RD50

Silicon Detectors for the sLHC - an Overview of Recent RD50 Results

Giulio Pellegrini *
On behalf of CERN RD50 collaboration

*Centro Nacional de Microelectronica IMB-CSIC, Barcelona Spain

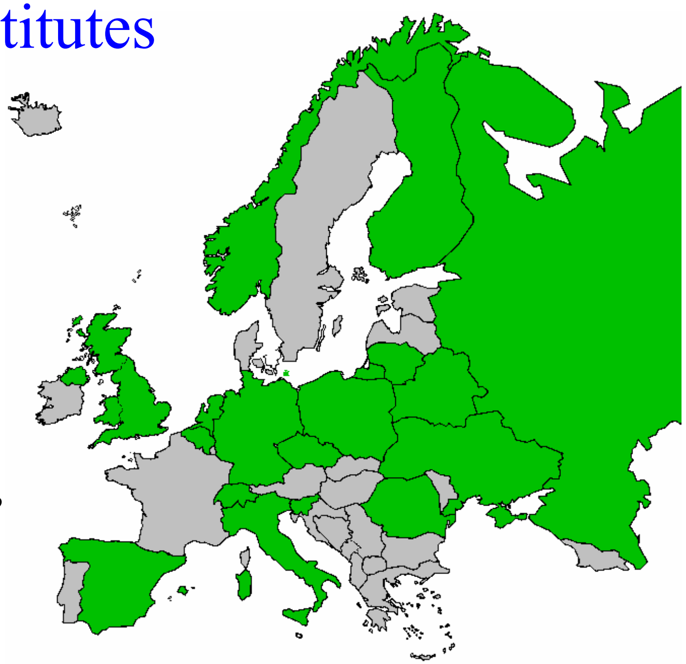
http://www.cern.ch/rd50

Overview

- Radiation environment and requirements for silicon sensors at SLHC
- Introduction of the RD50 Collaboration
- Some results from the five research lines within RD50
    - This report cannot be complete!
    - See Status Report for more details
- Recommendations for SLHC

RD50 Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

256 Members from 49 Institutes



41 European and Asian institutes

Belarus (Minsk), **Belgium** (Louvain), **Czech Republic** (Prague (3x)), **Finland** (Helsinki), **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), **Ucraina** (KINR), **United Kingdom** (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 Scientific Organization of RD50

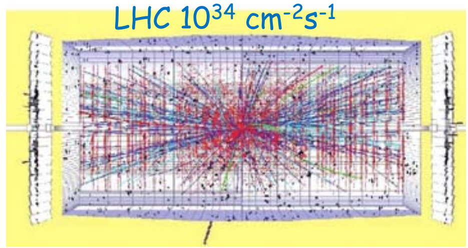
Development of Radiation Hard Semiconductor Devices for High Luminosity Colliders

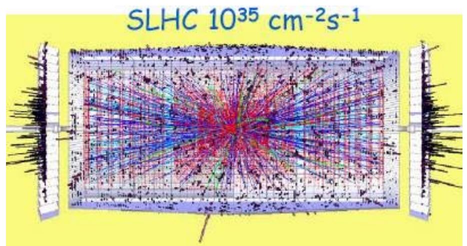
Spokespersons
Mara Bruzzi, Michael Moll
INFN Florence, CERN ECP

Defect / Material Characterization *Bengt Svensson* (Oslo University)	Defect Engineering *Eckhart Fretwurst* (Hamburg University)	Pad Detector Characterization *G. Kramberger* (Ljubljana)	New Structures *R. Bates* (Glasgow University)	Full Detector Systems *Gianluigi Casse* (Liverpool University)
Characterization of microscopic properties of standard-, defect engineered and new materials pre- and post-irradiation WODEAN project (G. Lindstroem)	Development and testing of defect engineered silicon: - Epitaxial Silicon - High res. CZ, MCZ - Other impurities H, N, Ge, … - Thermal donors - Pre-irradiation	•Test structure characterization IV, CV, CCE •NIEL •Device modeling •Operational conditions •Common irrad. •Standardisation of macroscopic measurements (A.Chilingarov)	•3D detectors •Thin detectors •Cost effective solutions •3D (M. Boscardin) •Semi 3D (Z.Li)	•LHC-like tests •Links to HEP •Links to R&D of electronics •Comparison: pad-mini-full detectors •Comparison of detectors different producers (Eremin) • pixel group (D. Bortoletto,T. Rohe)

