Development of 3D Detectors for Very High Luminosity Colliders

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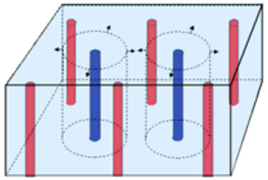
University of Glasgow

October 30, 2007

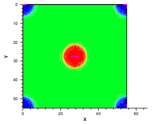
On behalf of the CERN-RD50 Collaboration

This talk shows a review of the work of RD50 on the use of 3D detectors as trackers in high radiation environments

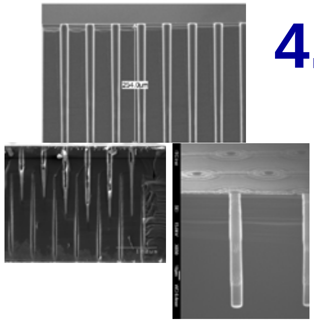
1. The CERN-RD50 collaboration



2. Silicon 3D detectors



3. Simulation work

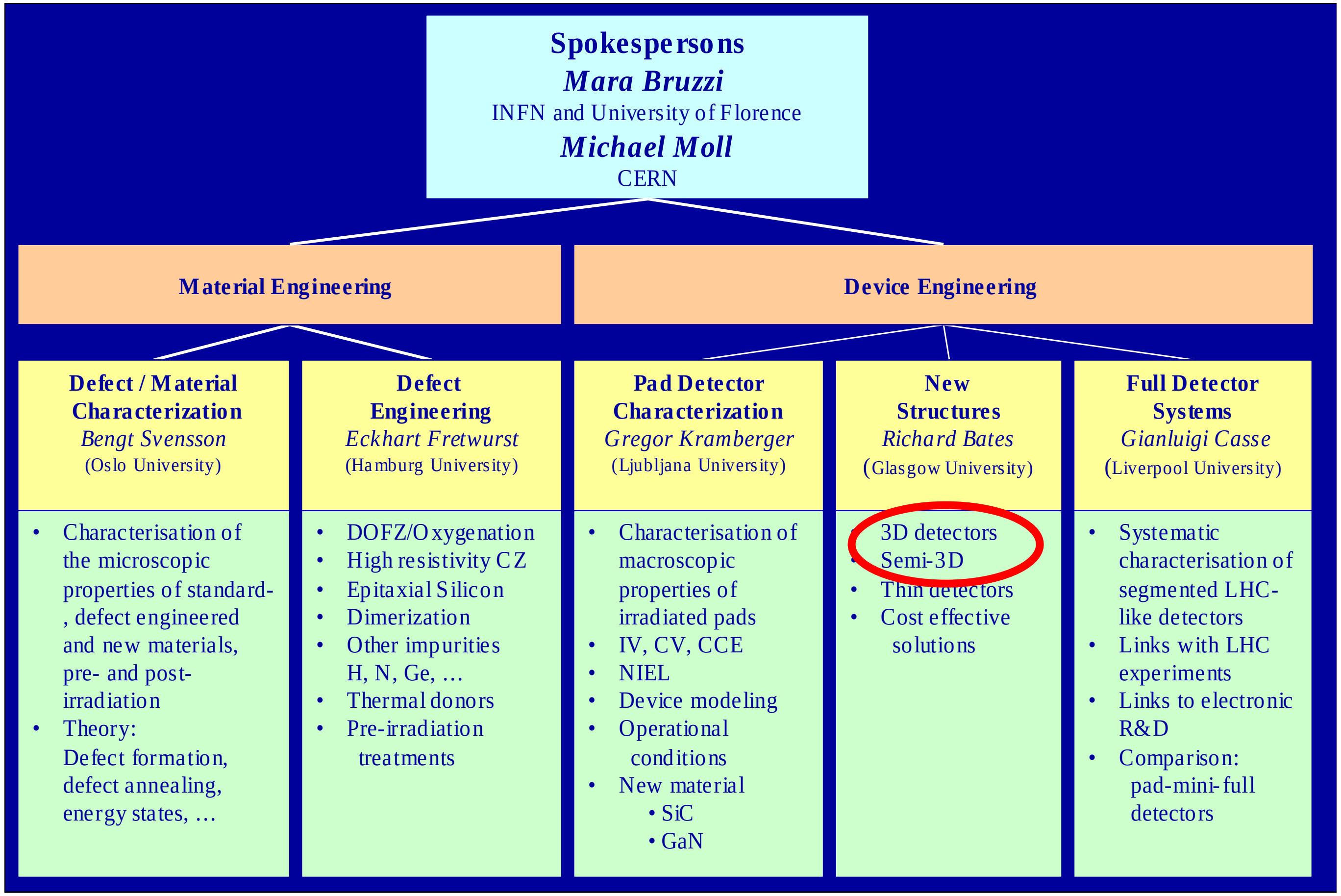


4. Different approaches

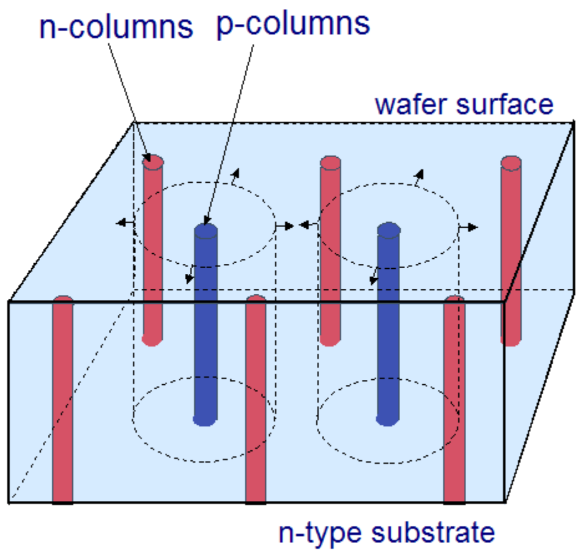
- **Single sided 3D**
- **Double sided 3D**
- **Full 3D**

The CERN-RD50 Collaboration

- Aims to develop solid state detectors capable of operating in extreme radiation environments
