Comparison of Radiation Hardness Properties of p^+n^- & n^+p^- Si Strip Sensors Using Simulation Approach

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- Work done for CMS-HPK Simulation group

Contents of presentation

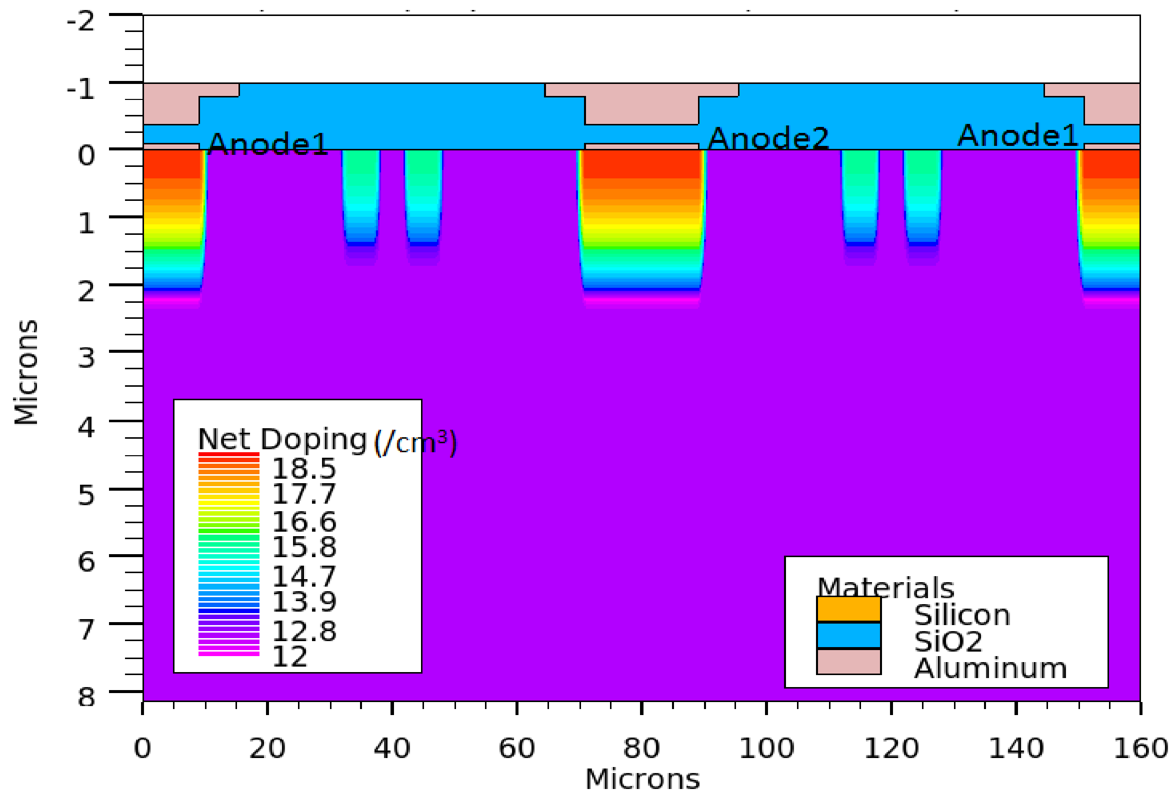
- **Simulation framework**
- **Comparison of Interstrip properties of p-in-n and n-in-p sensors**
  - Cint comparison
  - Rint comparison
- **E field comparison of p-in-n and n-in-p type irradiated strip sensor**
  - Correlation with measured non-Gaussian Noise
- **E field simulations for irradiated p-in-n sensors :**
  - Effect of oxide charge density variation
    - Measured non-Gaussian noise for different type of irradiation
  - Effect of strip pitch variation
    - Measured non-Gaussian noise for different pitch
  - Effect of temperature variation
    - Comparison with measurements
- **Summary**

Simulation structure

- Bulk doping = 3e12cm-3
- 2-D simulations

For n+p- sensors
-Double p-stops (P-type)
- Each 4µm wide separated by 6µm
- P-stop doping = 5e15cm-2
  P-stop doping depth = 1.6um

CMS HPK tracker upgrade campaign parameters [1]
- Simulations using Silvaco TCAD



A . Deirlamm, 2012 JINST 7 C01110 ,
THE 9th INTERNATIONAL CONFERENCE ON POSITION SENSITIVE DETECTORS, 12–16 SEPTEMBER 2011,

Bulk + Surface damage model

- Two more acceptors & one donor in addition to two deep levels
- Able to remove accumulation e-
- Produce very high E field near n+
- Reproduce experimental observed Rint and Cint

Trap	Energy Level	Intro.	σ_e (cm^{-2})	σ_h (cm^{-2})
Acceptor	0.525eV	3.0	$1x10^{-14}$	$1.4x10^{-14}$
Acceptor	0.45eV	40	$8x10^{-15}$	$2x10^{-14}$
Acceptor	0.40eV	40	$8x10^{-15}$	$2x10^{-14}$
Donor	0.50eV	0.6	$4x10^{-14}$	$4x10^{-14}$
Donor	0.45eV	20	$4x10^{-14}$	$4x10^{-14}$

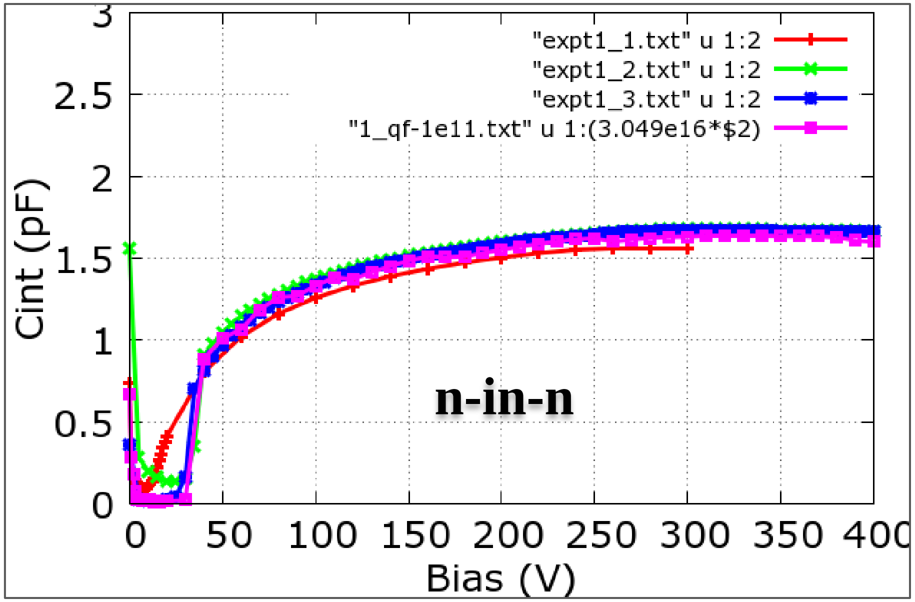
- ➢ Along with radiation damage (fluence, particle type), oxide charge density is a complex function of fabrication process, annealing steps, humidity etc.
- ➢ Hence, instead of taking one value of Q_F, for a given flux of hadron irradiation, surface damage is incorporated in simulation by considering range of Q_F for a given fluence.

