# Status of the development of 3D silicon detectors at ITC-irst

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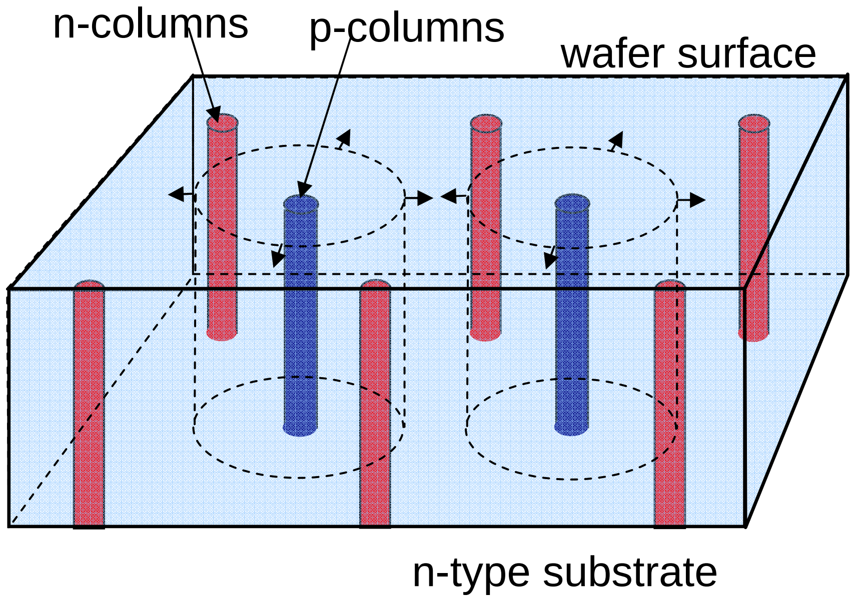
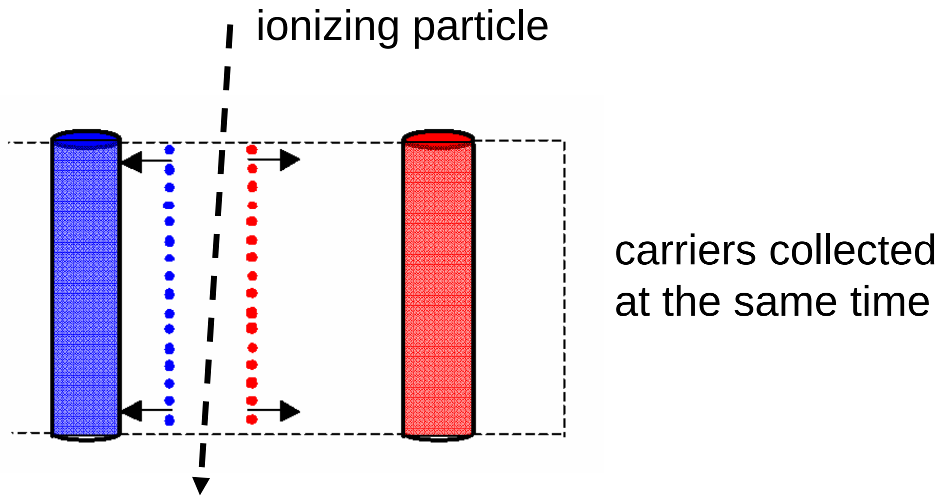
# Outline

- **Introduction**
- **Single-Type Column 3D detector**
  - Simulation of the static and functional characteristics
  - Description of the fabricated devices
  - Experimental characterization
- **Future developments**

# "Standard" 3D detectors - concept

[Parker et al. NIMA395 (1997)]




Distance between *n* and p electrodes can be made very short

➡ **extremely radiation hard detector**

(low full depl. volt. and high CCE even at very high fluences)

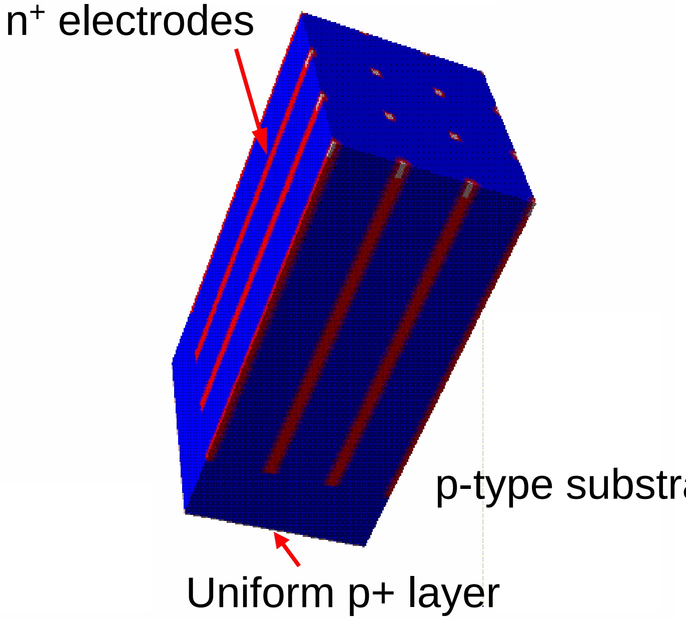
**Drawbacks**: - electrodes are dead regions (or partially)

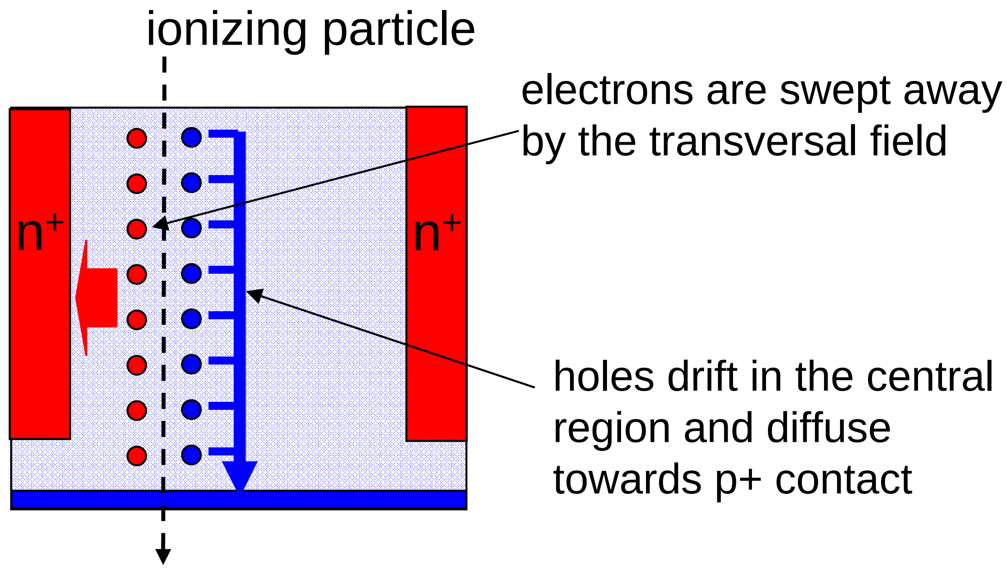
- feasibility of large scale production still to be verified

