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/cm²)	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

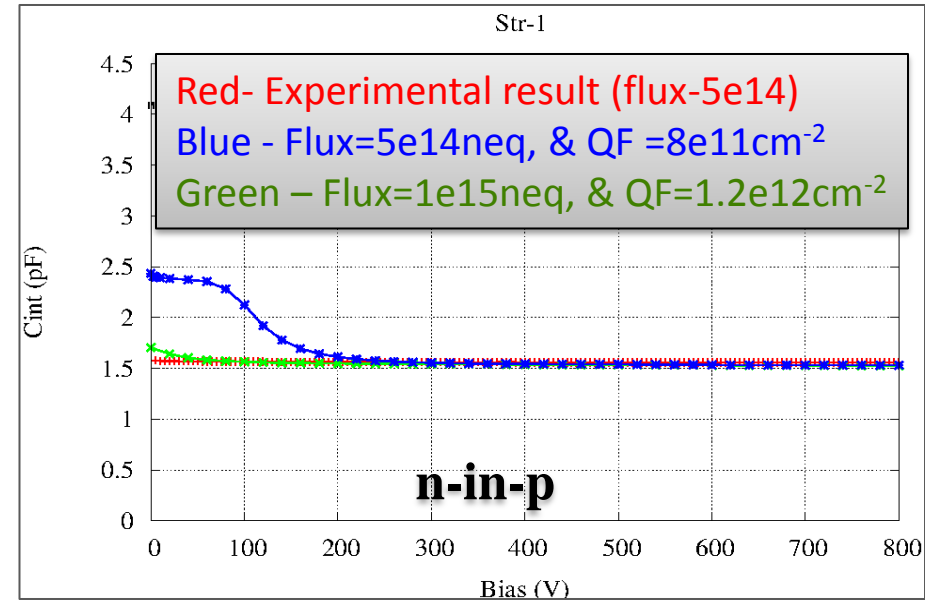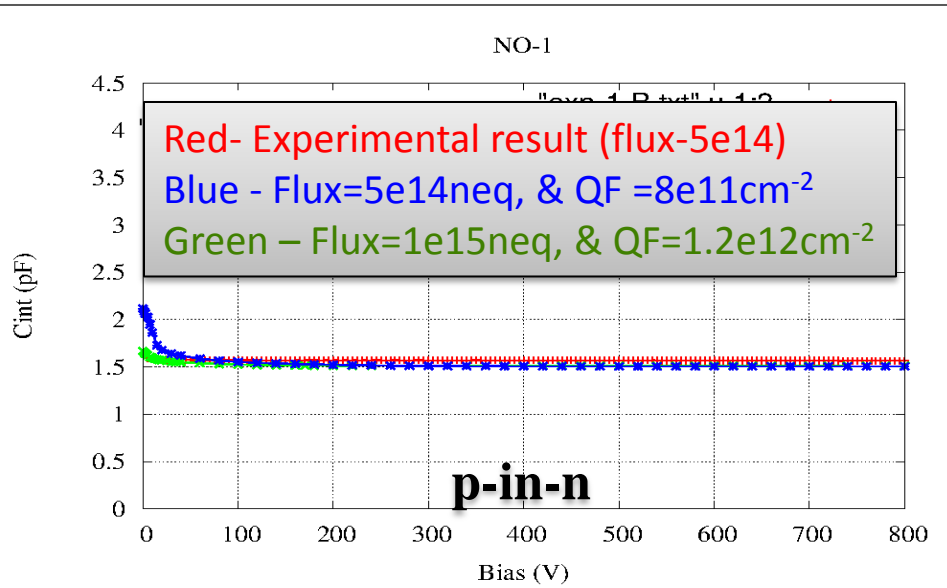**Simulation vs. Measurement**

n-in-n
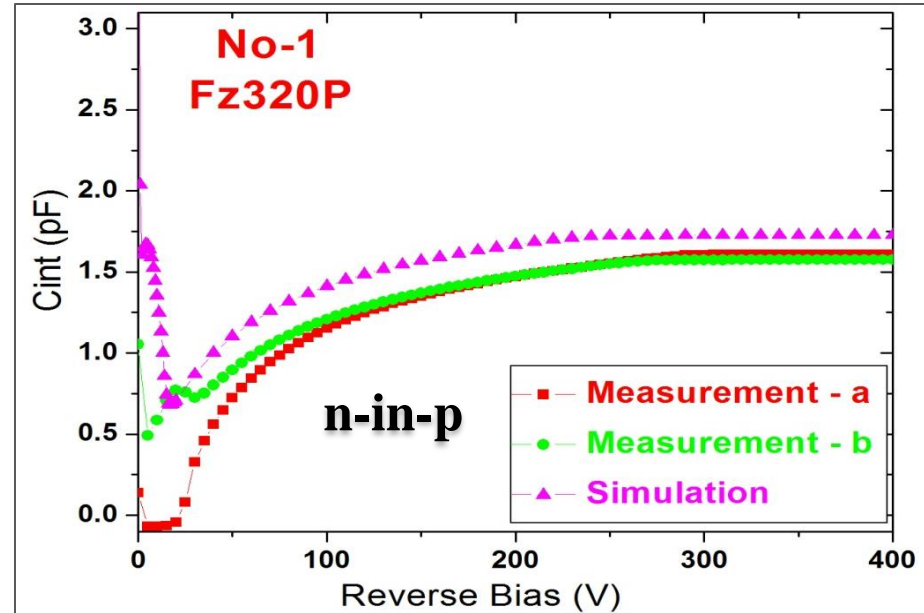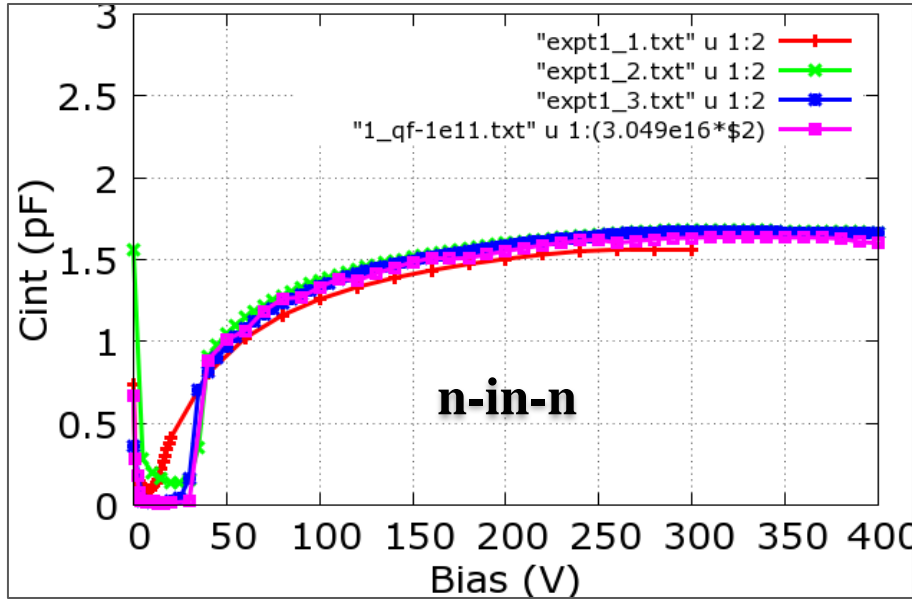
n-in-p

