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Middle/Outer Radii: R&D plan in Europe

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OUTLINE

- Presentation of the RD50 collaboration
- Achievement and plans targeted to the middle/outer radius (micro-strip devices)
- A few words on activities targeted to the inner radius

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The RD50 CERN Collaboration

Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

- **Collaboration formed in November 2001 - http://www.cern.ch/rd50**
- **Experiment approved as RD50 by CERN in June 2002**
- **Main objective:**

Development of ultra-radiation hard semiconductor detectors for the luminosity upgrade of the LHC to 10^{35} $cm^{-2}s^{-1}$ ("Super-LHC").

- **Presently 280 Members from 55 Institutes**

Belgium (Louvain), Canada (Montreal), Czech Republic (Prague (2x)), Finland (Helsinki (2x), Oulu), Germany (Berlin, Dortmund, Erfurt, Halle, Hamburg, Karlsruhe), Greece (Athens), Israel (Tel Aviv), Italy (Bari, Bologna, Florence, Milano, Modena, Padova, Perugia, Pisa, Trento, Trieste, Turin), Lithuania (Vilnius), Norway (Oslo (2x)), Poland (Warsaw), Romania (Bucharest (2x)), Russia (Moscow (2x), St.Petersburg), Slovenia (Ljubljana), Spain (Barcelona, Valencia), Sweden (Lund) Switzerland (CERN, PSI), Ukraine (Kiev), United Kingdom (Exeter, Glasgow, Lancaster, Liverpool, London, Sheffield, University of Surrey), USA (Fermilab, Purdue University, Rutgers University, Syracuse University, BNL, University of New Mexico)

Scientific strategies

- **Material Engineering**
  - Defect and Material Characterisation
  - Defect engineering of silicon
  - New detector materials (SiC, ..)

- **Device Engineering**
  - Improvement of present planar detector structures (3D detectors, thin detectors, cost effective detectors,…)
  - Tests of LHC-like detector systems produced with radiation-hard technology
  - Variation on the operational conditions

RADIATION FACILITIES within RD50

- **24 GeV/c protons, PS-CERN**
  up to 10^{16} cm^{-2}
- **TRIGA reactor neutrons, Ljubljana**
  up to 8x10^{15} cm^{-2}
- **24 MeV protons, Karlsruhe**
  up to .. x10^{15} cm^{-2}
- **10-50 MeV protons, Jyvaskyla +Helsinki**
  up to 3x10^{14} cm^{-2}
- **^{60}Co dose, BNL, USA**
  up to 1.5GRad
- **58 MeV Li ions, Legnaro/ Padova**
- **900 MeV electrons, Trieste**
- **15MeV electrons, Oslo**

Rad-Hard Materials presently under investigation

Property	Si	4H SiC	Diamond	
Material Quality	Cz, FZ, DOFZ epi	Epi and bulk	Polycrystalline	single crystal
E_g [eV]	1.12	3.3	5.5	5.5
$E_{breakdown}$ [V/cm]	$3 \cdot 10^5$	$2.2 \cdot 10^6$	10^7	10^7
μ_e [cm^2/Vs]	1450	800	1800	>1800
μ_h [cm^2/Vs]	450	115	1200	>1200
v_{sat} [cm/s]	$0.8 \cdot 10^7$	$2 \cdot 10^7$	$2.2 \cdot 10^7$	$2.2 \cdot 10^7$
Z	14	14/6	6	6
ε_r	11.9	9.7	5.7	5.7
e-h energy [eV]	3.6	7.6	13	13
Density [g/cm^3]	2.33	3.22	3.515	3.515
e-h/μm for mips	89	55	36	36
Max initial ccd [μm]	>500	40	280	500
Max wafer ϕ tested	6”	2”	6”	6mm
Producer	Several	Cree-Alenia, IKZ	Element-Six	Element-Six
Max fluence[cm^{-2}]	10^{16} 24 GeV p,n	10^{16} 24GeV p	$2\mathrm{x}10^{15}$ n, π, p	-
CERN R&Ds	RD50, RD39	RD50	RD42	RD42

