

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

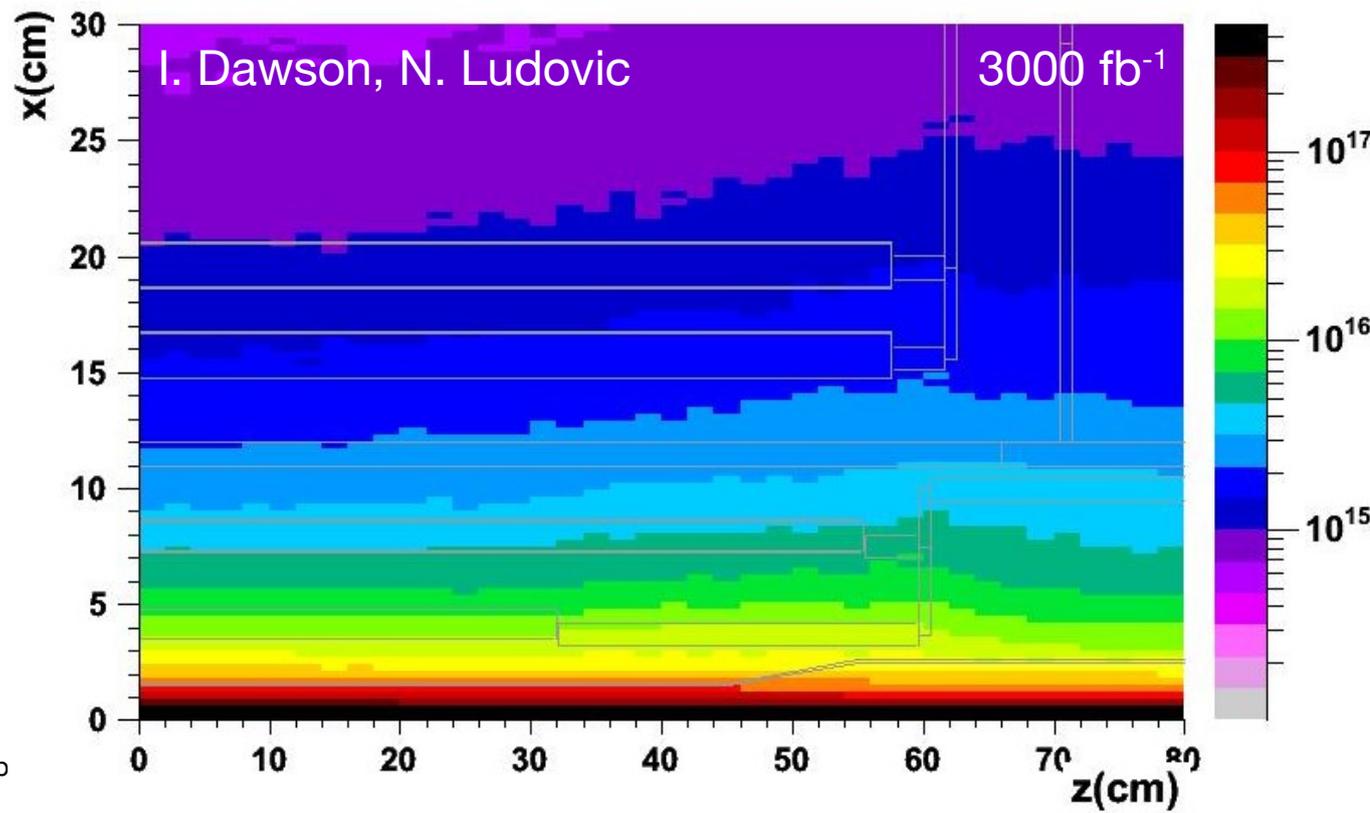


*Daniel Muenstermann  
on behalf of the  
ATLAS Planar Pixel Sensor R&D Project*



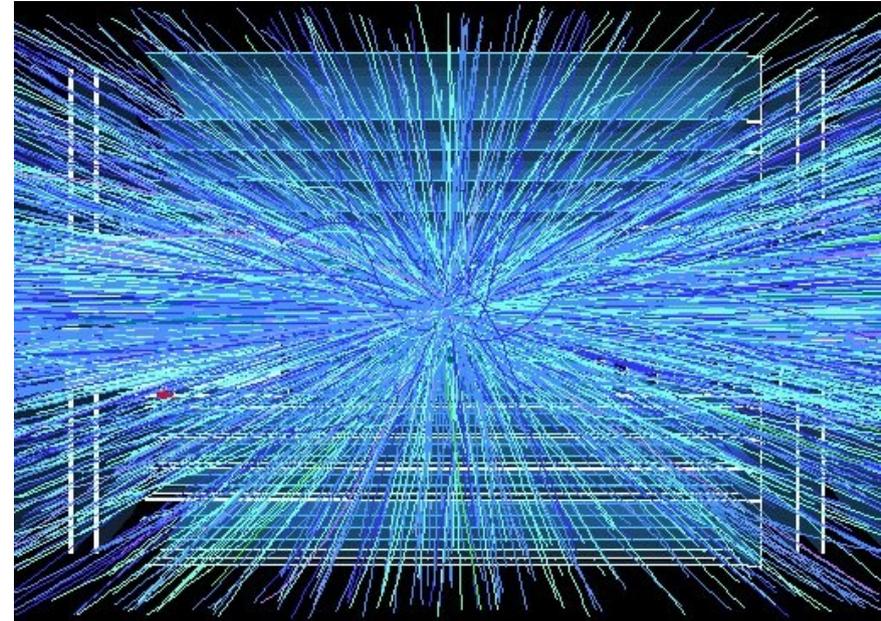
# SuperLHC and its implications

- There are physics motivations for extending the integrated luminosity target from  $\sim 700 \text{ fb}^{-1}$  to some  $1000 \text{ fb}^{-1}$  while keeping the same energy and dipole magnets
- Such an upgrade is based on advanced collimation, focusing, more intense bunches and the use of crab-cavities (in the preferred FCC-scenario)
- The environment will get a lot harsher:
  - Up to  $2 \cdot 10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$  fluence for the b-layer at  $3000 \text{ fb}^{-1}$
  - Without luminosity levelling: up to  $1 \cdot 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$   
400 pile-up events/bc
  - With luminosity levelling: up to  $5 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$   
200 pile-up events/bc



## Demands to the upgraded tracker

- Large number of pile-up events increases occupancy and data rate
  - higher granularity:
    - all-silicon tracker
    - short strips (2.5 cm) instead of long strips (10 cm) for 30-70 cm radius
    - smaller pixels ( $250\ \mu\text{m} \cdot 50\ \mu\text{m}$ ) below about 35 cm radius (transition radius to be optimised, increased area!)
  - higher data rate:
    - new readout chip(s) ABCN and FE-I4 (plus evolution)
    - new data links
- Large fluences demand higher radiation hardness
  - electron-collecting sensor configuration for strips (n-in-p instead of p-in-n)
  - operation at very high bias voltages ( $>1000\text{V}$ )
  - radiation hardness of planar silicon sufficient for innermost radii?



# The ATLAS Upgrade Planar Pixel Sensors R&D Project

## Aims:

- explore the suitability of the planar sensor technology for SLHC fluences
  - investigate cost reduction options to be able to instrument also large radii
  - reduce the inactive edge width to enable a flat arrangement of modules on the staves with only acceptable efficiency losses ('slim edges')
  - contribute to MC efforts in specific questions like pixel size impact
  - gain experience with detector operation close to the thresholds
  - demonstrate the suitability of planar sensors for the IBL
- 
- Project approved by ATLAS EB
  - 17 institutes from 9 countries with more than 80 scientists