- Strip pitch 120µm

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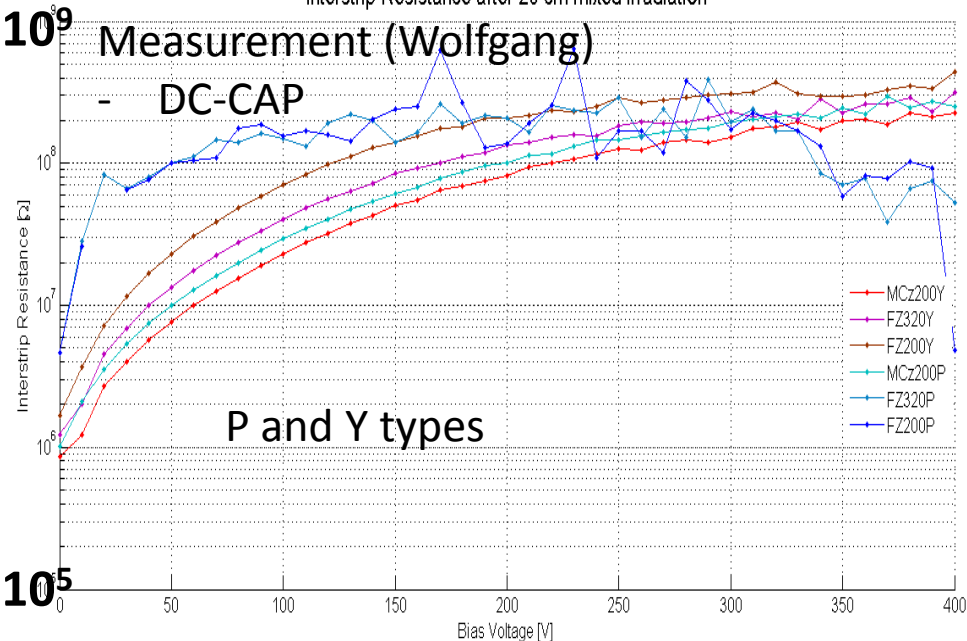
Simulation vs. Measurement

- 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**

Interstrip Resistance after 20 cm mixed irradiation

Measurement (Wolfgang)
- DC-CAP

P and Y types

10^9

10^5

Rint for n+p- strip sensor for flux=1e15cm-2
QF-vary, Temp=253K, Strip length=1cm

Simulation (F = 1×10^{15} cm^{-2})

Different Q_F
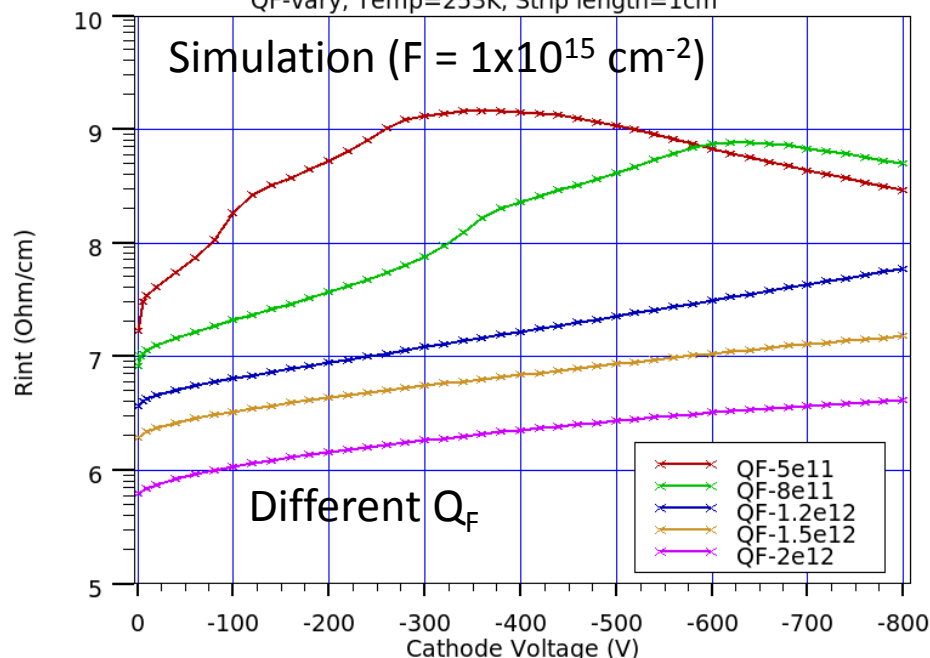
Rint for P-type strip sensor for QF=5e11cm-2
Flux=vary, Double-Pstops HPK (5e15cm-3), Temp-253K, Strip length=1cm

Simulation

Different Flux
$Q_F = 5 \times 10^{11}$cm^{-2}

• Simulated R_{int} show trends similar to the Measurements.

