Update of 3D activity at ITC-irst

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Outline

- Single-Type Column 3D detector concept
- Simulation
- Design and Process
- First Characterization
- Future Activity

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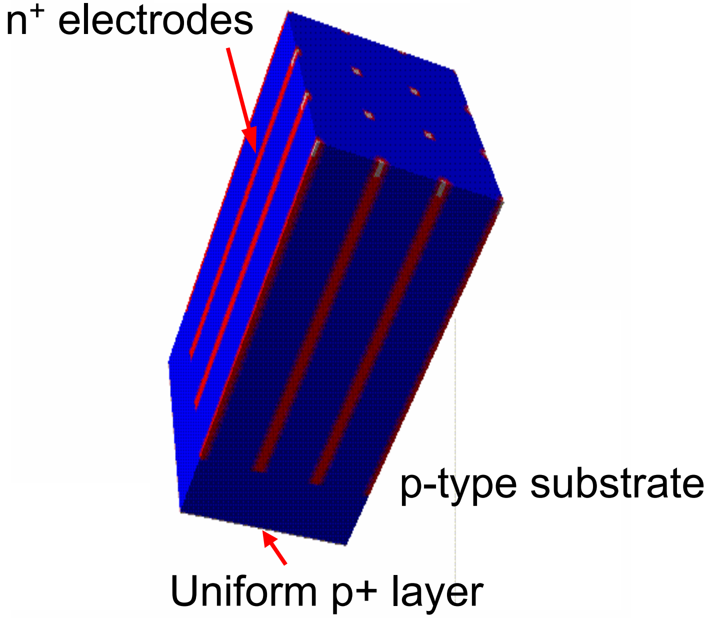
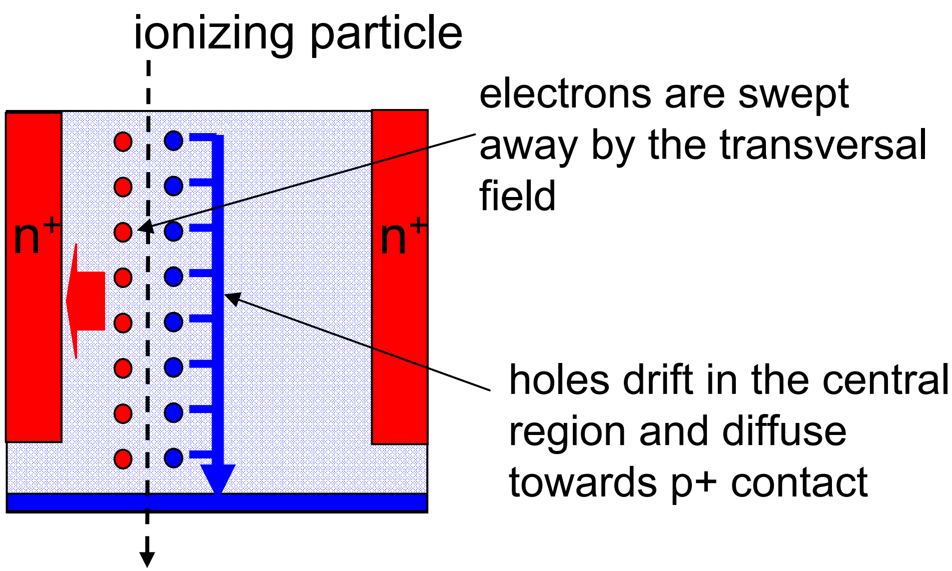
Single-Type-Column 3D detectors - concept

[C. Piemonte et al NIMA 541 (2205)]

…on the way to a fully 3D device: 3D-STC





Fabrication process is much simpler:

- column etching and doping performed only once
- holes not etched all through the wafer

…**BUT** collection mechanism is not very efficient (see slides on signal formation)

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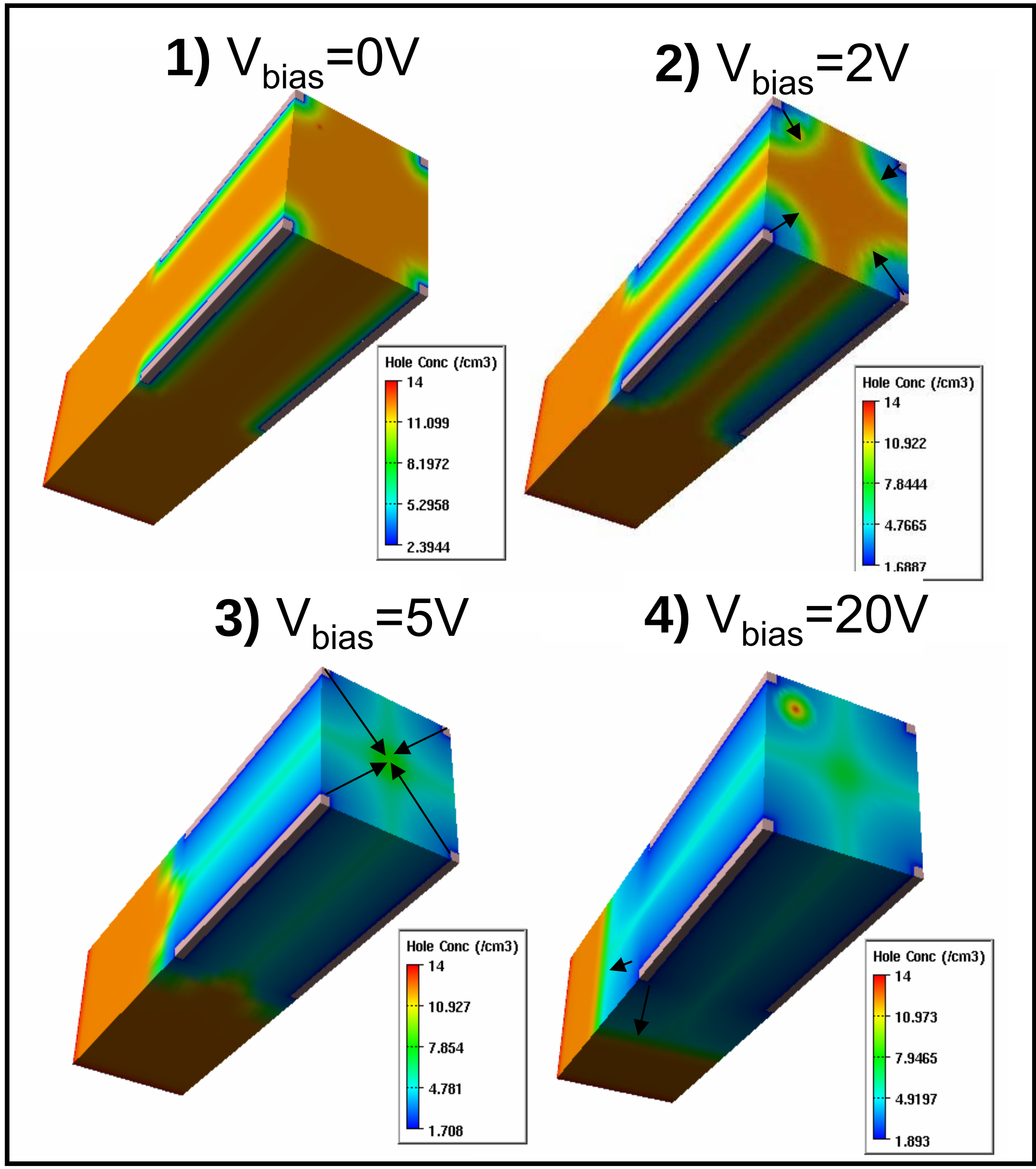
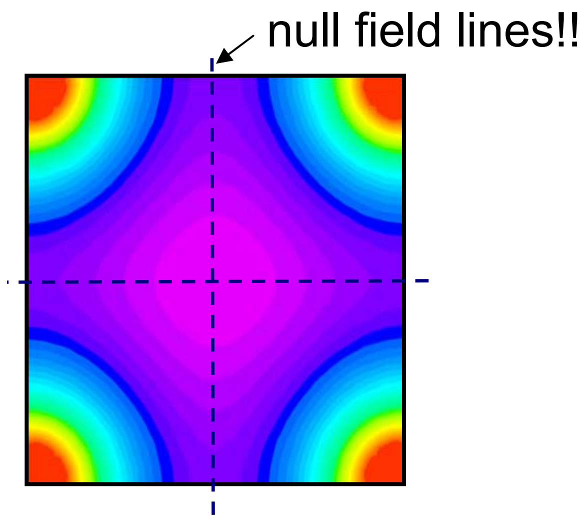
Static device simulations



