85 meeting of the LHCC, 21 November 2007

RD50 STATUS REPORT 2007

Development of radiation hard sensors for very high luminosity colliders

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[2]CERN- PH-DT2 - Geneva - Switzerland

on behalf of RD50

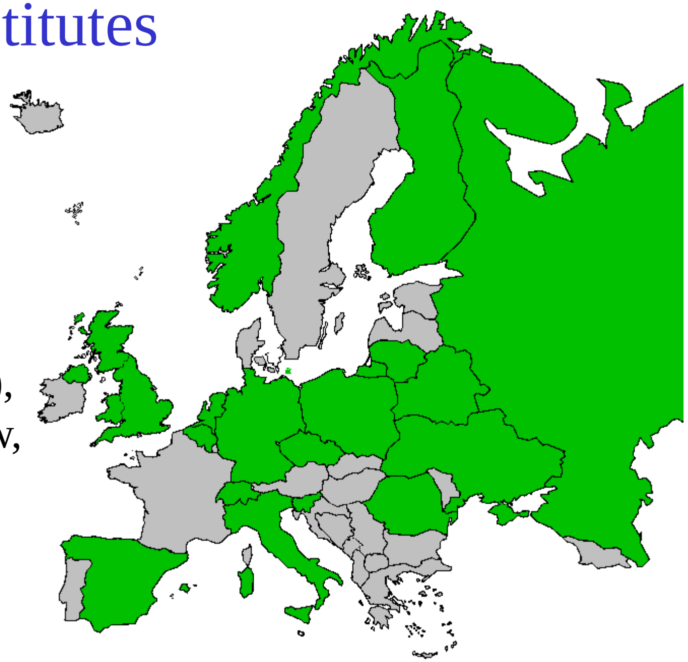
OUTLINE

- **The RD50 collaboration**
- **Results obtained in 2007**
- **Work plan for 2008**
- **Resources request for 2008**

http://www.cern.ch/rd50

RD50 Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

257 Members from 50 Institutes



41 European and Asian institutes

Belarus (Minsk), **Belgium** (Louvain), **Czech Republic** (Prague (3x)), **Finland** (Helsinki) , Laappeenranta), **Germany** (Dortmund, Erfurt, Freiburg, Hamburg, Karlsruhe, Munich), **Italy** (Bari, Bologna, Florence, Padova, Perugia, Pisa, Torino, Trento), **Lithuania** (Vilnius), **Netherlands** (NIKHEF), **Norway** (Oslo (2x)), **Poland** (Warsaw(2x)), **Romania** (Bucharest (2x)), **Russia** (Moscow, St.Petersburg), **Slovenia** (Ljubljana), **Spain** (Barcelona, Valencia), **Switzerland** (CERN, PSI), **Ukraine** (Kiev), **United Kingdom** (Exeter, Glasgow, Lancaster, Liverpool)

8 North-American institutes

Canada (Montreal), **USA** (BNL, Fermilab, New Mexico, Purdue, Rochester, Santa Cruz, Syracuse)

1 Middle East institute

Israel (Tel Aviv)

Detailed member list: http://cern.ch/rd50

RD50 — RD50 approaches to develop radiation harder tracking detectors

- **Material Engineering -- Defect Engineering of Silicon**
  - **Understanding radiation damage**
    - **Macroscopic effects and Microscopic defects**
    - Simulation of defect properties & kinetics
    - Irradiation with different particles & energies
  - **Oxygen rich Silicon**
    - **DOFZ, Cz, MCZ, EPI**
  - Oxygen dimer & hydrogen enriched Silicon
  - Influence of processing technology

Radiation Damage to Sensors:

- **Bulk damage due to NIEL**
  - **Change of effective doping concentration**
  - **Increase of leakage current**
  - **Increase of charge carrier trapping**
- **Surface damage due to IEL**

  (accumulation of positive charge in oxide & interface charges)

- **Material Engineering-New Materials** (work concluded)
  - Silicon Carbide (SiC), Gallium Nitride (GaN)

- **Device Engineering (New Detector Designs)**
  - **p-type silicon detectors (n-in-p)**
  - **thin detectors**
  - **3D detectors**
  - Simulation of highly irradiated detectors
  - Semi 3D detectors and Stripixels
  - Cost effective detectors

Related Works – Not conducted by RD50

- **"Cryogenic Tracking Detectors"** (CERN RD39)
- **"Diamond detectors"** (CERN RD42)
- **Monolithic silicon detectors**
- **Detector electronics**

- Development of test equipment and measurement recommendations

RD50 Silicon Materials under Investigation

standard for particle detectors

used for LHC Pixel detectors

"new" silicon material

New in 2007

Material	Thickness [μm]	Symbol	ρ (Ωcm)	$[O_i]$ (cm^{-3})
Standard FZ (n- and p-type)	50,100,150, 300	FZ	$1–30\times10^3$	$< 5\times10^{16}$
Diffusion oxygenated FZ (n- and p-type)	300	DOFZ	$1–7\times10^3$	$\sim 1–2\times10^{17}$
Magnetic Czochralski Si, Okmetic, Finland (n- and p-type)	100, 300	MCz	$\sim 1\times10^3$	$\sim 5\times10^{17}$
Czochralski Si, Sumitomo, Japan (n-type)	300	Cz	$\sim 1\times10^3$	$\sim 8\text{-}9\times10^{17}$
Epitaxial layers on Cz-substrates, ITME, Poland (n- and p-type)	25, 50, 75, 100,150	EPI	50 – 100	$< 1\times10^{17}$
Diffusion oxyg. Epitaxial layers on CZ	75	EPI–DO	50 – 100	$\sim 7\times10^{17}$

- **DOFZ silicon** - Enriched with oxygen on wafer level, inhomogeneous distribution of oxygen
- **CZ/MCZ silicon** - high Oi (oxygen) and O_{2i} (oxygen dimer) concentration (homogeneous)
  - formation of shallow Thermal Donors possible
- **Epi silicon** - high O_i, O_{2i} content due to out-diffusion from the CZ substrate (inhomogeneous)
  - thin layers: high doping possible (low starting resistivity)
- **Epi-Do silicon** - as EPI, however additional O_i diffused reaching homogeneous O_i content

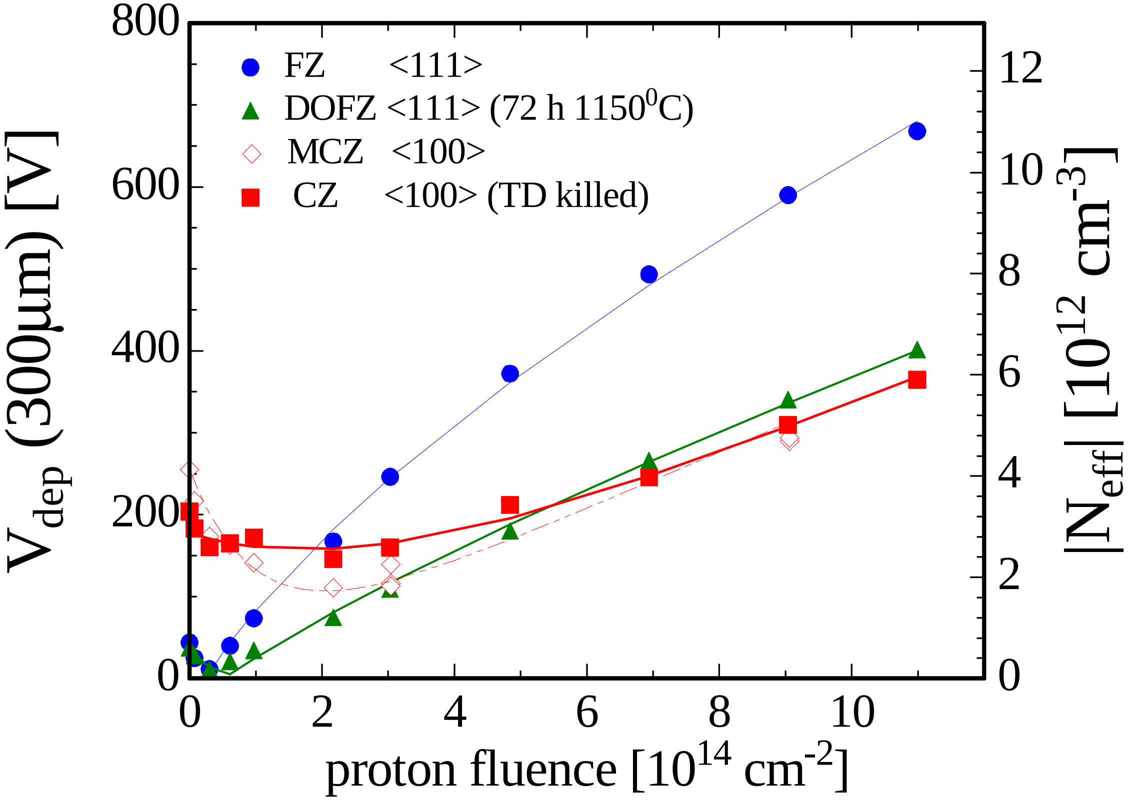
FZ, DOFZ, Cz and MCz Silicon

- **Strong differences in V_{dep}**
  - **Standard FZ silicon**
  - **Oxygenated FZ (DOFZ)**
  - **CZ silicon and MCZ silicon**