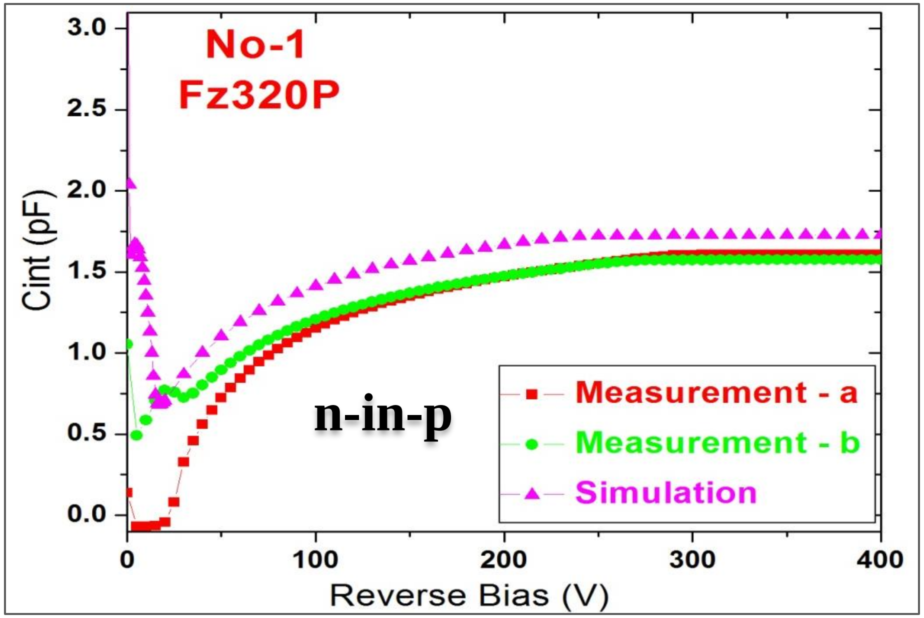
Ranges of Oxide charge density (Q_F) used

Irradiation fluence (neq/cm^2)	Range of Q_F (cm^{-2})
0	5e10 to 5e11
$1x10^{14}$	1e11 to 8e11cm-2
$5x10^{14}$	5e11 to 1.2e12
$1x10^{15}$	8e11 to 2e12

Simulation of strip sensor : C_{int} vs. V_{bias} (un-irradiated)

Simulation vs. Measurement



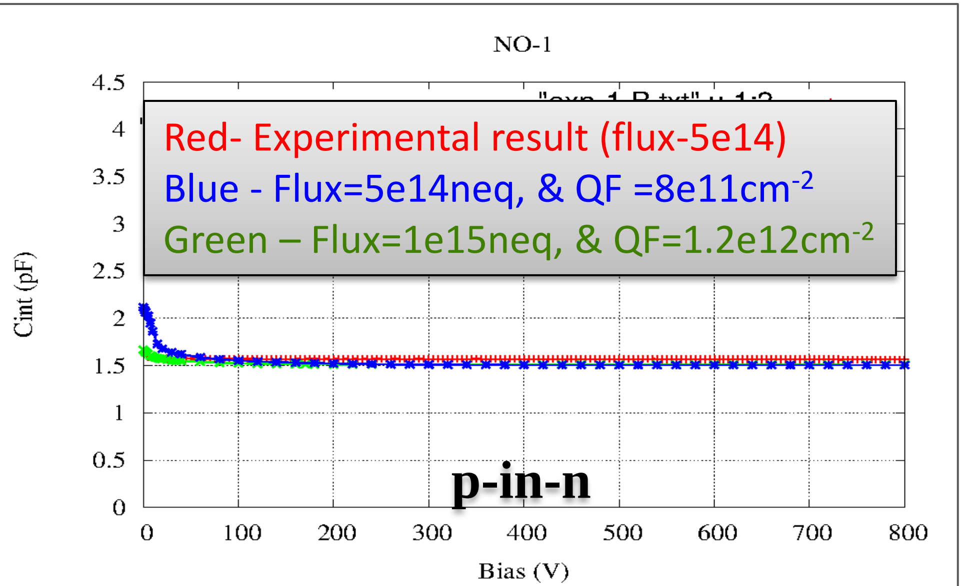


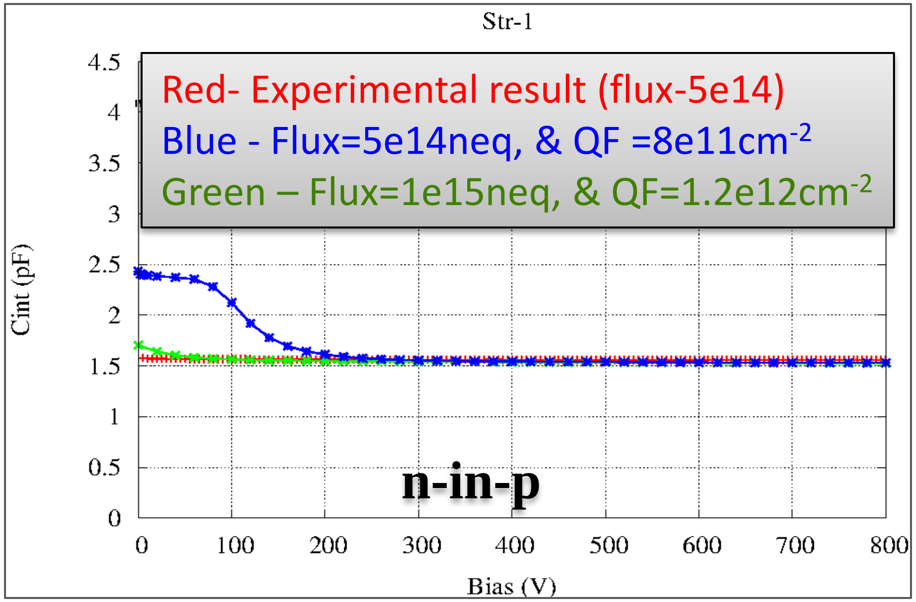
- Strip pitch 120µm

- **Simulations are mostly in good agreement with measurements for both p-in-n and n-in-p type of strip sensors.**

Simulation of strip sensors : C_{int} vs. V_{bias} (Irradiated)