→ Depletion mechanism

pitch = 80μm
hole depth = 150μm
subst. hole conc. = 5e12cm^{-3}
=>
lateral full dep. volt. ~ 5V
vertical full dep. volt ~ 40V



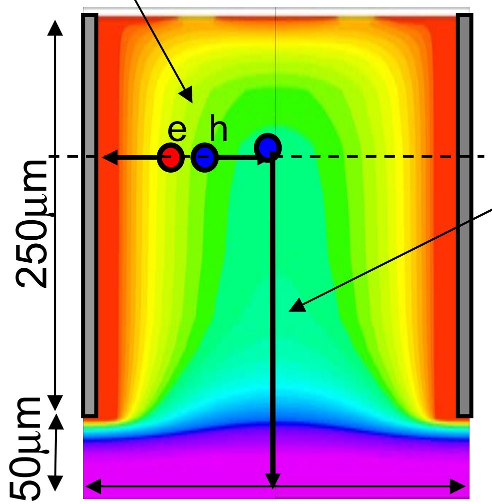
Full charge collection time

First phase

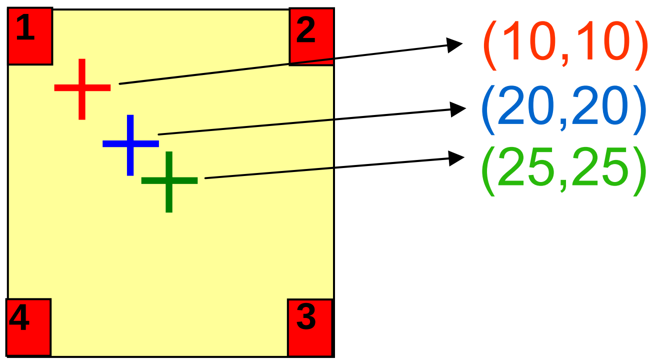
Transversal movement

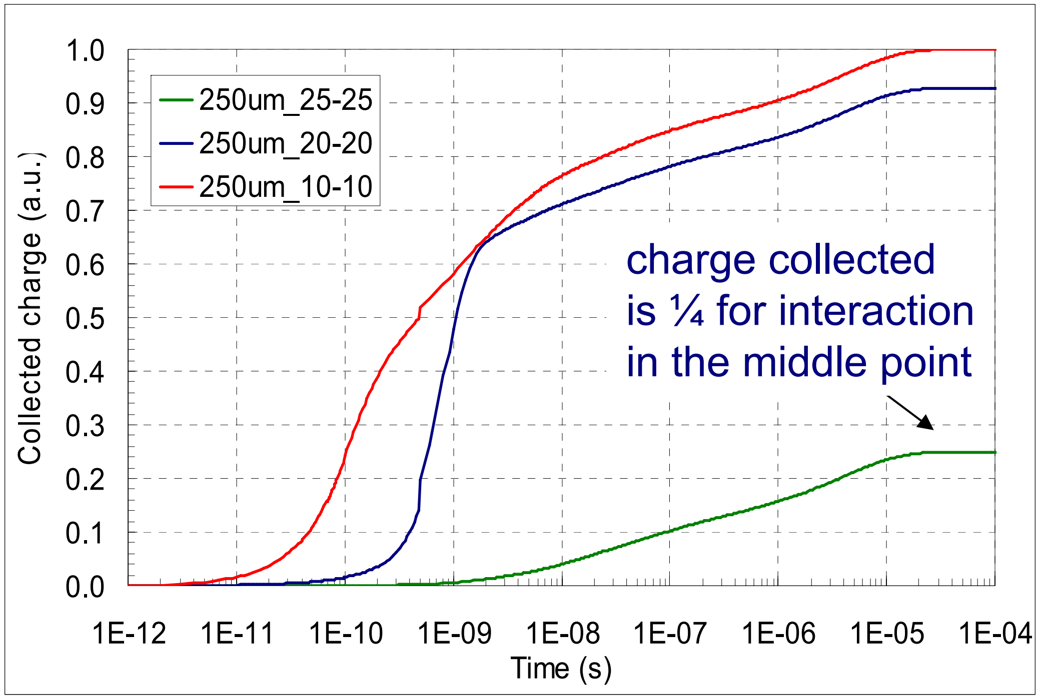
Second phase

Hole vertical movement



Same V_{bias}, different impact point





In the worst case of a track centered the central region, 50% of the charge is collected at t ~ 300ns

Outside this region, 50% of the charge is collected within 1ns.