# 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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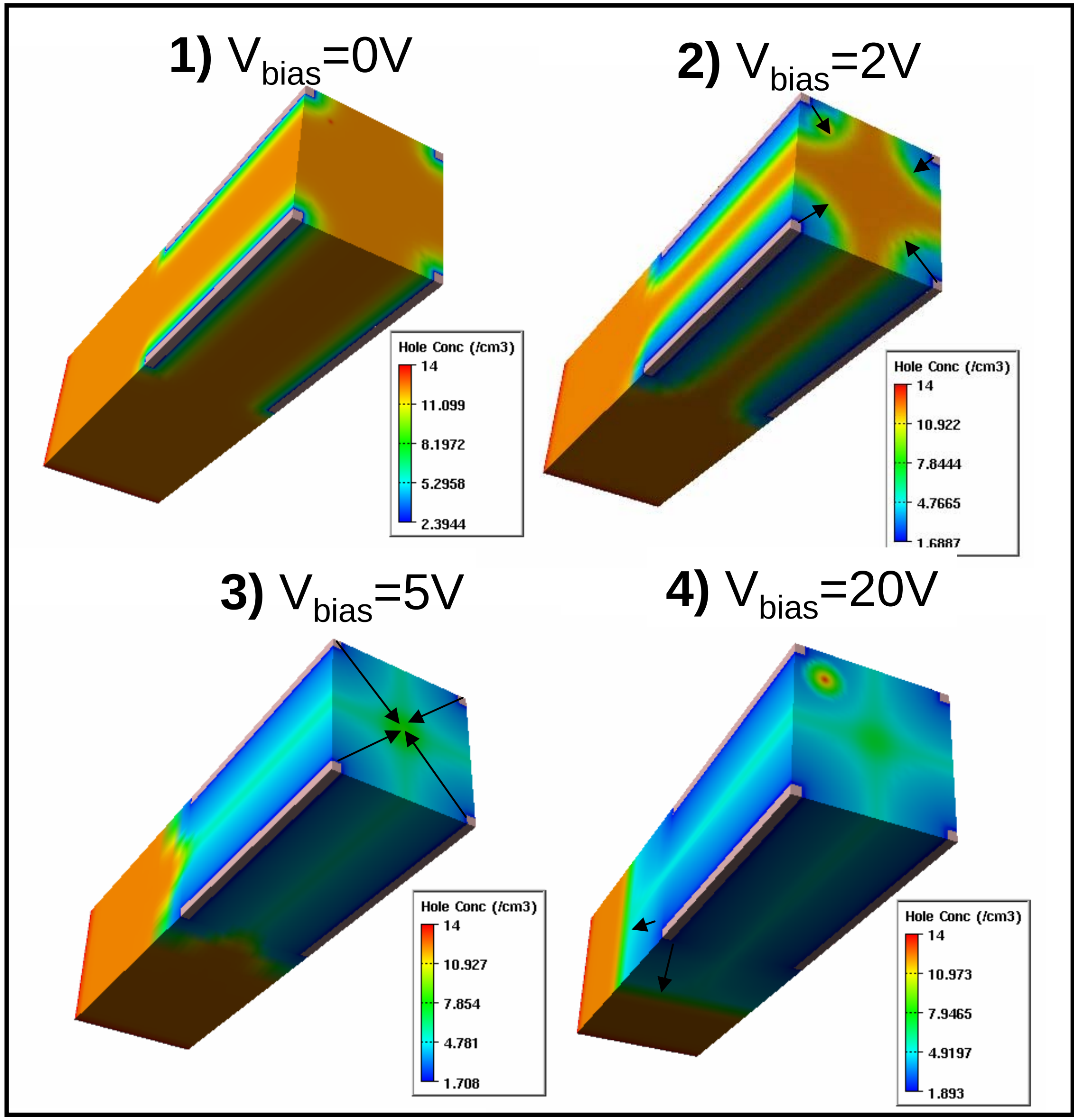
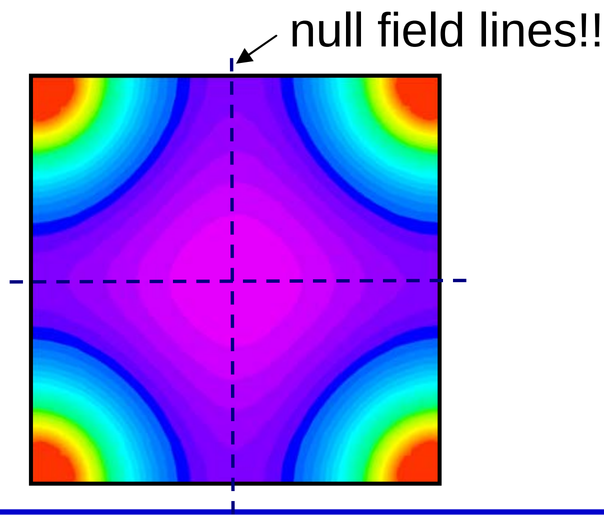
# Static device simulations (1)

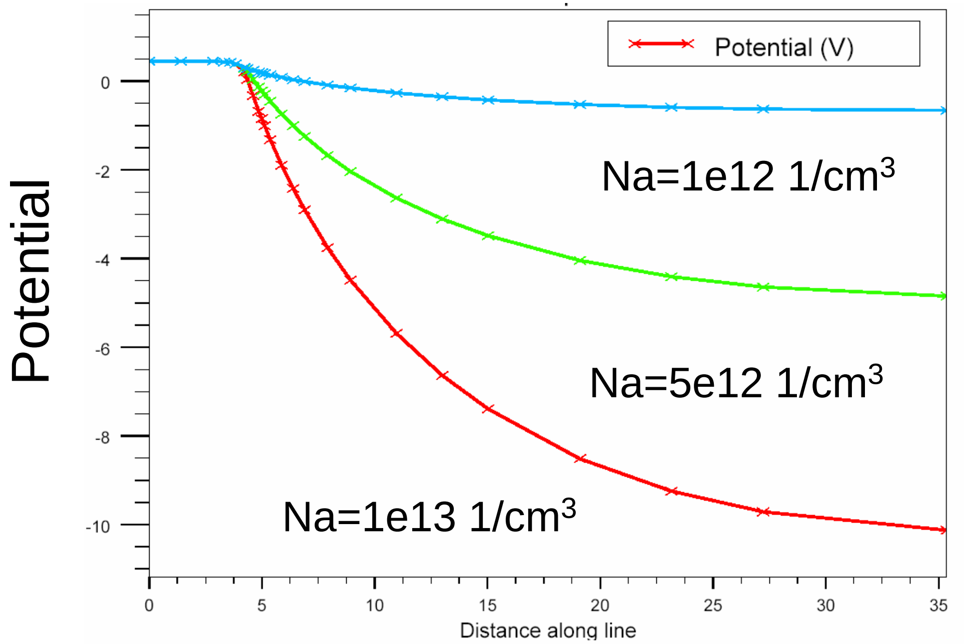


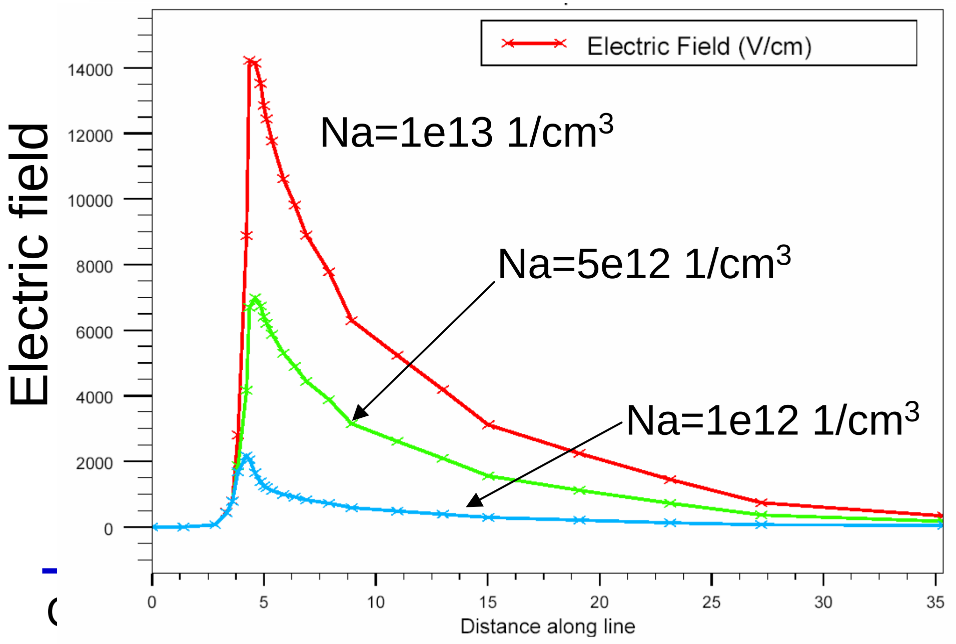

→ **Depletion mechanism**

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

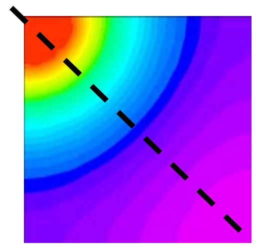


# Static device simulations (2)



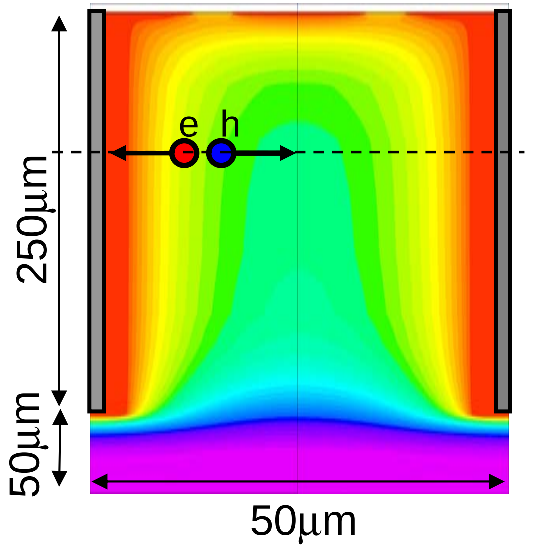

Profiles along the cutline



High subst. dopant conc. implies <u>smaller null field region</u> and <u>higher electric field</u>.