### CERN

D. Dobos, B. Di Girolamo, H. Pernegger, S. Roe, A. La Rosa

### AS CR, Prague (Czech Rep.)

V. Vrba, P. Sicho, J. Popule, M. Tomasek, L. Tomasek, J. Stastny, M. Marcisovsky, M. Havranek, J. Bohm

### LAL Orsay (France)

A. Lounis, N. Dinu, M. Benoit, R. Tanaka

### LPNHE / Paris VI (France)

G. Calderini, D. Lacour, H. Lebbolo, G. Marchiori, J. Ocariz, P. Schwemling

### University of Bonn (Germany)

M. Barbero, F. Hüggling, H. Krüger, N. Wermes

### HU Berlin (Germany)

H. Lackner

### DESY (Germany)

I. M. Gregor, U. Husemann, P. Kostka

### TU Dortmund (Germany)

C. Gößling, R. Kligenberg, D. Muenstermann, A. Rummler, G. Troska, T. Wittig, R. Wunstorf

### University of Goettingen (Germany)

J. Grosse-Knetter, M. George, A. Quadt, J. Weingarten

### MPP und HLL Munich (Germany)

L. Andricek, M. Beimforde, A. Macchiolo, H.-G. Moser, R. Nisius, R. Richter, P. Weigell

### Università degli Studi di Udine – INFN (Italy)

D. Cauz, M. Cobal, C. del Papa, D. Esseni, M. P. Giordani, P. Palestri, G. Pauletta, L. Selmi

### KEK (Japan)

Y. Unno, S. Terada, Y. Ikegami

### IFAE-CNM, Barcelona (Spain)

M. Cavalli, I. Korolkov, M. Lozano, C. Padilla, G. Pellegrini, M. Ullan

### University of Liverpool (UK)

T. Affolder, P. Allport, G. Casse, T. Greenshaw, I. Tsurin

### UC Berkeley/LBNL (USA)

M. Battaglia, T. Kim, S. Zalusky

### UNM, Albuquerque (USA)

I. Gorelov, M. Hoeferkamp, S. Seidel, K. Toms

### UCSC, Santa Cruz (USA)

V. Fadeyev, A. Grillo, J. Nielsen, H. Sadrozinski, B. Schumm, A. Seiden

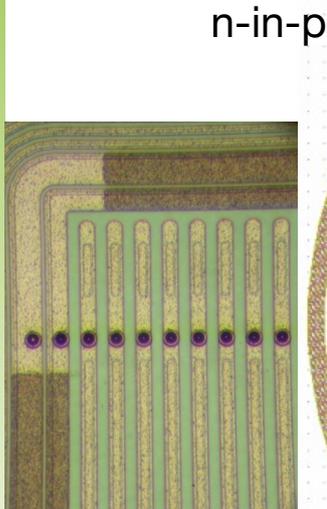
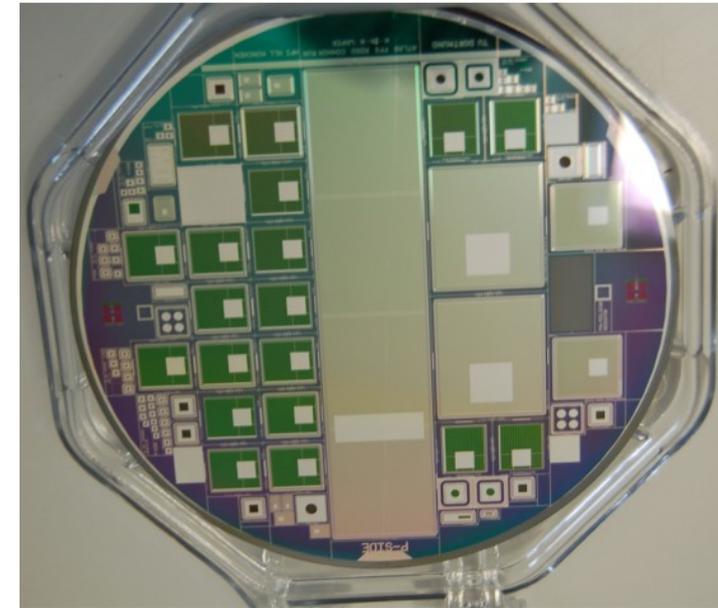


## Sensor Design

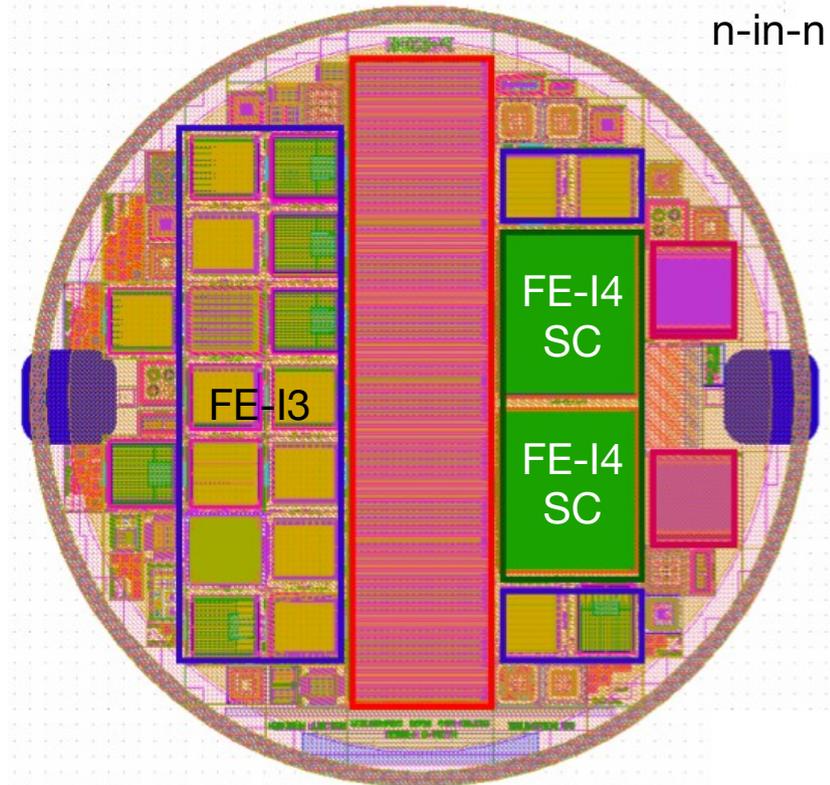
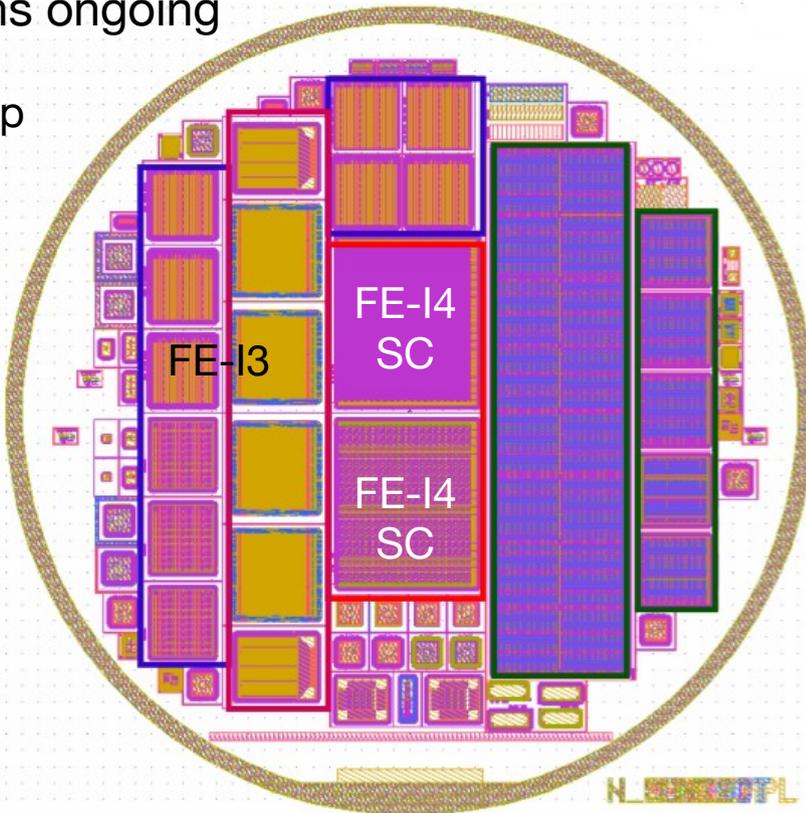
- To explore their specific advantages, both n-in-n and n-in-p designs are pursued:
  - n-in-n: proven technology, slim edges easier to achieve
  - n-in-p: single-sided sensors promise more vendors and reduced cost
- A first PPS/RD50 common production was produced in 2009 with CiS both with n-bulk and p-bulk wafers [this presentation](#)
- Several dedicated IBL-related productions are currently ongoing:
  - n-bulk with CiS with different wafer thicknesses [this presentation](#)
  - p-bulk SOI with HLL [A. Macchiolo](#)
  - p-bulk in 320  $\mu\text{m}$  and 150  $\mu\text{m}$  with Hamamatsu Photonics [N. Unno](#)
  - p-bulk with Micron [I. Tsurin](#)

