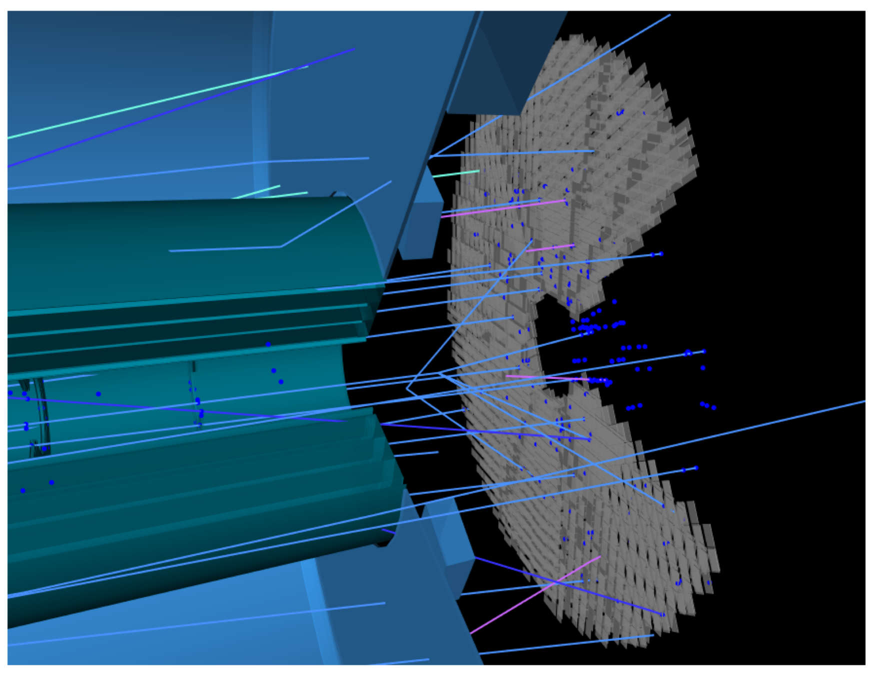
Radiation hardness of Carbon enriched LGAD sensor developed by IHEP-IME

WU Kewei[12](wukw@ihep.ac.cn), Xuewei Jia[12] , ZHAO Mei[1], YANG Tao[12], Mengzhao Li[12] João Pedro Barreiro Guimarães da Costa[1], LIANG Zhijun[1], SHI Xin[1]
1.Institute of High Energy Physics, Chinese Academy of Science, Beijing, China; 2.University of Chinese Academy of Science, Beijing, China.

Introduction

One of the most important parameters of the HGTD will be the radiation hardness of the sensors and electronics. Since the HGTD will be installed with a pseudo-rapidity coverage of $2.4 < |\eta| < 4.0$, it is essential that the detector can withstand the radiation levels throughout the HL-LHC operations. By going to higher fluences the increase in bias voltage can only partially compensate for the loss in gain due to the acceptor removal. A charge of 4 fC was found to be the lower limit that still satisfies the HGTD science requirements in terms of hit efficiency and time resolution taking into account the ALTIROC jitter.[1] But operation in high voltage (> 700 V) is highly risky for SEB (single event burnout) which is unrecoverable.

Keywords: Radiation hardness, Gain, Acceptor removal, Charge collection, Time resolution, Single event burnout.