- Created in 2002. 261 members, 50 institutes, 25 countries

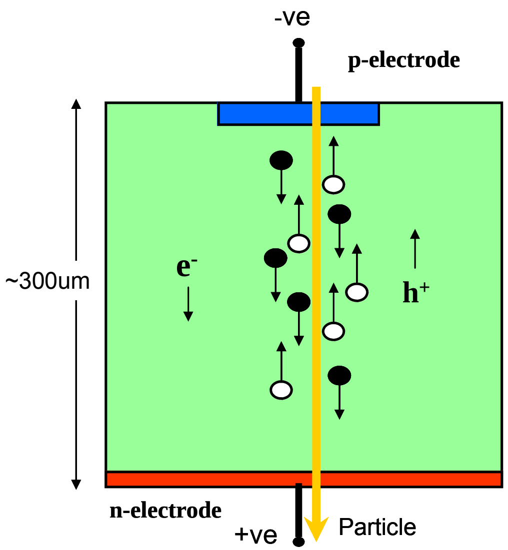


3D detectors

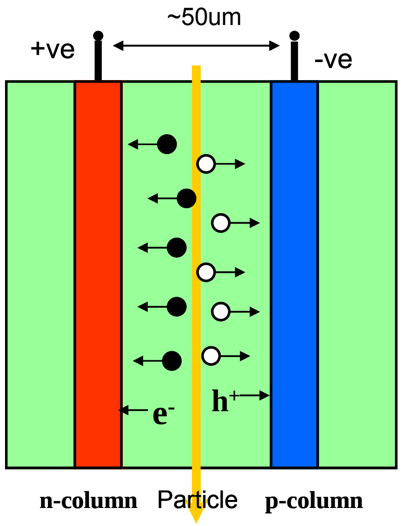


- Proposed by S. Parker et al. NIMA395 (1997).
- 3-d array of p and n electrodes that penetrate into the detector bulk
- **Lateral depletion**
  - Maximum drift and depletion distance set by electrode spacing
  - Thicker detectors possible
  - Reduced charge sharing
  - Reduced collection time and depletion voltage ⟵ **Rad hard**
- **Technologically complex**

planar



3D



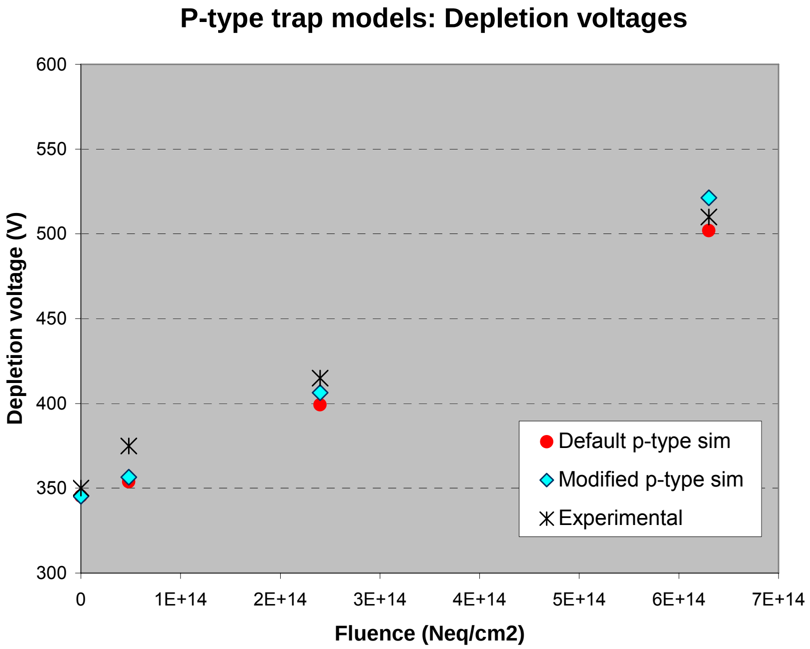
Simulation study of 3D sensors

- University of Glasgow
- Modified Perugia 3-level trap model
  - Trap parameters modified to match experimental trapping times
- Model accuracy assessed by comparing with results from planar devices