# Completed sensor productions

- First run with FE-I4 compatible sensors with CiS as combined PPS/RD50 submission was delivered early 2010
- n-in-n and n-in-p on DOFZ and MCz wafers
- UBM was applied by IZM, dicing done at IZM and TU Dortmund
- First testbeam data being analysed
- irradiations ongoing



n-in-p

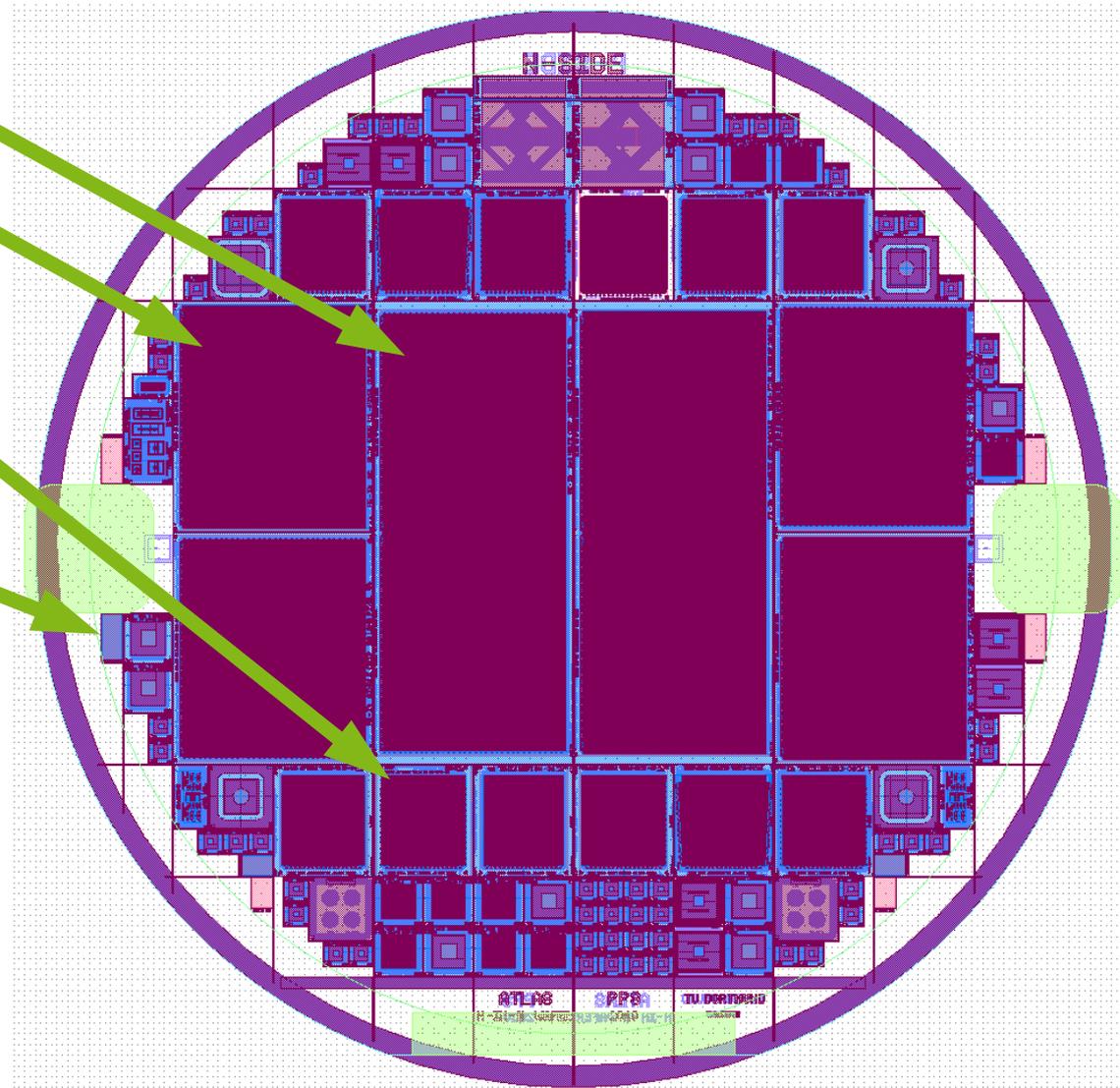


n-in-n

# IBL sensor productions: n-in-n with CiS

- Wafer layout
  - FE-I4 2x1 MultiChip-sensors
  - FE-I4 SingleChip-sensors
  - FE-I3 SC sensors
    - IBL designs
    - test designs
  - diodes, ...
- production is underway
- delivery on September 20th
- standard thickness: 250  $\mu\text{m}$
- additional thicknesses being processed:
  - 225, 200, 175 and 150  $\mu\text{m}$

R. Röder



# IBL sensor productions: n-in-p

Three manufacturers:

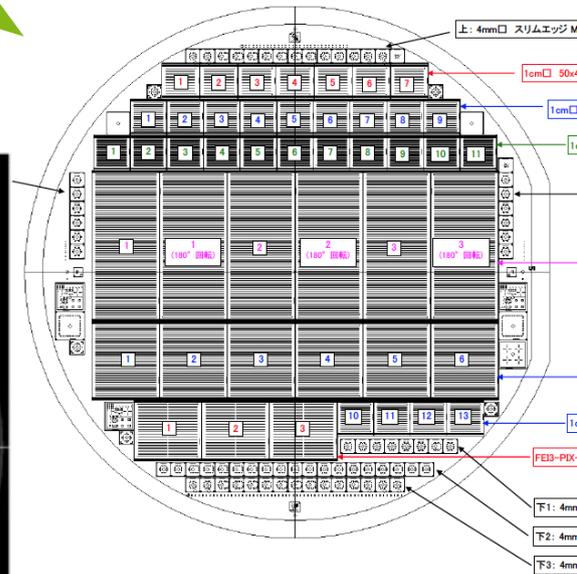
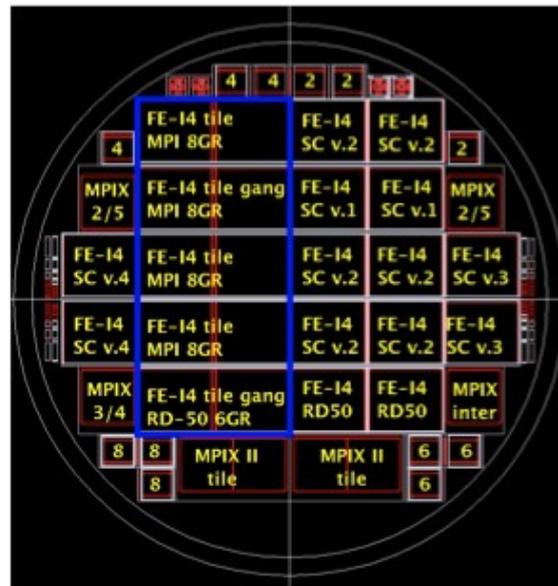
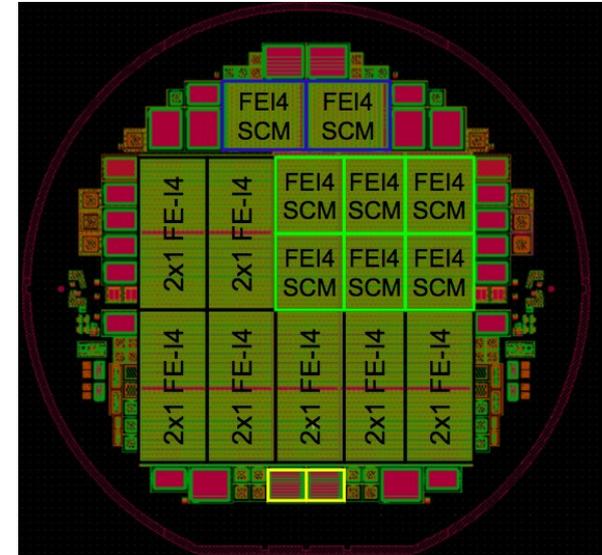
- MPI Halbleiterlabor (MPI fuer Physik, Munich)
  - Handling-wafer based SOI-process
  - Stable sensors, adjustable thickness
- Hamamatsu Photonics (KEK)
  - few guard rings
  - very high breakdown voltage
- Micron Semiconductors (University of Liverpool)
  - multiple guard-ring designs
  - flexible manufacturer

A. Macchiolo

N. Unno

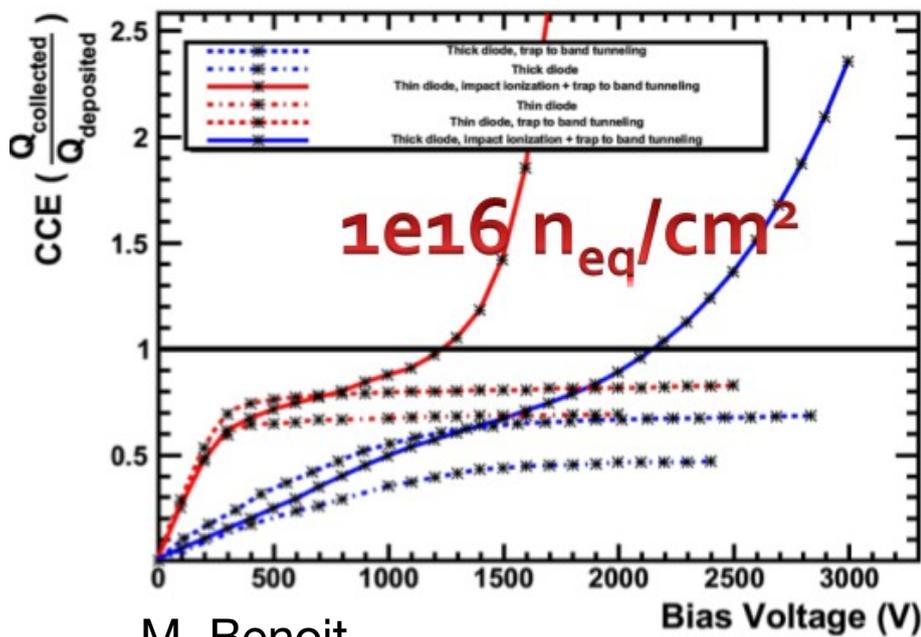
I. Tsurin

- common design features:
  - thin sensors (150  $\mu\text{m}$ )
  - single-sided processing
  - 6" wafers