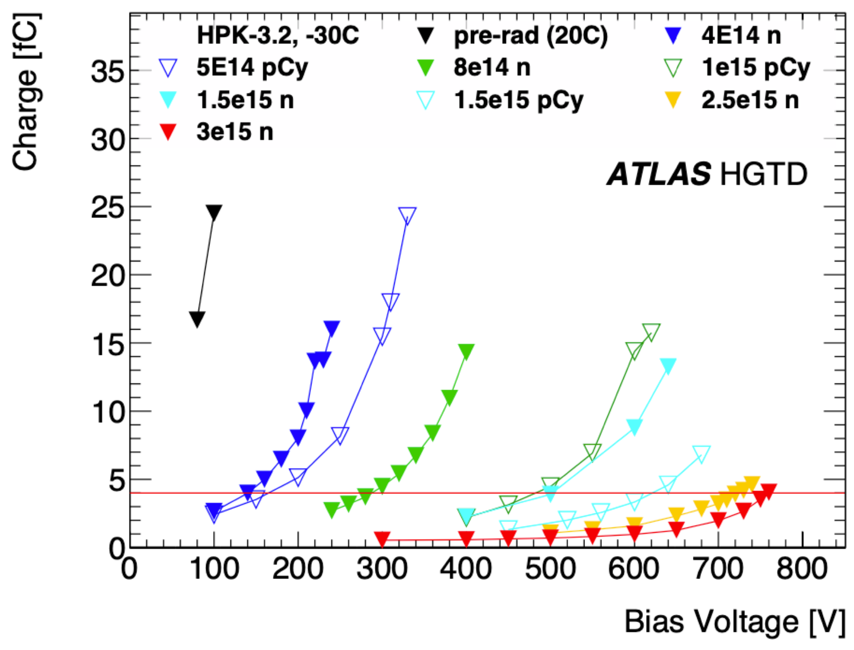
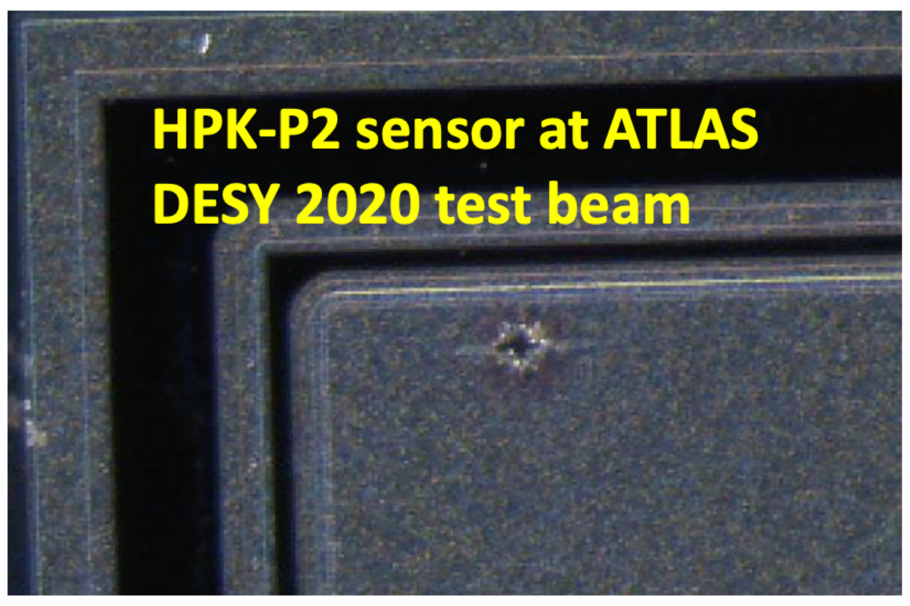


Figure 1 (left): Visualization of a simulated QCD dijet event showing the trajectories of charged particles and the resulting simulated hits in the HGTD.[1] (right): Various components of HGTD.[1]