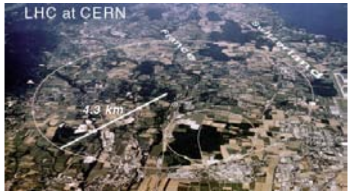
Motivation

LHC upgrade to Super-LHC:





Luminosity of LHC: L ~ 10^{34} $cm^{-2}s^{-1}$ and fluence of fast hadrons at r=4cm ~ $3 \cdot 10^{15} cm^{-2}$



→ Super-LHC: *L* ~ 10^{35} $cm^{-2}s^{-1}$, expected fast hadron fluence at r=4cm ~ 1.6×10^{16} cm^{-2}.

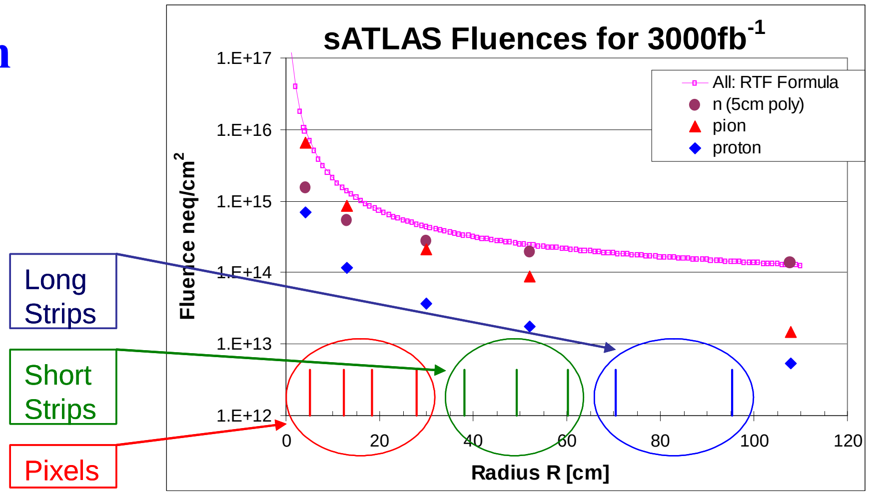
The main constraint is the survival of the silicon tracker in the hostile radiation environment.

Fluence in proposed sATLAS Tracker

- **Mix of neutrons, protons, pions depending on radius R**
- **Long and short strips damage largely due to neutrons**
- **Pixels damage due to neutrons and pions**

Design fluences for sensors (includes 2x safety factor) **:**

Innermost Pixel Layer:	1-1.6*10^{16} n_{eq}/cm^2 = 500 Mrad
Outer Pixel Layers:	3*10^{15} n_{eq}/cm^2 = 150 Mrad
Short strips:	**1*10^{15} n_{eq}/cm^2 = 50 Mrad**
Long strips:	**4*10^{14} n_{eq}/cm^2 = 20 Mrad**