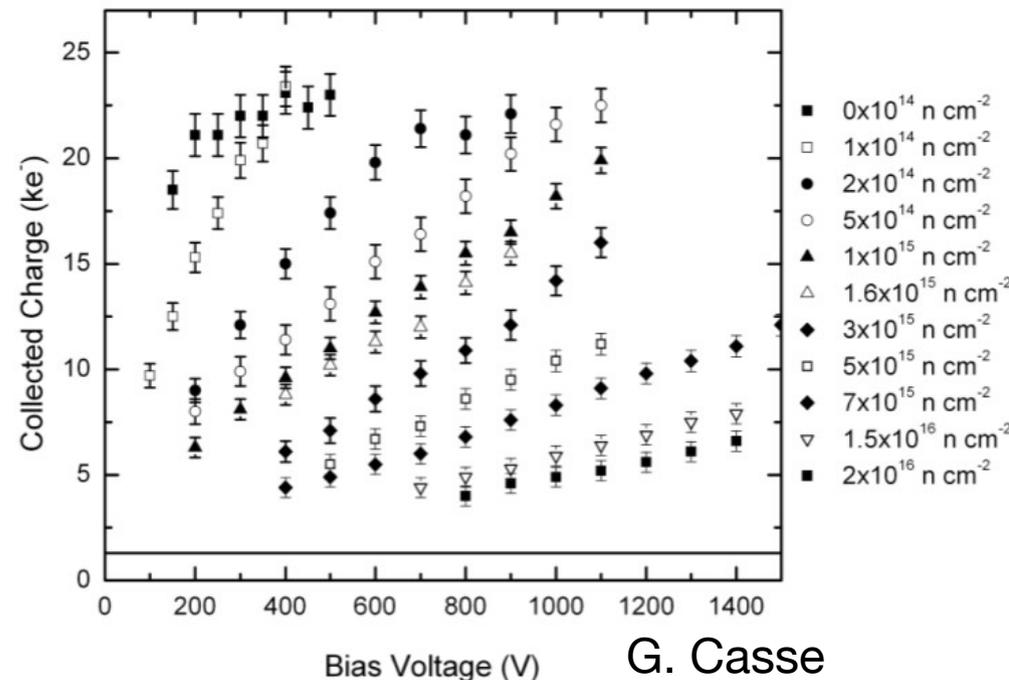


# Radiation Hardness

- Many measurements with strip sensors exhibit suprisingly large collected charge at high bias voltages
- Current hypothesis:
  - charge amplification by impact ionization in high-field regions beneath the  $n^+$ -implants
  - radiation induced trapping quenches the avalanche
- TCAD simulations qualitatively support this assumption



M. Benoit

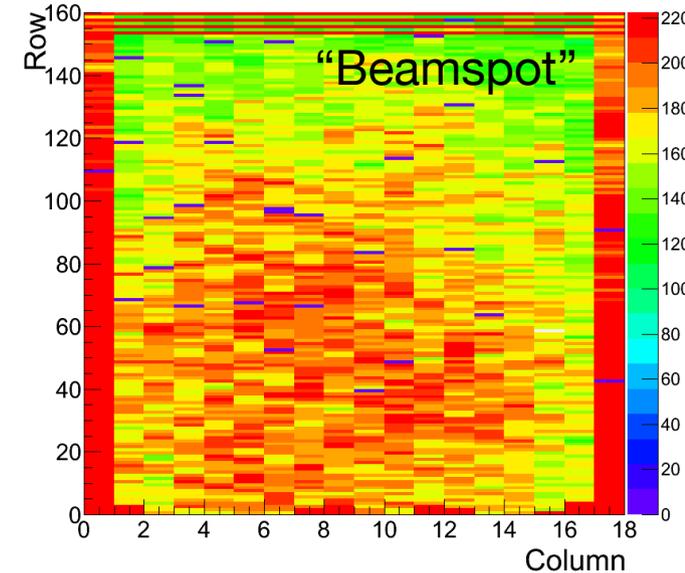


G. Casse

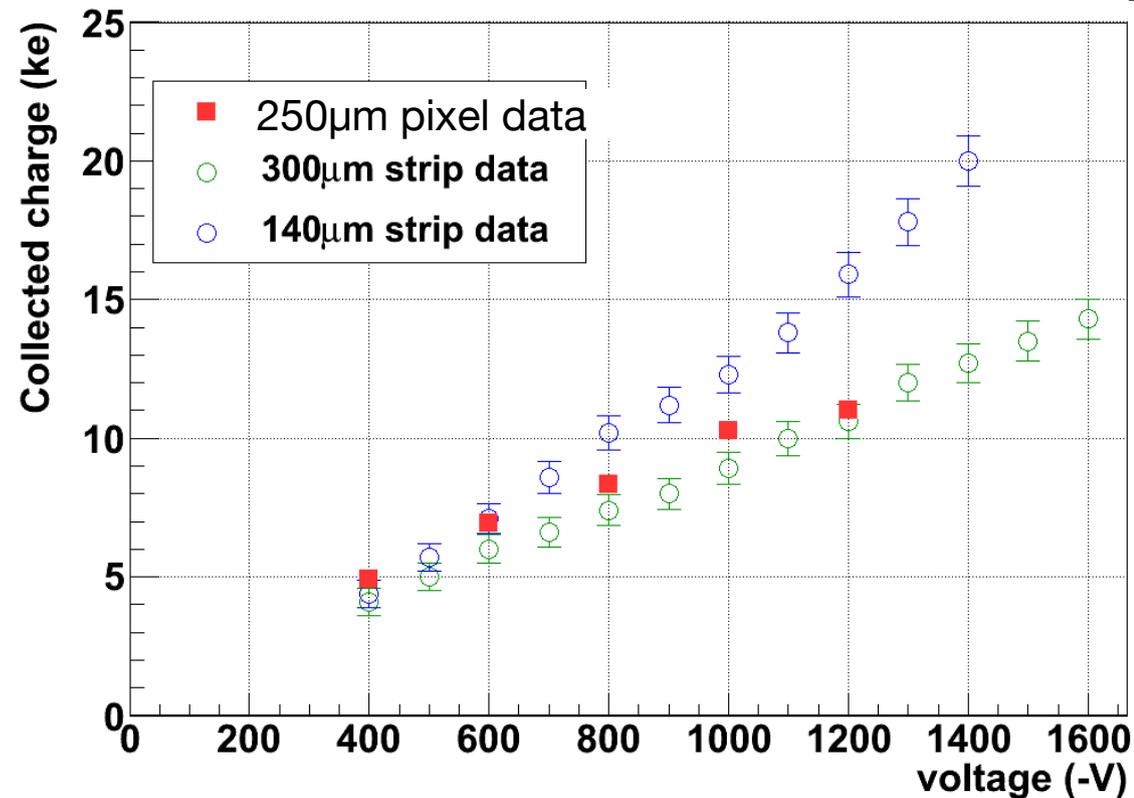
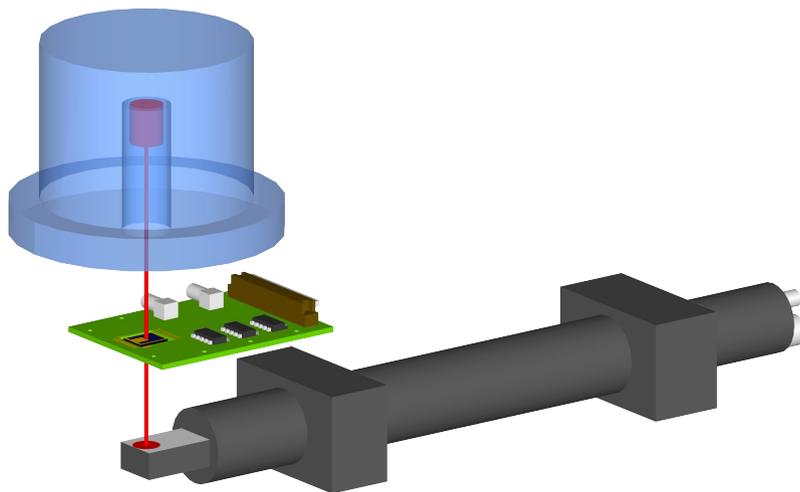


# Radiation hardness

- $^{90}\text{Sr}$  based lab measurements n-bulk of planar pixel pixel SingleChipAssemblies neutron-irradiated to  $5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$  have been done
- Collected charge in agreement with measurements on strips
- Main challenge: effects of irradiated readout chip
- Waiting for (more rad-hard) FE-I4 for comparison



D. Muenstermann (poster)



## Cost reduction activities

- Why cost reduction R&D? To enable the instrumentation of large radii
- Natural expectation: Pixel detectors should be less expensive than strip detectors per unit area (only one sensor necessary to obtain rphi and z coordinates)
- Cost driver identification: Bump bonding
- Ideas for cost reduction
  - reduce handling: SingleChip-Modules, no rework
  - reduce machine time: faster, more coarse pick-and-place
    - Daisy-chain trial programme underway with IZM **Th. Fritzsch**
  - replace/streamline galvanic solder deposition: C4NP?
  - reduce UBM cost: electroless processes?