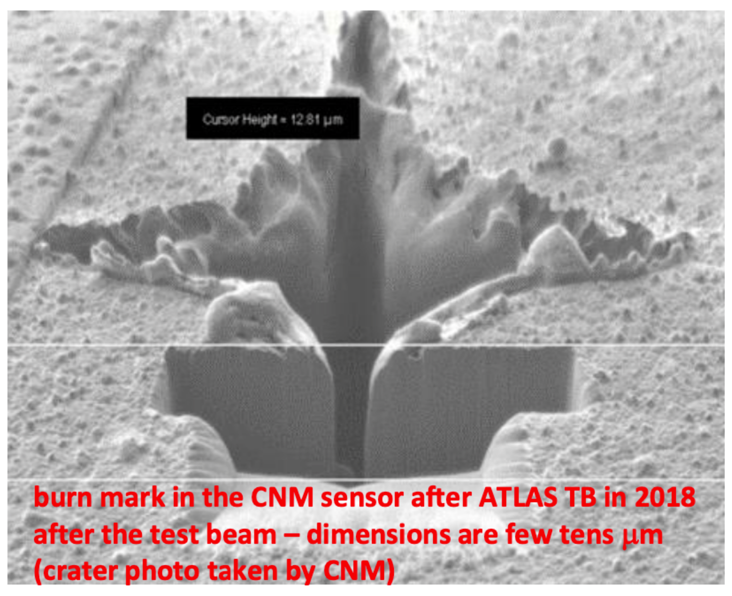
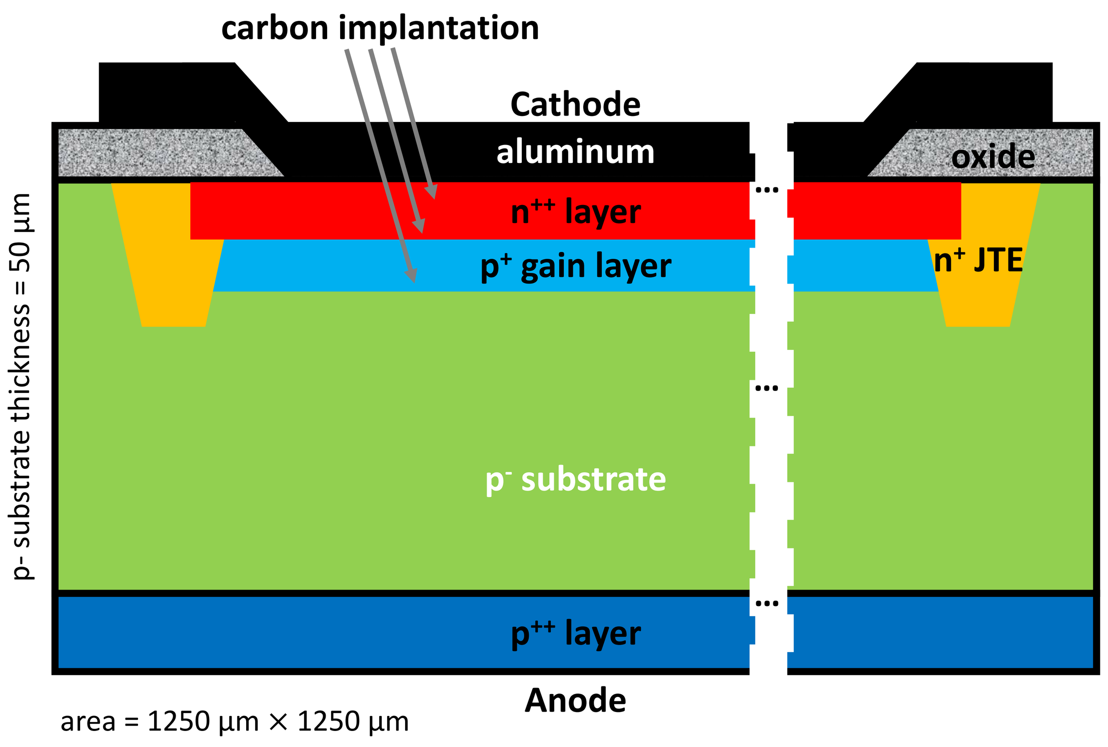


Figure 2 (left): Burning damage on HPK LGAD sensor during test beam at DESY (right): Burn mark in the CNM LGAD sensor after test beam.

