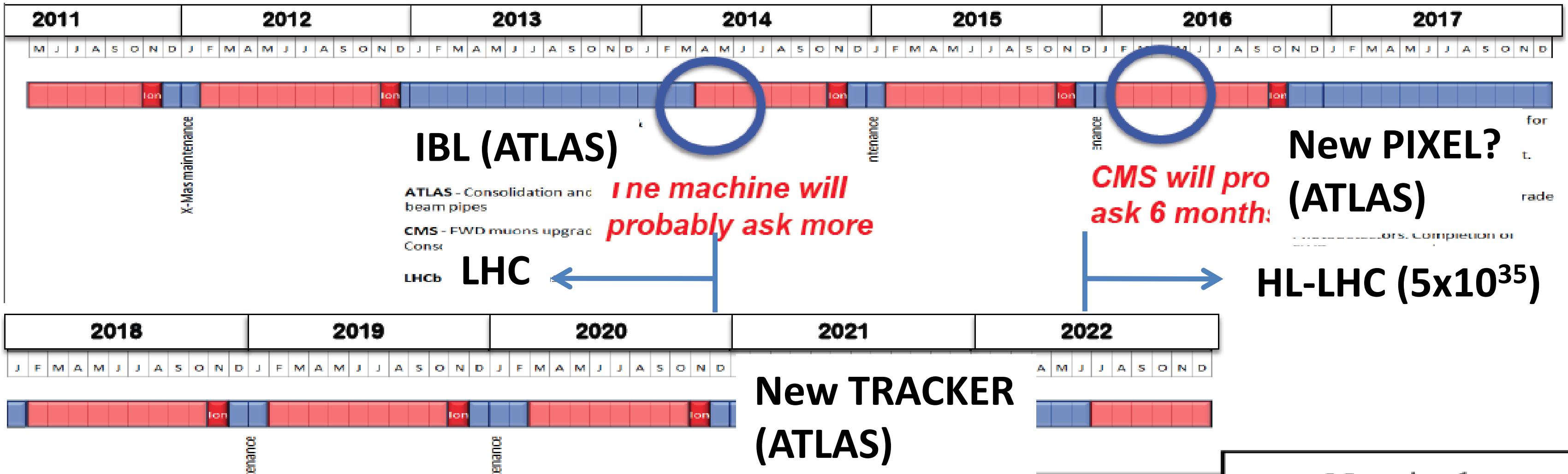
Latest results in developing n-in-p pixel and microstrip sensors for very high radiation environments

Y. Unno, S. Mitsui, Y. Ikegami, Y. Takubo, S. Terada (KEK), K. Hara, Y. Takahashi (Univ. Tsukuba), O. Jinnouchi, R. Nagai, T. Kishida (Tokyo Inst. Tech.), K. Yorita (Waseda Univ.), K. Hanagaki (Osaka Univ.), R. Takashima (Kyoto Univ. Edu.), S. Kamada, A. Ishida, K. Yamamura (Hamamatsu K.K.)

From LHC to HL/S-LHC



IBL (ATLAS)

The machine will probably ask more

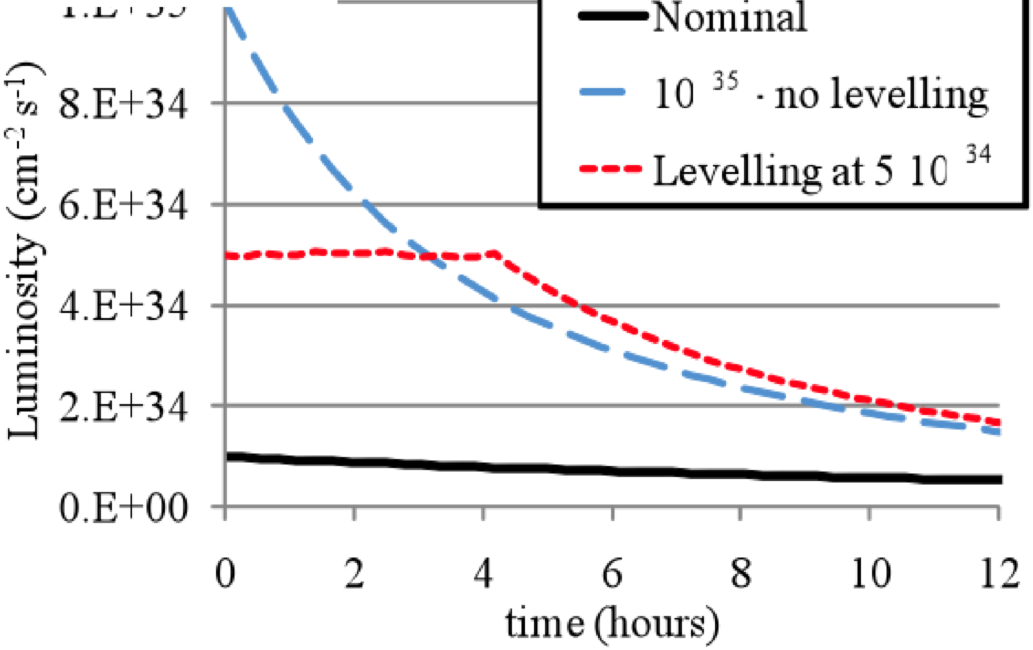
CMS will pro
ask 6 month

New PIXEL? (ATLAS)

LHC

HL-LHC (5×10^{35})

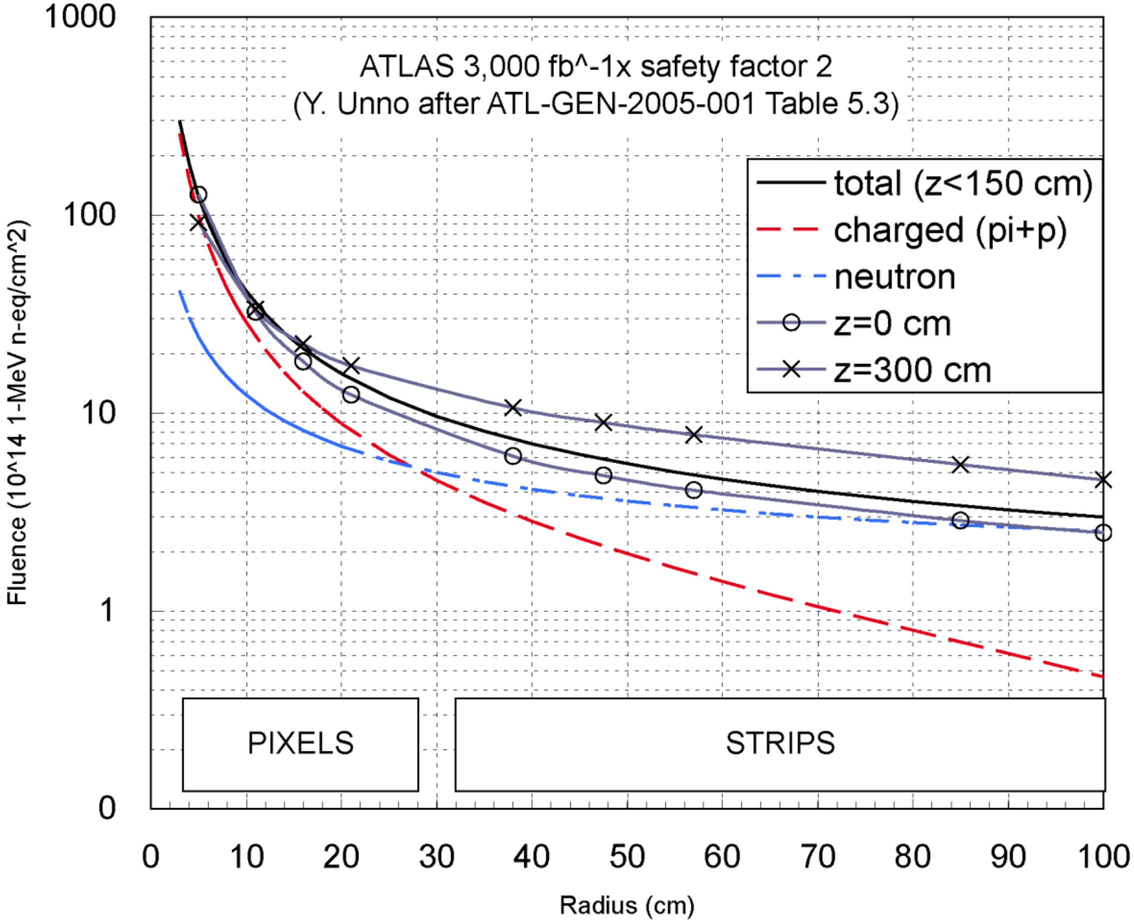
New TRACKER (ATLAS)



- LHC (-2020)
  - **~300 fb^{-1}** by 2020
- HL-LHC (2022-2034):
  - **250 fb^{-1}** per year
  - **3000 fb^{-1}** in 12 yrs
- Construction of "New Tracker"
  - may start in ~2016

Particle fluences in ATLAS

- IBL (LHC)
  - Insertable B-layer pixel
  - r = 3.2 cm
    - Flunece ~2x10^{15}
    - at Int.L~300 fb^{-1}
- PIXELs (HL-LHC)
  - New IBL ~2x10^{16}
  - r = 10 cm, e.g.
    - Fluence ~4x10^{15}
- STRIPs (HL-LHC)
  - r = 30 cm, e.g.
    - Fluence ~1x10^{15}