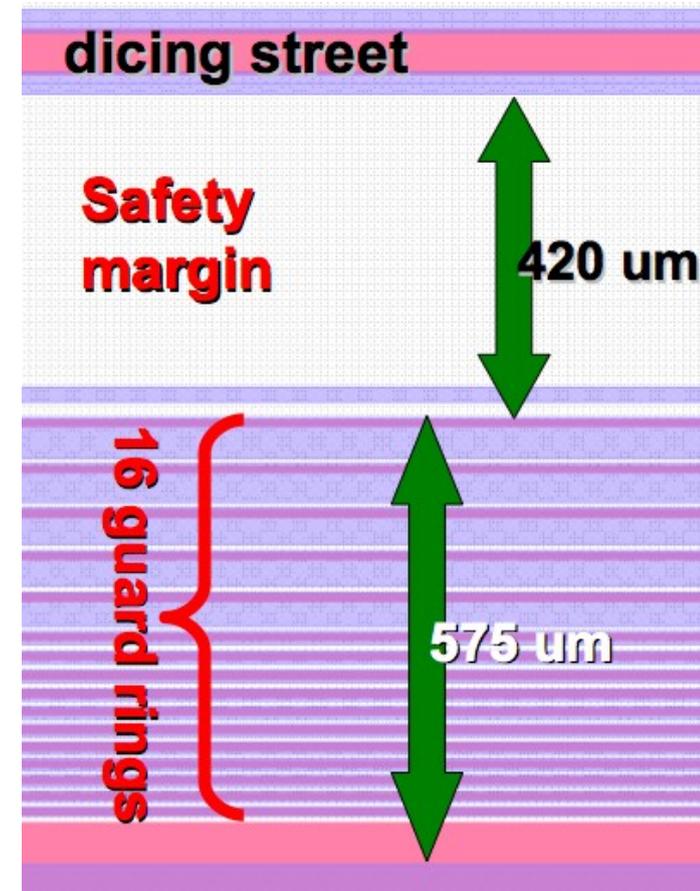
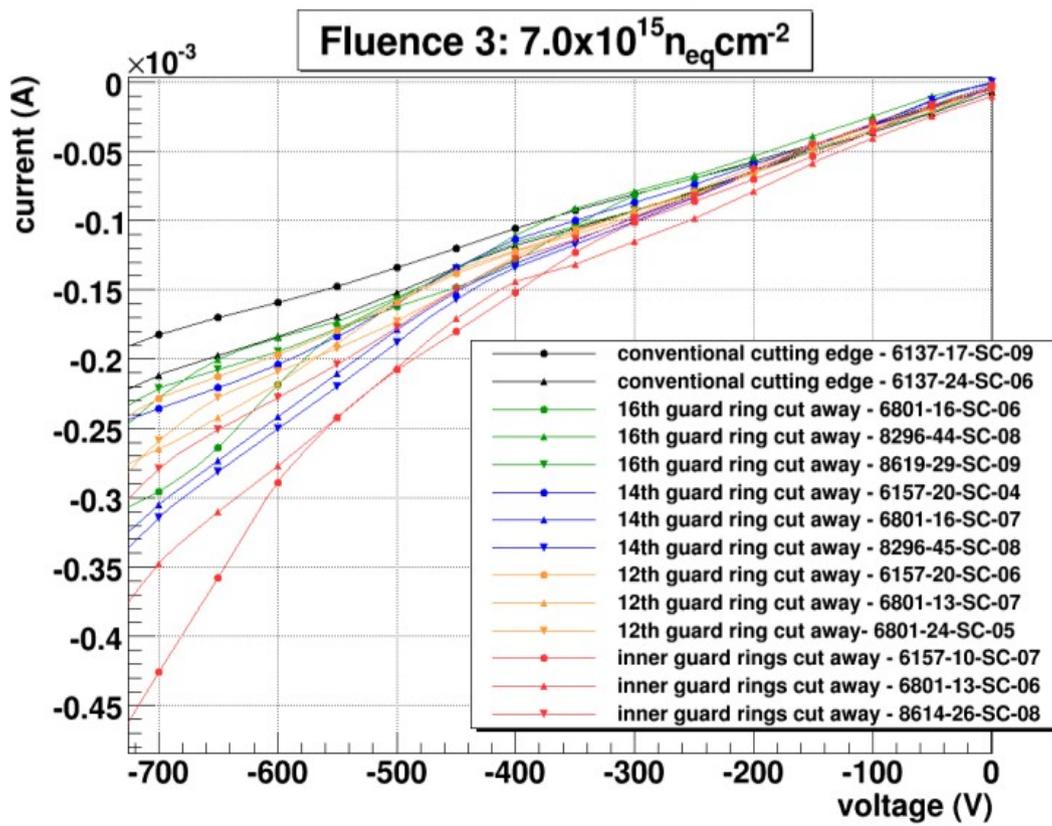
Item (per module)	ATLAS cost (CHF)	cost goal (CHF)	first cost model (CHF)
bump bonding	1900	< 500	≈ 400
readout electronics	1500	much less	≈ 250
sensor	550	equal or less	≈ 350
sum	4000	< 1500	≈ 1000



## Slim edges

- Current ATLAS n-in-n design:
  - ~600  $\mu\text{m}$  of guard rings
  - ~400  $\mu\text{m}$  safety margin
  - ~1000  $\mu\text{m}$  inactive edge!
- Flat module arrangement for IBL needs slim edges < 450  $\mu\text{m}$  to limit geometric inefficiency

