Novel Semi-3d Detector Structures for Improved Radiation Tolerance*

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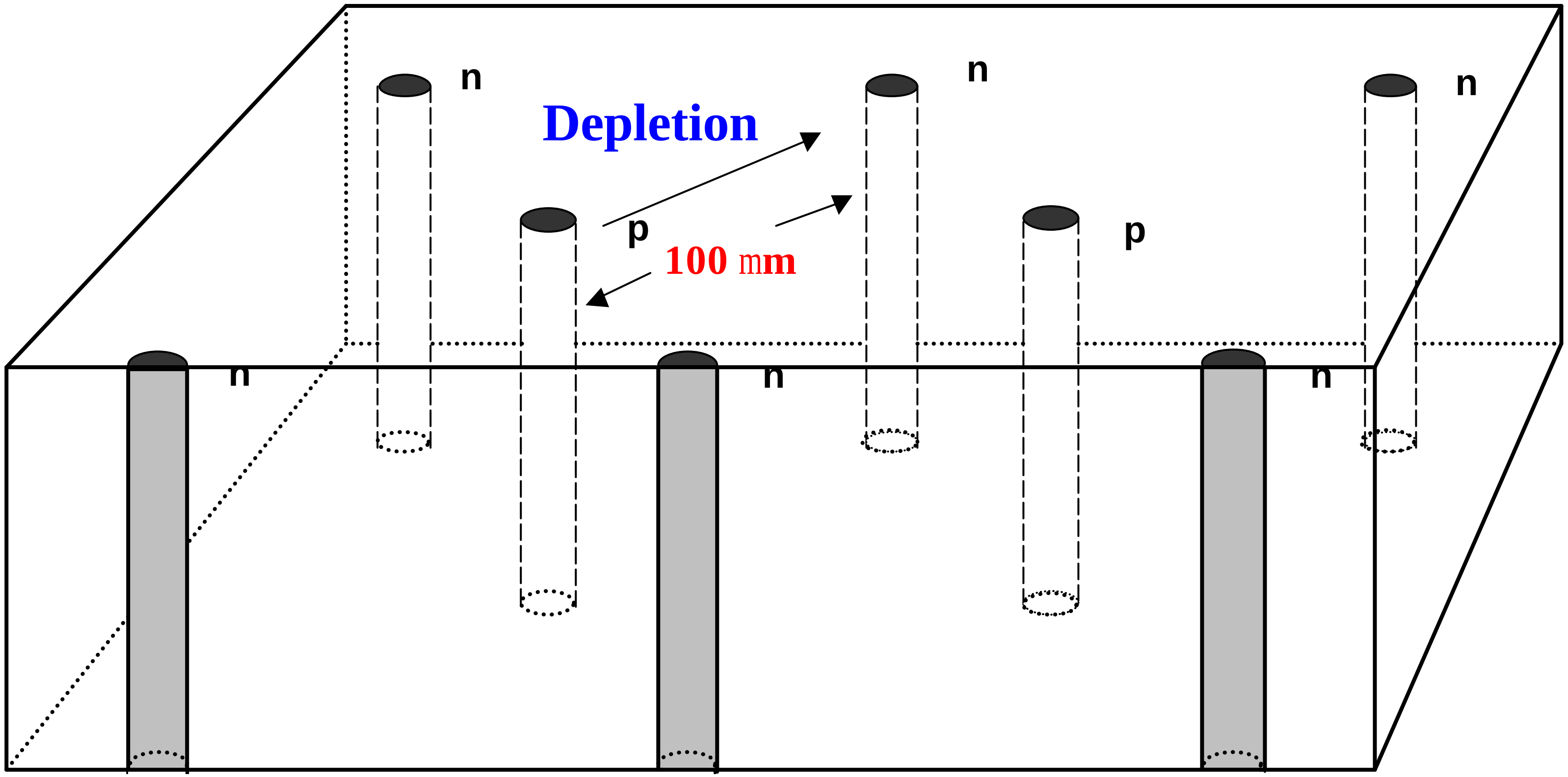
OUTLINE

- Review of 3d detector
- Novel semi-3d detector structures
  - ⌫ **p^+-n^+/n/ p^+-n^+ (symmetrical and asymmetrical)**
  - ⌫ **p^+/n/ n^+ (low R, CZ or FZ Si)**
  - ⌫ **p^+-n^+/n/ p^+ (low R, CZ or FZ Si)**
  - ⌫ **p^+-n^+/n/ n^+ (medium or high R Si)**
  - ⌫ **p^+-n^+/p/ n^+ (high R Si)**
- Electric potential and field simulations
- Future Trends
- Summary

