RD50: P-type Sensor Results

G. Casse

OUTLINE:

- Introduction
- Motivations for using p-type substrates in high radiation environments
- Earlier results
- RD50 -results
- CCE with MCz p-type detectors (ATLAS miniature prototypes from HPK)
- New and preliminary: thin (150μm) vs *standard* (300μm) detectors
- Summary and future work

RD50: Radiation hard semiconductor devices for very high luminosity colliders

See http://rd50.web.cern.ch/rd50/

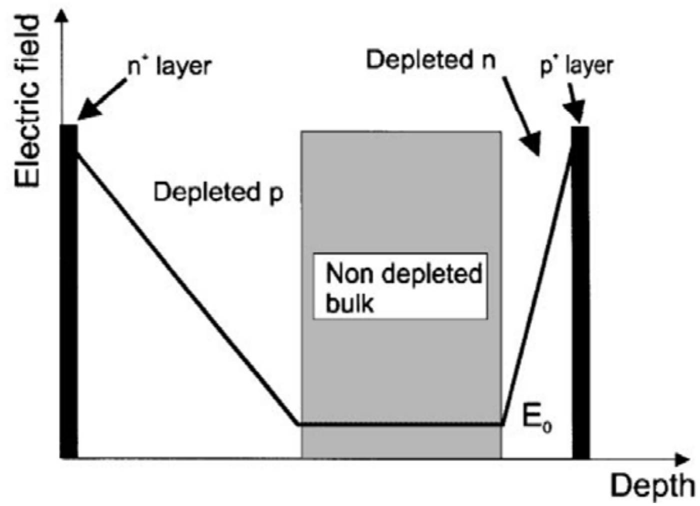
Spokespersons
Mara Bruzzi, Michael Moll
INFN Florence, CERN ECP

Defect / Material Characterization	Defect Engineering	New Materials	Pad Detector Characterization	New Structures	Full Detector Systems
Bengt Svensson (Oslo University)	*Eckhart Fretwurst* (Hamburg University)	*E. Verbitskaya* (Ioffe St. Petersburg)	*G. Kramberger* (Ljubljana)	*R. Bates* (Glasgow University)	*Gianluigi Casse* (Liverpool University)
Characterization of microscopic defects • properties of standard-, defect engineered and new materials pre- and post-irradiation	Defect engineered silicon: • Epitaxial Silicon • CZ, MCZ • Other impurities H, N, Ge, … • Thermal donors • Pre-irradiation • Oxygen Dimer	Development of new radiation tolerant materials: • SiC • GaN •other materials	• Test structure characterization IV, CV, CCE • NIEL • Device modeling • Common irrad. • Standardization of measurements	Evaluation of new detector structures • 3D detectors • Thin detectors • Cost effective solutions • Semi 3D	•LHC-like tests •Links to HEP •Links to R&D on electronics •Comparison: pad-mini-full detectors • Pixel group

This talk will concentrate on activities concerning micro-strip detector (many other activities in RD50 performed with pad detectors).

N-side read-out for tracking in high radiation environments?

Schematic changes of Electric field after irradiation



Effect of trapping on the Charge Collection Efficiency (CCE)

$$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$$

Collecting electrons provide a sensitive advantage with respect to holes due to a much shorter t_c. P-type detectors are the most natural solution for *e* collection on the segmented side.

N-side read out to keep lower t_c

Motivation for p-type:

N-side read-out can be implemented on n-type substrates (with numerous successful examples). But requires double sided processing (backplane guard rings patterning). Will be effective after space charge sign inversion to *p-type*.

P-type substrate more natural choice: no type inversion, no backplane processing.

… and

ADVANTAGES:

Easier to handle (not to take ca
special gluing on the backside (
the presence of guard-rings,
possibility of operating under-
depleting also before irradiatior

…. Up to 60% discount with respect to n-in-n!!

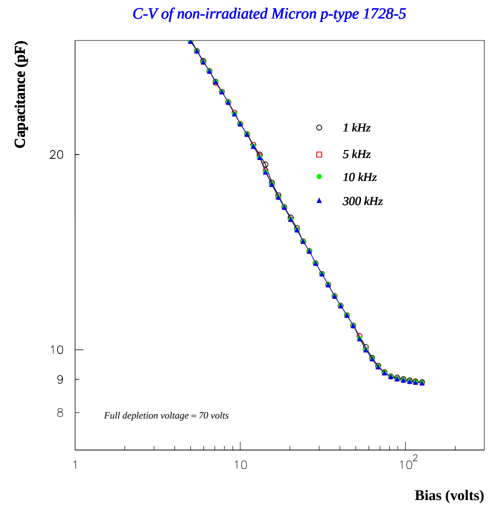
Early results:

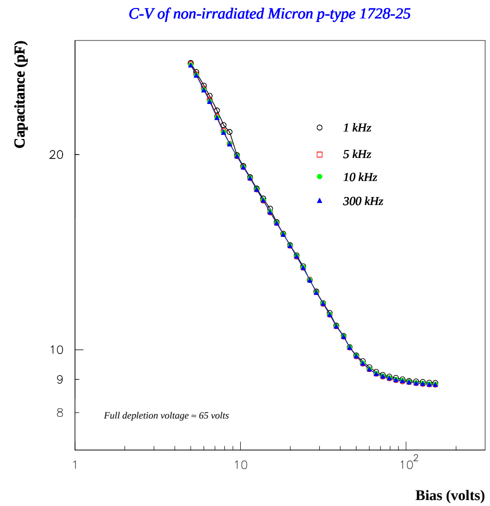
Micron Semiconductor, with Liverpool design: ATLAS barrel like full size detectors (6 wafers)

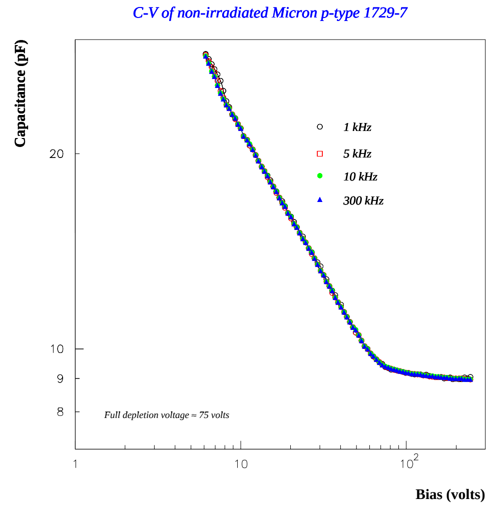
CNM Barcelona: miniature detectors (1x1 cm^{-2}) and large area detectors on Liverpool design (mini-detectors were irradiated)

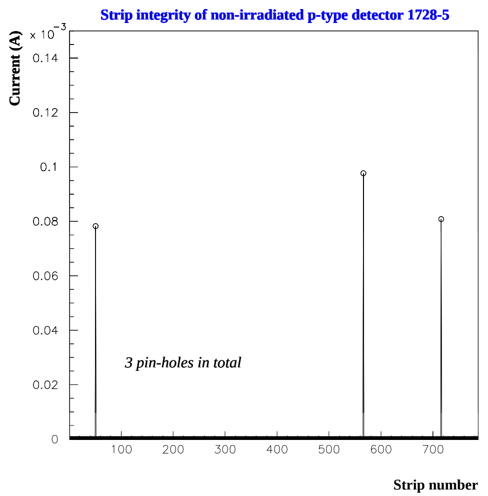
Early results

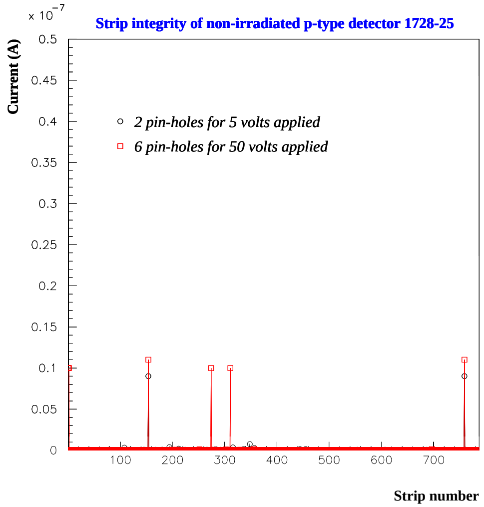
P-type detectors with individual p-stops processed by Micron on Liverpool masks (ATLAS SCT full size devices). Pre-irradiation characterisations

