Fabrication and Radiation Damage Study of a Silicon Detector

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Outline of the Presentation

1. Introduction
2. Working Principle of a Silicon Detector
3. Fabrication of a Silicon Detector
4. Radiation Damage of a Silicon Detector
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Introduction

FoCAL (Forward Calorimeter) is expected to replace the PMD in the future runs of LHC.

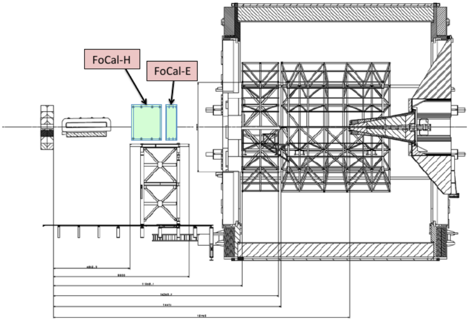

Figure 1: Installation of the FoCal-E at 7m location with FoCal-H detector installed.

→ Covers η range of 3.3 - 5.3

Physics Capabilities

FoCAL will add following capabilities to the existing ALICE experiment

- high precision measurements of direct photons in p+ p and p+A collisions.
- allows reconstruction of π^0 at forward rapidity of large transverse momenta $p_T > 20$ GeV/c.

It is a high-granularity compact silicon-tungsten (Si/W) sampling electromagnetic calorimeter with longitudinal segmentation.

FoCAL Detector

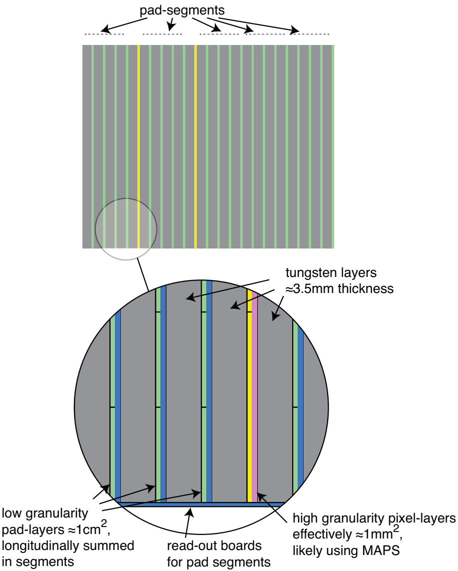

Figure 2: Schematic view of the longitudinal structure of the FoCal-E detector.

Silicon Particle Detector

A lot of semiconducting materials are knows to us. But, Silicon has an unique combination of properties like

- Small band gap (1.12 eV at room temperature)
- High density (2.33 $\mathrm{g/cm^3}$) leads to a large energy loss per traversed length of the ionizing particle
- Mobility of electrons and holes is surprisingly high
- Excellent mechanical rigidity; integration with readout electronics
- Simultaneous precise measurement of energy and position with high readout speed
- Direct availability of signals in electronic form

Working Principle of a Silicon Detector

In a 300 μm thick sensor, MIP[1] creates $\sim$ 25000 e-h pairs whereas, the intrinsic concentration of e-h pairs at 300 K is $\sim 10^{11}\text{cm}^{-3}$.

A simple p-n junction can be used to detect particles.

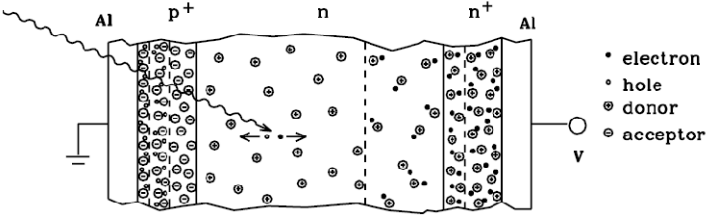

Figure 3: A p-n junction, creation of e-h pairs by the incoming particle.

[1]Minimum Ionizing Particle corresponds to 90 KeV in Silicon

Fabrication of a Silicon Detector

Like any other electronic device, the starting element is silicon wafers, obtained after extensive purification and distillation of simple mined quartz sand $(\mathrm{SiO_2})$.

Checklist:

1. Silicon wafer type is decided (n or p, 110 or 111)
2. Lithography patterning masks are ready

Fabrication of a Silicon Detector

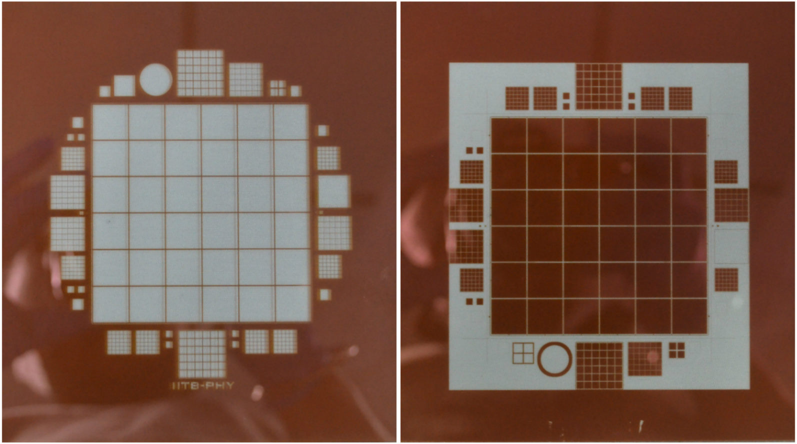

Figure 4: (Left) SiO_2 patterning, (Right) Aluminum patterning mask plates for a pad detector.