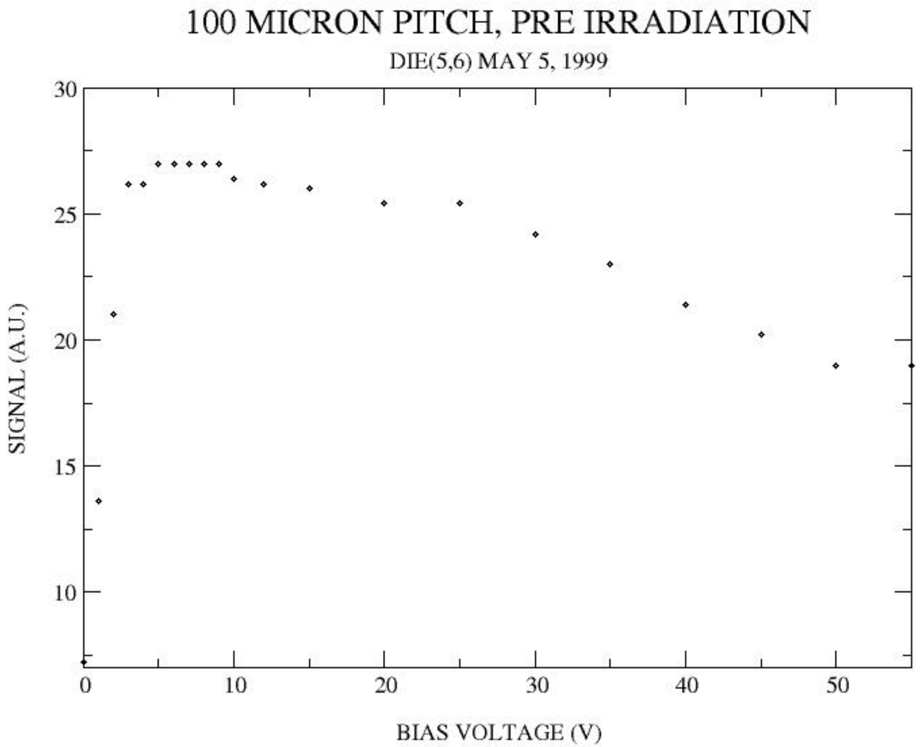
3-d Detector

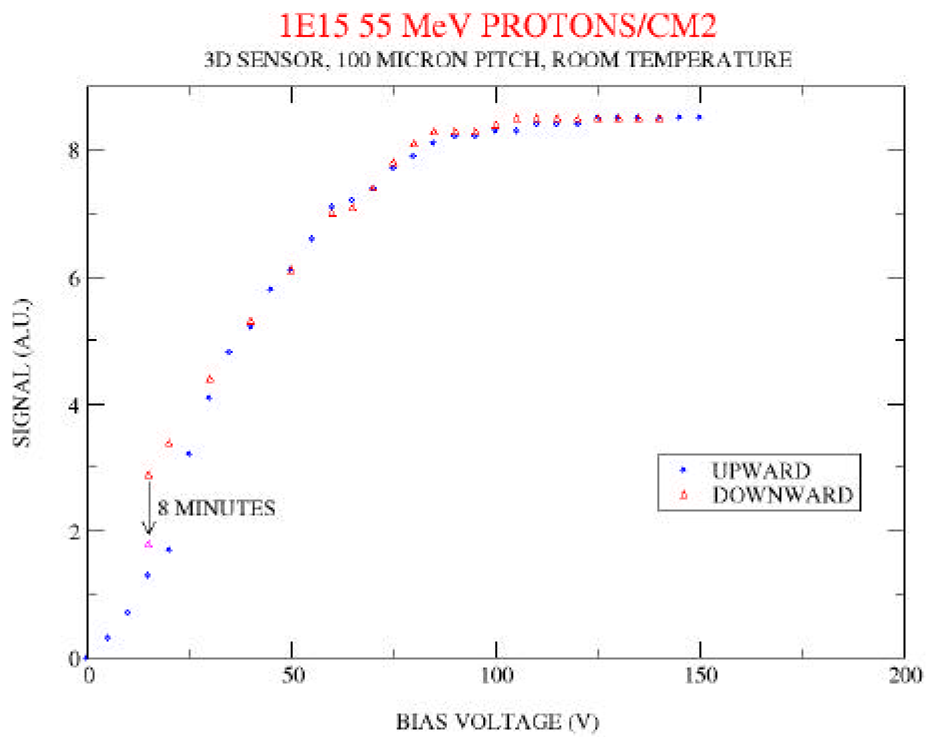
- Differ from conventional planar technology, p^+ and n^+ electrodes are diffused in small holes along the detector thickness ("3-d" processing)
- Depletion develops laterally (can be 50 to 100 mm): not sensitive to thickness
- Much less voltage used --- much higher radiation tolerance



Sherwood I. Parker et al., UH 511-959-00

3-d Detector





V_{fd} reduced up to a factor of 8-10

Sherwood I. Parker et al., UH 511-959-00

Novel Semi-3d Structures

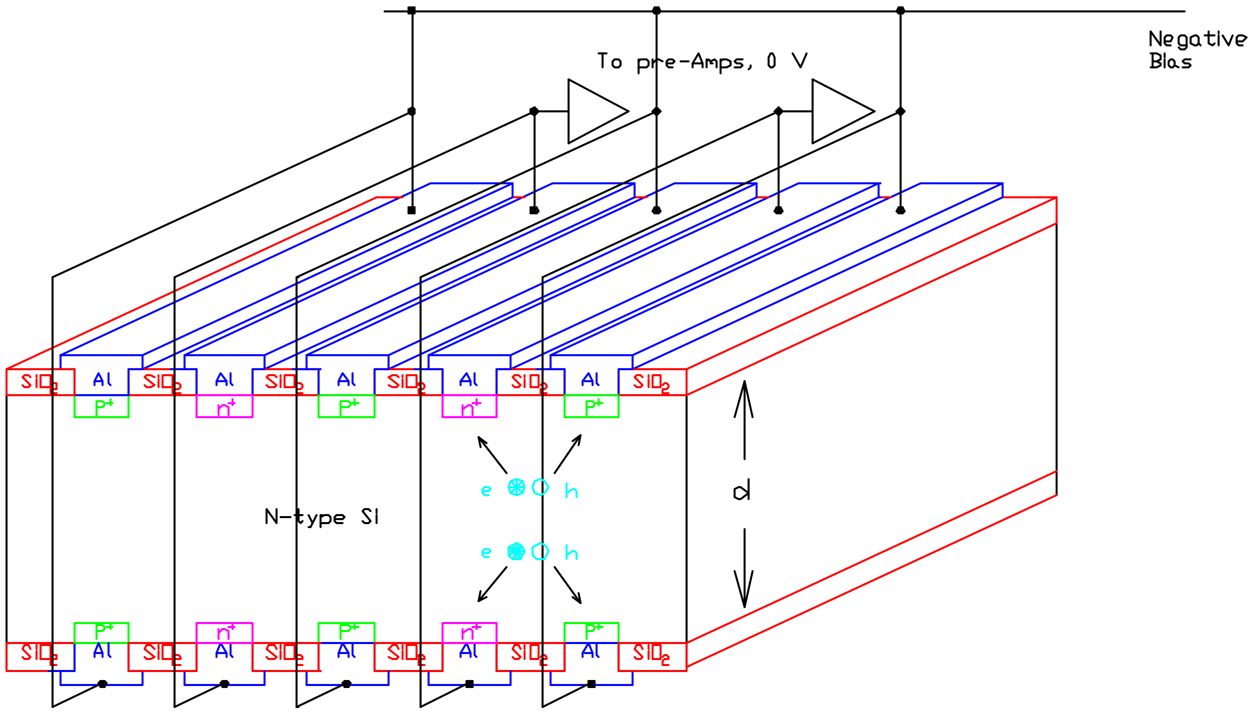
BNL developed novel detectors structures:

- **Still planar technology --- much easier and simpler than 3-d**
- V_{fd} **may be reduced by a factor of 2-4**
- **Insensitive to SCSI**
- **Depletion from both sides and laterally**
- **Real low resistivity Si (100 Wcm) may be used (no SCSI up to 10^{15} n/cm^2**
- **Better power balance possible**

Novel Structures

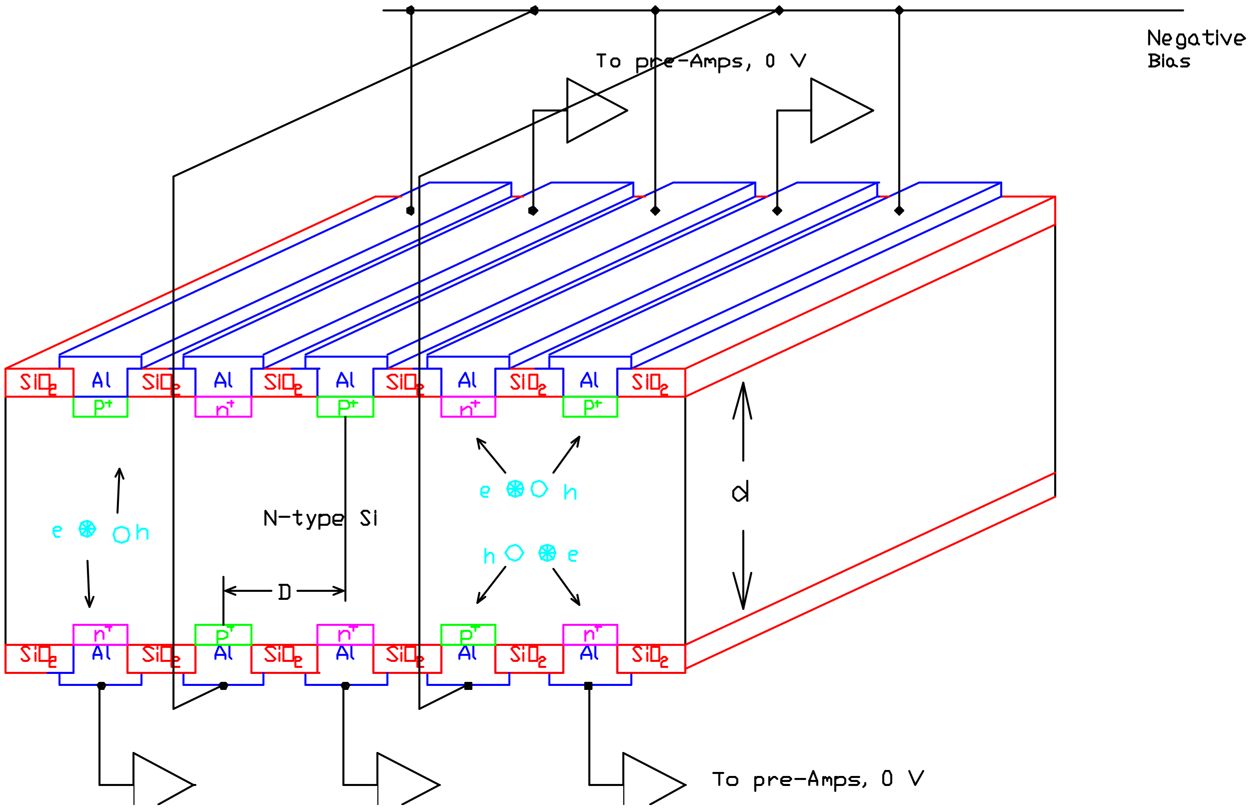
Symmetrical semi-3d SSD

- Depletion from both sides of the detector and laterally
- Full depletion voltage may be reduced by more than a factor of 1.5
- With n^+ as read-out electrode (the high field contact after radiation over SCSI), better CCE is obtained
- 2-sided planar process, easier than the real 3-d detectors (S.



