the Poisson equation and the continuity equations for electrons and holes
- Possibility to create a spatially confined charge cloud (Gaussian profiles)



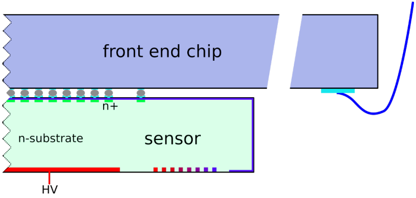

At the moment still simulating the not irradiated devices—stay tuned.



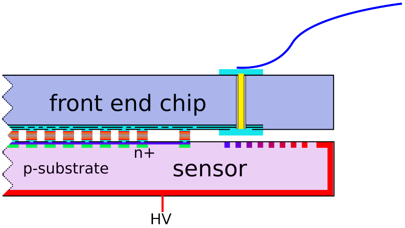
# SLID Module Measurements

# Our Pixel Module Concept

## Present design



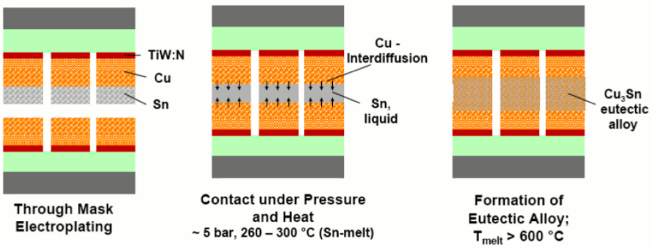

## Thin sensors + ICV-SLID




## Four new technologies

- N-in-p bulk material
  - Cost reduction
- Thin sensors (MPP-HLL process)
  - Higher signals after irradiation
  - Less multiple scattering
  - Lower occupancy
  - Better resolution
- SLID: Solid Liquid Inter-Diffusion
  - Allows for vertical integration/separation of analogue and digital parts (with ICV))
- ICV: Inter-Chip-Vias
  - More compact: „balcony“ for signal-extraction not needed
  - Enlargement of active area

# SLID: Solid Liquid Inter-Diffusion




Alternative to bump bonding

## Pros

- Allows for vertical integration ($T_{melt}$).
- Arbitrary geometries possible and smaller pitches.
- Less process steps → lower cost.
- Wafer to wafer and chip to wafer possible.
- Strength: 0.01 N per connection

## Cons

- Planarity of 1 $\mu$m needed.
- No rework possible
- Chip-to-chip not possible at the moment
- Homogeneous pressure needed

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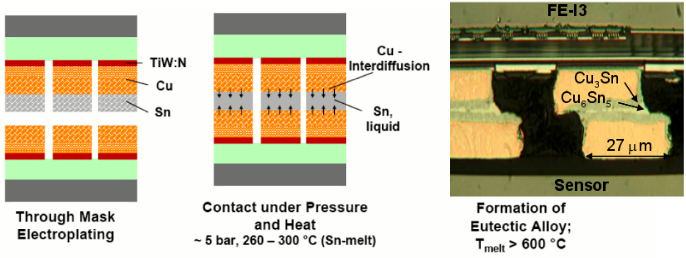


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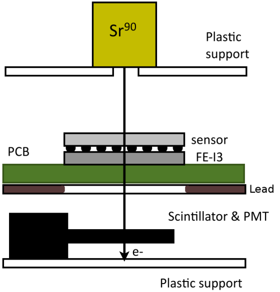
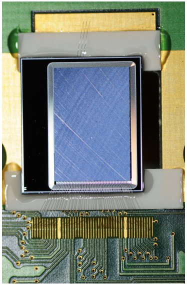
**Cons**

- Planarity of 1 μm needed.
- No rework possible
- Chip-to-chip not possible at the moment
- Homogeneous pressure needed

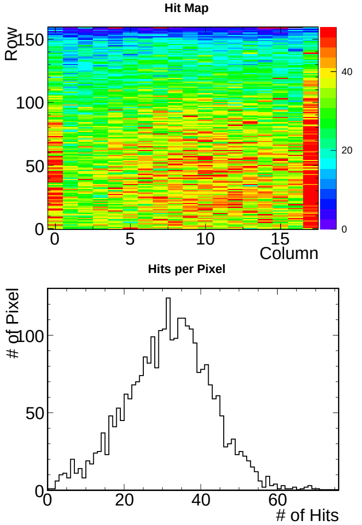
# Source Measurements

- Six assemblies with 75 $\mu$m thick sensors built.
- $^{90}$Sr and $^{241}$Am sources are used to to determine the charge collection.
- External trigger via scintillator (for $^{90}$Sr) and internal chip trigger (for $^{241}$Am).



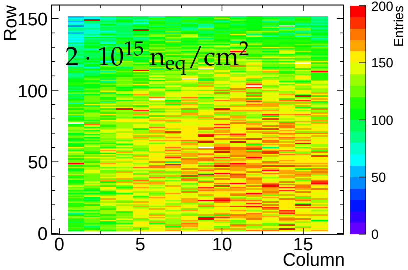
## Example SLID 10, 250 k events



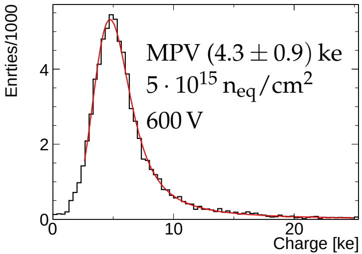
# Charge Collection after Irradiation

- Irradiations
  - Ljubljana: $(2\,\&\,5)\cdot 10^{15}\,n_{eq}/cm^2$
  - KIT: $6\cdot 10^{14}\,n_{eq}/cm^2$
- Tuned threshold of (2500–3500) e, Noise of 170 e
- Full charge recovered for all fluences
- All channels conencted after irradiation, thermal cycles