Process Description

Summarizing the detector fabrication steps

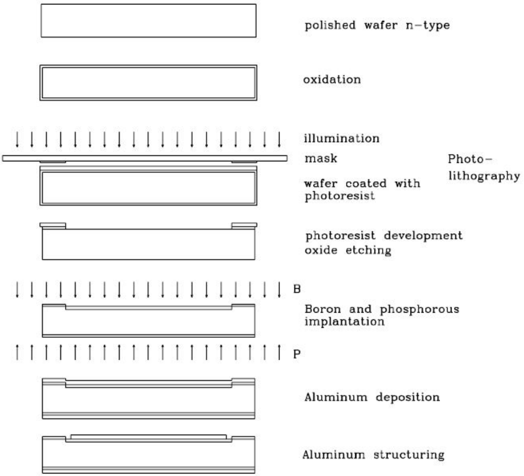

Figure 5: Some basic steps in the silicon device fabrication process [1].

SIMS Analysis

Maximizing the sensitive region of the diode and the parameters to optimize are,

→ Doping concentration

→ Annealing temperature and time

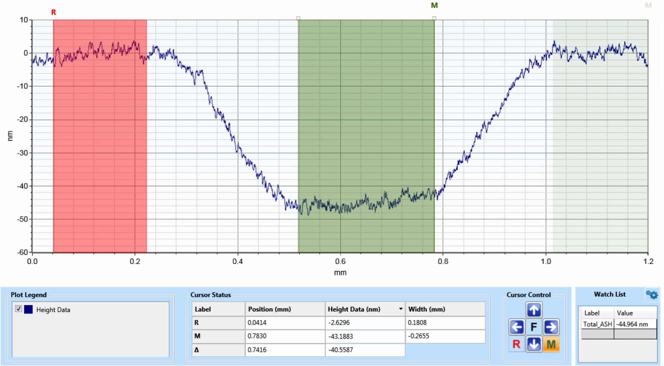

Figure 6: Profilometer graph of the crater depth .

First Detector

First pad detector prototype

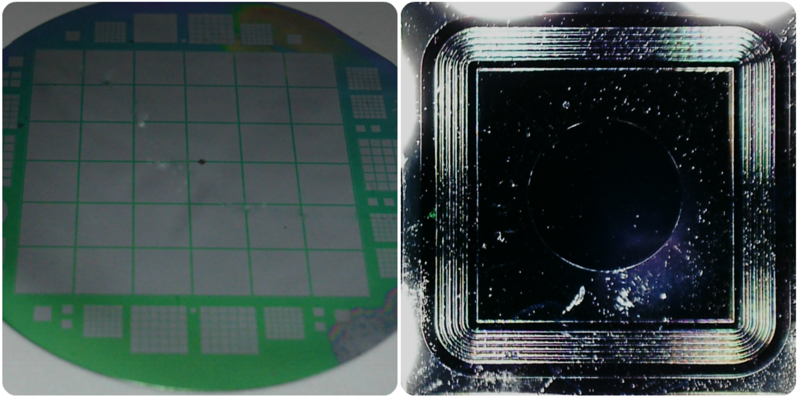

Figure 7: Silicon pad detector fabricated at IITBNF.

Characterization

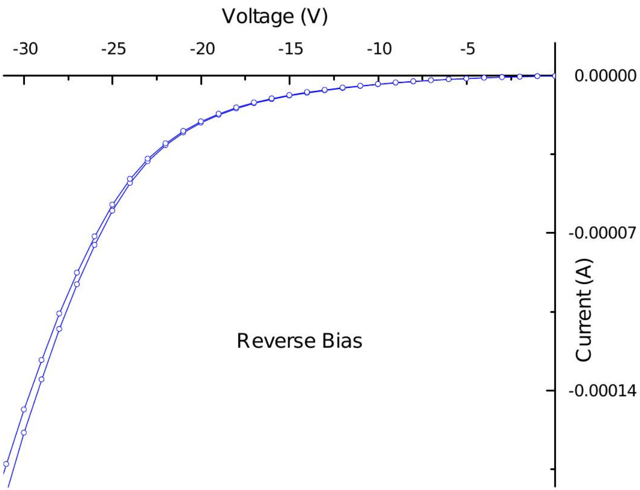

Figure 8: I-V Characteristics of silicon pad detector fabricated at IITBNF.