⇒ for p-type subst. the detector works better after irradiation

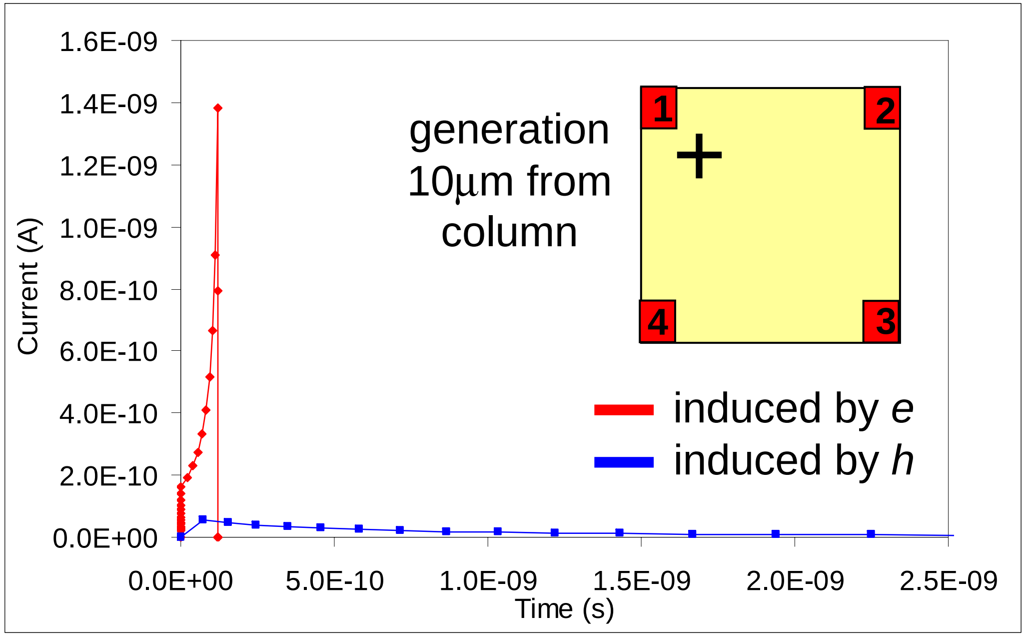
# Signal formation in 3D-STC (1)

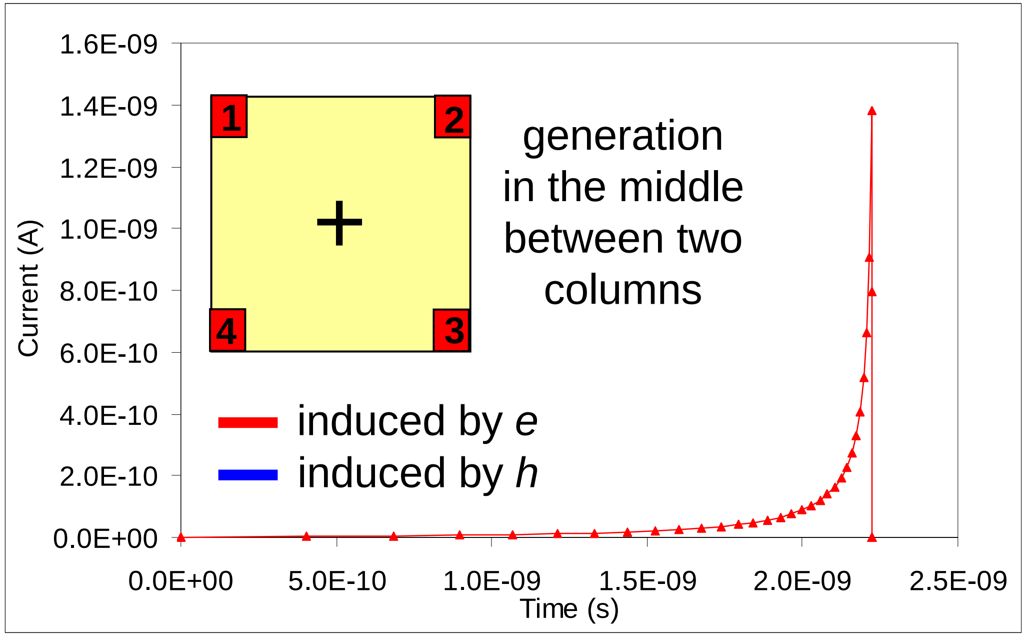



**First phase: transversal movement**

Electron drifts towards the column
Hole drifts towards the middle region

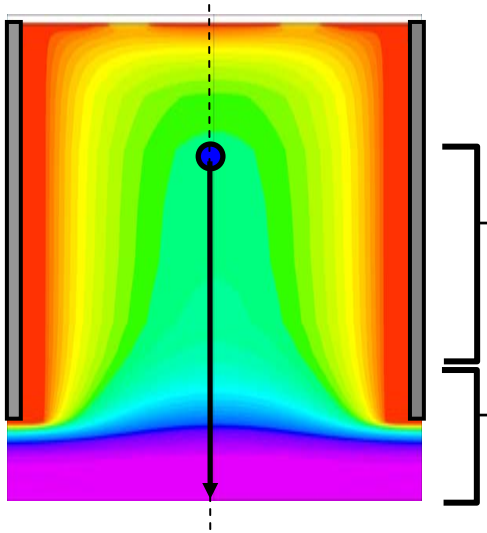
Induced current on El1 evaluated with Ramo theorem



# Signal formation in 3D-STC (2)

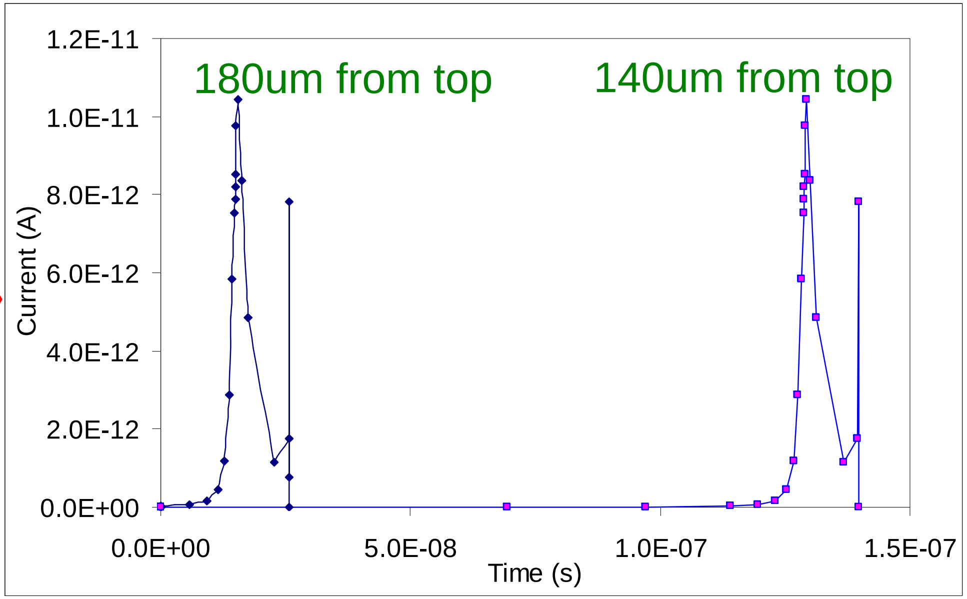
## Second phase: hole vertical movement



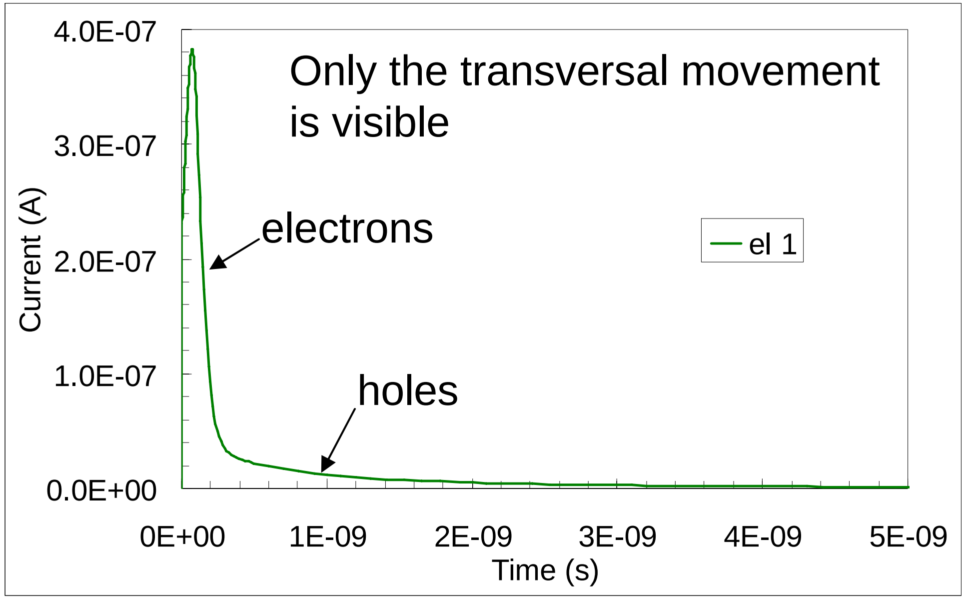
hole drift is orthogonal to weighting field
⇒ no signal induced

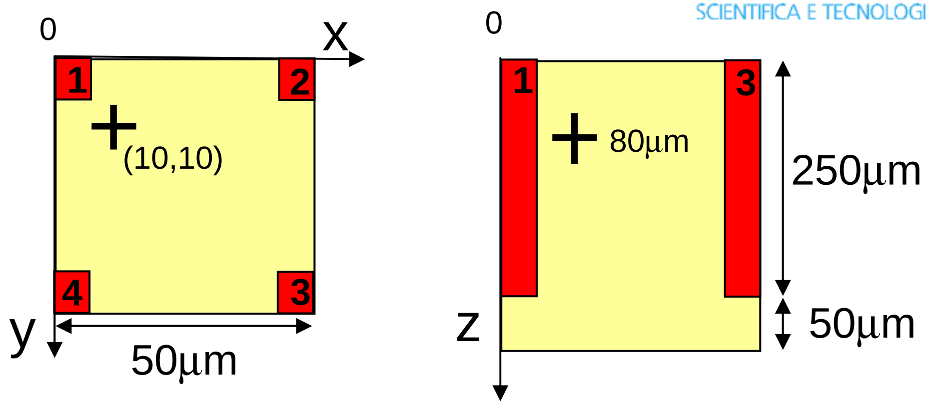
weighting field no longer orthogonal
⇒ signal induced

a hole moving towards the back induces a current pulse shifted in time according to the generation depth