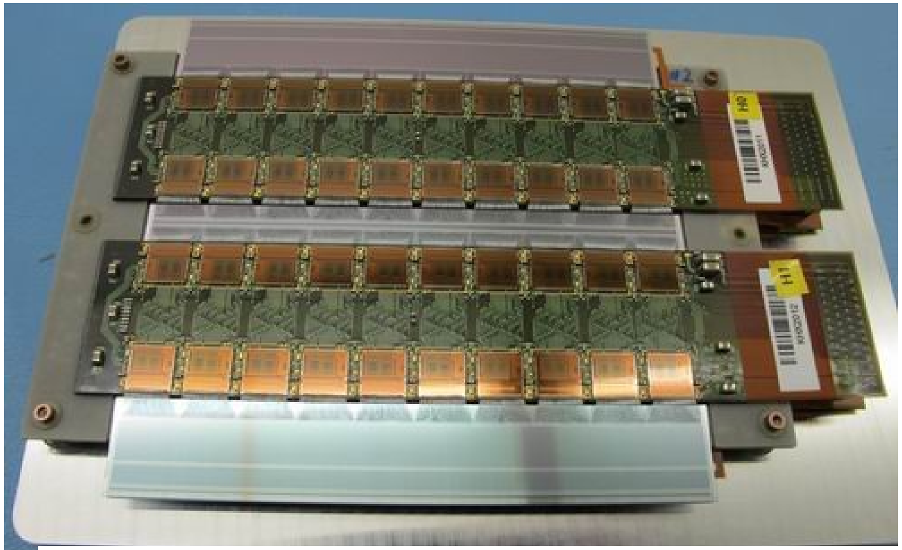
Outline

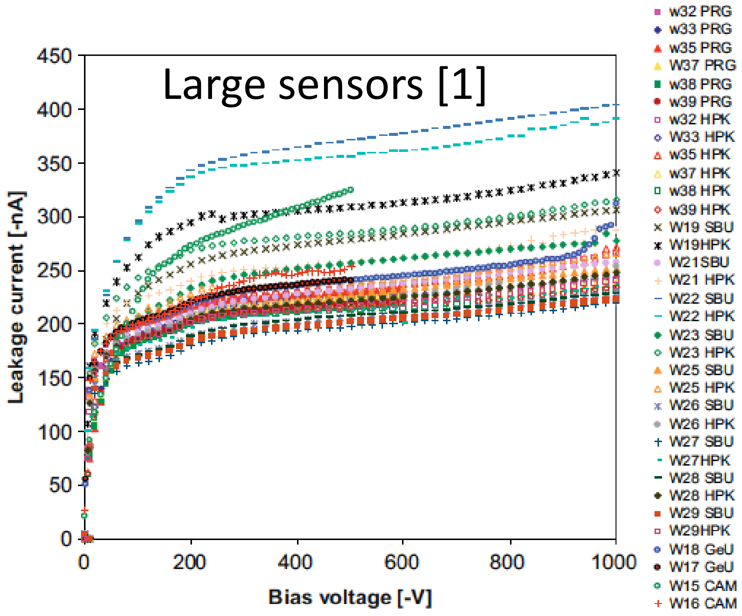
- N-in-p silicon microstrip sensors
  - 6-in. wafer process in HPK
    - Large area strip sensor and miniature sensors
    - Proton, neutron irradiations
    - γ irradiation (preliminary)
  - New punch-thru-protection (PTP) structures
- N-in-p silicon pixel sensors
  - 6-in. wafer process in HPK
    - ATLAS FE-I3 and FE-I4 pixel sensors
    - Thinned sensors
  - FE-I3 n-in-p single-chip module (SCM) for testbeam
    - Charge collection
  - Bump-bonding at HPK
  - Insulating the edge
- CYRIC irradiation
  - Diodes for study of lateral depletion/edge breakdown
  - Miniature strip sensors with new PTP structures

N-in-p Strip Sensors

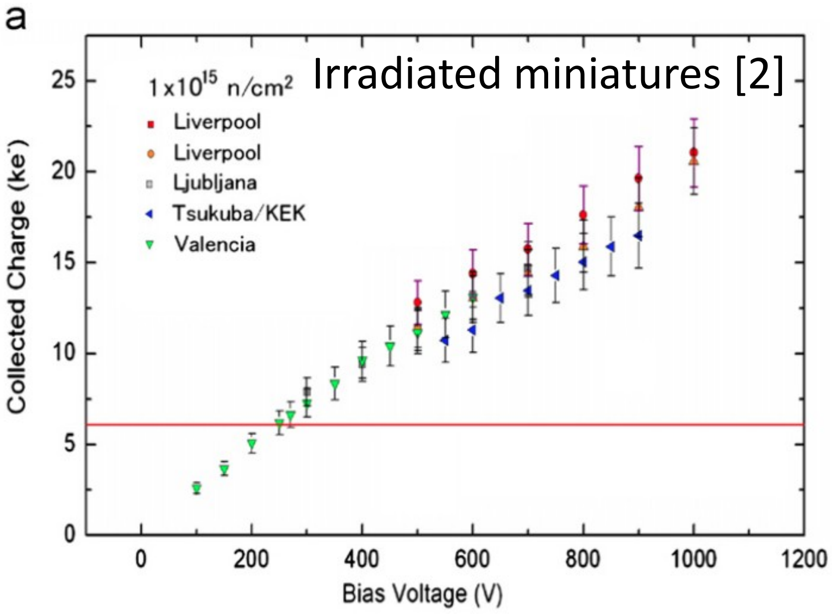
- Successful fabrication of large-area and miniatures (for irradiation) sensors
  - reported in Hiroshima09 conf.

UniGe/KEK modules





Large sensors [1]

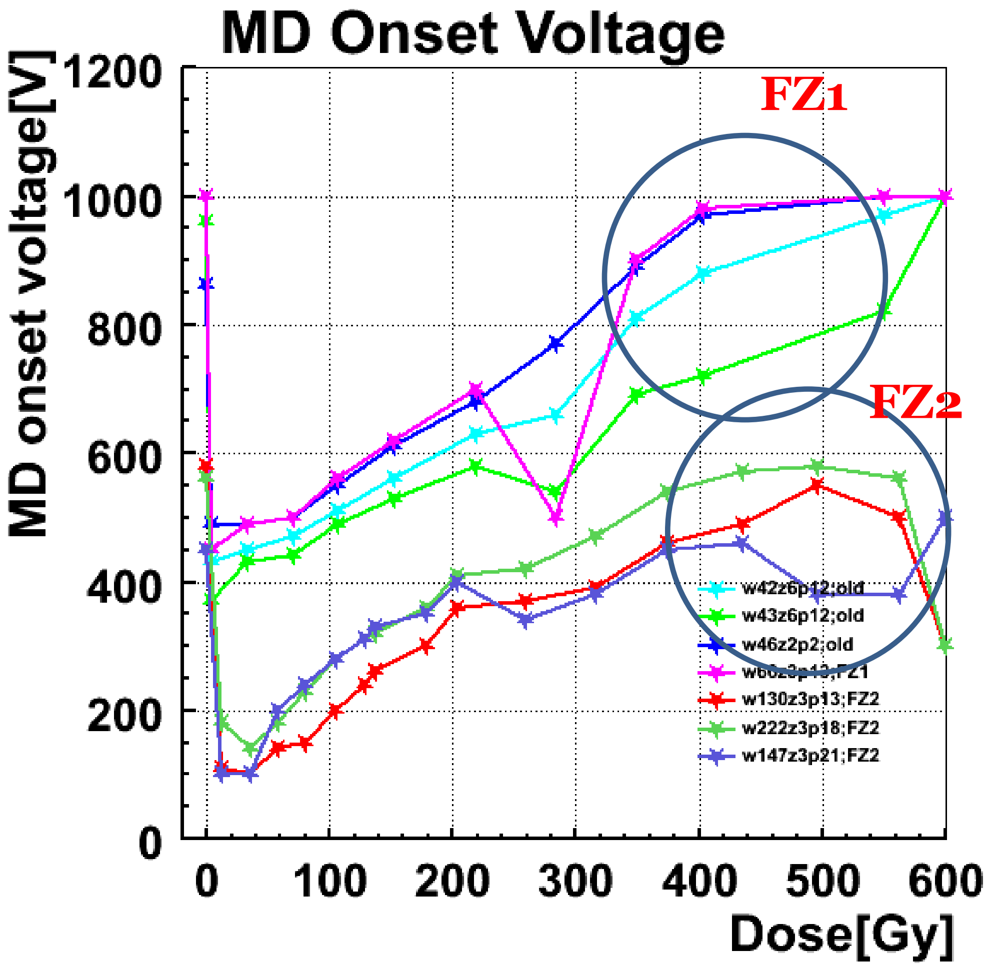


Irradiated miniatures [2]

[1] J. Bohm et al., HSTD7, Nucl. Instr. Meth. A636

[2] K. Hara et al., HSTD7, Nucl. Instr. Meth. A636

γ Irradiation (Preliminary)