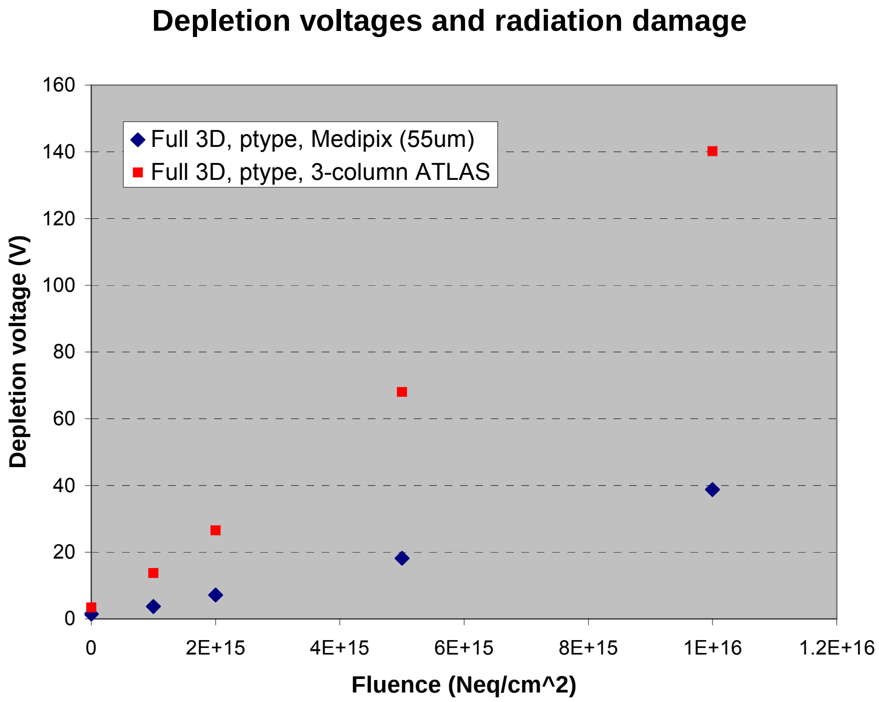
P-type FZ trap model

Type	Energy (eV)	Trap	σ_e (cm^2)	σ_h (cm^2)	η (cm^{-1})
Acceptor	Ec-0.42	VV	9.5×10^{-15}	9.5×10^{-14}	1.613
Acceptor	Ec-0.46	VVV	5.0×10^{-15}	5.0×10^{-14}	0.9
Donor	Ev+0.36	CiOi	3.23×10^{-13}	3.23×10^{-14}	0.9

[D. Pennicard et al., 10th RD50 Workshop, June 2007]



(Data from M. Lozano et al., IEEE Trans. Nucl. Sci., vol. 52 (2005))



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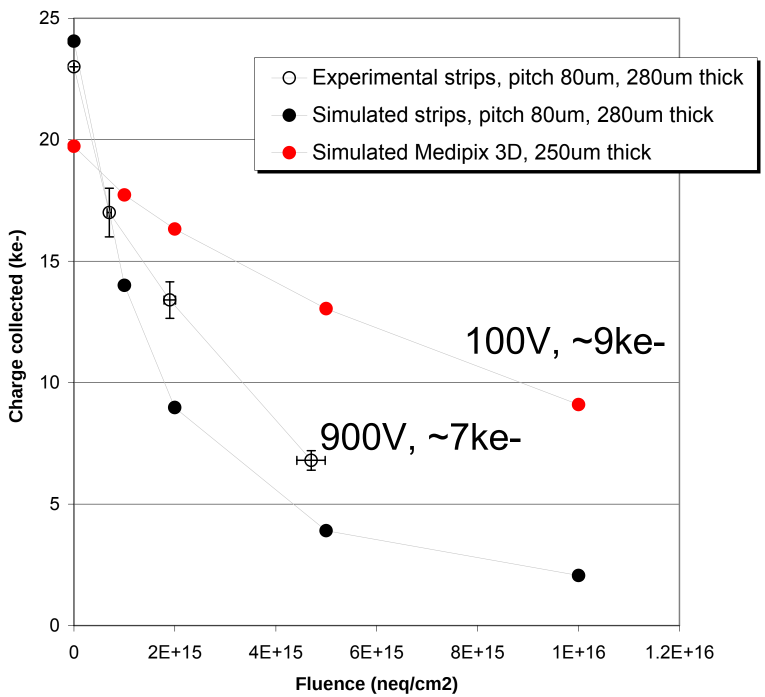
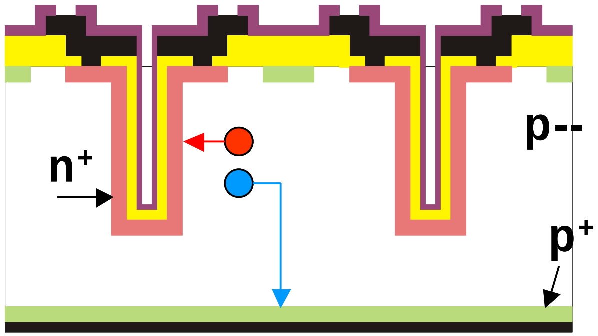
Simulated CCE in p-type detectors



