Planar pixel sensors for ATLAS ITk and beyond

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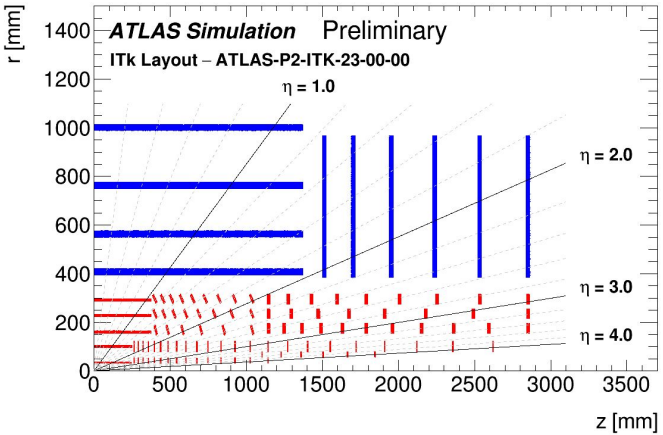
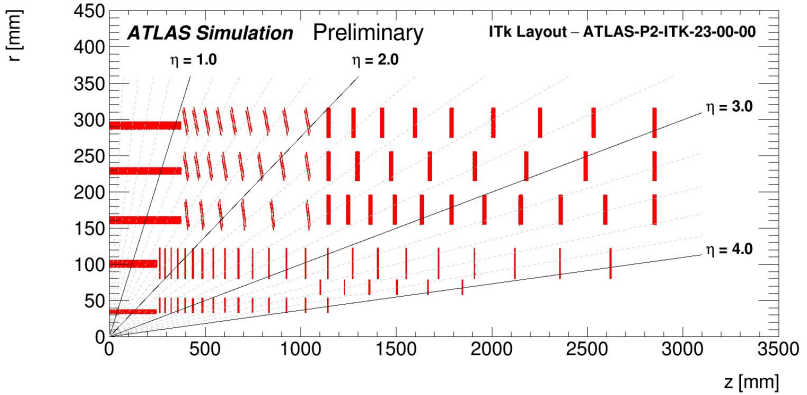
(IJCLab, IRFU, LPNHE)