Simulation vs. Measurement

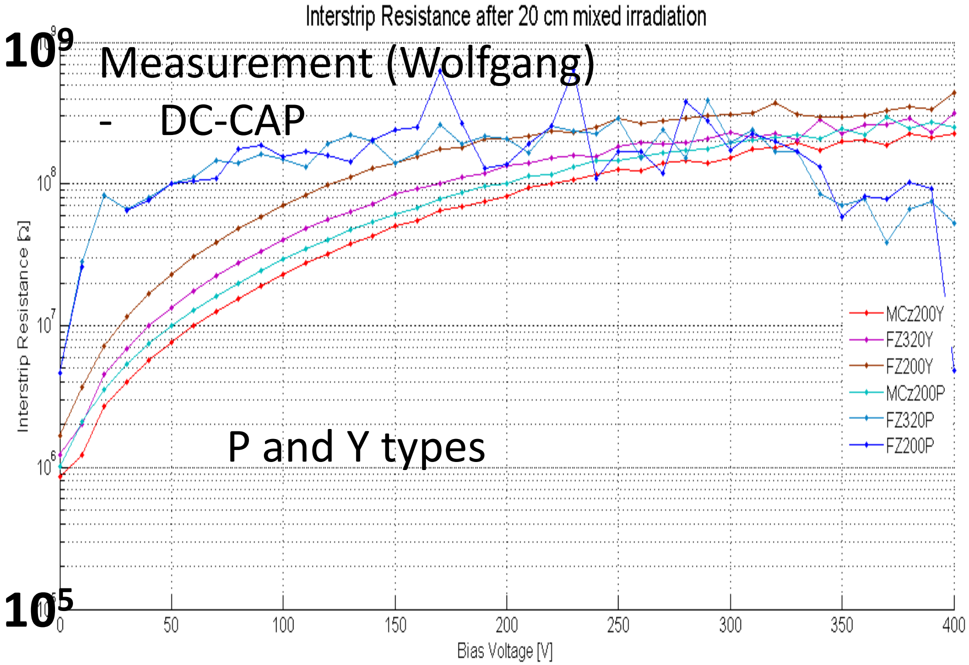


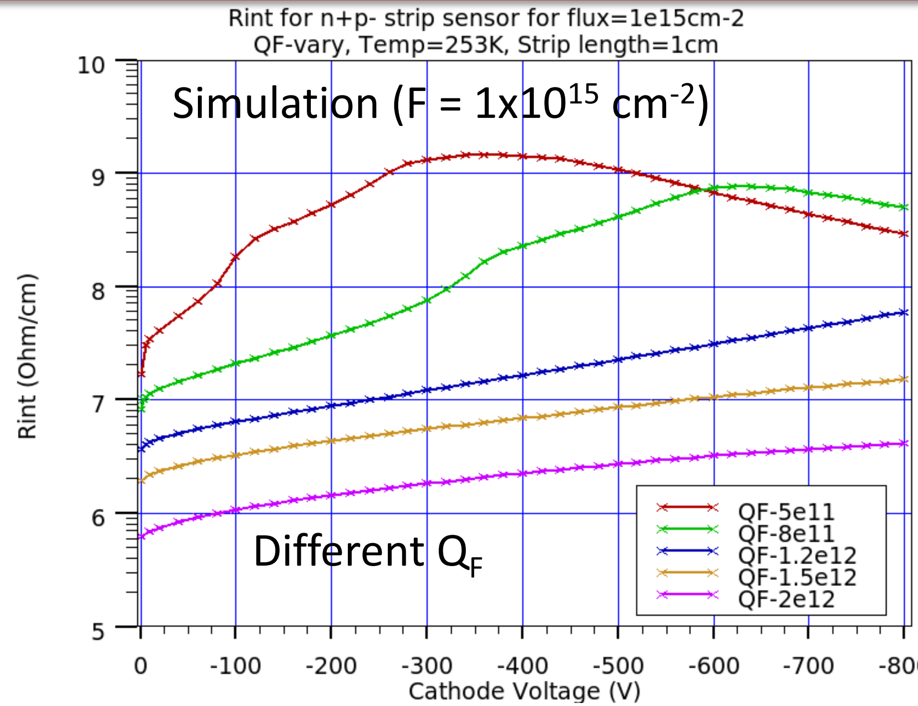


- Strip pitch 120µm

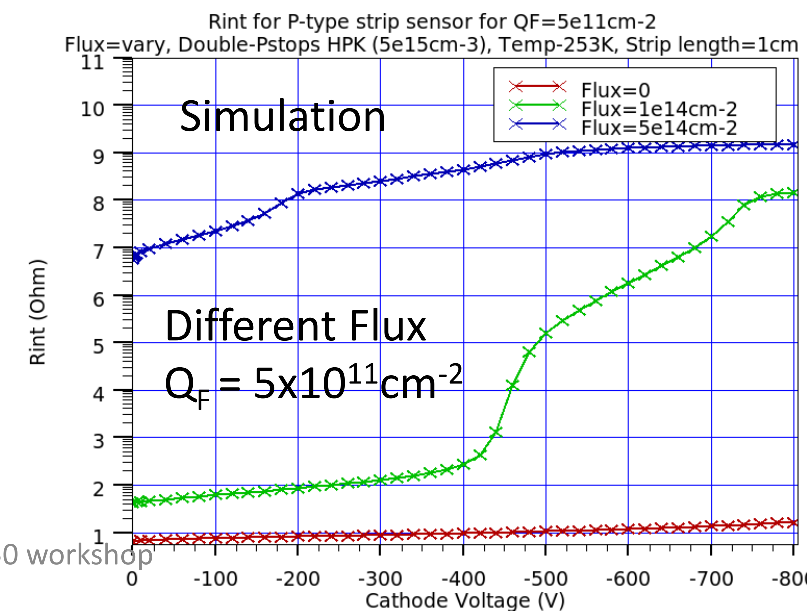
- **Simulation is mostly in good agreement with measurements for both p-in-n and n-in-p type strip sensor**
- **C_{int} is quite similar for both type of sensors**