Asymmetrical semi-3d SSD

- The shift between the p+ strips on two sides D = pitch (P)
- Same advantages as symmetrical semi-3d SSD (D=0)
- D can be between 0 and P
- Both configurations can be also applied in pixel detectors



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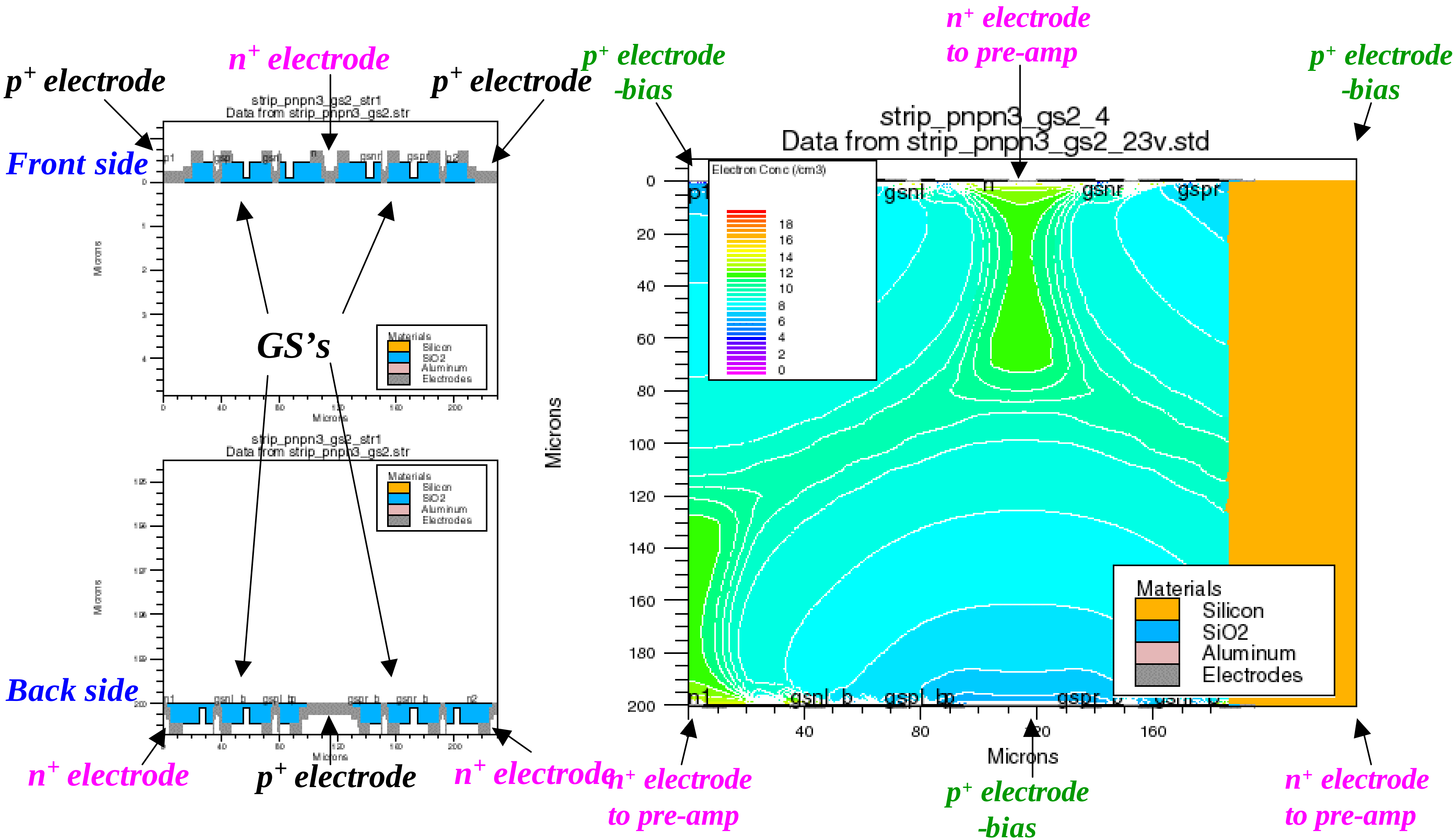
Asymmetrical semi-3d SSD

- **Before radiation, N_{eff}= +1x10^{12} /cm^{3} (4 kW-cm)**
- **Junction on the p^{+} contacts**

Electron contour (simulation), V = 23 volts



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Asymmetrical semi-3d SSD

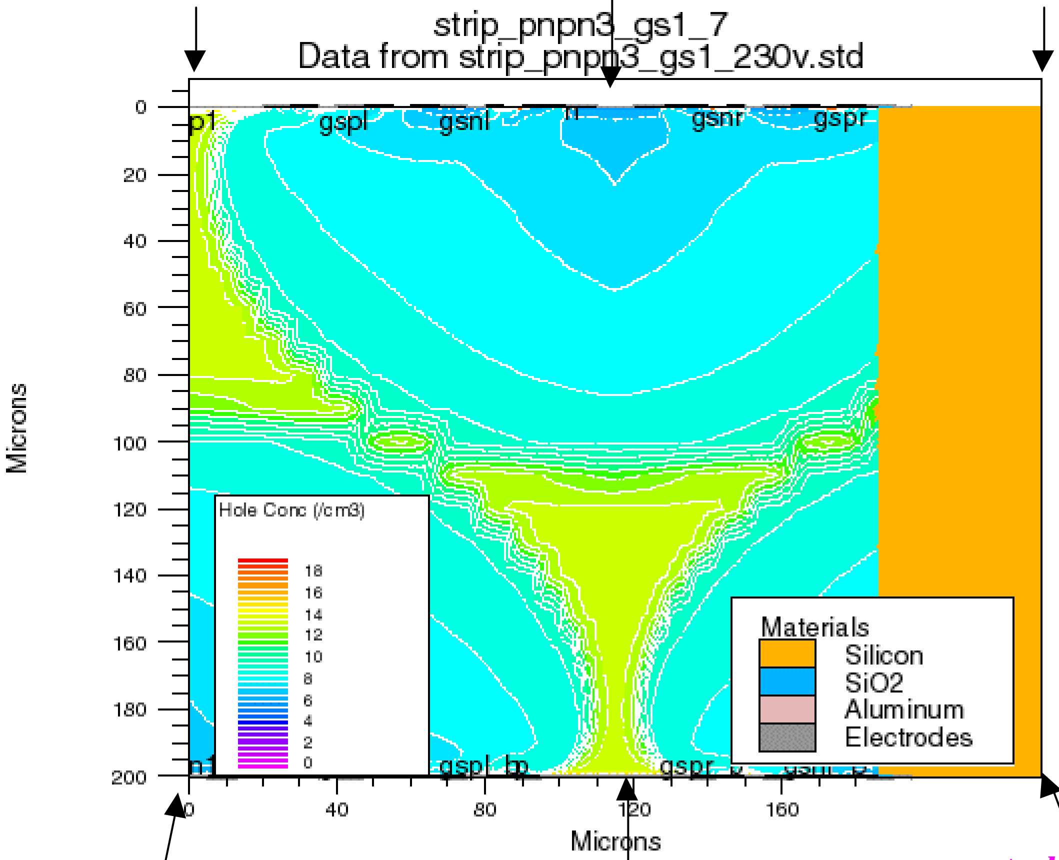
- **After radiation, N_{eff}= -1×10^{13} /cm^3 (5×10^{14}n/cm^2)**
- **Junction on the n^+ contacts**