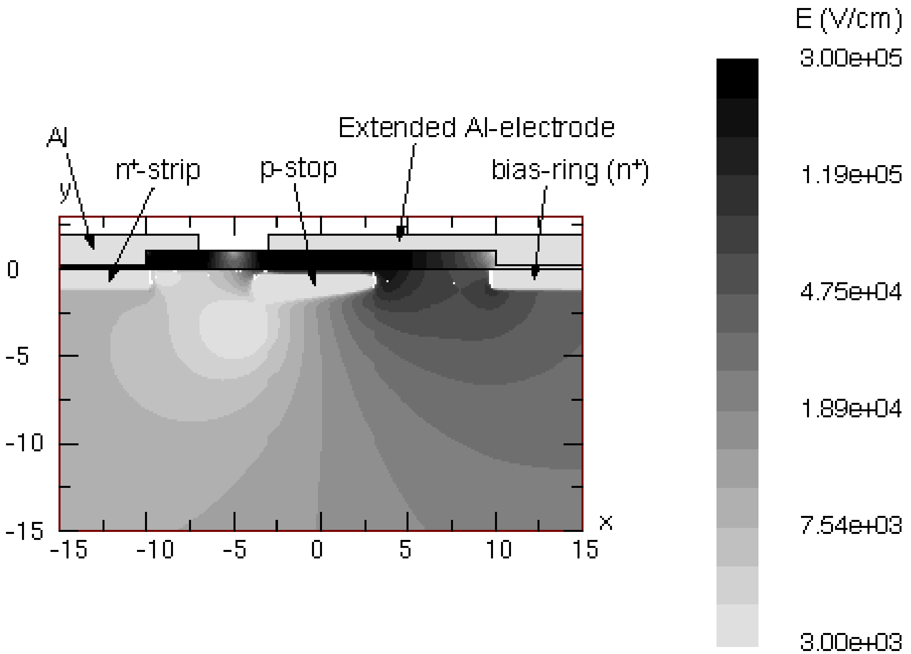


K. Takahashi, K. Hara
(U.Tsukuba)

- Dose rate
  - 200 Gy/h
    - 1000 Gy/h later
- Samples
  - Z3, i.e., the same as the main sensor
  - Wafer material
    - FZ1: default wafer
    - FZ2: higher crystal defects
- Results
  - Those with higher crystal defect concentration revealed much lower onset voltage
  - Sharp decrease of onset voltage of microdischarge (MD), then gradual recovery
    - Those with low onset voltage of MD stayed as the same onset voltage

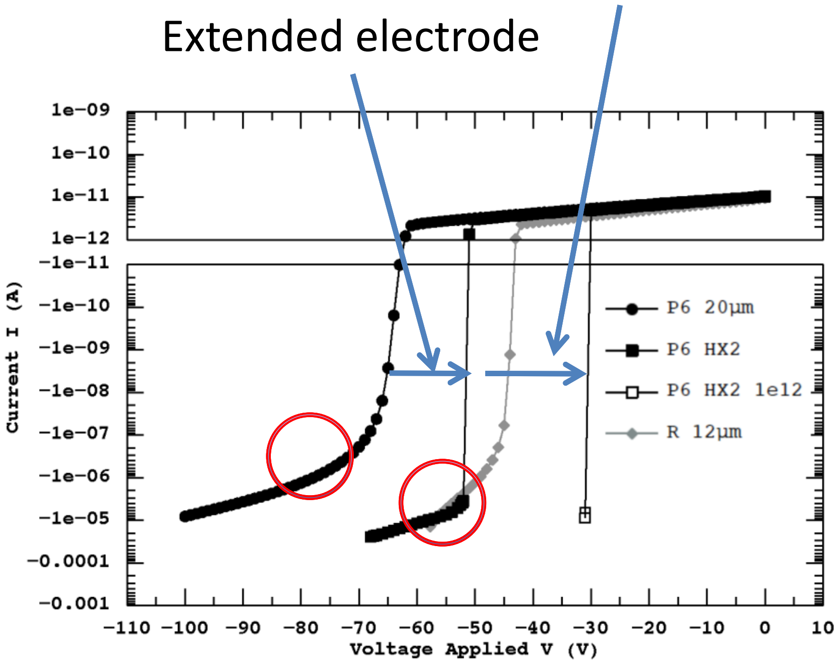
New PTP Structures

- Motivation
  - To decrease the turn-on voltage of punch-thru-protection (PTP)
  - To sharpen the turn-on
  - To lower the saturation resistance
- Extended electrode over p-stop



+ more oxide charge

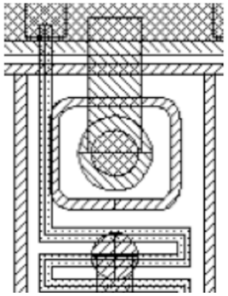
Extended electrode



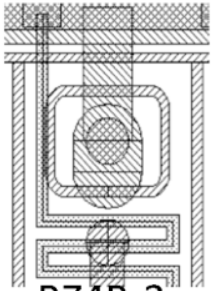
Ref. [1] TCAD simulations

[1] Y. Unno et al., HSTD7, Nucl. Insr. Meth. A633

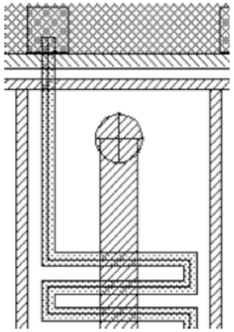
New PTP Structures



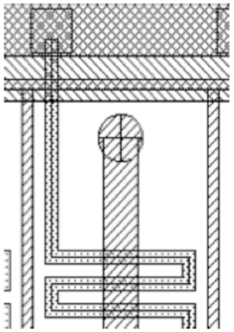
BZ4B-2



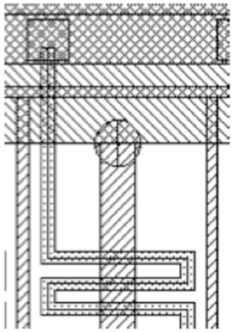
BZ4B-3



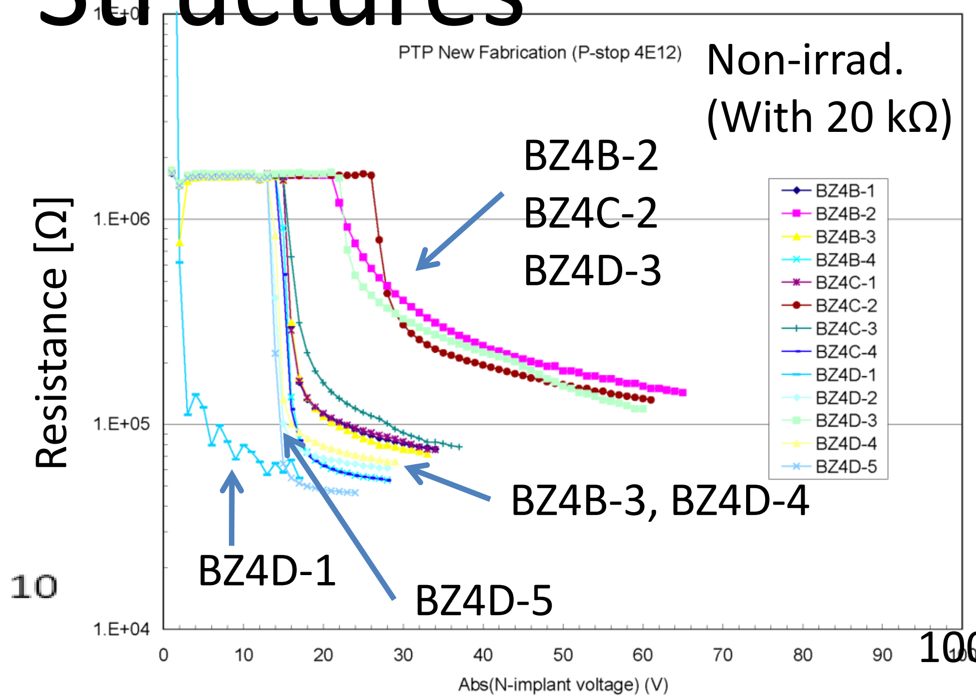
BZ4D-3



BZ4D-4



BZ4D-5



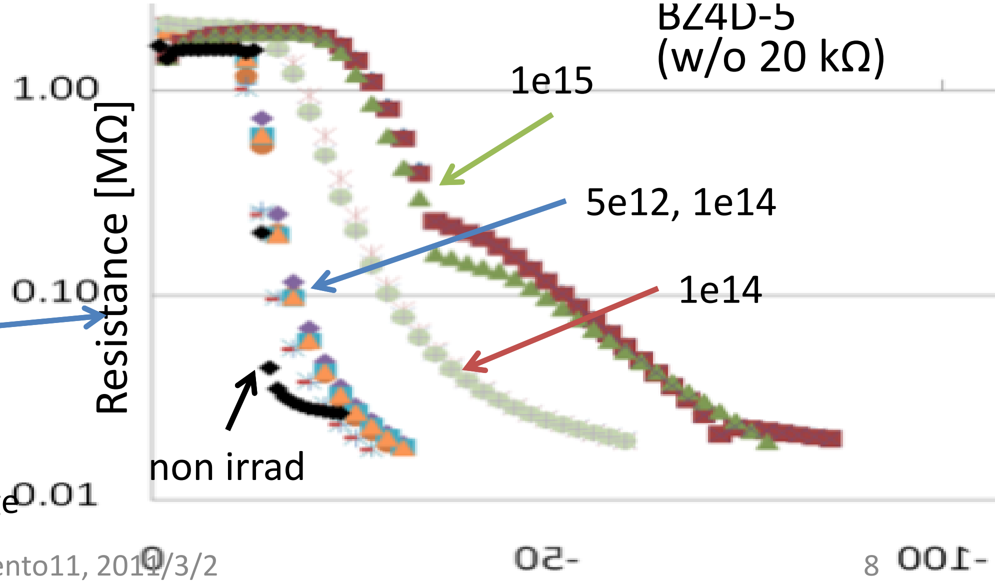
Non-irrad.
(With 20 kΩ)