- **Strong differences in internal electric field shape**
  (type inversion, double junction,…)

- **Different impact on pad and strip detector operation!**
  - **e.g.: a lower V_{dep} or $|N_{eff}|$ does not necessarily correspond to a higher CCE for strip detectors (see later)!**

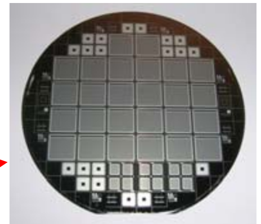
24 GeV/c proton irradiation (n-type silicon)



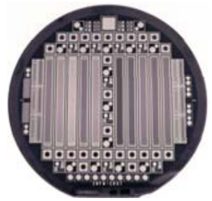
- **Common to all materials (after hadron irradiation):**
  - **reverse current increase**
  - **increase of trapping (electrons and holes) within ~ 20%**

RD50 RD50 Test Sensor Production Runs (2005-2007)

- **Recent production of Silicon Strip, Pixel and Pad detectors (<u>non exclusive list</u>):**

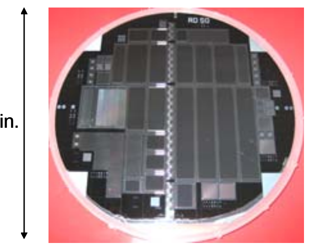


  - **CIS Erfurt, Germany**
    - **2005/2006/2007 (RD50): Several runs with various epi 4" wafers only pad detectors**
  - **CNM Barcelona, Spain**
    - **2006 (RD50): 22 wafers (4"), (20 pad, 26 strip, 12 pixel),(p- and n-type),(MCZ, EPI, FZ)**
    - **2006 (RD50/RADMON): several wafers (4"), (100 pad), (p- and n-type),(MCZ, EPI, FZ)**



  - **HIP, Helsinki, Finland**
    - **2006 (RD50/RADMON): several wafers (4"), only pad devices, (n-type),(MCZ, EPI, FZ)**
    - **2006 (RD50) : pad devices, p-type MCz-Si wafers, 5 p-spray doses, Thermal Donor compensation**
    - **2006 (RD50) : full size strip detectors with 768 channels, n-type MCz-Si wafers**

  - **IRST, Trento, Italy**
    - **2004 (RD50/SMART): 20 wafers 4" (n-type), (MCZ, FZ, EPI), mini-strip, pad 200-500μm**
    - **2004 (RD50/SMART): 23 wafers 4" (p-type), (MCZ, FZ), two p-spray doses 3E12 amd 5E12 cm^{-2}**
    - **2005 (RD50/SMART): 4" p-type EPI**
    - **2006 (RD50/SMART): new SMART mask designed**
  - **Micron Semiconductor L.t.d (UK)**
    - **2006 (RD50): 4", microstrip detectors on 140 and 300μm thick p-type FZ and DOFZ Si.**
    - **2006/2007 (RD50): 93 wafers, <u>6 inch wafers</u>, (p- and n-type), (MCZ and FZ), (strip, pixel, pad)**



  - **Sintef, Oslo, Norway**
    - **2005 (RD50/US CMS Pixel) n-type MCZ and FZ Si Wafers**
  - **Hamamatsu, Japan [ATLAS ID project – not RD50]**
    - **In 2005 Hamamatsu started to work on p-type silicon in collaboration with ATLAS upgrade groups (surely influenced by RD50 results on this material)**

Hundreds of samples (pad/strip/pixel) recently produced on various materials (n- and p-type).

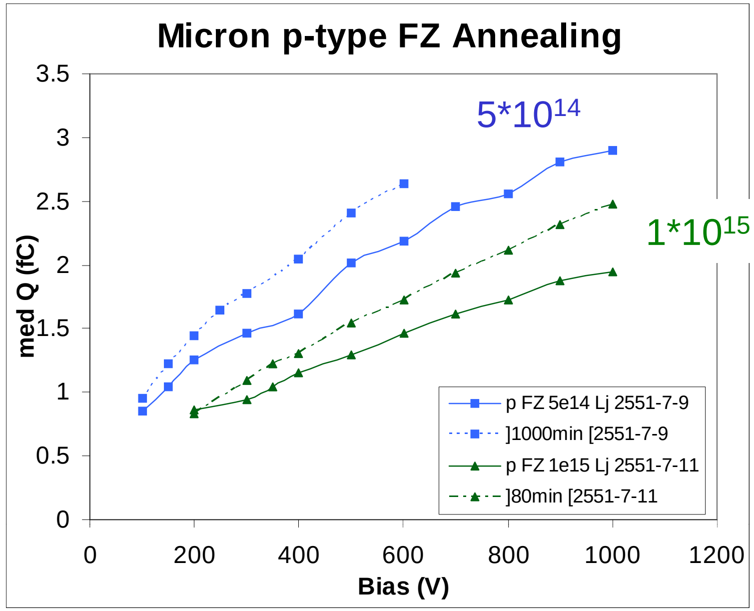
- M.Lozano, 8th RD50 Workshop, Prague, June 2006
- A.Pozza, 2nd Trento Meeting, February 2006
- G.Casse, 2nd Trento Meeting, February 2006
- D. Bortoletto, 6th RD50 Workshop, Helsinki, June 2005
- N.Zorzi, Trento Workshop, February 2005
- H. Sadrozinski, rd50 Workshop, Nov. 2007

RD50 – 6” Sensor Production at Micron

- **Common RD50 - 6” production run at Micron**
  - **The used materials (96 wafers ordered):**
    - **6 inch wafers, <100>, 300 µm thickness, p-spray isolation**
  - **The structures:** strip (various, e.g. 80,50,100 µm pitch, 1,3,6 cm length,..), pixel (various) , diodes, 2D, ….
  - **Irradiation performed in 2nd half of 2007**
    - **Neutrons** (Ljubljana and Louvain)
    - **Protons** (CERN-PS, Karlsruhe)
    - **Pions** (PSI, Villigen)

Type	Si	resistivity [Ωcm]	Structure
p-type	FZ	~ 14000 Ωcm	N – P
p-type	MCZ	~ 1500 Ωcm	N – P
n-type	MCZ	500 Ωcm	P – N
n-type	FZ	3000 Ωcm	P – N
n-type	MCZ	500 Ωcm	N – N
n-type	FZ	3000 Ωcm	N - N

- **First results after neutron irradiation:**
  - **Binary electronics (100ns shaping)**
  - **Median Charge [fC] plotted**