• R_{int} decreases on increasing the Q_F.
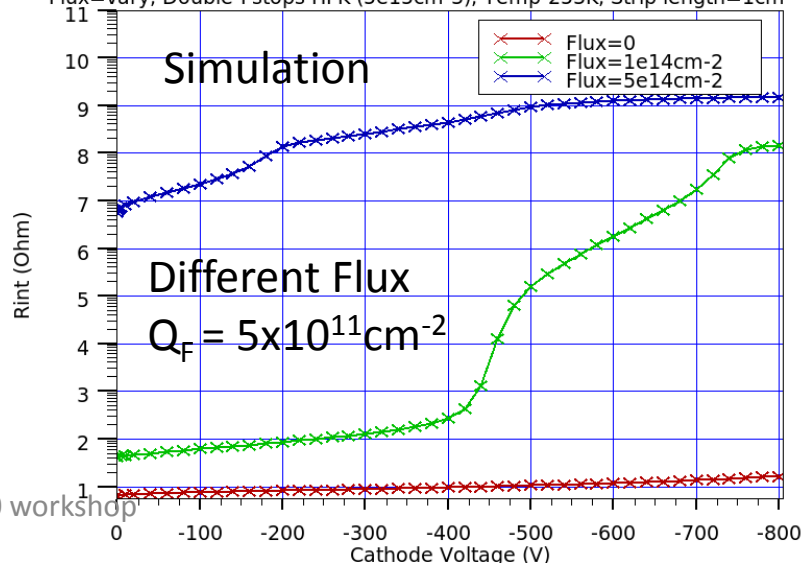
• R_{int} is a strong function of the combination of surface damage (Q_F) and Bulk Damage (flux). Bulk damage compensates for surface damage.

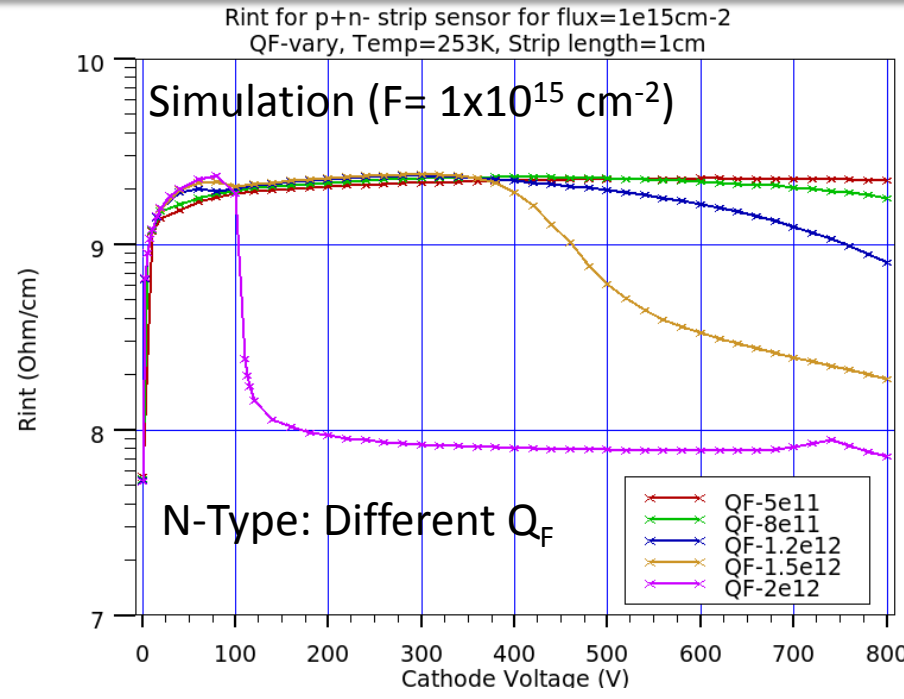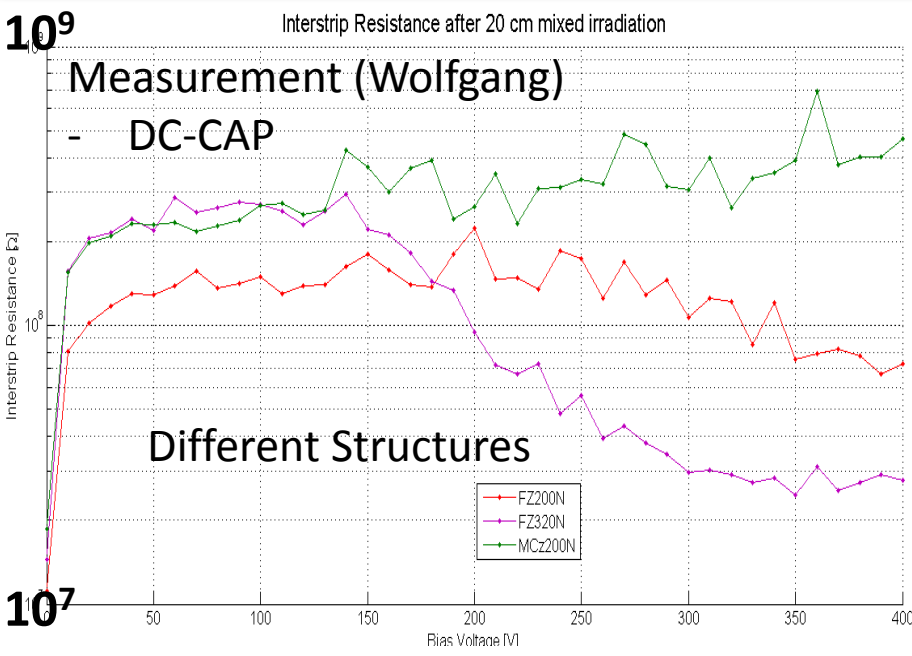   • Good isolation even at high flux and high Q_F.

