Recent Progress of the ATLAS Upgrade Planar Pixel Sensor R&D Project

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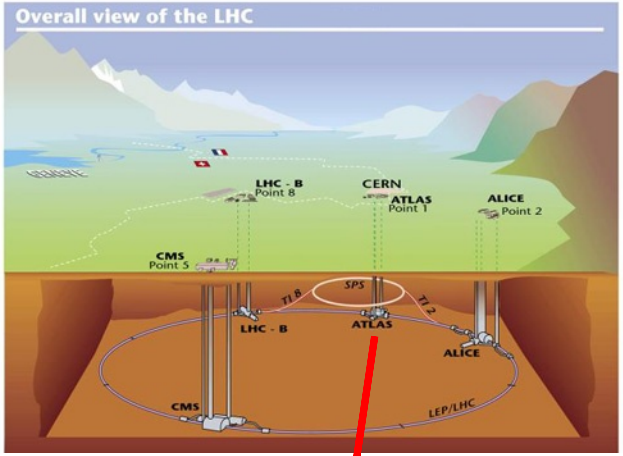
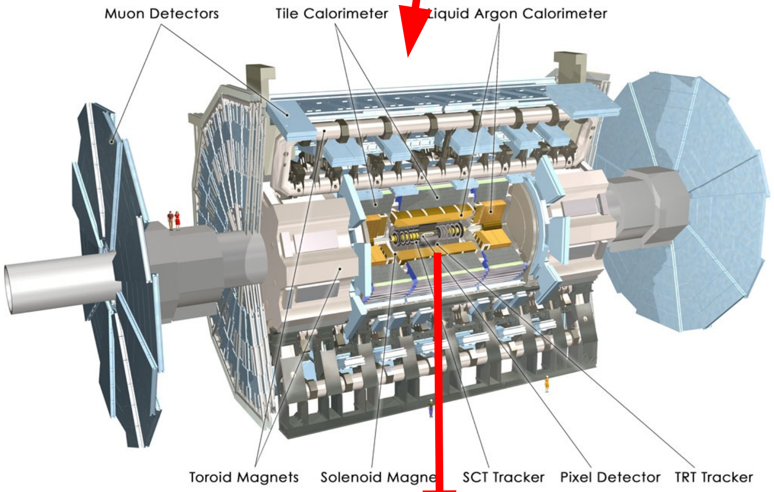
for the ATLAS PPS Upgrade Collaboration

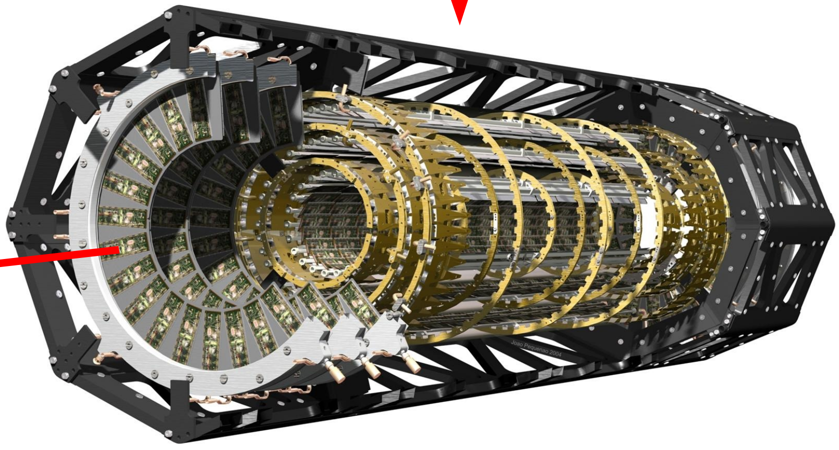
GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

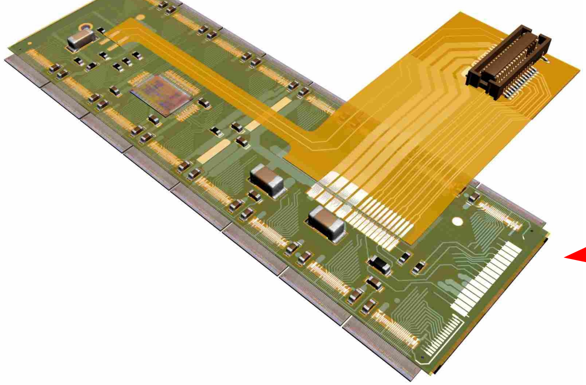
Overview

- the LHC at CERN is the largest particle accelerator
  - length of 27km
  - energy up to 7+7 TeV
- the ATLAS detector is one of the four large experiments
- its pixel detector is the innermost part of the tracking system
  - three layers surrounding the interaction point
  - 3 +3 endcap discs
  - consists of 1744 modules



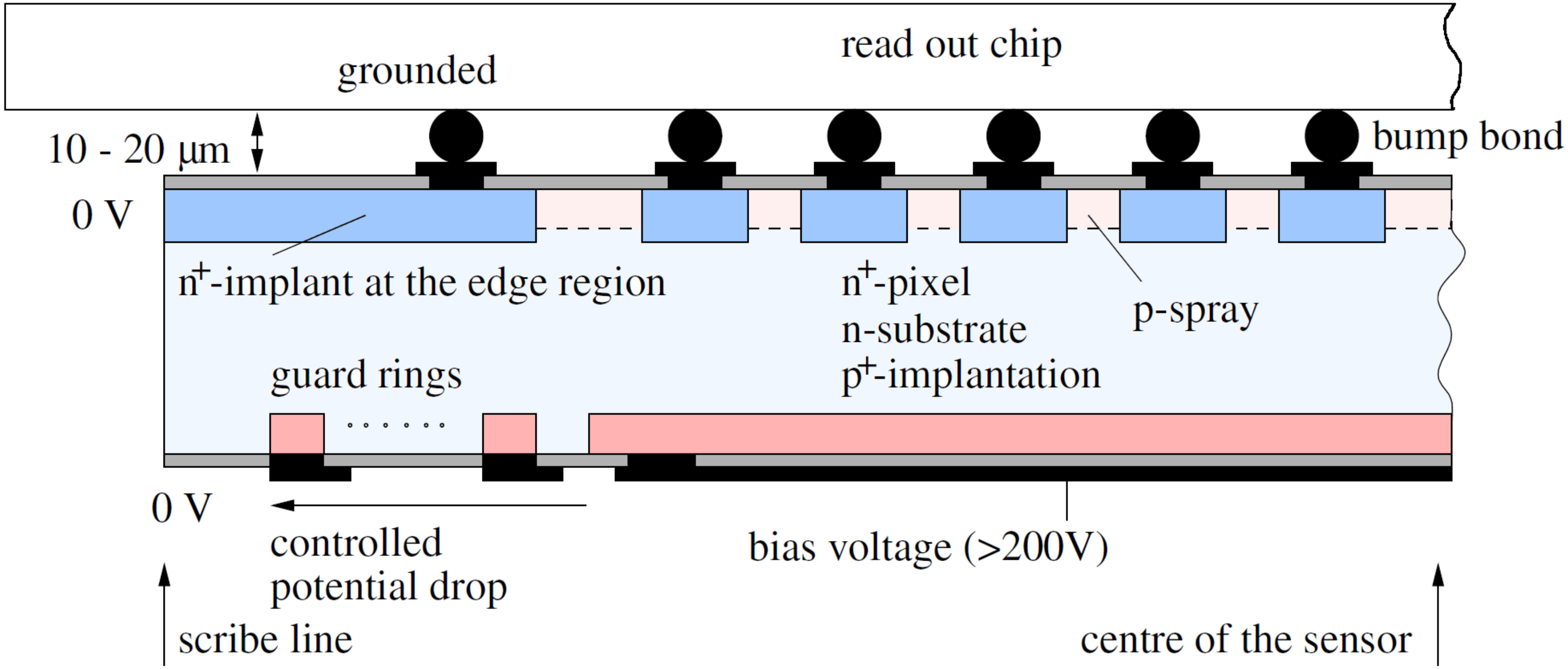




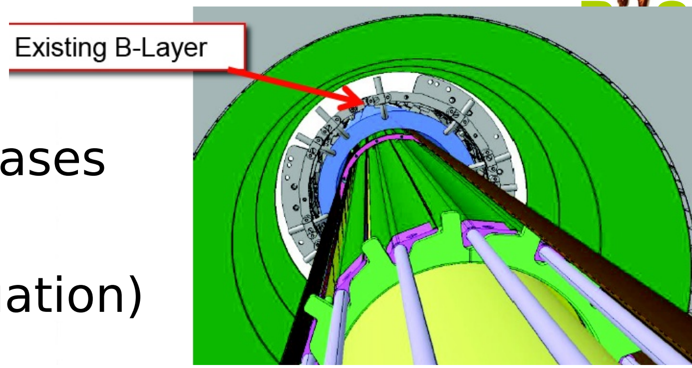


present ATLAS pixel module

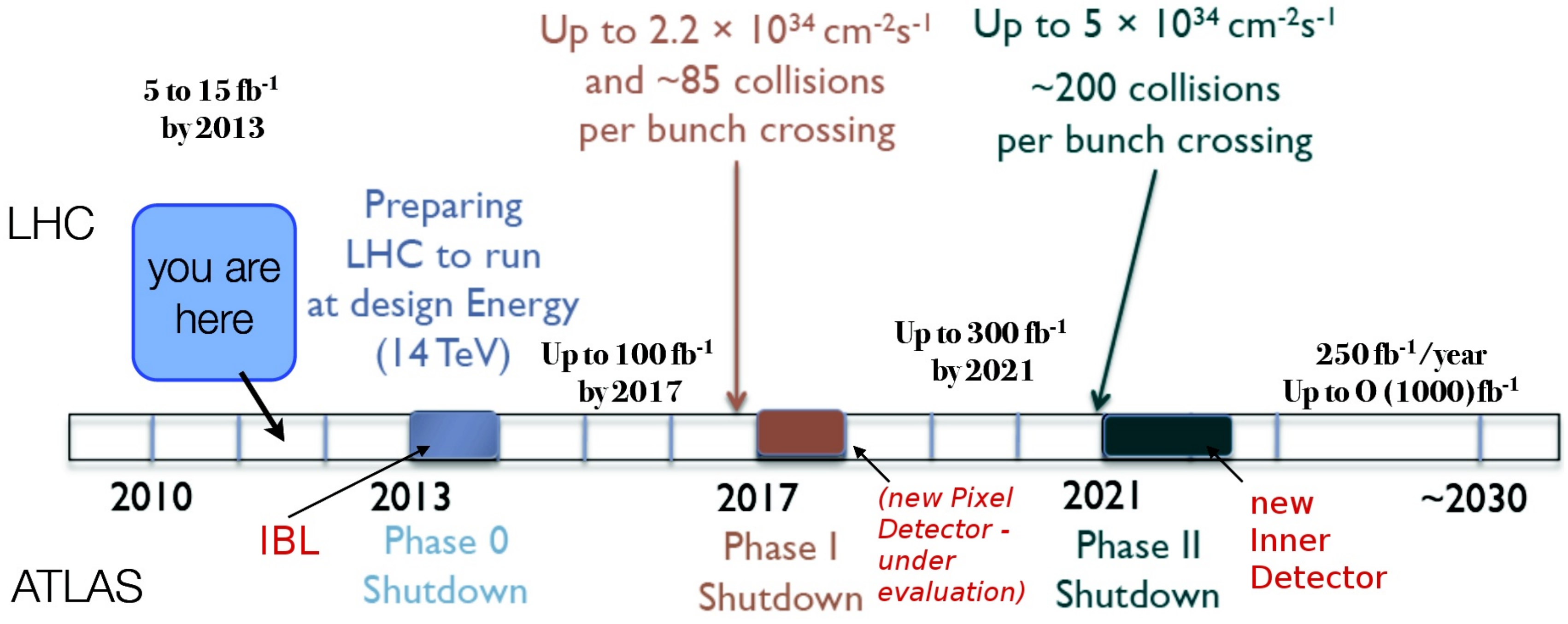
- planar n-in-n silicon sensor
    - n+ pixel
    - n bulk, 250um thick, DOFZ
    - p+ implantation
    - guard rings to reduce HV stepwise
    - 46,080 pixel cells, 400um x 50um



time schedule of ATLAS upgrades



- ATLAS upgrades are divided into several phases
  - phase 0: insertable b-layer (IBL)
  - phase I: *new pixel detector* (under evaluation)
  - phase II: new inner detector
- increasing luminosity
- increasing number of bunch crossings per event



Up to 2.2 × 10^{34} $cm^{-2}s^{-1}$ and ~85 collisions per bunch crossing

Up to 5 × 10^{34} $cm^{-2}s^{-1}$ ~200 collisions per bunch crossing

5 to 15 fb^{-1} by 2013

LHC

you are here

Preparing LHC to run at design Energy (14 TeV)

Up to 100 fb^{-1} by 2017

Up to 300 fb^{-1} by 2021

250 fb^{-1}/year Up to O (1000) fb^{-1}

2010

IBL

2013 Phase 0 Shutdown

2017 Phase I Shutdown

(new Pixel Detector - under evaluation)