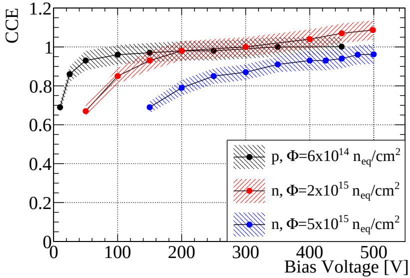
## Hitmap




## $^{90}$Sr Measurement

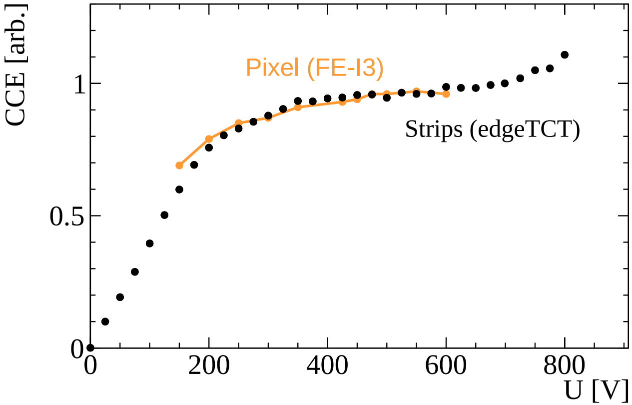



## CCE



# Pixel vs. Strip Measurements

For 75 $\mu$m at $5 \cdot 10^{15}\ n_{eq}/cm^2$ data obtained with both methods is available → very good agreement in the shape.

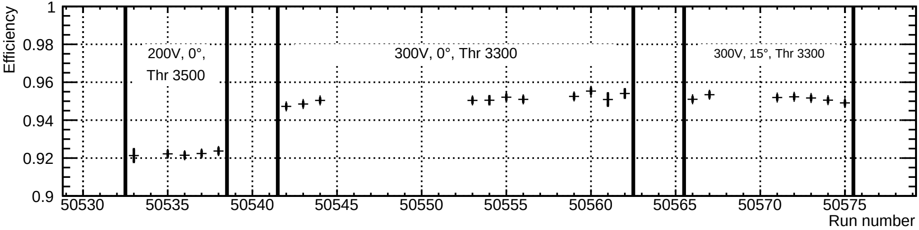



No absolute scale known for edgeTCT measurements → rescaled for comparison.

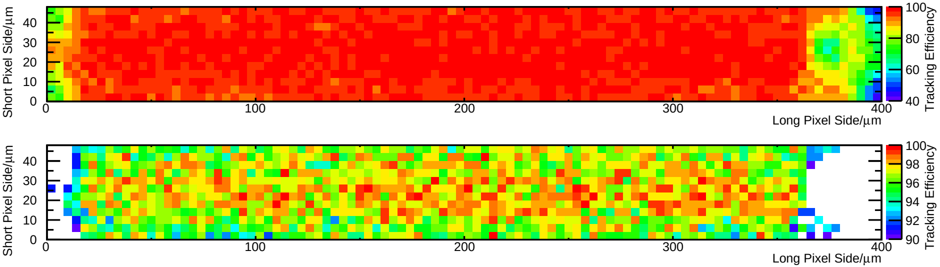
Plan: Send pixel sensor for irradiation to $10^{16}\ n_{eq}/cm^2$.

# Beam Test Measurements

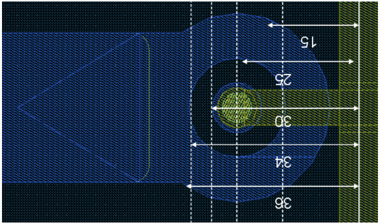
- Irradiated: KIT $6 \cdot 10^{14}\,n_{neq}/cm^2$.
- Challenge: FE-I3 was not designed for low thresholds! Solution: FE-I4 ($\rightarrow$ See Anna's talk)
- Two thresholds & voltages: Clearly seen in the data.
- Overall efficiency for second tuning at 95 %. Main effect high threshold. Central region has higher efficiency (next slide).
- No improvement due to 15°, since longer trajectory is compensated by more pixels below threshold.



# Beam Test Measurements - Explanations




- Lower efficiency in the punch through and corner regions due to implant structure.
- Efficiency in the main pixel region ∼97.2 % MPV for the charge 3.8 ke, threshold of 3.3 ke.
- Tuning to lower thresholds not possible due to disconnected channels



# Summary & Plans

## Summary

- Charge collection measurements for 75 $\mu$m and 150 $\mu$m thick sensors irradiated up to $10^{16}$ $n_{eq}/cm^2$.
  - 75 $\mu$m and $5 \cdot 10^{15}$ $n_{eq}/cm^2$
    - Saturation above $\sim 300\,V$
    - Absolute measurement indicates that CCE after saturation is $\sim 1$
    - No clear sign of multiplication below 800 V
  - 75 $\mu$m and $10^{16}$ $n_{eq}/cm^2$
    - Rise of signal above 700 V
  - 150 $\mu$m
    - No saturation found up to 1000 V
- Efficiency challenged by high thresholds of FE-I3 $\rightarrow$ solved by FE-I4

## Plans

- Extend beam test measurements and analysis
- Simulate edgeTCT measurements