BZ4B-2
BZ4C-2
BZ4D-3

BZ4B-3, BZ4D-4

BZ4D-1

BZ4D-5



BZ4D-5
(w/o 20 kΩ)

1e15

5e12, 1e14

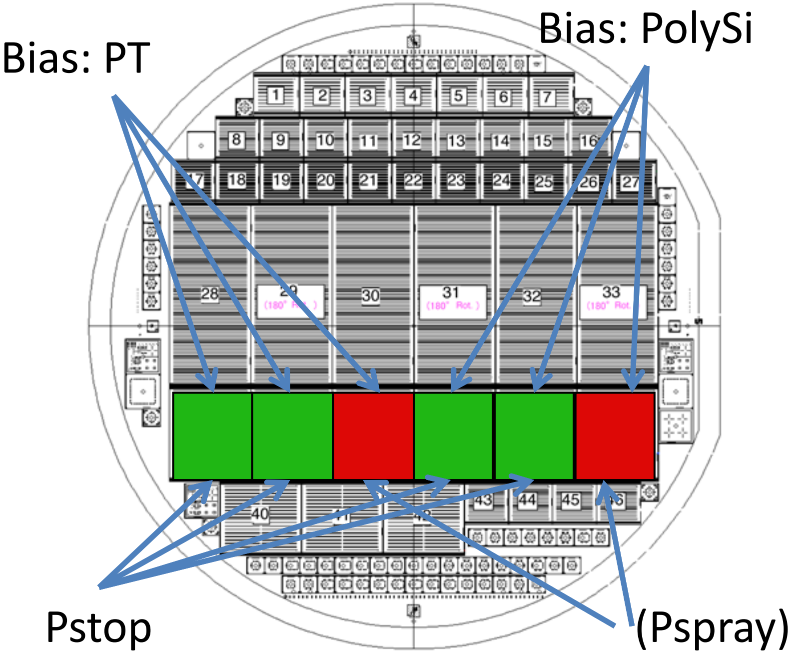
1e14

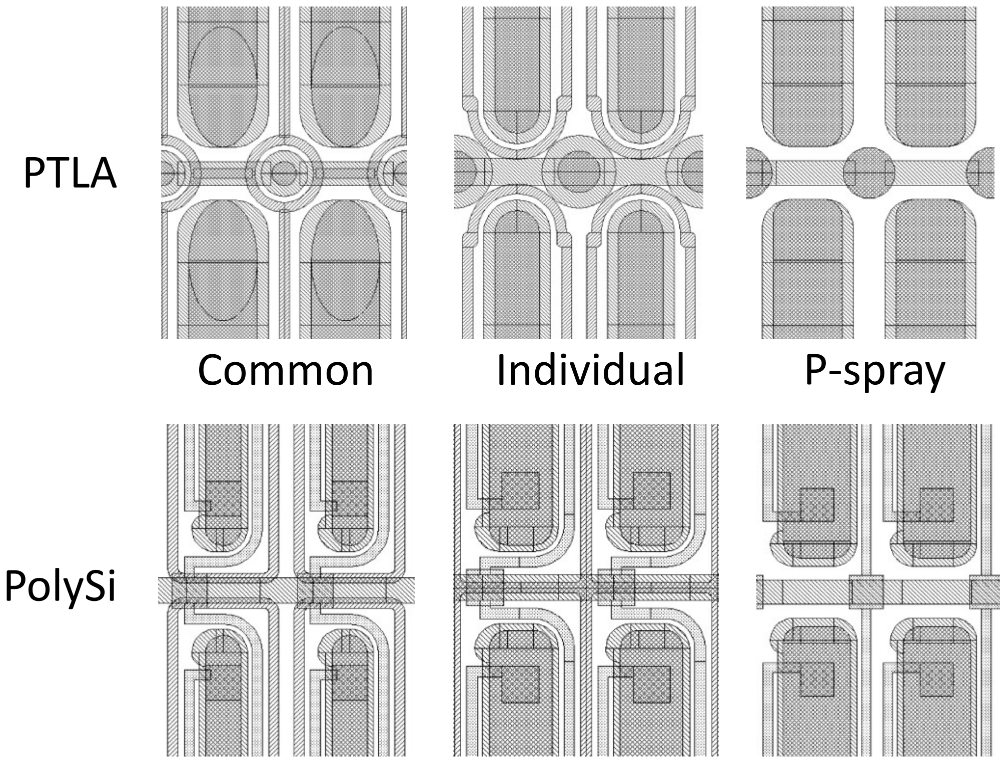
non irrad

- Samples
  - BZ4B-2: miniature originally in the 6-in. fab.
  - BZ4D-3, BZ4D-3, -4, -5 etc.: extended electrode over p-stop
- Irradiation data
  - See the irradiated data to be presented by S. Mitsui
  - More effect than simple increase of oxide charge

N-in-p Pixel Sensors

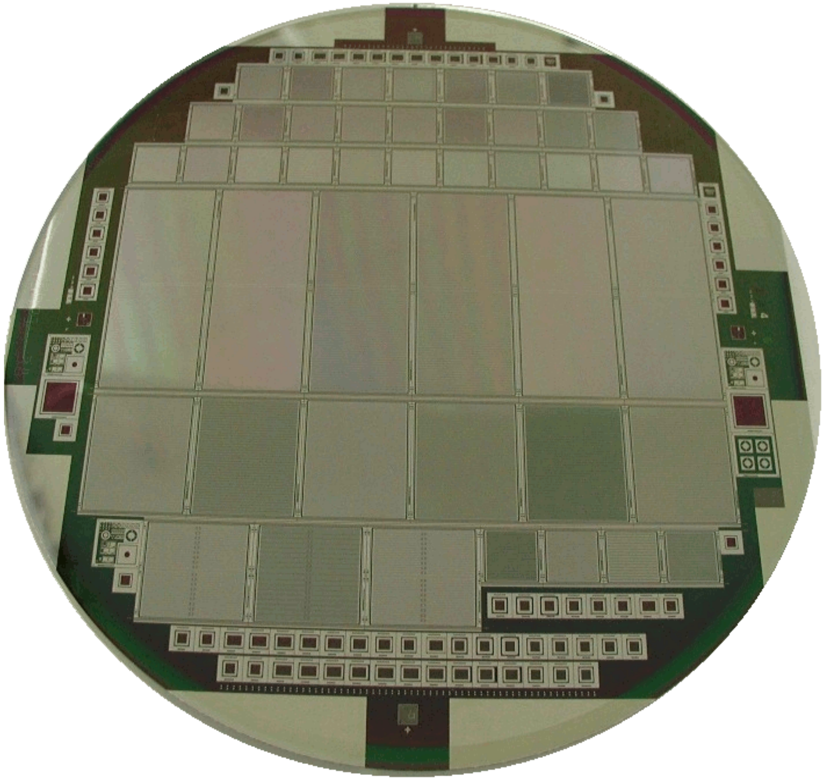
- 6-in. wafer process in HPK
  - ATLAS FE-I3 and FE-I4 pixel sensors
  - Bias: Punth-thru (PT, corner(LA)), PolySi
  - Isolation: p-stop (common, individual), p-spray