2021 Phase II Shutdown

new Inner Detector

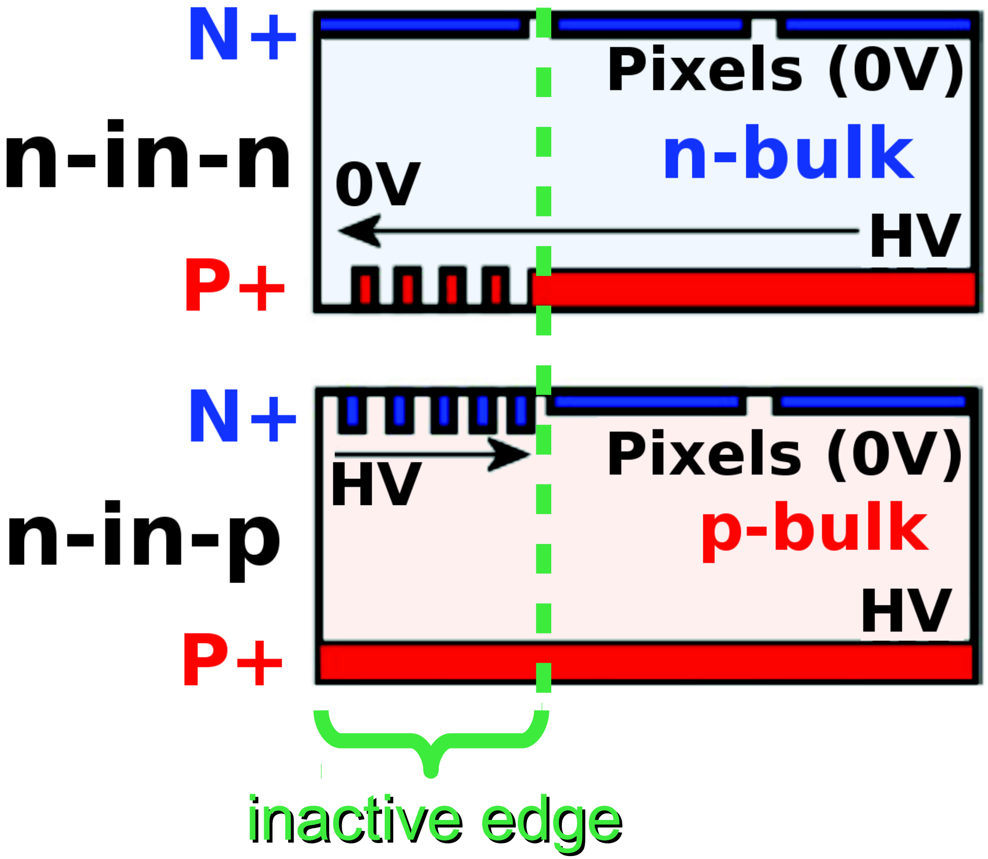
~2030

ATLAS

ATLAS planar pixel sensor group

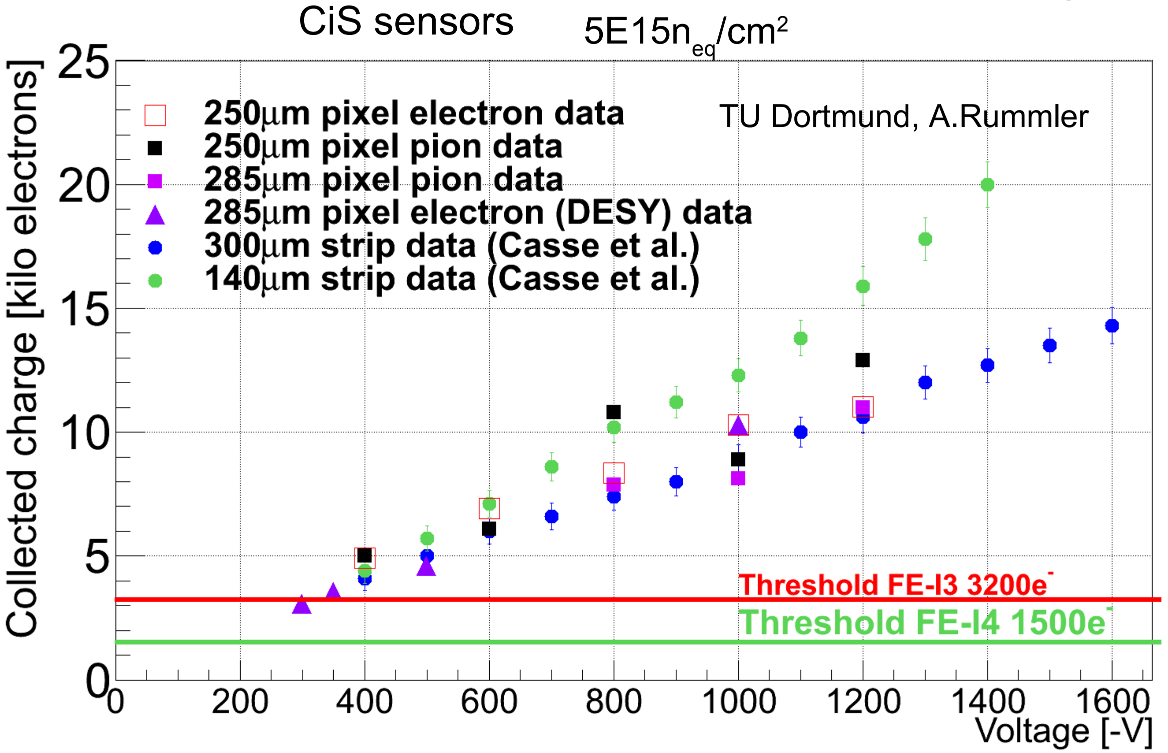
- official ATLAS R&D project
- 17 institutes, ~80 scientists

- fields of research:
  - radiation hardness
  - TCAD simulations for sensor optimization
  - low cost for large area layers
  - slim/active edges



n-in-n sensors

- required collected charges & hit efficiencies can be obtained by increasing the sensor bias voltage
- IBL conditions (5E15n_{eq}/cm^2)
  - hit efficiency of 99.6% was measured
  - more than 10ke at 1kV are collected

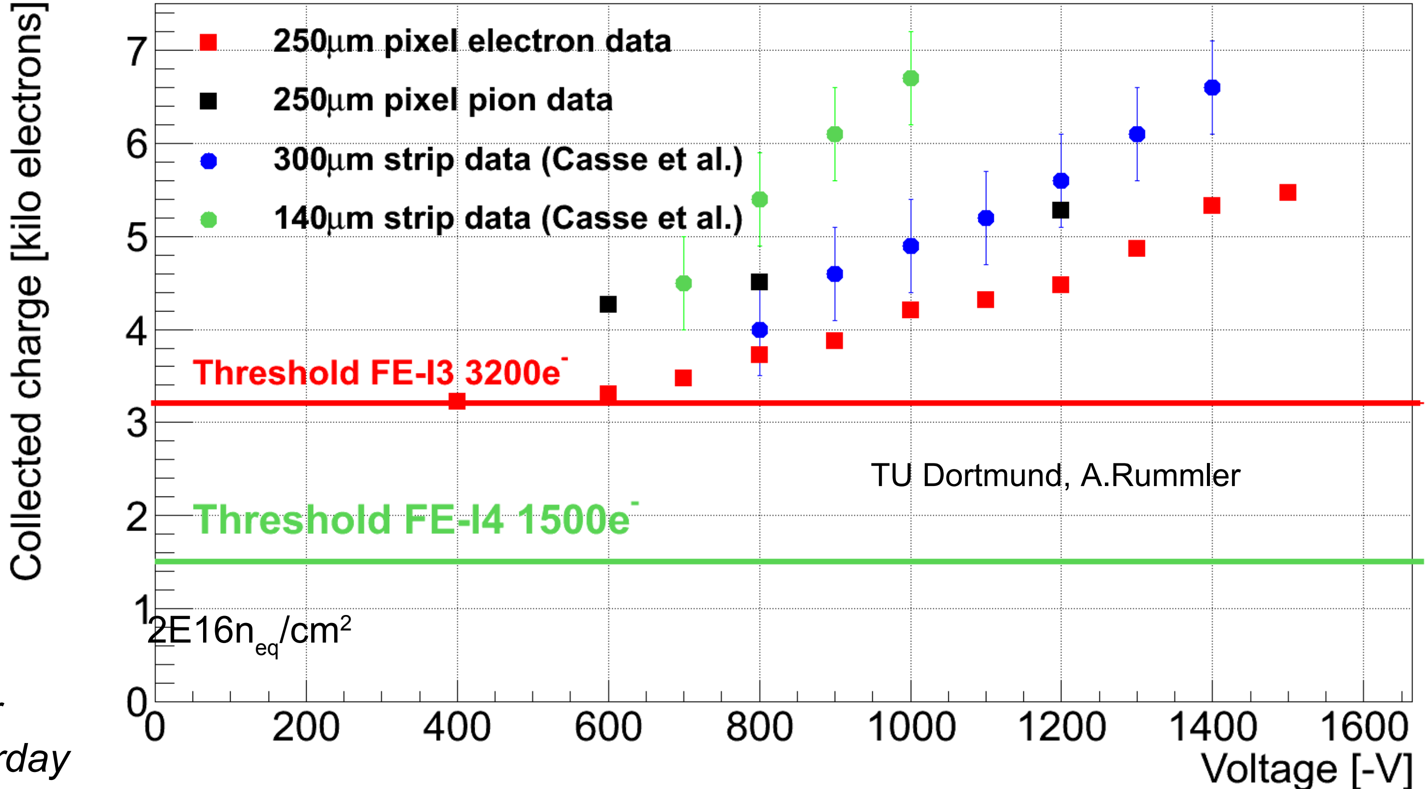


see A.Rummler's poster for further details yesterday

n-in-n sensors

- required collected charges & hit efficiencies can be obtained by increasing the sensor bias voltage
- phase II conditions (2E16n_{eq}/cm^2)
  - well above threshold

CiS sensors

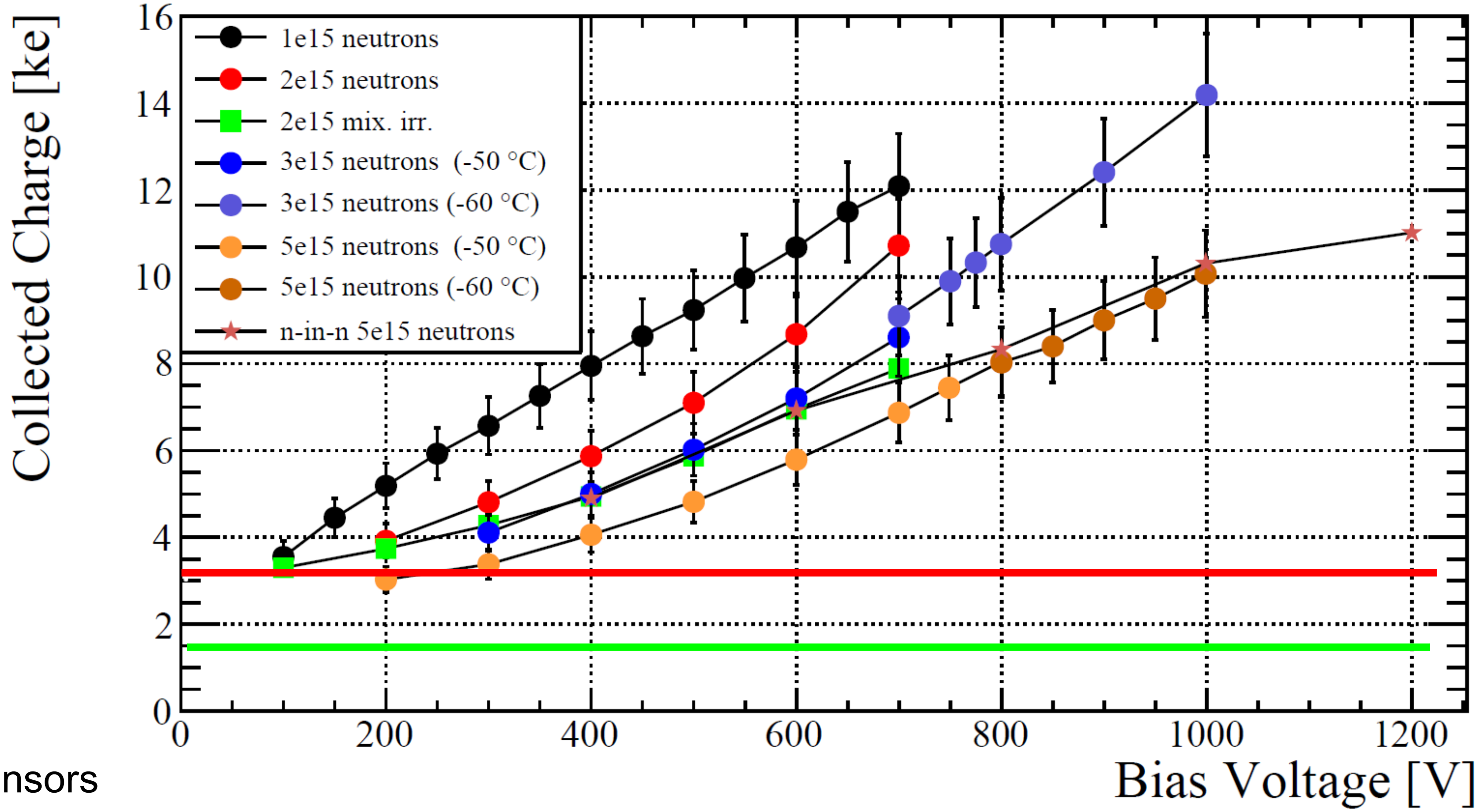


see A.Rummlers poster for further details yesterday

n-in-p sensors

- assemblies irradiated to IBL fluence (5E15n_{eq}/cm^2), also proton & neutron combined
    - charge collection well above threshold