(Data from PP Allport et al., IEEE Trans. Nucl. Sci. 52 (2005))

- Simulation floods pixel with uniform charge to get "average" CCE
- Charge collected by the simulated 3D device in 10ns
- **Good charge collection** predicted, even for high (s-LHC) irradiation levels

Single type column detectors (ITC-irst)

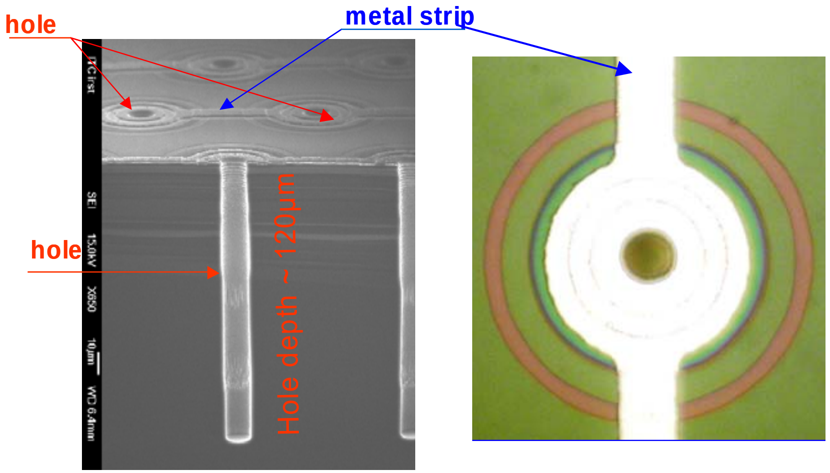


Electrons swept away by transversal field and drift to nearest column (~40 μm)

Holes drift in central region and diffuse/drift to p+ contact (~300-500 μm)

- **2-stage depletion**
  1. Lateral depletion
  2. Planar-like depletion towards the back contact

(Confirmed with C-V and CCE measurements, see Scaringella et al., NIMA 579 (2007))

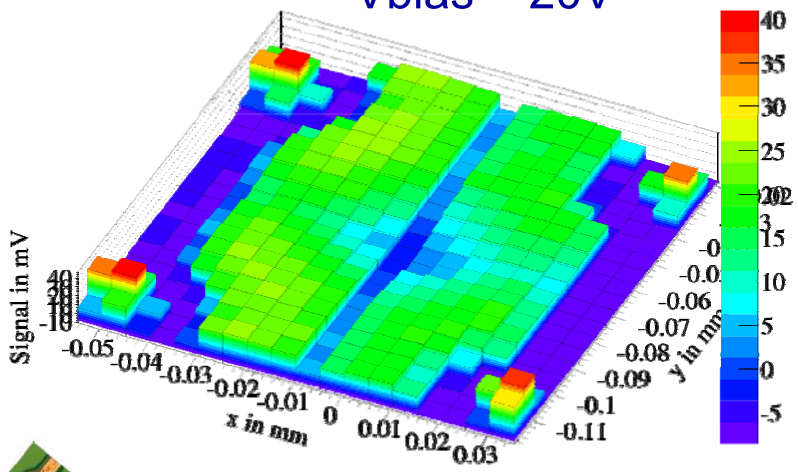


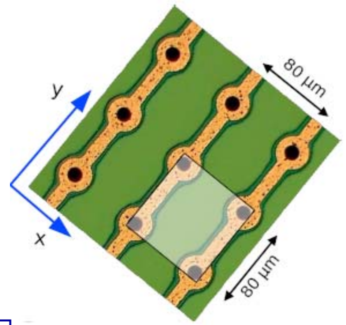
- **Fabricated** by ITC-irst/CNM
  - Strip, pad detectors
  - 300 or 500 μm p-type substrate
  - Hole depth 130-150 μm, diameter ~10 μm
  - Columns not filled, just passivated
- **Variation** of the STC-3D developed at BNL
  - Ohmic contact is implemented on the same side of the column etching: true one-sided detector (backside not processed)