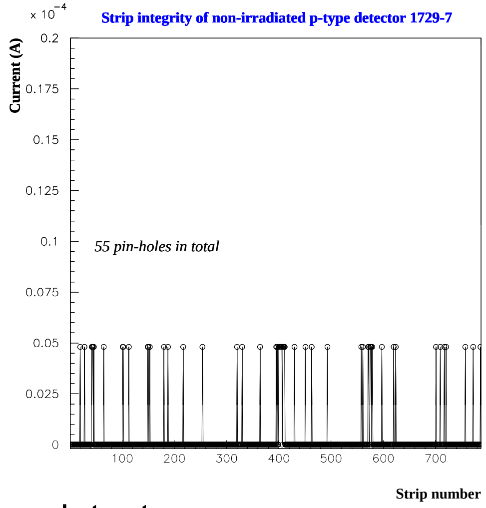








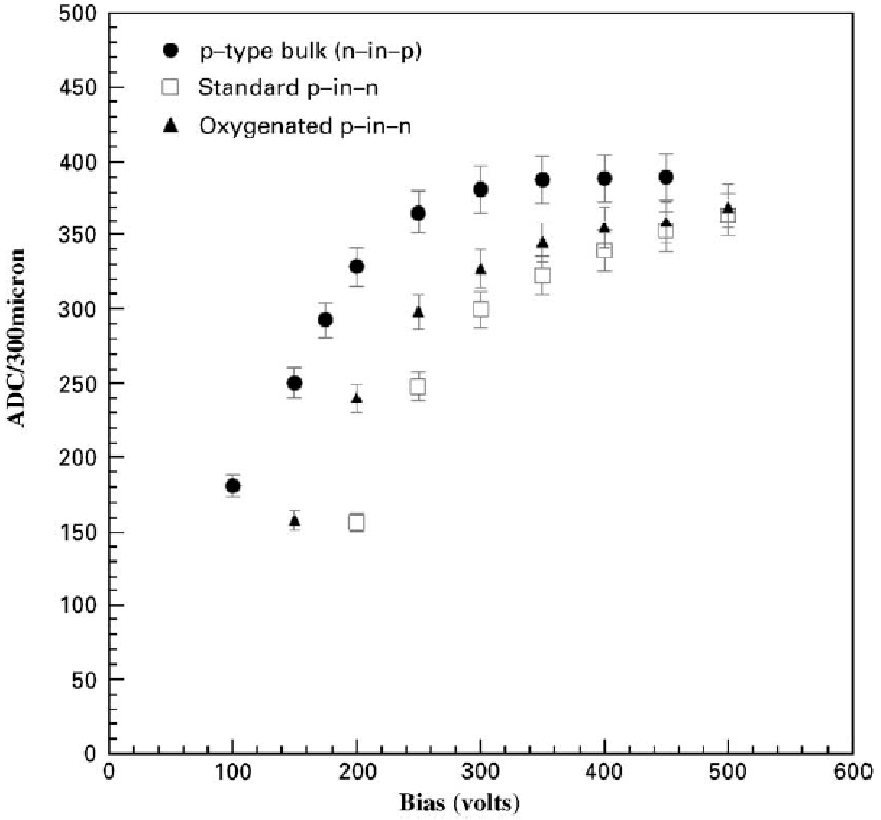


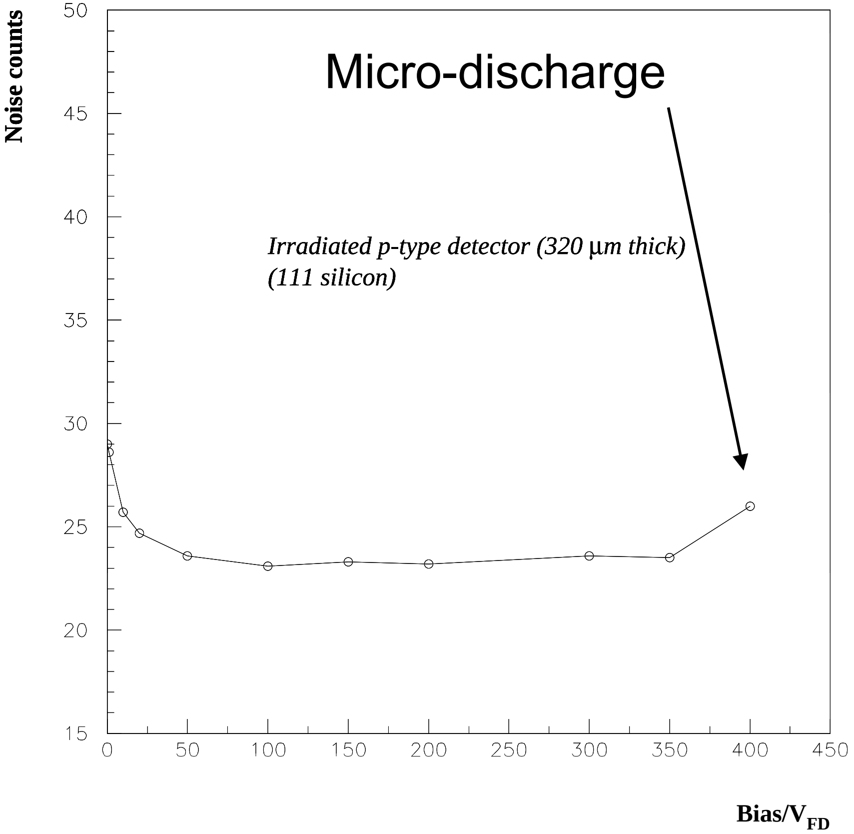


Early results

……. and signal and noise performances after 3.10^{14} cm^{-2}

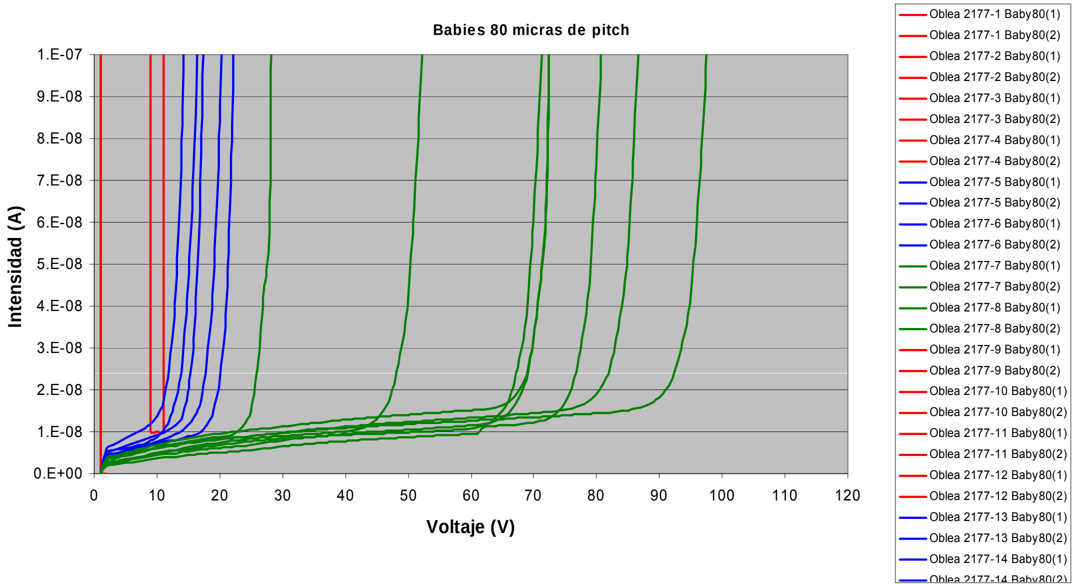
Signal vs V of p-type, std and oxy. n-type