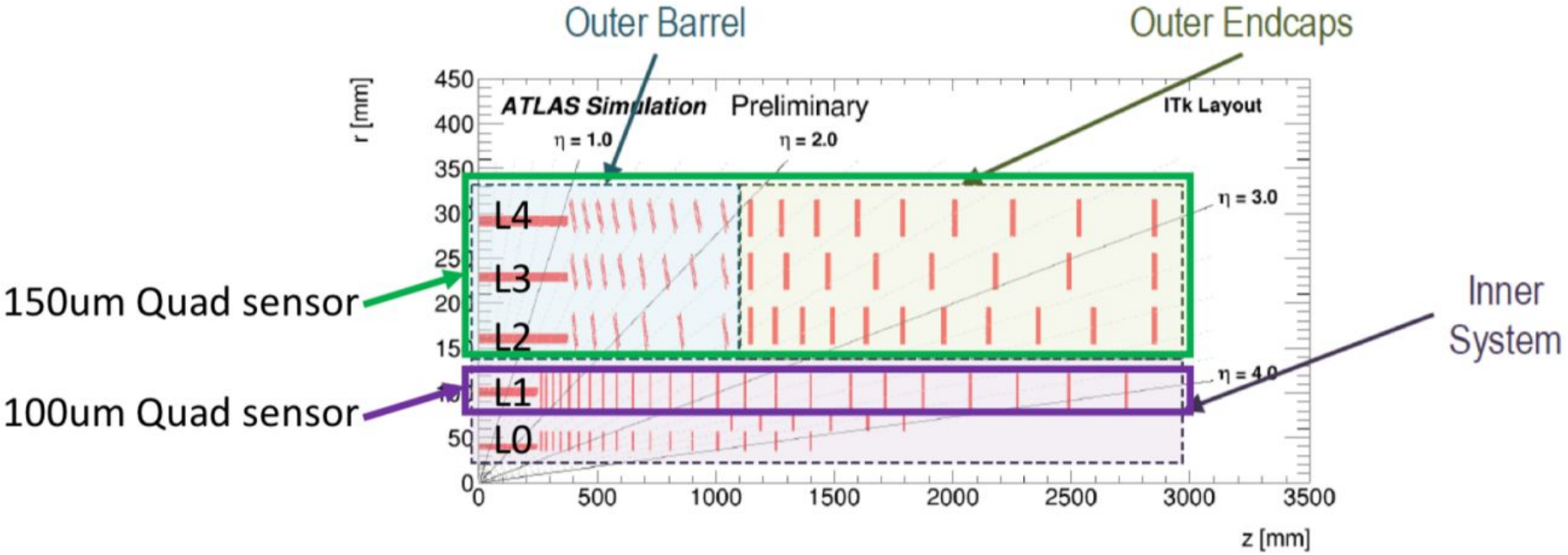
ATLAS & ITk

- ITk is the tracker upgrade for ATLAS @ HL-LHC (Phase-II)
  - Full Silicon tracker: strips & pixels
  - L_{inst} = 5-7x10^{34} $cm^{-2}s^{-1}$
  - Expected Fluence for pixels
    - 1-2x10^{16} n_{eq}/cm^2 for innermost layer (3D pixel)
    - 2-3x10^{15} n_{eq}/cm^2 for outer layers (planar pixel)



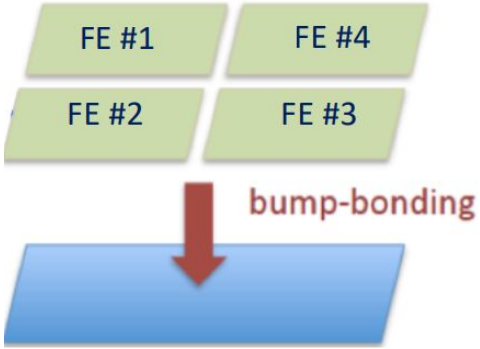


ITk pixel layout

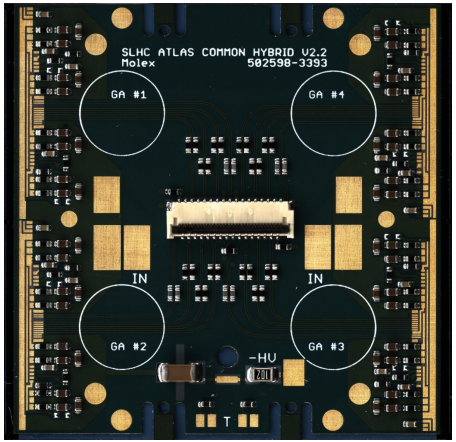


ITk planar sensor pixels

- Pitch 50x50 μm^2
- n-in-p technology
- 100 µm thin sensors for L1
- 150 µm thin sensors for L2-L4
- ITk pixel FR chip is 20x19.2 mm2 (400x384)
  - Planar sensors produced for 4x FE chips: Quad module