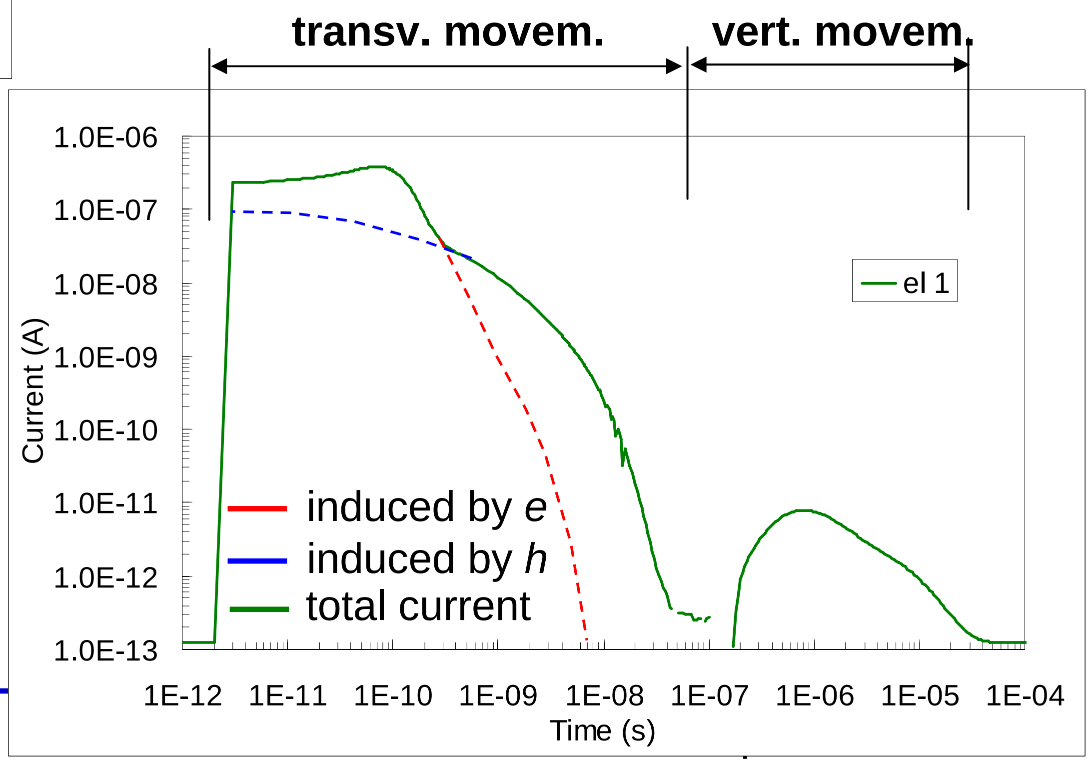
# Simulation of a localized charge deposition



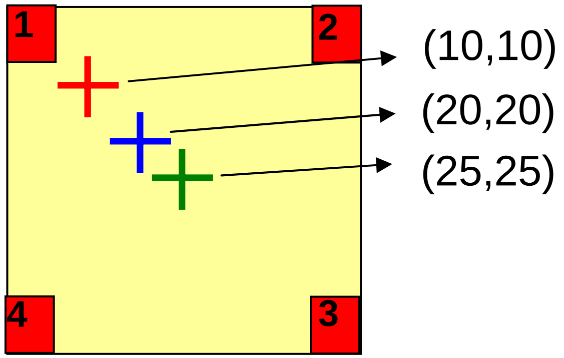



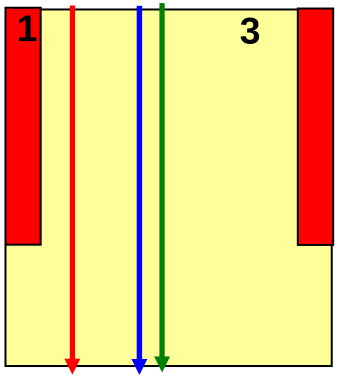

The current plot in log-log scale shows very clearly the fast transversal component and the slow vertical one.

⇒ results in agreement with prediction with Ramo theorem



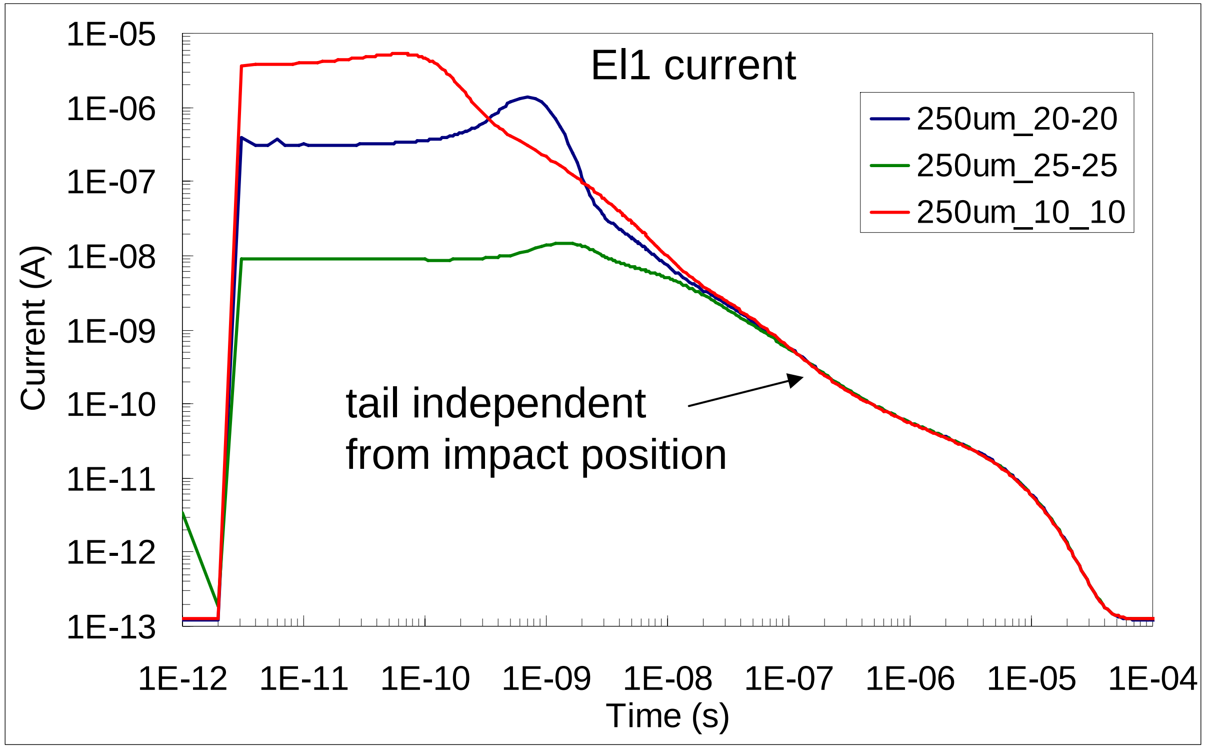
# Simulation of a uniform charge deposition