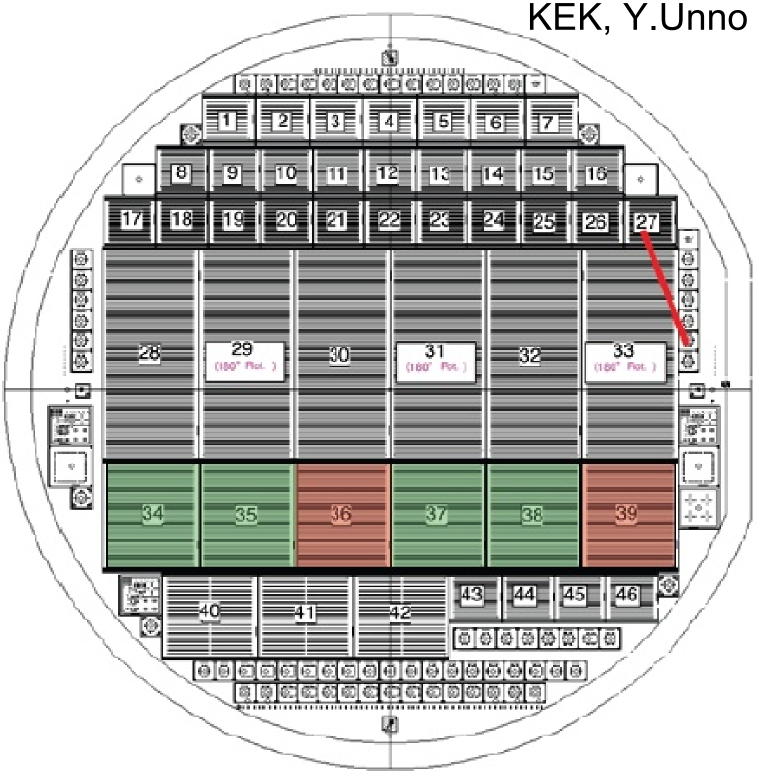
MPI, P.Weigell



CiS sensors

n-in-p sensors

KEK, Y.Unno

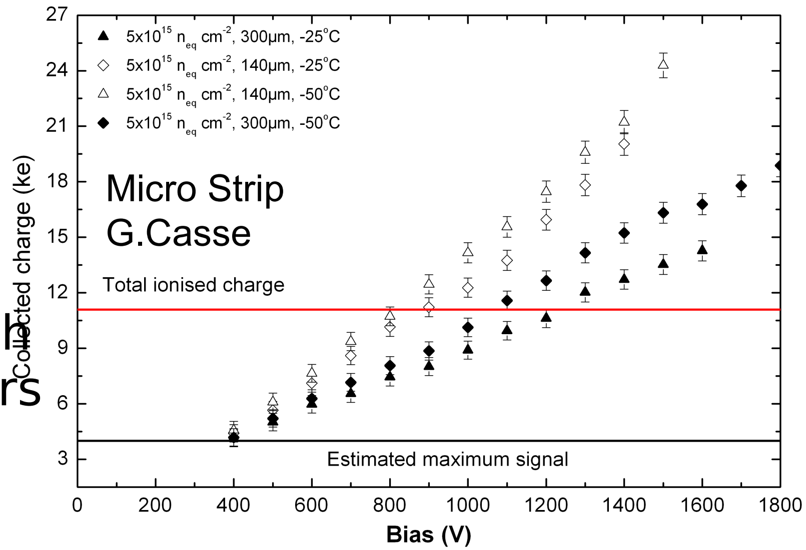


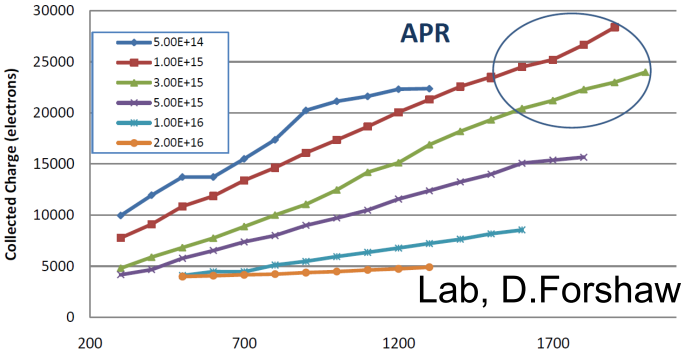
- unirradiated and irradiated assemblies show good results (HPK, KEK)
- 150um thin 6'' wafers were produced and first FE-I4 Assemblies are currently under construction
- -> Low cost sensor production for larger radii

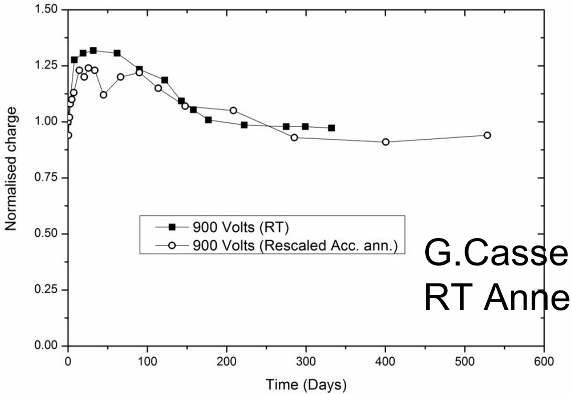
n-in-p sensors

see following talk of P.Allport

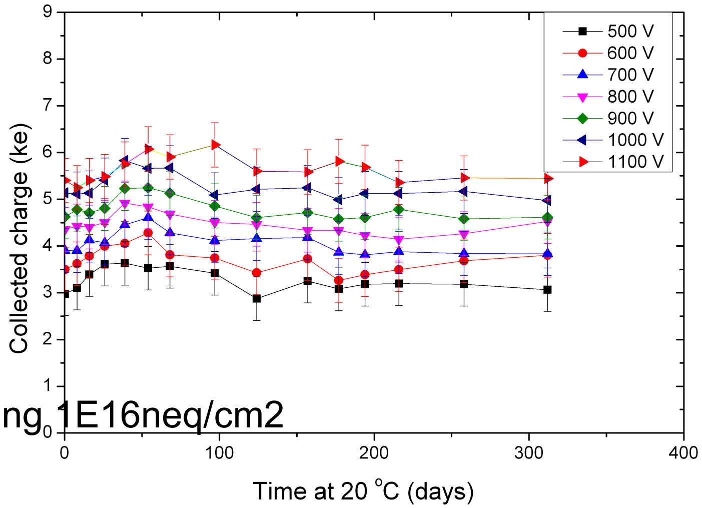
- tests with Micron sensors (Liverpool)
  - evidence of charge multiplication with micro strip and analogue pixel sensors
- annealing studies
  - leakage current decreases
  - changes of collected charge
    - ~25% increase for ~50 days at RT
    - for longer periods decreases
  - comparative investigations between room temperature and accelerated annealing ongoing
    - still trying to optimize time conversion factor





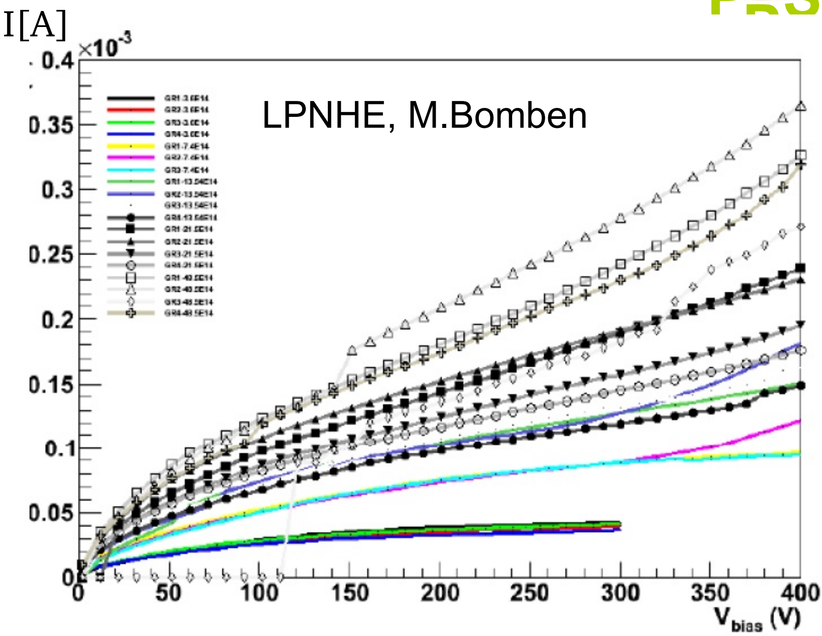


G.Casse
RT Annealing 1E16neq/cm2



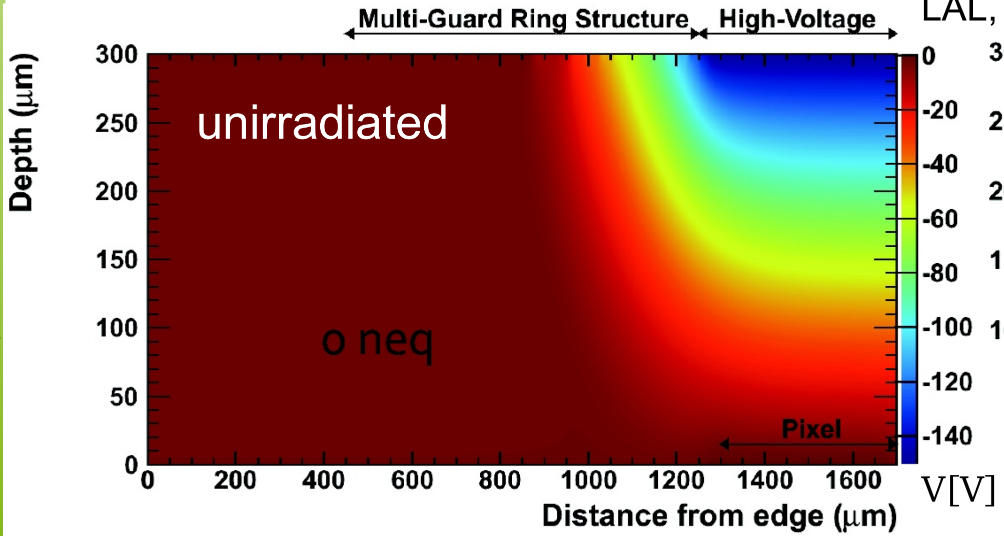
Device simulation

- TCAD simulations are done to help sensor optimizations
    - E-fields
    - potential drops in the edge region
    - leakage currents and breakdown behaviours
- decision of sensor design & thickness
- for digitization model