Position resolved CCE in STC-3D strip detectors

- **Laser tests with ATLAS SCT readout**
- University of Freiburg
- 40MHz ATLAS SCT EndCap electronics
  - Binary readout
  - Shaping time 20ns
- Laser spot 4-5μm, penetration 100μm
- STC-3D AC coupled strip detector

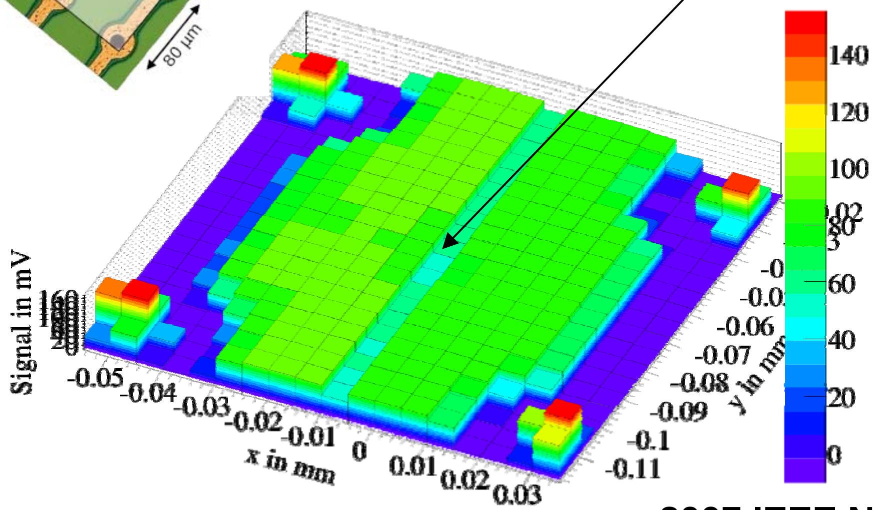
Vbias = 20V





~25% signal drop

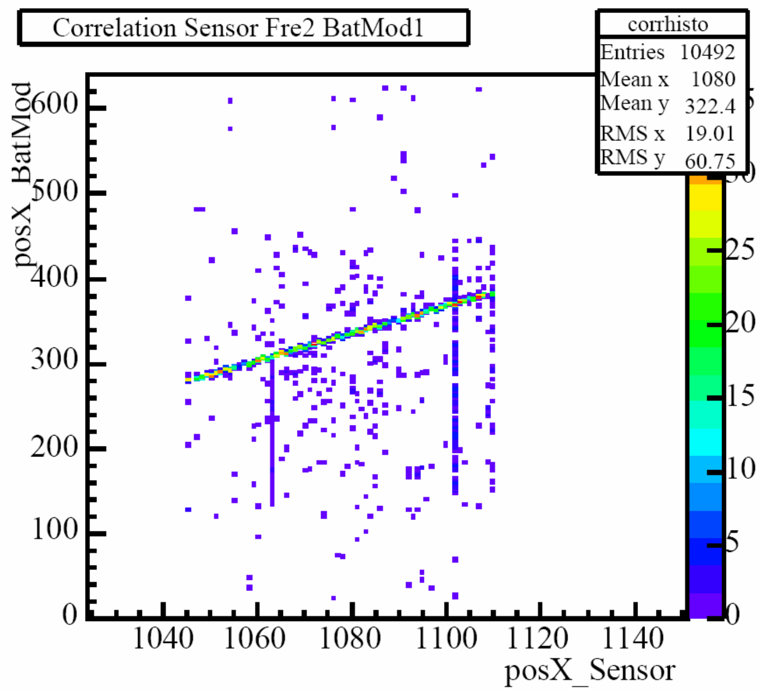
Vbias = 80V



- **Lateral depletion ~20V**
- **Non-homogenous** response: low field region in interstrip area
- Results after irradiation and with β source in S. Kuehn's talk (N44-2)

October'07 beam test

- Organized by the ATLAS 3D R&D Group
- Carried out by Freiburg/Glasgow
- 180 GeV pions in CERN H8 beam line
- 2 Single-type column 3D strip detectors (p-spray, mod p-spray)
- Beetle front-end chip and TELL1 DAQ LHCb interfacce board
- Trigger and timing information from Bonn ATLAS telescope