Hole contour (simulation), V = 230 volts (<< 370 volts)

p^+ electrode -bias

n^+ electrode to pre-amp

p^+ electrode -bias



n^+ electrode to pre-amp

p^+ electrode - bias

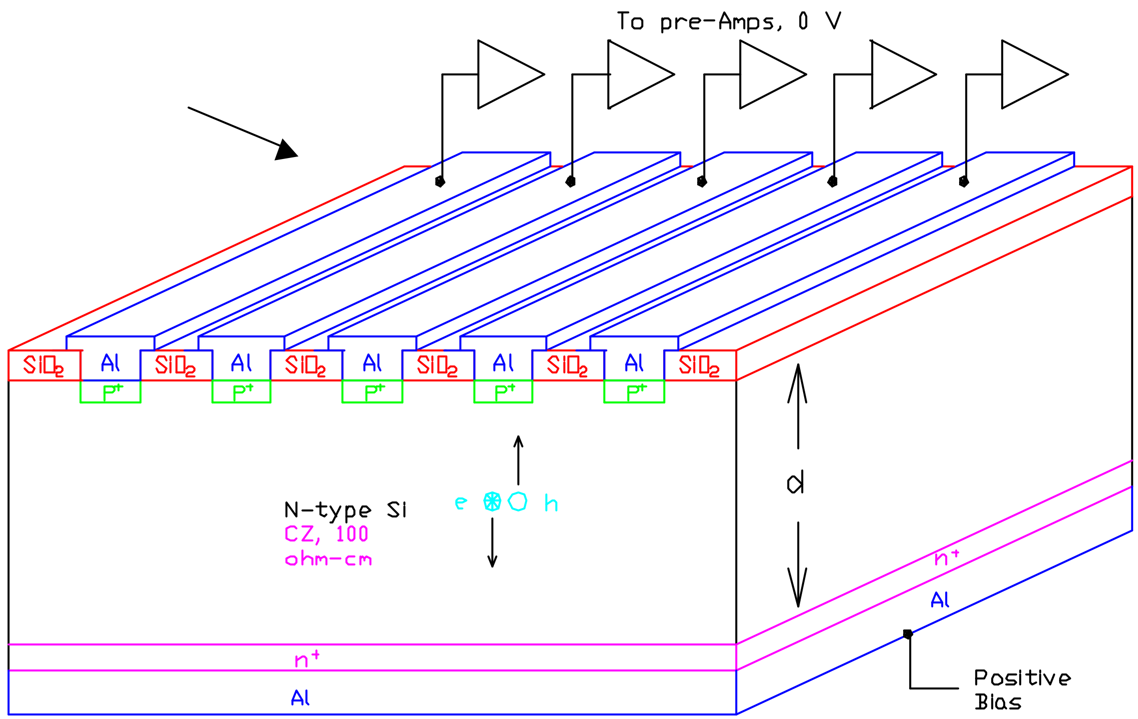
n^+ electrode to pre-amp

Low resistivity n-type SSD and SPD: more radiation tolerance

- **Low resistivity FZ/ CZ (high [O]) n-type Si (cheap material)**
- **No SCSI up to $1x10^{15}$ n/cm^2 rad.**
- **V_{fd} decrease with rad, I increases with rad., power dissipation almost stays constant: power balance**

p^+ /n/n^+ configuration
1-sided process
Partial depletion at the beginning

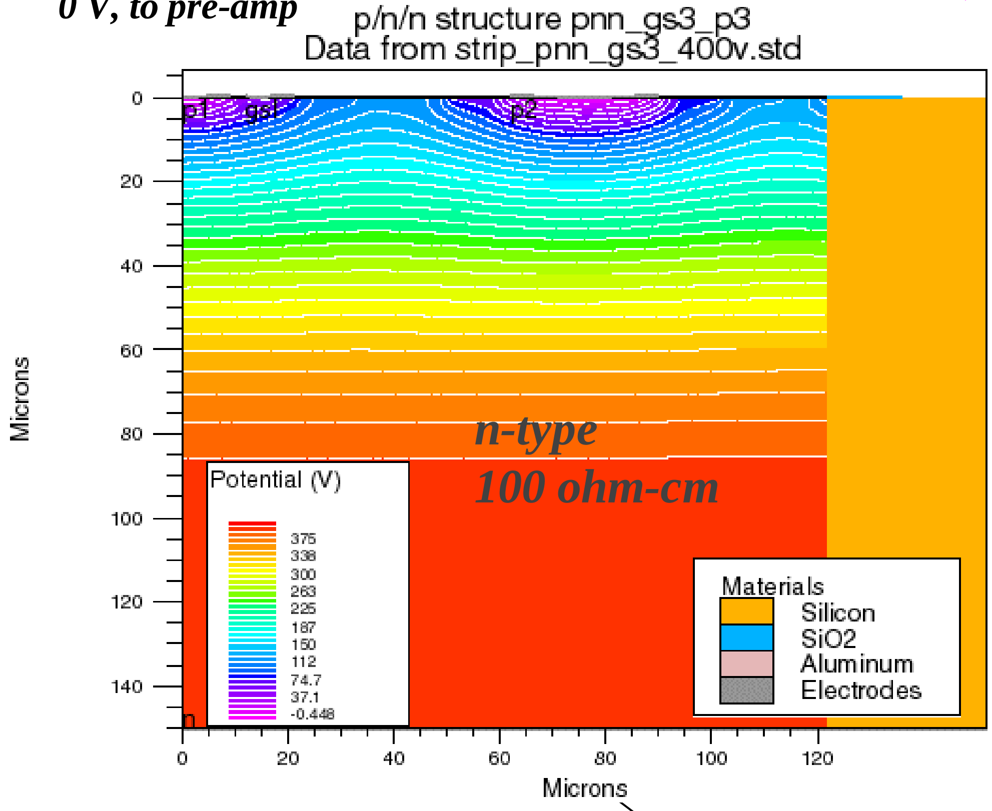
Depletion depth increases with rad.
Z.Li et al. NIMA409 (1998) 180



$p^+/n/n^+$ configuration
(low resistivity)