Simulations vs measurement : R_{int} for n-in-p sensor

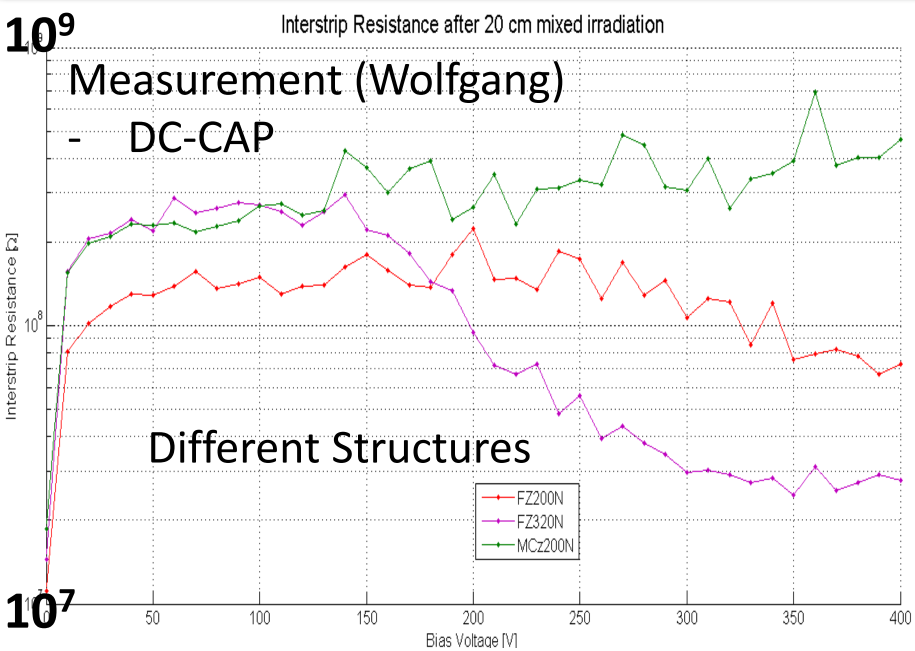


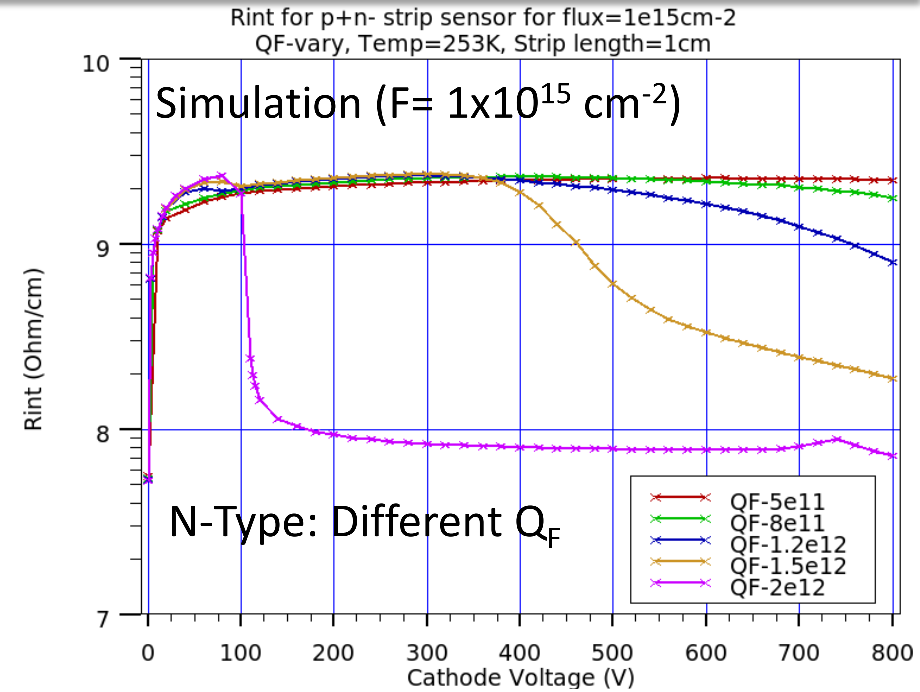


- Simulated R_{int} show trends similar to the Measurements.
- R_{int} decreases on increasing the Q_F.
- R_{int} is a strong function of the combination of surface damage (Q_F) and Bulk Damage (flux). Bulk damage compensates for surface damage.
  - Good isolation even at high flux and high Q_F.



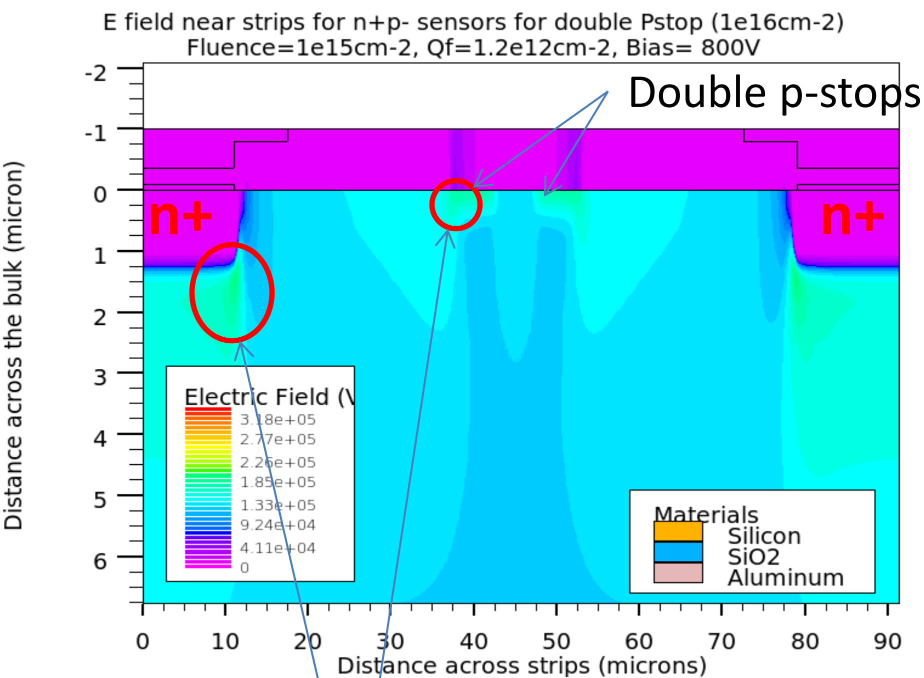
Simulations vs measurement : R_{int} for p-in-n sensor

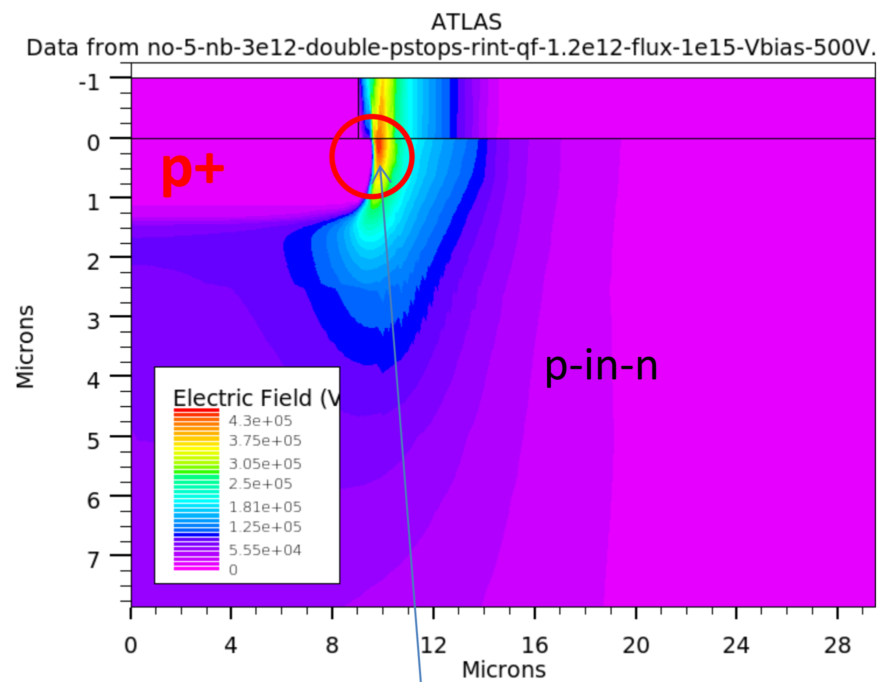




- Isolation remains good for all values of Q_F.
- Simulation shows decrease in R_{int} for high values of Q_F at high Bias values. Experimentally different structures show similar behaviour.
  - Electric field near the curvature of p+ strip is quite high & increases with Q_F . This high E field can initiate a localized avalanche & can decrease R_{int}

