Recent Achievements of the ATLAS Upgrade Planar Pixel Sensors R&D Project

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for the ATLAS PPS Collaboration

LHC Upgrade

- Planar IBL Production
- Radiation Hardness
- Thin sensors
- Slim/Active edge
- HL-LHC Intermediate Layers
- Simulation
- Testbeams

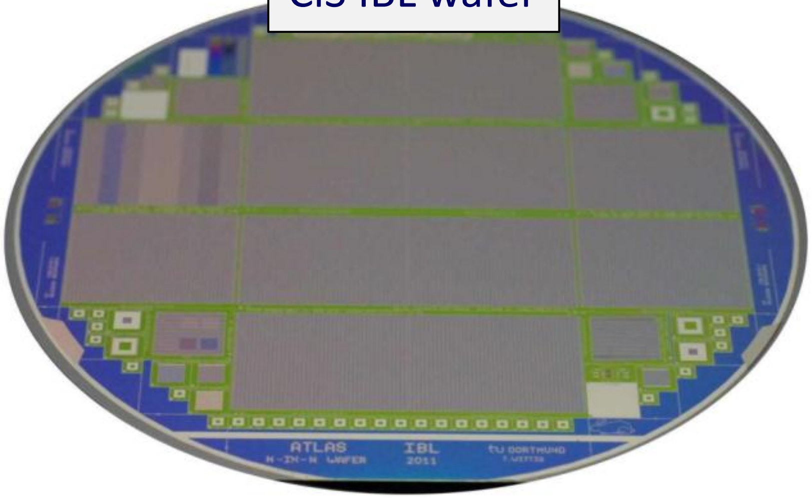
Presenting the work of many people.

Sorry, if I mislabelled/-represented your plots/results/work.

Planar IBL Production

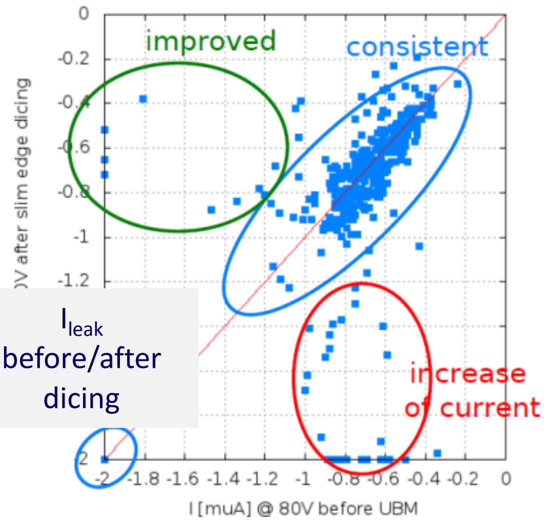
IBL sensor production finished:

- 9 batches from CiS, 150 accepted wafers
  → 544 functional double-chip sensors (target was 448 DC)
  plus 409 single-chip sensors (R&D)
  → 160 tiles built into modules
  → 220 available with UBM

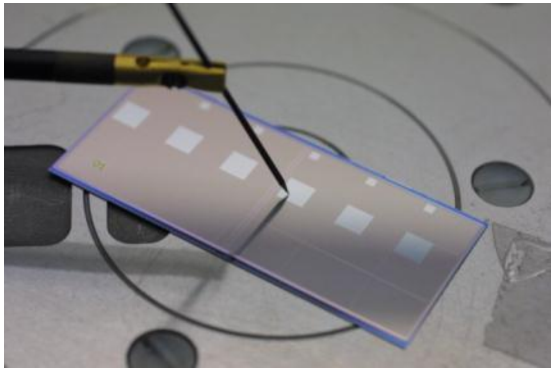


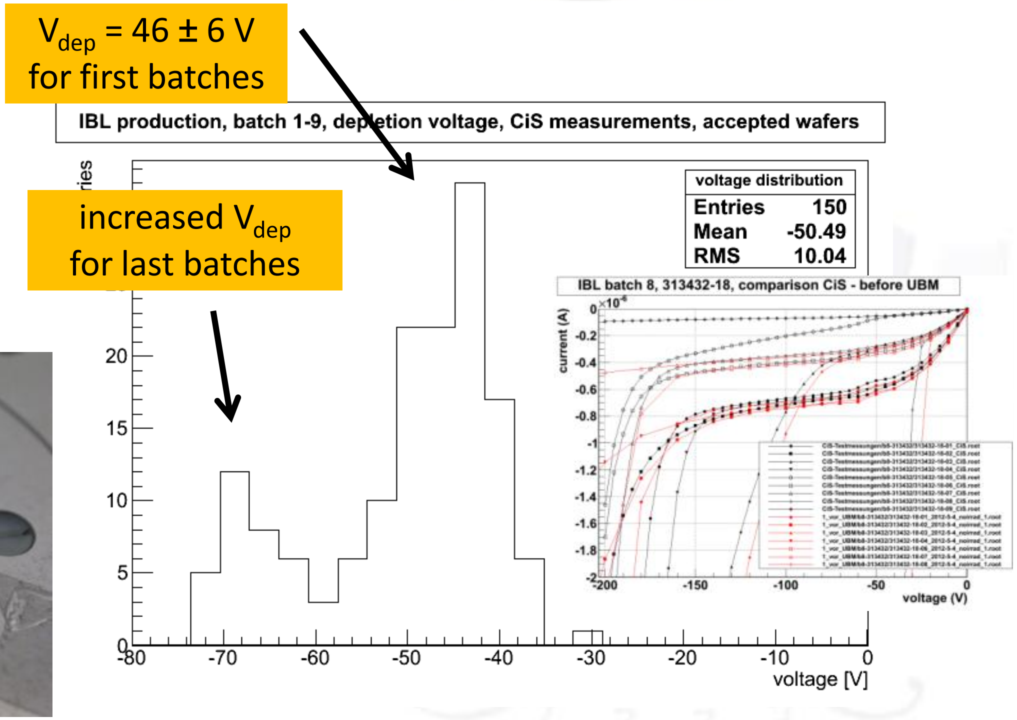
CiS IBL wafer

	batch 1	batch 2	batch 3	batch 4	batch 5	batch 6	batches 7-9	sum
received wafers	20	22	18	20	17	22	31	150
received DCS	80	88	72	80	68	88	124	600
good DCS	69	76	64	70	62	83	121	544
yield	86.3%	86.4%	88.9%	87.5%	91.2%	94.3%	97.6%	90.6%