Tracks centered in three different positions

Current peak delayed as we move from the column to the center



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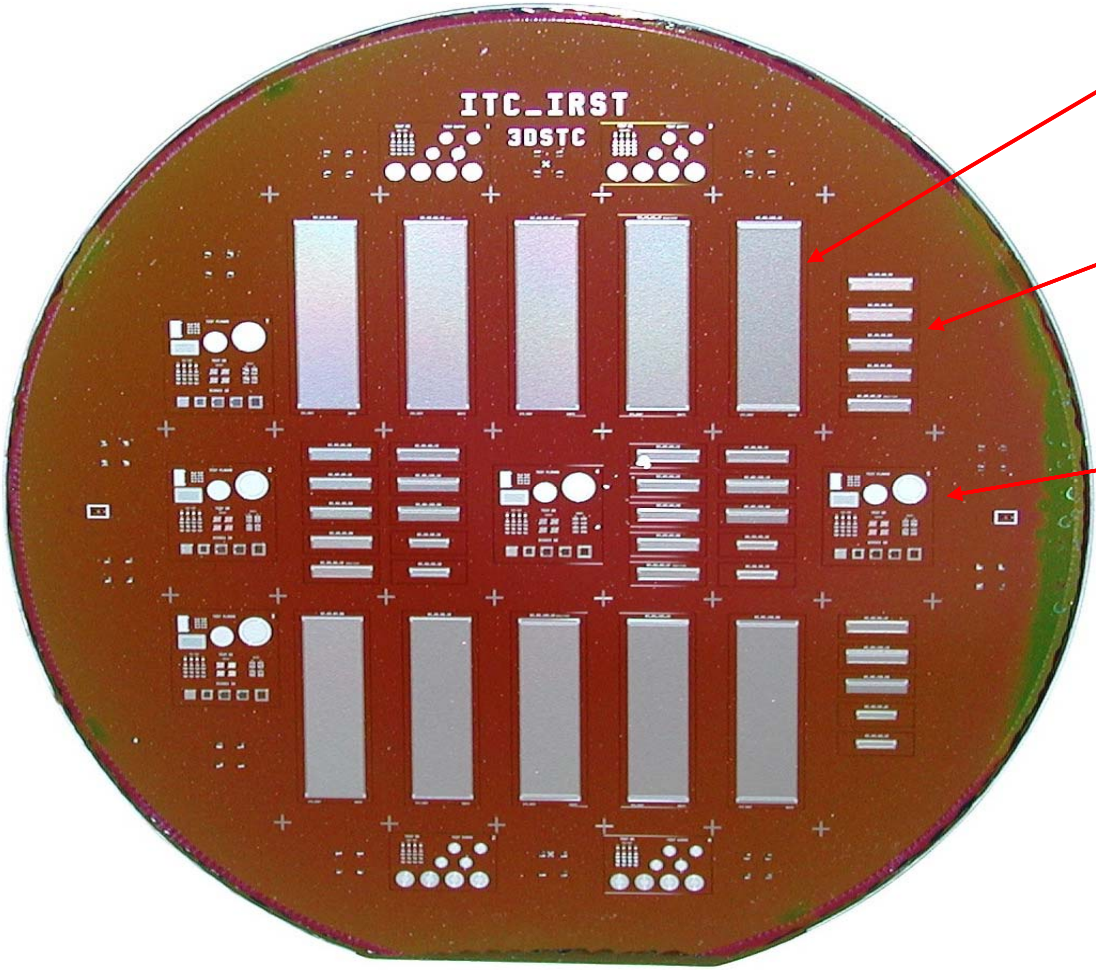
# Mask layout




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

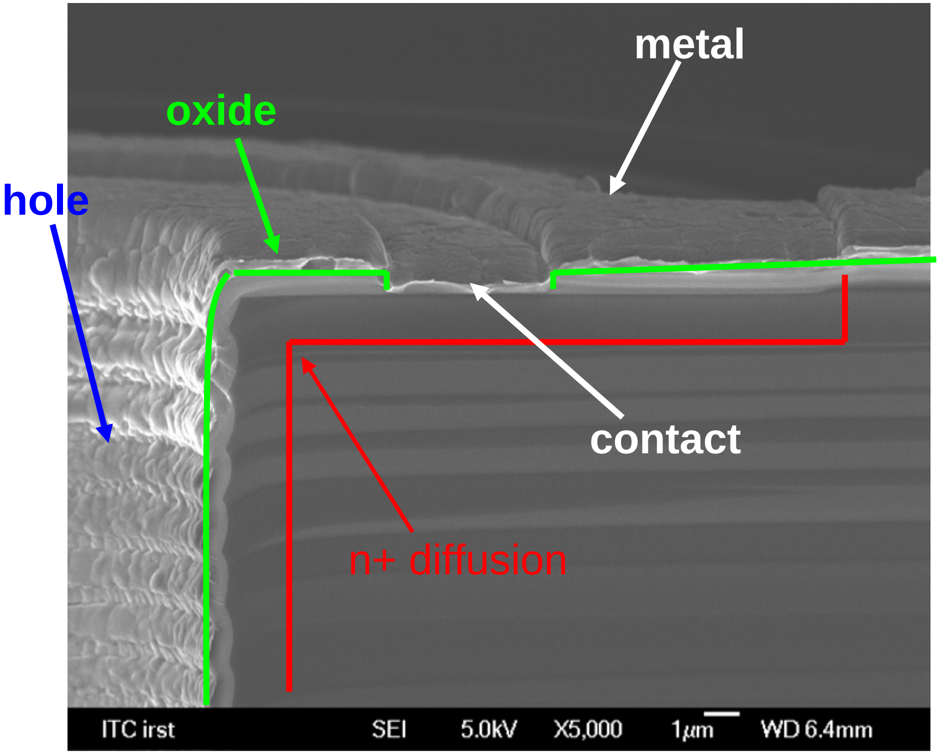
"Short" strip detectors
~ $0.8x5mm^2$ 64 strips
10 col./strip

Planar and 3D test structures

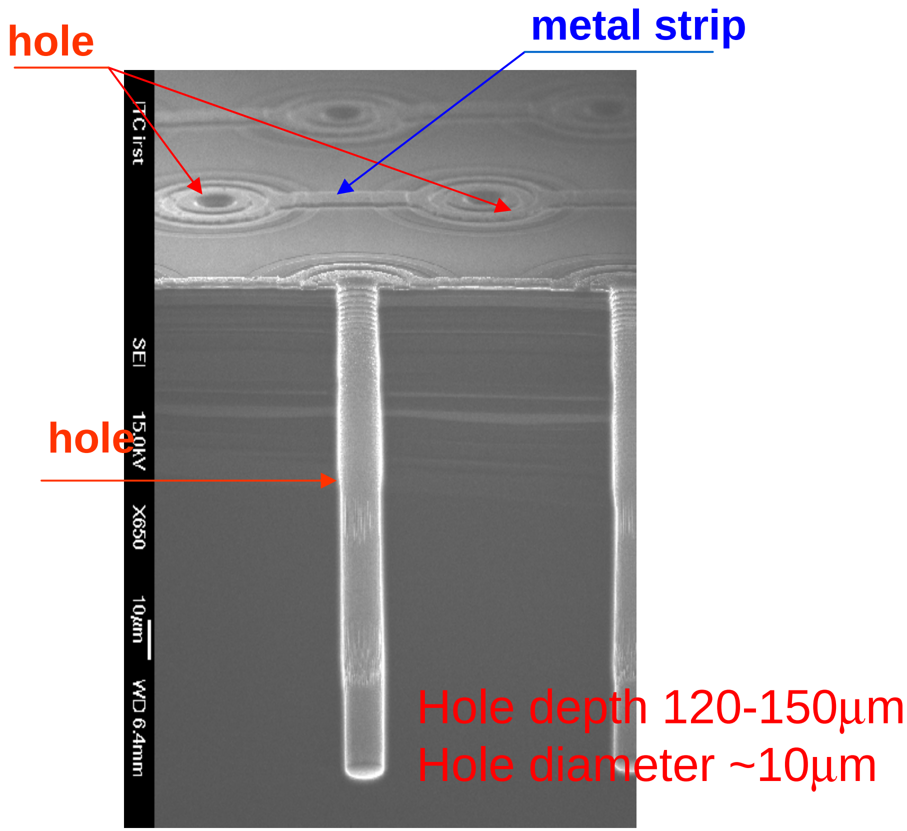
1. "Low density layout" to increase mechanical robustness of the wafer
2. Strip detector = "easy" to (electrically) test

# 3D process

performed @ IRST




- Hole etching with Deep-RIE technology
- Wide superficial n+ diffusion in which the contact is located
- Passivation of holes with oxide




- Si High Resistivity, p-type, <100>
- Surface isolation: p-stop *or* p-spray
- Holes are “empty”

# Column etching

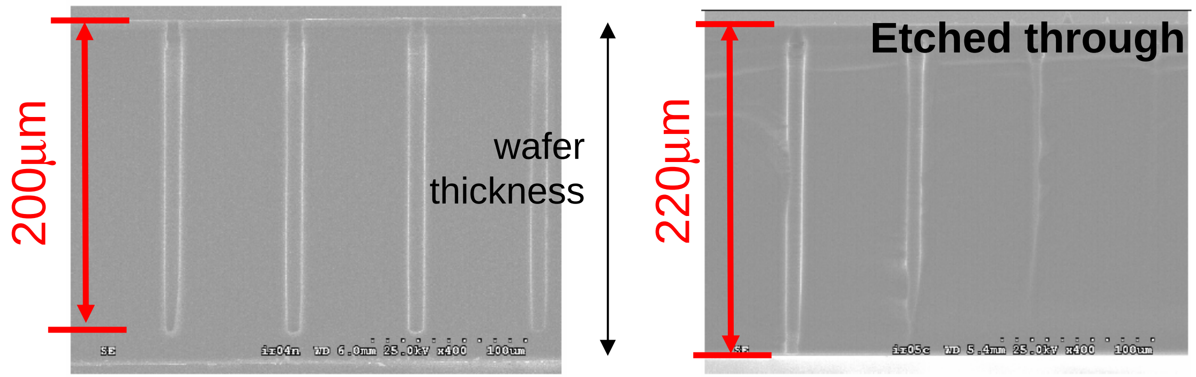
**So far, 3 runs have been fabricated**:

2 runs with holes etched by CNM (Barcelona);

1 run with holes etched by a company providing microtechnology services;

Important, in both cases:
- same column parameters;
- extremely good process yield (leakage current).

Furthermore, etching test have been performed with a third provider, again, with good results.