Future Work

In the next couple of months,

1. Characterization of strip and pad detectors.
2. Integrate it with read-out boards.
3. Compare the performance of 100 and 111 silicon wafer detectors.
4. Particle beam testing.

Effect of Particles on a Detector

The creation of e-h pairs through ionization is a reversible process. On the contrary, bulk damage is caused by interaction of incident particles with the nuclei of the lattice atoms which is not reversible in most cases.

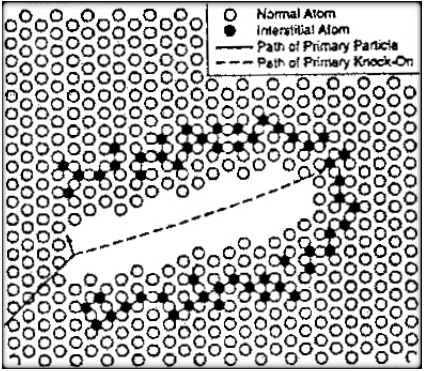

Figure 9: Schematic of the displacement of atoms to interstitial site [3].

Radiation Damage

The damage caused by different particles is compared using the Non Ionizing Energy Loss (NIEL) hypothesis. It summarizes all the energy deposited in the bulk which has not been used for fully reversible process of ionization.

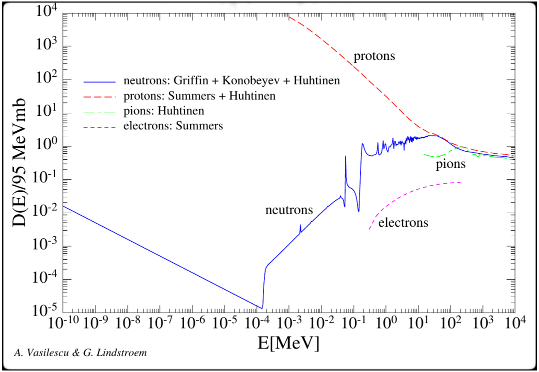

Figure 10: Displacement damage functions D(E) normalized to 95 MeVmb for neutrons, protons, electrons and pions with incident kinetic energy E[MeV] [4].

Radiation Damage

We used Geant4 & Fluka to simulate the particle transport in material; integrated PYTHIA to generate LHC like events.

Tracking in Geant

- Pre-assigned decay products and energy
- Each track has multiple steps and each step has at least two points in the detector volume
- Information of a particle can be extracted at such points in the volume

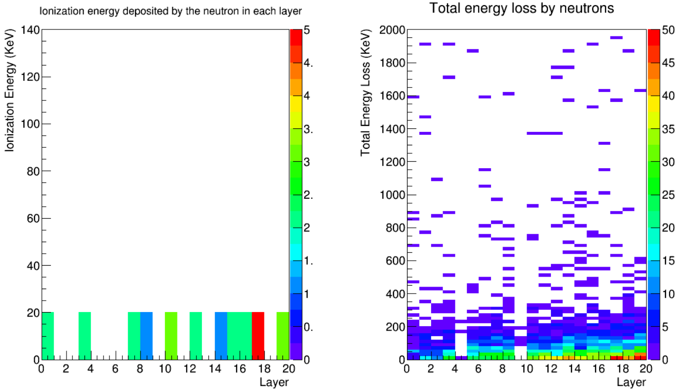

Figure 11: Plots of a) ionization energy deposited, b) total energy lost in each layer.

So, we decided to use the NIEL data and the incoming kinetic energy distribution to estimate the 1 MeV Neutron equivalent flux.

The annular region of $8 < r < 20$ cm receives the maximum flux

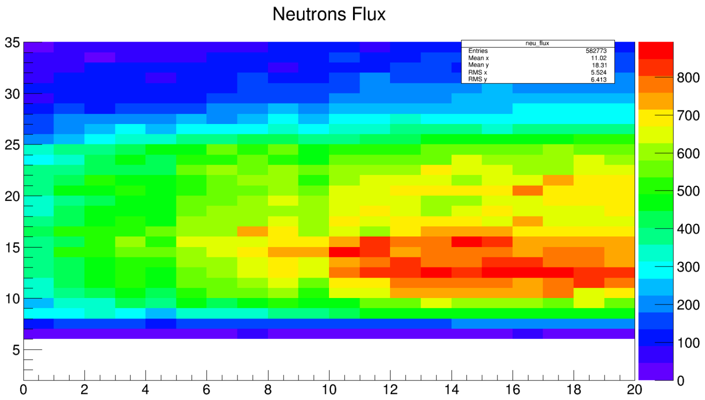

Figure 12: Radial distribution of Neutron flux in each layer

Comparison between Geant4 and Fluka [2]