Interstrip Resistance after 20 cm mixed irradiation

10^9

Measurement (Wolfgang)
- DC-CAP

Different Structures

- FZ200N
- FZ320N
- MCz200N

Interstrip Resistance [Ω]

Bias Voltage [V]

10^7

Rint for p+n- strip sensor for flux=1e15cm-2
QF-vary, Temp=253K, Strip length=1cm

Simulation (F= 1x10^{15} cm^{-2})

N-Type: Different Q_F

Rint (Ohm/cm)

Cathode Voltage (V)

- QF-5e11
- QF-8e11
- QF-1.2e12
- QF-1.5e12
- QF-2e12

➢ 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

E field near strips for n+p- sensors for double Pstop (1e16cm-2)
Fluence=1e15cm-2, Qf=1.2e12cm-2, Bias= 800V

Double p-stops

n+   n+

Distance across the bulk (micron)

Distance across strips (microns)

Electric Field (V
3.18e+05
2.77e+05
2.26e+05
1.85e+05
1.33e+05
9.24e+04
4.11e+04
0

Materials
Silicon
SiO2
Aluminum

ATLAS
Data from no-5-nb-3e12-double-pstops-rint-qf-1.2e12-flux-1e15-Vbias-500V.

p+

p-in-n

Microns

Microns

Electric Field (V
4.3e+05
3.75e+05
3.05e+05
2.5e+05
1.81e+05
1.25e+05
5.55e+04
0

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
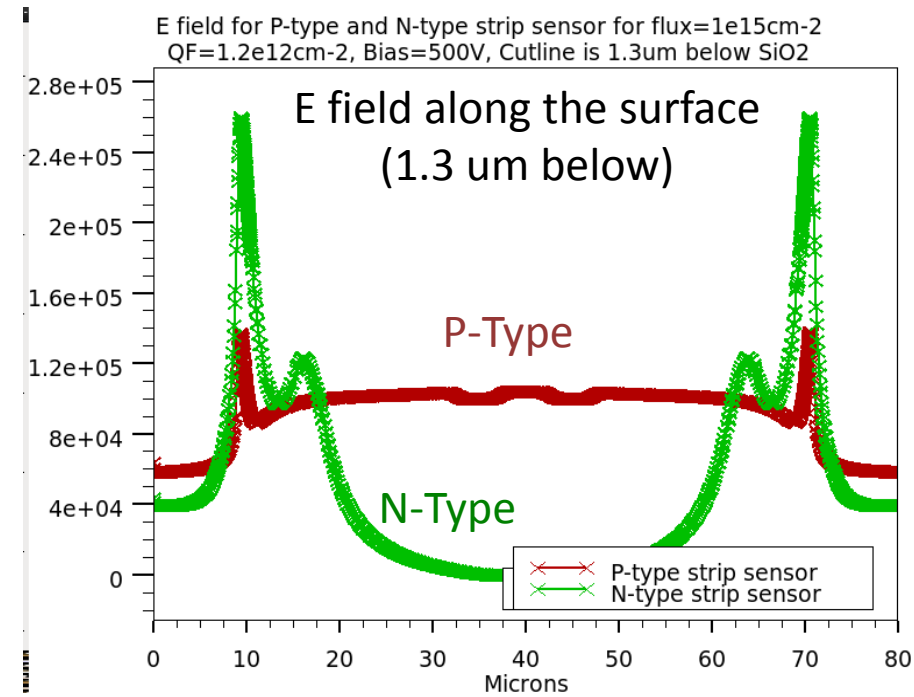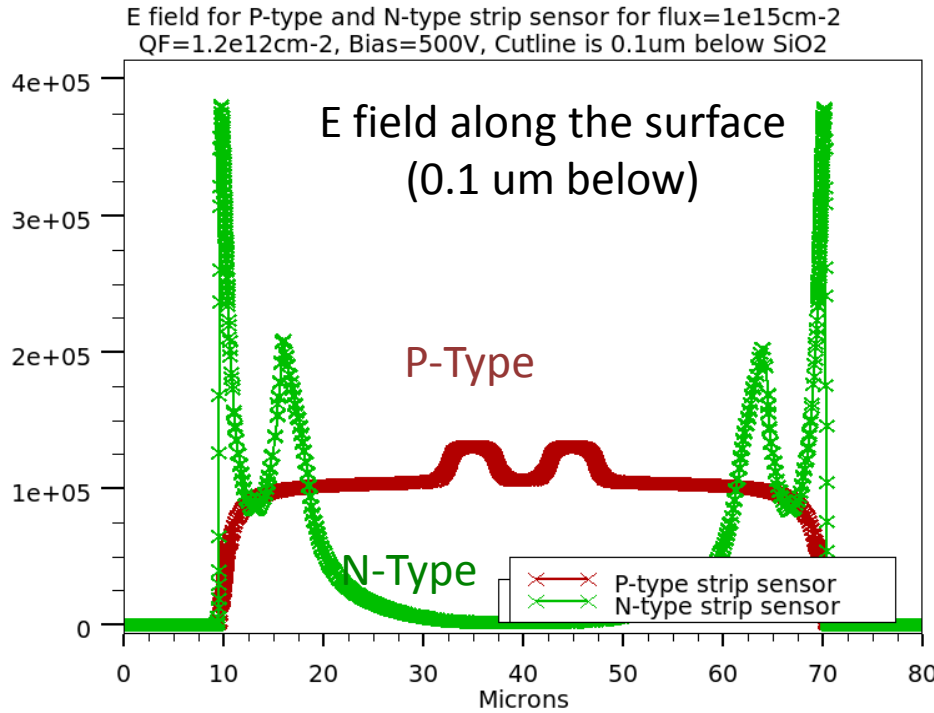- Shown by cutline 1.3µm below SiO2/Si interface