← Cryogenic operation of Silicon detectors

Also on investigation GaN (RD50)

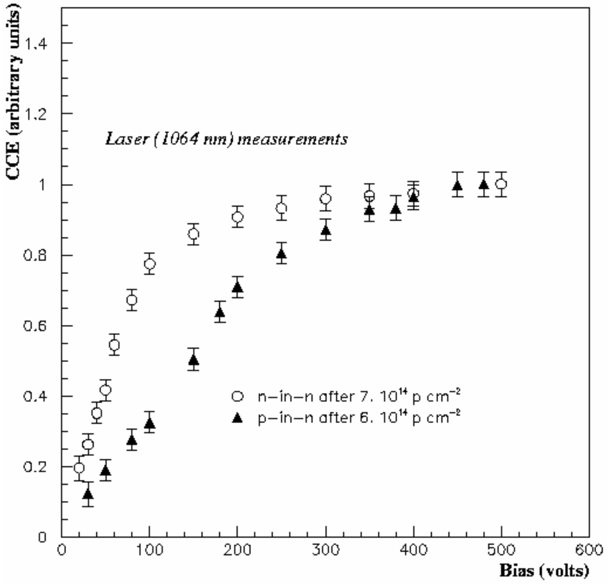
Nonetheless, Si is realistically the material that will be used in the upgrade timescale.

Accepted facts about Si segmented devices for increased radiation hardness:

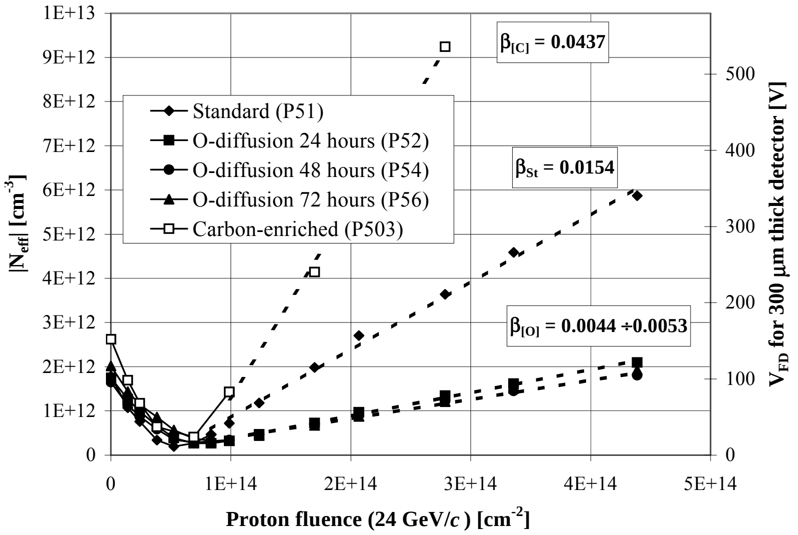
N-side read-out on n-type substrates gives the main advantage (ATLAS and CMS pixels, LHCb-VELO microstrips).

Some help from O enriched Si in term of degradation of the full depletion voltage (V_{FD}) with fluence.

Comparison n to p-side read out



Benefits of O enriched on V_{FD} changes



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Alternative Si crystals under investigation

Other option for Si materials that need to be compared with the state of the art n-in-n diode structure are:

P-type float-zone (FZ) silicon to produce n-side read-out detectors (n-in-p). Needs single sided processing only (almost 50% cheaper than n-in-n, junction side always on read-out side).

High resistivity Magnetic Czochralski (MCz) silicon (P and n-type). P-type as above, non-inverting n-type crystal thought to be rad-hard to high doses (with p-in-n diode structure)

Epitaxial silicon (P and n-type) P-type as above, non-inverting n-type crystal up to significantly high doses, thin sensitive layer, suitable for thin devices.