I_{leak} before/after dicing





V_{dep} = 46 ± 6 V for first batches

increased V_{dep} for last batches

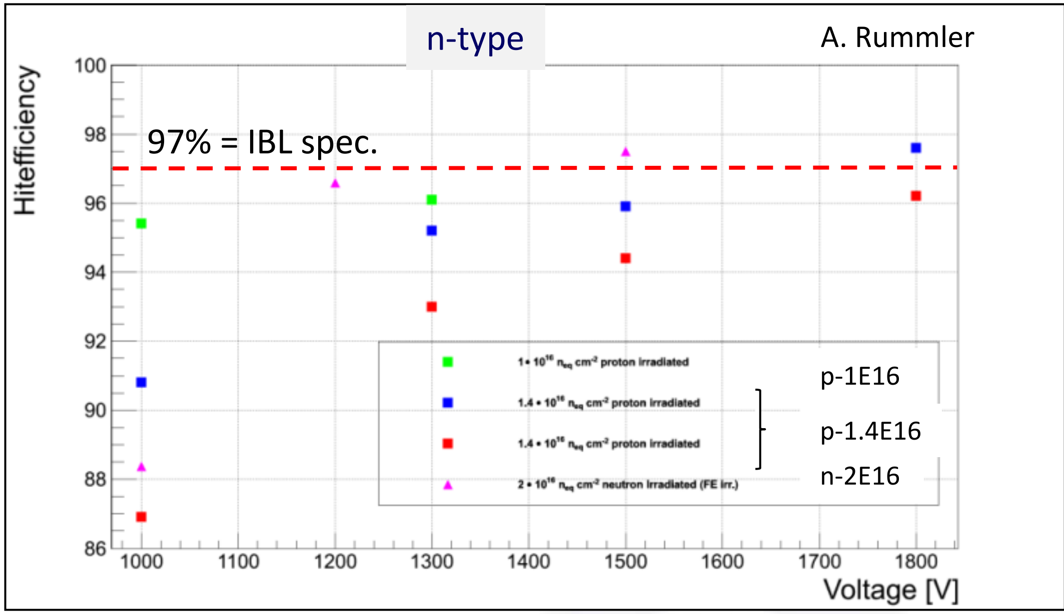
Plots stolen from T. Wittig

Radiation Hardness

Radiation hardness of planar n- and p-bulk sensors

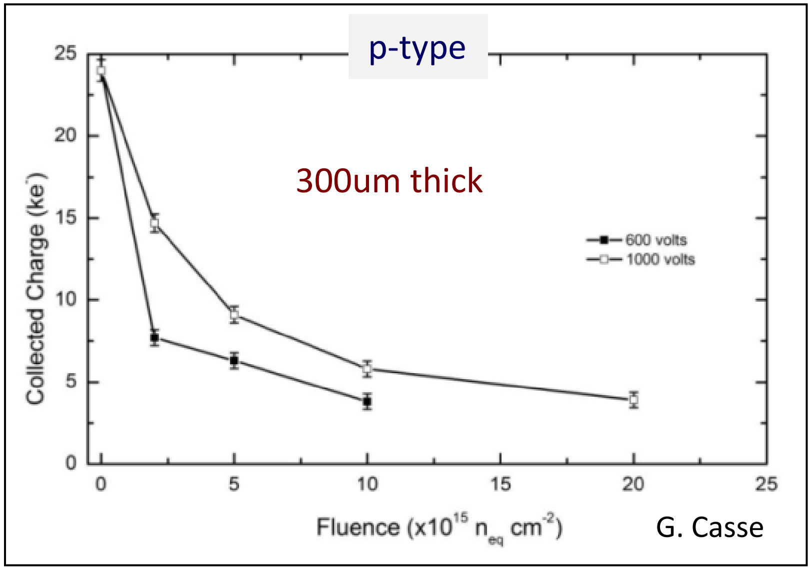
→ Irradiations reaching the 1-2E16 n_{eq}/cm^2 region:
(here: compare 'thick' sensors, O(300um))

- n-type sensors shown to work at 2E16 n_{eq}/cm^2
  (old ATLAS production, V_{bias} >= 1kV, 4ke < Q_{mip} < 8ke)
- p-type sensors shown to work at 1E16 n_{eq}/cm^2
  (MPP CiS production, V_{bias} <= 1kV, Q_{mip} <= 6ke)
- p-type strip sensors studied up to 2E16 n_{eq}/cm^2
  (Liverpool Micron production, V_{bias} <= 1kV, Q_{mip} < 5ke)



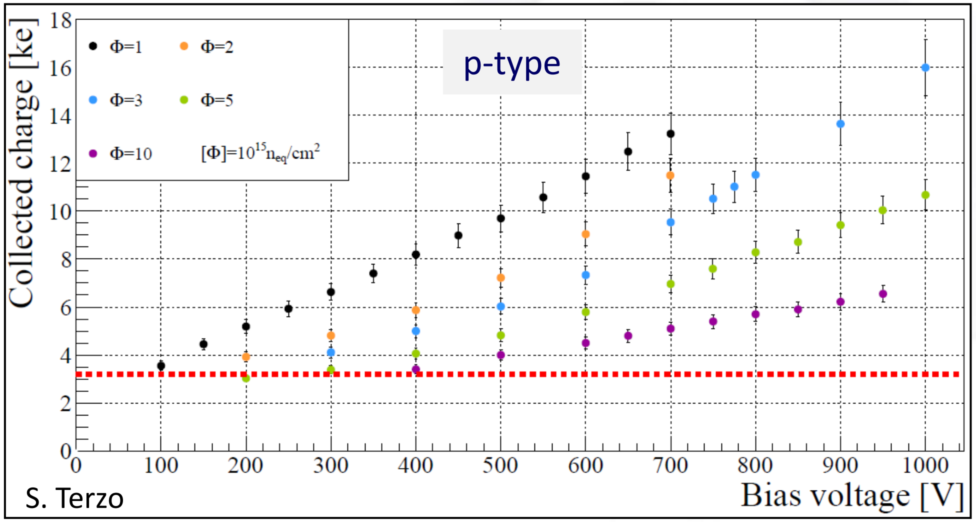
n-type

A. Rummler



p-type

G. Casse



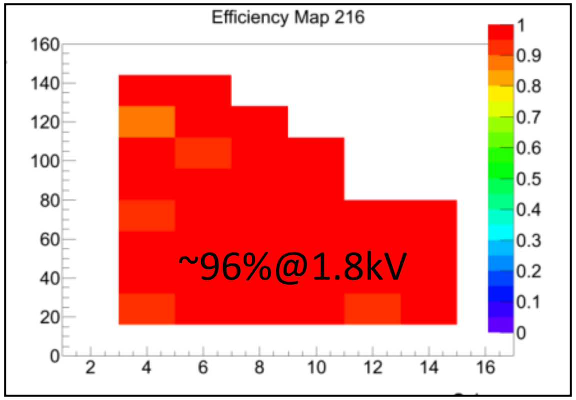
p-type

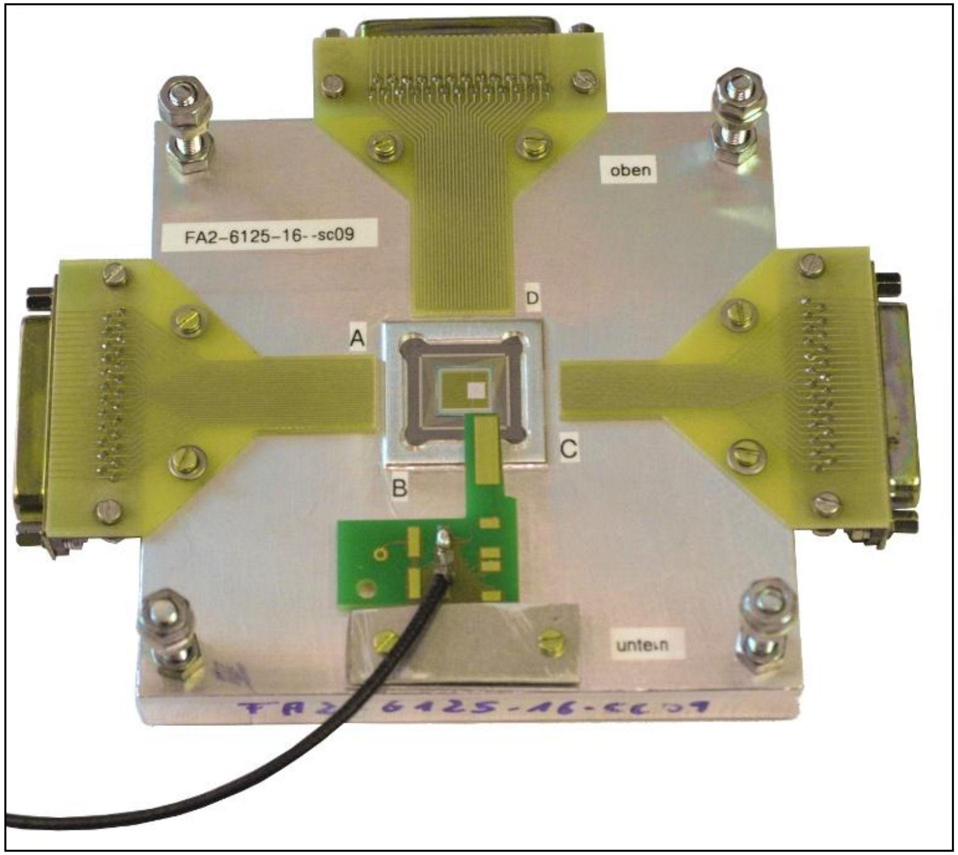
S. Terzo

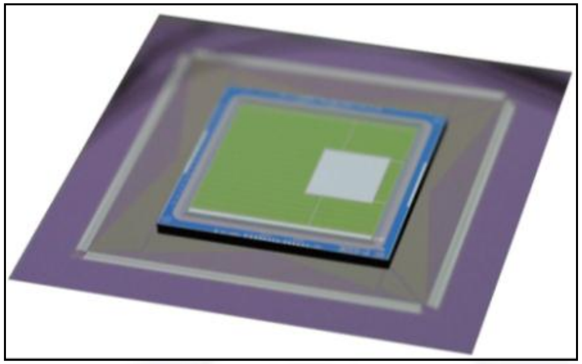
Radiation Hardness

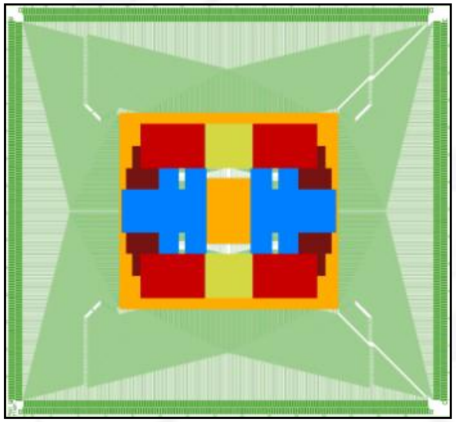
Try to separate FE- and sensor effects:

- ‘low temperature’ In bumping (FE-I3)
- new fan-out structure to connect pixels to external readout (e.g. ALIBAVA or commercial CSA)









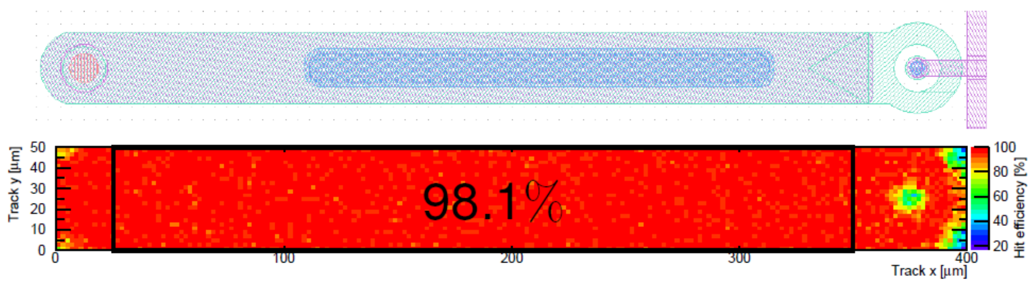
Plots from Dortmund (A. Rummler and T. Plümer)

Radiation Hardness

One of the earliest testbeam results:

Main loss of hit efficiency at the bias dot and the trail leading to it ('bias rail').

(True for both n- and p-bulk sensors)

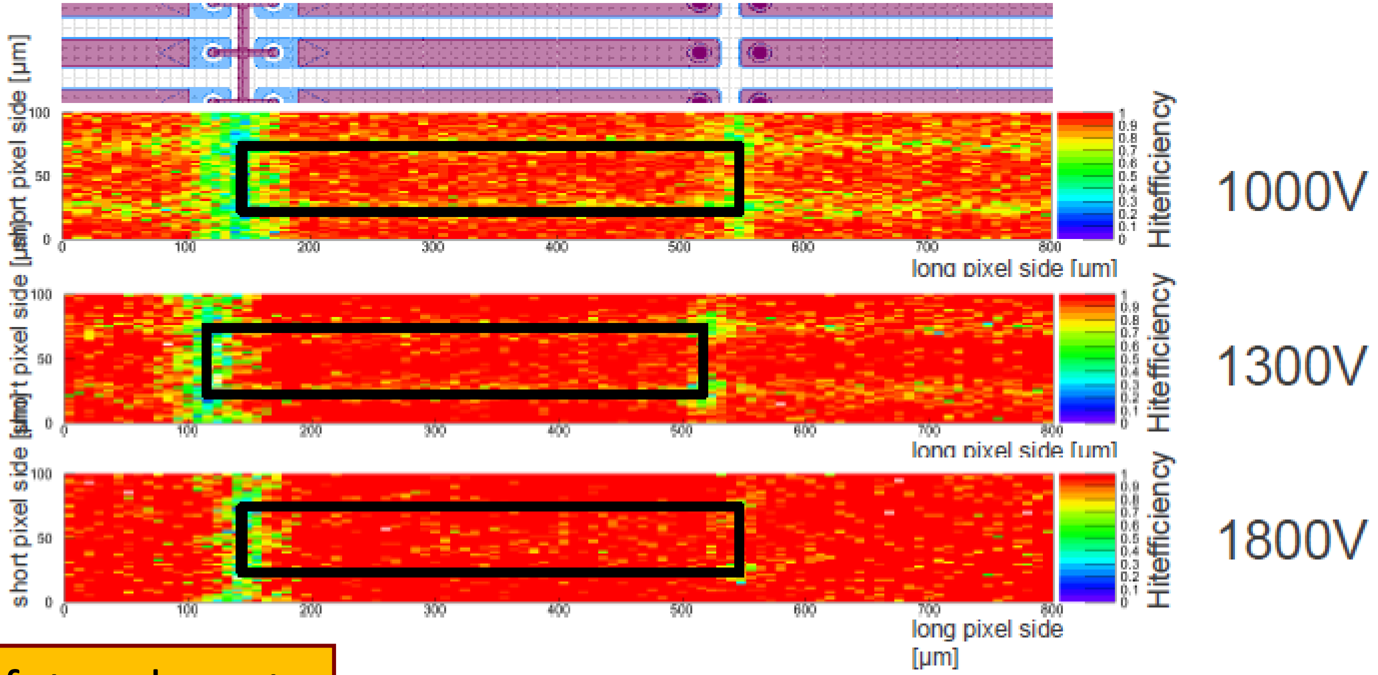


285um thick p-bulk , 1E16 n_{eq}/cm^2
TB: ϕ=0°
→ avg. hit efficiency 97.2%
→ central region 98.1%

S. Terzo

250um n-bulk,
2E16 n_{eq}/cm^2
TB: ϕ=0°

A. Rummler



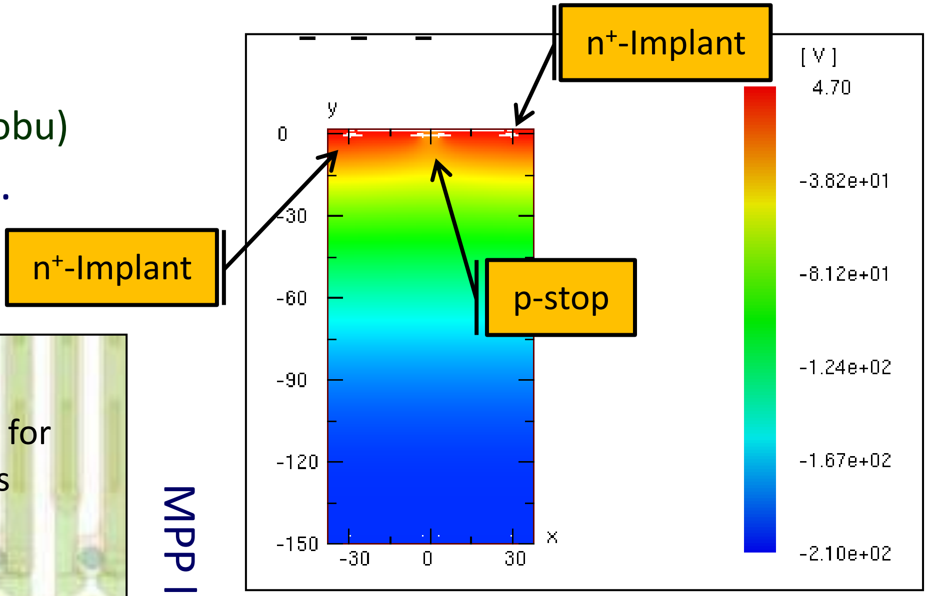
→ improve bias grid design in future layouts

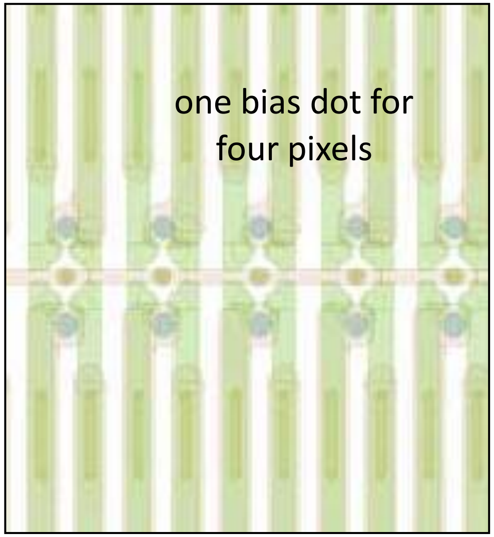
Radiation Hardness

After many discussions and simulations (more from Nobu) several new bias grid/rail layouts under investigation.