Carbonated LGAD

The addition of Carbon in the gain layer reduces the acceptor removal. The required bias voltage is thus lower than for other types to reach the target charge of 4 fC at $2.5 \times 10^{15}\ n_{eq}\ cm^{-2}$. The presence of carbon leads to an Si self-interstitials (I) under saturation which, in turn, reduces boron diffusion.[2]



$C_s + I \leftrightarrow C_i$ vs $B_s + I \leftrightarrow B_i$

$C_s\ B_s$ competing for Interstitial

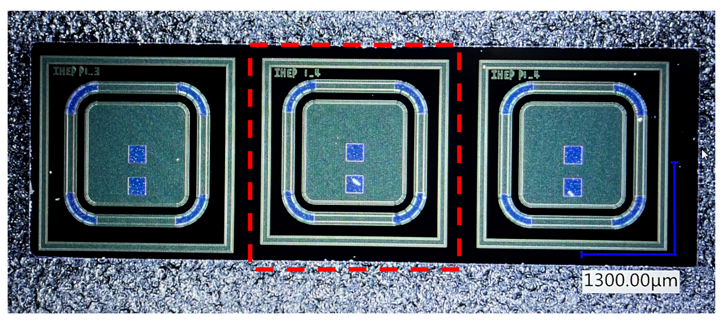
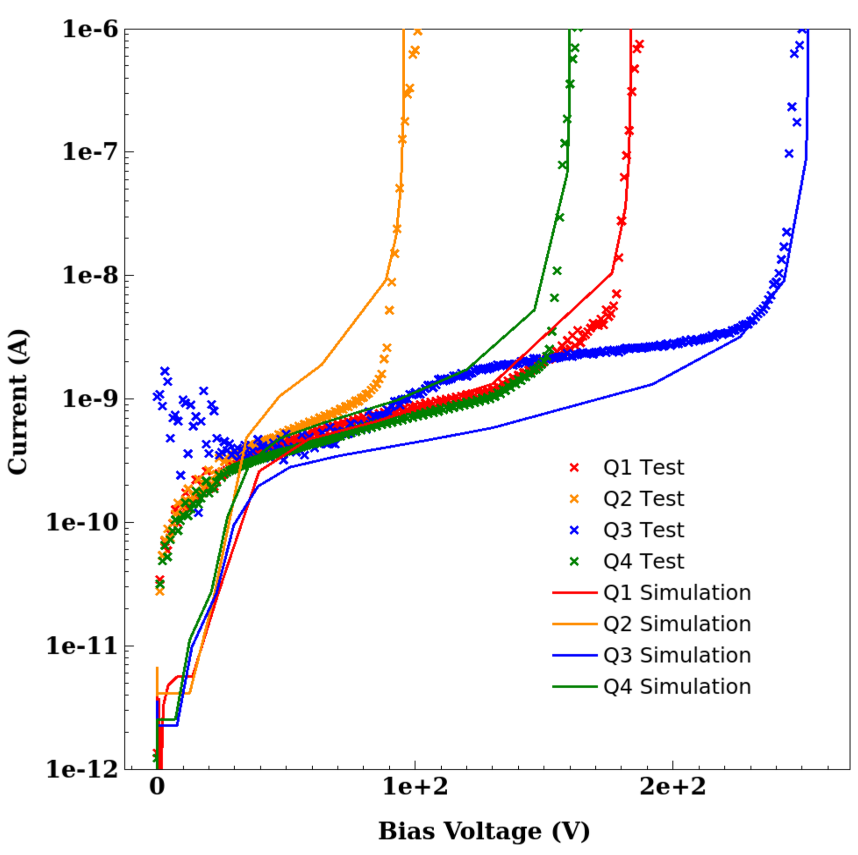


Figure 3 (left): Carbonated LGAD structure sketch (not to scale). (right): IHEP-IMEv2 test unit contains a LGAD sensor and two PIN Sensors.

Sensor Design



Simulation Calibration

Figure 4 shows the IV simulation results are in good consistent with IV test result. This benefit from the process simulation calibration and device simulation calibration based on IHEP-IMEv1 results.