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)
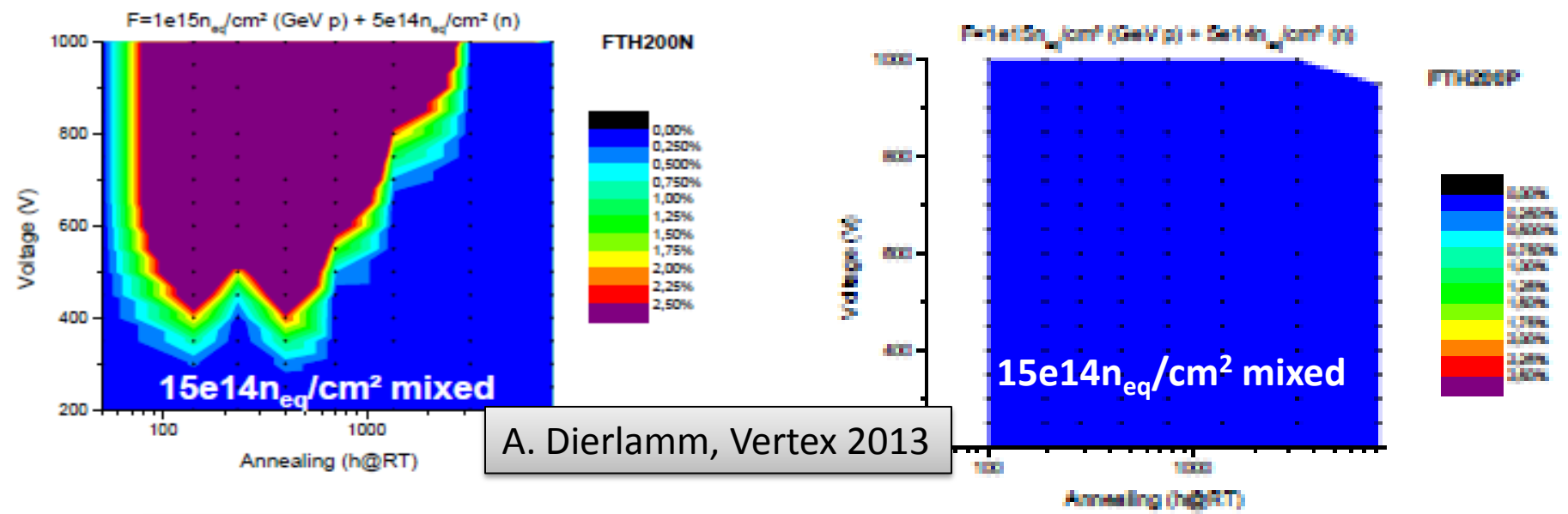
E field for P-type and N-type strip sensor for flux=1e15cm-2
QF=1.2e12cm-2, Bias=500V, Cutline is 0.1um below SiO2

E field along the surface
(0.1 um below)

P-Type

N-Type

P-type strip sensor
N-type strip sensor

E field for P-type and N-type strip sensor for flux=1e15cm-2
QF=1.2e12cm-2, Bias=500V, Cutline is 1.3um below SiO2

E field along the surface
(1.3 um below)

P-Type

N-Type

P-type strip sensor
N-type strip sensor

Flux = $1 \times 10^{15} cm^{-2}$; Q_F = $1.2 \times 10^{12} cm^{-2}$; 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.

F=1e15n$_{eq}$/cm^2 (GeV p) + 5e14n$_{eq}$/cm^2 (n)

FTH200N

15e14n$_{eq}$/cm^2 mixed

A. Dierlamm, Vertex 2013

N-type sensor

P-type sensor

15e14n$_{eq}$/cm^2 mixed
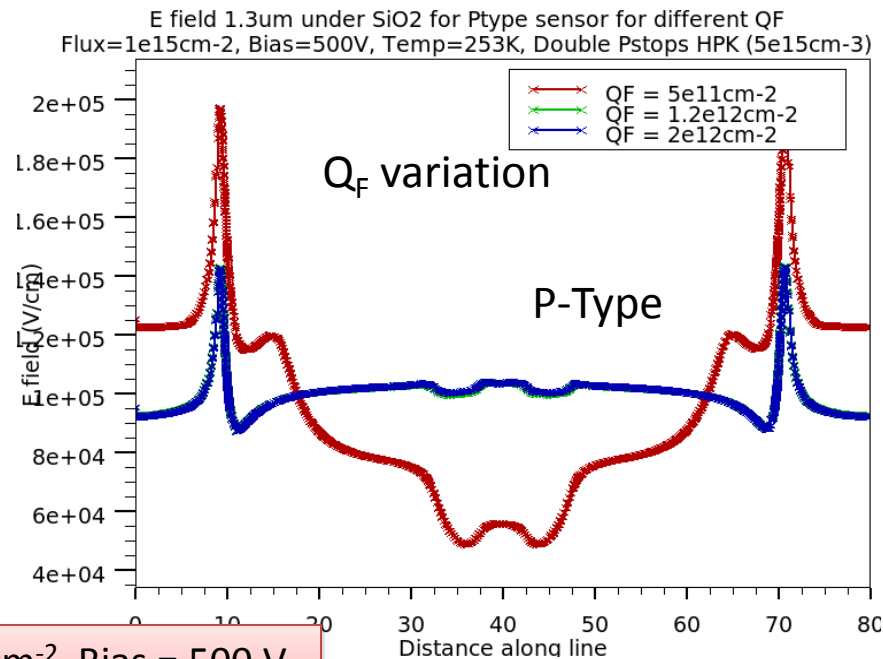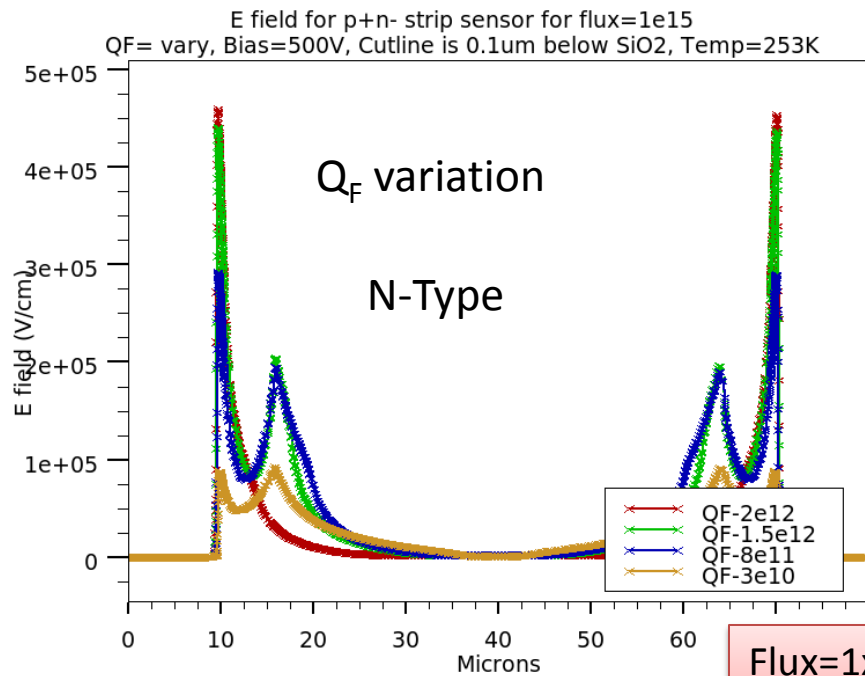
➢ Significant amount of non-Gaussian noise (RGH) observed in p-in-n sensor (n-type)
➢ Very less amount of RGH rates observed for n-in-p (p-type) sensor