0 V, to pre-amp

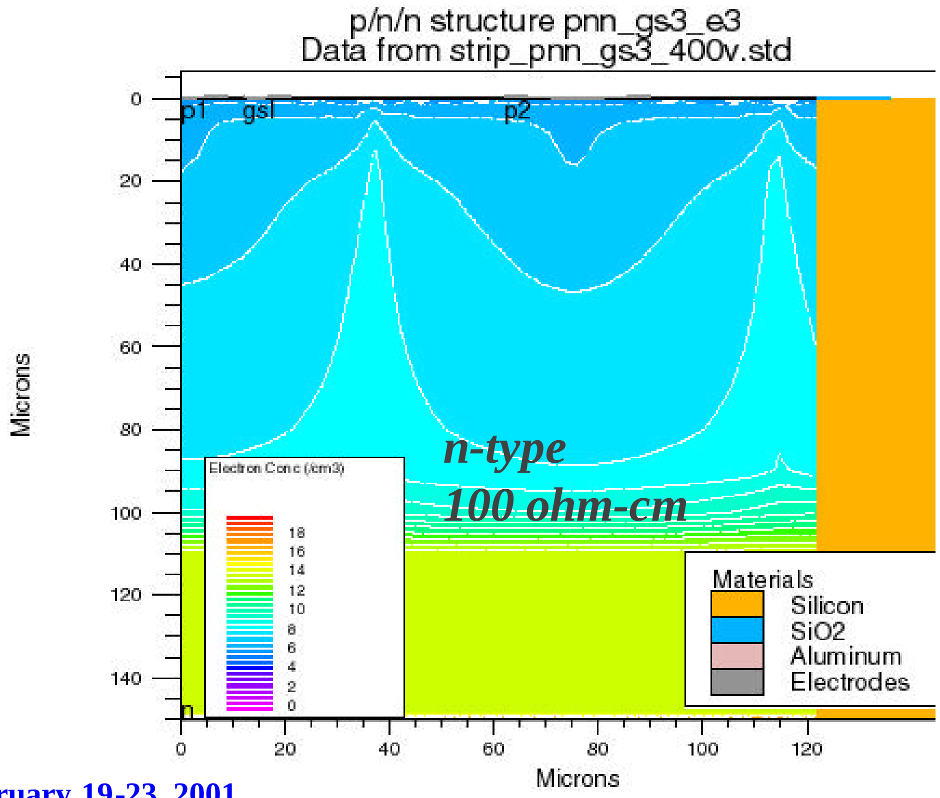
0 V, to pre-amp



400V

Potential

Electron concentration



p^+- n^+ /n/p^+ configuration
(low resistivity)