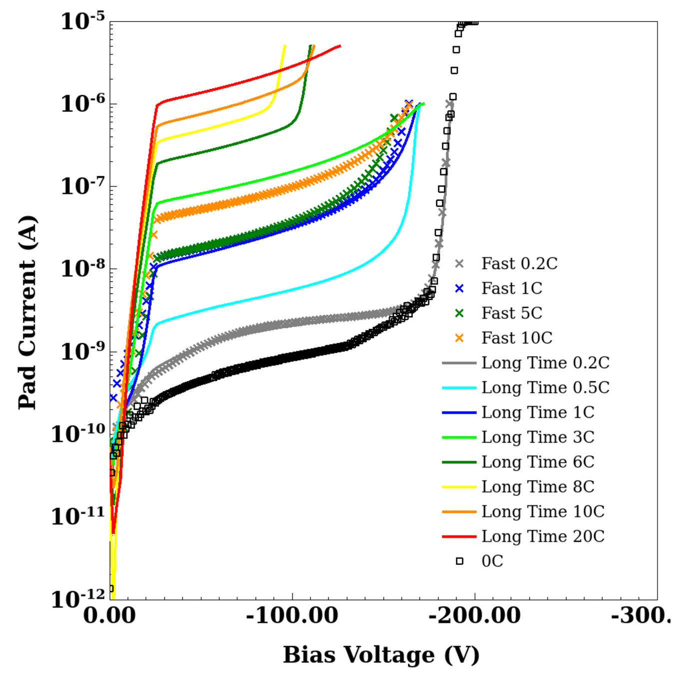
Wafer	Quadrant	Boron	Phosphorus
1	I	Medium	Low
1	II	High	Low
1	III	Medium	High
1	IV	High	High

Figure 4: IV Simulation comparing with calibrated TCAD Simulation

Non-Irradiated Sensor Test

Carbonated LGAD Sensor IV & CV

IV shows the leakage currents largely increase with carbon dose, CV shows the V_{gl} slightly increase with carbon dose.



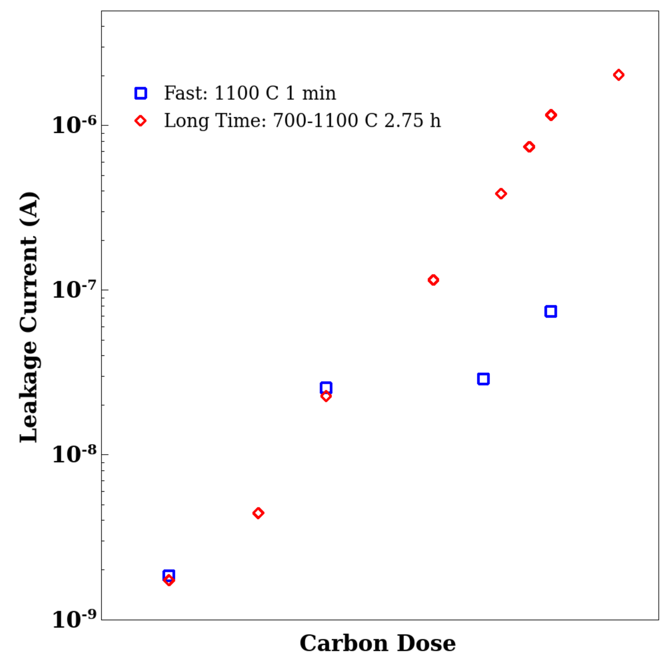
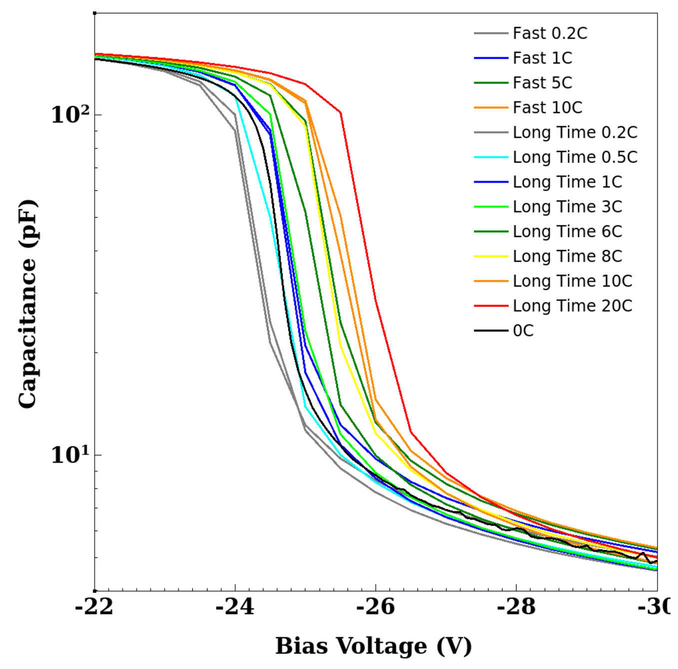