Sensor productions ongoing:

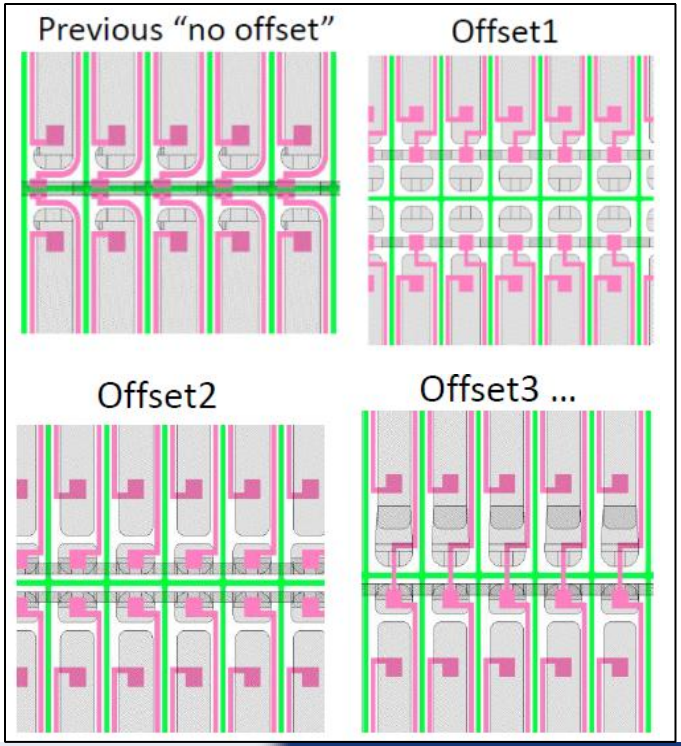
- CiS n-bulk
- CiS p-bulk
- HPK p-bulk



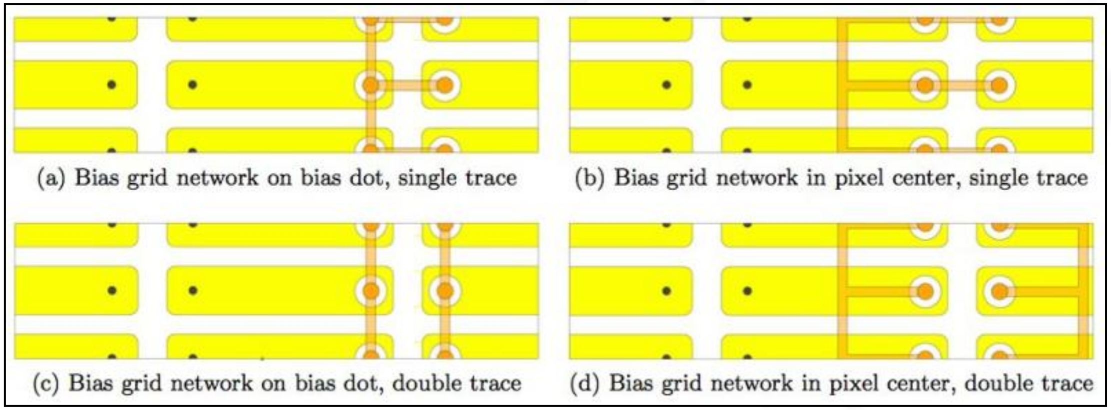


MPP layout

KEK layout



Dortmund layout



(a) Bias grid network on bias dot, single trace

(b) Bias grid network in pixel center, single trace

(c) Bias grid network on bias dot, double trace

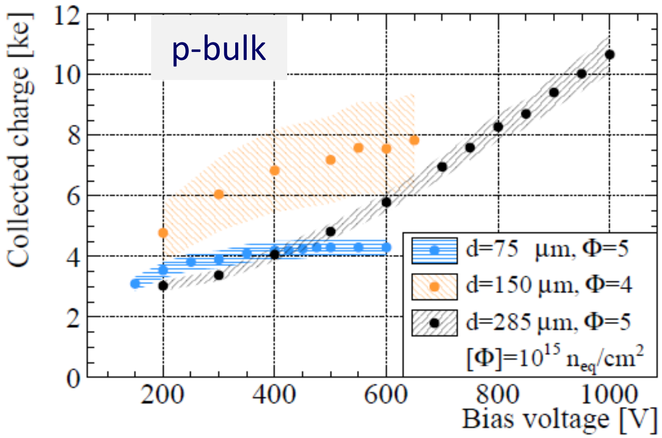
(d) Bias grid network in pixel center, double trace

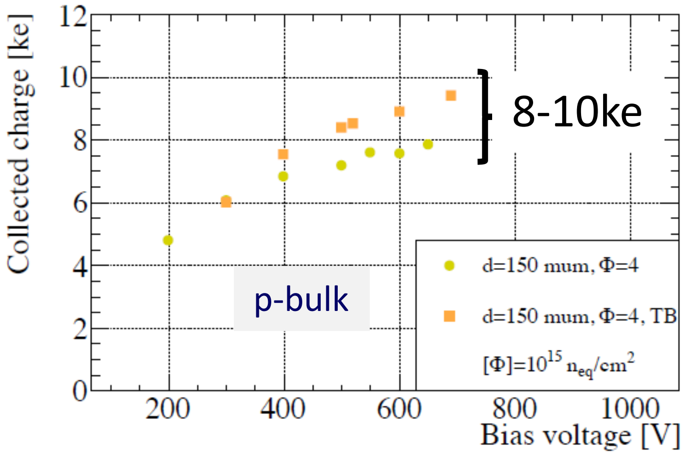
Thin Sensors

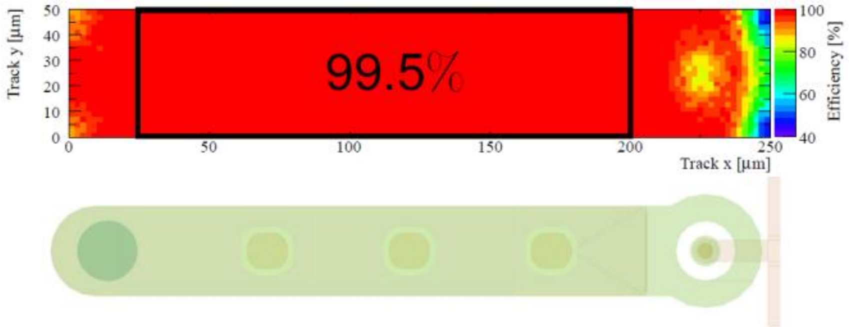
Thin sensors

- perform as expected (similar to thick ones) before irradiation
- offer substantial advantages above fluences of 5E15 n_{eq}/cm^2
- studying thickness between 150um and 75um
- samples irradiated up to 2E16 n_{eq}/cm^2

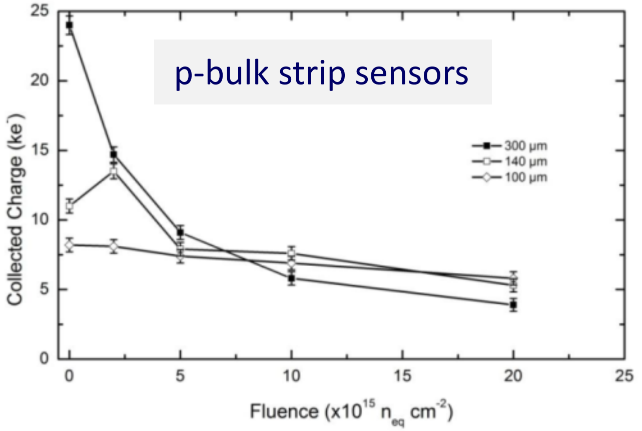
➔ much more detail in the next few talks