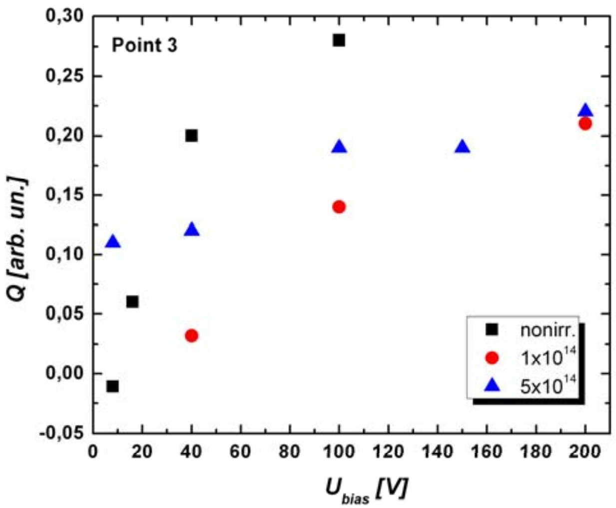


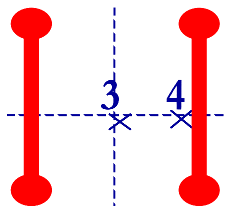
CCE in STC-3D irradiated strip detectors

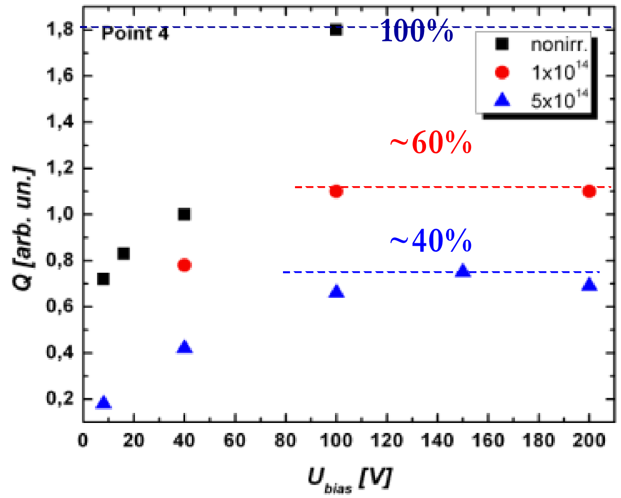
- **Position sensitive TCT measurements** in Ljubljana (see poster N24-150)
  - IR laser, FWHM ~7µm
  - STC-3D DC coupled detector, 64 x 10 columns
  - 80µm pitch, 80µm between holes

CCE after **neutron irradiation**

25ns transient current integration





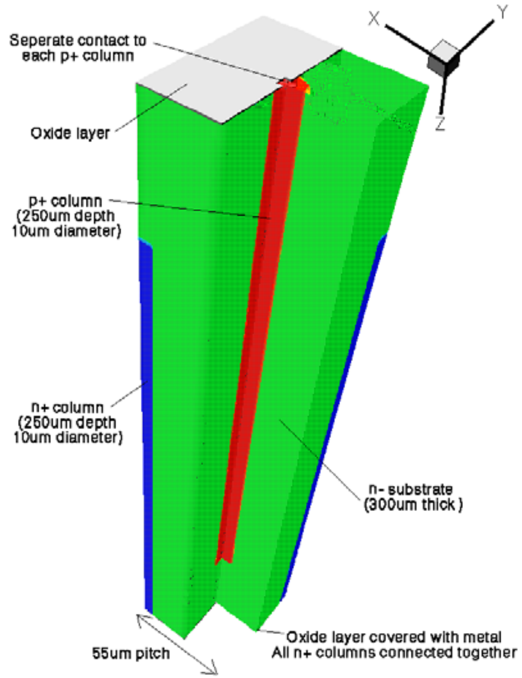


[G.Kramberger et al., 10th RD50 Workshop, June 2007]

- As expected, STC-3D are **not** radiation hard:
  - E-field determined by doping (higher doping large E).
  - When the volume between columns is fully depleted, the electric field cannot be increased further
  - Essential to counteract trapping
- Very non-homogenous response due to variations in the electric field (saddle in mid-region)