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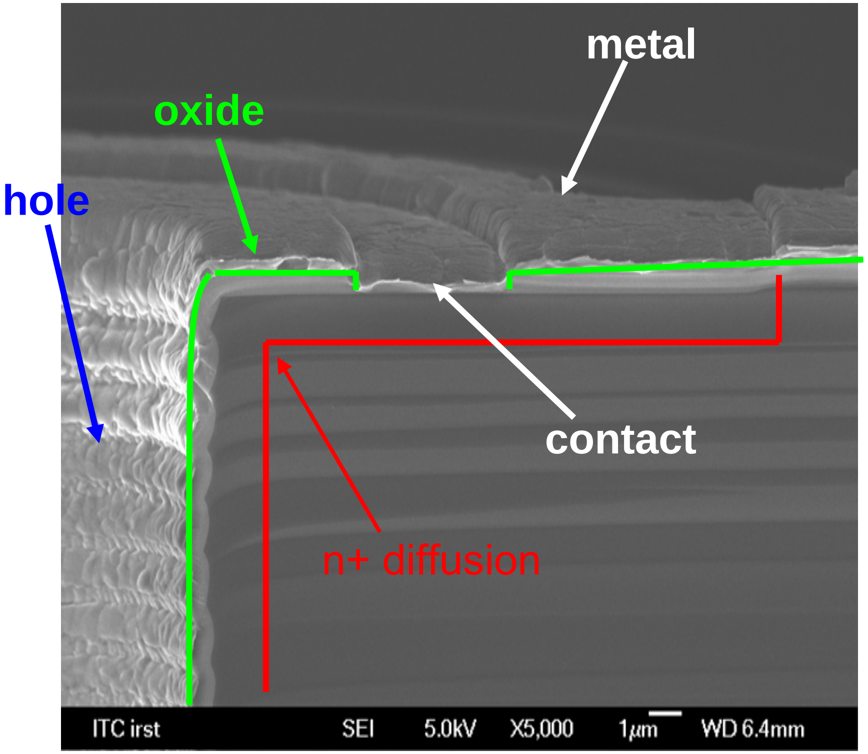
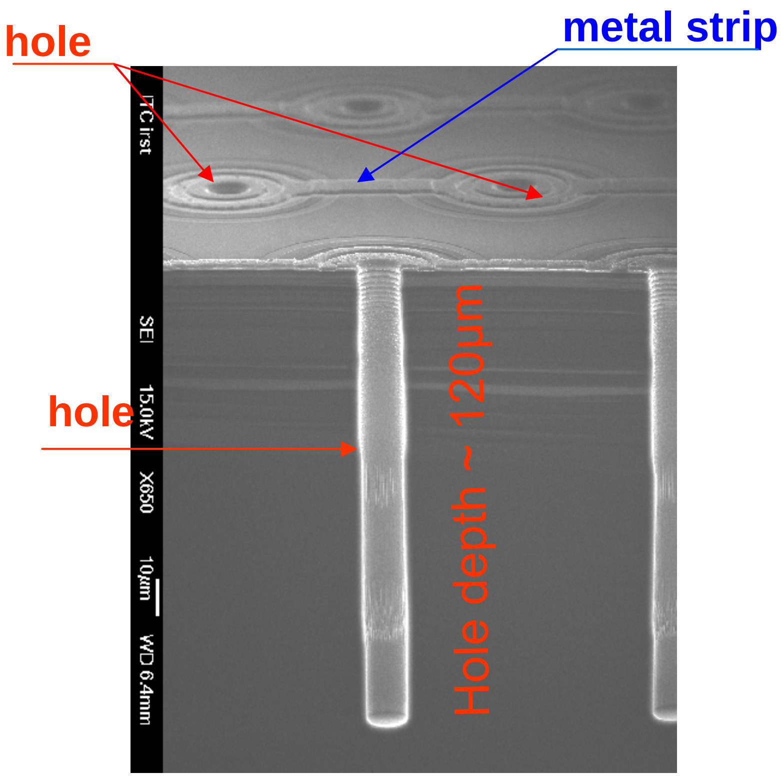
3D process

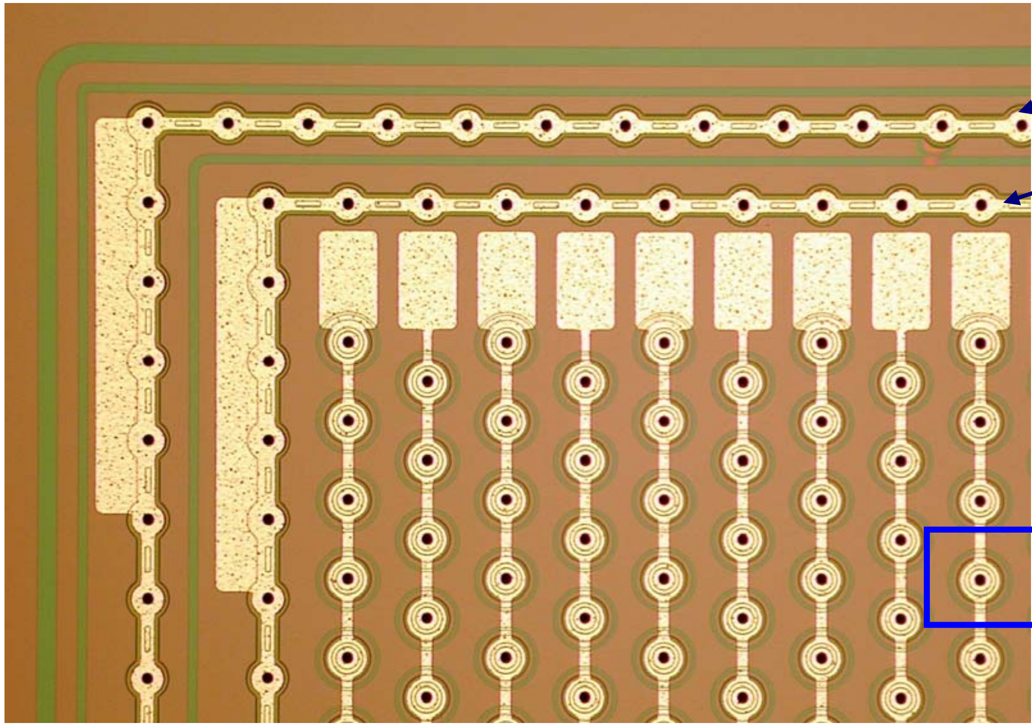


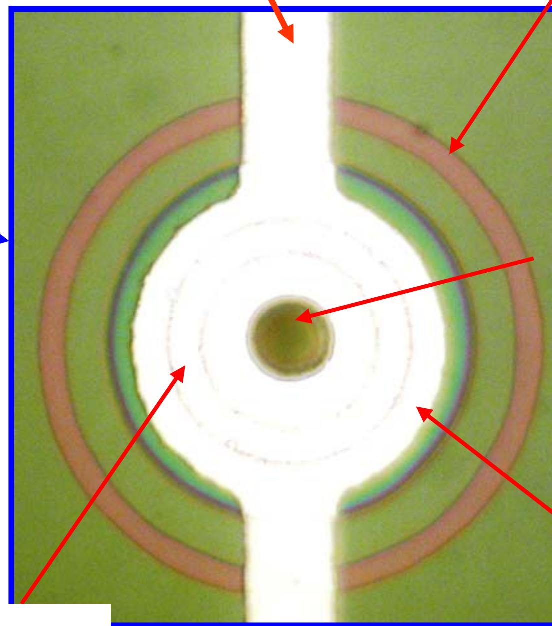
- Deep RIE
- Wide superficial n+ diffusion
- Passivation of holes with oxide
- Holes are "empty"