**column etching and treatment are not critical**

# Outline

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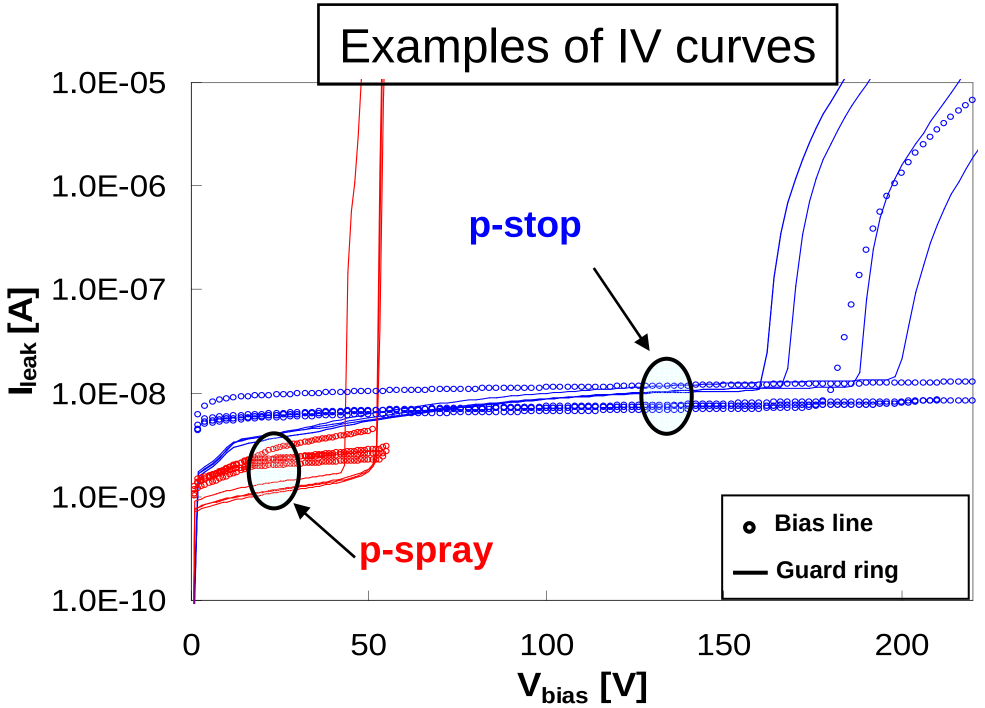
# Leakage current & yield

Measurement on “long” strips (area about 1cm$^2$)




- Increase of current caused by surface effects. No guard rings were implemented.
- Number of columns per detector: 12000 – 15000

⇒ Average leakage current **< 1pA/column**

Measured more than 100 devices 90% showing characteristics similar to those reported in the plot ⇒

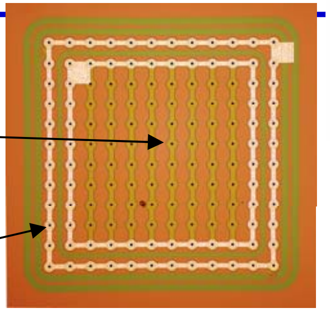
- **Low leakage current**
- **Good process yield**

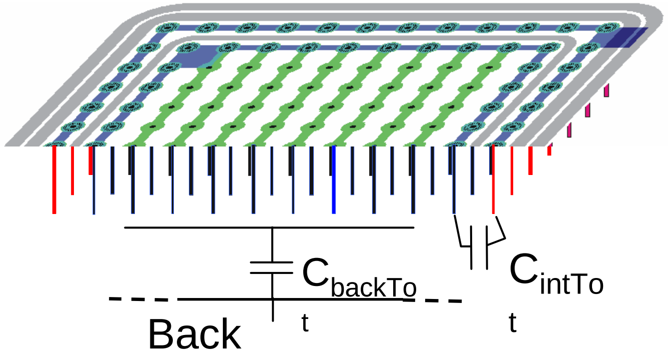
# Full depletion evaluation in 3D-stc

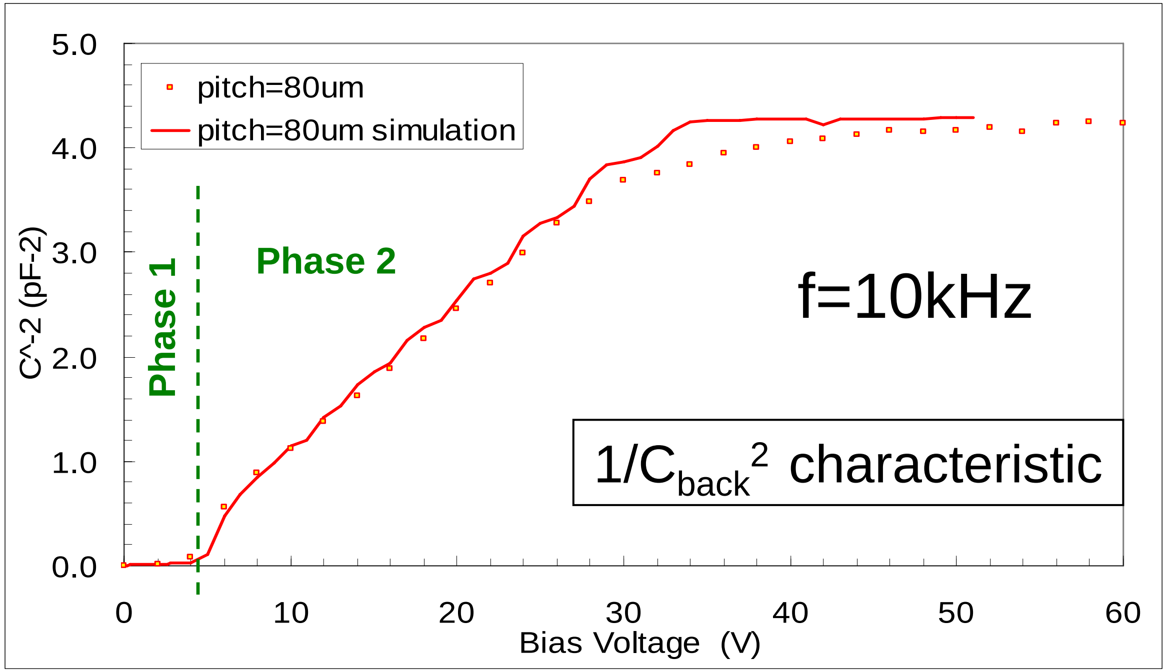
3D diode

matrix of 10x10 holes

guard ring

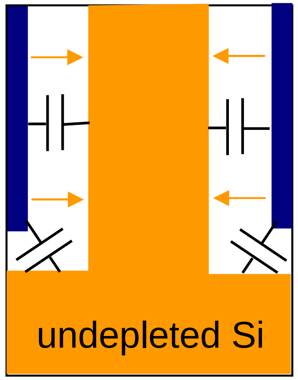




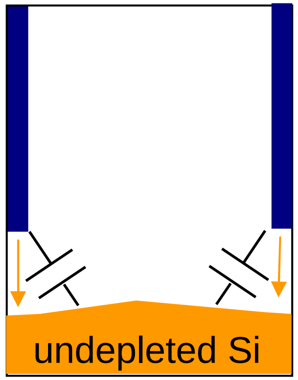

**Phase 1**

- high $C_{back}$
- ~ zero $C_{int}$




**Phase 2**

- max $C_{int}$
- slowly dec. $C_{back}$




**From $1/C^2$ curves** one can determine:

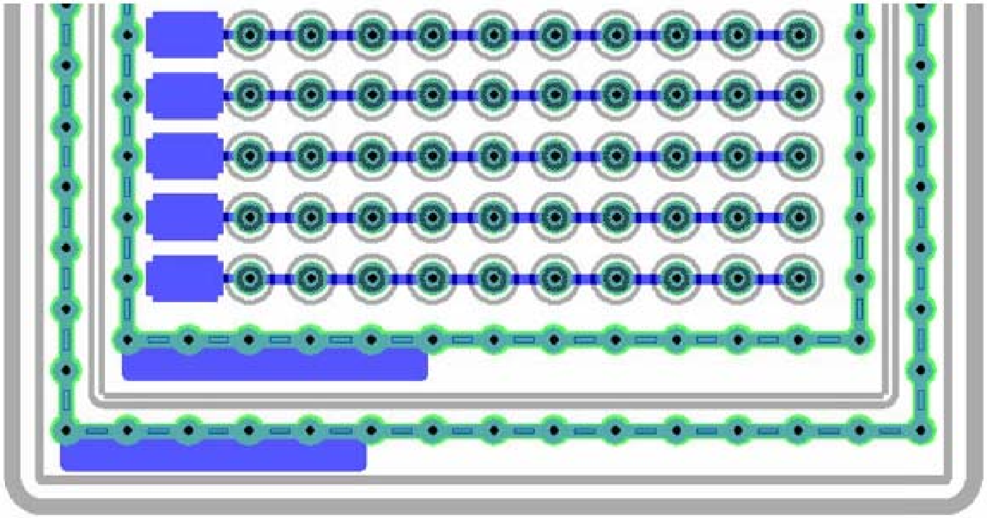
- **full depletion between columns** (in this case ~5V for 80µm col. pitch)
- **full depletion of the bottom region** (~35V for col depth of 150µm)