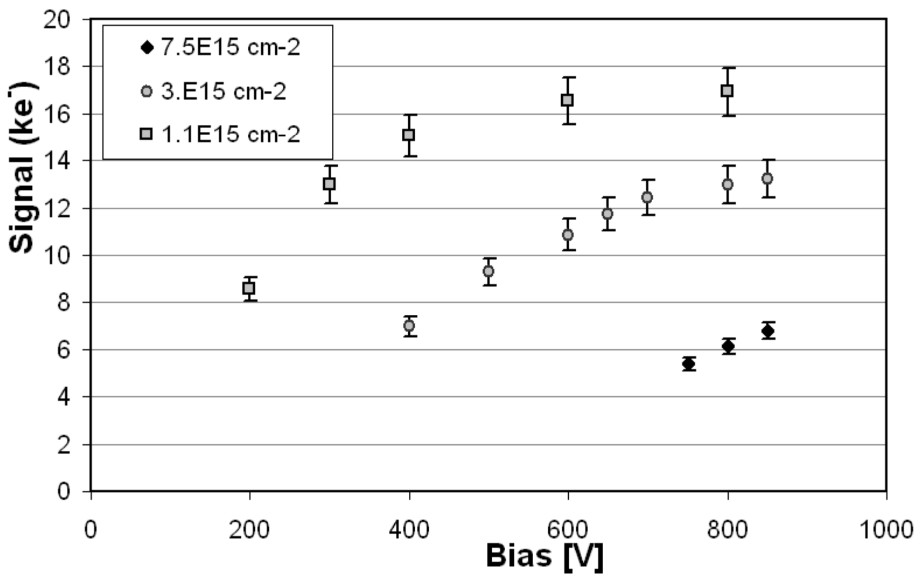
P-type miniature detectors from CNM

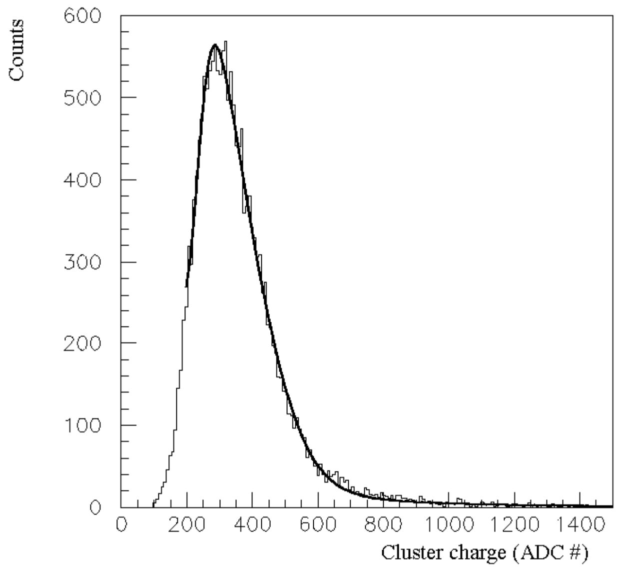
This was the very first attempt at p-type silicon manufacturing from CNM. Various p-stop doses were tried with miniature (1x1 cm^{-2}) detectors made with a masked designed by Liverpool. The measurements on non-irradiated devices were disappointing in term of break-down properties. Only the higher p-stop doses were able to guarantee sufficient edge isolation and lower currents to reach about full depletion.



P-type miniature detectors from CNM

Nevertheless, extremely good performances in term of charge collection after unprecedented doses (1., 3.5., and 7.5 10^{15} p cm^{-2}) were obtained with these devices!!





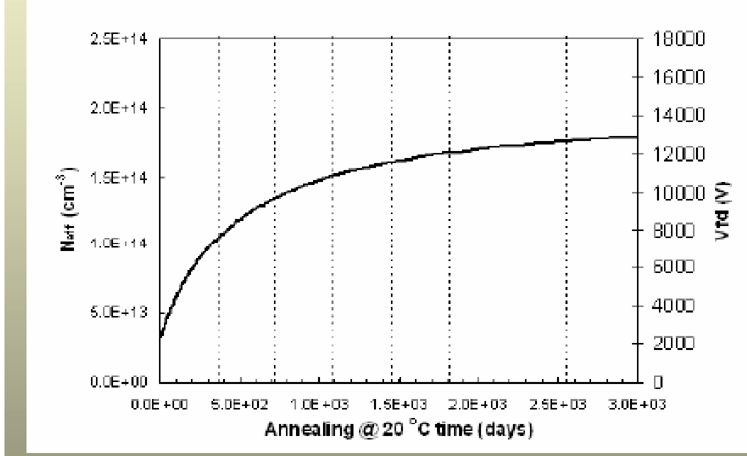
P-type miniature detectors from CNM

Another effect that has changed the way to regard at the reverse annealing has been measured on these devices. The reverse annealing has been always considered as a possible cause of early failure of Si detectors in the experiments if not controlled by mean of low temperature (not only during operations but also during maintenance/shut down periods). This was originated by accurate measurements of the annealing behaviour of the full depletion voltage in diodes measured with the CV method.

Expected changes of full depletion voltage with time after irradiation (as measured with the C-V method) for detector irradiated to 7.5 10^{15} p cm^{-2}.

Please notice that according to CV measurements the so called V_{FD} changes from <3kV to >12kV!

Initial V_{FD} ~ 2800V



Predictions from RD48 parameters for Oxygen enriched devices (best scenario: after 7 RT annealing years the V_{fd} goes from ~2800V to ~12000 V!

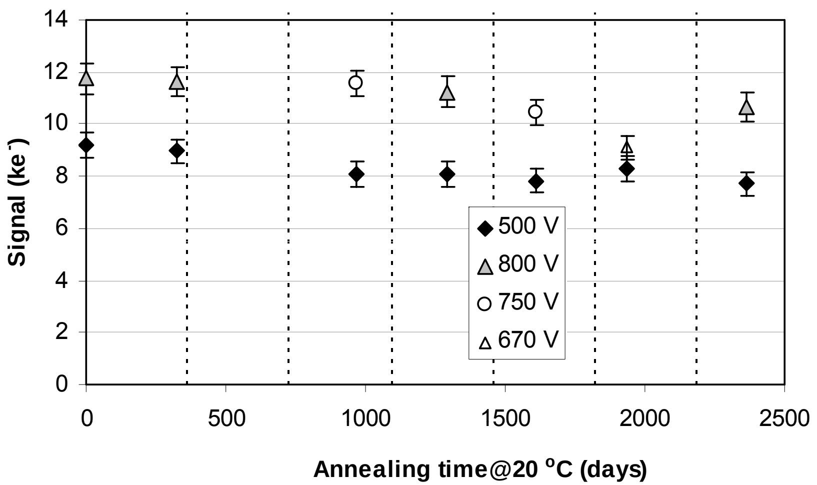
P-type miniature detectors from CNM

For the first time the CCE was measured as a function of the accelerated annealing time with LHC speed electronics (SCT128A chip), and the results were really surprising!!