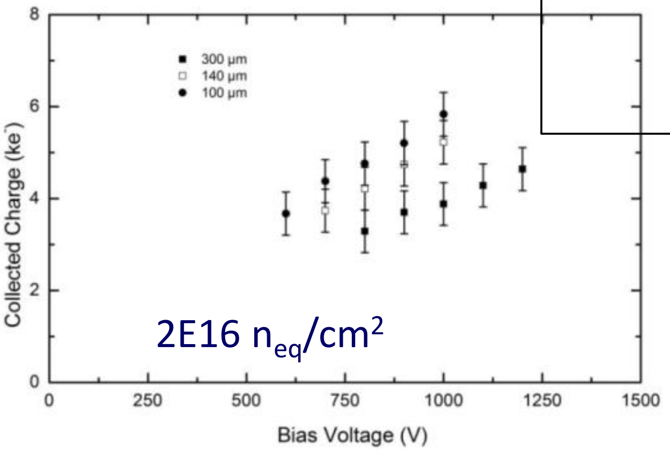






p-bulk 150um, p-4E15 n_{eq}/cm^2,
Vbias=690V, TB ϕ=0°,
avg. hit efficiency 97.7%



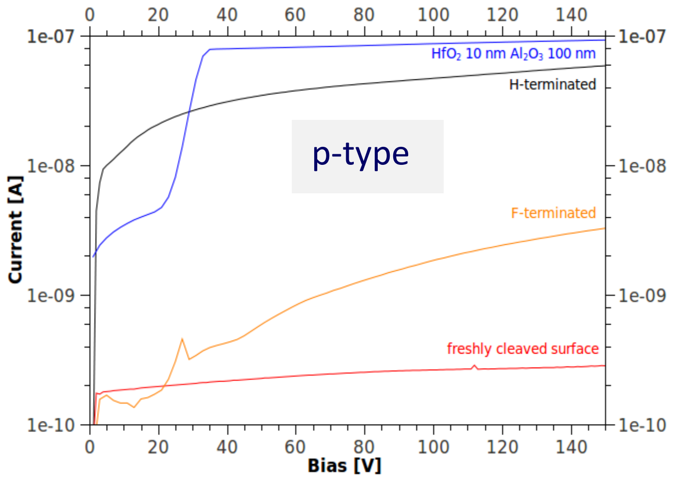


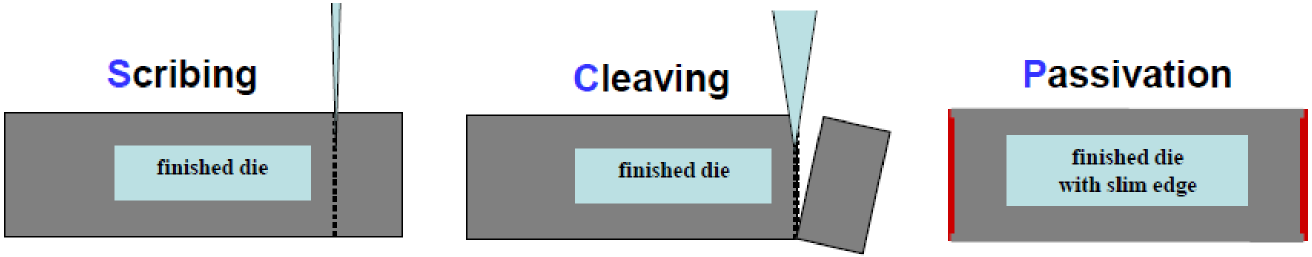
Plots stolen from S. Terzo and G. Casse

Slim/Active Edge

Scribe-Cleave-Passivate technology

- reduce edge width significantly
- treatment is post-processing and low-temperature
- different scribe-techniques, DRIE looks most promising
- trying to industrialize cleaving
- surface termination non-trivial