Also under investigation:

Thickness optimisation

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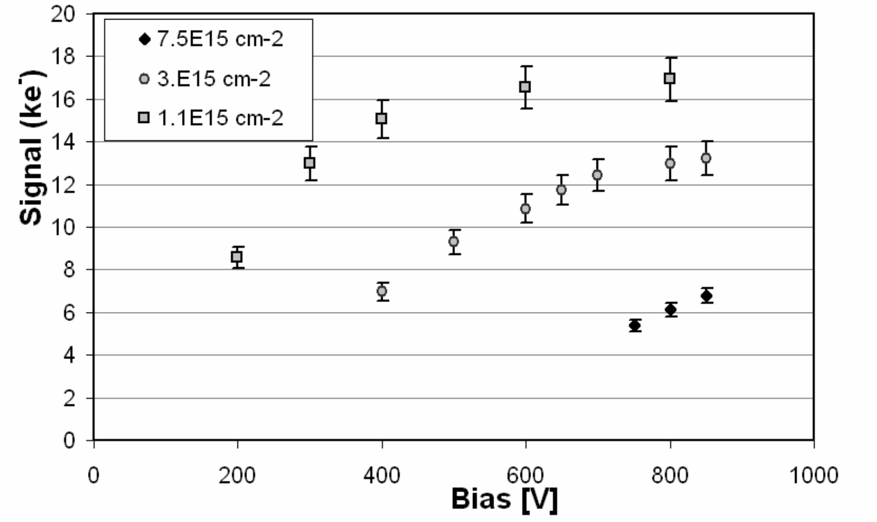
Recent facts about Si segmented devices for increased radiation hardness: n strip read-out on p-type silicon

After 7.5 10^{15} p cm^{-2} 7000e are collected at 900V.

The charge collected at these doses is determined predominantly by trapping.

The noise is INDEPENDENT on the applied voltage and dose.

Those effects are both consequences of the very low free carrier concentration in highly irradiated silicon



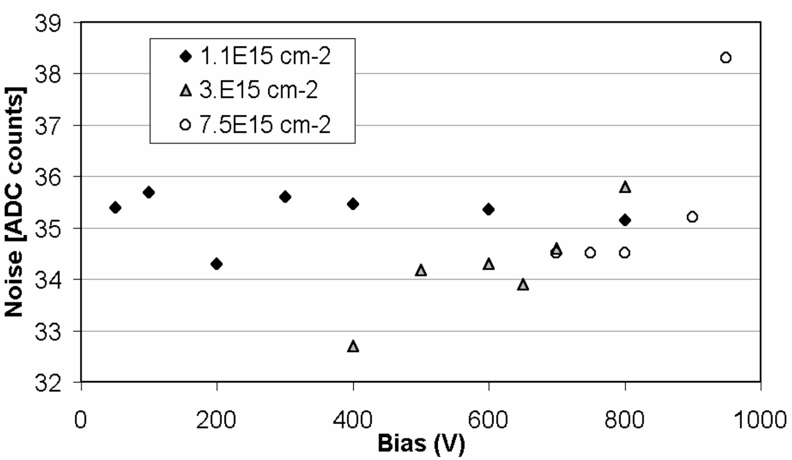


Fig. 1 Noise as a function of the applied voltage for the three different irradiation doses. The pre-irradiation value is about 35 ADC counts, similar to the value found after irradiation.

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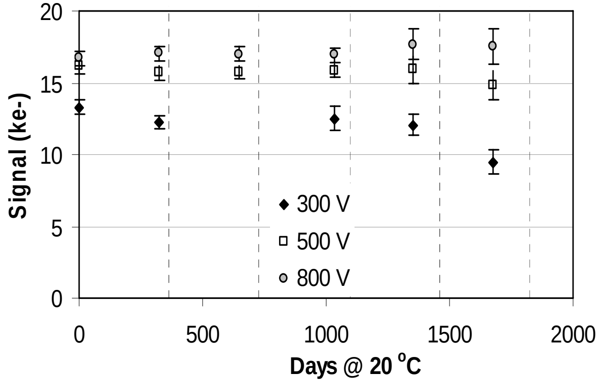
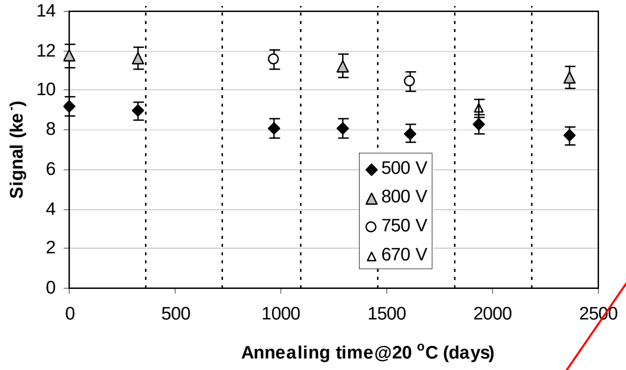
Recent facts about Si segmented devices for increased radiation hardness: n strip read-out on p-type silicon