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

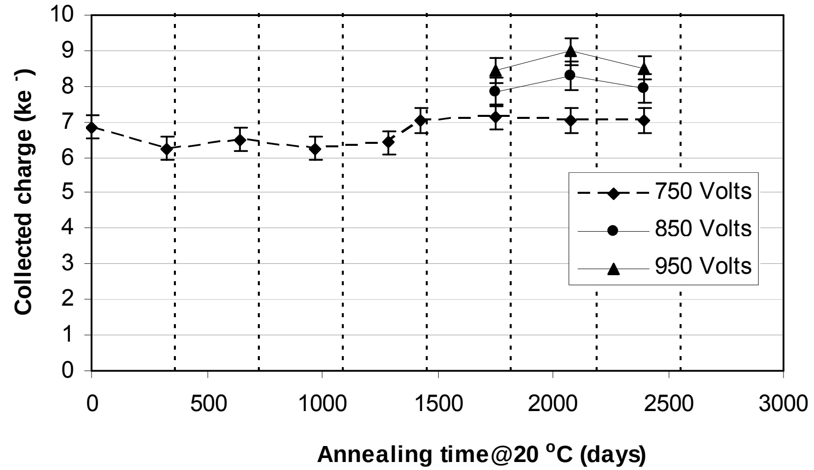
Initial V_{FD} ~ 1300V

final ~ 6000V



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

Initial V_{FD} ~ 2800V,
final ~12000 V!



Systematic studies of p-type sensors within RD50

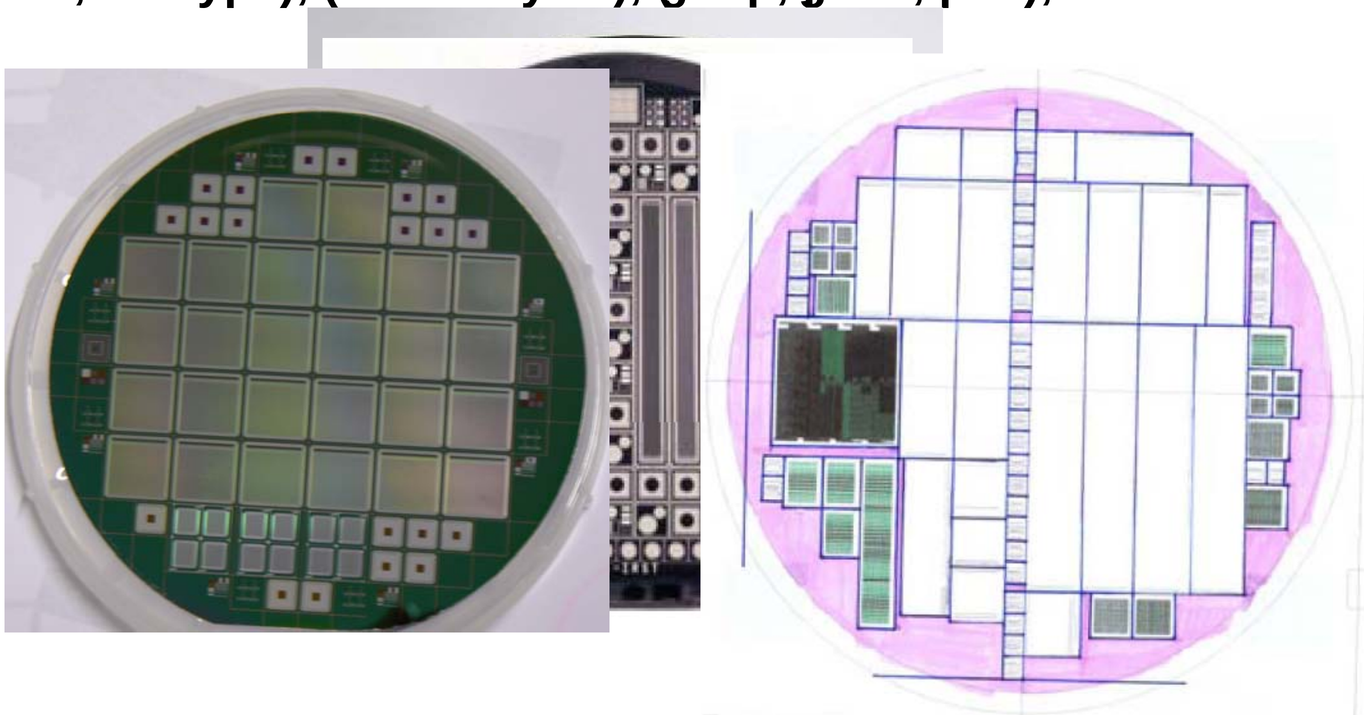
Several projects to explore the variety of geometries and substrates have been launched:

Micron, 2 masks, 4" (p-type), (MCZ, FZ), thick p-type FZ and DOFZ Si, 3E12 and 5E12 cm^{-2}

SMART (IRST): 4" wafers (20 pad, 26 strip, 12 pixel),(p- and n-type),(MCZ, EPI, FZ)

6" wafers (p- and n-type), (MCZ and FZ), (strip, pixel, pad), 93 wafers

4" p-type EPI, new mask being designed



Systematic studies of p-type sensors within RD50

Several projects to explore the variety of geometries and substrates have been launched:

CNM: 22 wafers (4”),

(20 pad, 26 strip, 12 pixel),(p- and n-type),(MCZ, EPI, FZ)

SMART (IRST): 23 wafers 4” (p-type), (MCZ, FZ), two p-spray doses 3E12 and 5E12 cm^{-2}
4” p-type EPI, new mask currently being designed

Micron 4”, microstrip detectors on 140 and 300μm thick p-type FZ and DOFZ Si.
Micron 6” wafers, (p- and n-type), (MCZ and FZ), (strip, pixel, pad), 93 wafers

Other processing in 2006

HPK prototypes for ATLAS-SCT upgrade : large area and miniature with FZ and MCz substrates.

Results with CNM manufactured devices (FZ p-type)

Studies for optimisation of the p-spray isolation.

CCE studies in *diode configuration*.

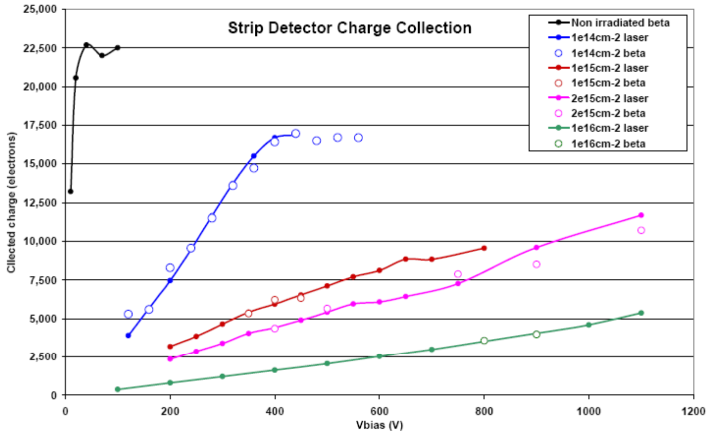


Fig.8-2. Collected Charge-Voltage plots of n-in-p microstrip detectors irradiated with neutrons for different fluences [9]. Signal induced by fast electrons (^{90}Sr) and laser [6]. Measurements performed in diode configuration.