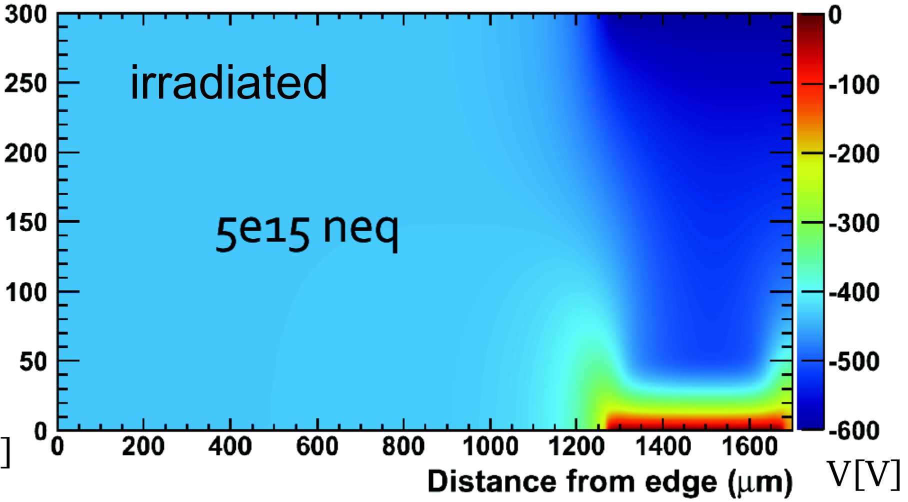
LPNHE, M.Bomben

LAL, M.Benoit



unirradiated

0 neq



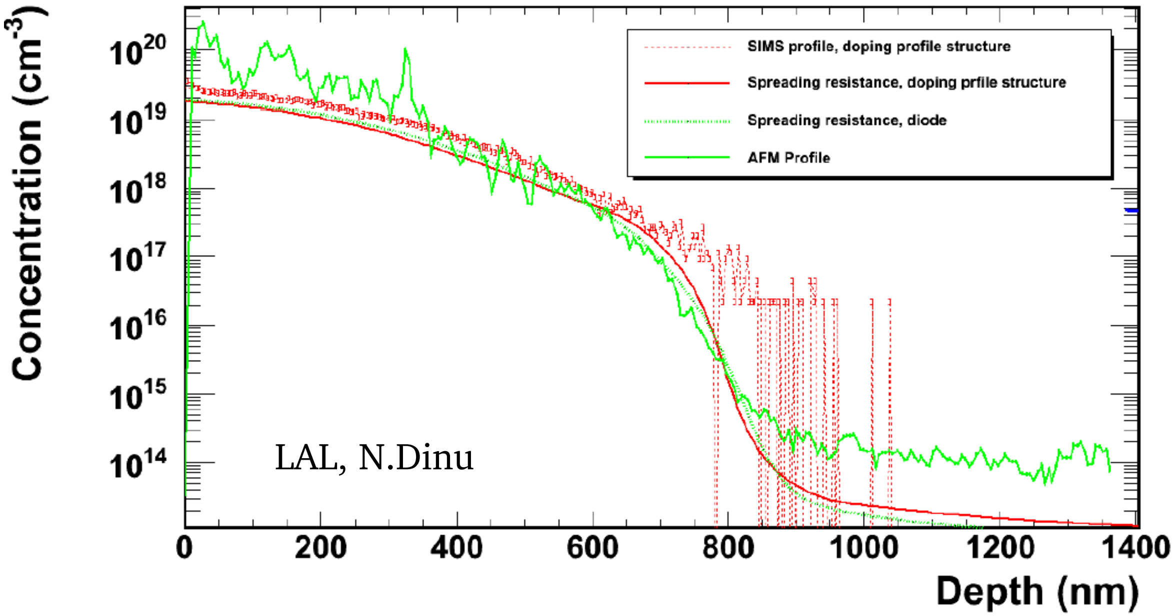
irradiated

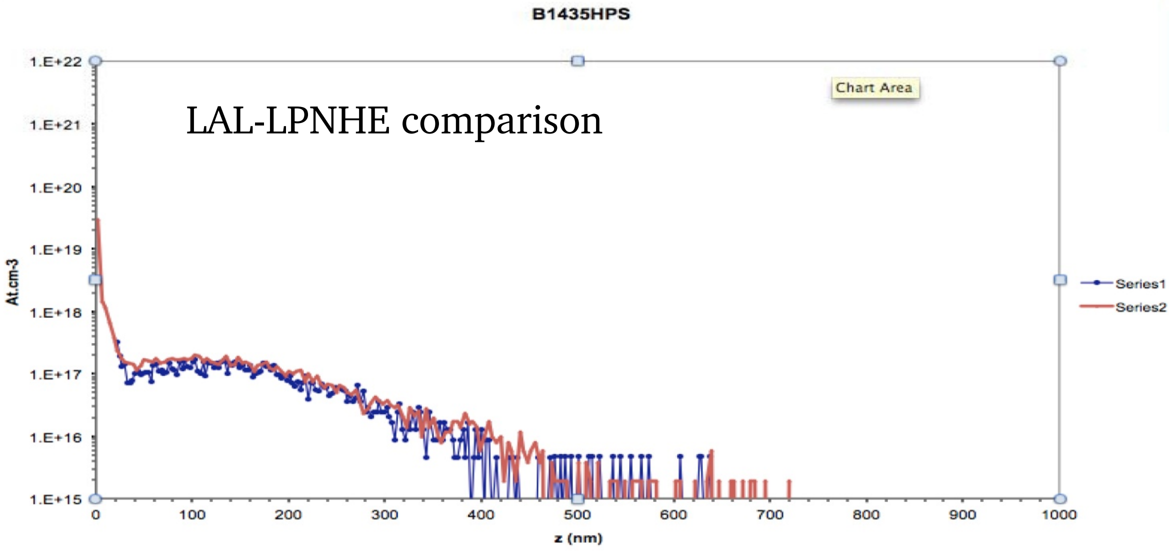
5e15 neq

Device simulation

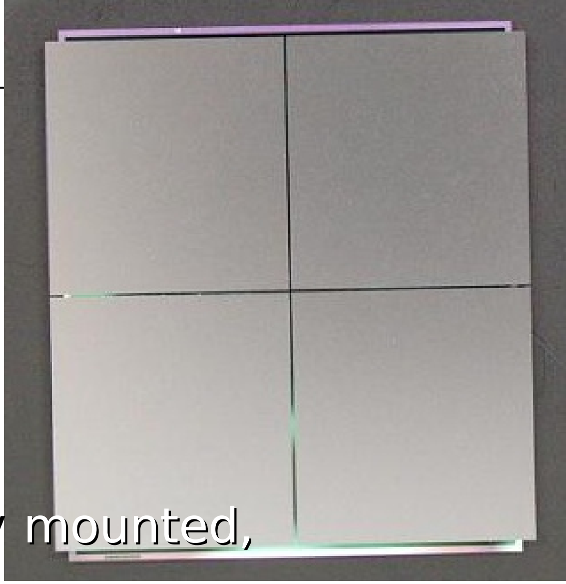
- TCAD simulations are calibrated with results of two measurement methods
  - SIMS (Secondary Ion Mass Spectrometry) -> total dopant density profile
  - SRP (Spreading Resistance Profiling) -> carrier density profiles
  - good agreement

SIMS, SRP and SSRM comparison





KEK, Y.Unno



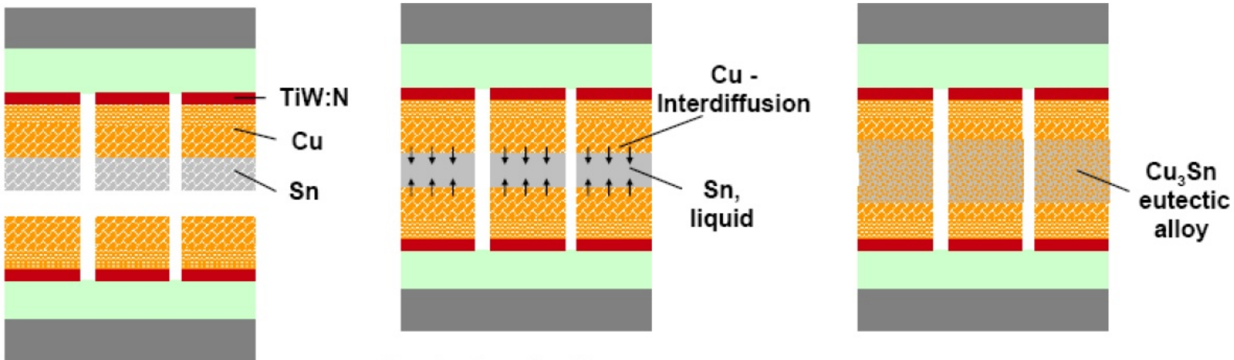
low cost / flip chipping

- bump bonding is one main cost driver
  - done at Fraunhofer IZM, Berlin
    - long time positive experiences
  - alternative bump bonding vendor is HPK (KEK)
    - dummy sensor-chip assemblies successfully mounted,
    - tests with real chips are planned

- SLID - Solid Liquid Interdiffusion (MPI & Fraunhofer EMFT)
  - could be a low cost alternative to bump bond
  - small pitches possible (~20um)
  - first modules are functional
  - still challenges left due to disconnected channels

MPI, A.Macchiolo

see P.Weigell's talk, yesterday

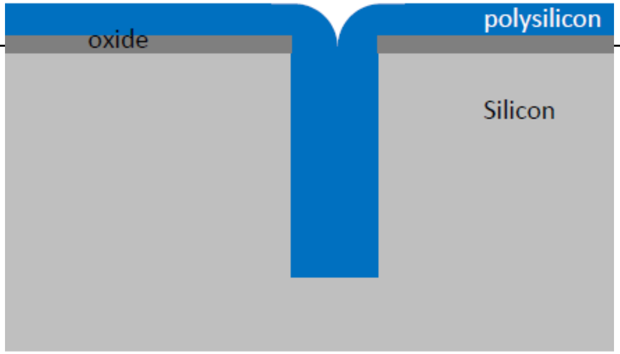


Through Mask Electroplating

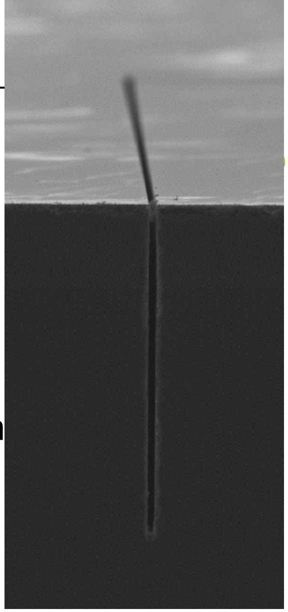
Contact under Pressure and Heat
~ 5 bar, 260 – 300 °C (Sn-melt)

Formation of Eutectic Alloy; T_{melt} > 600 °C

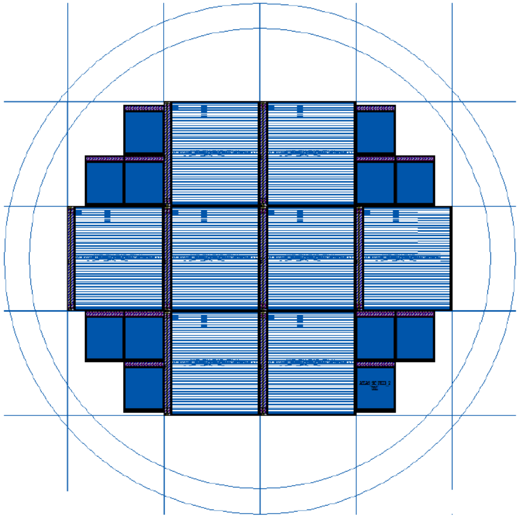
slim / active edges

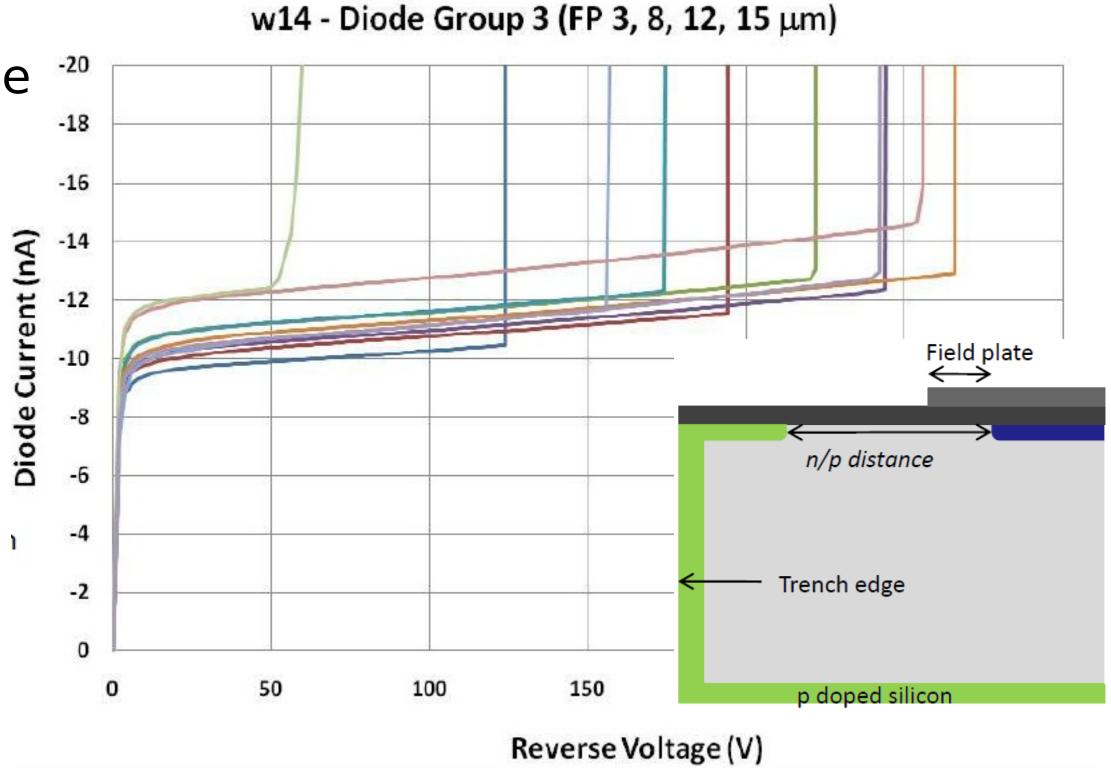


FBK/LPNHE, M.Bomben



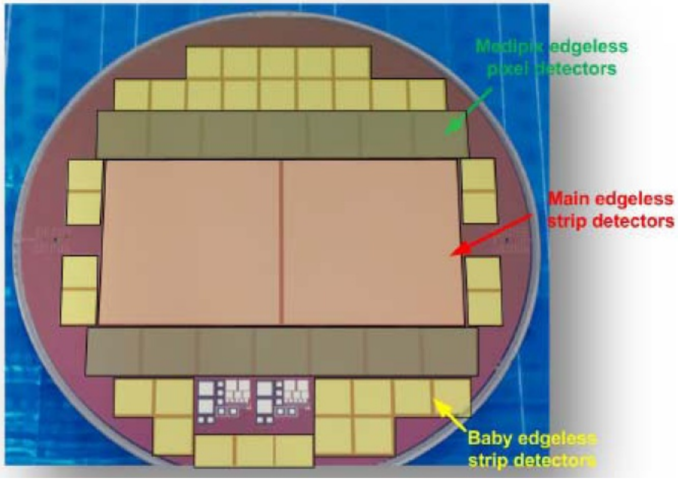
- trench etching (DRIE, Deep Reactive Ion Etching) and filling with polysilicon
  - principle already works well
  - process optimizations ongoing
- active edge sensors will be produced in an upcoming wafer submission