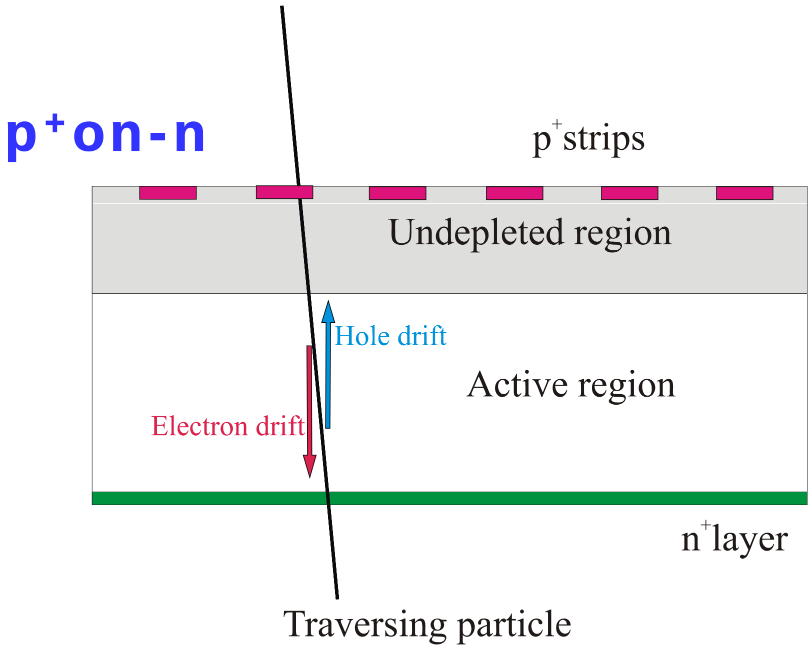


H.Sadrozinski – 12.11.2007 – RD50 Workshop

Device engineering

p-in-n versus n-in-p detectors

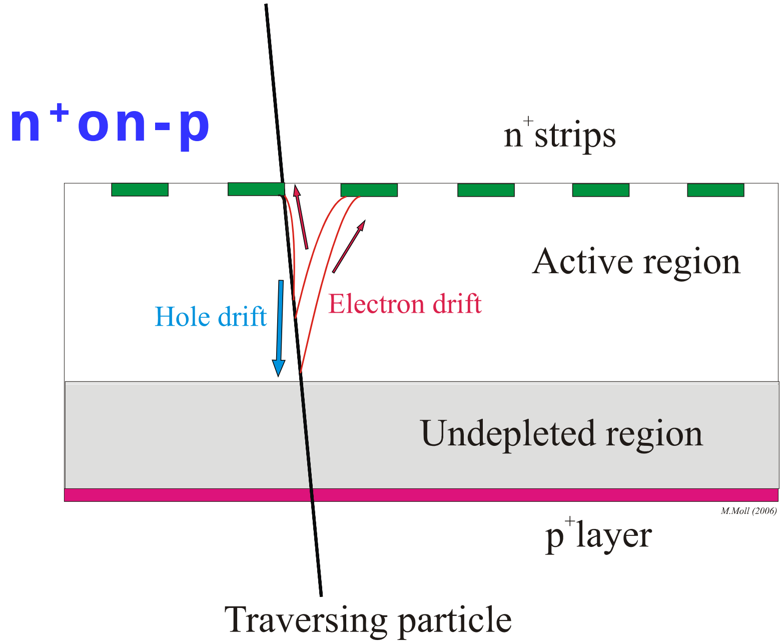
n-type silicon after high fluences:



p-on-n silicon, under-depleted:

- **Charge spread – degraded resolution**
- **Charge loss – reduced CCE**

p-type silicon after high fluences:



n-on-p silicon, under-depleted:

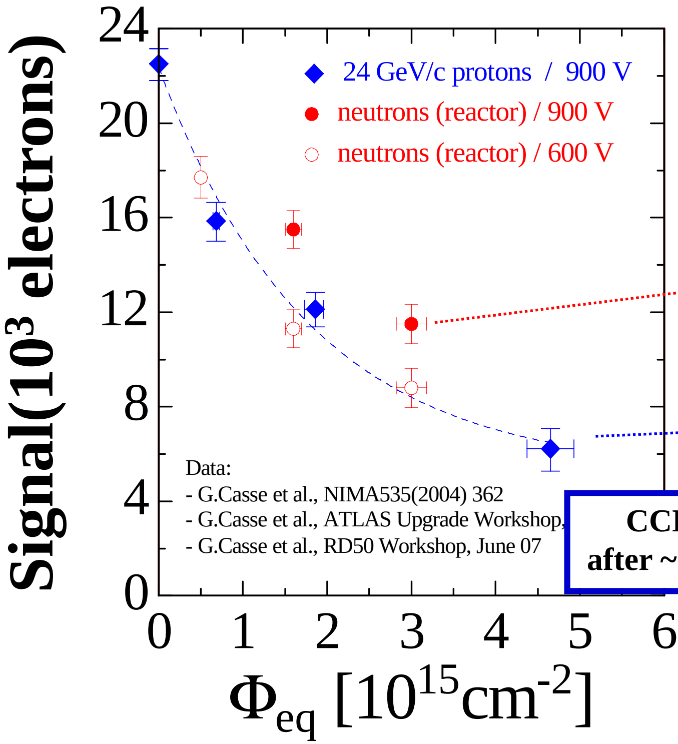
- **Limited loss in CCE**
- **Less degradation with under-depletion**
- **Collect electrons (fast)**

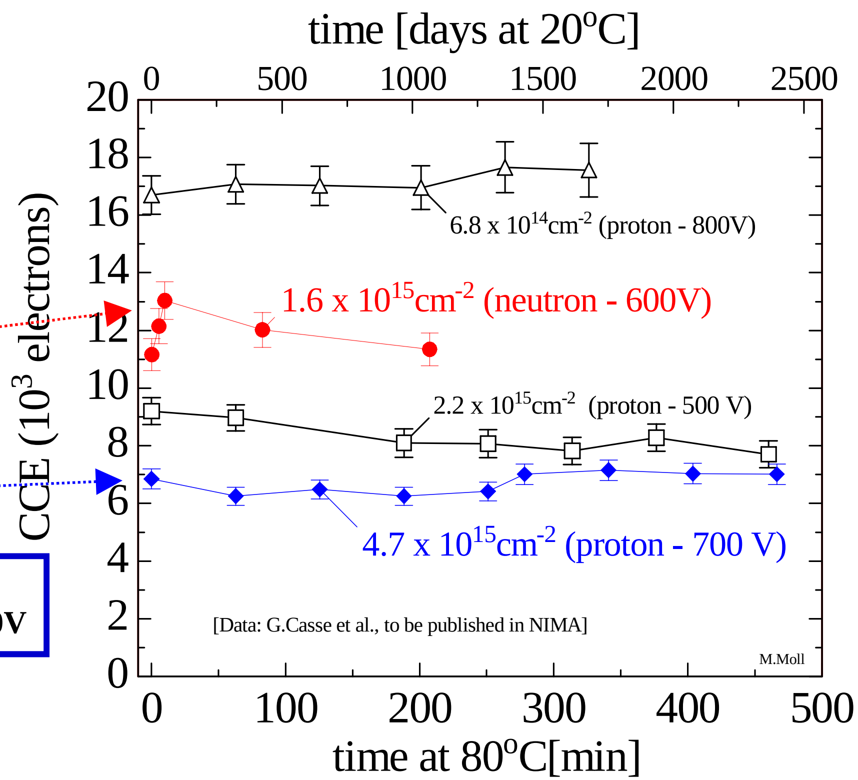
Be careful, this is a very schematic explanation, reality is more complex (e.g. double junction)!

n-in-p microstrip detectors

n-in-p: - no type inversion, high electric field stays on structured side
- collection of electrons

- n-in-p microstrip p-type FZ detectors (Micron, 280 or 300µm thick, 80µm pitch, 18µm implant)
- Detectors read-out with 40MHz (SCT 128A)





CCE ~ 6500 e (30%)
after ~ 5×10^{15}cm^{-2} at 900V

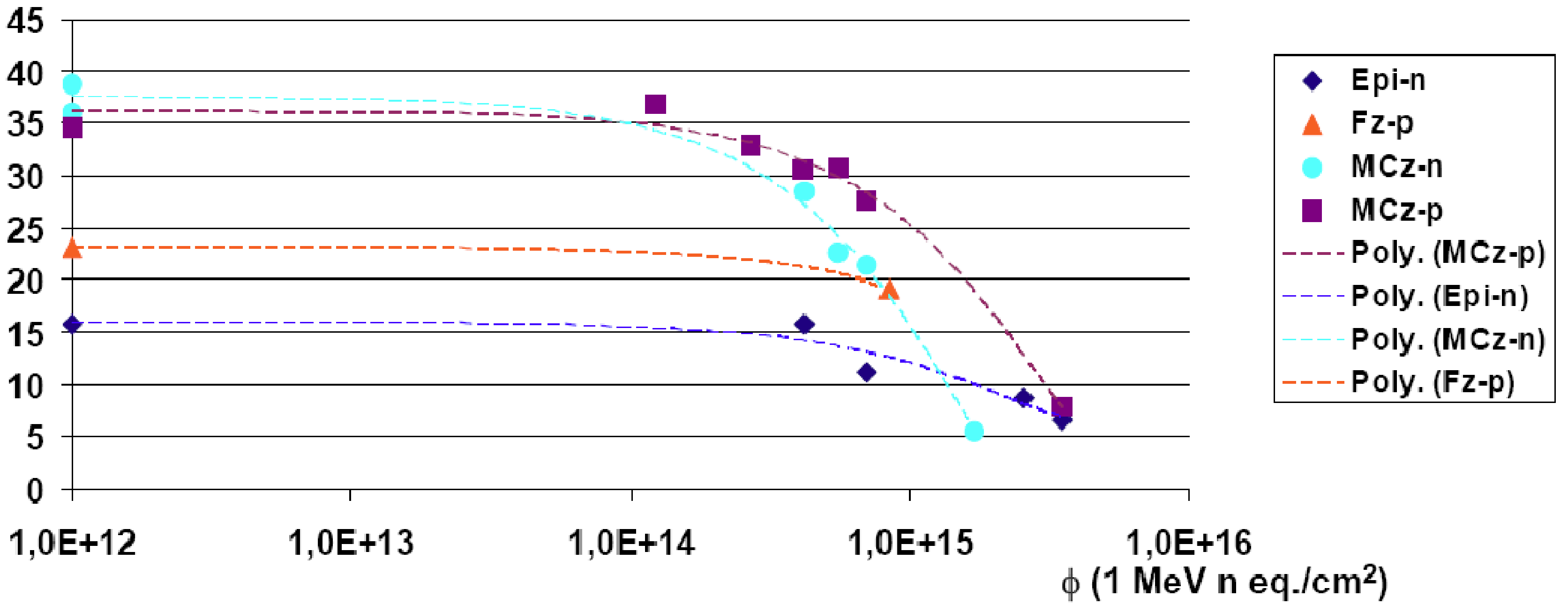
- **n-in-p sensors are now strongly considered for ATLAS upgrade** (previously p-in-n was used)