Flux=1×10^{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**
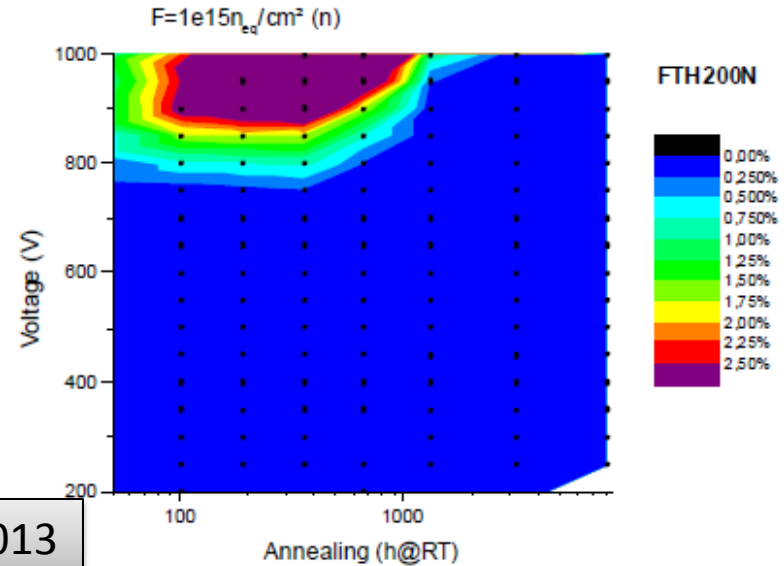
- **P-type (n-in-p)**
  - **Peak field is much less compare to p-in-n sensors**
  - **As Q_F increases = > Peak E field decreases.**

7e14n$_{eq}$/cm² mixed

F=3e14n$_{eq}$/cm² (GeV p) + 4e14n$_{eq}$/cm² (n)

10e14n$_{eq}$/cm² neutrons

F=1e15n$_{eq}$/cm² (n)

A. Dierlamm, Vertex 2013

F=1e15n$_{eq}$/cm² (GeV p) + 5e14n$_{eq}$/cm² (n)

15e14n$_{eq}$/cm² mixed
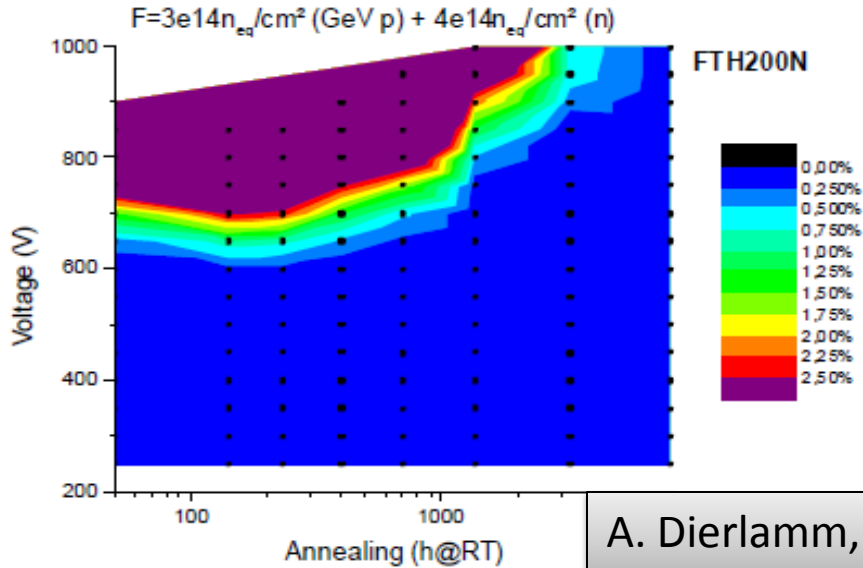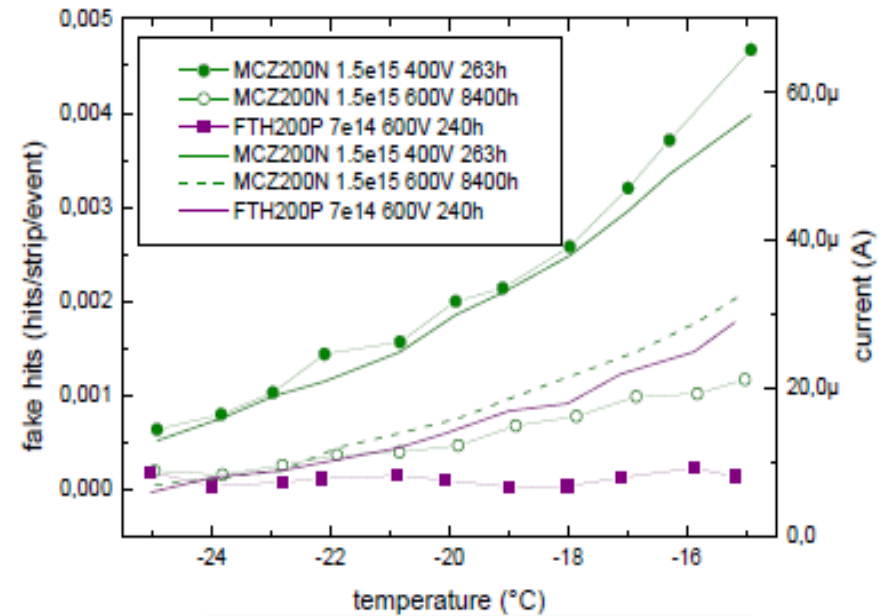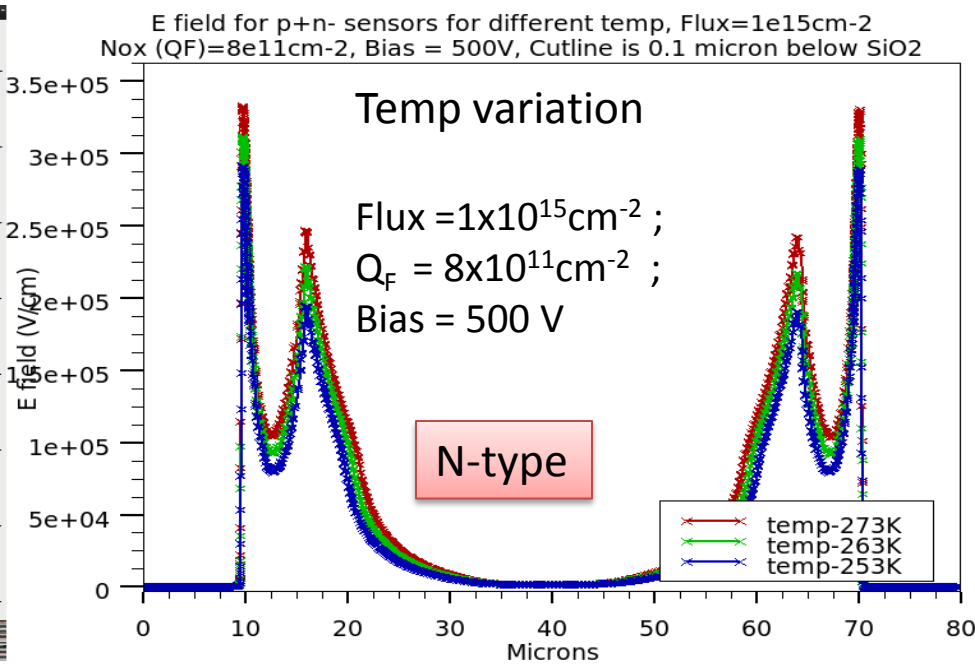
➢ Much less RGH for neutron irradiation clearly indicate the role of surface damage
➢ The dependence on ionizing radiation hints toward a combined effect of bulk damage and surface damage
➢ The Q$_F$ effect simulation were carried out before these measurements
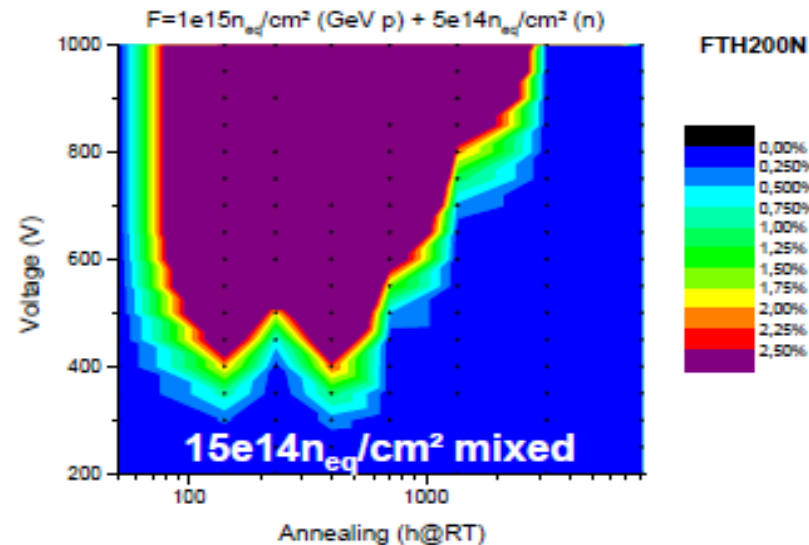
E field for p-in-n sensor : Effect of temp. variation

