Toward the SLHC: simulation of ultra radiation-hard silicon pixel tracking detectors

T. Lari and C. Troncon

INFN and University of Milano, Department of Physics, Milano, Italy

At the Large Hadron Collider the innermost layer of the vertex detectors will be exposed to a radiation fluence of 10^{15} $n_{eq}cm^{-2}$ after three years of operation at the design luminosity of 10^{34} $cm^{-2}s^{-1}$. This fluence is already close to the maximum tolerance of current silicon detector technology. An accelerator upgrade (SLHC) has been proposed, which would increase the luminosity to 10^{35} $cm^{-2}s^{-1}$. The bunch crossing rate will increase from 40 MHz to 80 MHz. The upgrade will require the replacement of the ATLAS and CMS trackers currently under construction. The vertex pixel detectors will be required to be 10 times more radiation-hard, to cope with an increased track density and to be equipped with faster electronics.

The CERN RD50 collaboration is developing silicon sensors with increased radiation hardness. Since the production, irradiation and characterization of segmented detectors of silicon detectors require considerable time and resources, numerical simulations of irradiated detectors are an invaluable tool in the rad-hard solid state detectors R&D.

We present a detailed simulation of irradiated and not irradiated silicon detectors which includes:

- a GEANT4 description of particle interactions with the active volume
- a description of the electric field map inside the sensor
- a model for electron and hole drift in silicon, including field-dependent mobility, diffusion and charge trapping
- a parametrization of radiation damage effects (space charge increase and trapping lifetimes) in different silicon materials
- a weighting field computation of signal induced by the moving charges on the pixel electrodes
- front-end electronic noise, threshold and cross talk

The simulation is used to investigated the use of silicon detectors at the upgraded LHC (SLHC). The detector response, in particular, charge collected, charge collection time, hit multiplicity and detection efficiency, are investigated as a function of radiation fluence.

Submitted to the 2004 IEEE NSS conference *17 May 2004*

The study is presented for sensors using different bulk materials: standard float-zone, diffusion oxygenated float-zone, Czochralski and epitaxial silicon. Both n-side and p-side readout are considered. The better performance is always obtained when the readout is on the side where the electric field is maximum. Different sensor thickness and pixel sizes, as well as different operating conditions (temperature and bias voltage) are investigated. Results are presented as a function of incidence angle and magnetic field, taking into account the effect of the Lorentz force.

Results obtained with the approximation of a constant radiation-induced space charge and with the double peak electric field distribution observed in irradiated sensors are compared.

The left plot of the figure shows the pulse shape of the signal induced on the pixel electrodes. As the fluence is increased the signal becomes shorter because of the reduced depleted depth and short charge carrier lifetime before trapping in the sensor, and the integral of the signal is reduced. The plot on the right shows the sensitivity of the readout electronics required to detect at least 97% of the particles is reported as a function of the fluence for different choices of the sensor material. It is a severe requirement placed on the readout electronic.

Several other results will be shown, with a particular emphasis on the performance which can be achieved at the SLHC under realistic operating conditions and the radiation hardness limits of the current silicon detector technology.

The simulation was developed within the activities of the RD50 collaboration and has been validated with test beam data taken with ATLAS Pixel irradiated detectors.

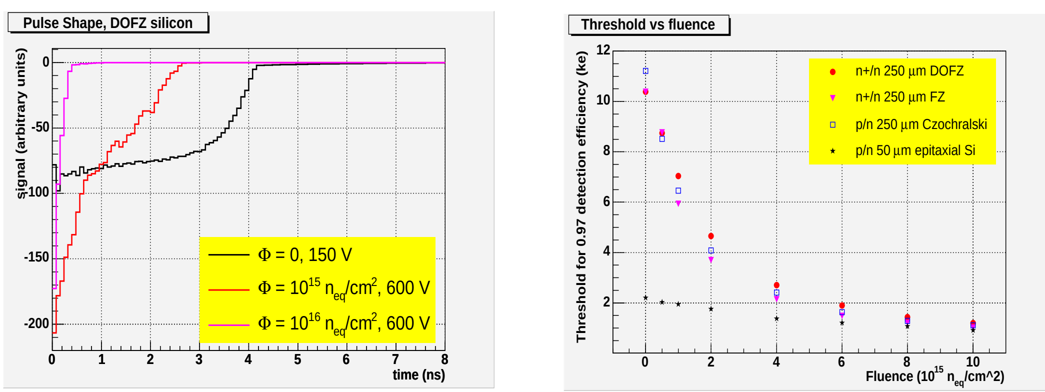

Fig. 1. Left: Signal time profile for DOFZ detectors at various fluences. Right: The detection charge threshold corresponding to a detection probability of 0.97 is reported as a function of the fluence, for different types of silicon pixel detectors.