Figure 5 (left): Non-Irradiated carbonated LGAD sensor IV test. (right): Non-Irradiated carbonated LGAD Sensor leakage current level at 80 V.



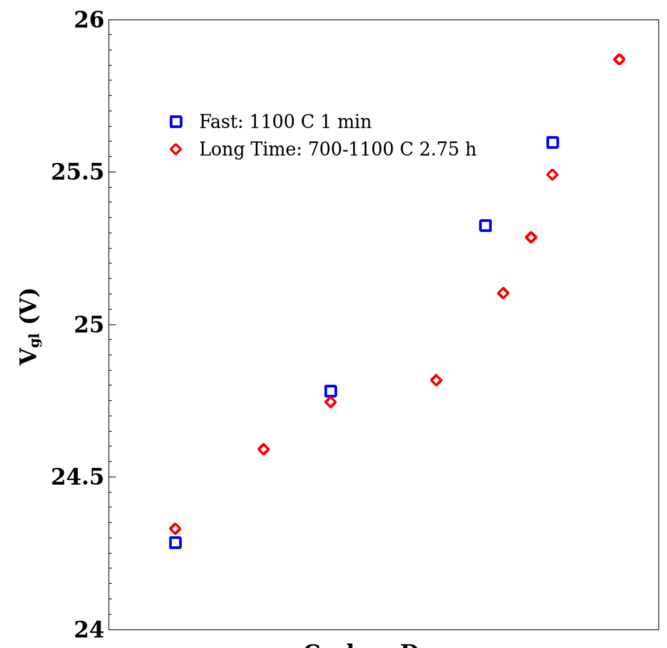
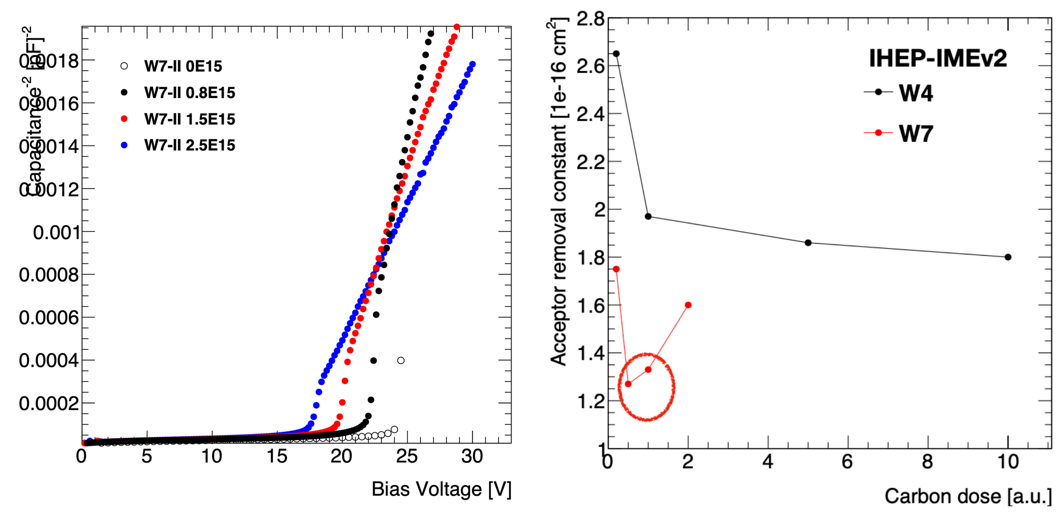