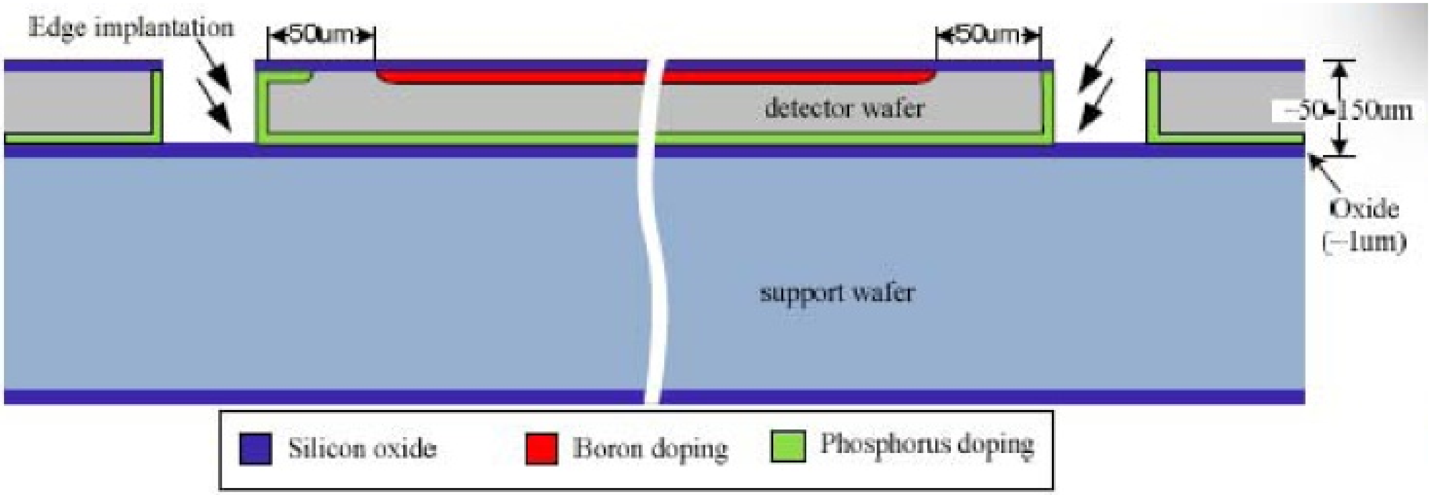




slim / active edges

- ongoing wafer production with VTT including active edge sensors

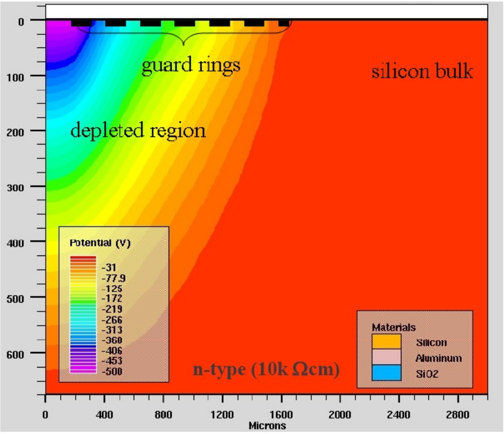


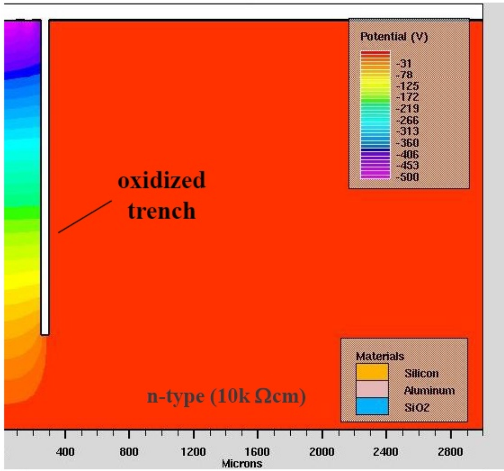


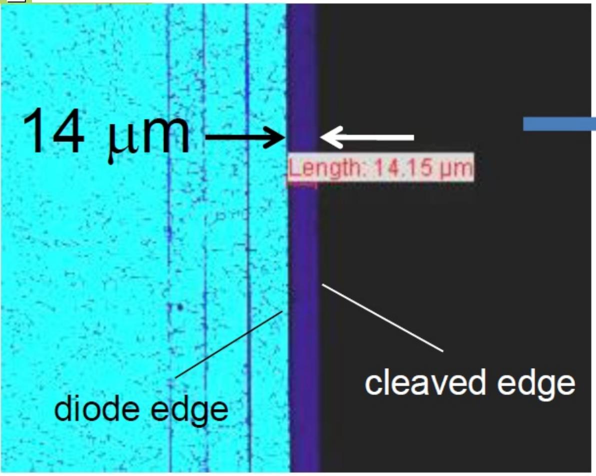
MPI, A.Macchiolo

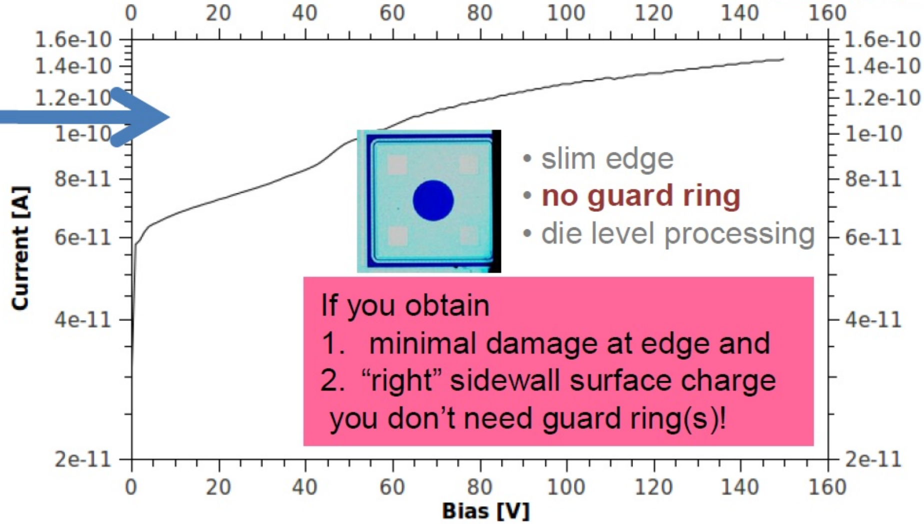
slim / active edges

- post processing (UCSC & NRL)
  - applicable for all sensor types
  - laser scribing and cleaving afterwards next to the active area
  - post treatment to passivate the edge
    - thermally grown oxide for n-bulk
    - Atomic Layer Deposition of Al_2O_3 for p-bulk
  - first very promising results with diodes: inactive margin down to ~14um









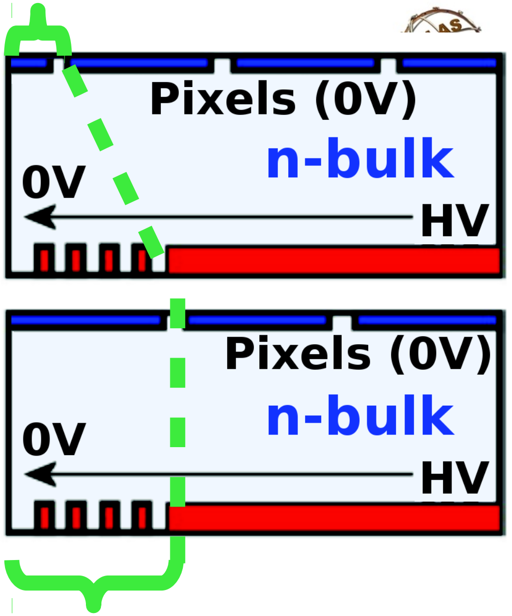
- slim edge
- **no guard ring**
- die level processing

If you obtain
1. minimal damage at edge and
2. “right” sidewall surface charge
you don’t need guard ring(s)!

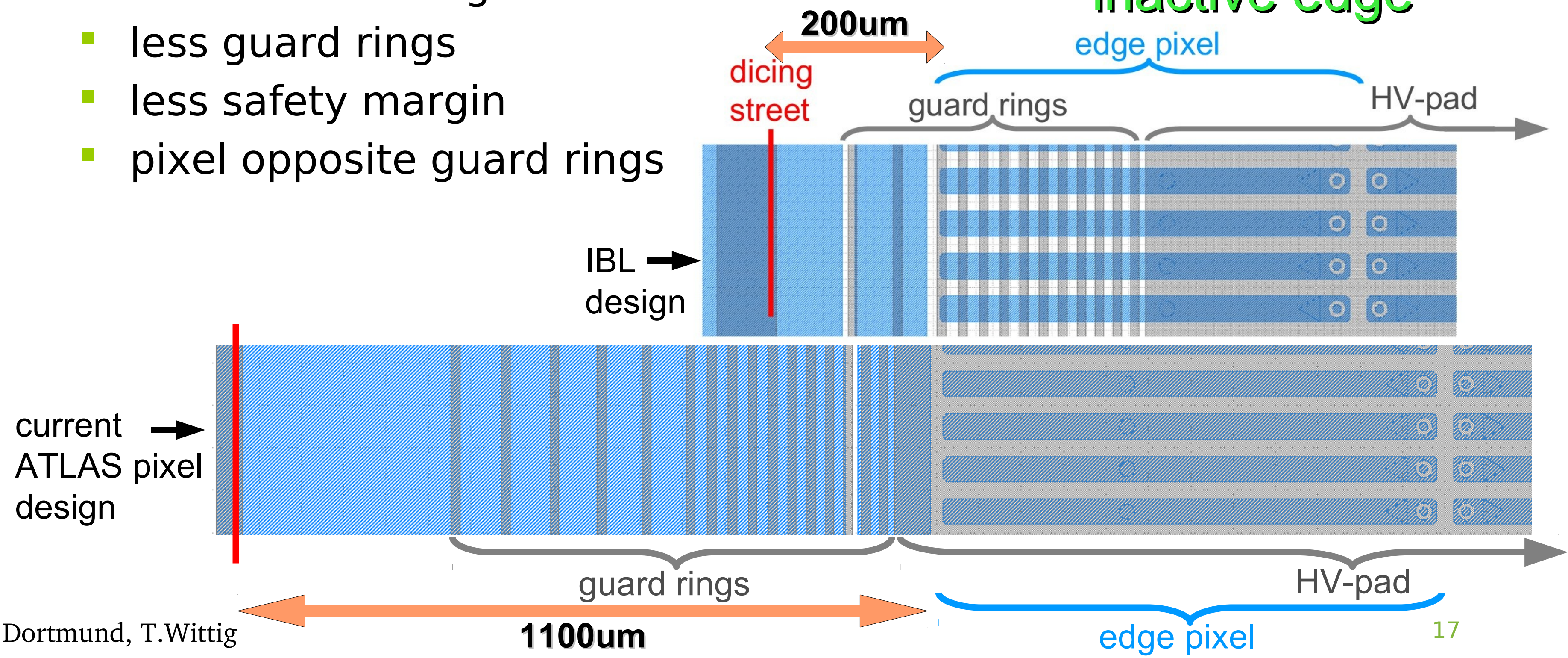
UCSC,
V.Fadeyev

IBL sensor layout

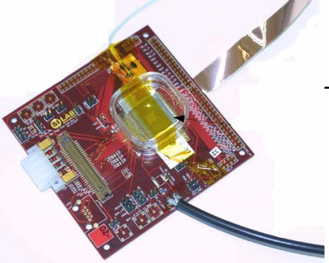
- planar n-in-n sensors are designated sensors for the IBL
    - 2x1 MultiChipModule: one sensor, two FE-I4 chips
- reduced bulk thickness (200um)
- reduced inactive edge
    - less guard rings
    - less safety margin
    - pixel opposite guard rings