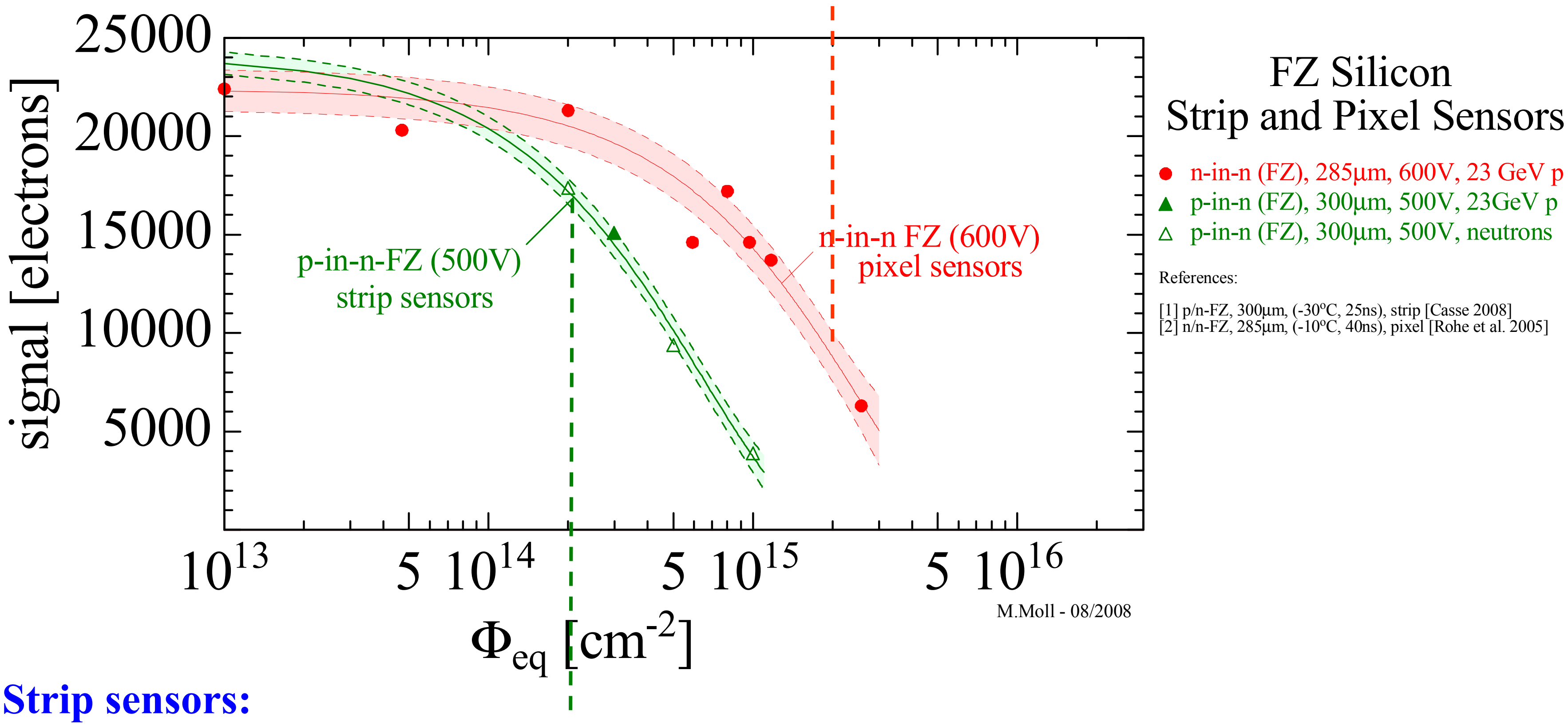


ATLAS Radiation Taskforce
http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RADIATION/RadiationTF_document.html

Radiation environment

Pixel sensors:

max. cumulated fluence for LHC



Strip sensors:

max. cumulated fluence for LHC

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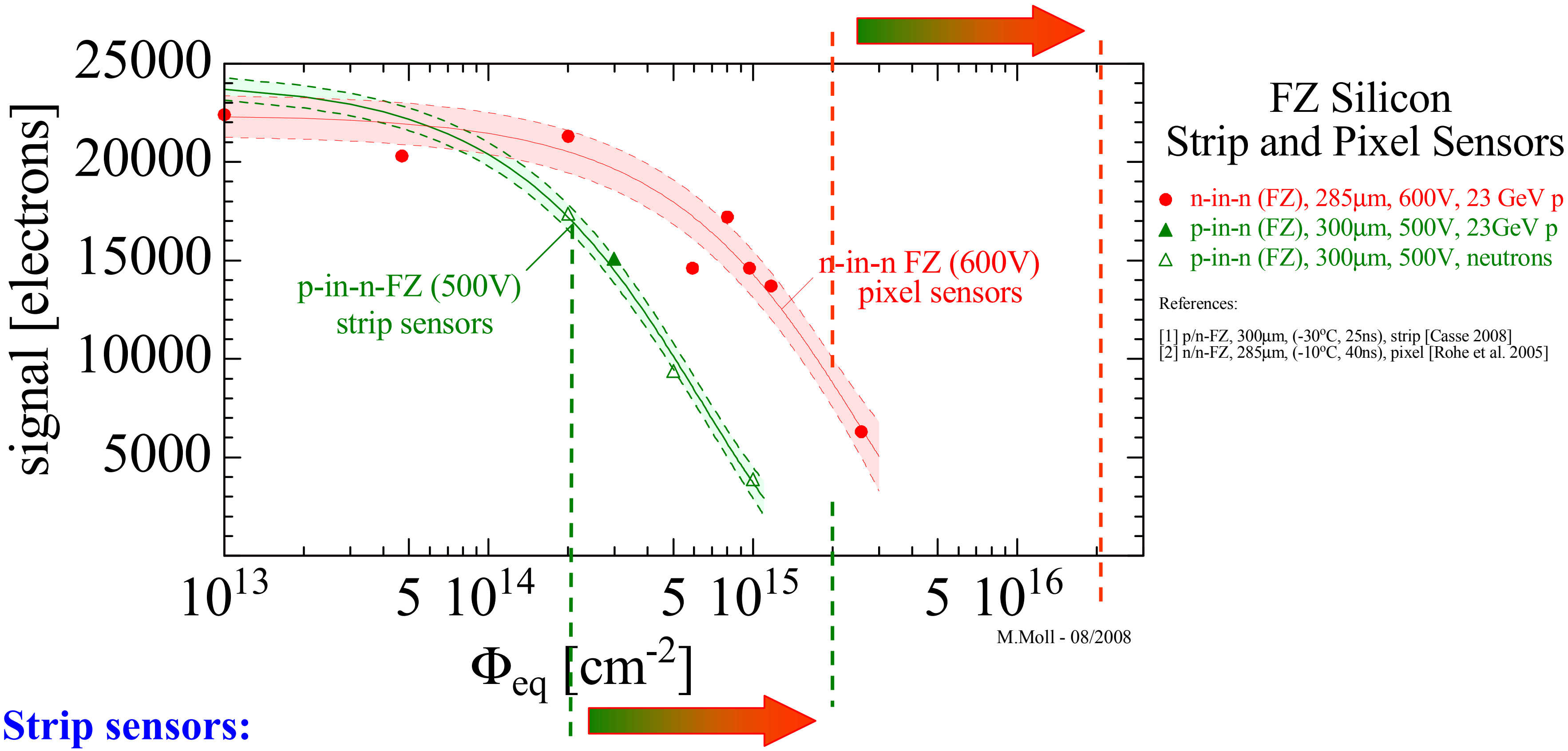
Radiation environment

Pixel sensors:

max. cumulated fluence for LHC and SLHC



Strip sensors:

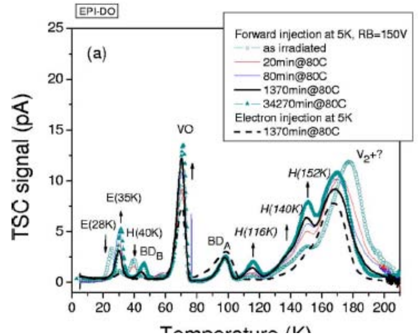
max. cumulated fluence for LHC and SLHC

Much higher radiation tolerance required at SLHC

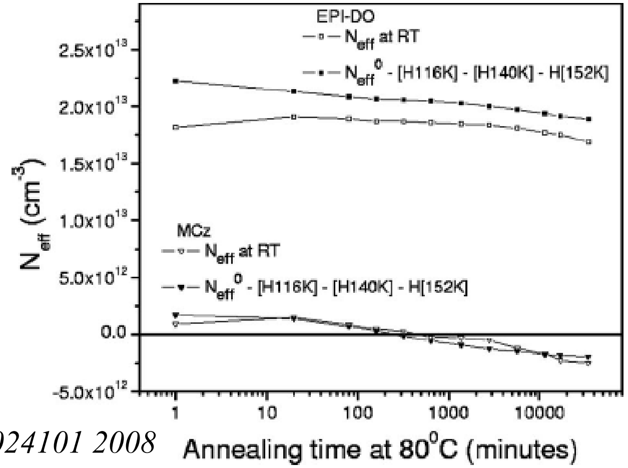
- Standard FZ material and operation not sufficient any more
- Need new sensor materials and/or technologies
- To find a suitable sensor technology for SLHC is the aim of RD50

RD50 Defect / Material Characterization

- 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



- The defect centres H(116K), H(140K), H(152K) are hole traps with acceptor like levels in the lower band gap (neg. space charge)
- They are not generated by gamma irradiation, thus cluster related
- Concentrations are increasing with annealing time
  - contribute to long term/reverse annealing
- Neff can be calculated from measured defect concentrations with TSC
- Comparison with Neff from CV measurements strikingly good



I. Pintilie, E. Fretwurst, and G. Lindström, APL ***92****, 024101 2008*

Defect Engineering

- 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

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

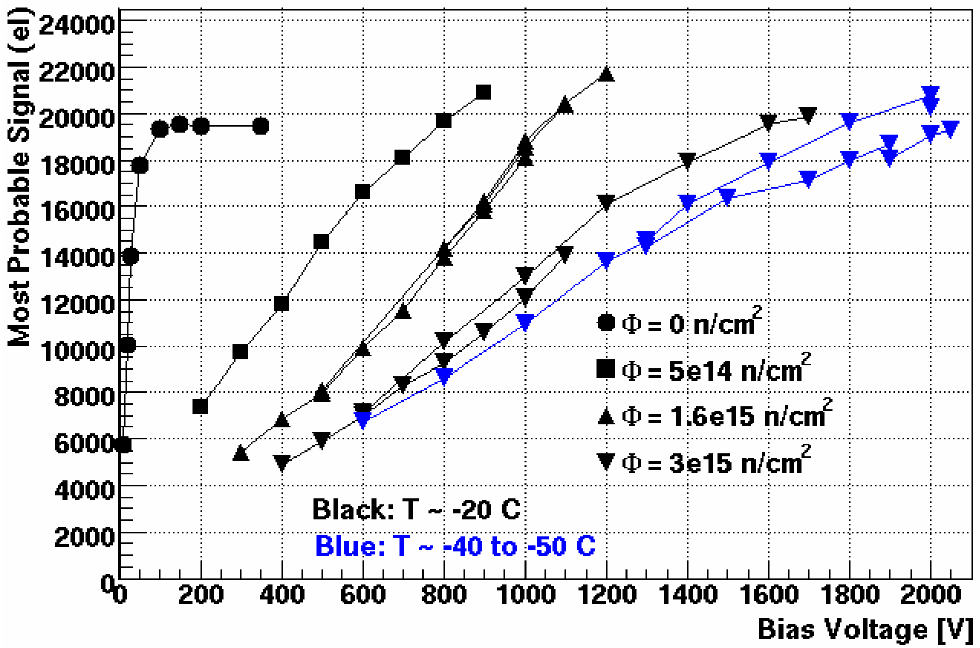
Available Irradiation Sources in RD50

- 24 GeV/c protons, PS-CERN
- 10-50 MeV protons, Jyvaskyla +Helsinki
- Fast neutrons, Louvain-la-Neuve
- 25 MeV protons, Karlsruhe
- TRIGA reactor neutrons, Ljubljana