- **no reverse annealing visible in CCE measurements !**
  for neutron and proton irradiated detectors

Strip detector tests: SMART/RD50

- **Experiment performed in framework of RD50 / SMART / CMS**
- **Irradiation:** 26 MeV protons, reactor neutrons
- **Measurement:** CMS DAQ (APV25, 25ns), -30°C
- **Signal/Noise representation:**

[A.Messineo, 11th RD50 Workshop, November 2007]

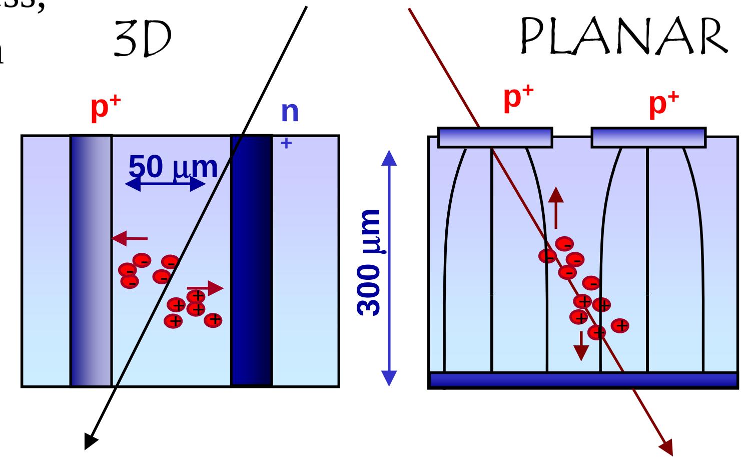


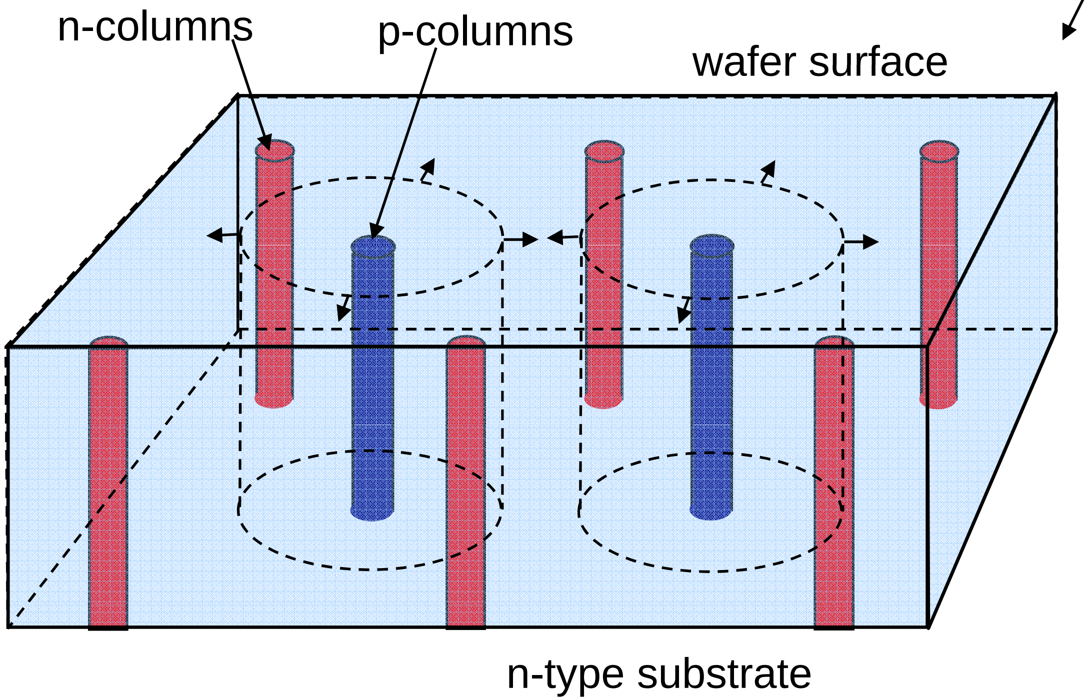
- **Material:** 150 μm Epitaxial silicon (n-type)
  300 μm MCZ silicon (n-type and p-type)
  200 μm FZ silicon (p-type)

3D detector - concept

Introduced by: S.I. Parker et al., NIMA 395 (1997) 328

- **"3D" electrodes:** - narrow columns along detector thickness,
  - diameter: 10µm, distance: 50 - 100µm
- **Lateral depletion:** - lower depletion voltage needed
  - thicker detectors possible
  - fast signal
  - radiation hard

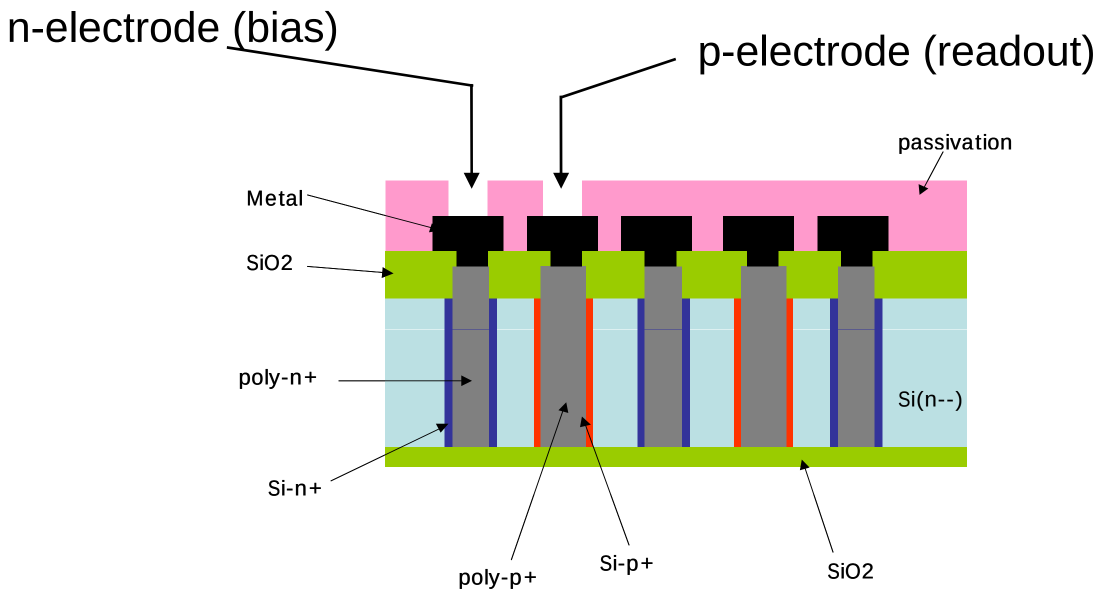




Processing of 3D detectors

- **After processing and testing single type column (STC-) 3D detectors in 2006/2007, the production of full 3D / double column 3D detectors has been started/finished in 2007 in 3 different facilities:**

- **1. Processing at IceMOS Technology Ltd.** (Belfast, Ireland)
  Collaboration between Glasgow University and Diamond Light Source in framework of RD50