G. Pellegrini et al., 10th RD50 Workshop

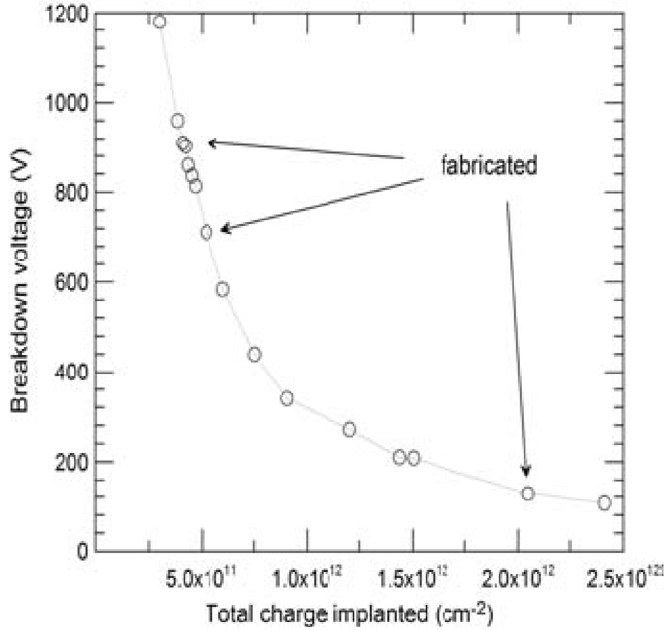
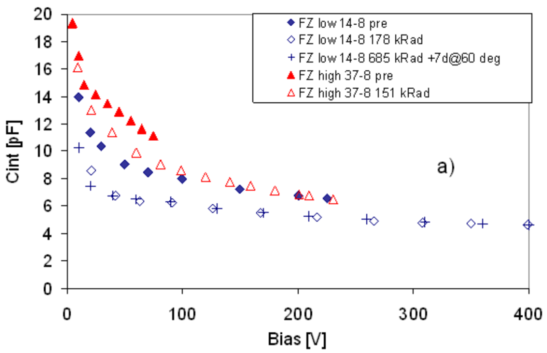


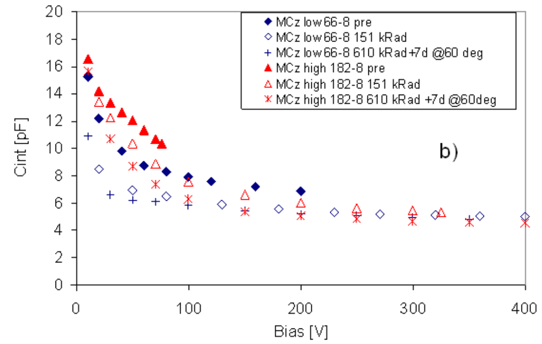
Fig.8-9. Variation of the breakdown voltage as a function of the total implanted charge for the definition of the p-spray insulation in no-irradiated detectors.

G. Pellegrini et al. NIM A 566

Results with **SMART detectors produced by IRST**

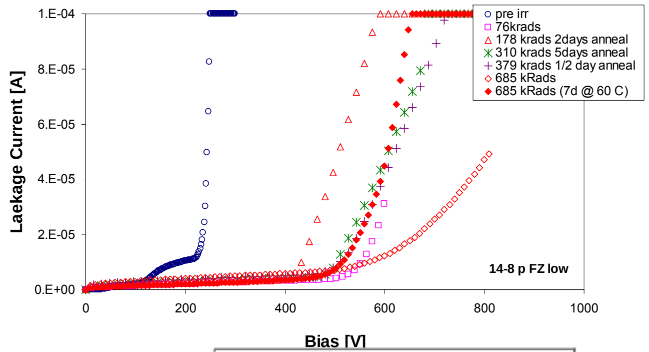
Study of the interstrip capacitance as a function of dose and p-spray concentration for FZ and MCz p-type substrates.



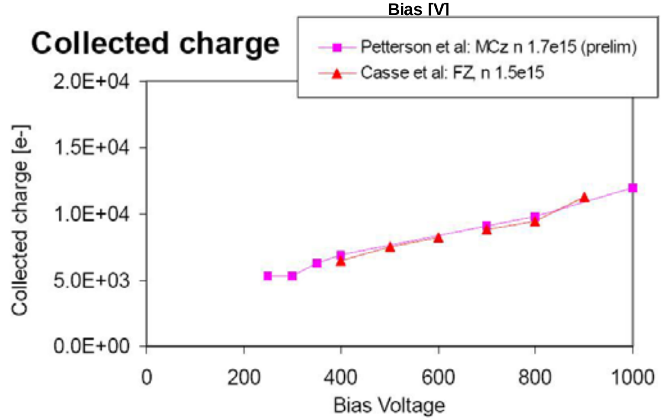


Dependence of the break-down voltage on the irradiation dose.

(SCIPP, H.Sadrozinski et al. + SMART collaboration)



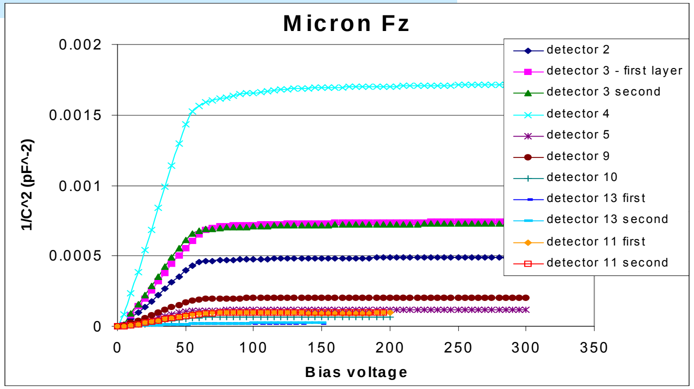
Comparison of CCE between MCz p-type from IRST and FZ p-type from Micron



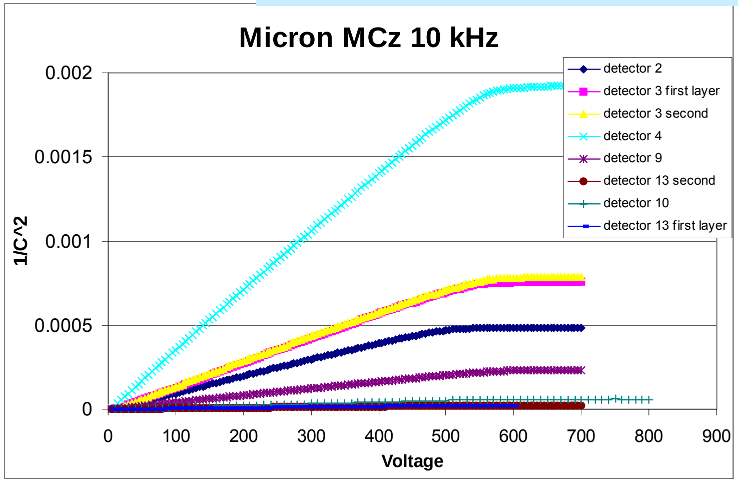
MCZ – p- type (SCIPP, H.Sadrozinski et al. + SMART collaboration)