# 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

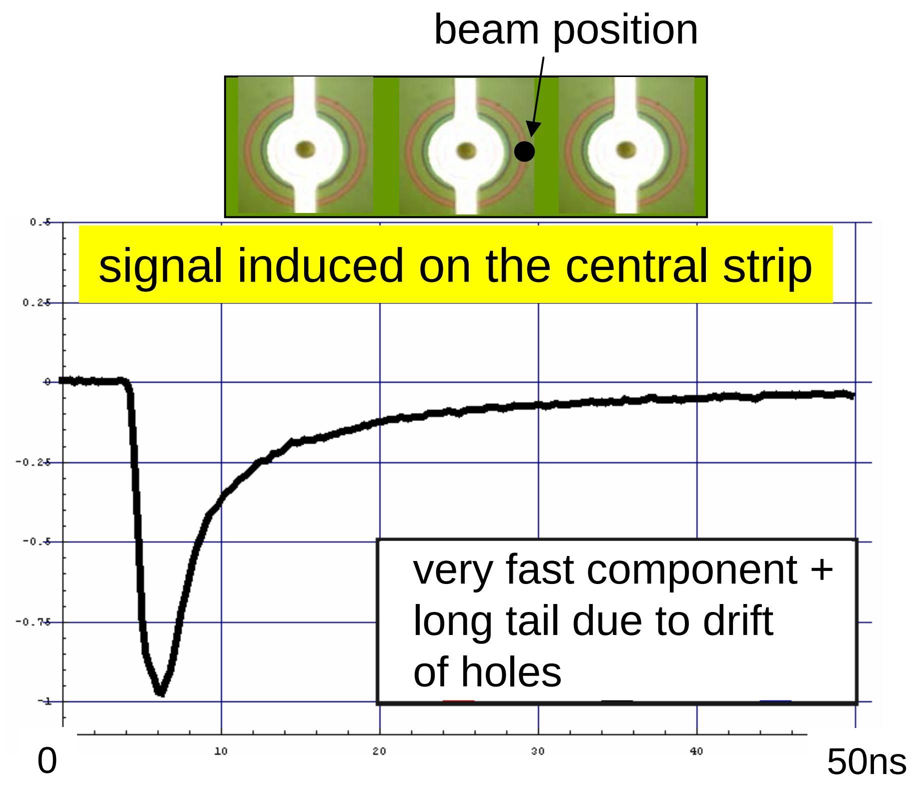


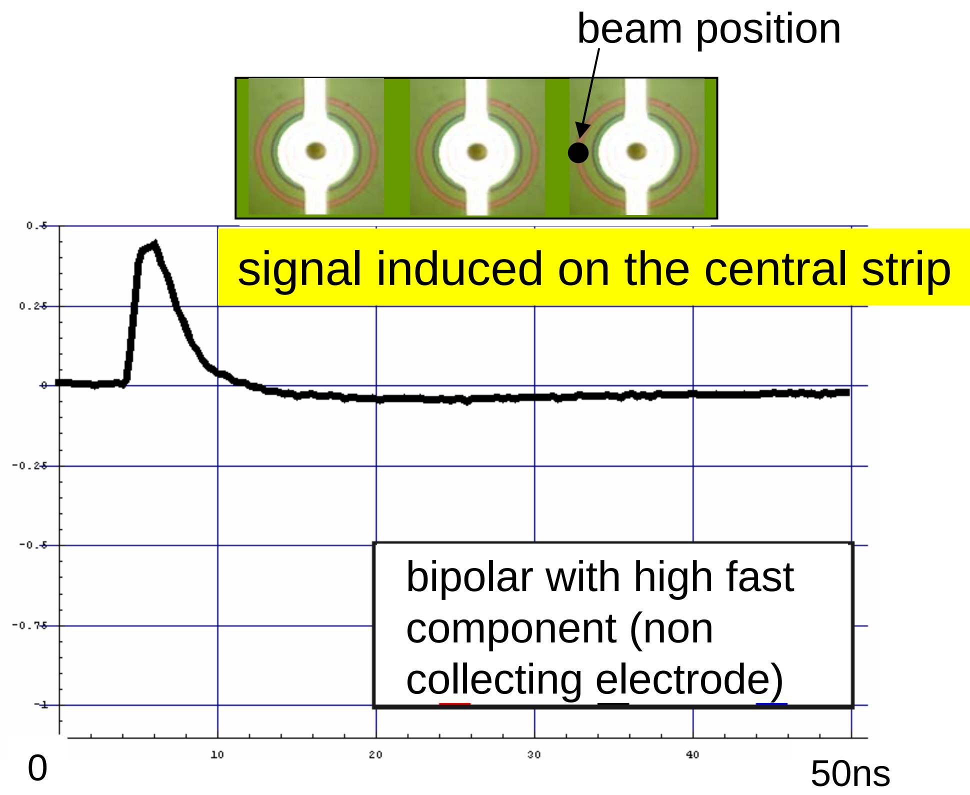
## SETUP:

- 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.



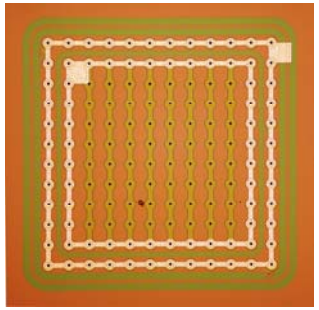




Measurements well reproduce the simulations previously reported!

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:

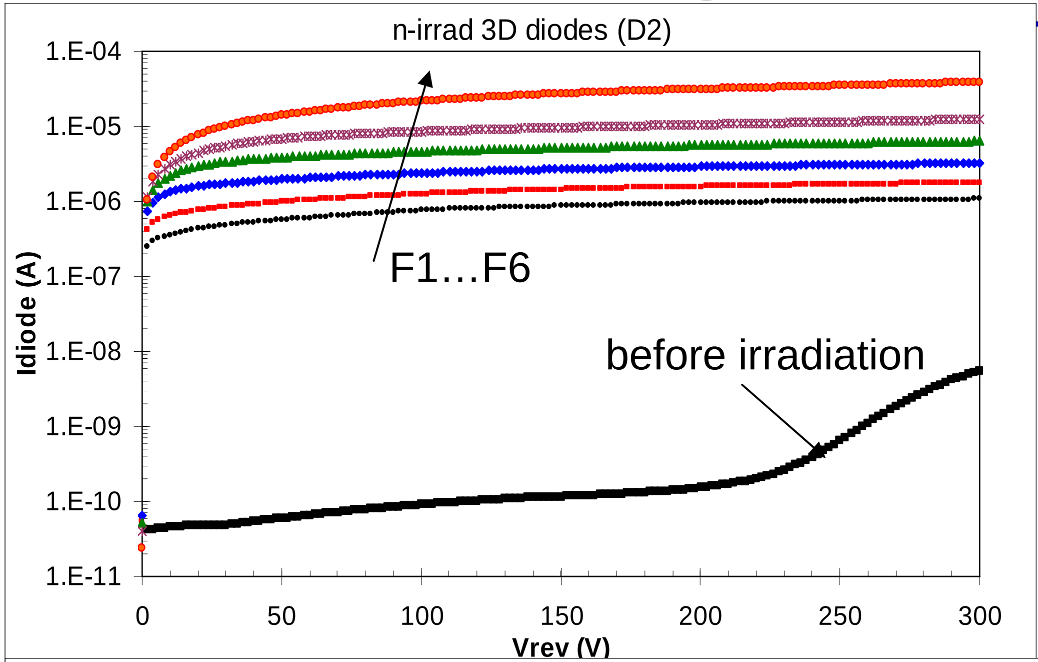
F1: 5e13n/cm$^2$
F2: 1e14n/cm$^2$
F3: 2e14n/cm$^2$
F4: 5e14n/cm$^2$
F5: 1e15n/cm$^2$
F6: 5e15n/cm$^2$

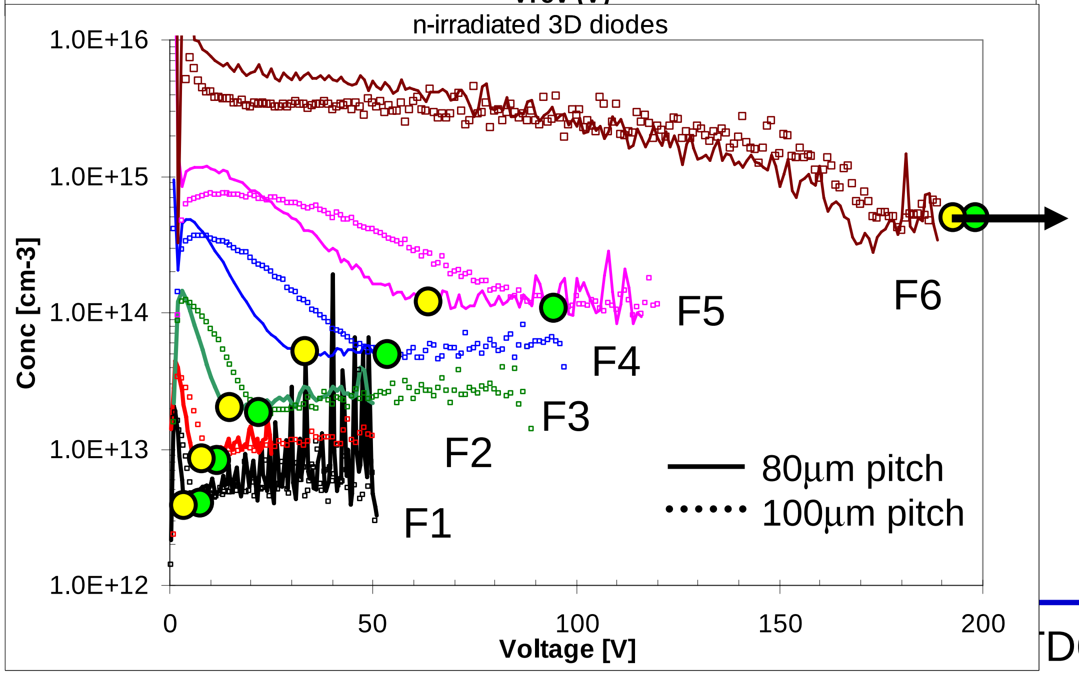
**Annealing:** 15 days at room temperature
(~ minimum depletion voltage).