E field for p+n- sensors for different temp, Flux=1e15cm-2
Nox (QF)=8e11cm-2, Bias = 500V, Cutline is 0.1 micron below SiO2

Temp variation

Flux =$1x10^{15}cm^{-2}$;
Q_F = $8x10^{11}cm^{-2}$;
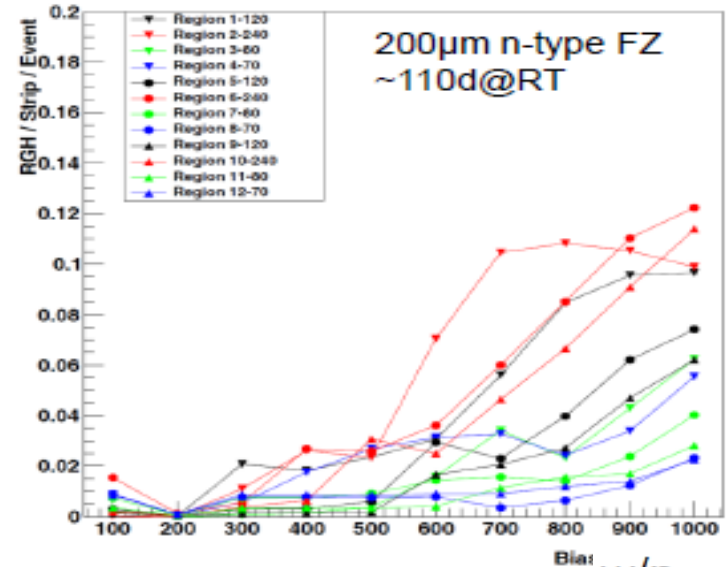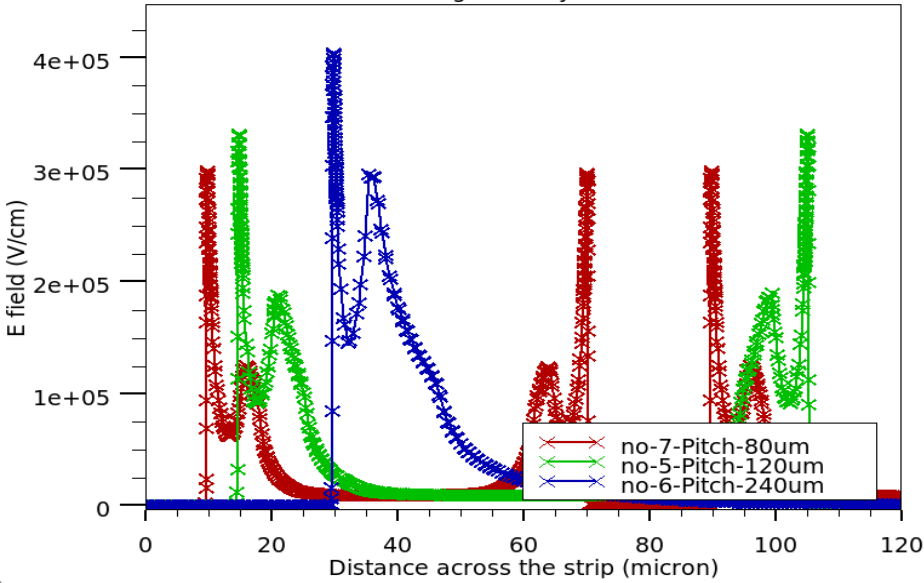Bias = 500 V