Maximum E field regions in p-type and n-type sensors





Maximum E field for n+p- MSSD is
near the curvature region of n+ strip
Or just near p-stop, just below SiO2/Si interface
- Shown by cutline 1.3µm below SiO2/Si interface

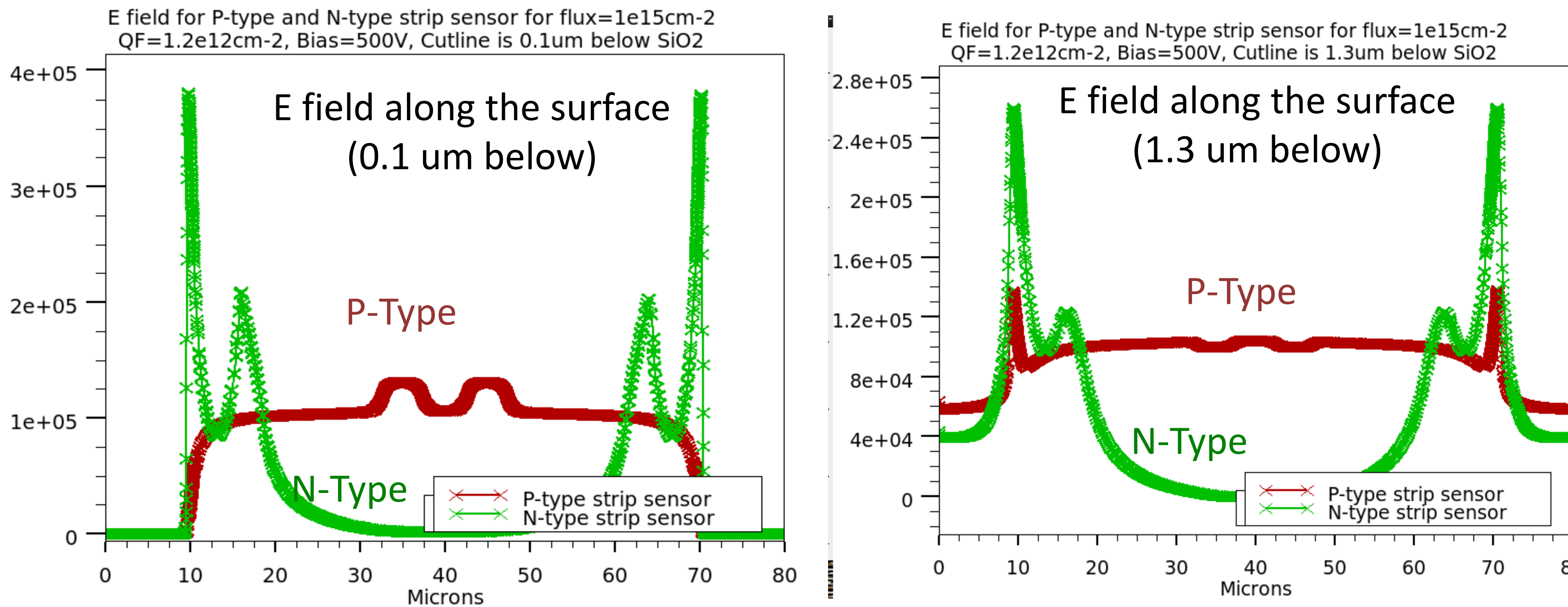
Maximum E field for p+n- MSSD is
just below SiO2/Si interface
- Shown by cutline 0.1µm below SiO2

Effect of very high E field in irradiated sensor

- E field inside irradiated sensors is a strong function of space charge .
- Very high E field in a region can initiate avalanche in that region.
- Once avalanche is started, a lot of free e/h pairs are produced which will compensate the nearby space charge, changing the electric field, thus stopping the further breakdown.

This mechanism may stop the avalanche from turning global and continuous. Thus high E field near the strips can be a reason of non – Gaussian noise events which occur randomly (RGH- Random Gaussian Hits)

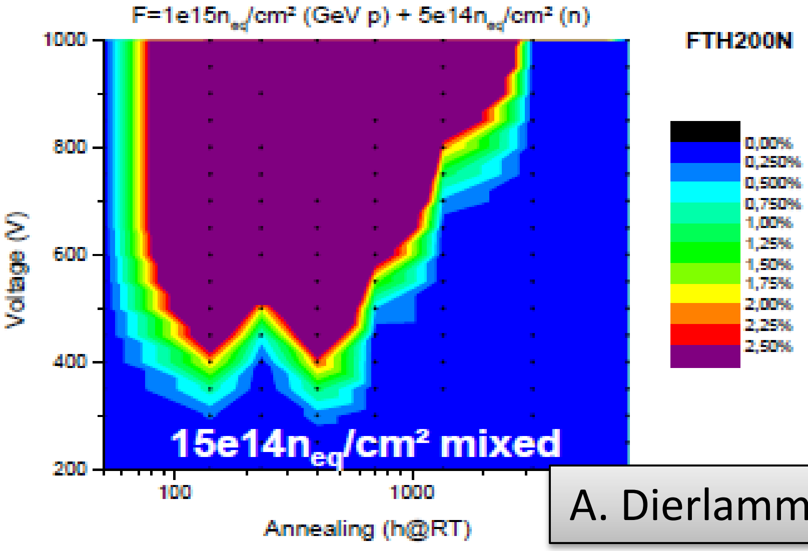
E. Field (Irradiated) comparison : p-in-n & n-in-p sensor



Flux = $1\text{x}10^{15}\text{cm}^{-2}$; $Q_F = 1.2\text{x}10^{12}\text{cm}^{-2}$; Bias = 500 V

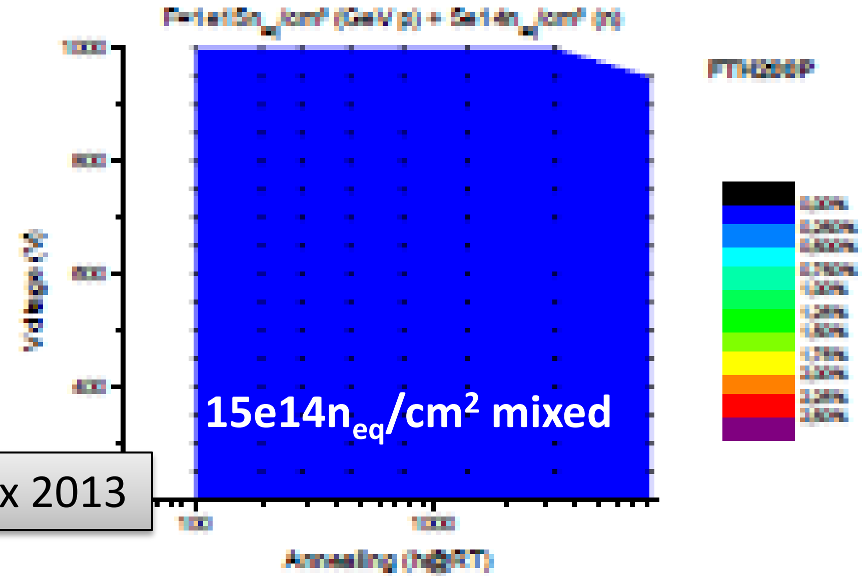
- Peak electric field is more for p-in-n (n-type) sensor as compared to n-in-p (p-type) sensor for a given bias.
    - Micro-discharge possibility is much more in p-in-n sensors.