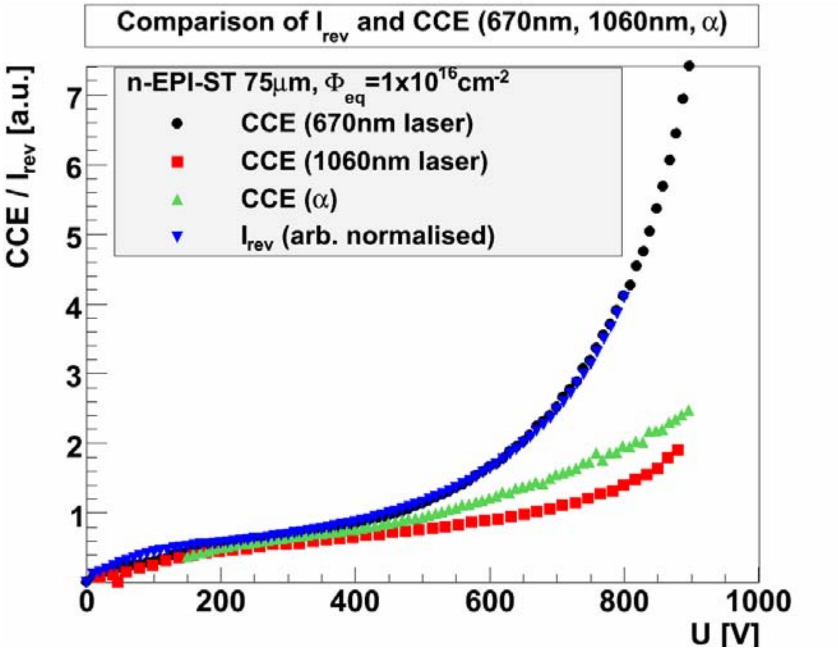
Material	Thickness [µm]	Symbol	ρ (Ωcm)	$[O_i]$ (cm^{-3})
Standard FZ (n- and p-type)	50,100,150,300	FZ	$1–30\times10^{3}$	$< 5\times10^{16}$
Diffusion oxygenated FZ (n- and p-type)	300	DOFZ	$1–7\times10^{3}$	$\sim 1–2\times10^{17}$
Magnetic Czochralski Si, Okmetic, Finland (n- and p-type)	100, 300	MCz	$\sim 1\times10^{3}$	$\sim 5\times10^{17}$
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	$\sim 7\times10^{17}$

Pad Detector Characterization

- CCE increases over expectation for very high fluence
- CCE > 100% for high bias voltage
- There is charge multiplication ! (Avalanche effect ?) Or other effect, like field dependent de-trapping? Even after heavy irradiation it is possible to recover the entire ionised charge



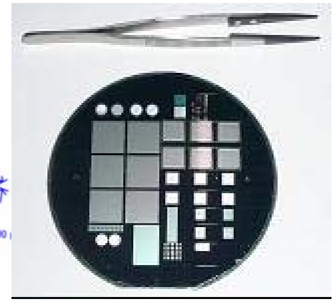
I. Mandic, 12th RD50 workshop, 2008



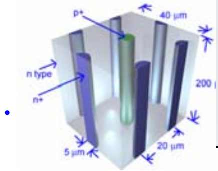
J. Lange et al., 14th RD50 workshop, 2009

New Structures

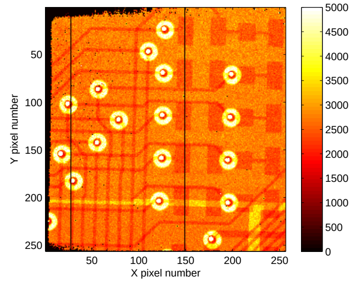
• 3D detectors



- Two manufactures CNM (Barcelona) and FBK-IRST (Trento)
- First test beam results in 2009
  - CERN SPS, H2 beamline, 225 GeV/c muons **(**CMS APV25).
  - Diamond light source (Medipix2)



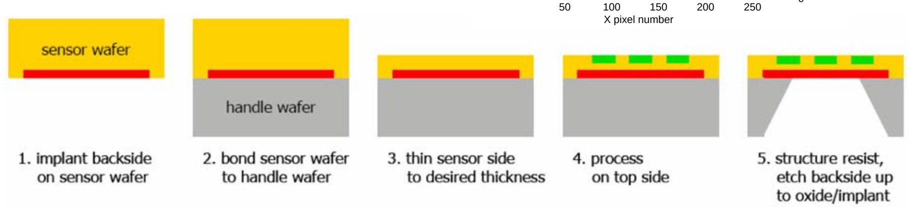
- Different geometries: Atlas pixels and strips
- Irradiation studies **$\Phi = 5 \times 10^{15}$ 1MeV n_{eq} cm^{-2} 12.8keV signal**