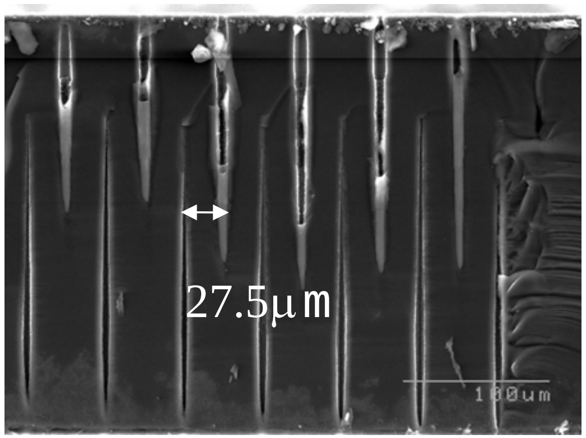
Double sided 3D detectors

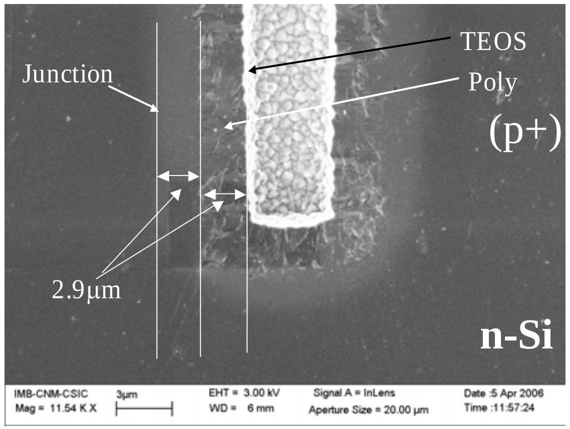
- Proposed by IMB-CNM (Spain)
- Electrodes etched from opposite sides of the wafer
- Double side processing
- No sacrificial wafer is required



✓ IMB-CNM currently processing a first run of n-type wafers with Medipix2, Pilatus2 and strip detectors

✓ Double-sided technology also being investigated by ITC-irst → see talk N18-3



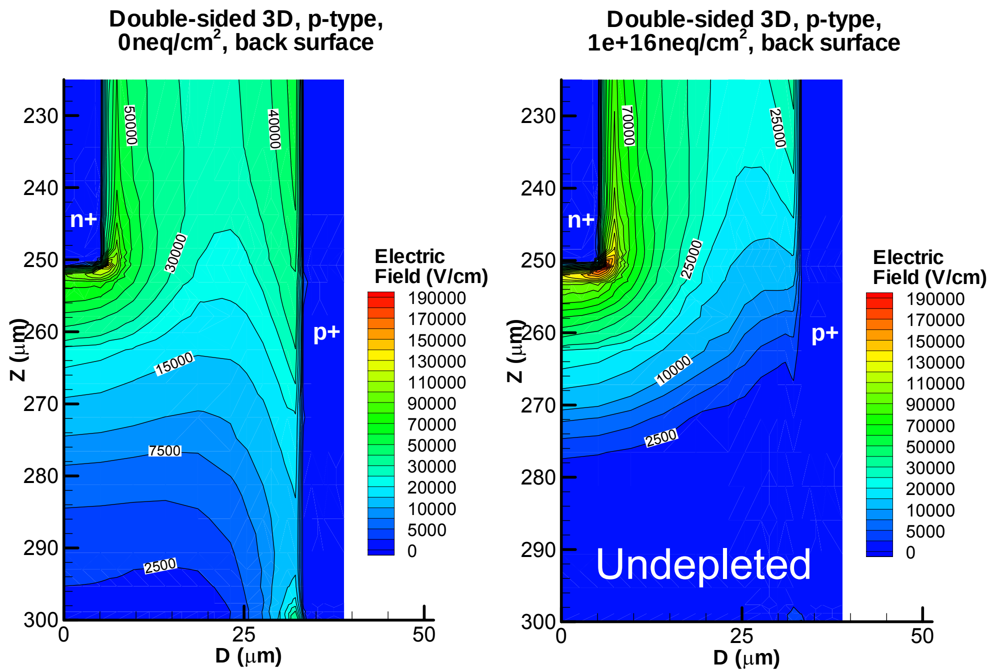


Double sided 3D detectors

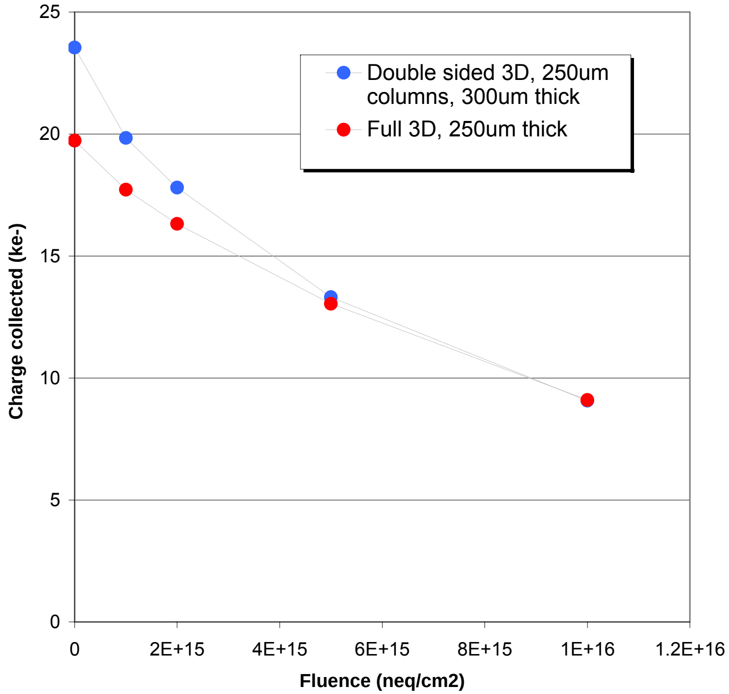
- Short charge collection times because both carrier types mainly drift horizontally
- High drift velocity as the electric field can be increased even after full depletion.
- Disadvantages: low field region below columns