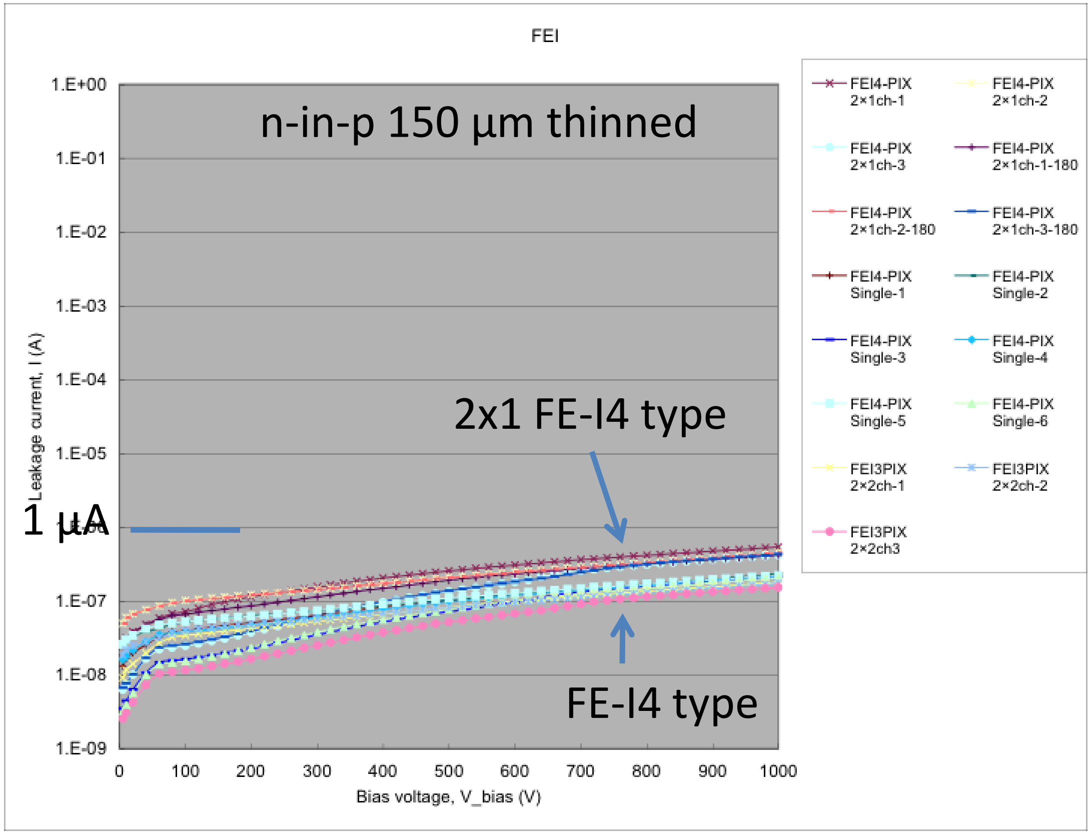




Priority	Wafer No.	Chip No.	type
1	17	34	PTLA-common
2	18	34	PTLA-common
3	17	37	PolySi-common
4	18	37	PolySi-common
5	17	35	PTLA-individual
6	17	38	PolySi-individual
7	33	36	PTLA-Pspray
8	33	39	PolySi-Pspray
9	18	35	PTLA-individual
10	18	38	Poly-Si individual
11	19	35	PTLA-individual
12	19	37	PolySi-common
13	19	38	Poly-Si individual

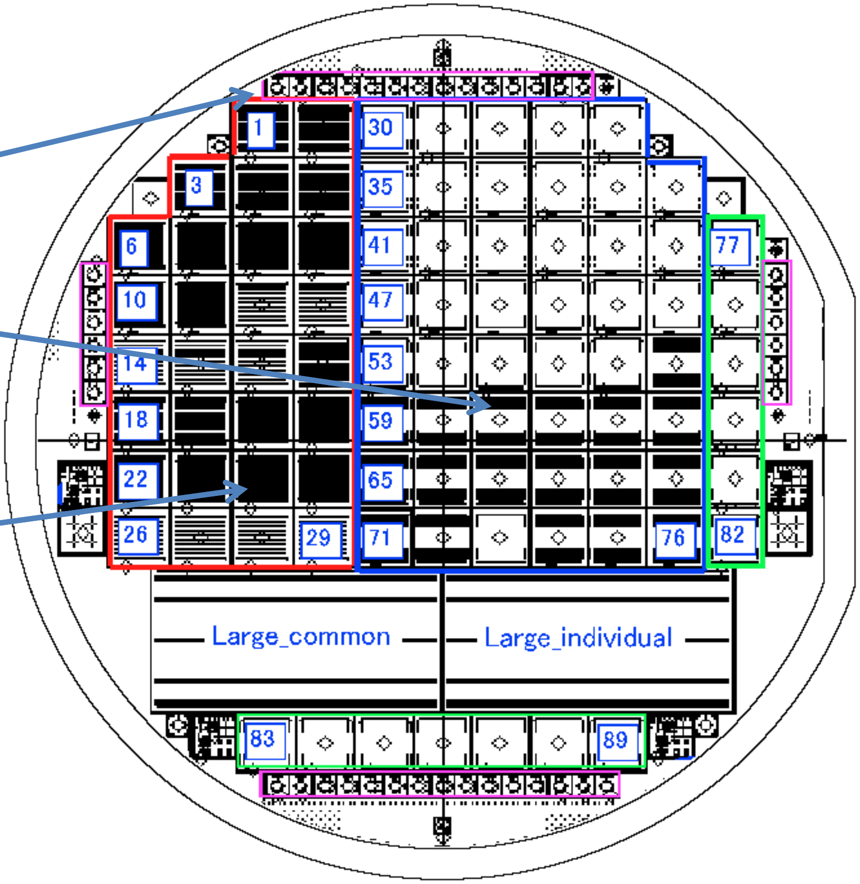
N-in-p 150 µm Thin Pixel Sensors





- Thinning is made as
  - Finishing 320 µm wafer process first
  - Thinning the wafers
  - Completing the backside
- Good I-V performance, although before dicing
- Making of FE-I4 pixel modules with the thin pixels
  - Number of wafers are at IZM for bump-bonding at present

Samples from Previous Wafers

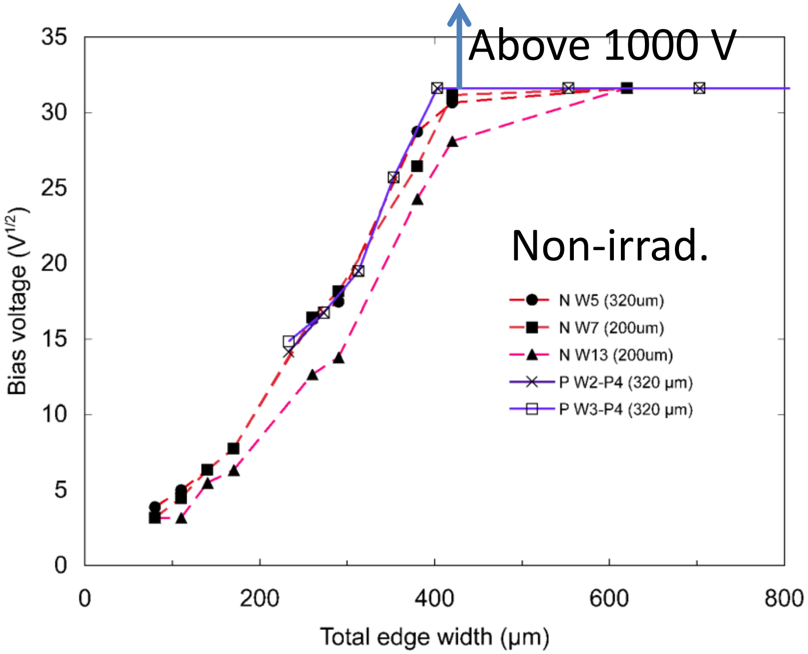


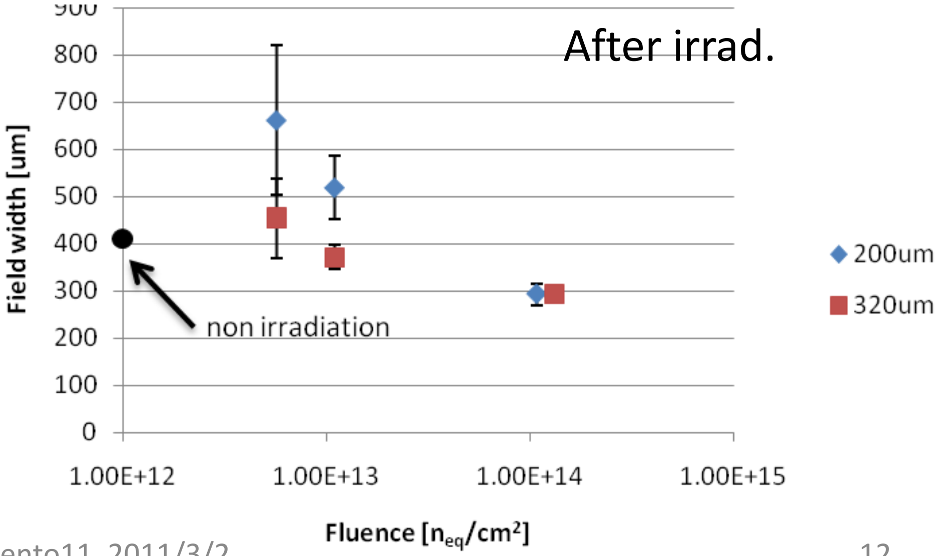
- Irradiation
  - and reported in this workshop
  - Diodes (4 x 4 mm^2)
  - Miniature strips (1 x 1 cm^2)
    - PTP study
- FE-I3 pixel sensors
  - PolySi bias resistor + p -stop
  - Bump-bonding at HPK to make FE-I3 single-chip module
  - 2 were in the testbeam in Oct. 2010, non-irrad.