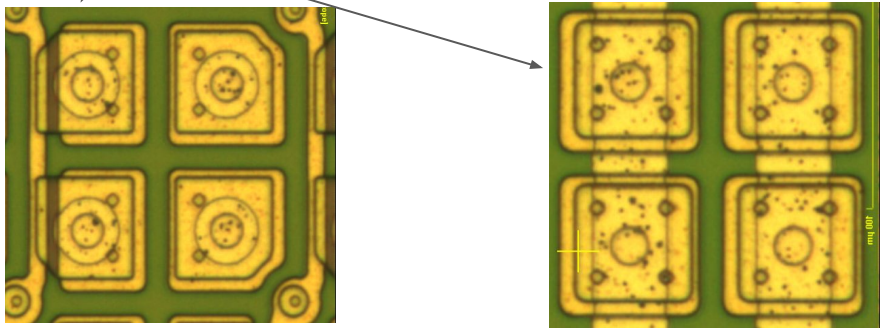


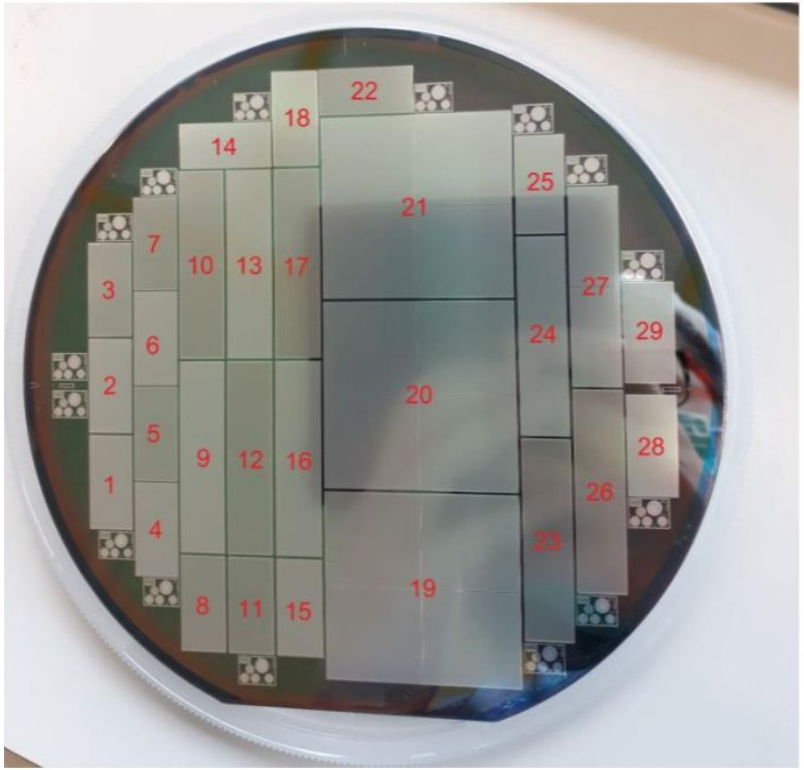
Quad planar sensor



R&D sensors for ITk

- Production 2019 @ FBK
- Single (RD53A), double (RD53A) and quad (ITk) design
- 50-**100-150** um thickness
- Biasing scheme
  - Punch through (different designs)
  - Temporary metal





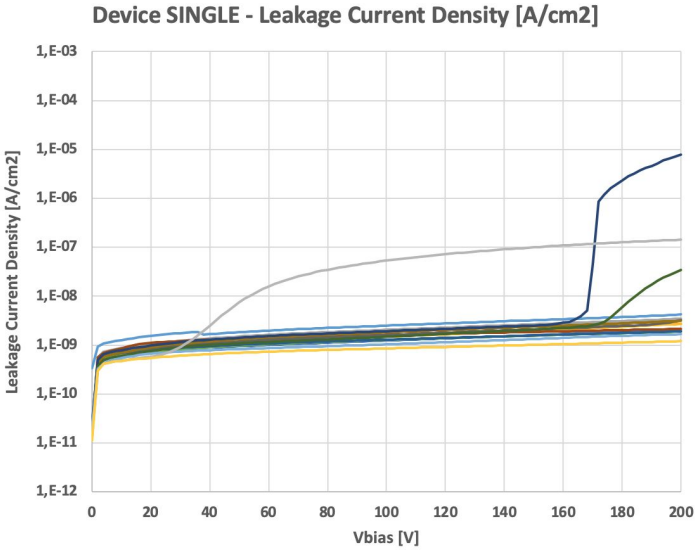
R&D sensors for ITk

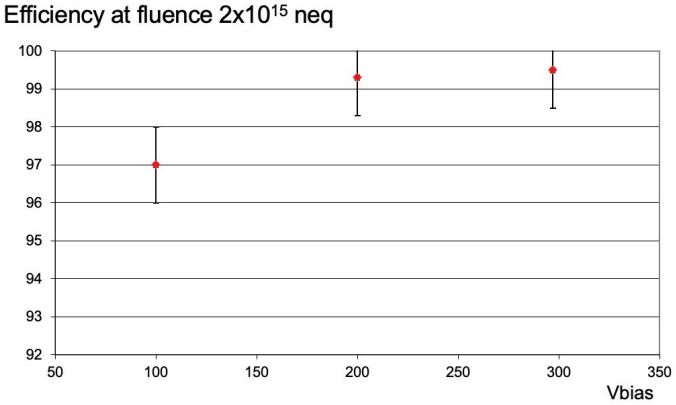
Depletion voltage:

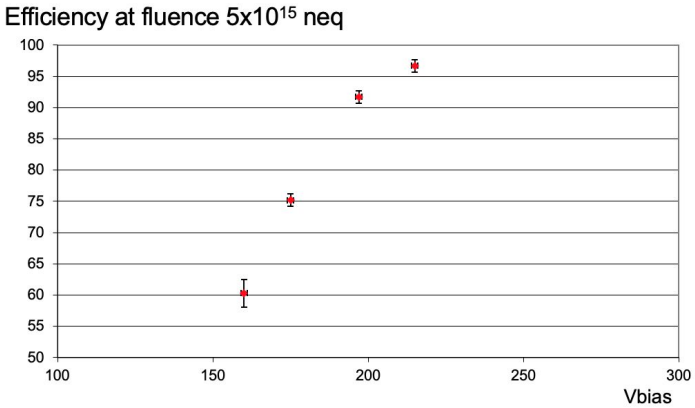
- 10-15 for 100 µm
- 20-30 for 150 µm

Tested at DESY after irradiation

- 2 x 10^15 n_{eq}/cm^2
- 5 x 10^15 n_{eq}/cm^2





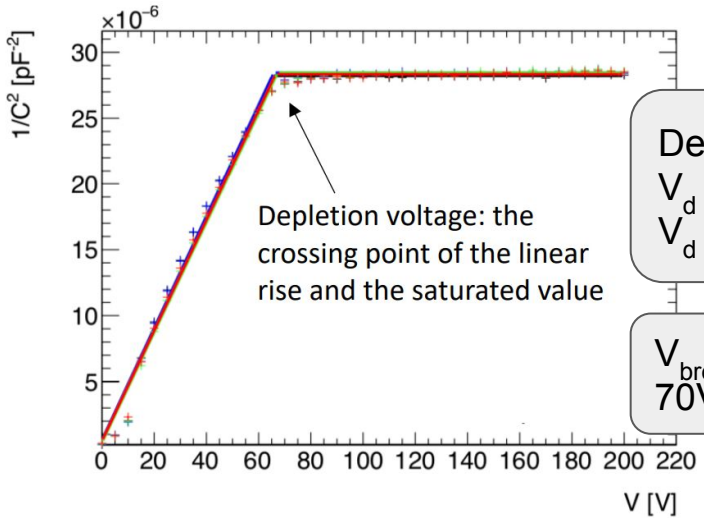


Most devices have breackdown > 200V

Market Survey for ITk

- Several vendors applied to supply ATLAS of ITk sensors
- In order to qualify fairly each vendor a strict procedure has been enstablished: Market Survey
- ITk institutes participate by performing the required measurements
  - Metrology
  - Electrical measurements

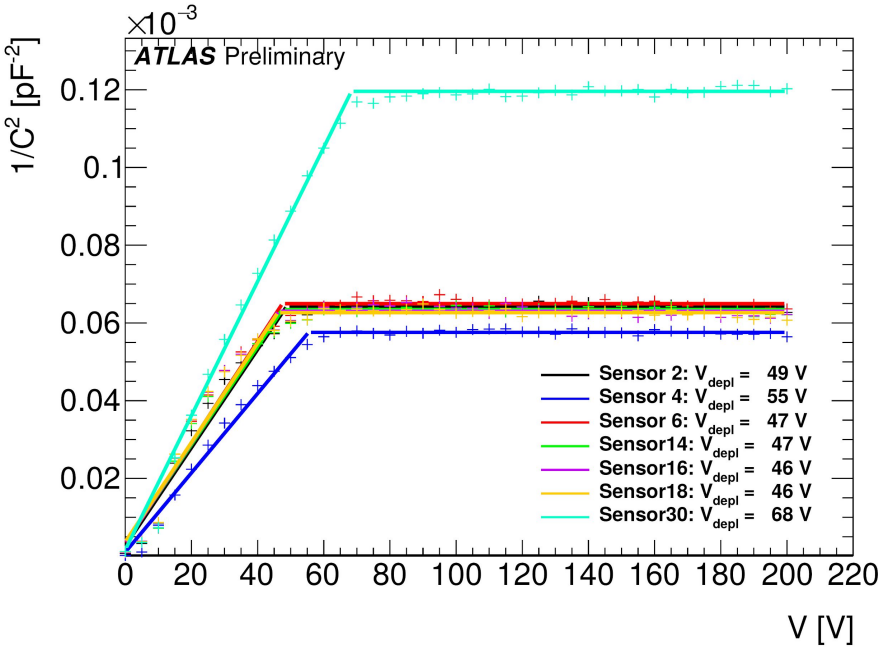
Deviation of average wafer thickness variation with respect to the specified thickness	≤ 15 µm
Physical sensor thickness variation inside a single sensor	≤ 15 µm
Wafer bow of 6” size	≤ 100 µm
Wafer bow of 8” size	≤ 150 µm
Sensor bow (4-chip geometry)	≤ 25 µm



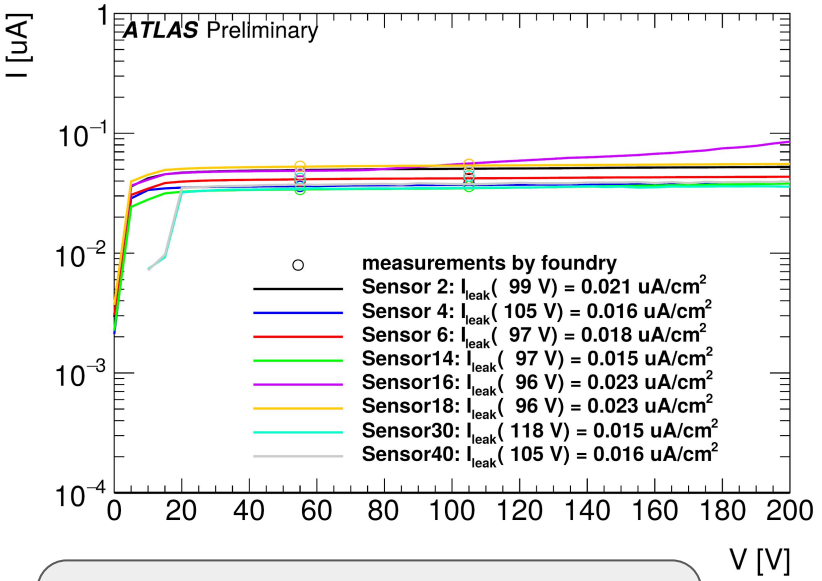
Depletion voltage
V_d < 60 V 100 µm
V_d < 100 V 150 µm