No damage

10^{16} neq/cm²



100V bias



- 250µm columns both devices
- DS-3D has slightly higher collection at low damage (*greater device thickness!*)
- But at high fluence, results match standard 3D

Performance comparable to standard 3D

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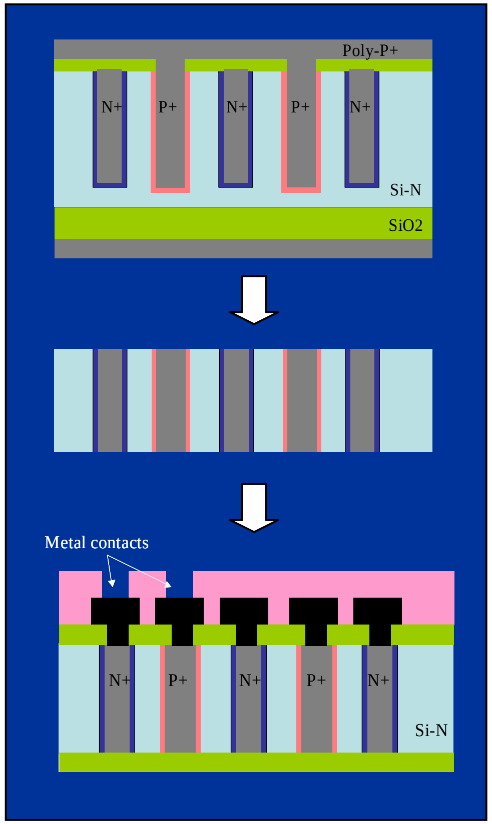
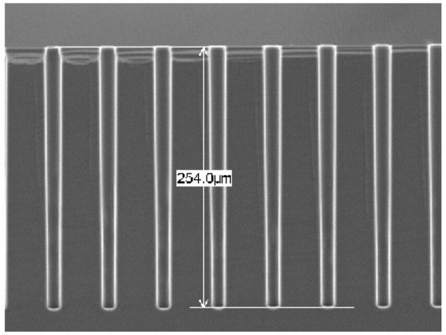
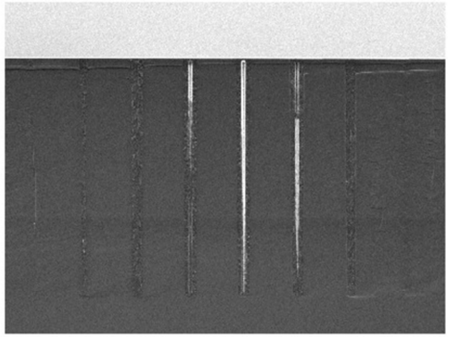
2007 IEEE NSS

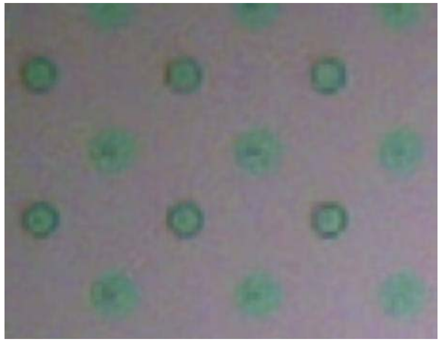
Full 3D detectors

- Project Glasgow/Diamond Light Source Synchrotron to develop 3D detectors for X-ray diffraction experiments
  - Fabrication by IceMOS Technology Ltd. (Northern Ireland)
- **Full 3D** detectors on **n-type Si**
- Prototype 3D detectors will be integrated and tested with existing r/o electronics:
  - **Medipix2**, **Pilatus2**, **Beetle** readout chips
  - Readout in p-electrodes → hole collection
  - All contacts on the top → need to route metal lines connecting all n-electrodes (biasing)
- Fabrication: start with a thick (~500 μm) wafer, create electrodes from the top (~250 μm), then grind/polish to expose electrodes.









Conclusions

- Ongoing work of RD50 in 3D detectors
    - Promising candidates as vertex sensors for extreme radiation environments
    - Low depletion voltage, good charge collection even for s-LHC irradiation levels
- STC-3D detectors fabricated and tested succesfully
    - \+ Simple fabrication process, useful to tune in the technology and gain experience with testing methods
    - \- Long charge collection times, can be used in experiments that do not need a fast response
- Double sided and full 3D available soon

- More information: http://rd50.web.cern.ch/RD50/