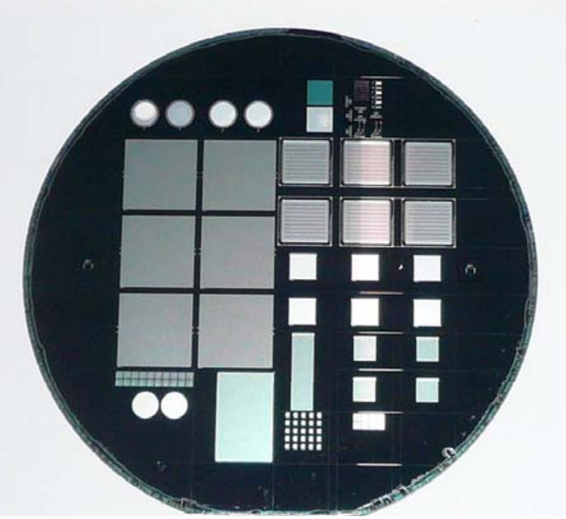
- **Particularity of the process:**
  - Holes (10 μm) are etched from top side of wafer to about 250 μm depth
  - Backside grind/polish takes then away the remaining 50 μm

⇨ **All contacts on the top**
  - need to route metal lines connecting all n-electrodes (biasing)

- **First evaluation run finished in November (4", n-type FZ)**
  - Pad, Strip (80,125μm pitch) and Pixel (Pilatus, Medipix2) devices on the mask

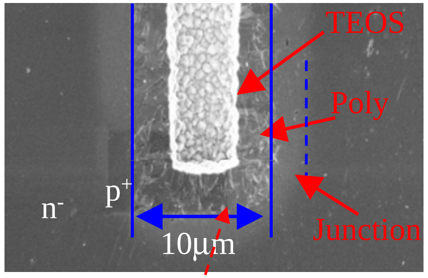
[G.Fleta, RD50 Workshop, June 2007]

Processing of Double-Column 3D detectors



2. CNM Barcelona (2 wafers fabricated in Nov. 2007)

- Double side processing with holes not all the way through
- n-type bulk
- Next step: - dice and test 1 wafer
  - bump bond 1 wafer to Medipix2 chips
- Further production (n and p-type) to follow)

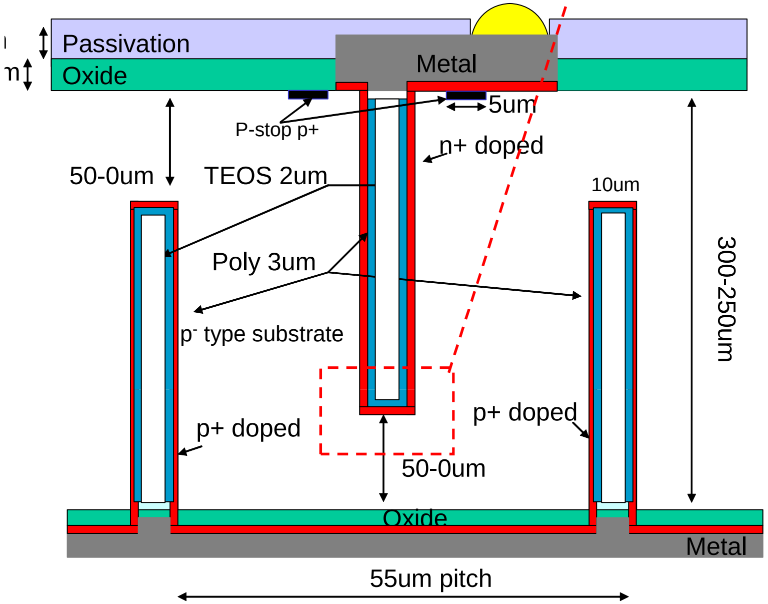


3. FBK (IRST-Trento)

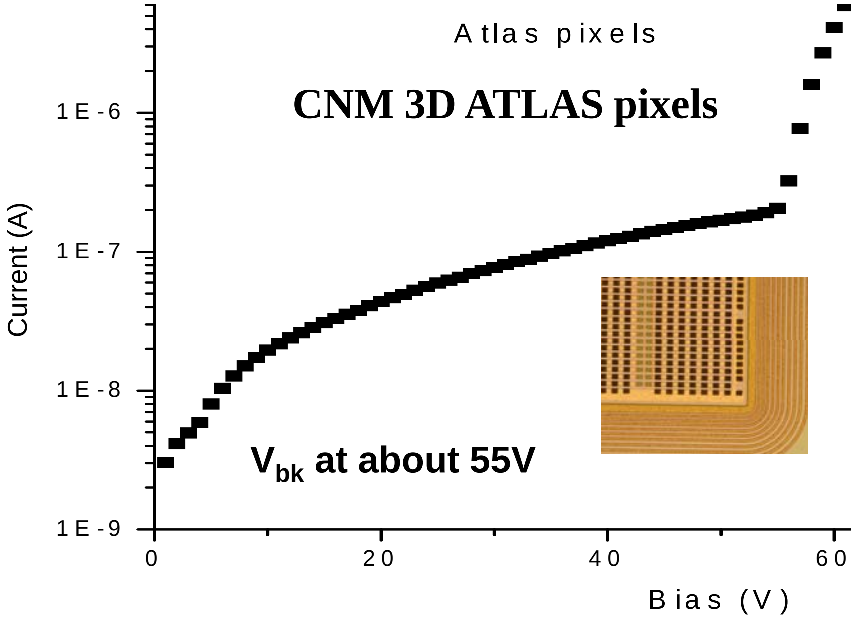
- very similar design to CNM
- 2 batches under production (n-type and p-type)

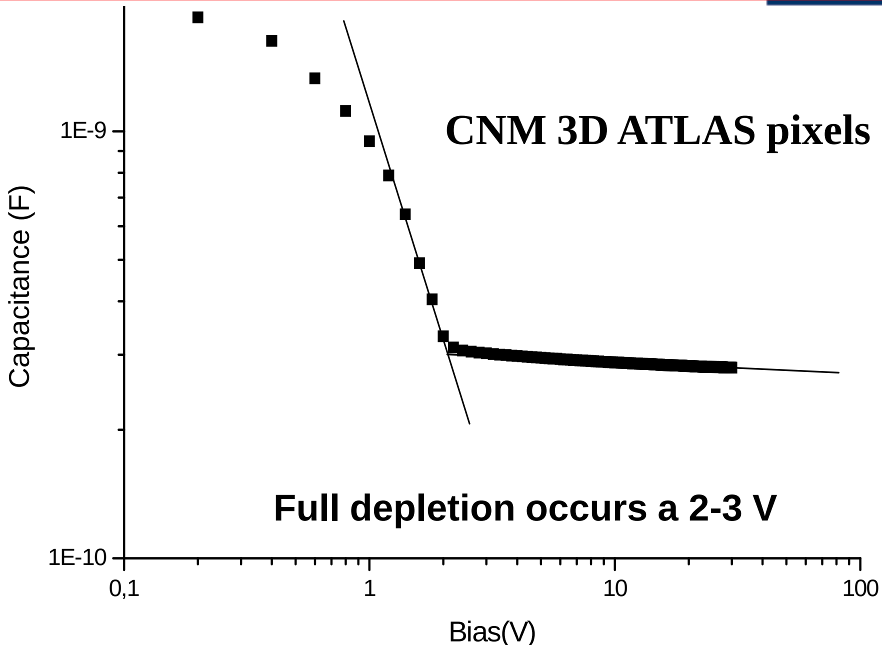
2 batches under fabrication at FBK

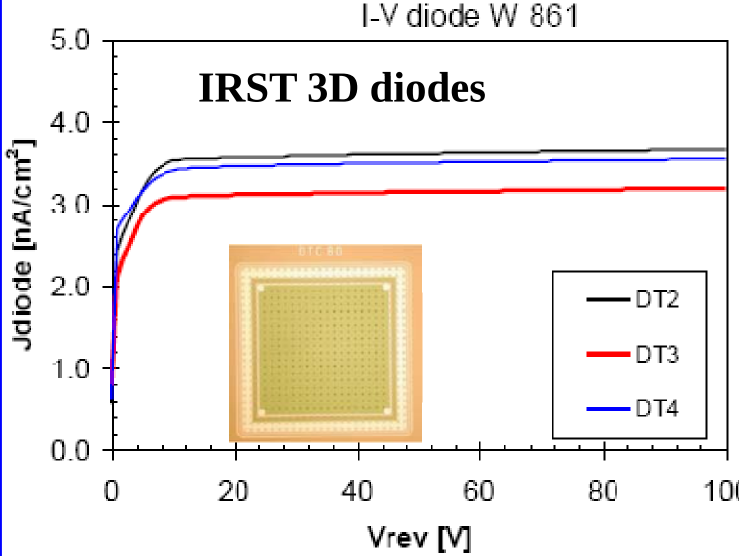
Batch	3D-DDTC 1	3D-DDTC 2
Substrate type	n-type	p-type
Substrate thickness (μm)	300	205 – 255
Column depth (μm)	180 – 200 (not optimized)	180 – 200 (optimized)
Strip design and pitch (μm)	AC/DC coupled, 80 – 100	AC/DC coupled, 80 – 100
Pixel design	ALICE MEDIPIX	ATLAS CMS
Currently at step	145 of 145	100 of 165
Due by	October 2007 Just finished !	End of 2007