After irradiation:  $7.0 \times 10^{15} \text{ neq/cm}^2$

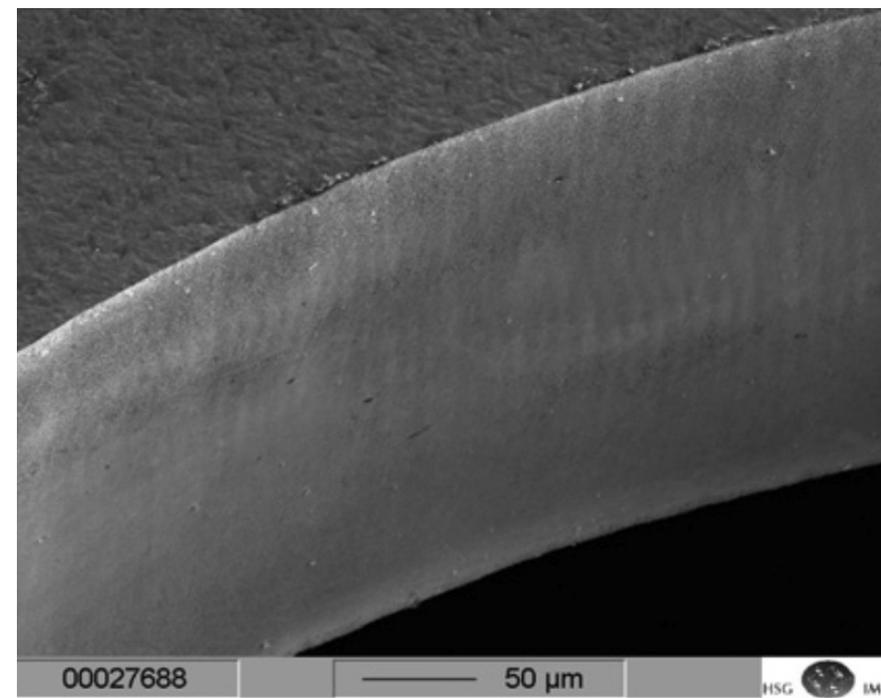
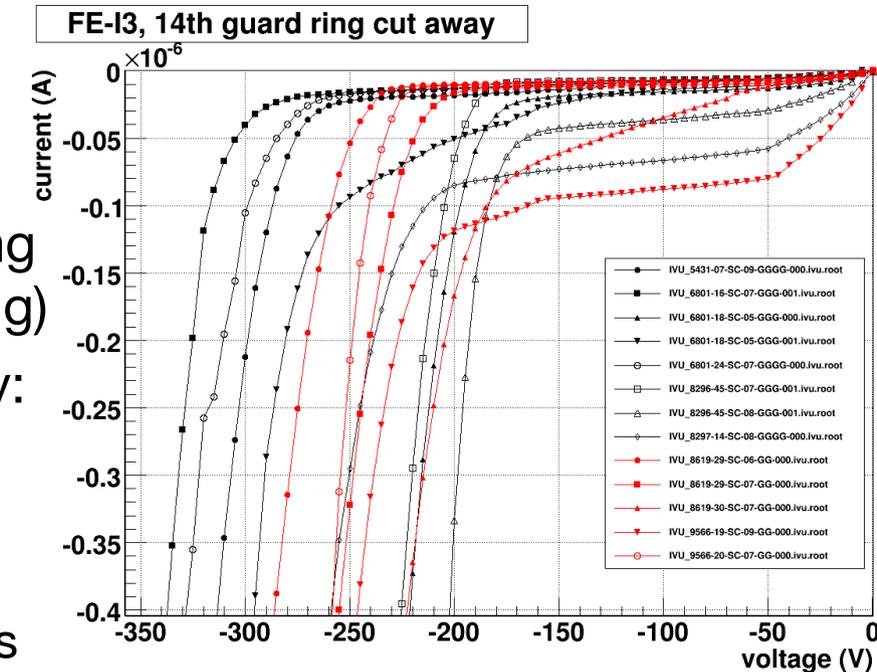
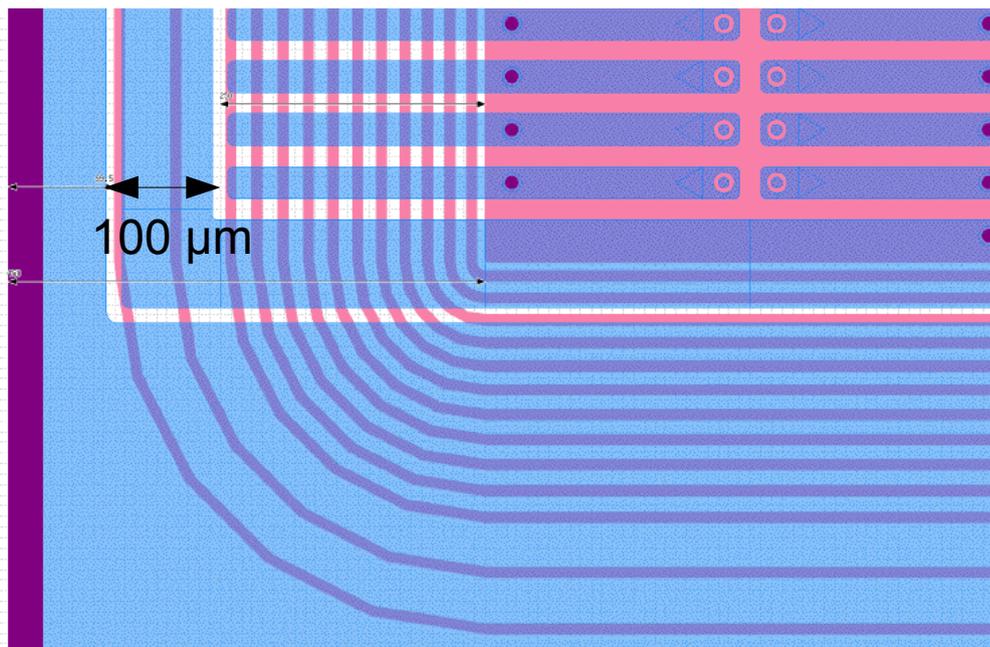


- Sensors only need  $V_{\text{breakdown}} > V_{\text{depl}} + 50 \text{ V}$  for safe depletion before irradiation, no breakdowns observed after type inversion with any guard ring arrangement!



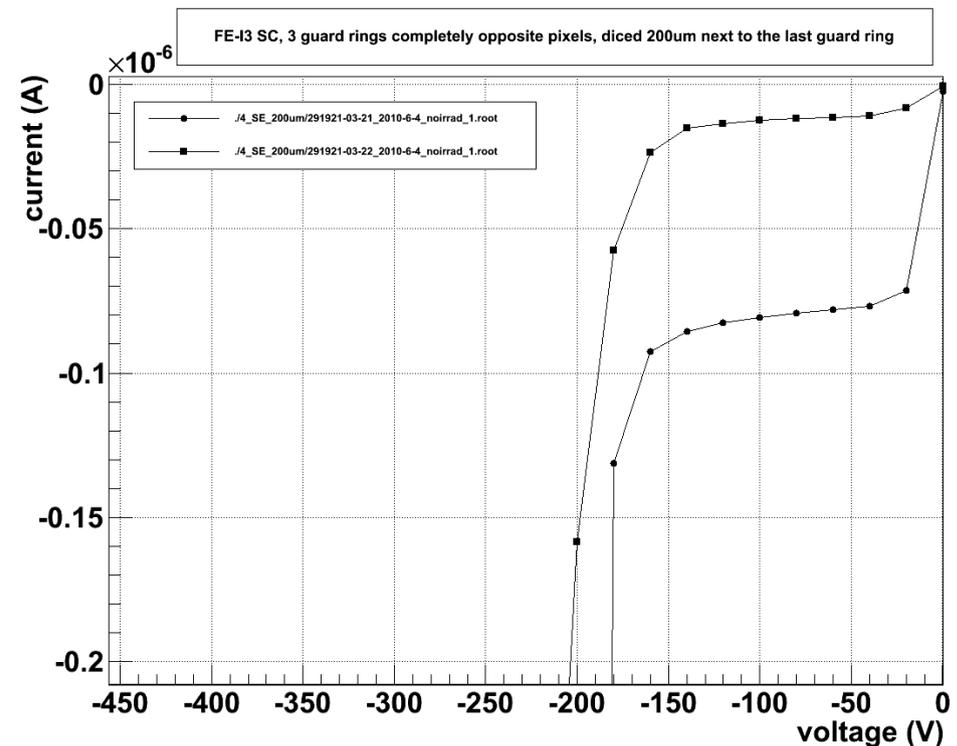
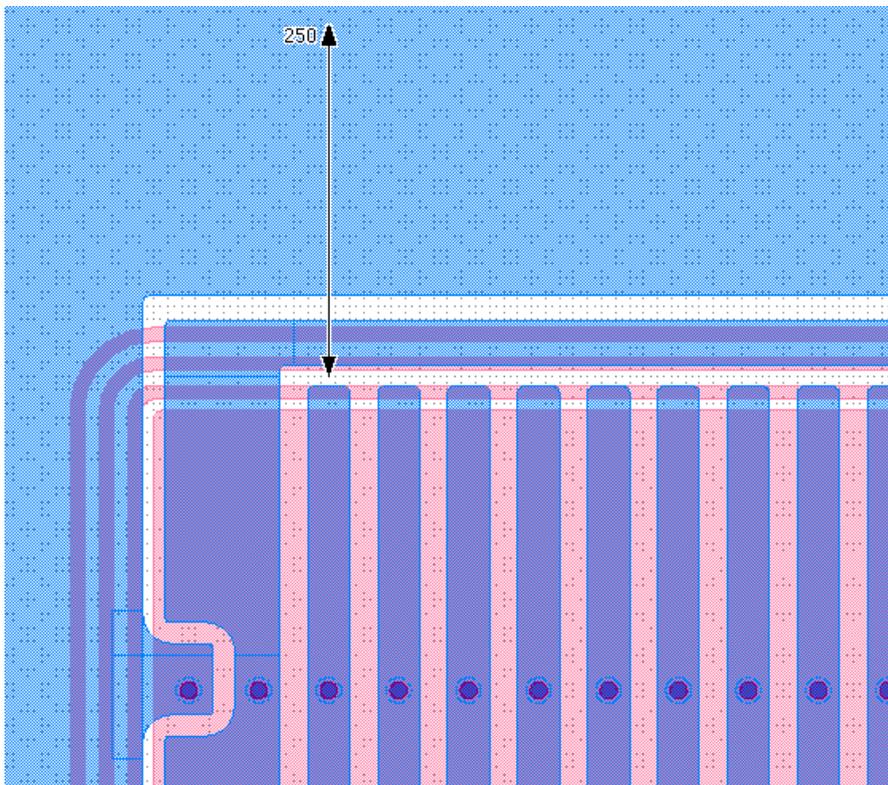
## Ideas to accomplish slim edges

- reduce number of guard rings
- reduce safety margin, test new less damaging dicing methods (ps-laser dicing, DRIE etching)
- shift guard rings (partially) into the pixel array:
  - possible for n-in-n designs
  - will lead to distorted field and possibly moderately reduced CCE before irradiation
  - after irradiation, negligible effects expected as charge is collected (and amplified) only directly beneath the pixel implants