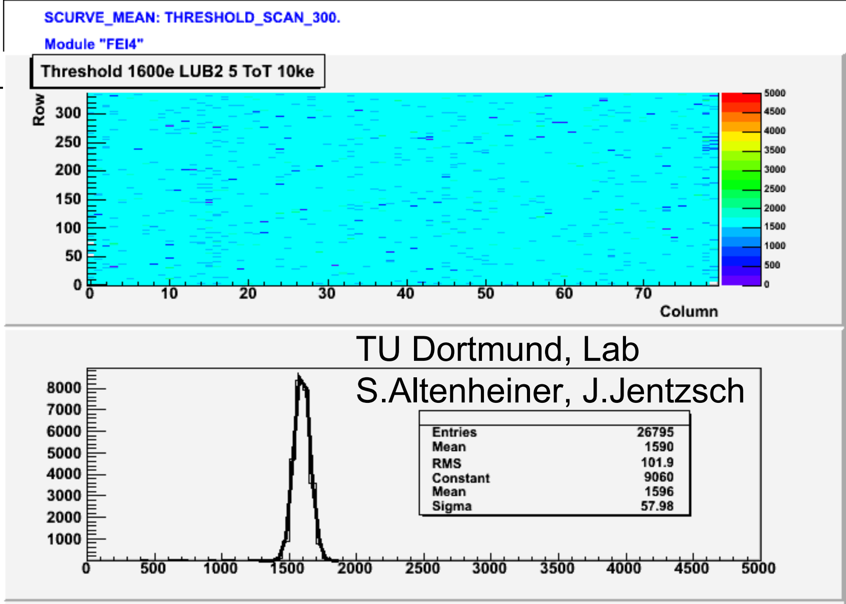


inactive edge



n-in-n IBL sensors

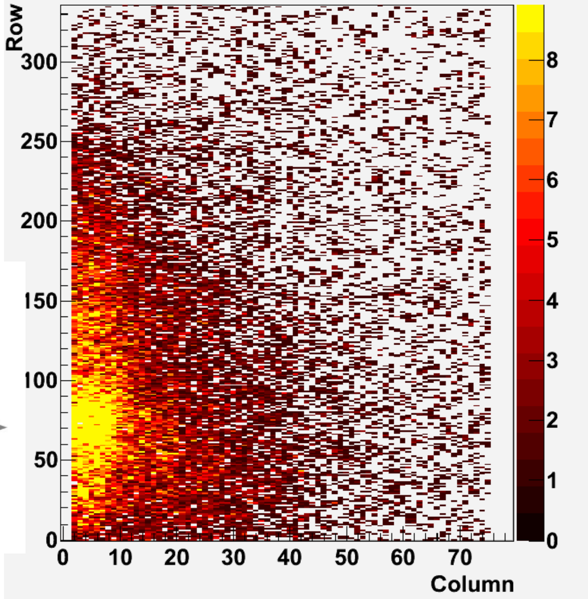


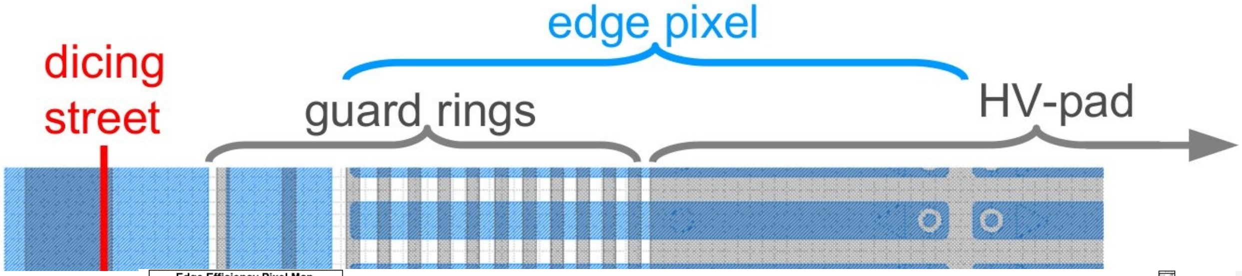


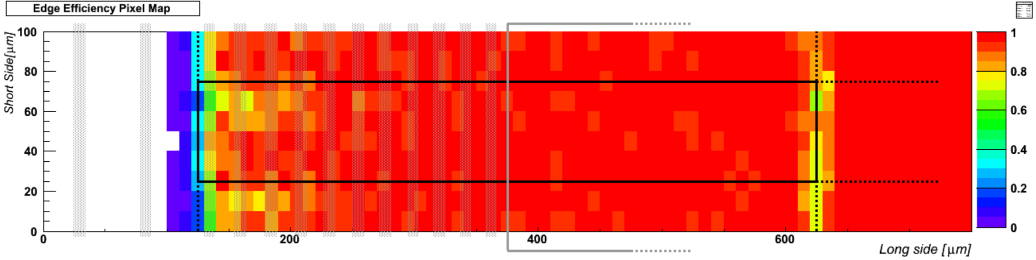
TU Dortmund, Lab
S.Altenheiner, J.Jentzsch

Entries	26795
Mean	1590
RMS	101.9
Constant	9060
Mean	1596
Sigma	57.98

- First FE-I4 Assemblies were investigated
  - before irradiation no problems
  - after irradiation to IBL fluence ($5E15n_{eq}/cm^2$)
    - still working fine
    - even tunings with low threshold look good
  - already proved their performance in test beam
    - reduction of inactive edge is possible





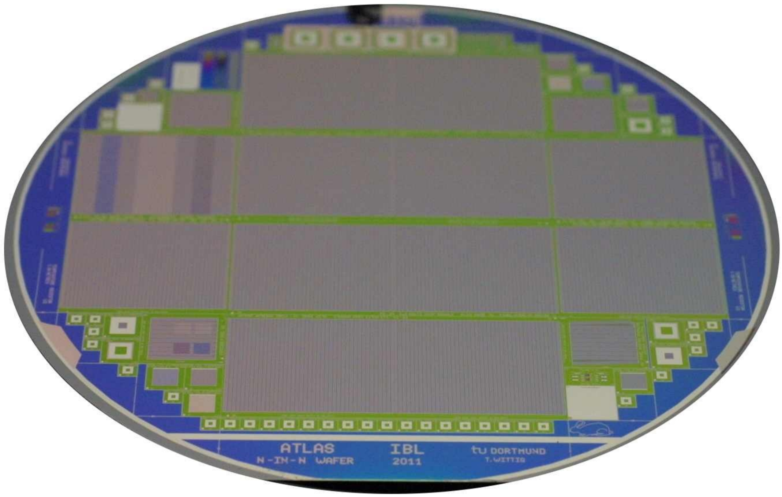


test beam
$5E15n_{eq}/cm^2$
1kV

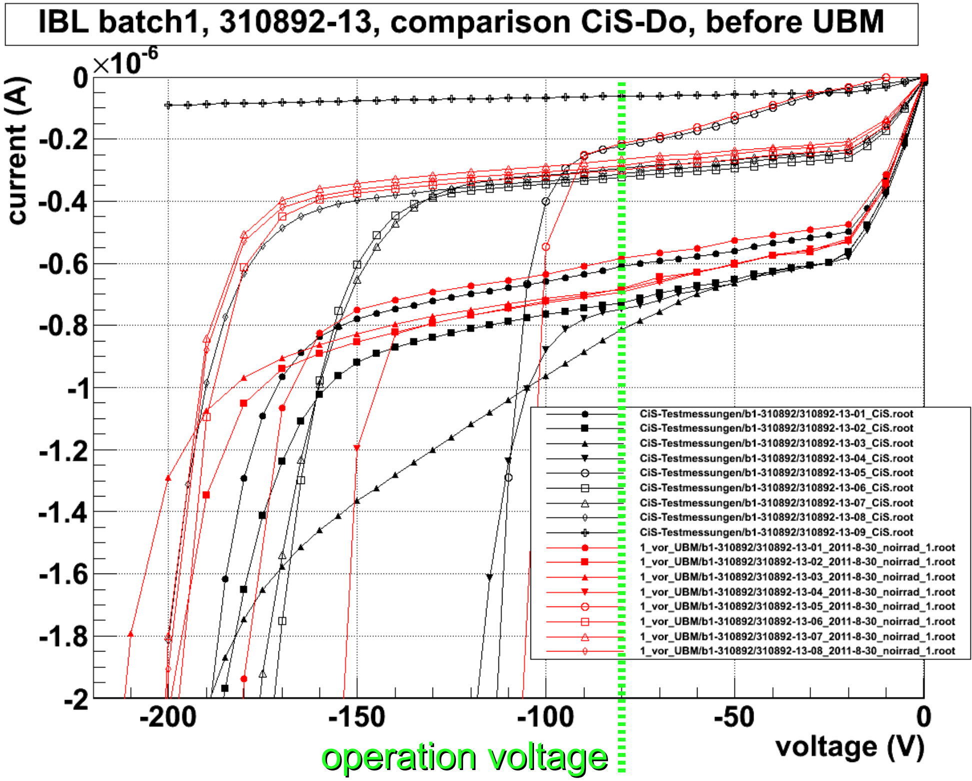
see T.Wittig's poster for further details (yesterday)

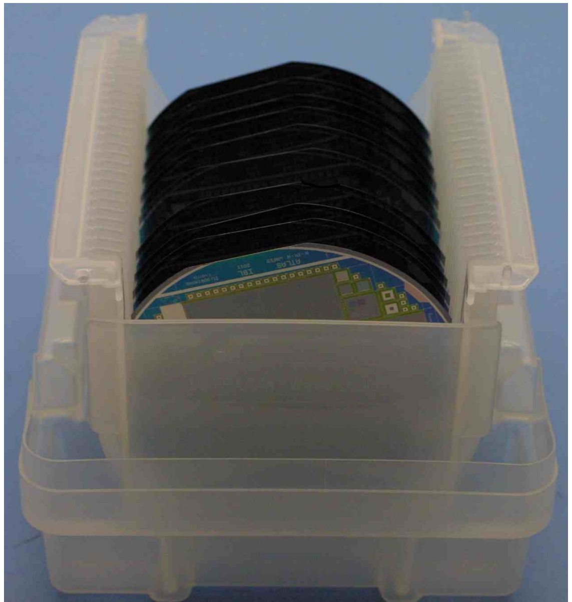
IBL sensor production

- production is ongoing and in time
- first batches already received
  - cross-checked
  - on it's way for UnderBumpMetal post-processing and Dicing
- high yield for MultiChipSensors



TU Dortmund, T.Wittig





Conclusions & Outlook

- planar silicon pixel sensors are considered sensors for all upgrade phases of ATLAS
  - have been selected as IBL sensors
  - promising candidates for high-lumi-LHC scenarios
- radiation hardness of n-in-n and n-in-p sensors is demonstrated
  - good signal-threshold ratio for phase 0 and phase II conditions
- low cost investigations for large area pixel layers
  - flip chip methods
  - large p-type modules
- progress of slim edge investigations
- mixed irradiations with MCz-bulk sensors are ongoing
- further evaluation of charge amplification

Backup

Annealing of collected charge

High fluences, high voltages:

I.Mandic, 17th RD50 Workshop

- Most probable charge drops due to short term annealing:

->N_{eff} drops -> smaller peak electric field -> less multiplication

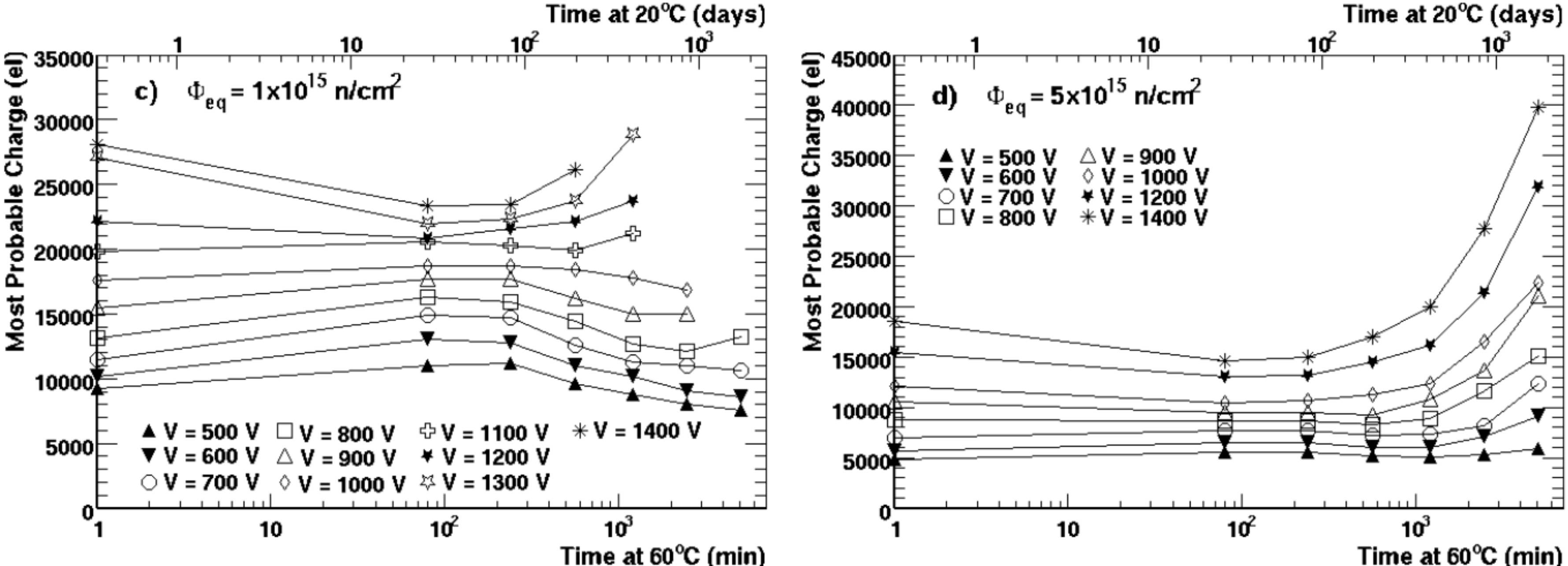
- Most probable charge rises due to long term annealing:

-> N_{eff} rises -> larger peak electric field -> more multiplication

- Breakdown voltage is lower at $5 \cdot 10^{14}$ and $1 \cdot 10^{15}$ than at $2 \cdot 10^{14}$ and $5 \cdot 10^{15}$

-> for detectors irradiated to $5 \cdot 10^{14}$ and $1 \cdot 10^{15}$

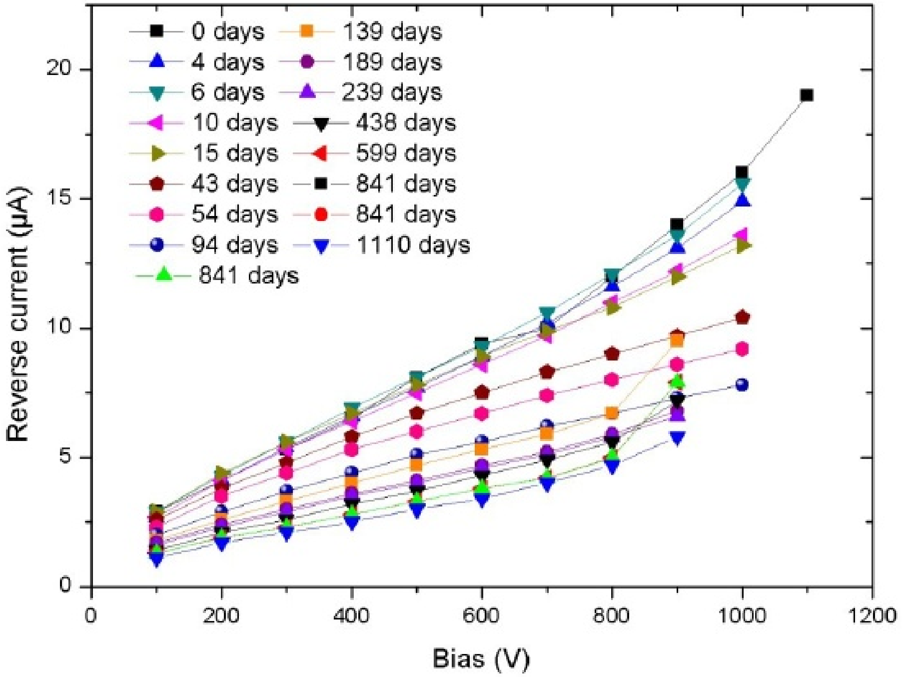
breakdown voltage decreases with reverse annealing



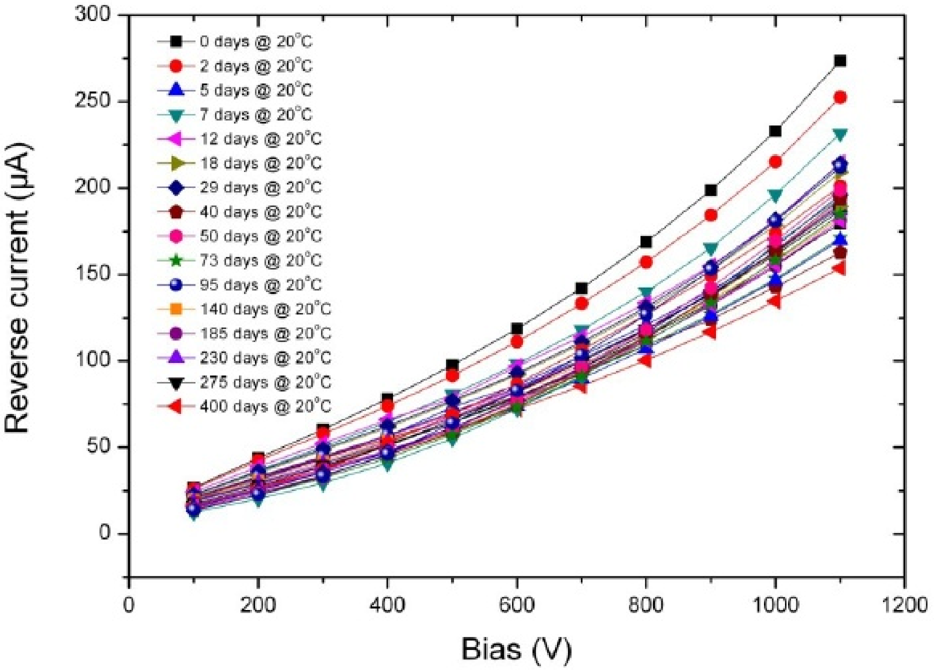
Accelerated Annealing of reverse current

G.Casse, Liverpool

$1E15n_{eq}/cm^2$



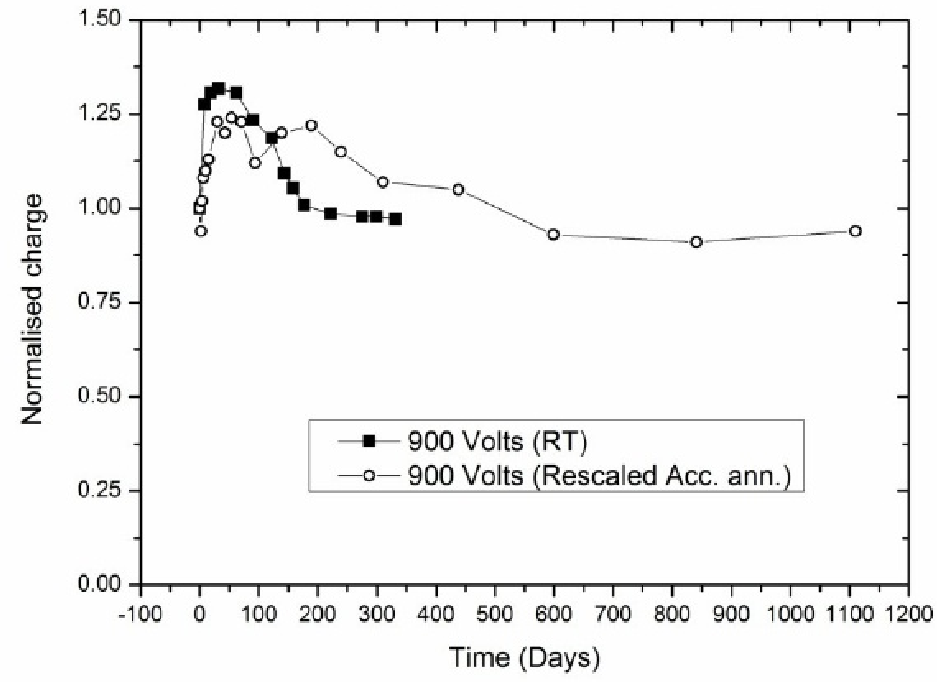
$1.5E16n_{eq}/cm^2$



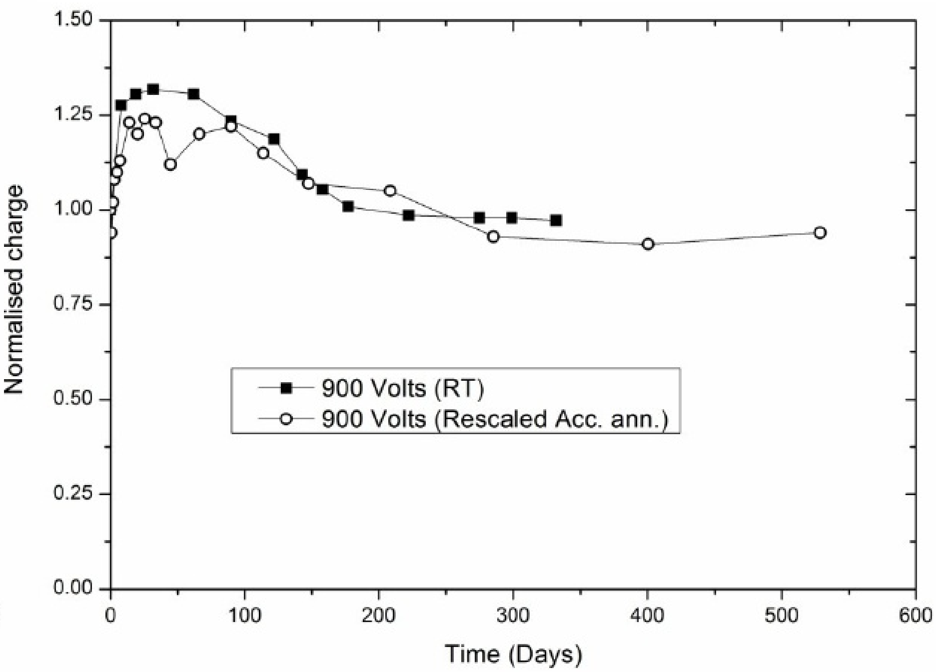
Comparison of Room Temperature and Accelerated Annealing of the collected charge