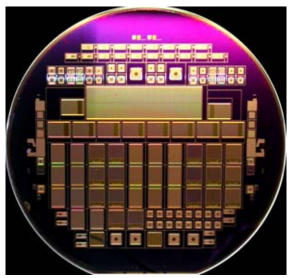


• Thin detectors, SOI wafers (CIS)

- Present thin SOI Production:
- 12 (13) 6" SOI wafers
- 4 ntype (ρ=360 Ωcm) and 8 ptype (ρ~2 kΩ·cm)
- 75μm and 150μm active thickness
- First characterizations of:

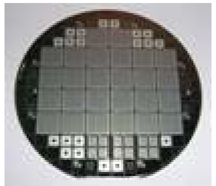
  Diodes, Strips,Pixel sensors
- 8 wafers (4 ntype, 4 ptype) are prepared for the SLID 3DIntegration. 4 wafers are characterized and prepared for irradiations.

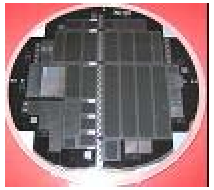
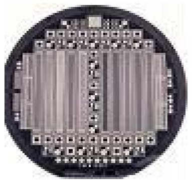




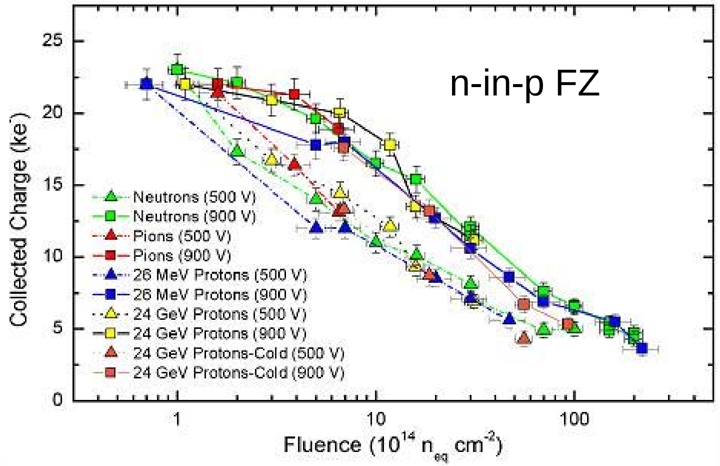
Full Detector Systems

- •Systematic evaluation of segmented (microstrip, pixels) detectors for S-LHC
- •Use of the LHC speed electronics to evaluate the "ultimate" parameters for operating the present segmented detectors (S/N, resolution).
- •Design and realization of radiation hard pixel-microstrip detectors in contact with manufactures :