Results with **Micron 6”**

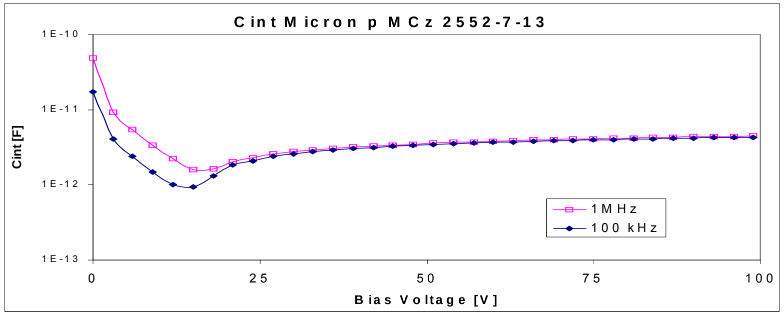
C-V Micron FZ

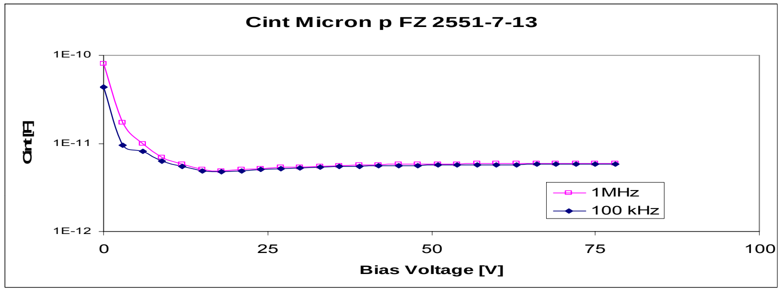


C-V Micron MCz

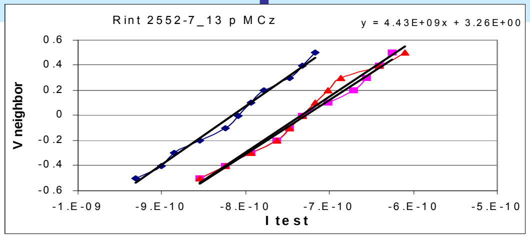


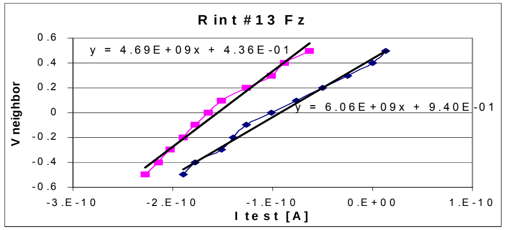
Interstrip Capacitance





Interstrip Resistance



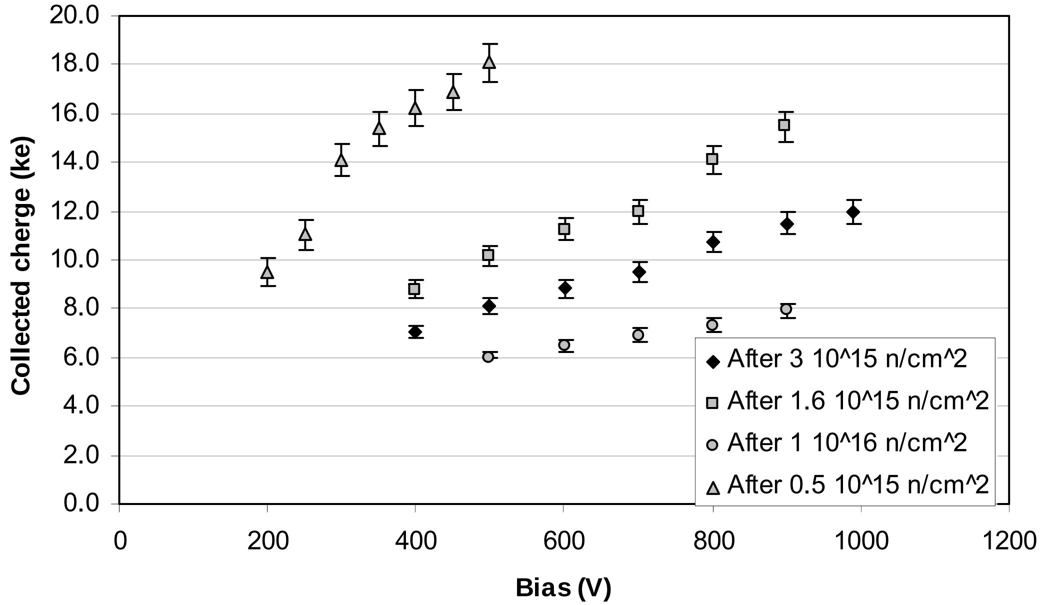


Very Good Isolation: Rint = 4-6*10^9

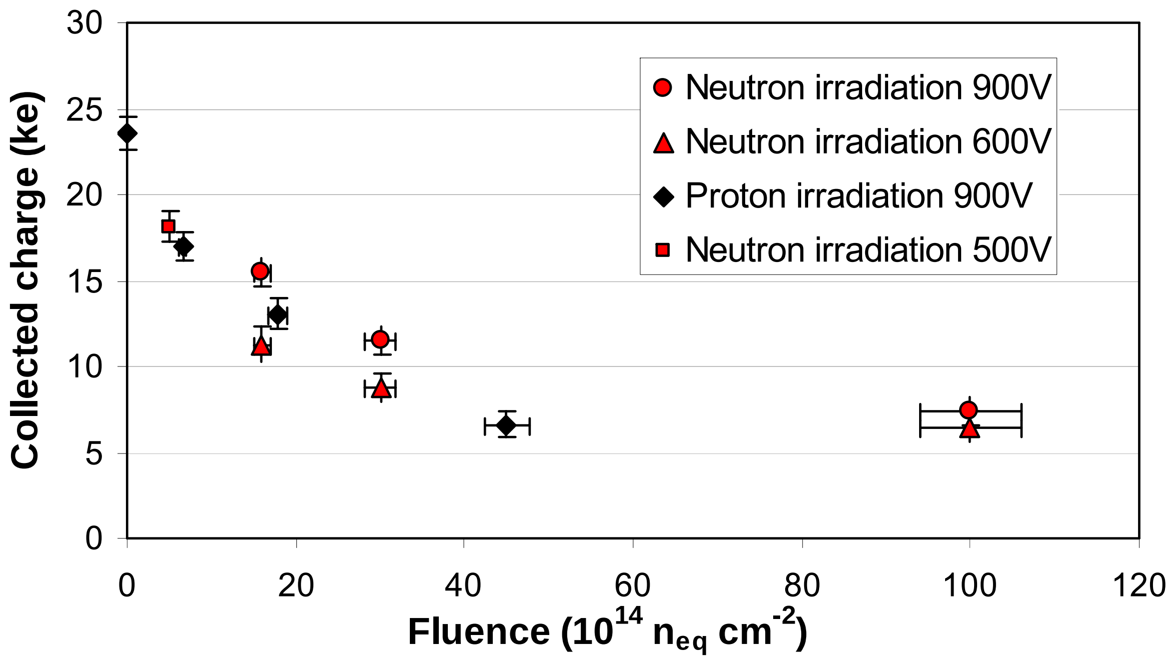
H. Sadrozinski et al., 10^{th} RD50 Workshop

Results with neutron irradiated Micron detectors: 4” mask

Now μ-strip detector CCE measurements up to $1x10^{16}$ n cm^{-2}!!



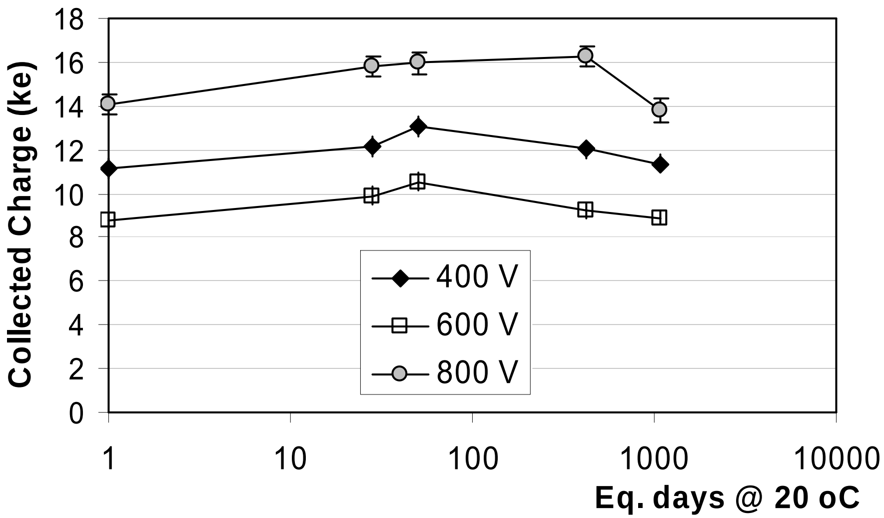
Charge collection efficiency vs fluence for micro-strip detectors irradiated with n and p read-out at LHC speed (40MHz, SCT128 chip).