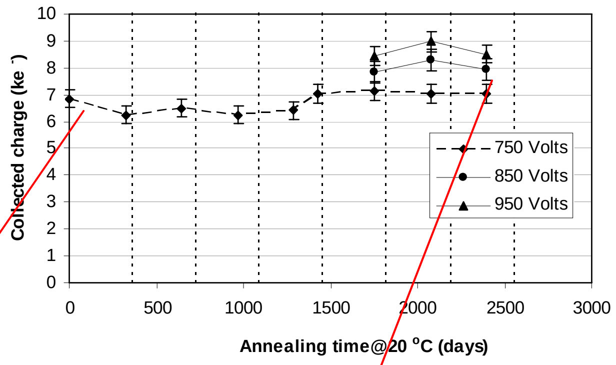
The signal is INDEPENDENT on annealing time up to 7y equivalent at room temperature (while V_{FD} is expected to rise from 2.8kV to 12kV)!



1.1 10^{15} p cm^{-2}

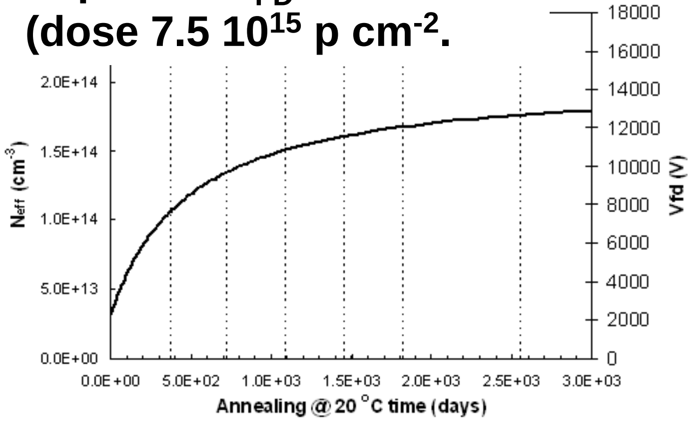


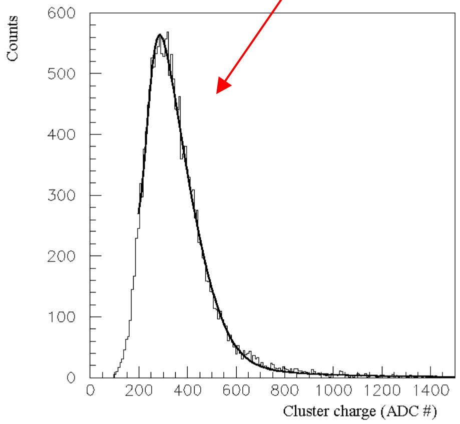
3.5 10^{15} p cm^{-2}

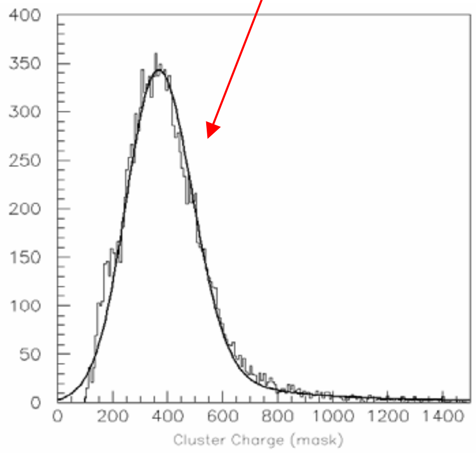


7.5 10^{15} p cm^{-2}

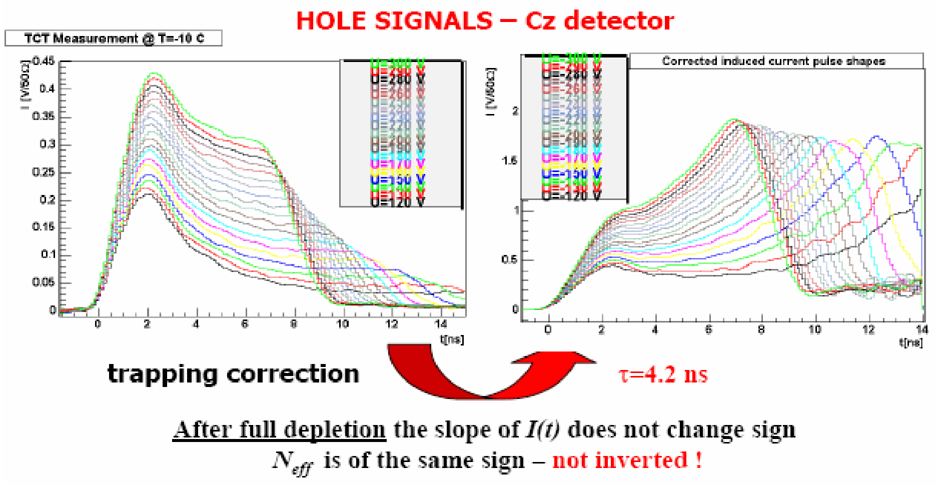
Expected V_{FD} from CV (dose 7.5 10^{15} p cm^{-2}.





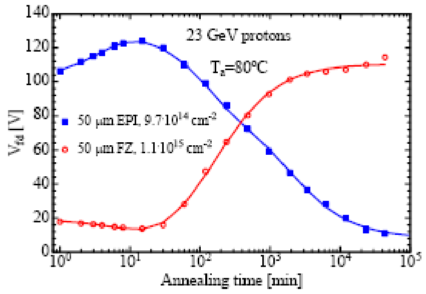


MCz and Epi materials (diode measurements)



trapping correction

After full depletion the slope of $I(t)$ does not change sign
N_{eff} is of the same sign – not inverted !

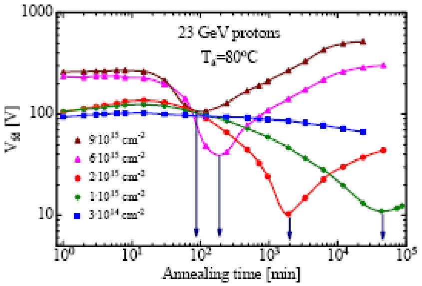


Comparison EPI- with FZ-device:

V_{fd} development:

short term: EPI increasing, FZ decreasing
long term: EPI decreasing, FZ increasing

→ EPI not inverted, FZ inverted



Typical annealing behavior of EPI-devices:

Inversion during annealing (↓)

Annealing time at which inversion appears decreases with increasing fluence

These n-type materials do not invert to p-type after high doses.

Consequences for signal at high doses to be investigated with segmented detectors.

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RD50 future processing plans

6” mask set

Prototyping demonstrator detectors relevant to all radii (pixels ⇒ 9cm strips) at sLHC.

Commercial manufacturers processing FZ, MCz, Epi n and p-type with the relevant diode structure (n or p read-out) Test structures: pad diodes, MOS, MOSFET, Gated diodes ……

4” mask set

Prototyping miniature detectors up to 3cm strips.