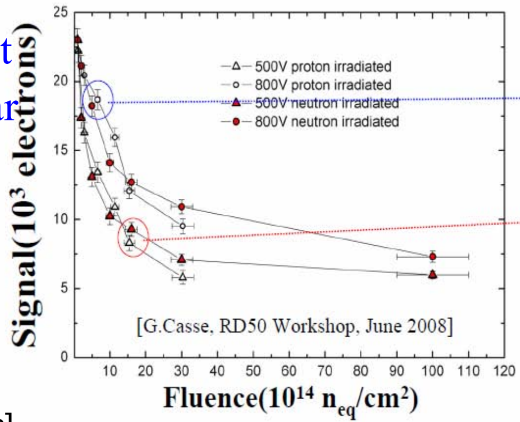


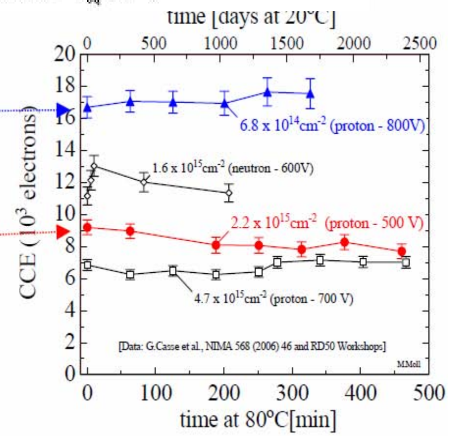



CIS Erfurt, Germany
CNM Barcelona, Spain
HIP, Helsinki, Finland
IRST, Trento, Italy
Micron Semiconductor L.t.d (UK)
Sintef, Oslo, Norway
Hamamatsu, Japan [ATLAS ID project – not RD50]



- N-in-P technology suitable for S-LHC environment
- At higher fluences, neutrons and protons are similar
- No CCE annealing observed for p-bulk
- Still sufficient signal (7000e-) in p-type FZ strip sensors after 10^{16} neq/cm² for 900V





Data: G.Casse et al., NIMA 568 (2006) 46 and RD50 Workshops]

Alibava system

- **ALIBAVA – A LIverpool BArcelona VAlencia collaboration**
- **System supported by RD50: Will enable more RD50 groups to investigate strip sensors with ‘LHC-like’ electronics**

Plug and Play System:

- Software part (PC) and hardware part connected by USB.
- Hardware part: a dual board based system connected by flat cable.

Mother board intended:

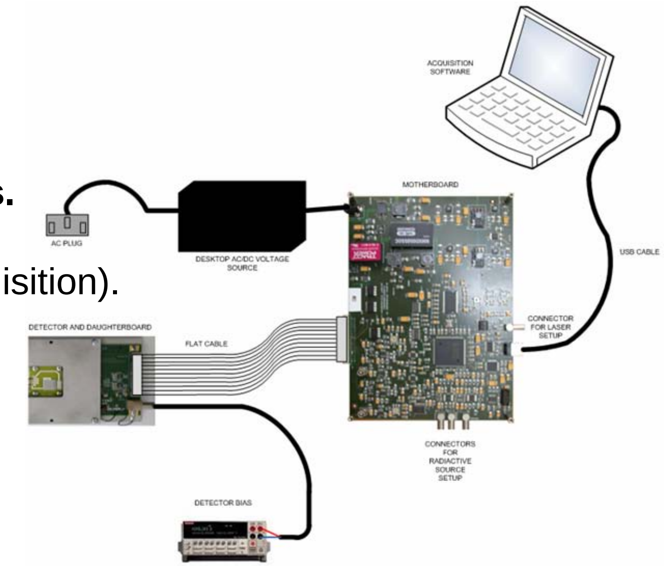
- **To process the analogue data that comes from the readout chips.**
- **To process the trigger input signal in case of radioactive source setup or to generate a trigger signal if a laser setup is used.**
- **To control the hardware part.**
- **To communicate with a PC via USB.**

Daughter board :

- **It contains two Beetle readout chips**
- **It has fan-ins and detector support to interface the sensors.**

Software part:

- It controls the whole system (configuration, calibration and acquisition).
- It generates an output file for further data processing.



The system can be acquired by non RD50 members

Contact person: Mr. Humberto Mata
D+T Microelectrónica,A.I.E.
Humberto.Mata@imb-cnm.csic.es

Recommendations for SLHC

- p-type silicon (brought forward by RD50 community) is now considered to be the base line option for the ATLAS Tracker upgrade
- MCZ material for the LHC upgrade
    - p-type MCZ and FZ did not show difference
    - n-type MCZ better than FZ in sense of radiation hardness
    - FZ have advantage of resistivity but higher price.
- RD50 results on reverse annealing of p-type silicon (no cooling during maintenance periods needed) are already taken into account by Experiments
- n- and p- type MCZ (introduced by RD50 community) are under investigation in ATLAS, CMS and LHCb:
- RD50 results on very highly irradiated silicon strip sensors have shown that planar pixel sensors are a promising option also for the upgrade of the Experiments

For all recent results of the whole RD50 collaboration see http://www.cern.ch/rd50