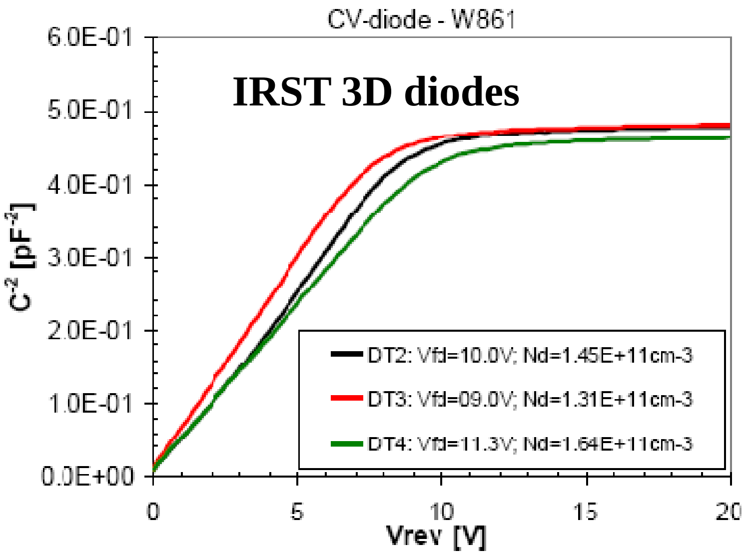


RD50 I-V and C-V of Double-Column 3D detectors





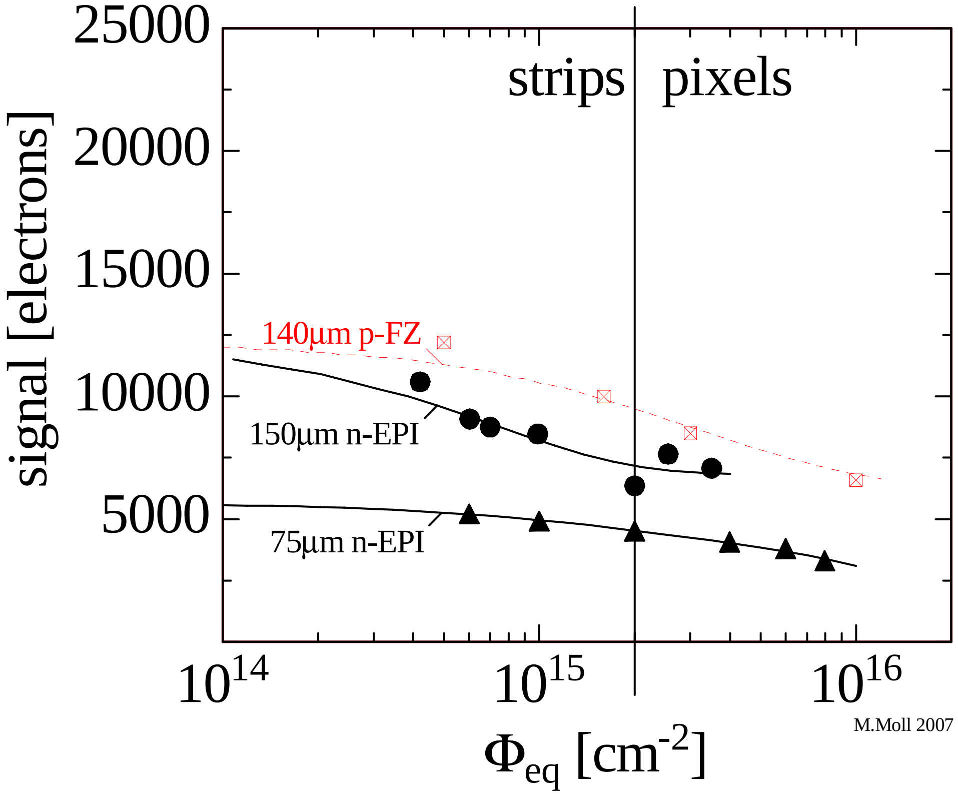




RD50 Silicon materials for Tracking Sensors

- **Signal comparison for various Silicon sensors**

Note: Measured partly under different conditions!
Lines to guide the eye
(no model/no fit)!



[1] 3D, double sided, 250µm columns, 300µm substrate [Pennicard 2007]
[2] p-FZ, 280µm, (-30°C, 25ns), strip [Casse 2007]
[3] p-FZ, 280µm, (-30°C, 25ns), strip [Casse 2004]
[4] p-MCZ, 300µm, (-30°C, µs), pad [Bruzzi 2006]
[5] p-MCZ, 300µm, (<0°C, µs), strip [Bernadini 2007]
[6] n-MCZ, 300µm, (-30°C, 25ns), strip [Messineo 2007]
[7] p-FZ, 140µm, (-30°C, 25ns), strip [Casse 2007]
[8] n-EPI, 150µm, (-30°C, 25ns), strip [Messineo 2007]
[9] n-epi Si, 150µm, (-30°C, 25ns), pad [Kramberger 2006]
[10] n-epi Si, 75µm, (-30°C, 25ns), pad [Kramberger 2006]

See also: [M. Bruzzi et al. NIM A 579 (2007) 754-761]
[H.Sadrozinski, IEEE NSS 2007, RD50 talk]

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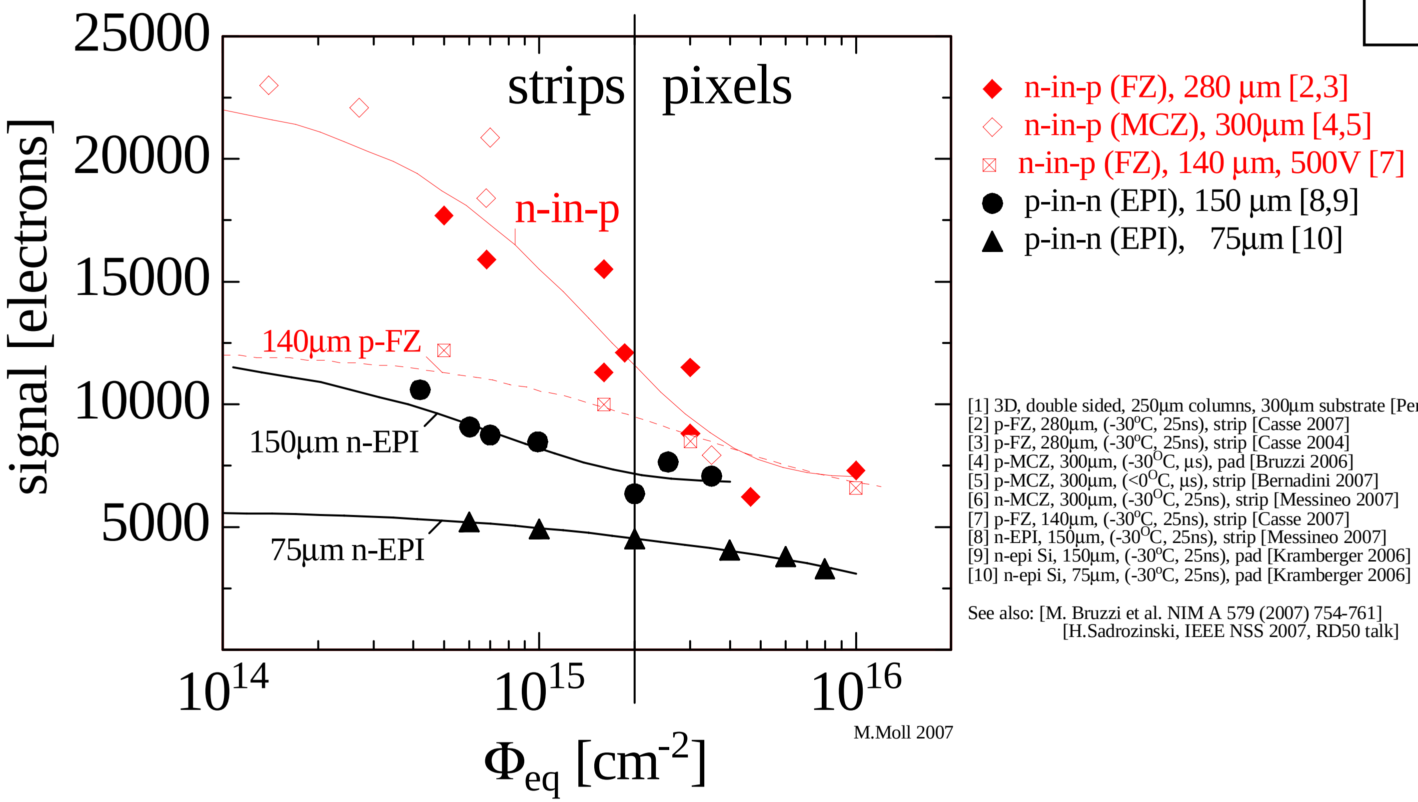