Amount of RGH for irra. n-type and p-type of sensor



A. Dierlamm, Vertex 2013

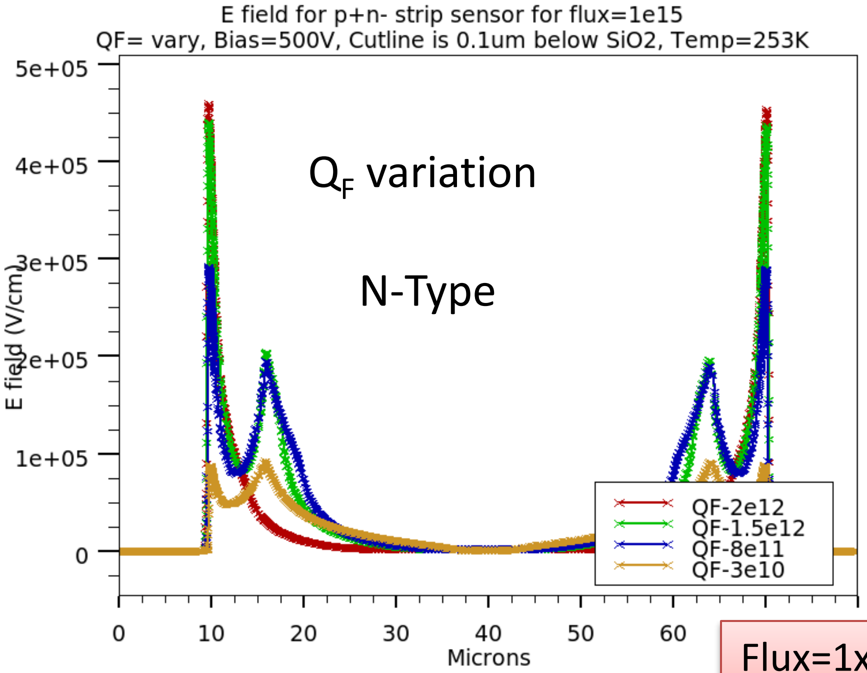
N-type sensor

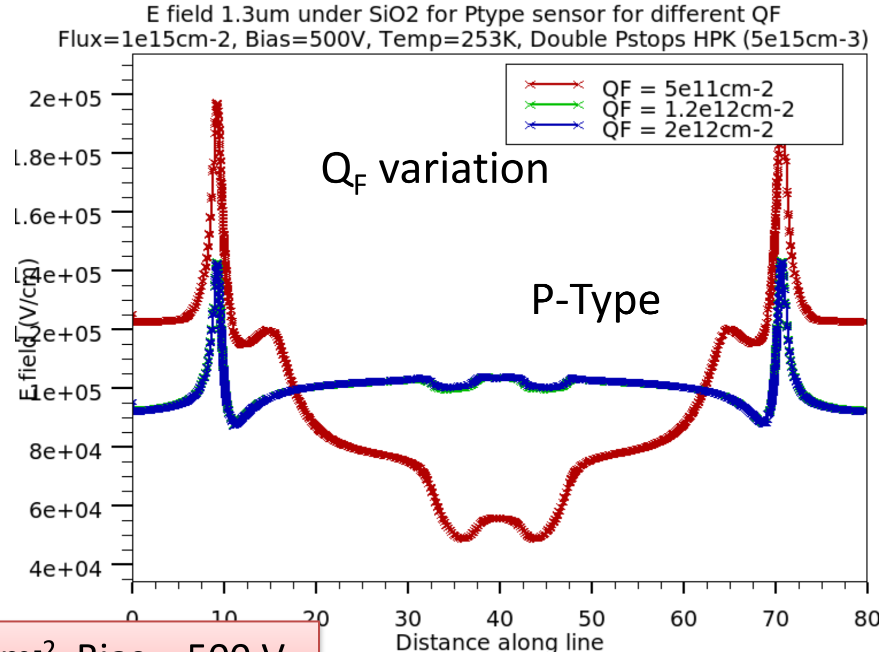


P-type sensor

- Significant amount of non-Gaussian noise (RGH) observed in p-in-n sensor (n-type)
- Very less amount of RGH rates observed for n-in-p (p-type) sensor

E. Field (Irradiated) : Effect of Q_F





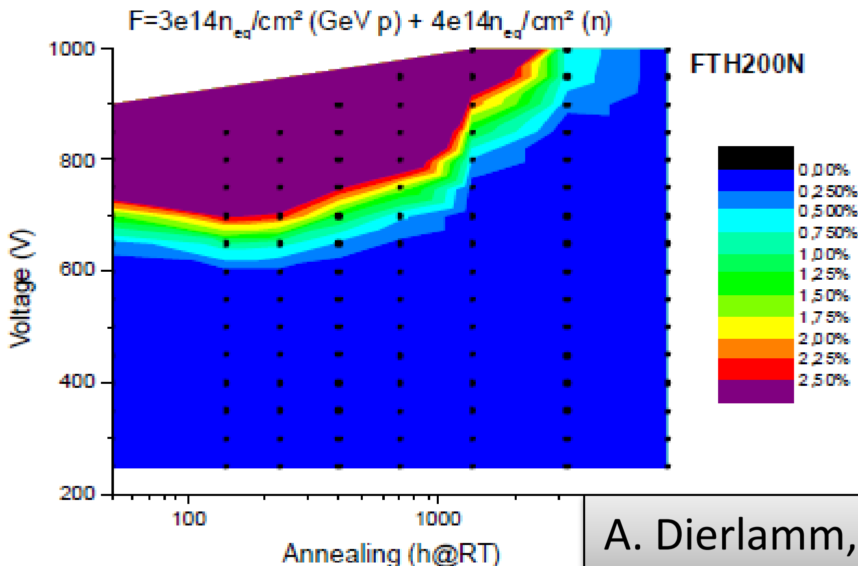
Flux=$1 \times 10^{15} cm^{-2}$ Bias = 500 V

- **N-type sensors (p-in-n)**
  - **As Q_F increases = > Peak Efield increases.**
  - **Micro-discharge possibility is more in N-type sensors after proton irradiation or less possibility after neutron irradiation**