N-type

temp-273K
temp-263K
temp-253K

A. Dierlamm, Vertex 2013

❖ Simulations shows small increase of Maximum Electric field with increase in temperature
❖ Measured RGH rate also increases with increase in temperature.
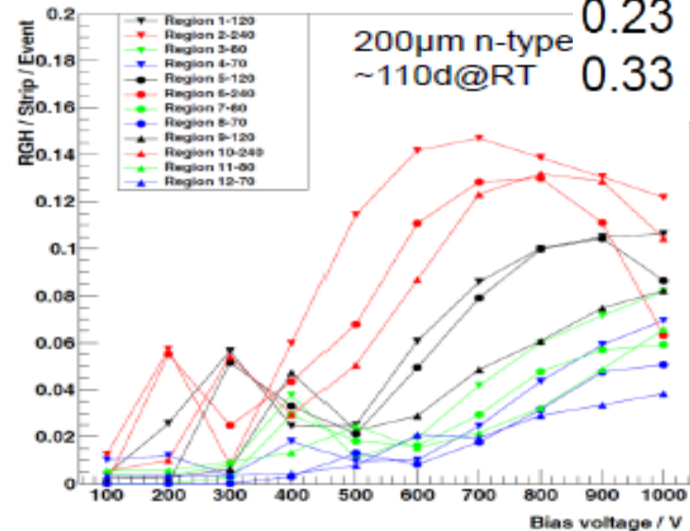
Effect of strip pitch variation on E field

E Field 0.1micron below SiO2/Si interface for p+n- sensors at 253K
Fluence = 5e14cm-2, Oxide charge density = 8e11cm-2, Bias = 800V

Legend:
- no-7-Pitch-80um
- no-5-Pitch-120um
- no-6-Pitch-240um

200μm n-type FZ
~110d@RT

A. Dierlamm, Vertex 2013

w/p	
0.13	▼
0.23	●
0.33	▲

Pitch:
- 70μm
- 80μm
- 120μm
- 240μm

200μm n-type
~110d@RT

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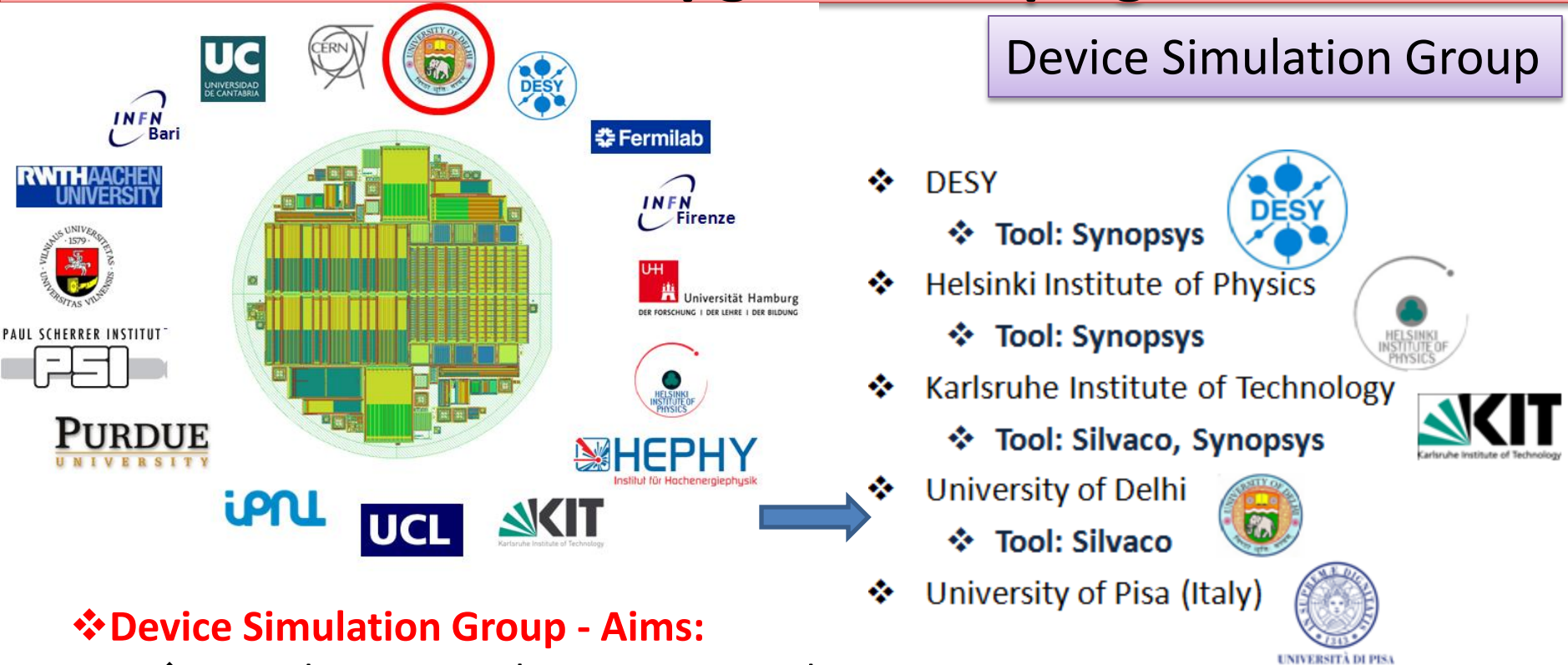➢ RGH also follow the similar trend.
➢ Maximum RGH are for 240μm strip pitch.

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!

Ranjeet, Delhi Uni. 23rd RD-50 workshop

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