RD50 research institutes processing FZ, MCz, Epi n and p-type with the relevant diode structure (n or p read-out)

Various width/pitch ratio on mini-detectors

Test structures: pad diodes, MOS, MOSFET, Gated diodes ……

RD50 workplan

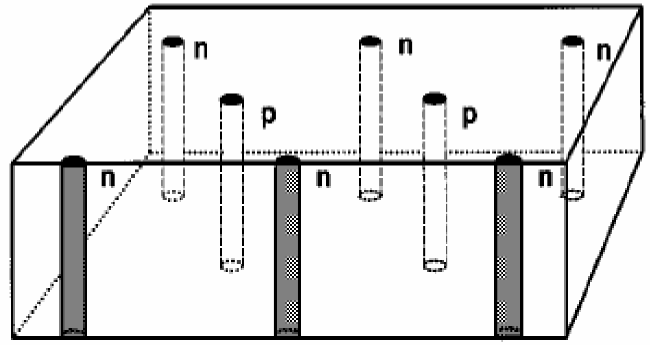
The detectors fabricated with the proposed mask sets in different substrates will be irradiated and used for the following studies:

Charge collection studies with min. ion. particles
Noise studies
Radiation damage *vs* particle type and energy.
Annealing studies.
N-strip isolation study
Different materials (MCz, Epi) comparison
Different thickness (Epi, thinned FZ) comparison
Geometry dependence of Signal/Noise parameters
System studies: cooling, high bias voltage operation
Process and manufacturer dependent effects

Detectors for use at r < 10cm

-3D detector were proposed by S.I. Parker, C.J. Kenney and J. Segal (NIM A 395 (1997) 328).

-Called 3D because, in contrast to silicon planar technology, have three dimensional (3D) electrodes penetrating the silicon substrate.



Picture taken from
C.J. Kenney et al., IEEE TNS 48 (2001) 189.

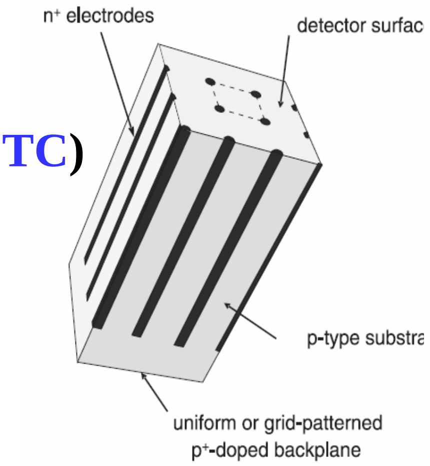
Advantages:

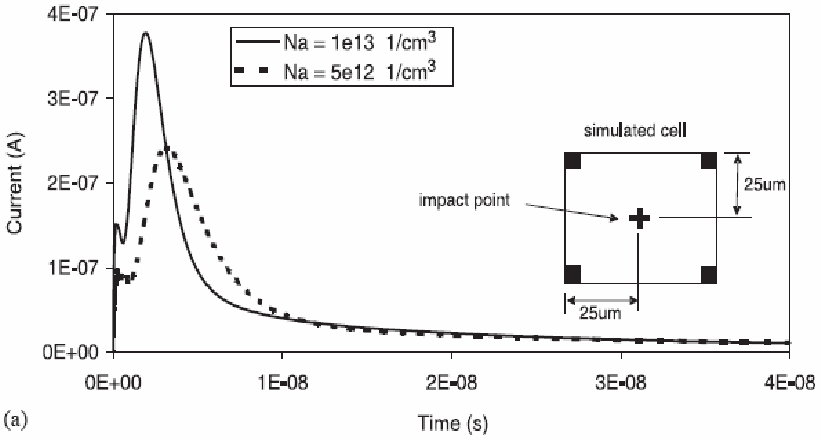
-depletion thickness depends on p^+ and n^+ electrode distance, not on the substrate thickness;

-lower collection length and time than planar technology.