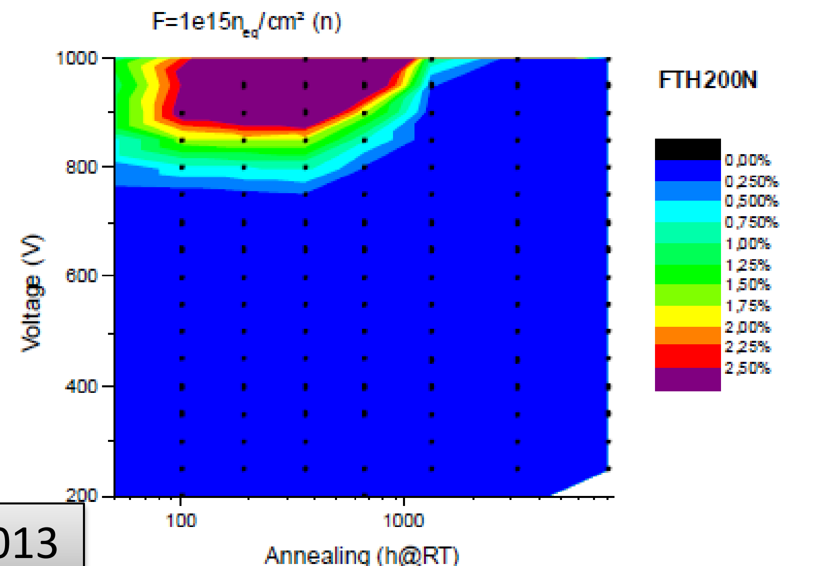
- **P-type (n-in-p)**
  - **Peak field is much less compare to p-in-n sensors**
  - **As Q_F increases = > Peak E field decreases.**

RGH for different type of irradiation (for p-in-n)

7e14n_{eq}/cm² mixed



10e14n_{eq}/cm² neutrons



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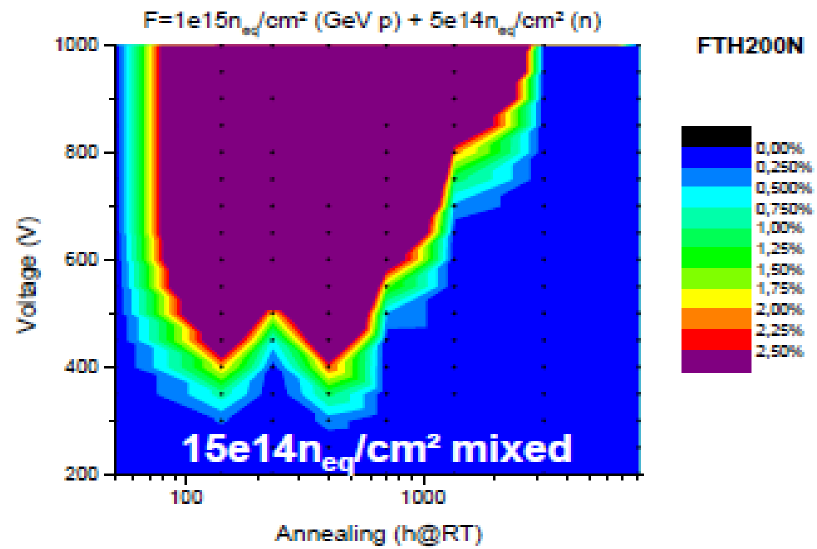
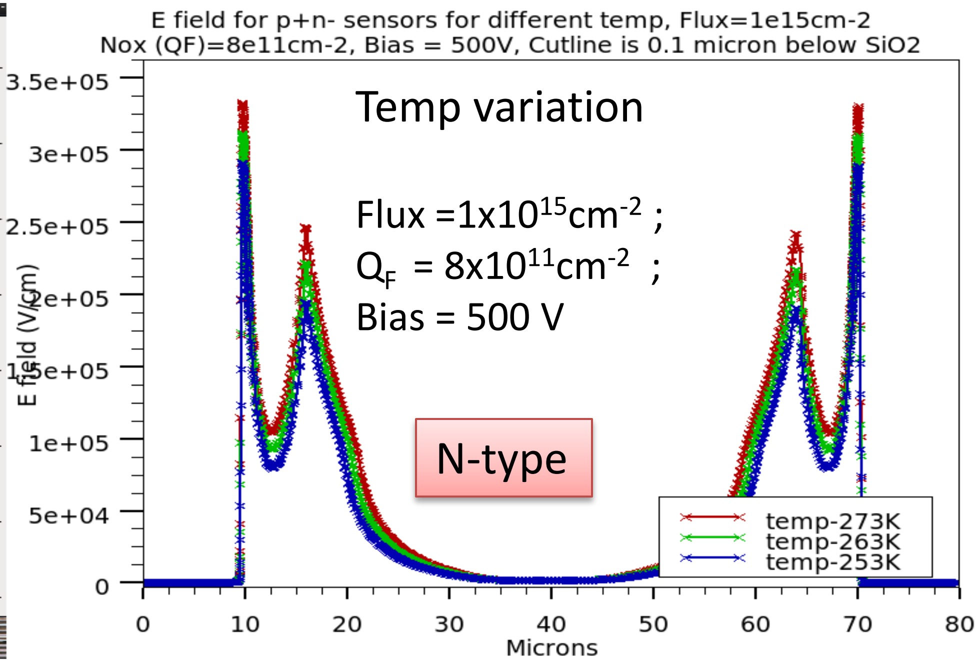
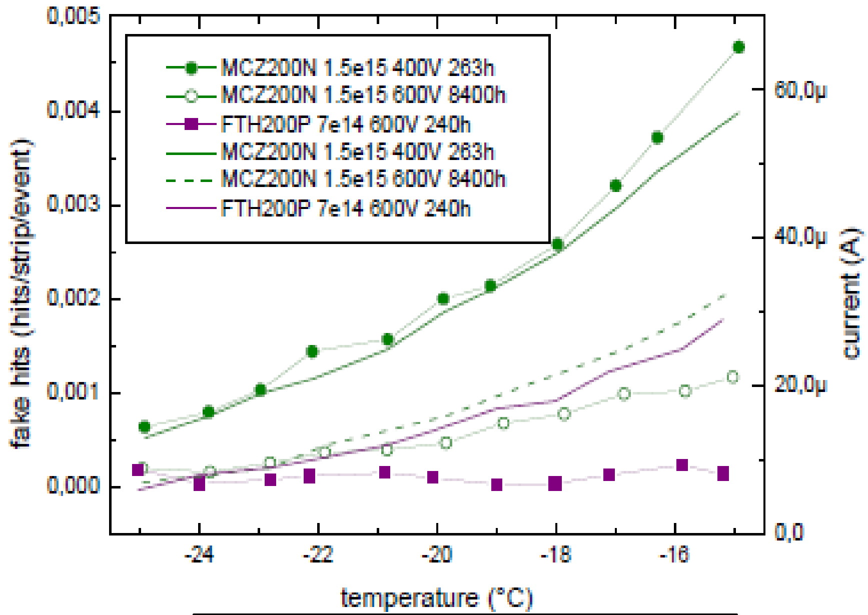


- Much less RGH for neutron irradiation clearly indicate the role of surface damage
- The dependence on ionizing radiation hints toward a combined effect of bulk damage and surface damage
- The Q_F effect simulation were carried out before these measurements