$V_{breakdown}$ > V_d + 70V

ITk Market Survey Electrical Measurements



MS public plots



Results include measurements done within the Paris ITk Cluster of labs

Beyond ITk

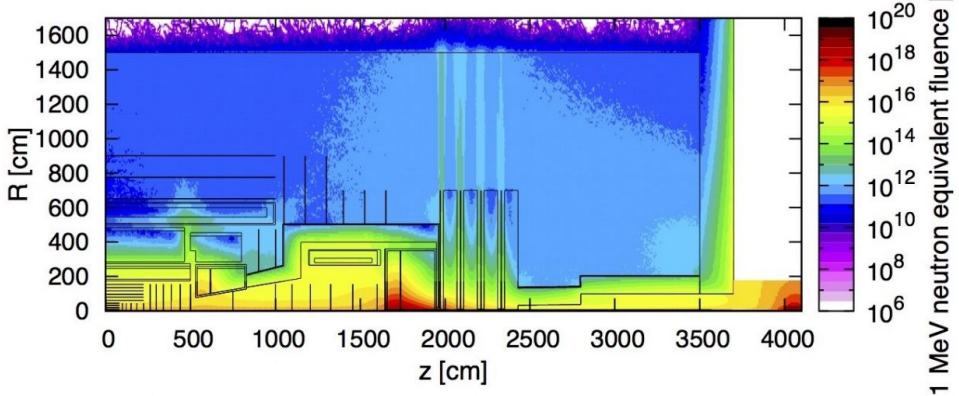
- Future **hadron** colliders will have much higher fluence
- FCC-hh up to 5.5x10^{17} n_{eq}/cm^2
- Thin sensors to keep the material budget very low

Long-term damage for Tracker after 30ab^{-1}

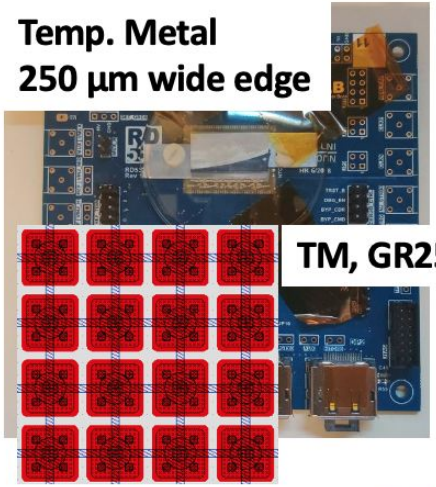
R [mm]	z[m]	Dose [MGy]	1 MeV equivalent Fluence [cm^{-2}]
25	0	320	$5.5\ 10^{17}$
60	0	88	$1.25\ 10^{17}$
100	0	40	$6\ 10^{16}$
150	0	23	$3.3\ 10^{16}$
270	0	8.8	$1.51\ 10^{16}$
900	0	0.65	$3.2\ 10^{15}$
25	5	410	$3.7\ 10^{17}$
50	16	250	$2\ 10^{17}$