3D-Single Type Column (3D-STC)

(C. Piemonte et al., NIM A541 (2005) 441)





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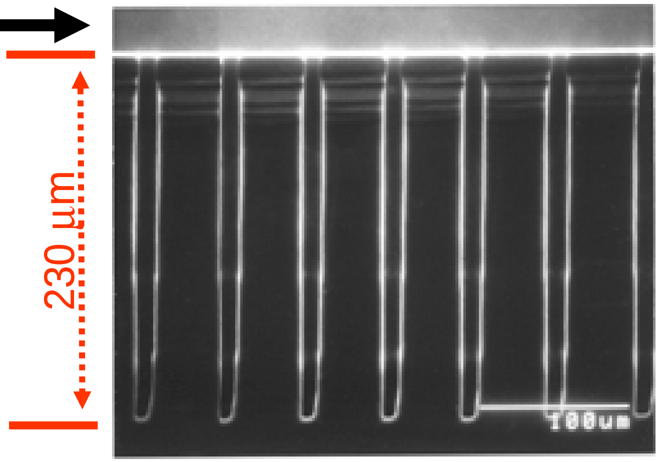
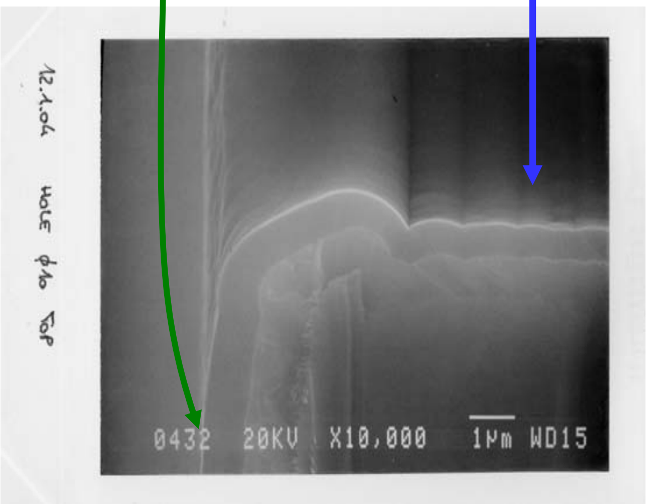
3D-Single Type Column detectors

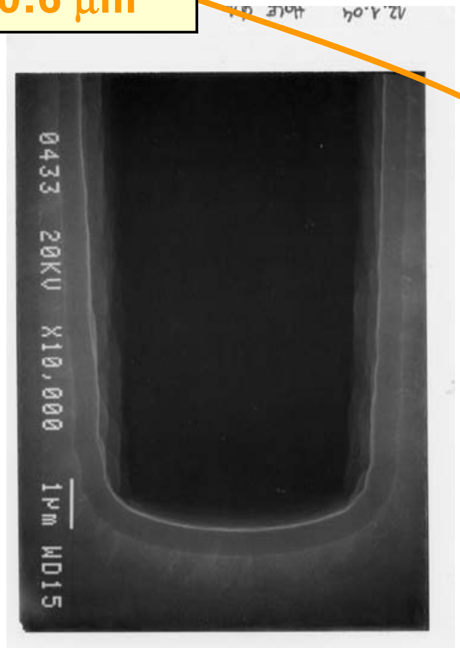
- Detector design and processing: ITC-irst (Trento)
- Deep reaction ion etching: CNM, Barcelona

Hole diameter 10 µm



	Surface	Top	Botton
Poly	**1.05µm**	**0.8µm**	**0.7µm**
TEOS	**0.96µm**	**0.7µm**	**0.6 µm**