Slim Edge Study – Lateral Depletion

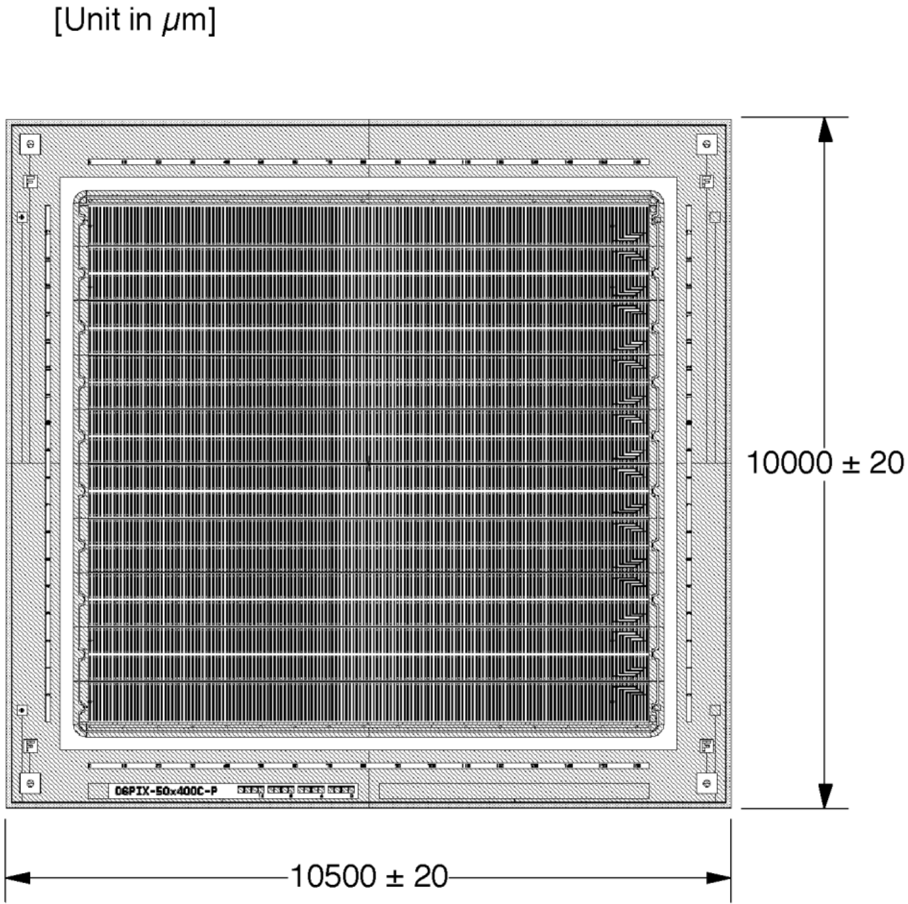
- Wafer thickness
    - 320 µm
    - Both N- and P-sub wafers
- Dependence of square root(V_bias) on the distance to edge
    - Linear, reflecting
    - the lateral depletion along the surface
- Distance to hold 1000 V
    - ~400-450 µm

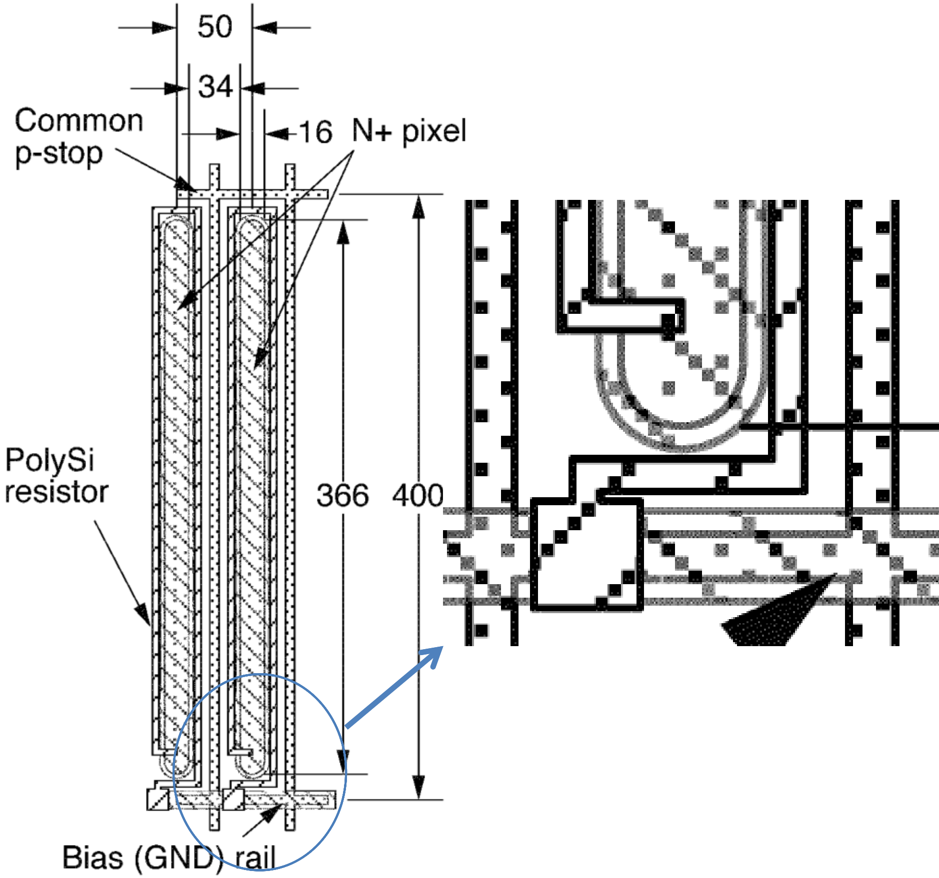
- After irradiation, see the presentation by S. Mitsui →
    - Edge width to reach ~1000V





FE-I3 n-in-p Pixel Sensor for Testbeam

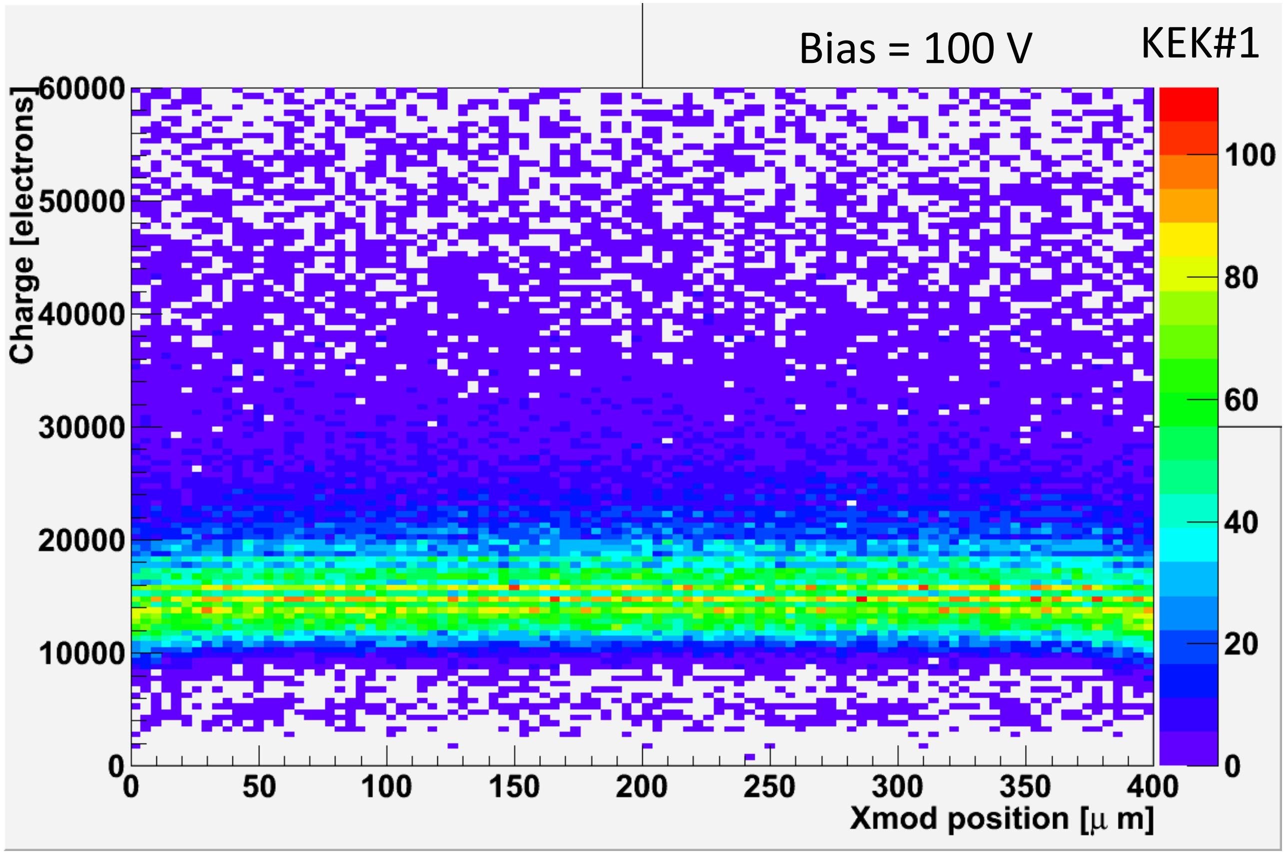




- Bias: PolySi
- Isolation: common p-stops
- What the motivation for making with PolySi is…