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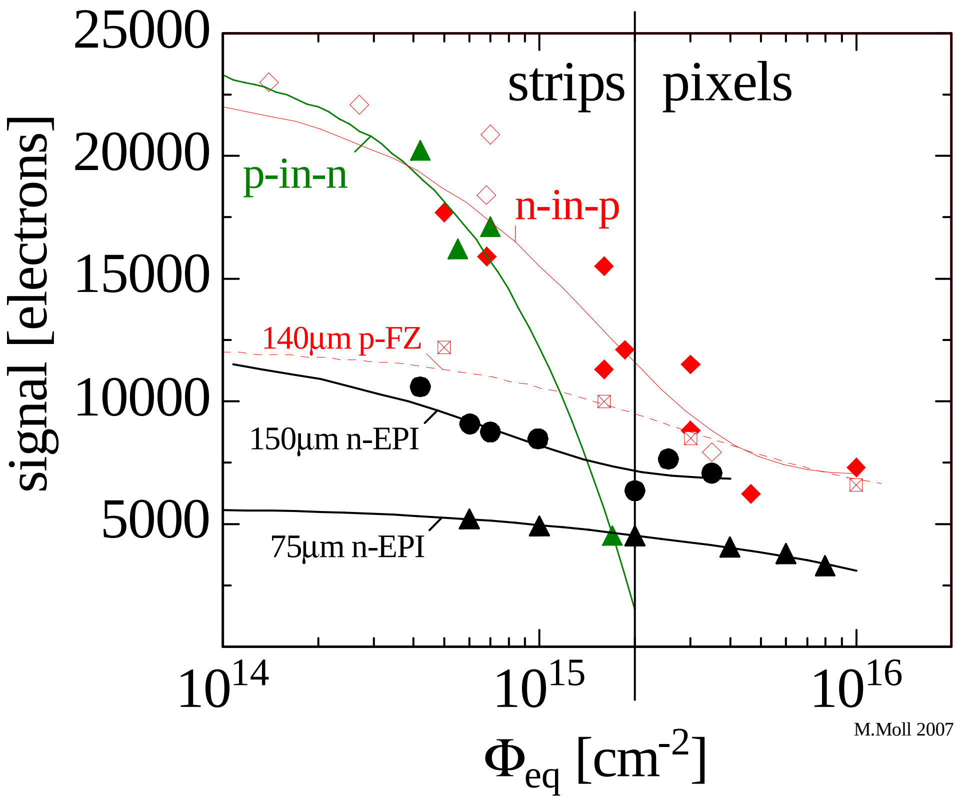

- ◆ n-in-p (FZ), 280 µm [2,3]
- ◇ n-in-p (MCZ), 300µm [4,5]
- ▲ p-in-n (MCZ), 300µm [6]
- ⊠ n-in-p (FZ), 140 µm, 500V [7]
- ● p-in-n (EPI), 150 µm [8,9]
- ▲ p-in-n (EPI), 75µm [10]

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See also: [M. Bruzzi et al. NIM A 579 (2007) 754-761]
[H.Sadrozinski, IEEE NSS 2007, RD50 talk]

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- **Signal comparison for various Silicon sensors**

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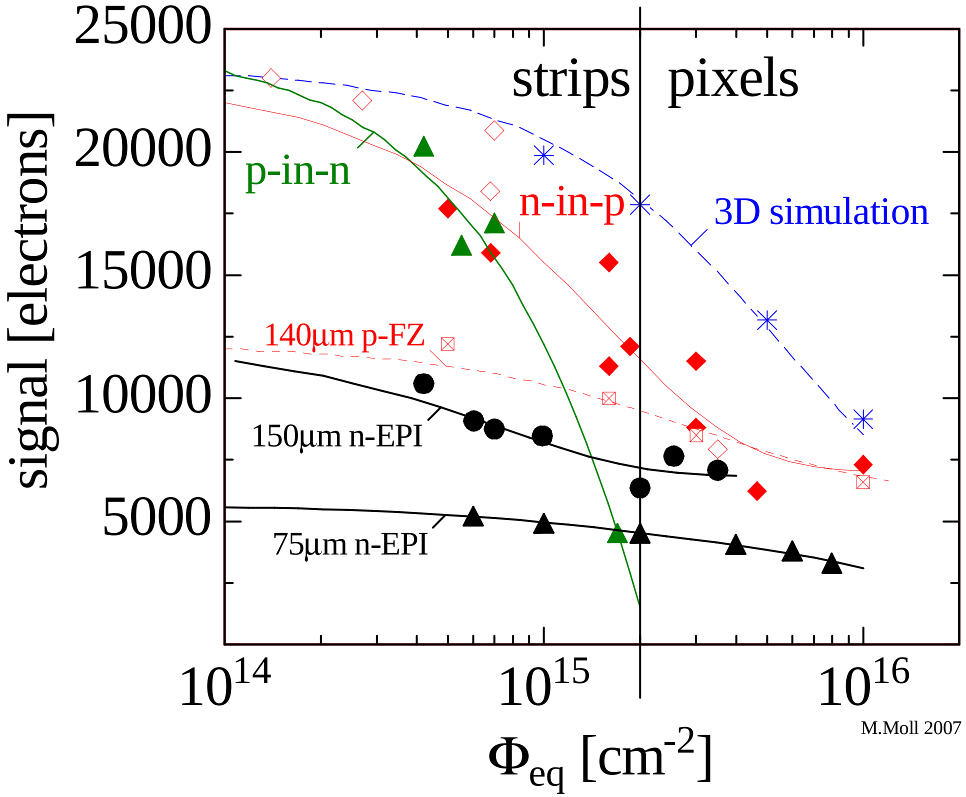

- ✳ Double-sided 3D, 250 µm, simulation! [1]
- ◆ n-in-p (FZ), 280 µm [2,3]
- ◇ n-in-p (MCZ), 300µm [4,5]
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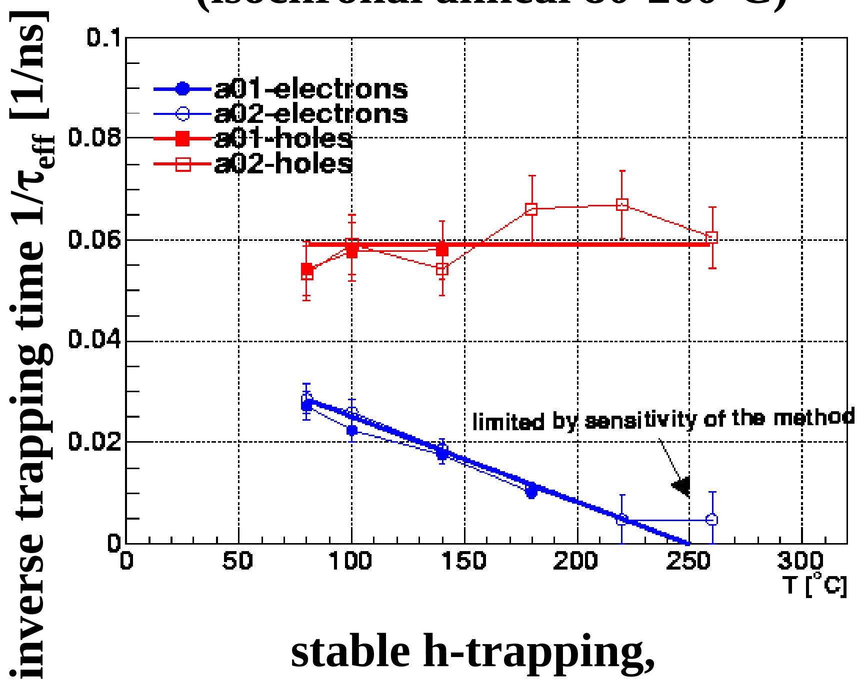
- **At a fluence of ~ 10^{15} n_{eq}/cm^2 all planar sensors loose sensitivity: on-set of trapping !**
- **No obvious material for innermost pixel layers:**
  - **Are 3-D sensors an option ??** (decoupling drift distance from active depth)
  - **Develop detectors that can live with very small signals ?? or regularly replace inner layers ??**