E field for p-in-n sensor : Effect of temp. variation





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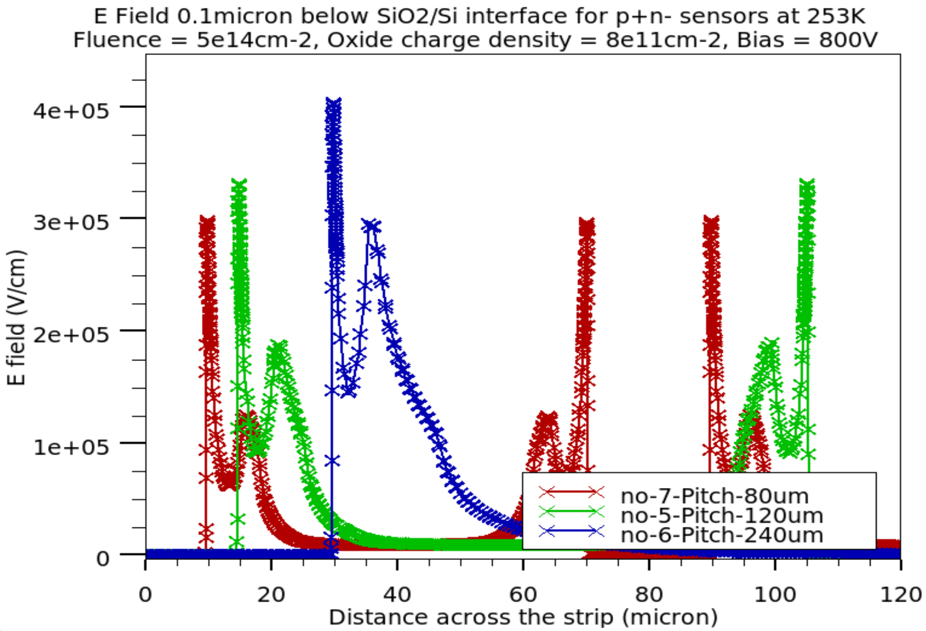
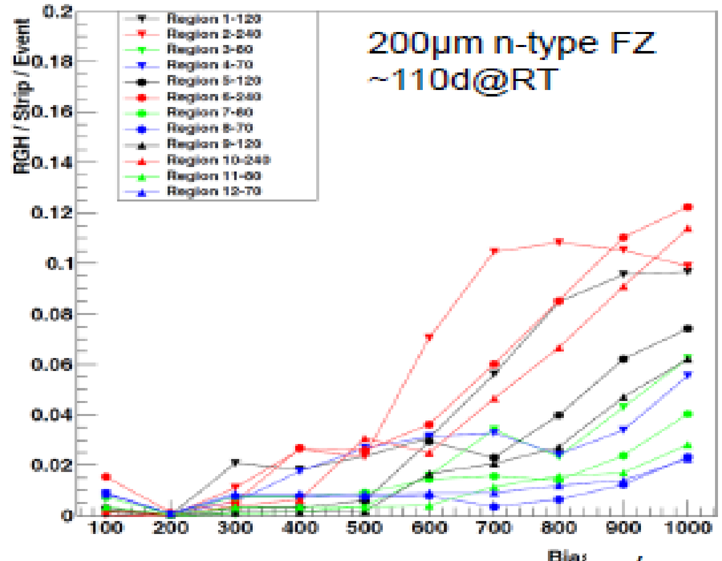
- Simulations shows small increase of Maximum Electric field with increase in temperature
- Measured RGH rate also increases with increase in temperature.

Effect of strip pitch variation on E field





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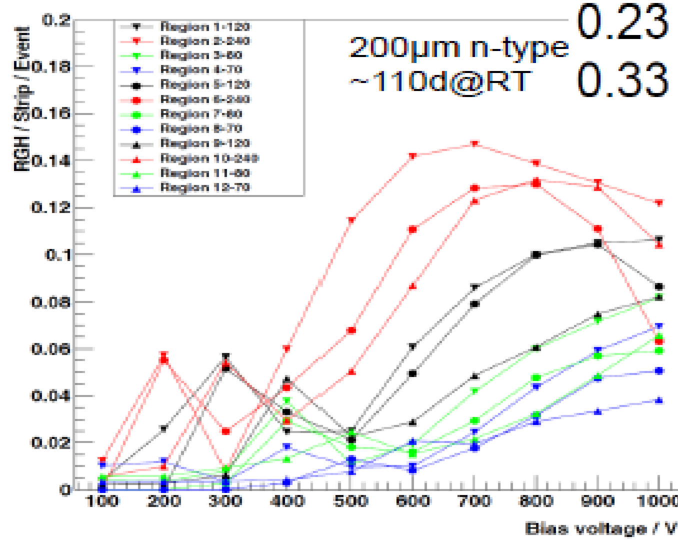
w/p
0.13 ▼
0.23 ●
0.33 ▲

Pitch:
70µm
80µm
120µm
240µm



- Simulated maximum E field near p+ curvature, just below SiO2/Si interface increases with increase in strip pitch
- RGH also follow the similar trend.
- Maximum RGH are for 240µm strip pitch.

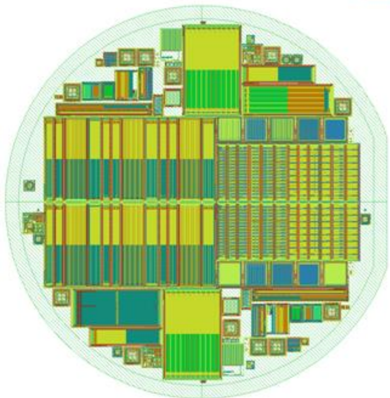
Summary/future outlooks

- No significant difference in C_{int} values for p-type and n-type sensors
- Similarly, good R_{int} can be expected for p-type sensors after irradiation, even for moderate/low p-stop doping density.
- Critical electric field study
  - P-type (n-in-p) sensors intrinsically better (compare to n-type) after irradiation – lower electric fields at the strips side

  (However high electric field appear on p-stop implant for high p-stop doping dose after irradiation – Avoid high p-stop doing)
- Non Gaussian noise problem
  - Very high E field may be cause of non-Gaussian noise events in irradiated sensors
  - p+n- sensors are more prone to micro-discharge problem
  - Simulations and measurements produce similar trends
- Edge TCT (Kramberger, Marcos) and TCT results will be used to further tune the bulk damage models
- Study to decrease the no. of traps in bulk damage model is going on

Thanks for your attention!

17 institutes currently involved in CMS-HPK Phase-II tracker upgrade campaign



Device Simulation Group

- DESY
  - **Tool: Synopsys**
- Helsinki Institute of Physics
  - **Tool: Synopsys**
- Karlsruhe Institute of Technology
  - **Tool: Silvaco, Synopsys**
- University of Delhi
  - **Tool: Silvaco**
- University of Pisa (Italy)

Device Simulation Group - Aims:

- Provide input to the CMS sensor designs
- Points under investigation:
  -- Device design – simulate capacitances, verify isolation techniques
- Charge collection and read-out, research optimal layout
- Radiation damage modeling of sensors→ derive a trap model
- Comparison of simulation tools