Contribution ID: **73** Type: **Oral**

Signal formation in heavily irradiated silicon particle sensors under charge multiplication

Monday 25 February 2019 15:20 (20 minutes)

Over the past years, an in-depth study of irradiated and annealed p-type silicon strip sensors as they will be used for HL-LHC Upgrades was performed. Measurements of the collected charge, noise and cluster size were regularly performed as a function of increasing annealing time and bias voltage. A large number of sensors under study showed a signal larger than the one originally deposited. This effect, known as charge multiplication (CM), can be attributed to an increase of the positive effective doping concentration, which in turn increases the electric field, in particular close to the n+ implants. This study reveals a number of interesting features which can enlighten the understanding of CM and have significant consequences for using these sensors at the HL-LHC after heavy irradiation. Beta source measurements with ALIBAVA readout and laser measurements in a TCT system were performed. In the TCT system, the transient current was recorded to correlate charge collection performance with signal formation. Emphasis is placed on two interesting results: when charge multiplication is significant, the signal pulses become significantly prolonged. The cluster size, which usually decreases in multiplication, gets broader.
This slow signal has not been reported before and constitutes a potential threat to HL-LHC applications which are based on fixed short signal shaping times due to the time structure of bunches in the LHC, where a large fraction if signal might be too late for the front-end ASICs. The delayed signal can be attributed to the large amount of holes generated by CM, that travel as a cloud to the backside of the sensor, generating a self-screening effect, or the so called "plasma"effect.

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Session Classification: Session 2: Planar Sensors (1)