Z. Drasal @ VERTEX 2017

Courtesy of M.I.Besana

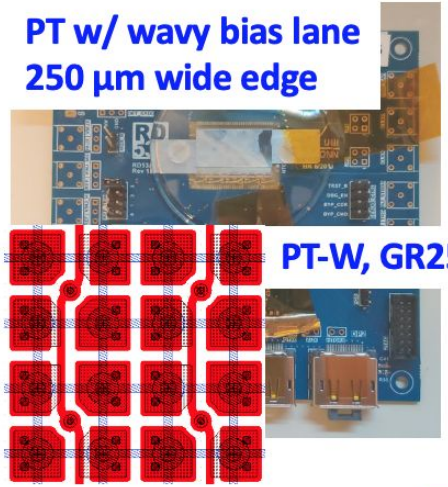


Temp. Metal
250 µm wide edge



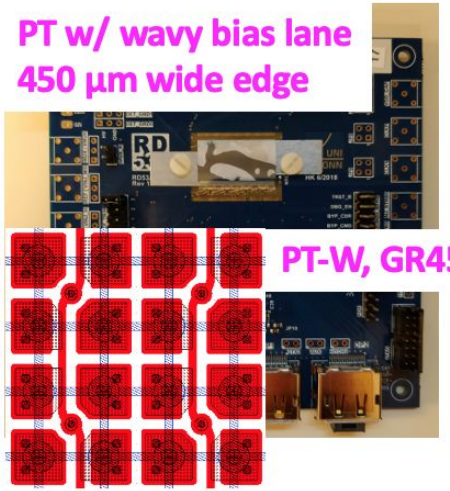
TM, GR250

PT w/ wavy bias lane
250 µm wide edge



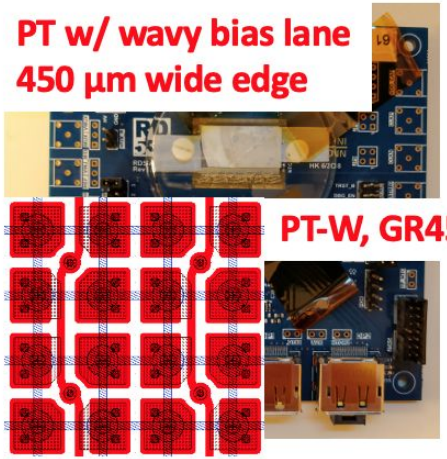
PT-W, GR250

PT w/ wavy bias lane
450 µm wide edge



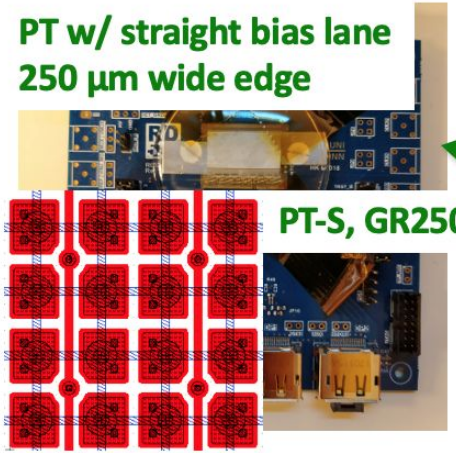
PT-W, GR450

PT w/ wavy bias lane
450 µm wide edge



PT-W, GR450

PT w/ straight bias lane
250 µm wide edge



PT-S, GR250

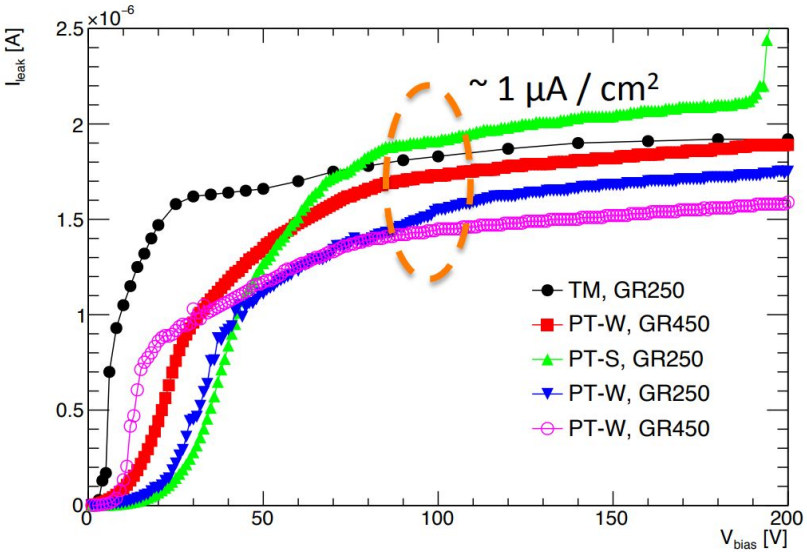
Unfortunately roc unresponsive so no data for this design