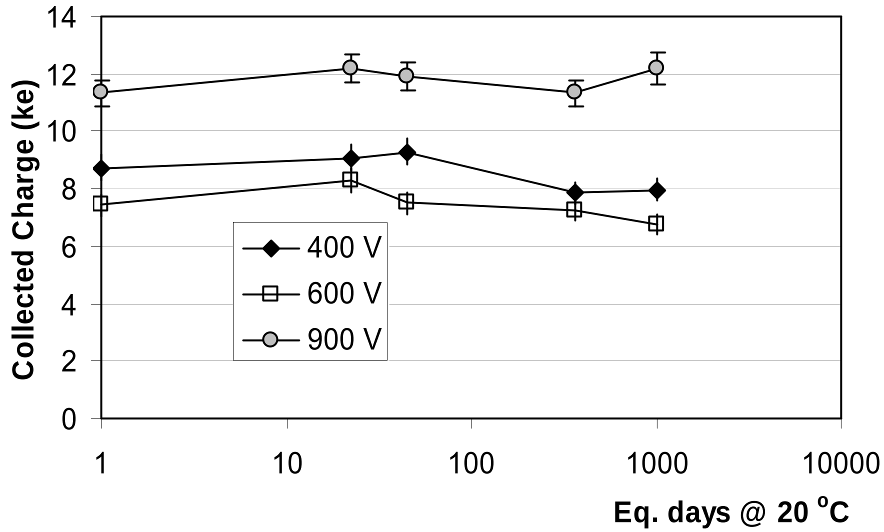
P-type miniature detectors from Micron

Annealing characterisation.

$1.6\ 10^{15}$ n cm^{-2}



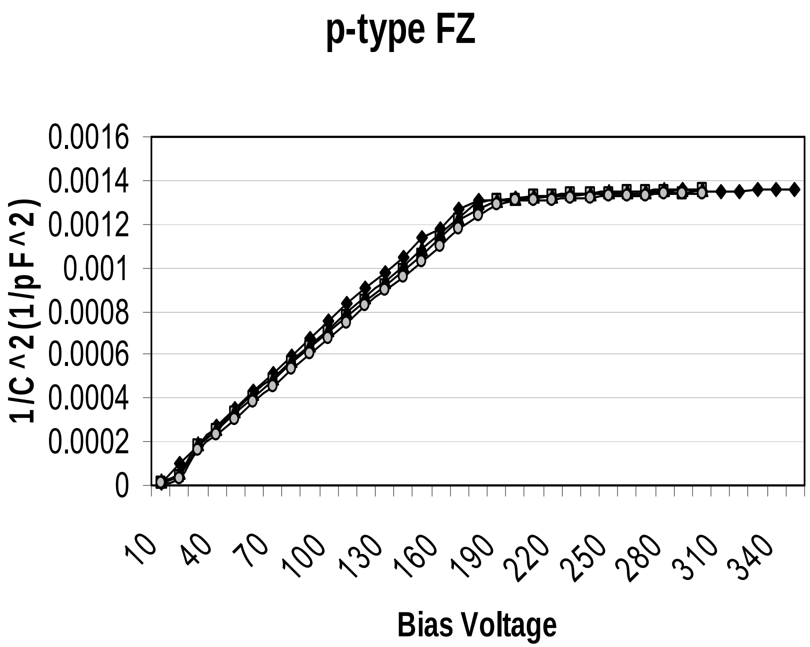
$3.0\ 10^{15}$ n cm^{-2}



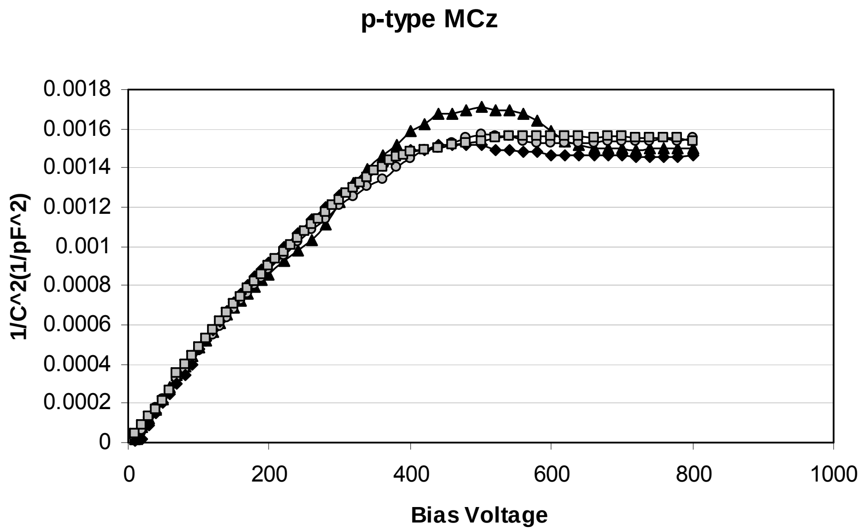
Lower resistivity FZ and MCz detectors from HPK

CV measurements show lower initial resistivity.