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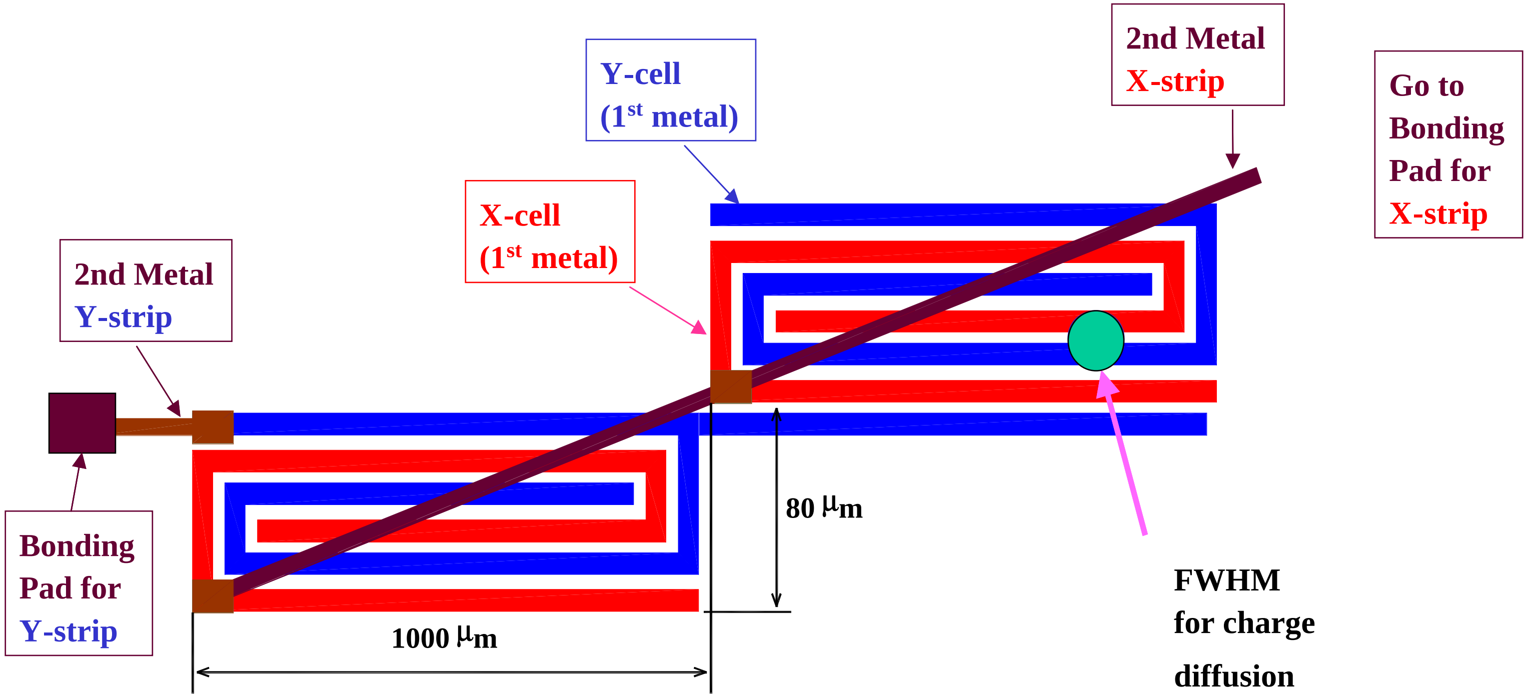
Alternative Options for Higher Radii: Stripixel Detector

Z. Li, D. Lissauer, D. Lynn, P. O'Connor, V. Radeka



Smaller signal would require shorter detector to have adequate signal-to-noise. Assuming a 100 μm x 2 cm strip length, global layout has 10^7 channels. Challenge: signal-to-noise due to additional capacitance of detector and halving of signal due to two readouts.

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OUTLOOK:

Production of 4” and 6” masks for R&D with manufacturers collaborating within RD50 (IRST, CNM …) and commercial European manufacturers (Micron, Sintef, …).

Key issues: optimisation of strip-insulation and pre-irradiation break-down performances. Optimisation of noise performances (input capacitance, robustness against micro-discharges). Possibility to apply very high voltages after irradiation (target 1000 V). Identification of manufacturer-dependent parameters.

2-D detectors are also investigated in RD50 as an alternative to back-to-back silicon for outer radii.

The innermost radii where traditional pixels and/or new technologies are required are also investigated: traditional pixels with all the new flavours of Si wafers and new structures with 3-d detector geometries.

N-side read-out (collecting electrons) proven to be operable up to about 10^{16} N_{eq} cm^{-2} but with signal limited by trapping