Scribing

finished die

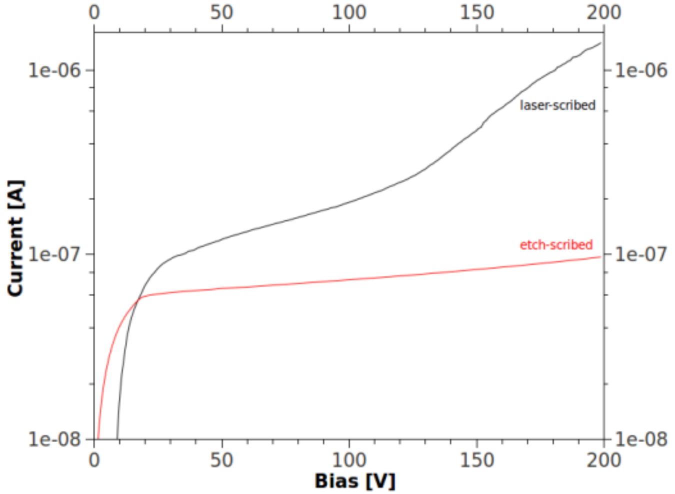
Cleaving

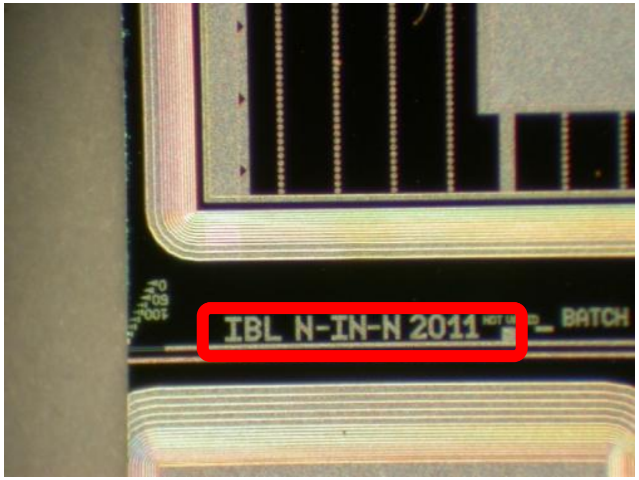
finished die

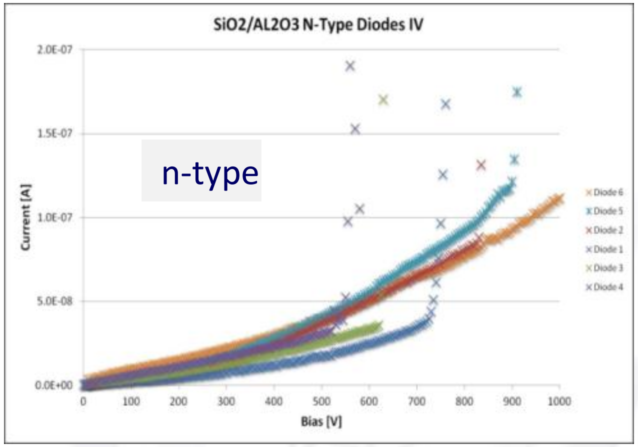
Passivation

finished die
with slim edge

tested on IBL sensors







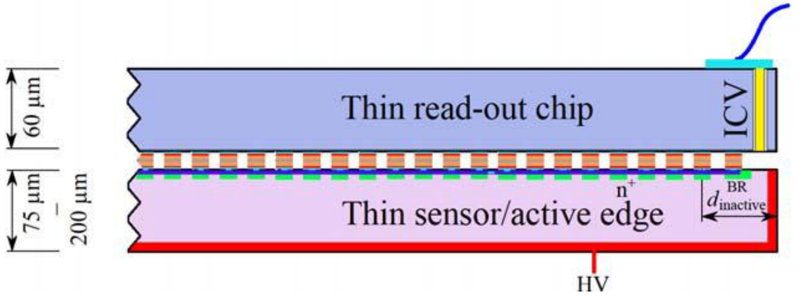
Plots stolen from V. Fadeyev

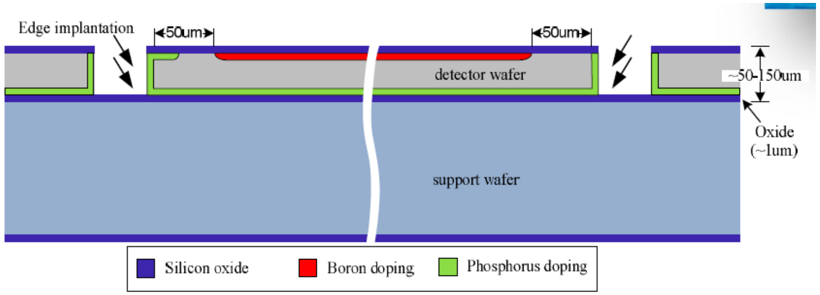
More details from H. Sadrozinski

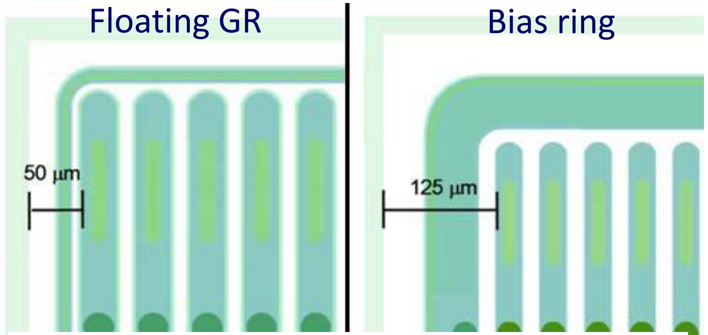
Slim/Active Edge

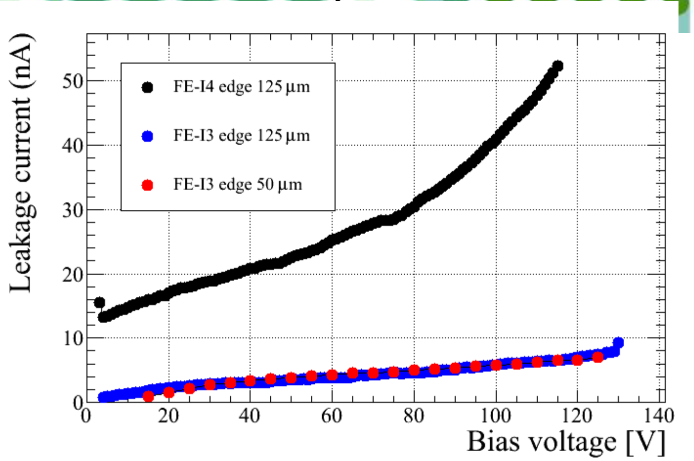
Active Edge sensors

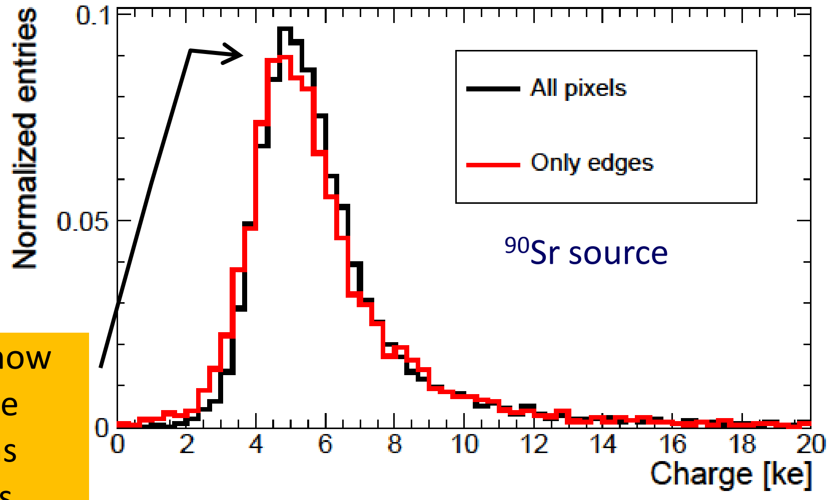
- MPP/VTT:
  - towards 4-side buttable sensors using TSV
  - MPW run at VTT: different edge designs, 100um and 200um thick, p-spray
  - flip-chip done at VTT
  - 100um samples: V_{dep} ~ 7-10V, V_{break} ~ 120V, Q_{mip} ~ 6±1ke









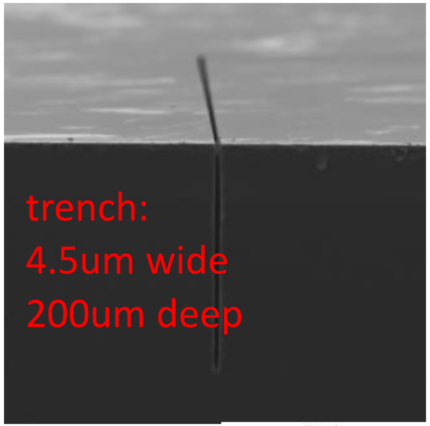


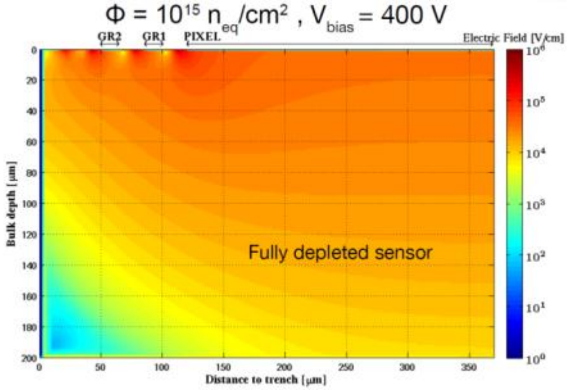
edge pixels show same charge collection as center ones

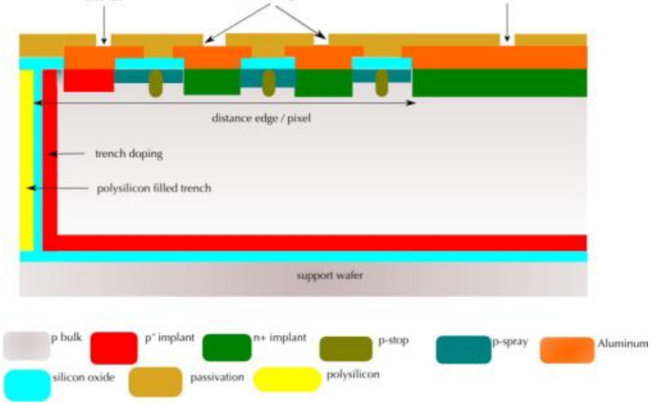
Plots stolen from A. Macchiolo

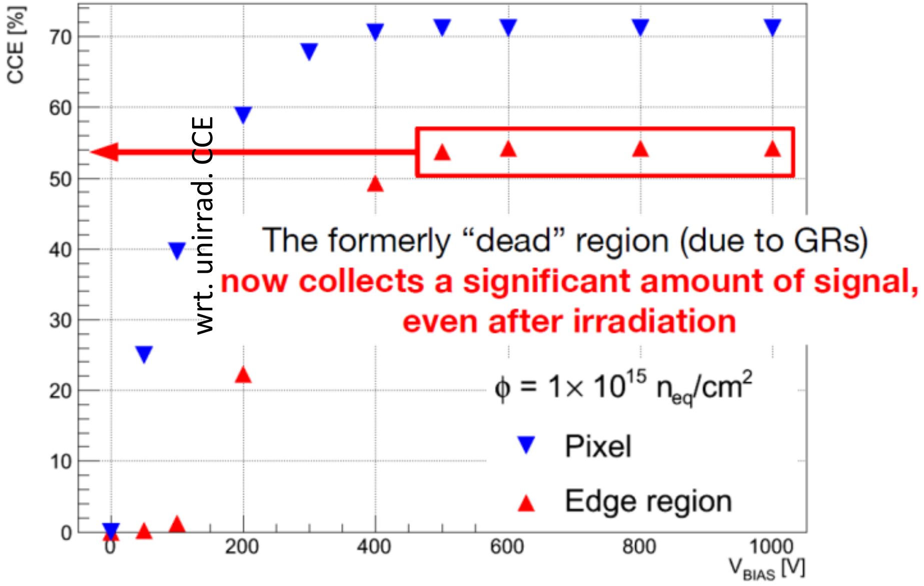
Slim/Active Edge

- LPNHE/FBK:
  - DRIE trench etching, sidewall doped by diffusion
  - different GR and edge designs
  - a lot of simulation done (Silvaco 2D TCAD)
  - first sensors in hand
    ➔ first measurements look promising

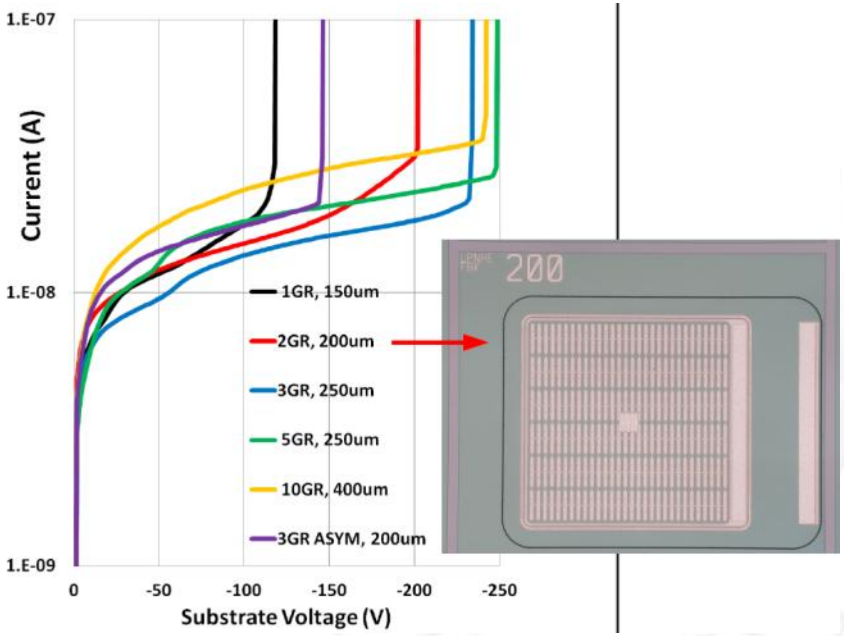








The formerly "dead" region (due to GRs)
now collects a significant amount of signal, even after irradiation

