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Investigation of low gain avalanche detectors exposed to proton fluences beyond $10^{15}\mathrm{n_{eq}/cm^2}$ and gamma dose up to 2.2 MGy

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Low gain avalanche detectors (LGADs) fabricated by Hamamatsu Photonics KK (HPK) and Fondazione Bruno Kessler (FBK) have been evaluated for performance before and after exposure to gamma and proton irradiation. LGADs promise excellent timing resolution, which can mitigate the pileup associated with high luminosity at hadron colliders. Their timing information can also be used to distinguish long-lived particles with resolvable secondary vertices at lepton colliders. The most highly irradiated LGADs at the HL-LHC will be subject $2.5 \times 10^{15}\mathrm{n_{eq}/cm^2}$ of hadron fluence and 2.2 MGy of total ionizing dose during the LHC's Run 4; their timing performance must tolerate this. HPK and FBK LGADs have been irradiated with 400 and 500 MeV protons respectively up to the Run 4 hadron equivalent fluence. HPK LGADs were also exposed to 2.2 MGy of gamma dose. Measurements of the irradiated LGADs' leakage current, capacitance, charge collection, and timing performance are presented. A timing resolution better than 70 ps is observed for all proton fluences. Charge collection is below 10 fC for the HPK sensors after $(0.74 \pm 0.22) \times 10^{15}\mathrm{n_{eq}/cm^2}$, and for the FBK sensors after $(0.75 \pm 0.20) \times 10^{15}\mathrm{n_{eq}/cm^2}$ for all operating voltages below 600 V. A set of 2x2 arrays of both the FBK and HPK LGADs were produced to study the inter-pad characteristics. The inter-pad resistance for the HPK LGADs stayed above 10 MΩ beyond $0.7 \times 10^{15}\mathrm{n_{eq}/cm^2}$, and the inter-pad resistance of the FBK LGADs fell slightly below 1 MOhm after $10^{15}\mathrm{n_{eq}/cm^2}$. Observations of the punch-through voltage and inter-pad isolation for fast signals are reported. The gamma irradiated devices show increase in leakage current and loss in inter-pad resistance comparable to those of the proton irradiated sensors, but minimal gain layer degradation.

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