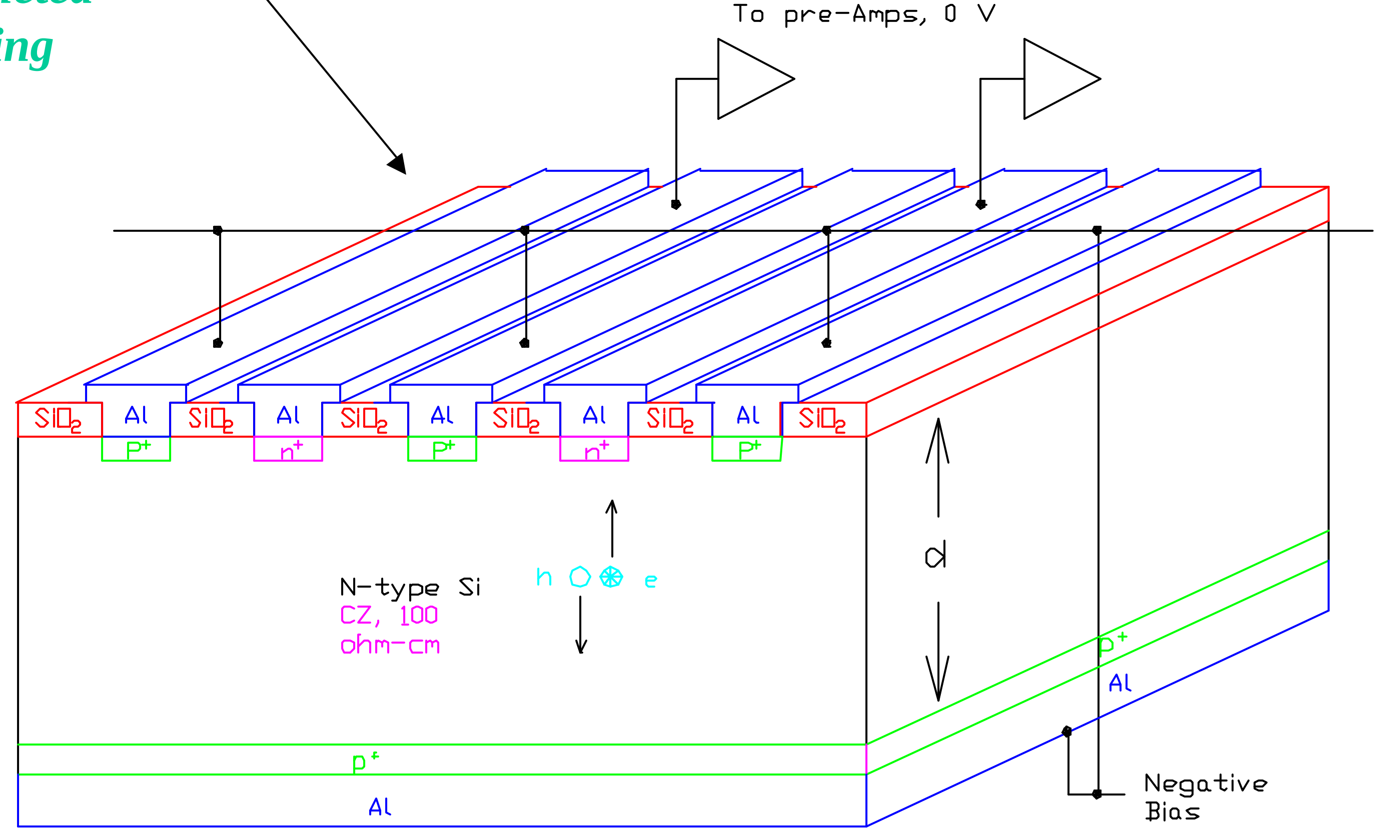
p^+- n^+ /n/p^+ configuration

2-sided process

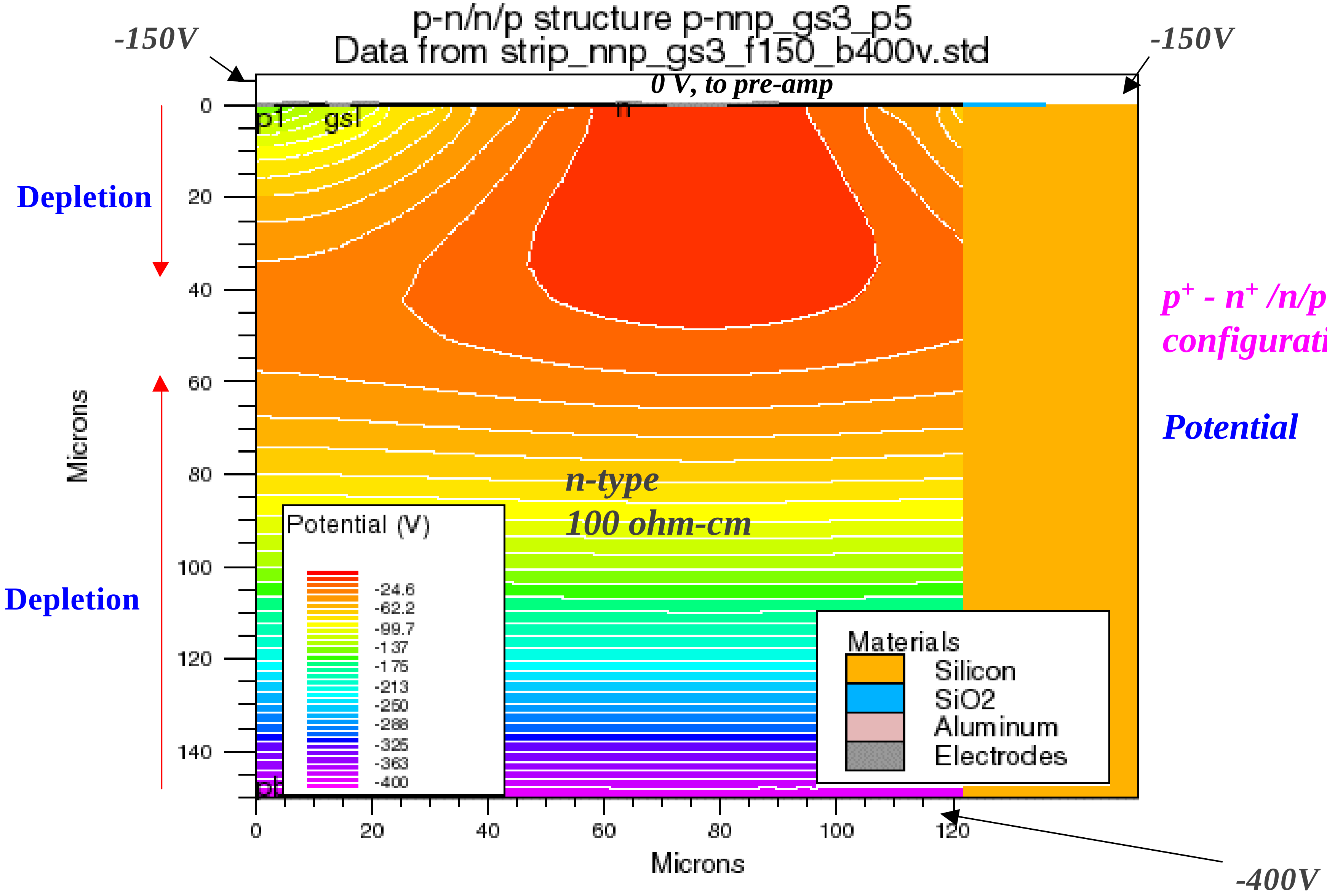
Depletion from both sides

Can be fully depleted

from the beginning



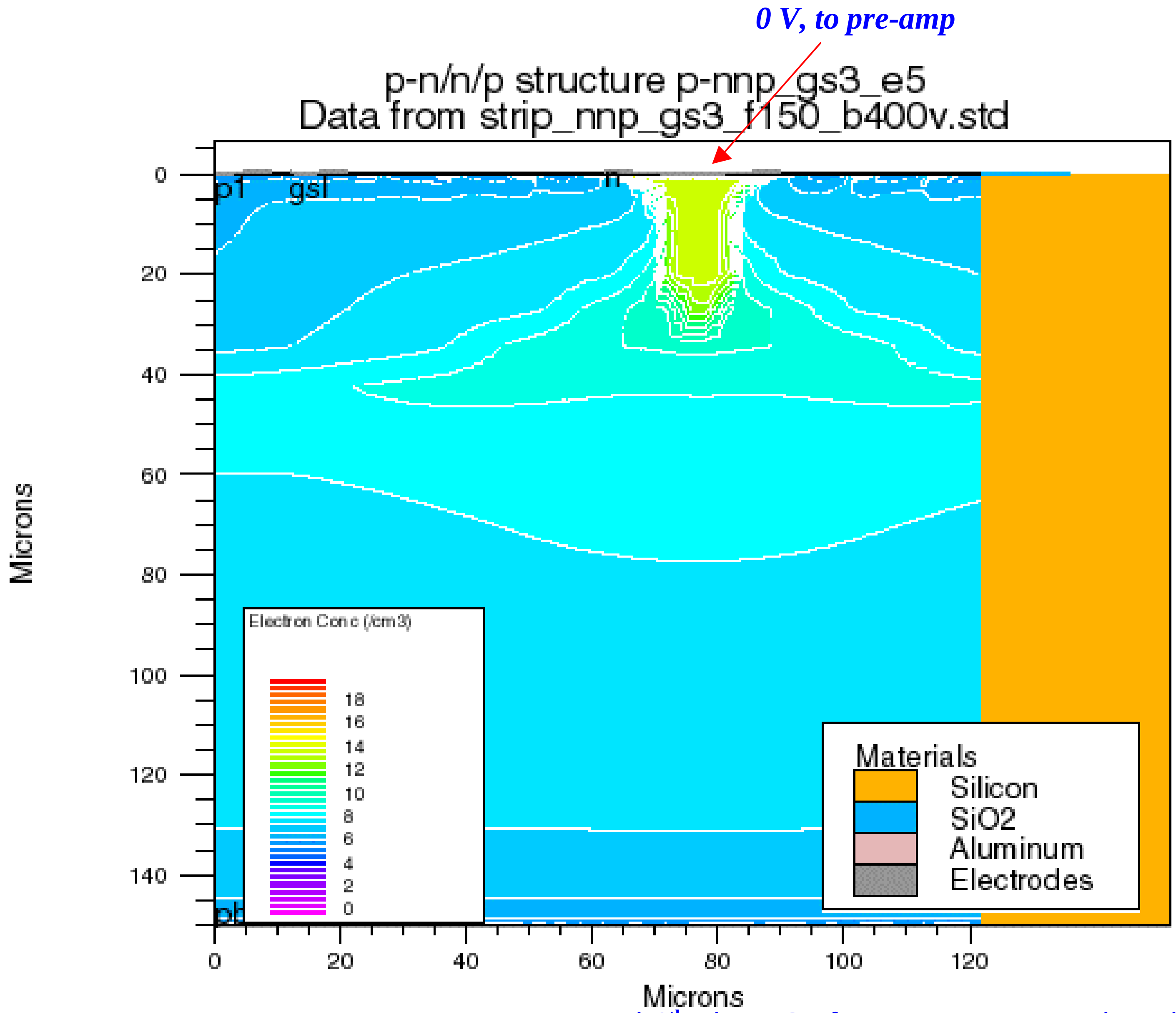
p^+- n^+ /n/p^+ configuration
(low resistivity)



p^+ - n^+ /n/p^+ configuration

Potential

p^+- n^+ /n/p^+ configuration (low resistivity)