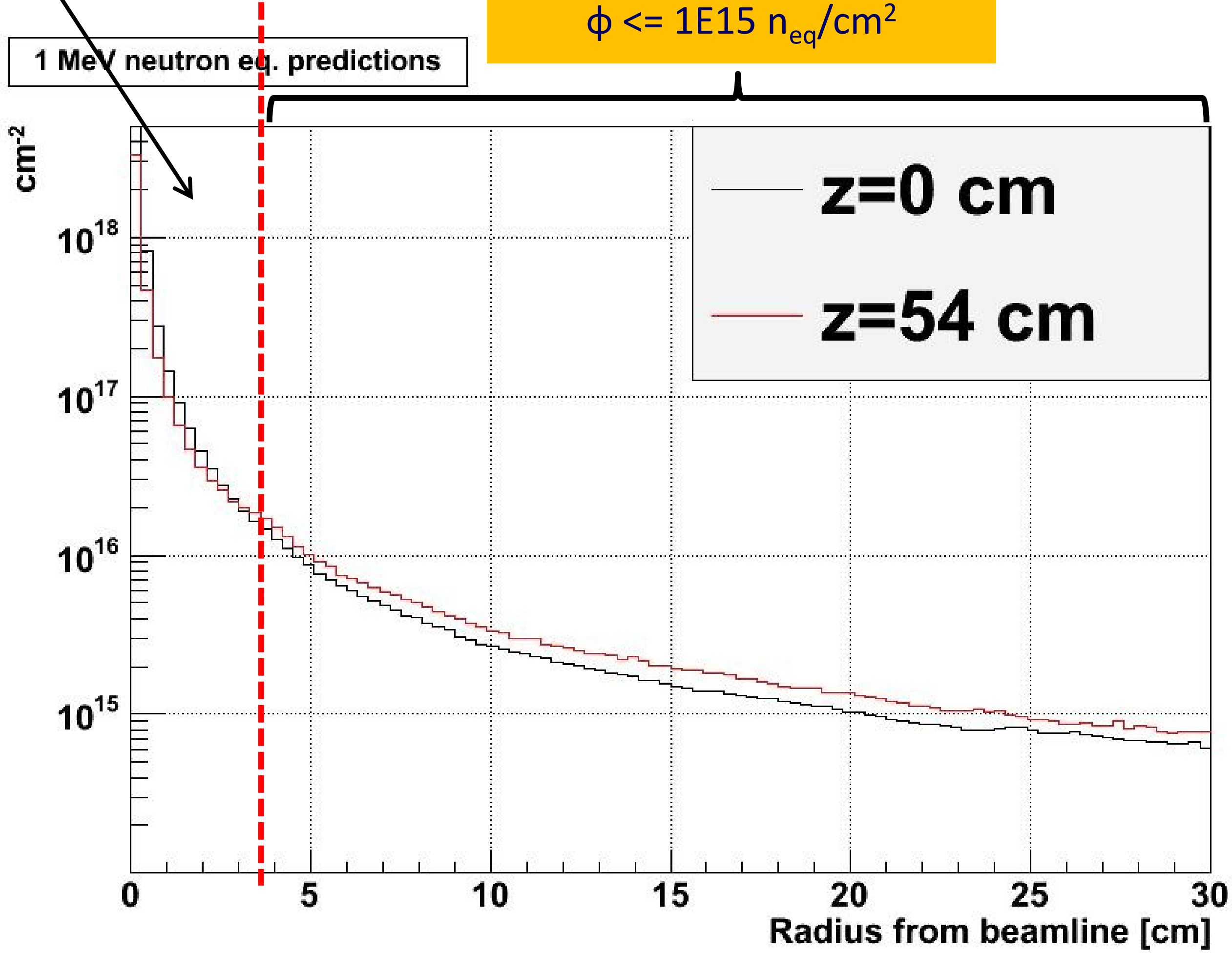


Plots stolen from M. Bomben

HL-LHC Intermediate Layers

inner layer:
$\phi = 2E16\ n_{eq}/cm^2$

intermediate layers:
$\phi <= 1E15\ n_{eq}/cm^2$

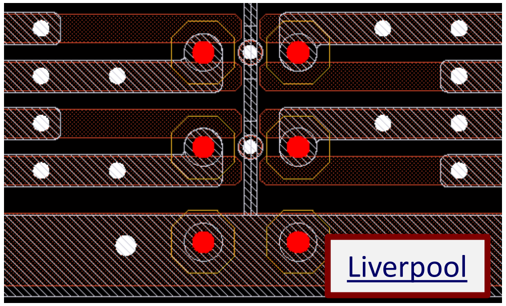


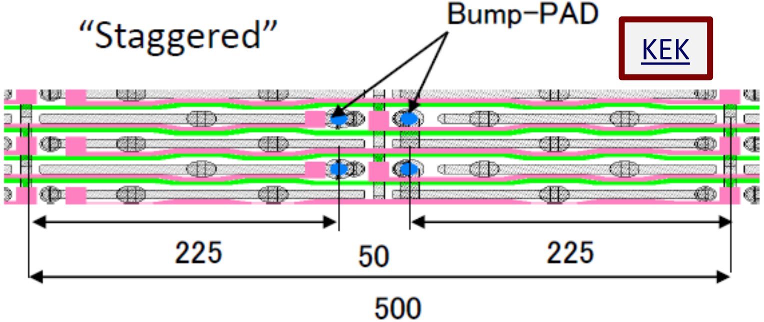
HL-LHC Intermediate Layers

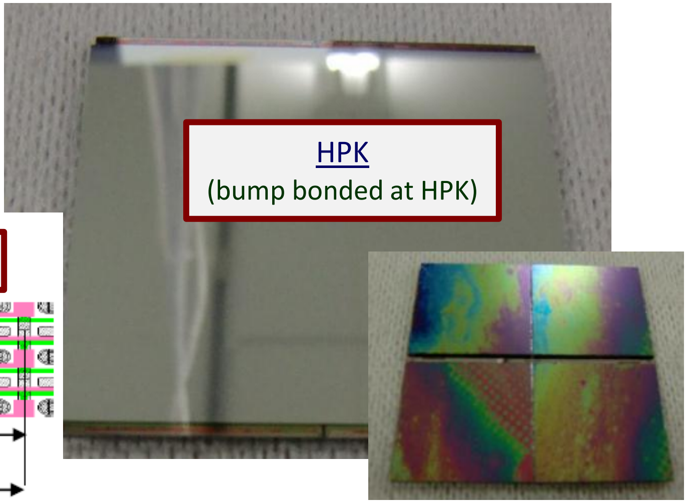
1. MCz seems promising in this mixed radiation field
   - irradiate, test , compare to DOFZ material
2. main topic: cost reduction

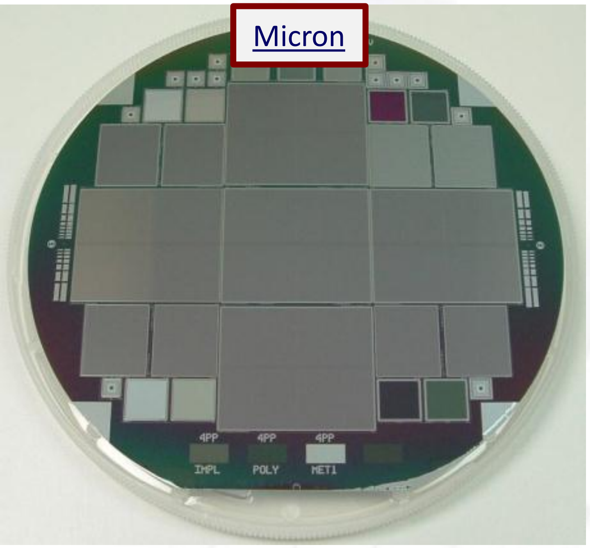
   ➔ 2x2 chip sensors to reduce handling cost
   - most institutes producing ‘pseudo’-quad modules using two existing 1x2 chip tiles
   - dedicated sensor productions planned or under way at CiS (n- and p-type), Micron, HPK
   - improving resolution in $R\phi$ by reducing pixel pitch

     → 25 x 500 um^2 (compatible w/ FE-I4 bump pattern)
   - (also working on PCB and R/O system (KEK))