- Si High Resistivity, p-type, <100>
- Surface isolation: p-stop *or* p-spray

Strip detectors - layout

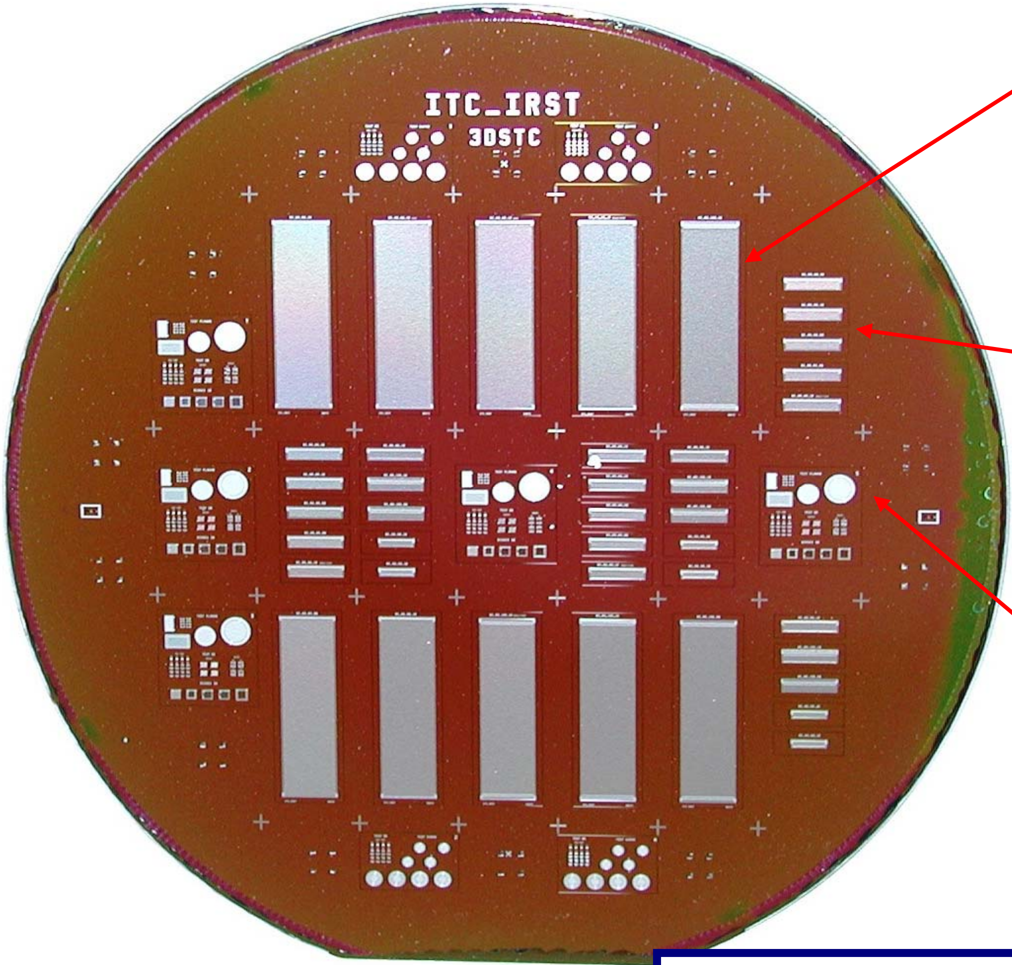




Different strip-detector layouts:

- Number of columns from 12000 to 15000
- Inter-columns pitch 80-100 μm
- Holes Ø 6 or 10 μm

Mask layout



"Long" strip-like detectors
~ 2x0.5cm^2 64strips
~230 col./strip

"Short" strip detectors
~ 0.8x5mm^2 64 strips
10 col./strip

Planar and 3D test structures

1. "Low density layout" to increase mechanical robustness of the wafer
2. Strip detector = "easy" to (electrically) test

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Fabrication process information

Two first productions:

- **Substrate: Si, p-type, <100>:**
  - ***FZ (525 μm) resistivity > 5.0 kΩ cm***
  - ***Cz (300μm) resistivity > 1.8 kΩ cm***

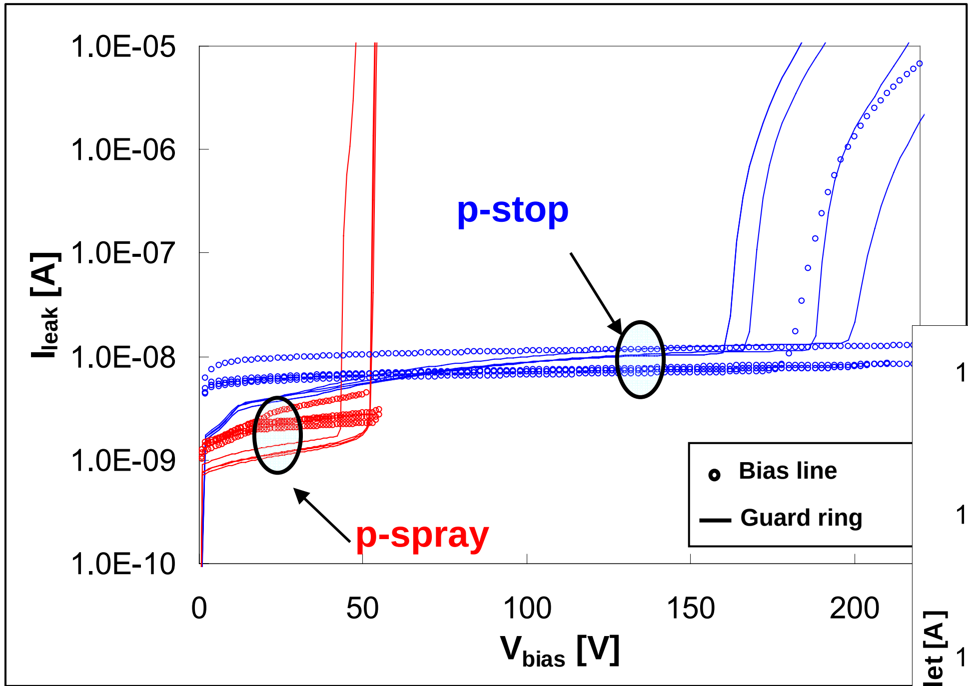
- **Surface isolation: p-spray or p-stop**
- **Holes performed at CNM (Barcelona, Spain): depth: 120-150 μm**

Third production:

- **Substrate: Si, Resistivity ~1.6 kΩcm , p-type, <111>, 380 μm**
- **Surface isolation: "combined" p-stop and p-spray (two differents doses)**
- **Holes performed by IBS (Peynier, France): depth: 180 μm**

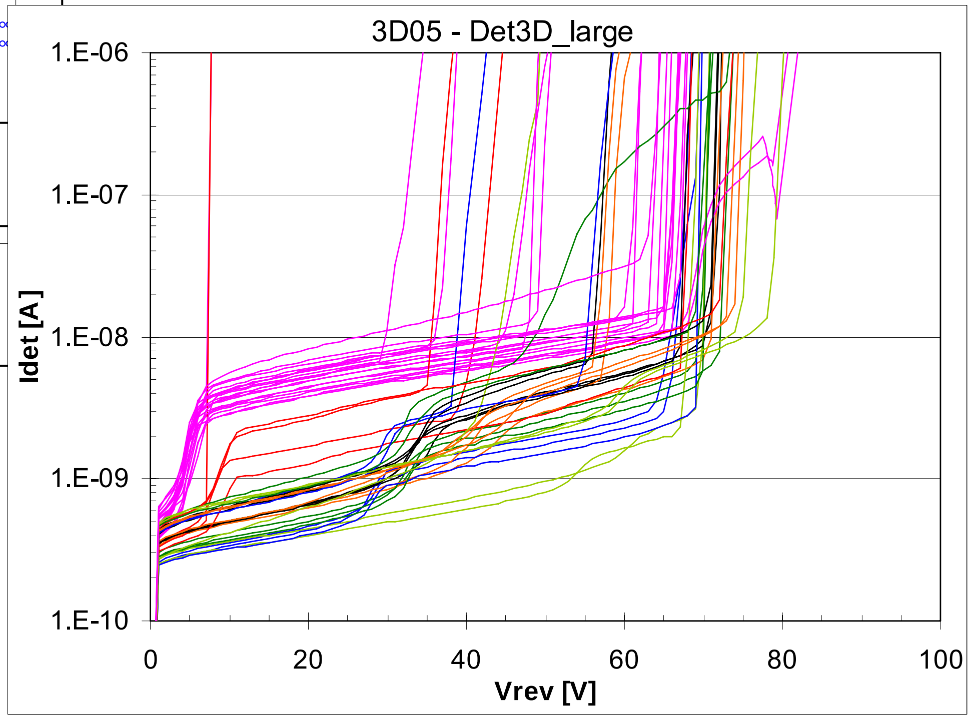
IV on "long" strips (area about 1cm^2)

First two runs



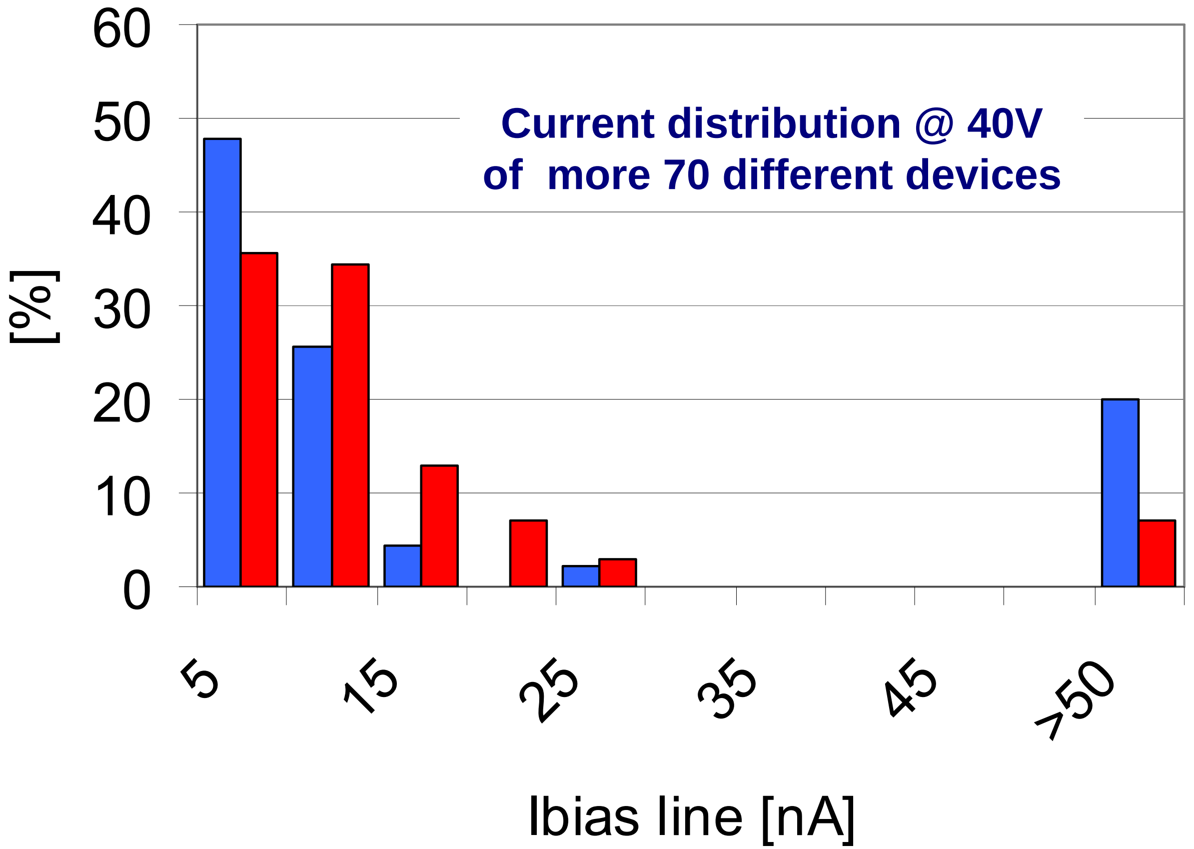
Increase of current caused by surface effects. No guard rings were implemented.