**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)

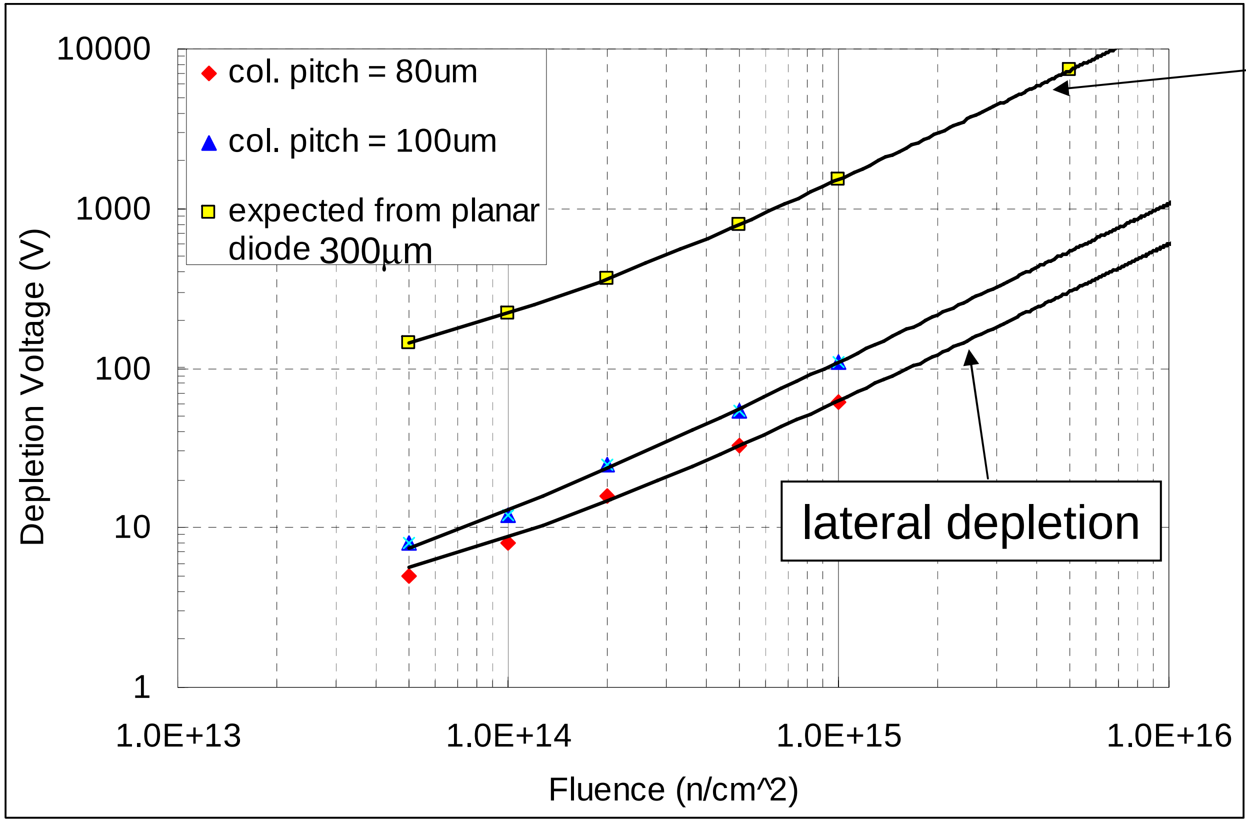
Normal current behavior:
current increases with fluence

## 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

**Conc ~ 1/d(1/Cback2)/dV**

# Radiation damage studies

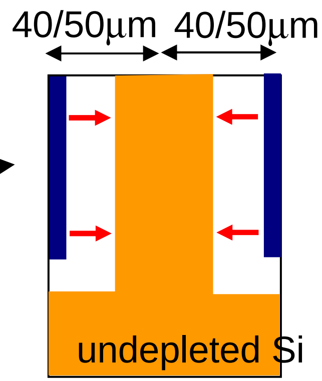



$$\Delta Neff=\beta*\Phi$$
$$\beta=0.021cm^{-1}$$ (*)

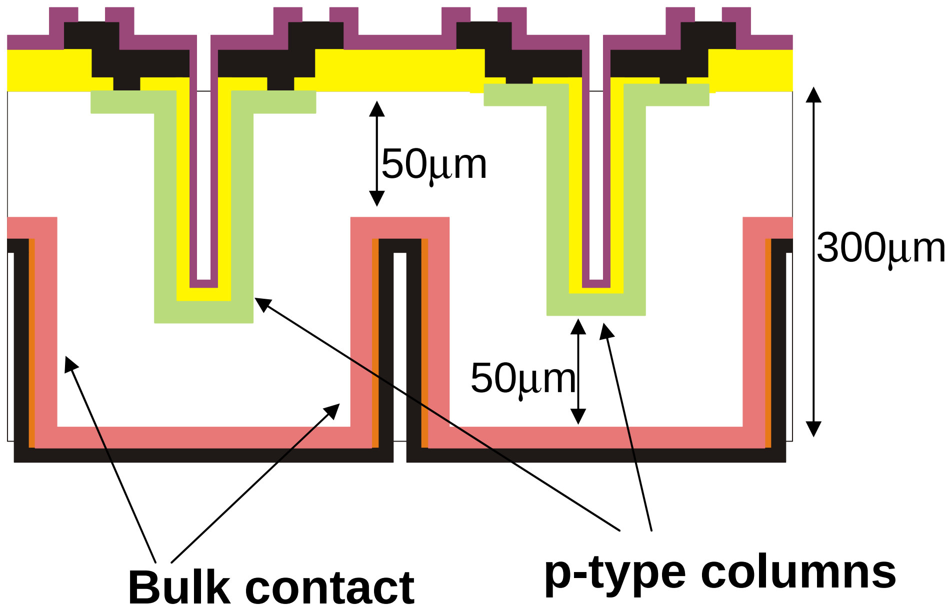
see Cindro's talk at 8th RD50 workshop: http://rd50.web.cern.ch/rd50/

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.**

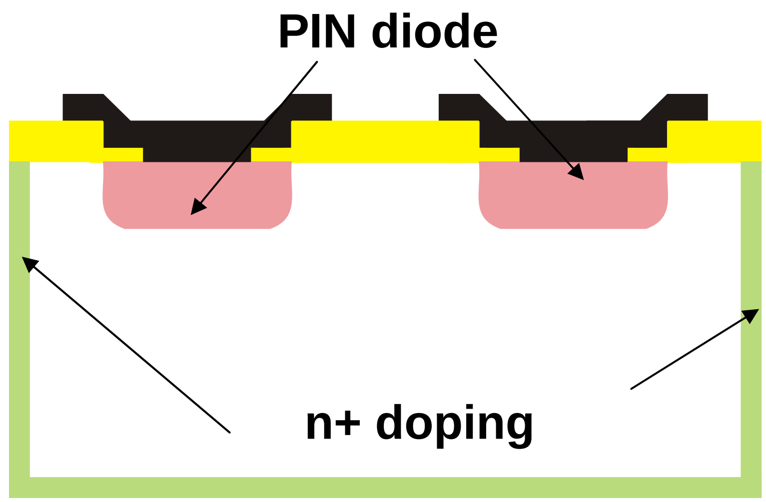


# Next technological steps




## 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.

## In this conference…

**Poster #59:** Charge collection efficiency measurements on 3D diodes and "long" strips by INFN Firenze and SCIPP.

**Poster #74:** Simulation and measurements on 3D-STC by Univ. of Glasgow and CNM.

3D detectors are developed within an agreement between INFN and IRST called **MEMS**.

MEMS includes 4 projects:

- Silicon photomultipliers (*sipm.itc.it*)
- 3D Silicon detectors (*infn-tredi.itc.it*)
- Microbolometer arrays
- Low Temperature Silicon Time Projection Chamber (TPC)

IRST works mainly on the development of the sensor
INFN on the application