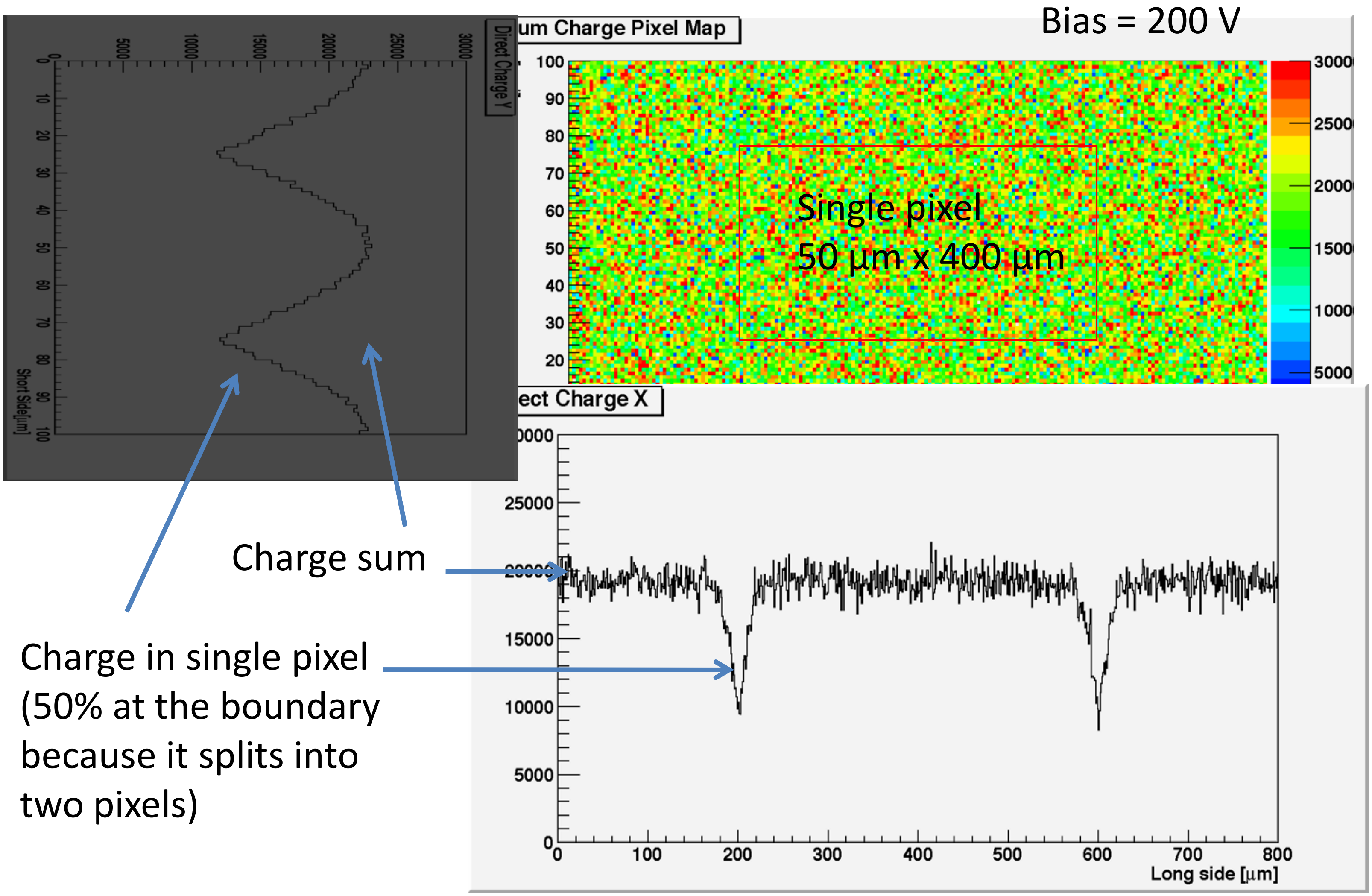
Charge Collection

R. Nagai



- One pixel "charge-sum map"
  - Uniformly collected charge – PolySi bias + Common p-stop
    - No bias dot
  - (even at) Bias 100 V (FDV ~ 200 V)

Collected Charge in a Pixel



Bias = 200 V

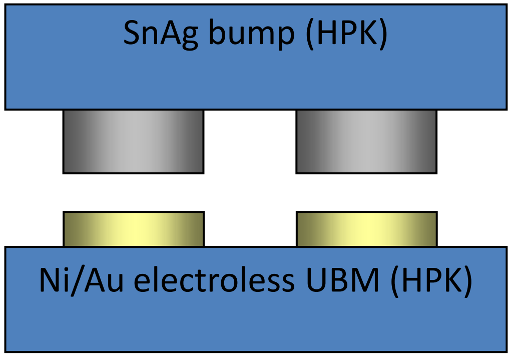
Single pixel
50 µm x 400 µm

Charge sum

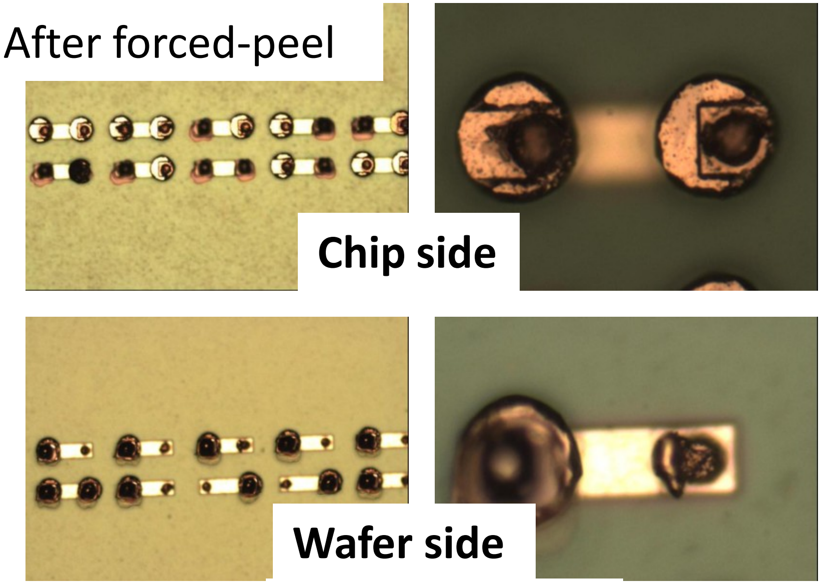
Charge in single pixel
(50% at the boundary
because it splits into
two pixels)