Third run "low" p-spray



Average leakage current
< 1pA/column
for both processes

Strip detectors – IV measurements



FIRST RUN

SECOND RUN

On going activity

- ✓ University of Glasgow (UK): CCE measurements with α, β, γ on 3D diodes and short strips
- ✓ SCIPP (USA): CCE measurements on large strips
- ✓ INFN Florence (Italy): CCE meas with β, on 3D diodes;
- ✓ University of Freiburg (D); measurements on short strips
- ✓ Ljubljana: TCT and neutron irradiation

Charge Collection in STC 3D detectors

SCIPP
INFN and University of Florence

2 CCE systems:
- ✓ Analog DAQ (Firenze); 2 msec shaping time, pad sensor
- ✓ Binary DAQ (Santa Cruz) 100 ns shaping time: strip sensor

CCE vs. voltage confirms simple picture
of depletion in single-column 3D sensors:

- Rapid depletion between columns (<10 V)
- Slow, planar-diode like depletion beyond

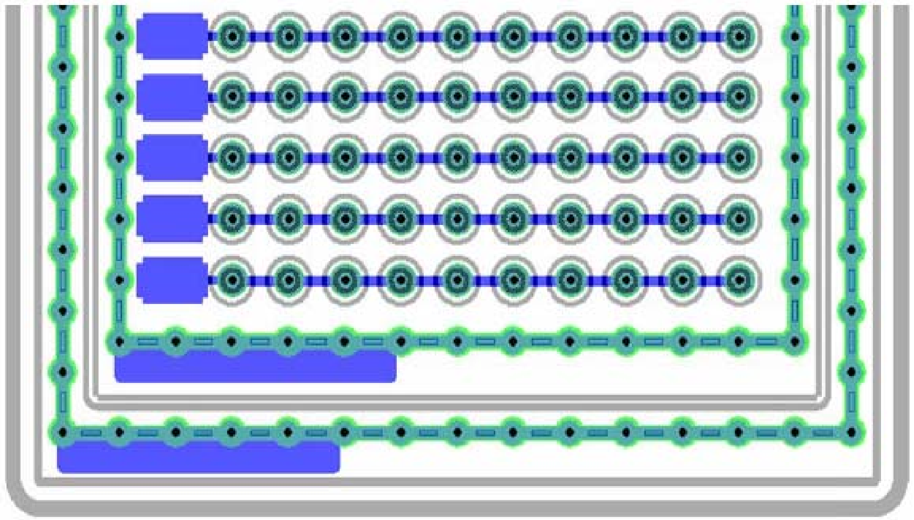
see Sadrozinsky's talk at 8th RD50 workshop: http://rd50.web.cern.ch/rd50/

Measured current signal in 3D-stc

Study performed in Ljubljana. See Kramberger's talk at 8th RD50 workshop: http://rd50.web.cern.ch/rd50/

DEVICES: small strip detectors

3D-stc DC coupled detector
(64 x 10 columns)
80 μm pitch
80 μm between holes
10 μm hole diameter

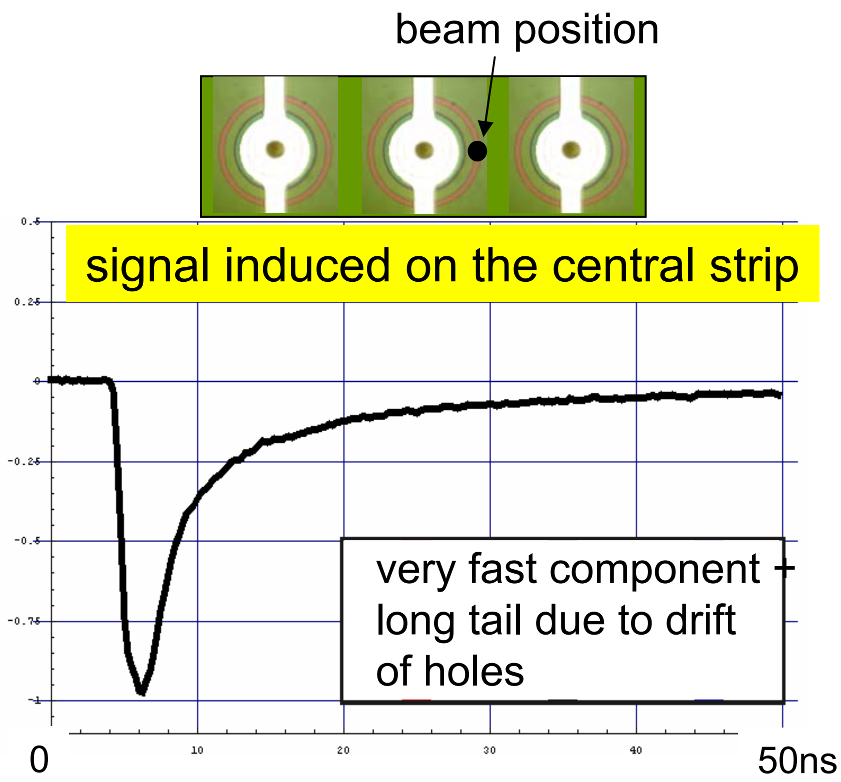


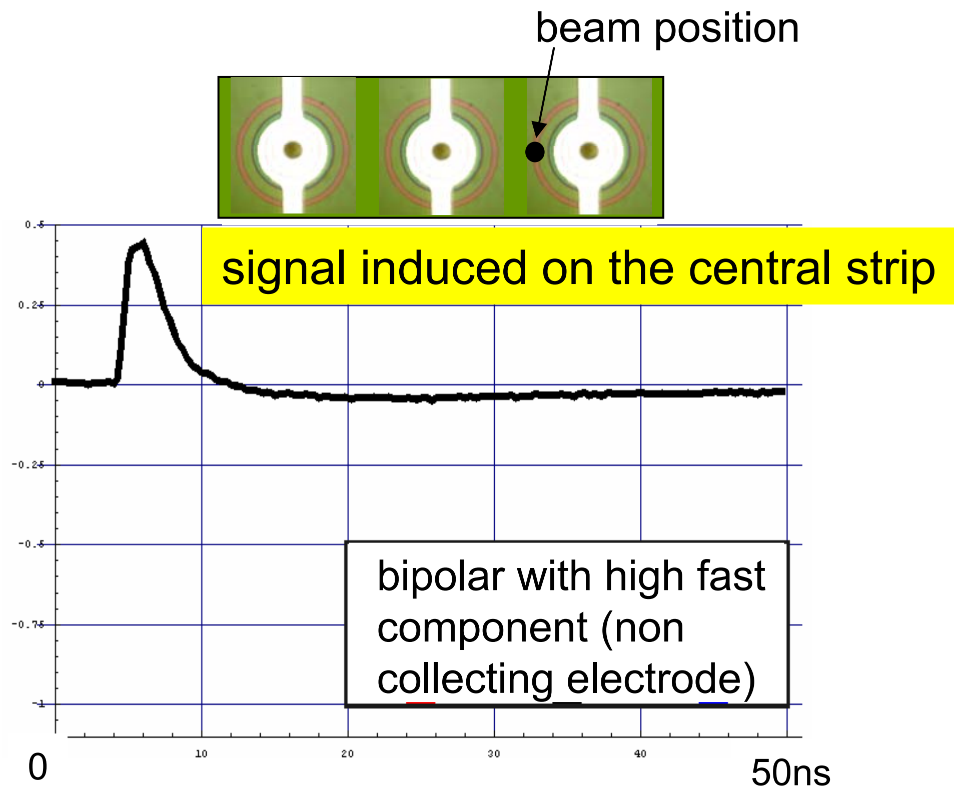
SETUP:

- IR laser (m.i.p. simulation) – beam diameter in the silicon FWHM~7 μm
- Width of light pulses ~ 1ns , repetition rate 100 Hz
- 3 independent channels – fast current amplifiers 1kHz-2GHz

Measured current signal in 3D-stc (2)

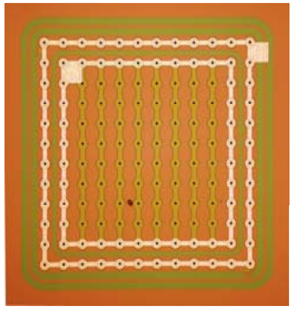
Many data available! Two examples shown below.