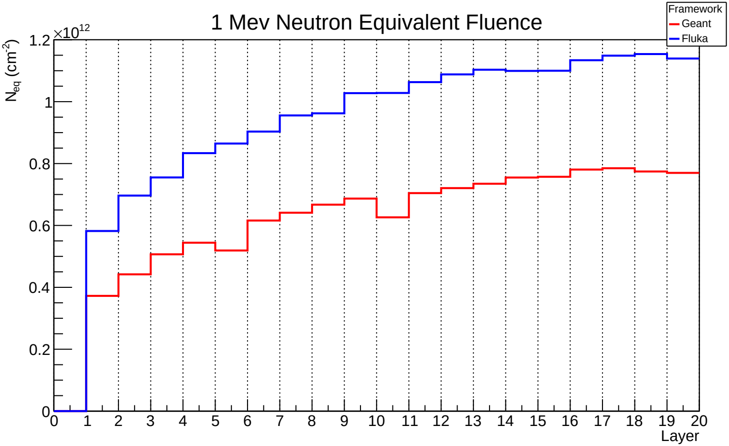

Figure 13: NIEL weighted 1 MeV Neutron equivalent fluence for an integrated luminosity of 10 nb^{-1} Pb-Pb + 50 nb^{-1} p-Pb + 6 pb^{-1} pp for each layer in FoCAL.

[2] ionizing radiation doses expected during ten years of operation

Comparison between Geant4 and Fluka

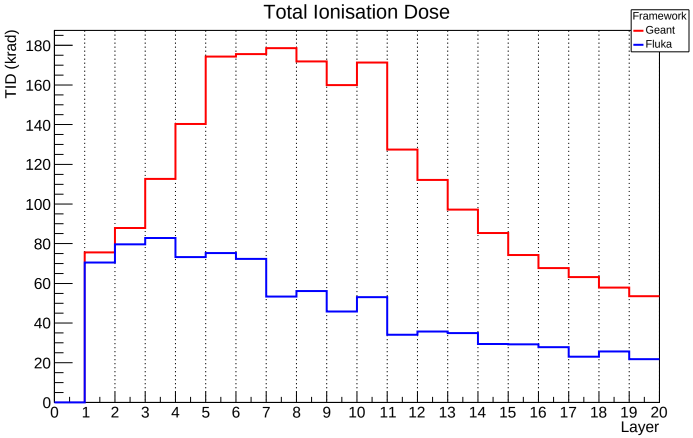

Figure 14: TID for an integrated luminosity of 10 nb^{-1} Pb-Pb + 50 nb^{-1} p-Pb + 6 pb^{-1} pp for each layer in FoCAL.

Results

	TID (krad)	1 MeV $N_{eq}(cm^{-2})$
FoCAL (Geant4)	118	$5.4 * 10^{11}$
FoCAL (Fluka)	178.5	$8.34 * 10^{11}$
ITS L0	54.0	$7.7 * 10^{11}$
ITS L3	0.94	$3.3 * 10^{11}$

Table 1: TID, 1 MeV Neutron equivalent and Charged particle fluence for an integrated luminosity of 10 nb^{-1} Pb-Pb + 50 nb^{-1} p-Pb + 6 pb^{-1} pp in FoCAL and ITS.

Conclusions

- ITS TDR reports MIMOSA chip sensor to tolerate dose of $\sim$ 1 Mrad and 10^{13} (1 MeV Neutron equivalent cm^{-2})
- Independent estimates from both, Geant4 and Fluka are in reasonable agreement and predict FoCAL detector to be safe from radiation damage due to high fluence as expected after LS2.

References

- Semiconductor Radiation Detectors, Gerhard Lutz, Chapter 4 & 5
- CMS Collaboration, CERN
- G.H. Kinchin and R.S. Pease, “The Displacement of Atoms in Solids by Radiation,” Reports on Progress in Physics, vol. 18, pp. 1-51, 1955.
- A. Vasilescu (INPE Bucharest) and G. Lindstroem (University of Hamburg), http://rd50.web.cern.ch/RD50/NIEL/default.html

Damage Function

$$D(E) := \sum_{0}^{E_{max}} \sigma_\nu(E) f_\nu(E, E_R) P(E_R) dE_R$$

The index ν indicates all possible interactions between the incoming particle with the Energy E and the silicon atoms in the lattice leading to displacements in the lattice. σ_ν is the cross section corresponding to the reaction with index ν and $f_\nu(E, E_R)$ gives the probability for the generation of a PKA with recoil energy E_R by a particle with Energy E undergoing the indicated reaction ν. $P(E_R)$ is the so called Lindhard partition function with which the portion of recoil energy that is deposited in form of displacement damage can be calculated analytically.

Thank You!