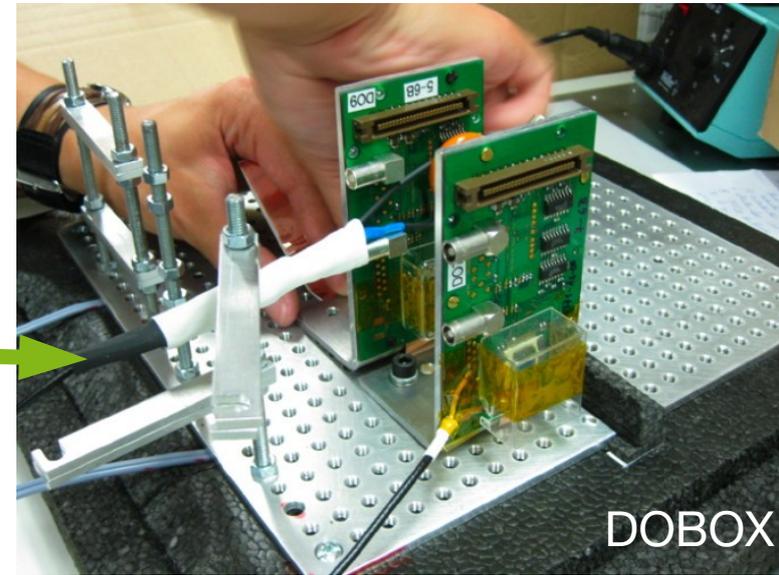
# Slim edges to the extremes

- To give an idea what might be possible with planar sensors:
  - just 3 guard rings, shifted underneath pixels
  - 200  $\mu\text{m}$  safety margin, tighter cut under investigation
  - $V_{\text{breakdown}} > 150 \text{ V}$



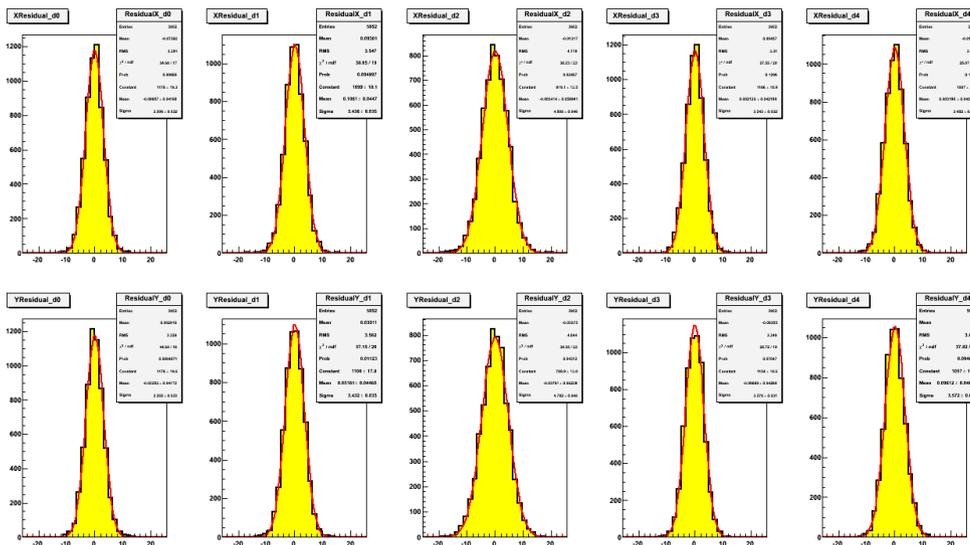
# Testbeam activities

- TurboDAQ has been integrated with the EUDET beam telescope
- Most recent testbeam done in July 2010 with Oslo-Box (Peltier) and DOBOX (dry ice cooling)
- Track reconstruction and data analysis are currently ongoing
- Some *preliminary* impressions: Reconstruction appears to work quite well