Measurements well reproduce the simulations previously reported!

More work has to be done, above all on irradiated detectors.



Radiation damage studies

[performed in collaboration with V. Cindro, Ljubljana]

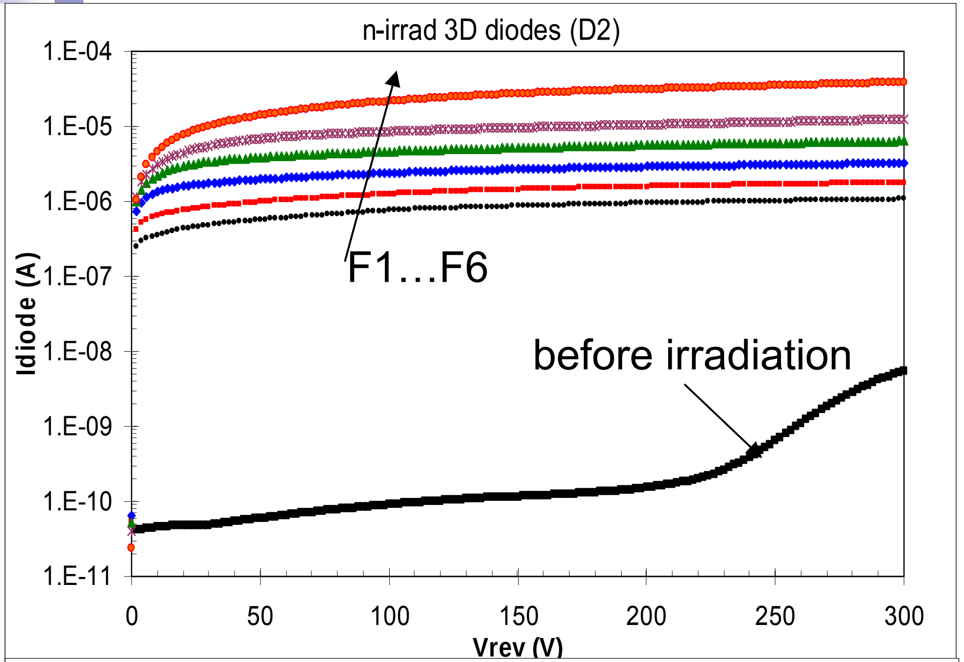
Devices:
3D diodes, p-type FZ 525μm thick substrate, p-stop isolation
+ planar diodes with same subst. characteristics.

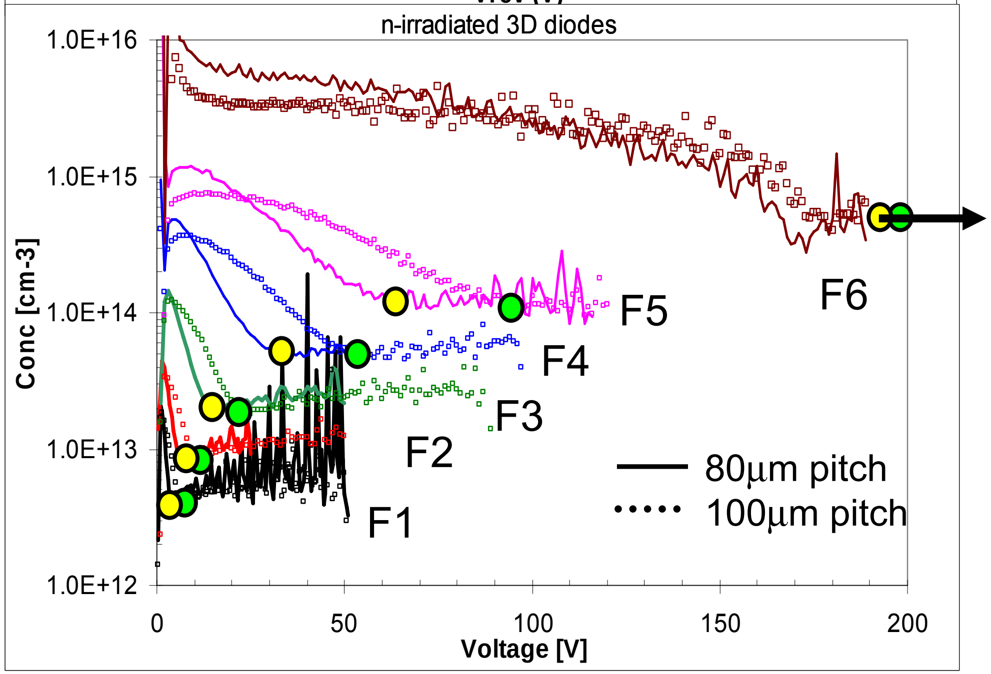
Irradiation: neutrons at TRIGA research reactor in Ljubljana;
6 fluences between 5e13n/cm^2 and 5e15n/cm^2

Annealing: 15 days at room temperature
(~ minimum depletion voltage).

Measurements: IV and CV (series model @10kHz) @ 23C

Aim: study of the depletion characteristic (at the moment)





Radiation damage studies

1) 3D Diode current

(80µm pitch)