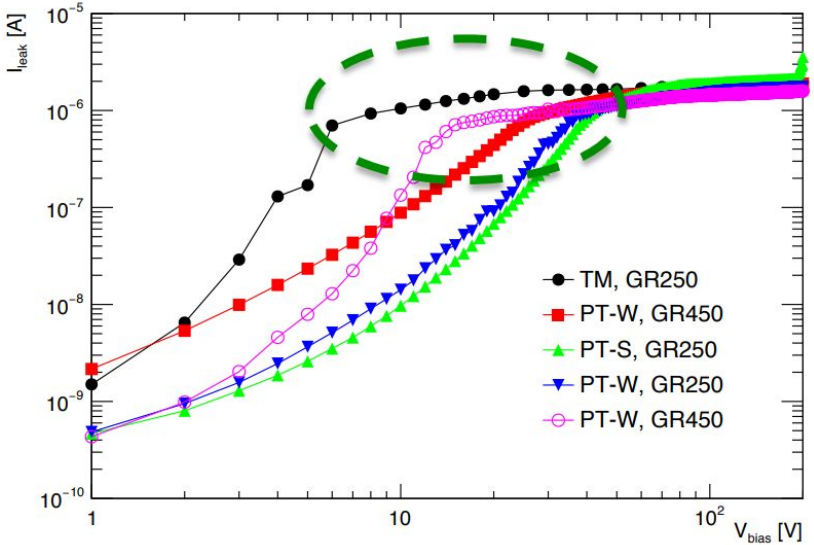
50 µm thickness production 2019

50 um thickness: IV Curve

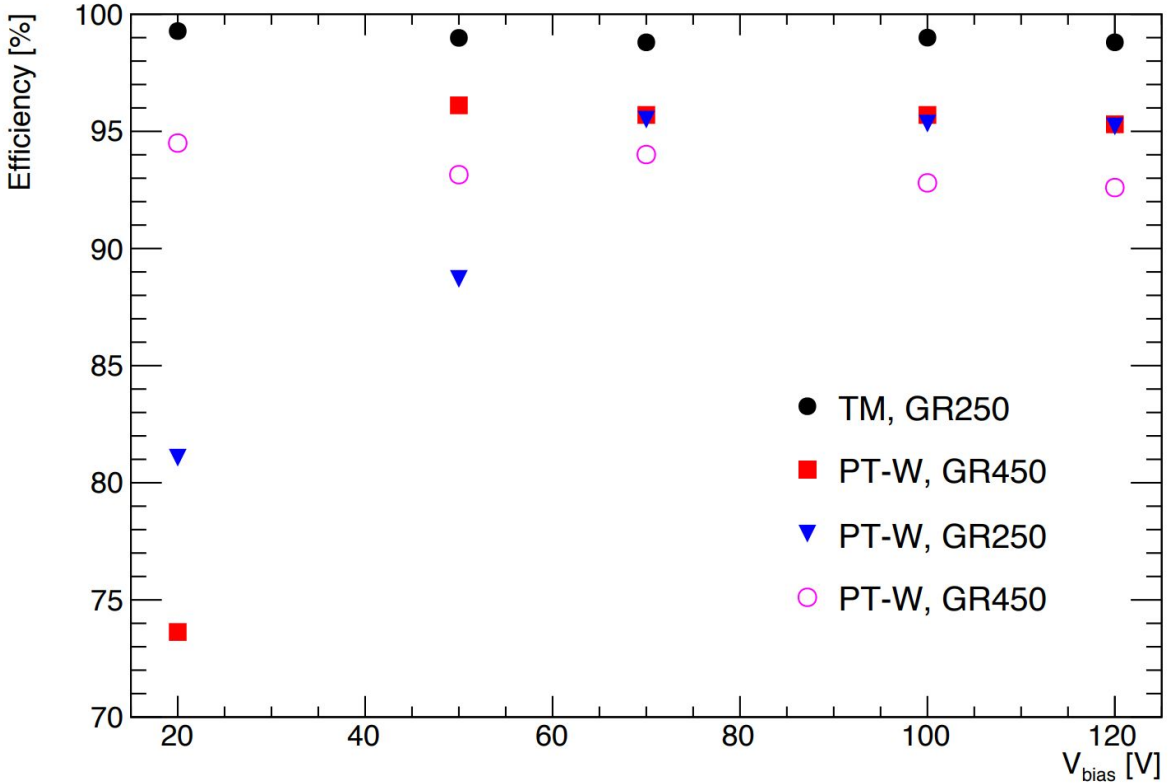
Breakdown > 200 V

Depletion 10-30 V



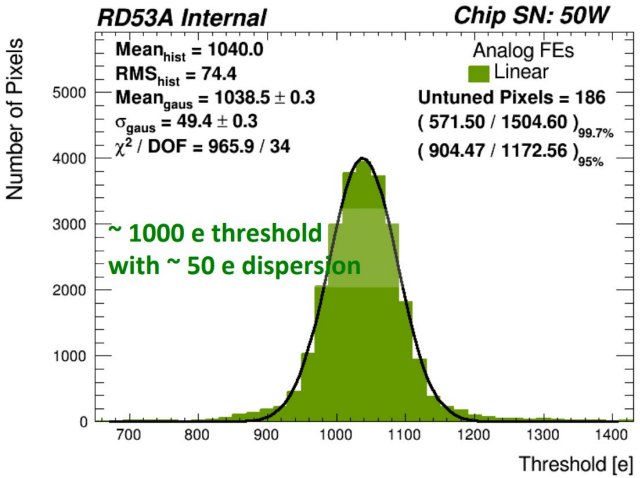


50 um thickness: hit efficiency



Efficiency 99% for temporary metal design

94-96% for punch through design (see next slide)