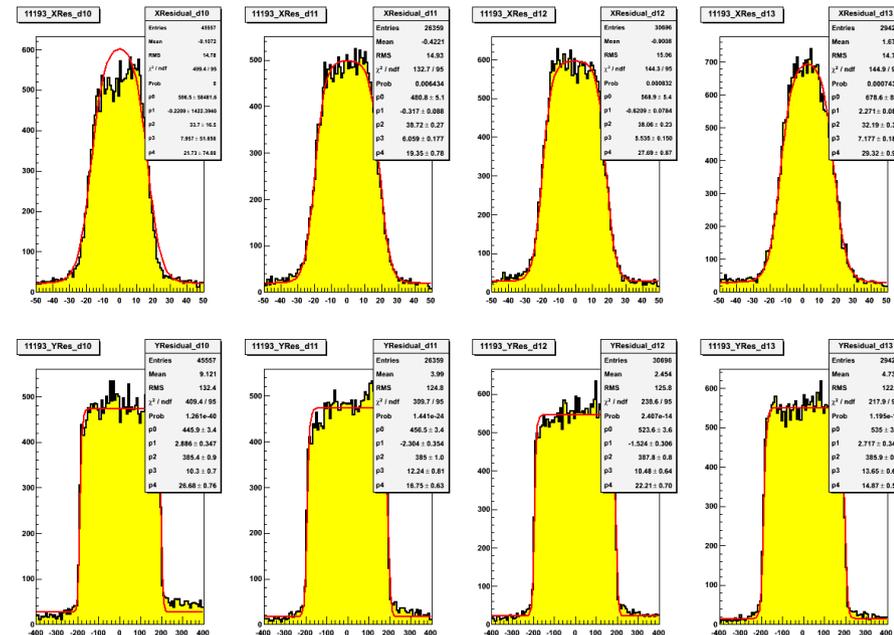


DOBOX

## EUDET telescope residuals

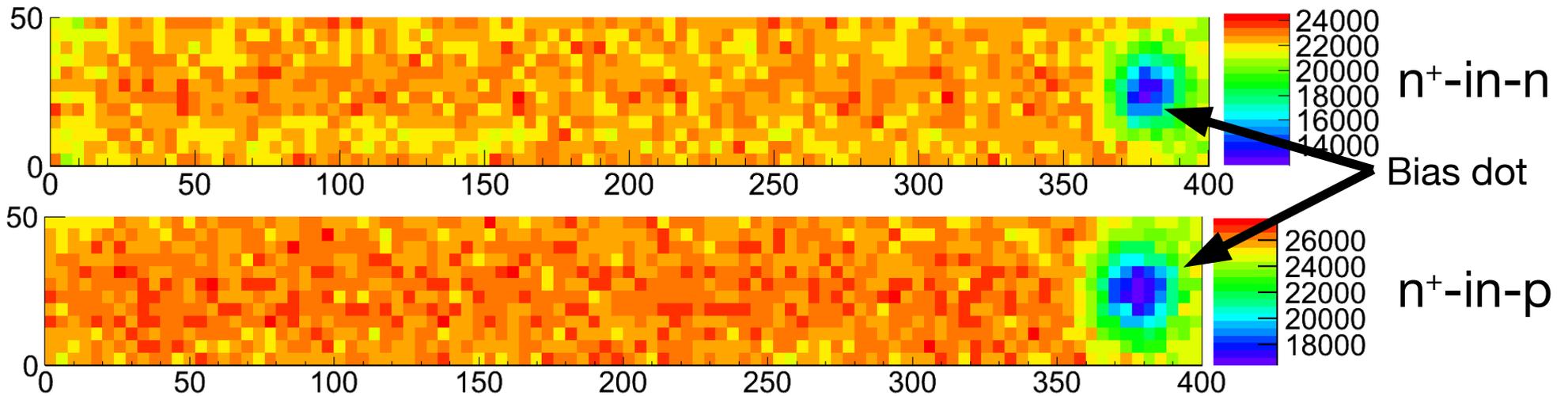


## DUT residuals

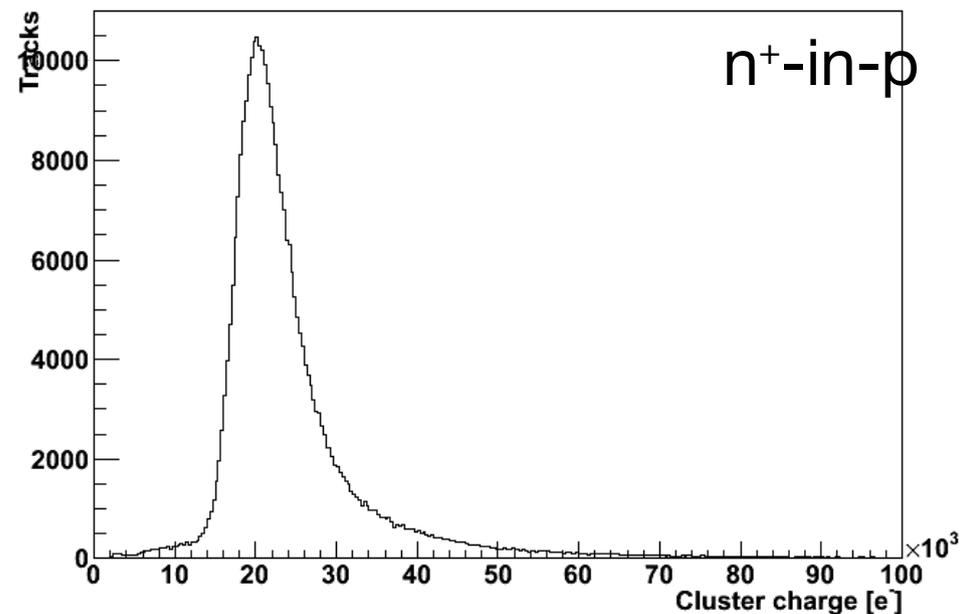
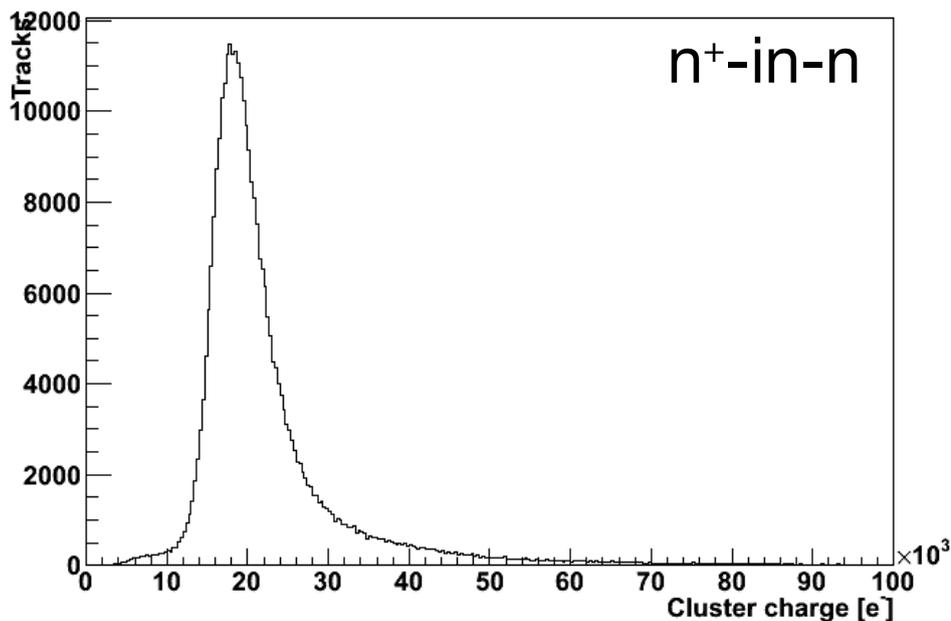


# Testbeam activities: *preliminary* impressions of data analysis

Collected charge within a pixel cell with respect to the pion's impact point



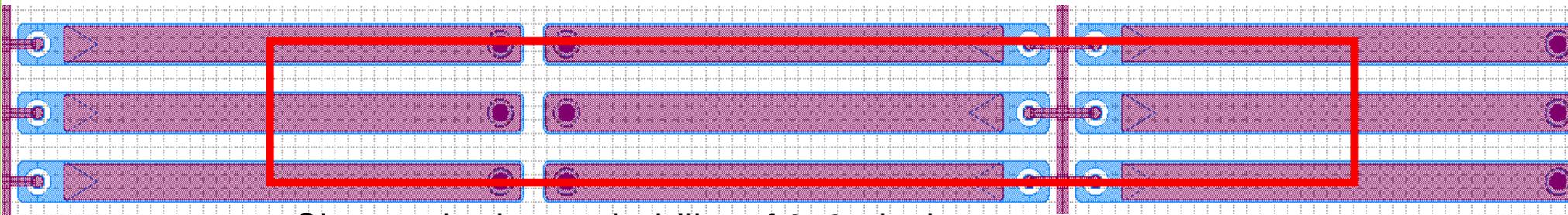
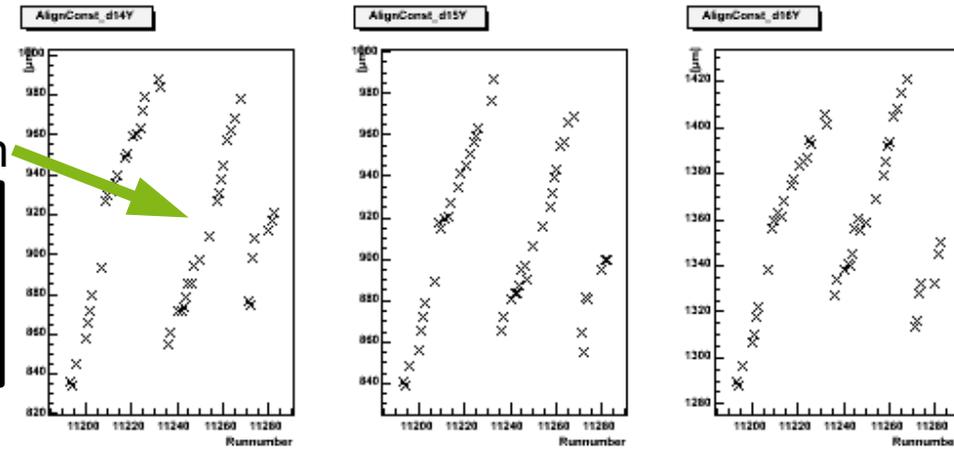
Cluster charge of unirradiated sensors



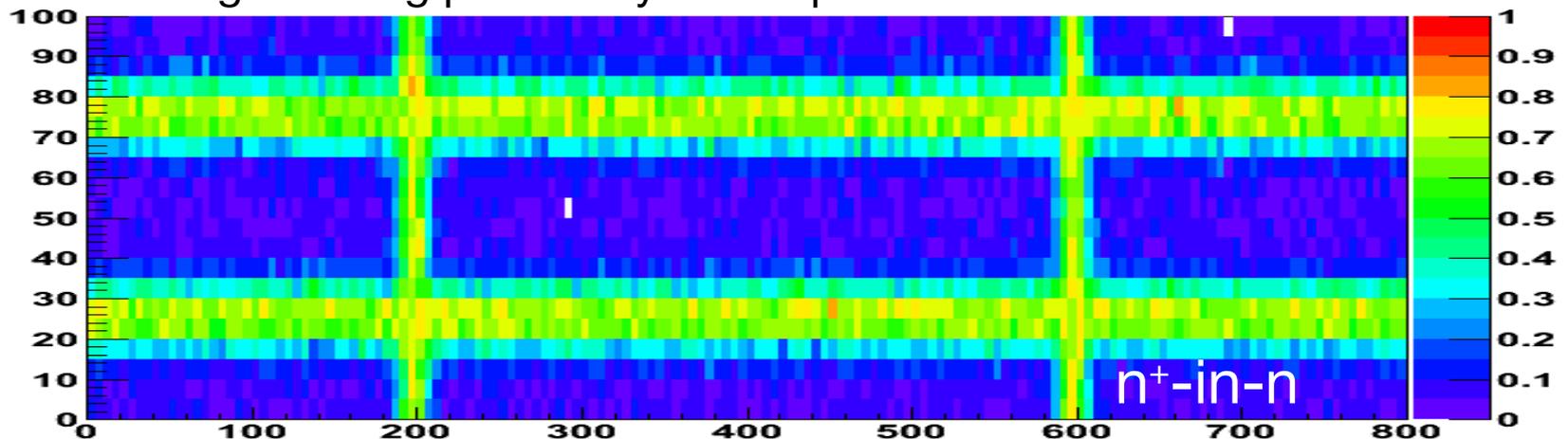
# Testbeam activities: *preliminary* impressions of data analysis

- Preliminary findings:
  - n-in-n and n-in-p sensors work quite well
  - DOBOX moved due to dry ice sublimation
  - device irradiated to  $5 \cdot 10^{15} \text{ neq/cm}^2$  works and shows nice landau distributions
  - slim-edge data obtained and look good

Sorry, no approved plots yet...



Charge sharing probability of 2x2 pixels



n<sup>+</sup>-in-n



## Conclusions and Outlook

- Planar pixel sensors are a proven and reliable sensor type
- Suitability for both highest fluences and large areas is being investigated
- The ATLAS Upgrade PPS R&D Project is making good progress:
  - Demonstration of sufficient rad-hardness for IBL in reach
  - Several IBL prototype sensor productions underway
  - Slim-edge concept ( $\sim 250 \mu\text{m}$ ) appears to be working very well
  - Cost-reduction activities entering active phase
  - Test-beam activities yielding first (exciting!) results
- Next steps in the coming months
  - Assembly and test of IBL prototype modules (FE-I3 and FE-I4)
  - Extension of rad-hardness measurements to SLHC fluences
  - Investigation of slim-edge hit efficiency after irradiation