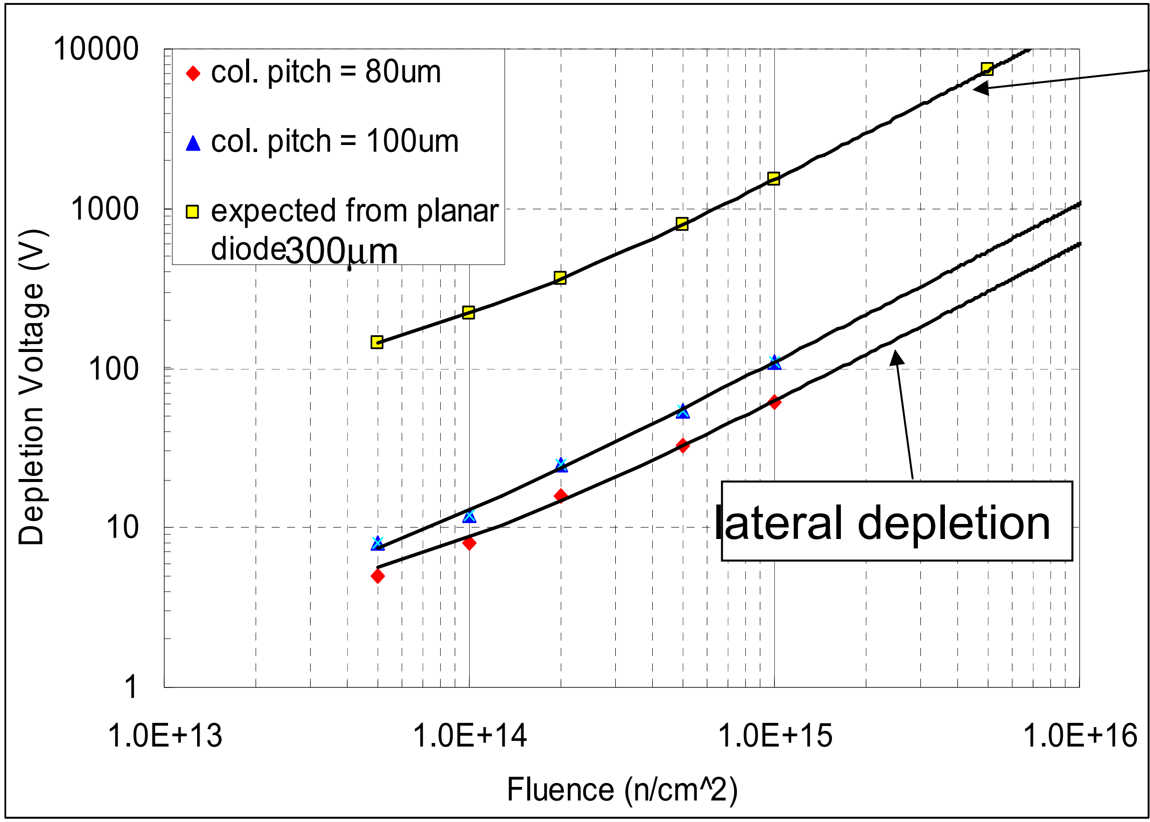
Normal current behavior:
current increases with fluence

2) CV measurements

difficult measurement as it depends on frequency and model (series/parallel)
⇒ we look only for kinks in the CV related to full lateral depletion

$$\text{Conc} \approx \frac{d}{dV}\left(\frac{1}{C_{\text{back}}^2}\right)$$

Radiation damage studies

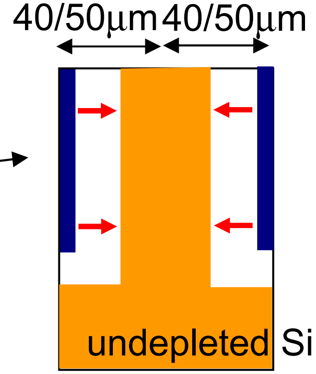


$\Delta Neff = \beta^* \Phi$ (*)

$\beta = 0.021 cm^{-1}$

see Cindro's talk at 8th RD50 workshop: http://rd50.web.cern.ch/rd50/

Simulating the full lateral depletion voltage with N_{sub} estimated from equation (*) we obtain values comparable with those reported on the plot.



Each column depletes half col. pitch

➡ the lateral depletion voltage is very low.

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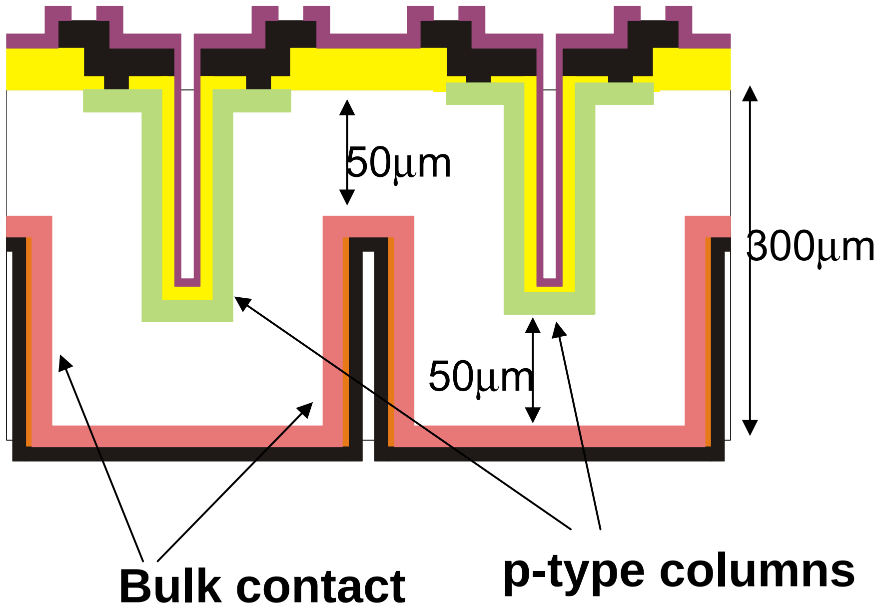
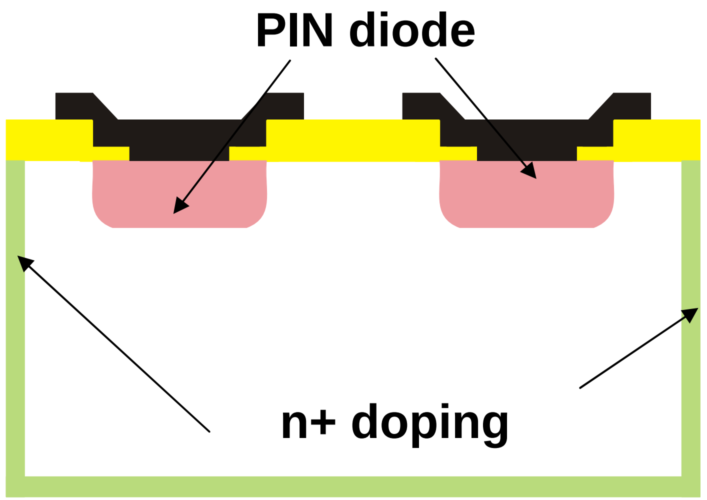
Next technological steps



Double-sided Double-Type-Column

front side identical to 3D-STC

- Layout designed, with pixel and strip detectors



Planar detectors with active edge

Conclusion

- IRST is developing the technology for the production of 3D detectors with encouraging results.

- First device produced: **3D-STC detector:**

  ⬆ "simple" fabrication process;

  extremely important step to learn aspects of the technology and to understand 3D functioning.

  ⬇ collection mechanism not very efficient;

  its possible usage should be verified.

- First irradiations and characterization of 3D-STC

FUTURE WORK

- CCE and signal shape measurements after irradiation;
- Early next year first prototypes of 3D-DTC will be available.