RD50 Defect Characterization - WODEAN

- **WODEAN project** (initiated in 2006, 10 RD50 institutes, guided by G.Lindstroem, Hamburg)
  - **Aim: Identify defects responsible for Trapping, Leakage Current, Change of N_{eff}**
  - **Method: Defect Analysis on identical samples performed with the various tools available inside the RD50 network:**
    - **C-DLTS** (Capacitance Deep Level Transient Spectroscopy)
    - **I-DLTS** (Current Deep Level Transient Spectroscopy)
    - **TSC** (Thermally Stimulated Currents)
    - **PITS** (Photo Induced Transient Spectroscopy)
    - **FTIR** (Fourier Transform Infrared Spectroscopy)
    - **RL** (Recombination Lifetime Measurements)
    - **PC** (Photo Conductivity Measurements)
    - **EPR** (Electron Paramagnetic Resonance)
    - **TCT** (Transient Charge Technique)
    - **CV/IV**
  - **240 samples irradiated with protons and neutrons in 2006/2007**
  - **first results presented on 2007 RD50 Workshops**

Electron & Hole Trapping (isochronal anneal 80-260°C)



stable h-trapping, e-trapping reduced by factor 5

[G.Kramberger, RD50/Wodean Workshop June 07]

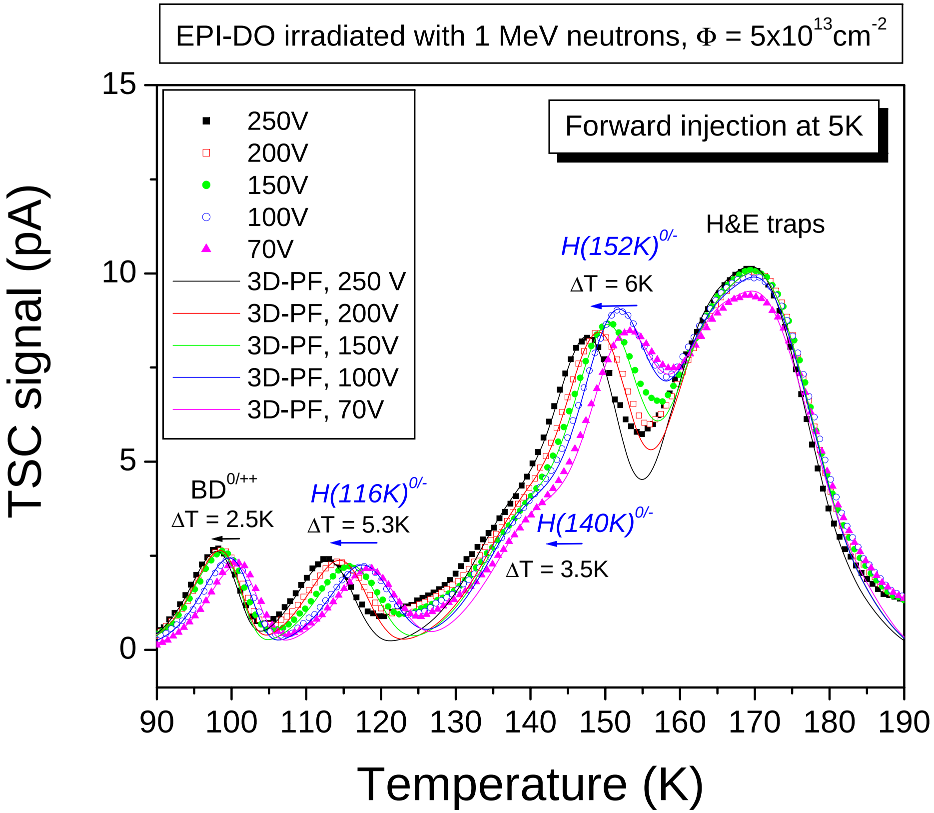
RD50 Characterization of microscopic defects
- γ and neutron irradiated silicon detectors -

- **2003: Major breakthrough on γ-irradiated samples** [I.Pintilie, APL, 82, 2169, March 2003]
  - For the first time macroscopic changes of the depletion voltage and leakage current can be explained by electrical properties of measured defects !
- **2007: Major breakthrough on n-irradiated samples** [I.Pintilie, RD50 Workshop, Nov 2007, submitted to APL]
  - Defects identified that contribute to negative space charge after neutron irradiation !

Defects H(116K), H(140K) and H(152K) identified to be deep acceptors in lower half of the bandgap

⇒ **contribute negative space charge!**

Concentration and annealing behavior of these defects in full agreement with changes of depletion voltage and reverse annealing!



RD50 Comment on links to LHC Experiments

- **Many RD50 groups are directly involved in ATLAS, CMS and LHCb upgrade activities (natural close contact). They report regularly to RD50 members and management.**
- **We are and were invited to present the RD50 work on ATLAS and CMS upgrade meetings (transfer of knowledge)**
- **Some RD50 members are holding positions inside ATLAS/CMS upgrade management:**
  - **CMS:** members of Upgrade Steering Group, convener for 'Sensor Upgrade'
  - **ATLAS:** WG convener for module integration
- **Devices matching ATLAS and CMS strip and pixel readout patterns on all recent RD50 4" and 6" masks !**
- **LHC speed front-end electronics (ATLAS, CMS and LHCb) used by RD50 members**
- **CMS/RD50 groups gathered and set up a beam telescope, first test beams on newly developed strip detectors performed in 2007**
- **3D detectors produced by RD50 groups tested in ATLAS Pixel test beam**
- **Common RD50/ATLAS beam request and irradiation tests at the PSI (pion irradiations in September 2007)**
- **….**

Workplan for 2008 (1/2)

Defect and Material Characterization	• Characterization of irradiated silicon: ▪ Continue WODEAN program ▪ Isochronal annealing studies with aim to identify defects responsible for trapping ▪ Modeling and understanding role of clusters ▪ Extend studies on p-type silicon detectors
Defect Engineering	• Continue study of epitaxial Si of increased thickness and p-type • Production of epitaxial silicon on FZ substrate • Hydrogenation of silicon detectors • Test uniformity of MCZ p-type silicon over the wafer
Pad Detector Characterization	• Characterization (IV, CV, CCE with α- and β-particles) of test structures produced with the common RD50 masks • Common irradiation program with fluences up to $10^{16}cm^{-2}$ • Study of double junction in n- and p-type silicon

Workplan for 2008 (2/2)

New Structures	• Measurement of charge collection after irradiation of the processed double column 3D detectors
Full Detector Systems	• Analysis of samples irradiated in 2007 (CCE of strip detectors with fast electronics) of common segmented structures (n- and p-type FZ, DOFZ, MCz and EPI) on 4” and 6” wafers • Further explore fluence range between 10^{15} and 10^{16} cm^{-2} • Long term annealing of segmented sensors • Investigation of the electric field profile in irradiated segmented sensors • Continue and strengthen activities linked to LHC experiments – achiever closer link to LHC experiments upgrade activities (e.g. common projects, test beams)

Resources requested for 2008

- **Common Fund:**

RD50 does not request a direct financial contribution to the RD50 common fund.

- **Lab space and technical support at CERN:**

As a member of the collaboration, the section PH-DT2/SD should provide (as in 2007) access to available **lab space in building 14** (characterization of irradiated detectors), **in building 28** (lab space for general work) and in the **Silicon Facility** (hall 186, clean space).

- **CERN Infrastructure:**

- One collaboration workshop in November 2008 and working group meetings
- Keeping the RD50 office in the barrack 591
- Administrative support at CERN (e.g. for updating member list in grey book!)