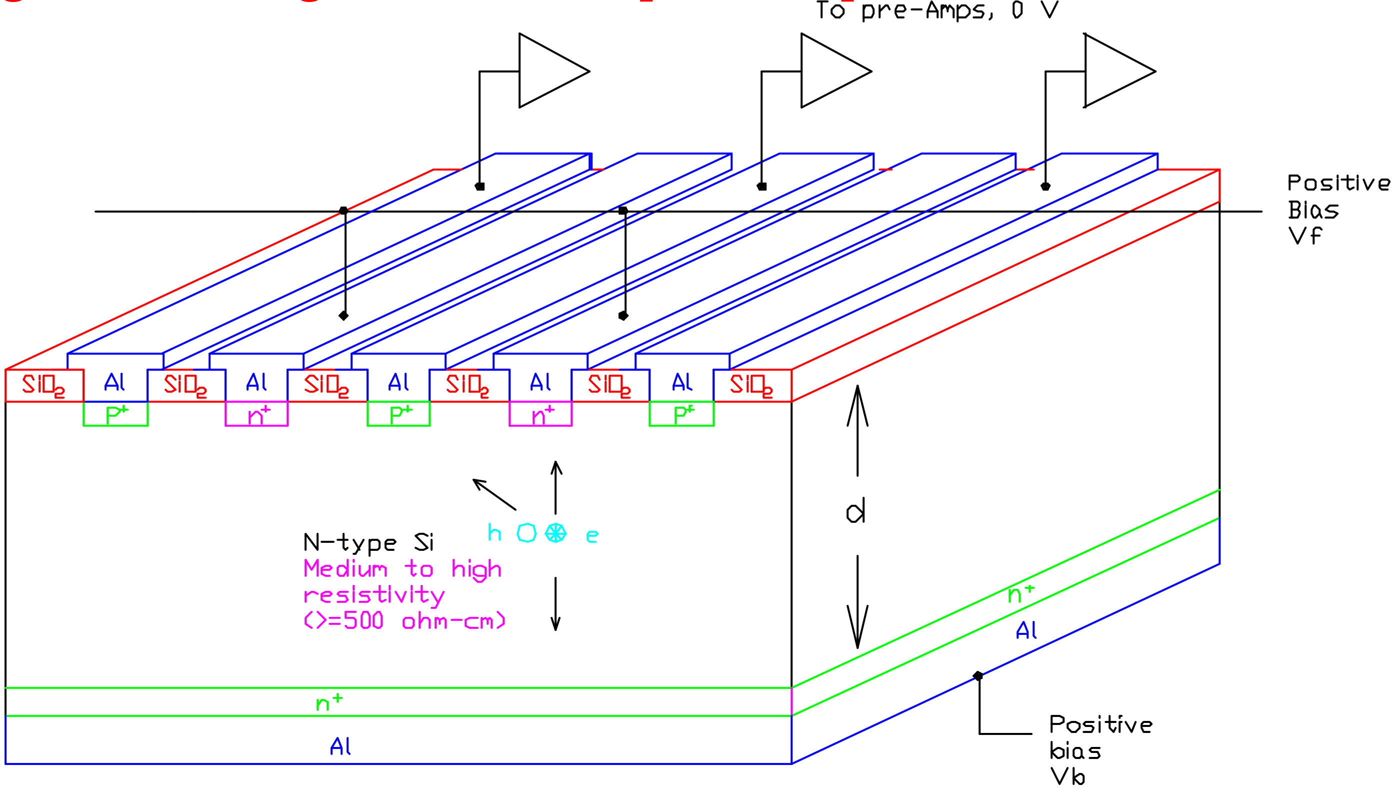
p^+ - n^+ /n/p^+ configuration

Electron concentration

Medium and High resistivity n-type SSD and SPD: more radiation tolerance

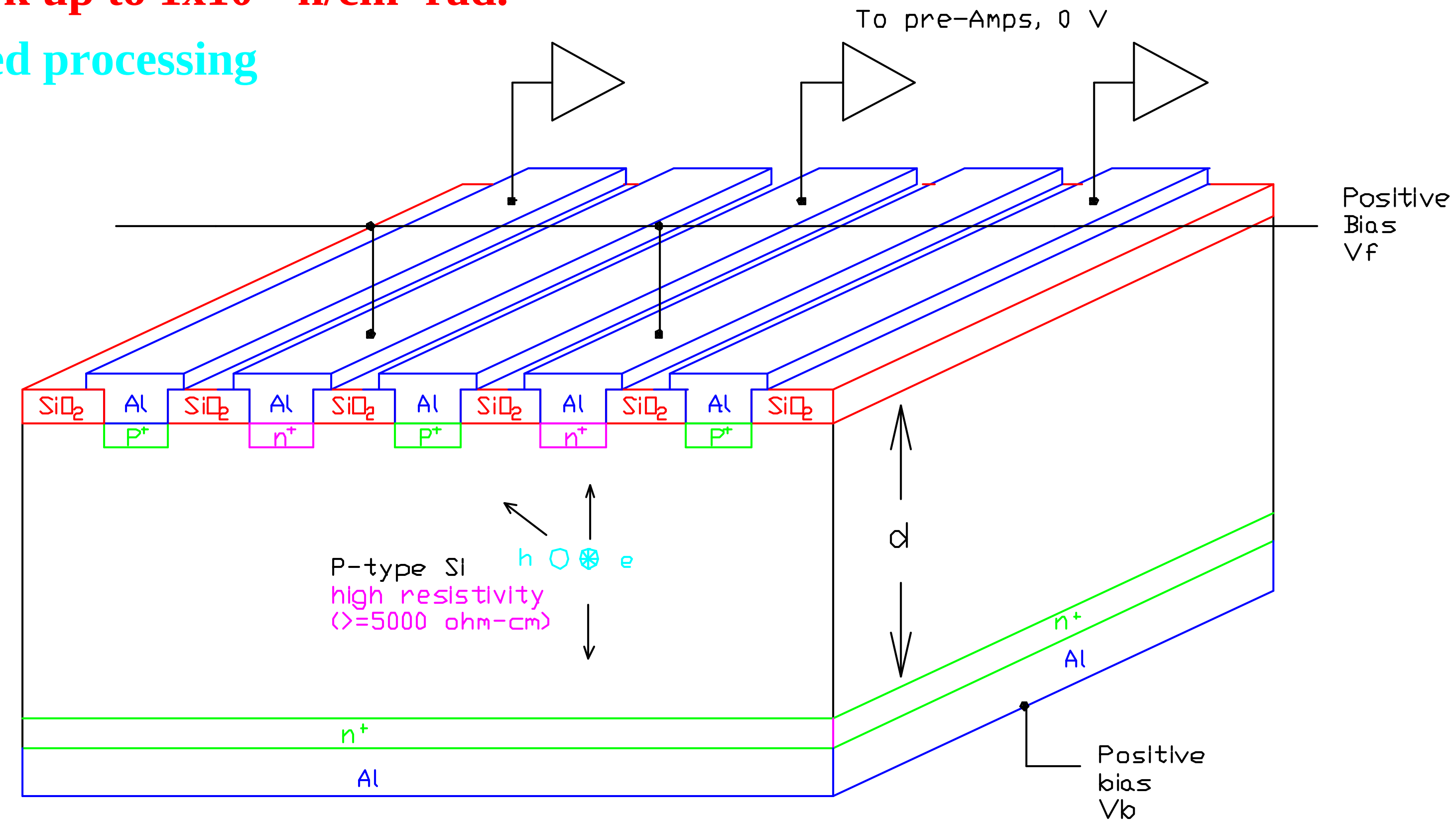
- **Low bias at the beginning**
- **p^+- n^+ /n/n^+ configuration:**
  - **Depletion from one side before SCSI**
  - **Depletion from both sides after SCSI**
- **May work up to 1×10^{15} n/cm^2 rad.**
- **One sided processing**
- **Bias Vb may be larger than Vf to get maximum depletion depth without break down**

p^+- n^+ /n/n^+ configuration
(Medium resistivity)



High resistivity p-type SSD and SPD: more radiation tolerance

- High resistivity FZ p-type Si : low bias at the beginning
- p^+- n^+ /p/n^+ configuration:
  - o No SCSI
  - o Depletion from both sides
- Bias V_b may be larger than V_f to get maximum depletion depth without break down
- May work up to $1x10^{15}$ n/cm^2 rad.
- Two-sided processing



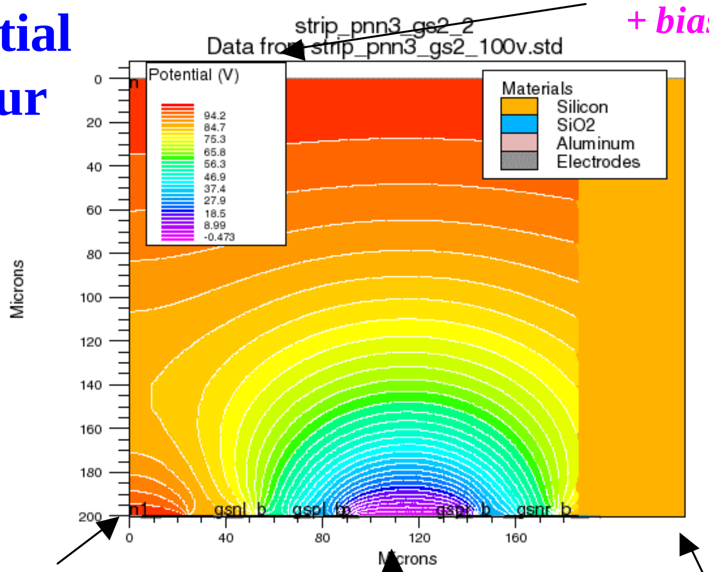
p^+- n^+ /n/n^+ configuration
(Medium resistivity)