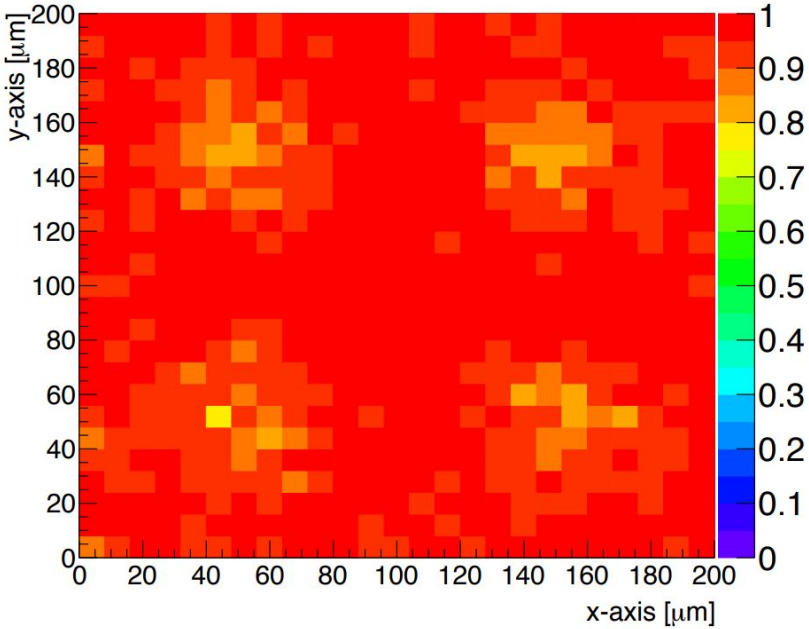


50 um thickness

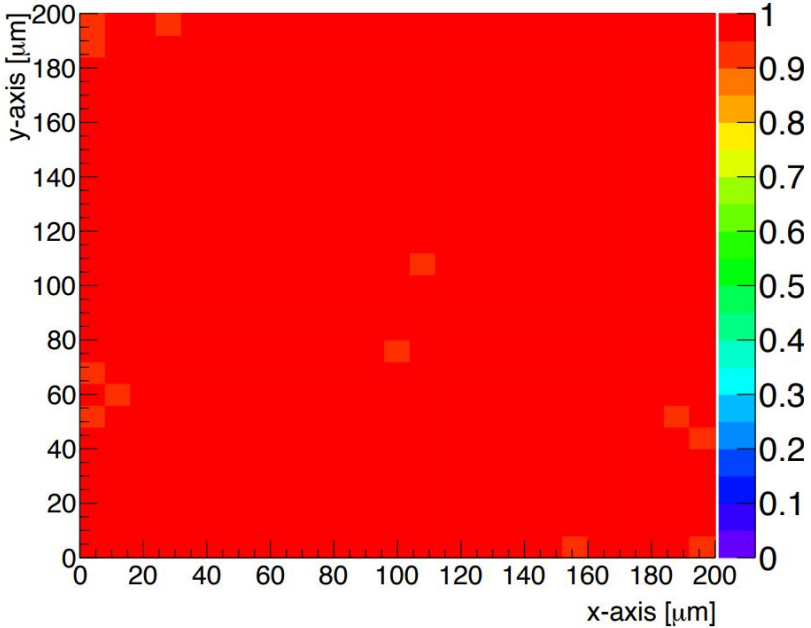
Localized loss of efficiency due to the punch through structure

N.B. tracks at normal incidence

Hit-eff. folded in a 4x4 pixel map



PT-W, GR250



TM, GR250

Conclusions

- The ITk upgrade for the ATLAS silicon tracker for HL-LHC is preparing for the production phase
  - Planar pixel sensors will be used in all but the innermost pixel layer
  - 100 μm and 150 μm sensors from various vendors are going through a qualification stage called Market Survey
    - All ITk institutes including the Paris Cluster institutes are involved in the Marked Survey effort through metrology and electrical measurements
- Future hadronic colliders impose light and high efficient silicon sensors for tracking in unprecedented harsh environments
  - Thin n-on-p pixels are promising candidates
  - Small pitches are becoming available
  - Very thin sensors (50 μm) show promising results before irradiation
    - two of them will be tested in DESY in next available test beam after irradiation to 5×10^{15} n_{eq}/cm^2