G.Casse, Liverpool

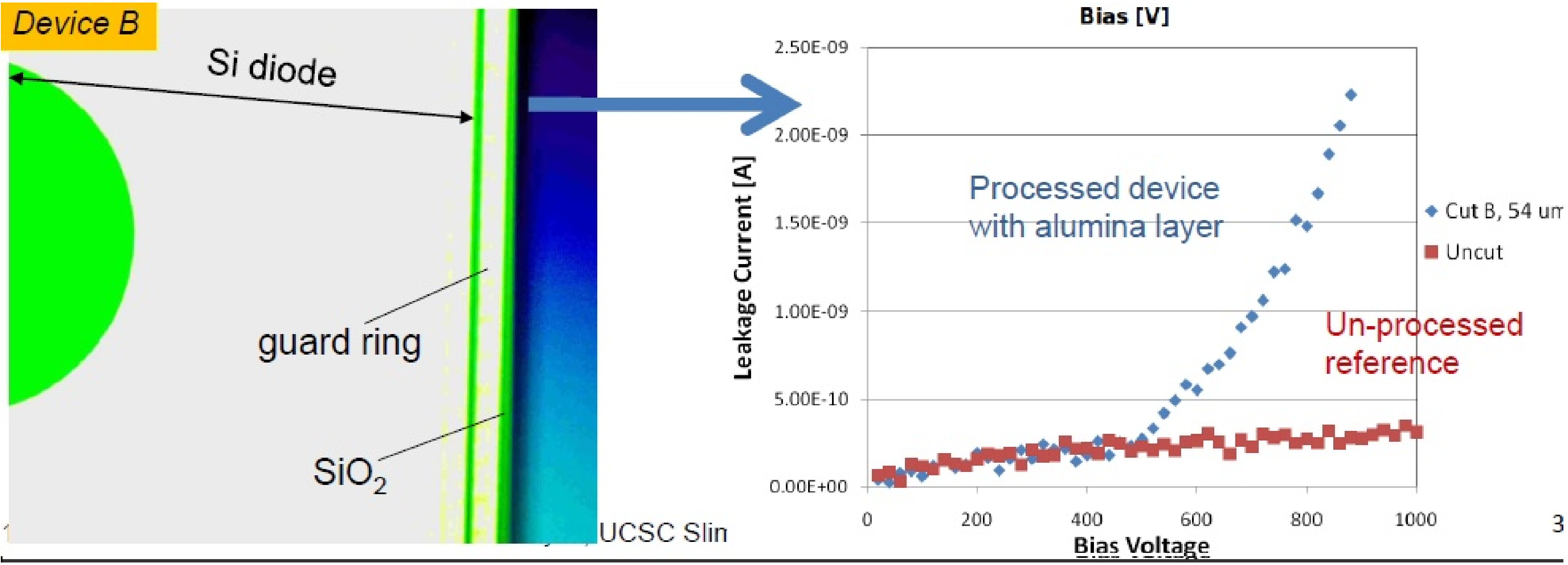
Accepted acceleration factor



Acceleration factor divided by 2.1

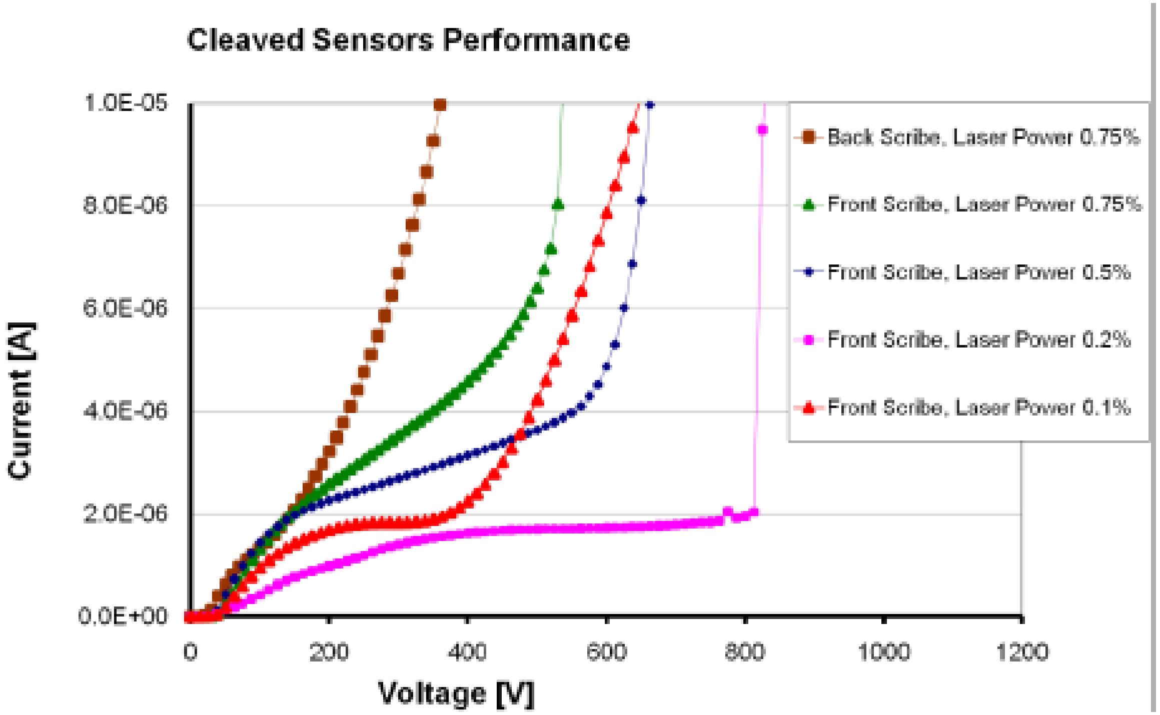


Slim Edge post processing, second device

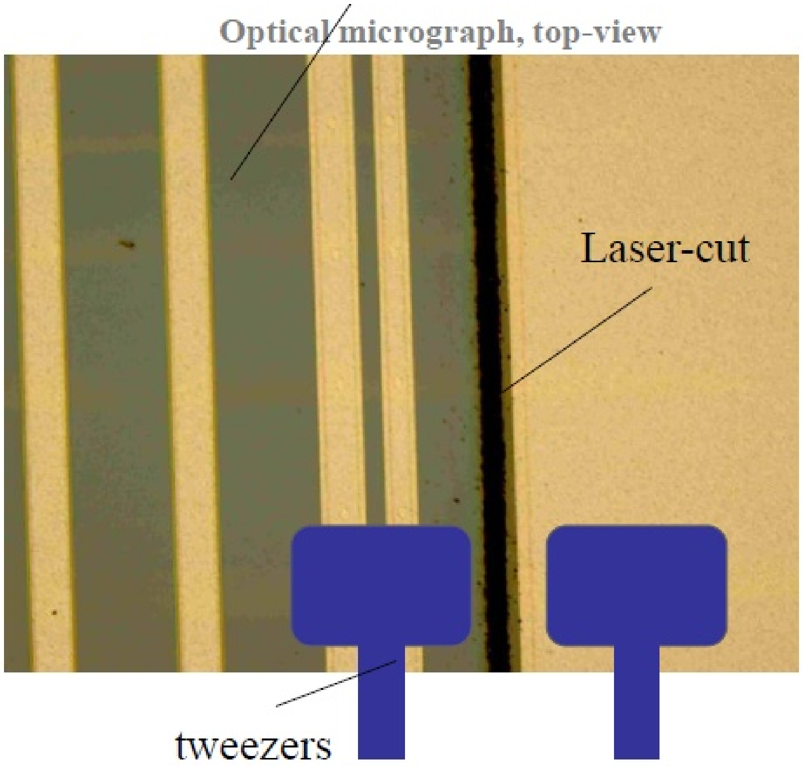


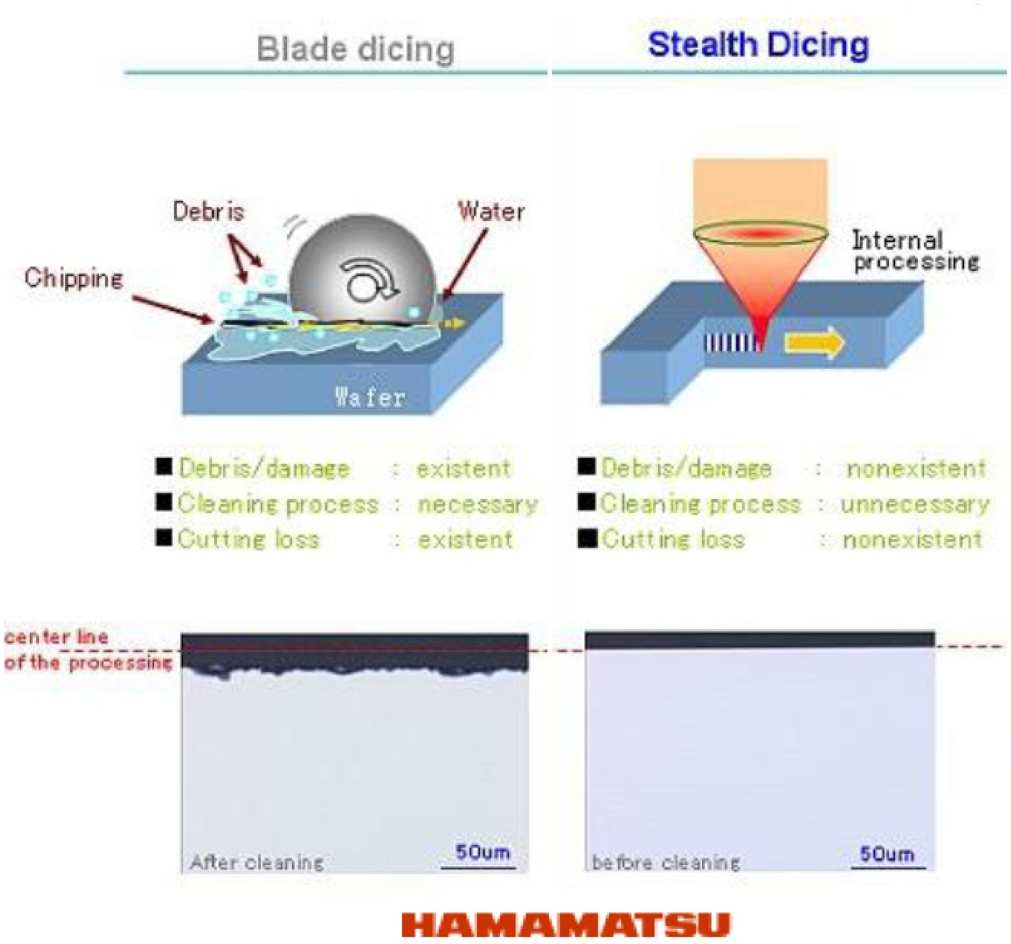
Slim Edge post processing, N-bulk sensors

- Processing of n-bulk sensors is easier, since formation of SiO_2 passivates the sidewall. Prototyped with p-on-n HPK sensors from GLAST/Fermi production



Laser Scribing and Cleaving

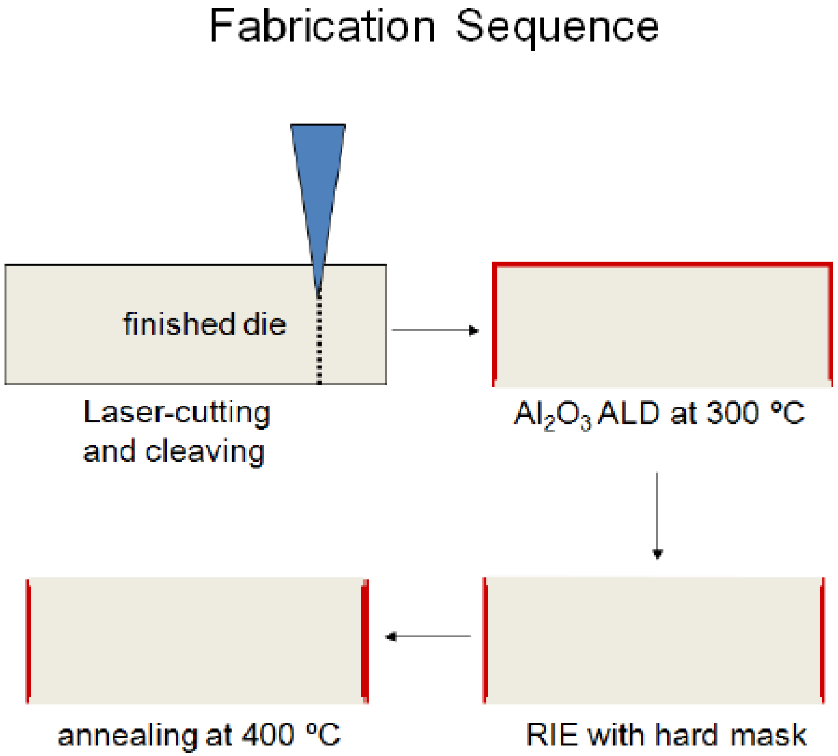


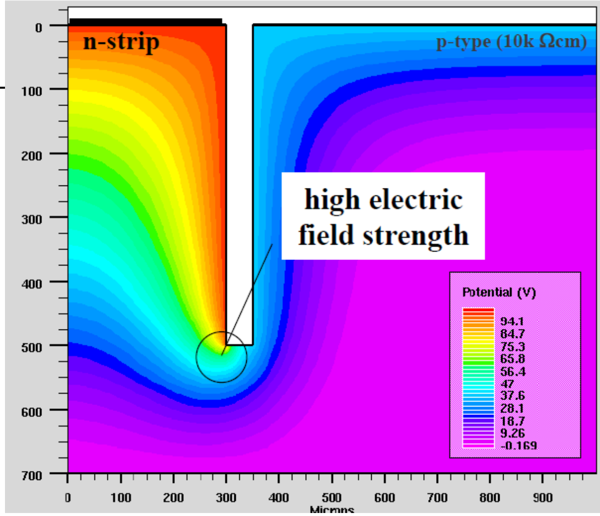


	Blade dicing	Stealth Dicing
Debris/damage	existent	nonexistent
Cleaning process	necessary	unnecessary
Cutting loss	existent	nonexistent

ALD Processing on p-type Sensors

- For p-type sensors the critical step is formation of proper passivationon the surface. The quickly forming Si oxide has a detrimental effect. Alumina deposition by ALD (left) leads to the desirable properties.
    - Also need to investigate radiation effects.





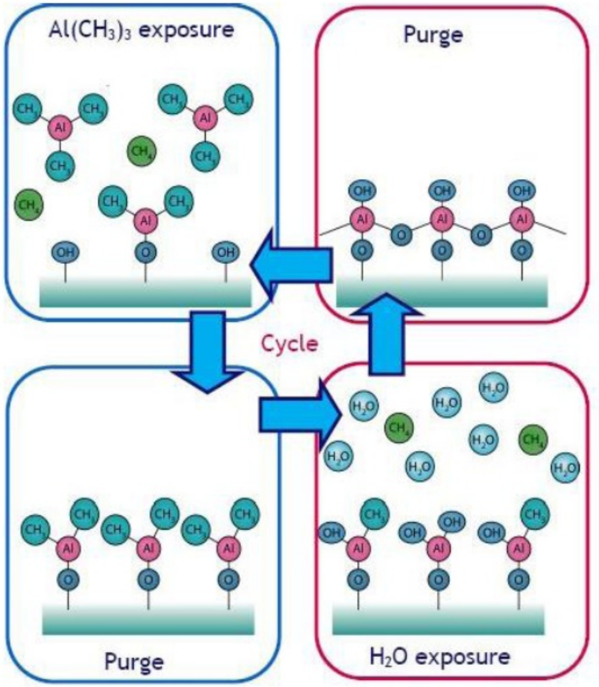
slim edge post processing, p-bulk

An oxidized trench leads to:

- high electric field at trench edge,
- no control potential drop toward the cut edge,
- no protection from saw cut edge.

ALD

- Similar in chemistry to CVD (chemical vapor deposition), except that the ALD (atomic layer deposition) reaction breaks the CVD reaction into two half-reactions, keeping the precursor materials separate during the reaction.
- ALD film growth is self-limited and based on surface reactions, which makes achieving atomic scale deposition control possible.
- Perfect 3-D conformality, 100% step coverage: uniform coatings on flat, inside porous and around particle samples.



IBL sensor layout