- **Before radiation, N_{eff}= +1x10^{12} /cm^3 (4 kW-cm)**
- **Junction on the p^+ contacts**

Simulation, V = 100 volts

Potential contour

n^+ electrode + bias

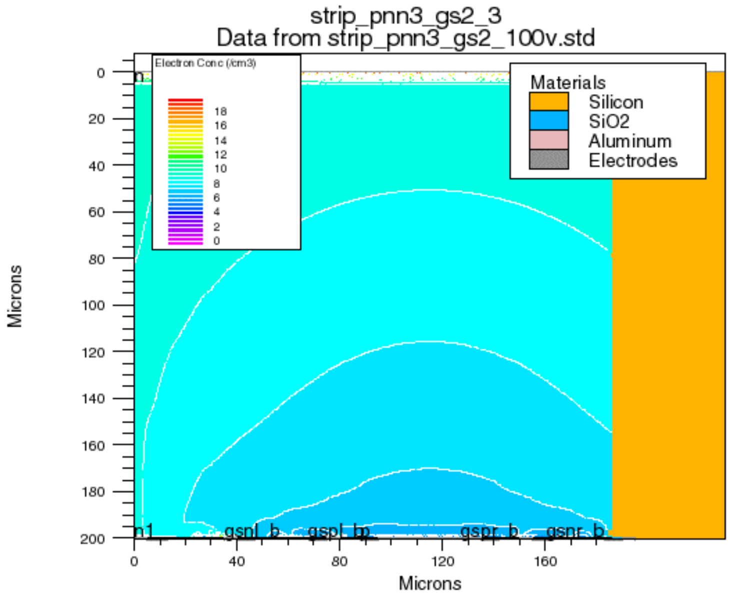


n^+ electrode + bias

p^+ electrode to pre-amps

n^+ electrode + bias

Electron concentration

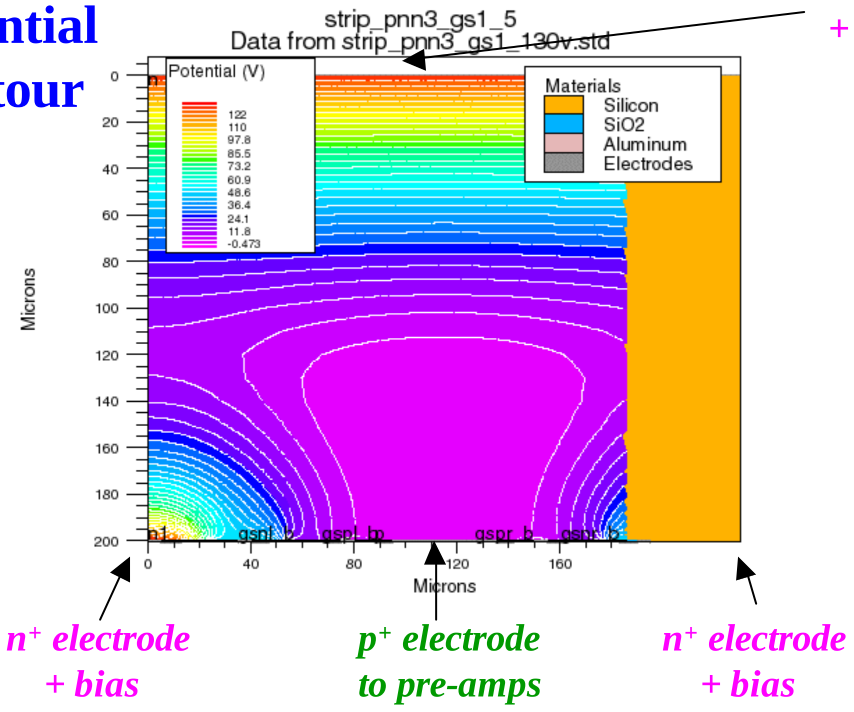


p^+- n^+ /n (or p)/n^+ configuration
(Medium resistivity)

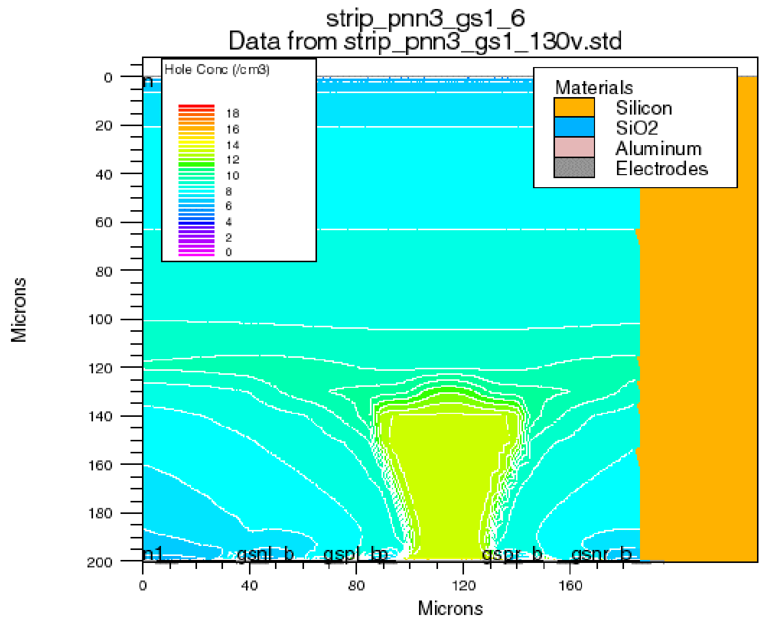
- **After radiation, N_{eff}= -1x10^{13} /cm^3 (5x10^{14}n/cm^2)**
- **Junction on the n^+ contacts**

Simulation, V = 130 volts (<<370 volts)

Potential contour



Hole concentration



Future Trends

o **More studies in the fields of (next 2-5 years):**
- **MIDE (Material/Impurity/Defect Engineering)**
  --- other impurities: H, Cl, N, etc.
- **DSE (Device Structure Engineering)**
  --- Realize 3D and semi-3D detectors
- **DOME (Detector Operation Mode Engineering)**
  --- Realize CID

(push rad-hardness/tolerance to $1x10^{15}$ n/cm^2)

o **Make detectors with the new technologies that combine the above three engineering methods (next 5-10 years):**
(push rad-hardness/tolerance to a few times of 10^{15} n/cm^2)

o **Other semiconductor materials for extremely high radiation (next 10-15 years)**
- **Diamond, SiC, etc.**

(push rad-hardness/tolerance to $1x10^{16}$ n/cm^2)

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Summary

o **Novel semi-3d detector structures can improve the detector radiation tolerance by up to a factor of 4**

o **Cheap low resistivity n-type Si can be utilized in a number of structures**

o **p-type Si may also be used**

o **One-sided and double sided planar technology can be used for all detector structures**

o **Most semi-3d detector structures are insensitive to the space charge sign inversion**

o **In factor, most semi-3d detector structures have used the SCSI to their advantage to deplete the detector from both sides.**

o **Combination of various engineering technologies may push the detector radiation hardness/tolerance to a few times of 10^{15} n/cm^2.**