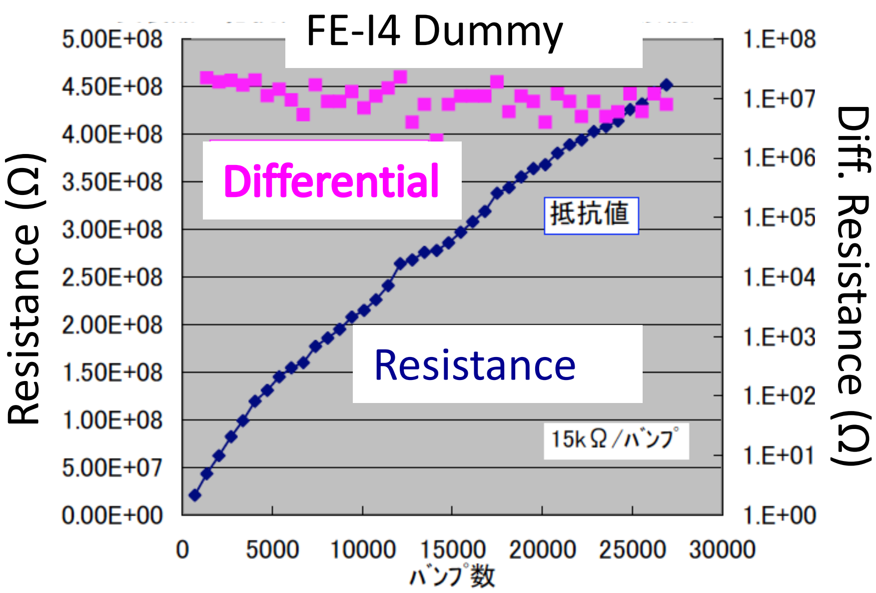
- Preliminary result by R. Nagai

Bump-bonding at HPK

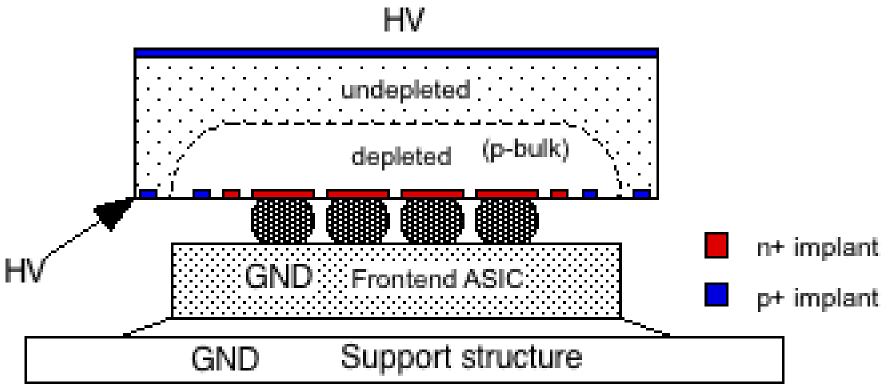


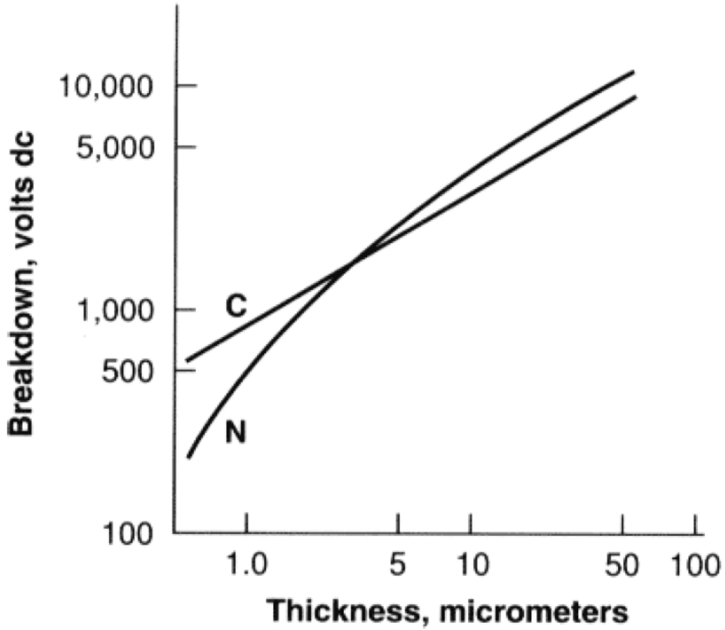
- PbSn bump-bonding was successful
  - e.g., FE-I3/I4 dummies, and FE-I3 SCMs for testbeam
- SnAg (Pb-free) bump-bonding under trial
  - With electroless UBM
  - Results
    - Mechanically successful, no open/short
      - Strong peel-strength
      - Chip cracks when peeled off
    - Peel from substrate/Solder fracture 50/50
  - Large contact resistance (~1kΩ/bump)
    - Thin insulating layer was identified by SEM between the surface aluminum and UBM metal
    - Possibly due to oxidation of aluminum in combination with UBM metalization

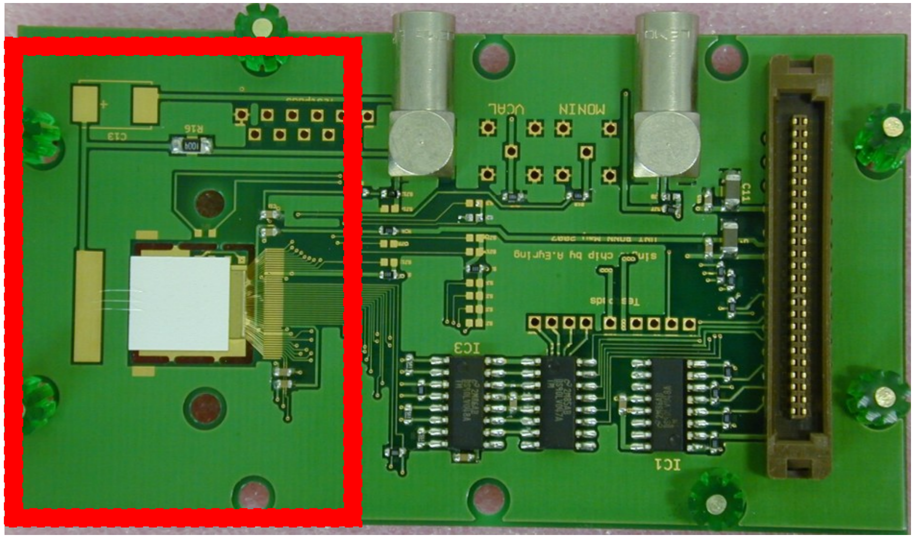




Insulating the edge





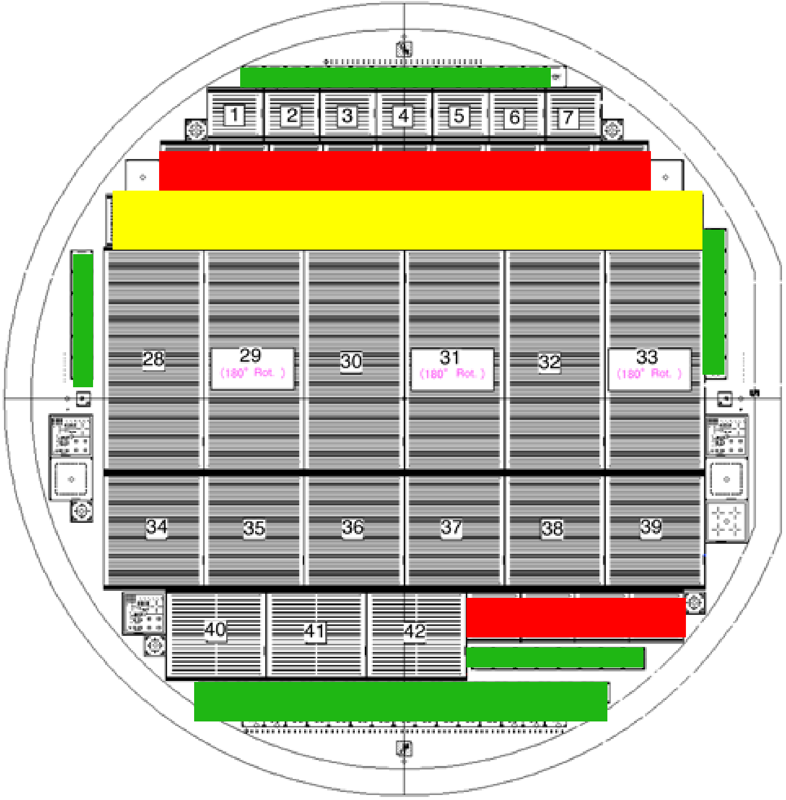


Single Chip Module (SCM) PCB

- Parylene conformal coating
  - Parylene "C" (than Parylene "N" (?))
    - ~800 V/μm for thin (1-3 μm) layer
  - 2-3 μm thickness
- In the SCM PCB, the region encircled in red
  - Done for the irradiation samples
  - No HV measurement before irradiation because in hurry, unfortunately
  - Will be HV-tested once it is returned

Irradiation in Japan

- Site
  - Site: CYRIC, 70 MeV protons
- Results presented in this workshop
  - Done in July 2010
- New irradiation on 16-19 Feb., 2011
  - $1\text{x}10^{14}$, $1\text{x}10^{15}$, $5\text{x}10^{15}$, $1\text{x}10^{16}$ n_{eq}/cm^2
- Samples
  - P-type wafers (N-in-p sensors)
  - Wafer material: p-FZ
  - Thickness: 320 µm and 150 µm
  - 4 x 4 mm^2 diodes (Green)
    - Slim edge+Guard ring studies
  - 100 x 300 $µm^2$ pixels (Yellow)
    - Probe/Bond-able pad size
    - Bias: PT, PolySi
    - Isolation: P-stop, P-spray
  - 50 x 250 $µm^2$ pixels (Red)
    - Only I-V
  - 2 FE-I3 pixel modules
    - was testbeam, now Parylene coated

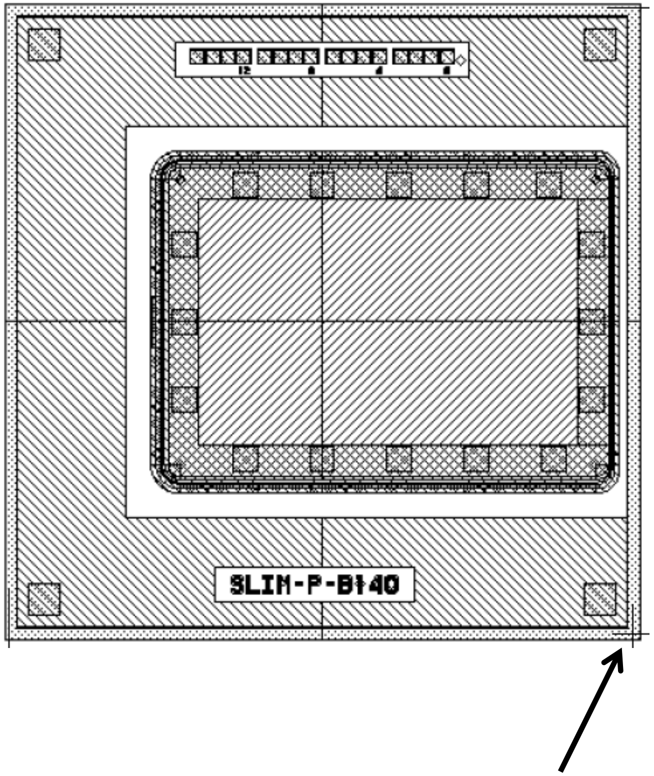


Summary

- N-in-p strip sensors are successfully shown for
  - Large-area sensor fabrication
    - Good I-V performance up to ~1000 V
  - Radiation tolerance in the miniatures
    - up to $1\text{x}10^{15}$ n_{eq}/cm^2, and γ irradiation
  - including final touch such as PTP structures
- N-in-p pixel sensors are under R&D, with
  - Normal thickness (320 µm) and thinned (150 µm)
    - Good I-V performance up to ~1000 V
  - PolySi bias and new PT structures (4-in-1)
  - Required edge width
    - Irradiated data are now available
  - PolySi samples (FE-I3 type) were testbeam-ed
    - showing uniform charge (sum) collection
  - SnAg bump-bonding at HPK being worked out
    - We are almost there
  - Insulating the edge
    - e.g. with Parylene coating
  - Radiation damage test of p-type samples, especially thinned ones
    - up to $1\text{x}10^{16}$ n_{eq}/cm^2

Backups

Slim Edge Study – Lateral Depletion



Only in one side, the distance-to-edge is varied from 80 to 1000 μm

- Evaluating the relation between the edge space and the bias voltage to hold
  - Lateral depletion along the surface