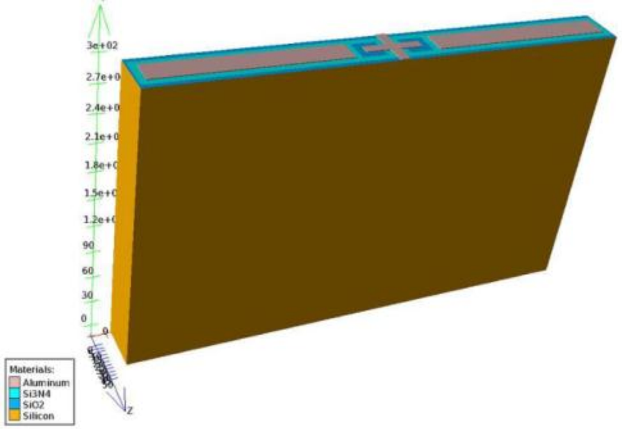






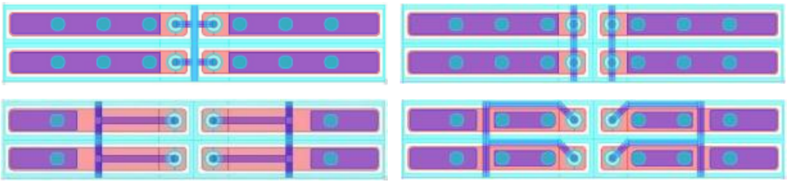


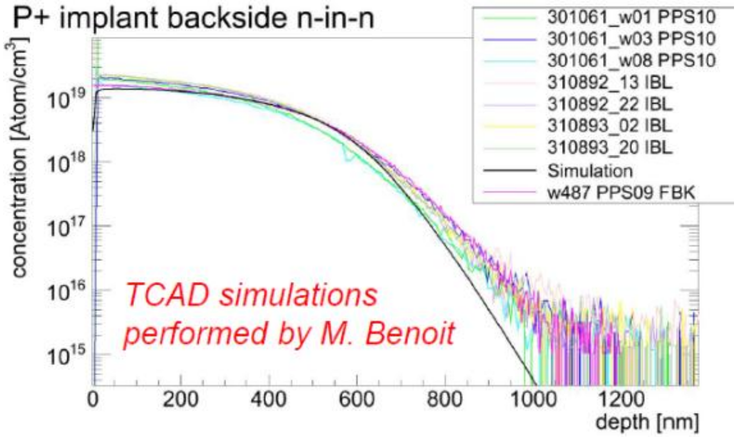
Simulation



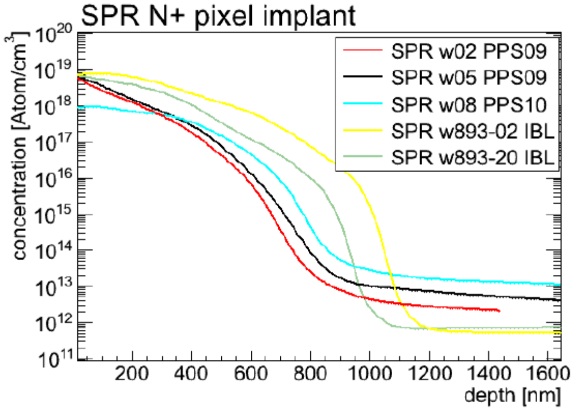
TCAD simulation activities

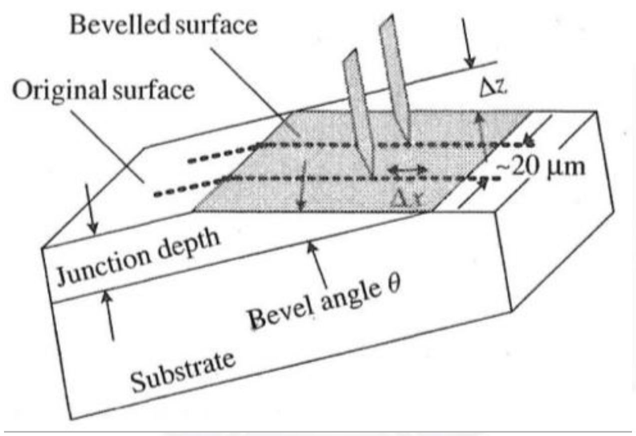
- trying to model 3D electric field distribution for two pixels
- model different bias grid designs
- problem: restricted number of mesh points (esp. on electrodes)
  ➔ numerical calculation doesn‘t converge for n-in-n and n-in-p samples
- improving simulation by accurate modeling of doping concentration
  ➔ dopant depth profiling by
  - Secondary Ion Mass Spectroscopy (SIMS):
    total dopant density profile
  - Spreading Resistance Profiling (SRP) or Scanning Spreading Resistance Measurement:
    carrier density profile





TCAD simulations performed by M. Benoit





Plots stolen from V. Linhard and N. Dinu

Testbeam

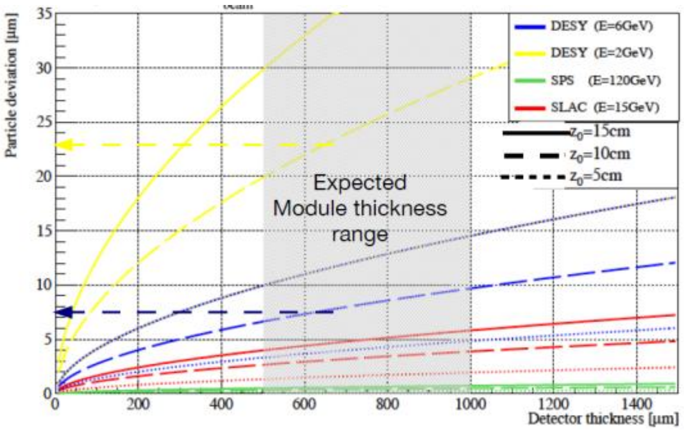
Testbeams in 2012 and beyond

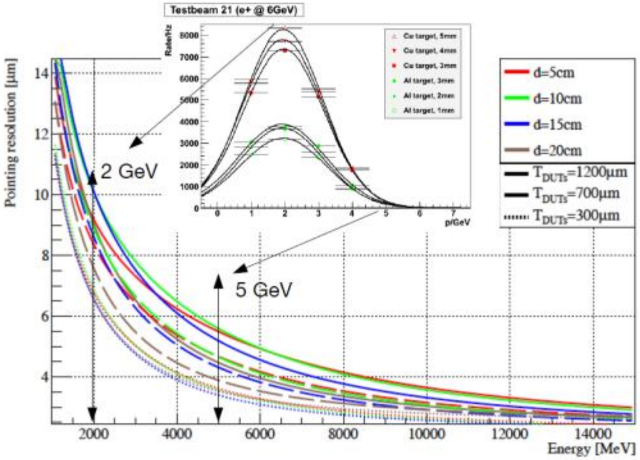
- ~62 days in 4 periods at DESY and CERN
- sometimes running on two beamlines in parallel
- took nearly 900 GB of data
- hundreds of configurations of different samples tested
- ‘Too many testbeams this year.’ M. Bomben
  - same people running TB and analyzing results
  - very busy getting analysis done in time
  - still produced the very nice results you have been seeing in this talk and many more!

- no beam at CERN in 2013, restart 2014 not clear yet
  - ➔ many requests submitted to DESY (4-6 GeV electrons, very busy)
  - ➔ beam time requested at SLAC (15 GeV electrons…

Very good and fruitful collaboration between ATLAS Pixel Upgrade R&D groups

- common hardware
- common beam requests
- ➔ simplified TB organization



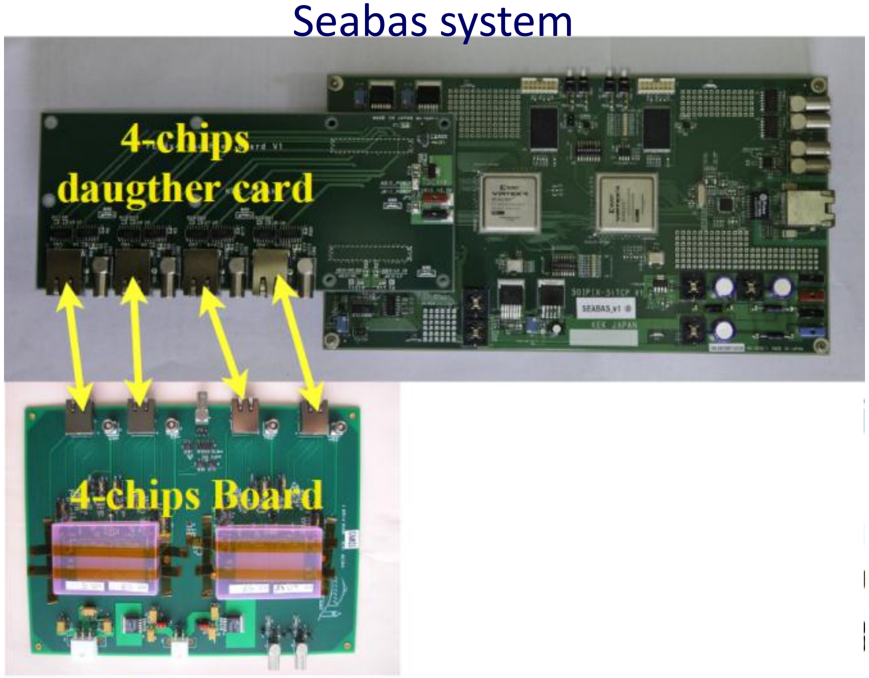


Plots and photo stolen from M. Bomben

Thank you for your attention.

HL-LHC Intermediate Layers

Seabas system



SLAC/LBL version