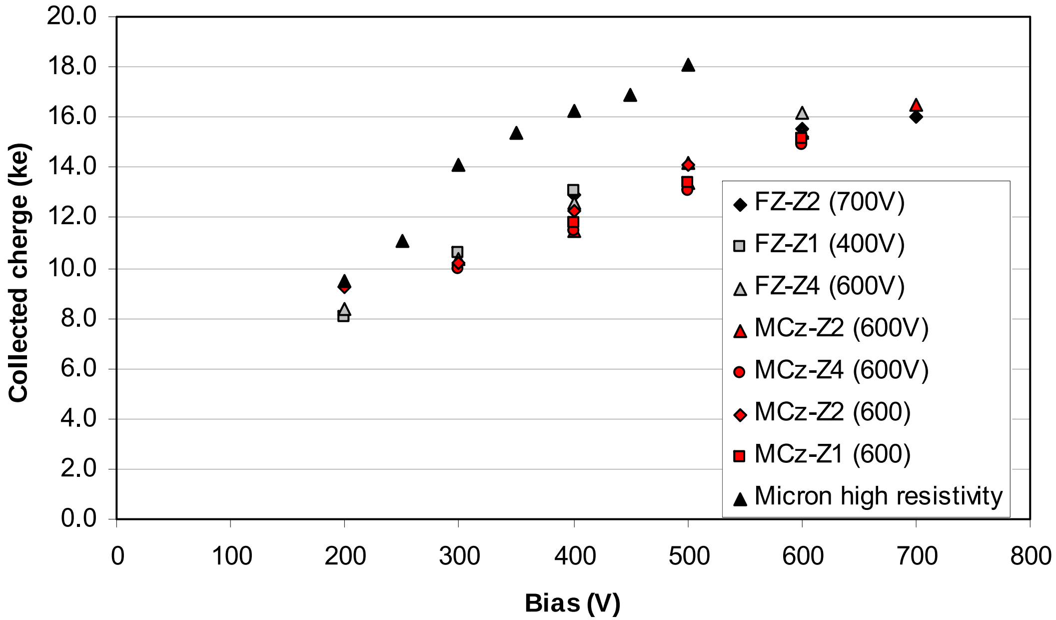
Resistivity of FZ p-type wafers ~ 5kΩ



Resistivity of MCz p-type wafers ~ 2kΩ

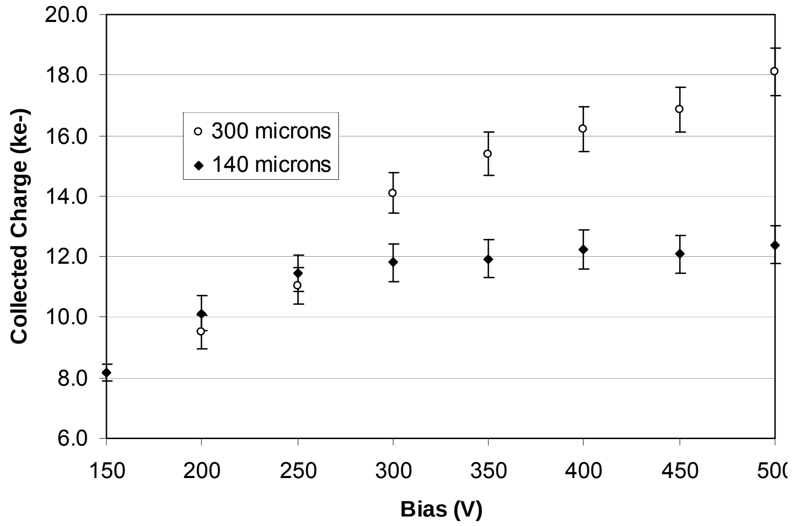


CCE after $5x10^{14}$ n_{eq} cm^{-2}

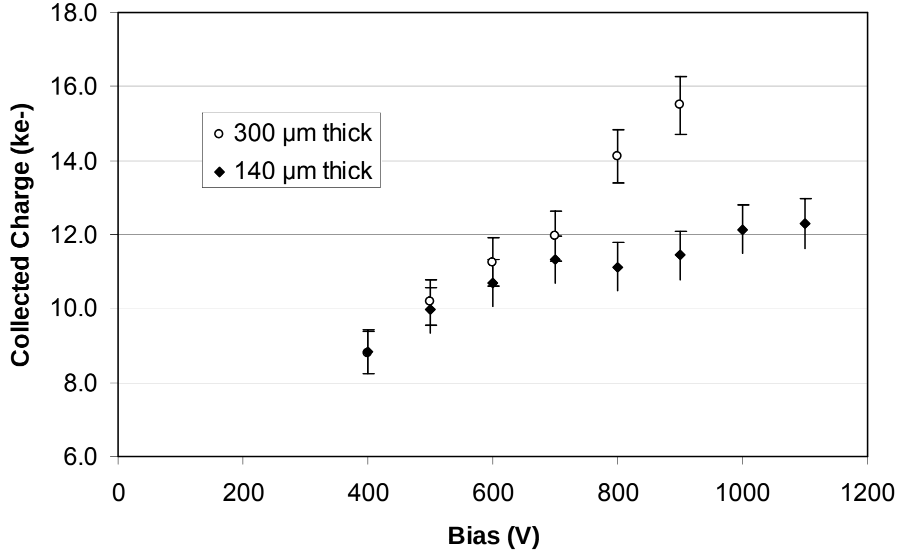


Comparison of CCE with 140µm and 300µm thick detectors from Micron irradiated to various n fluences, up to $1x10^{16}$ cm^{-2}!

$5x10^{14}$ n_{eq} cm^{-2}

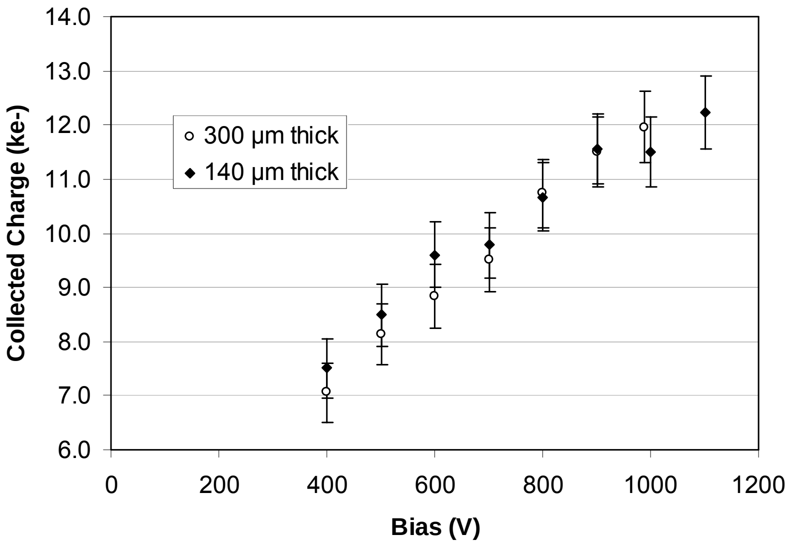


$1.6x10^{15}$ n_{eq} cm^{-2}

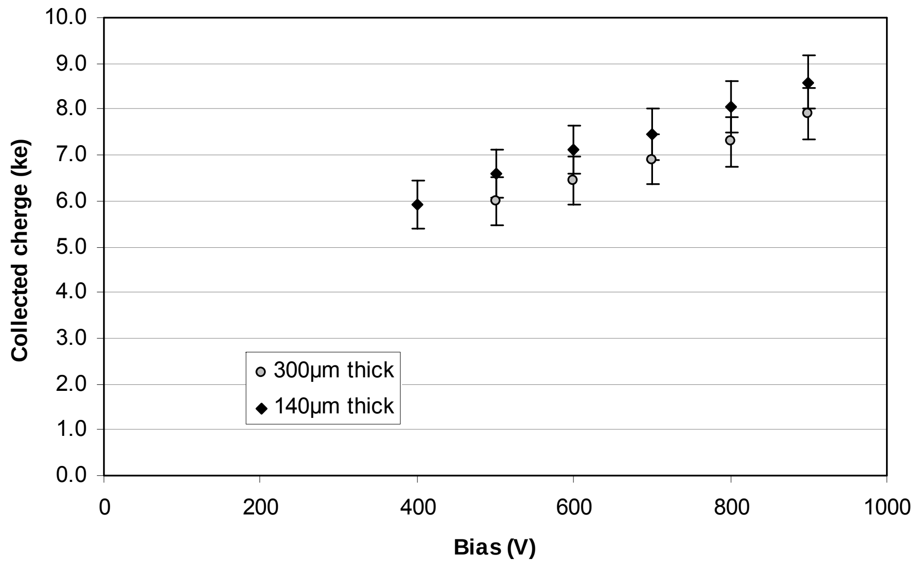


Comparison of CCE with 140µm and 300µm thick detectors from Micron irradiated to various n fluences, up to $1x10^{16}$ cm^{-2}!

$3x10^{15}$ n_{eq} cm^{-2}



$1x10^{16}$ n_{eq} cm^{-2}



SUMMARY:

Mature and well proven technology!

1 p-type module is already present in the LHCb-VELO detector and the replacement is anticipated to be all –p-type!

Exhibits the required radiation hardness, adequate for most of the LHC upgrade detectors

Cheaper and easier to handle than n-in-n

The n-side read-out makes the choice of smaller thickness dictated by the need of reducing the detector mass rather than increase of the signal after irradiation (at least up the remarkable dose of $1x10^{16}$ n cm^{-2}!!).

OUTLOOK:

Systematic investigation of the effect of oxygen in p-type silicon (comparison with results of MCz detectors irradiated with protons)

Systematic investigation of the effect of initial wafer resistivity

Investigate best solution for interstrip isolation (although good results have been obtained by all methods)