Figure 6 (left): Non-Irradiated carbonated LGAD sensor CV test. (right): Non-Irradiated carbonated LGAD sensor V_{gl}.

Irradiated Sensor Test

Carbonated LGAD Sensor Acceptor Removal Factor

CV and V_{gl} were tested after different radiation dose. the formula showed the c (acceptor removal factor) was the exponential term which describe the effective doping concentration changes.



$$V_{gl}(D_{rad}) = V_{gl}(0)e^{c \times D_{rad}}$$

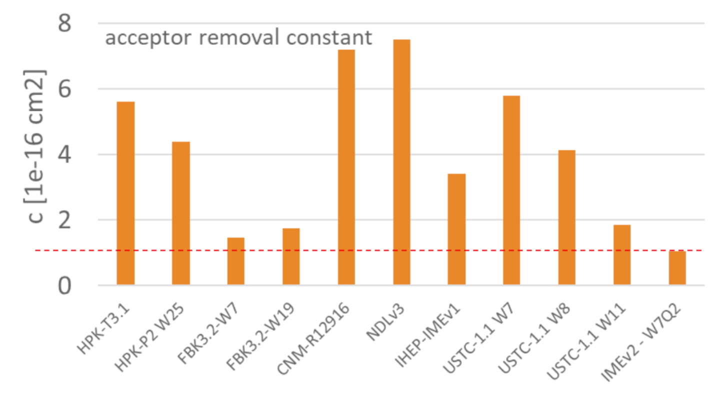
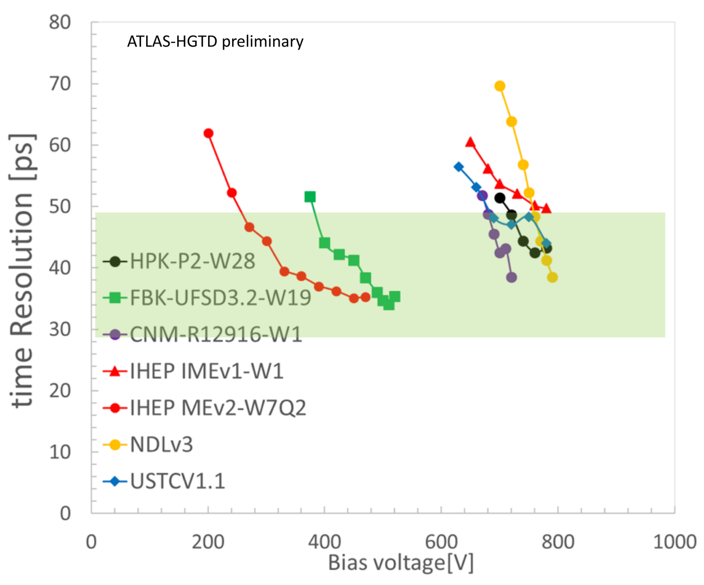


Figure 7 (left): CV measurement after different radiation dose showing V_{gl}. (mid): Acceptor removal factors of IHEP-IMEv2 sensors, W7Q2 has the smallest value among W4 andW7. (right): Acceptor removal factors of different vendors, IHEP-IMEv2 W7Q2 has the smallest value.

Time Resolution and Charge Collection

The β source test for checking time resolution and collected charge. The result from vendors around indicated IHEP-IMEv2 W7Q2 were the most radiation hard LGAD sensors.



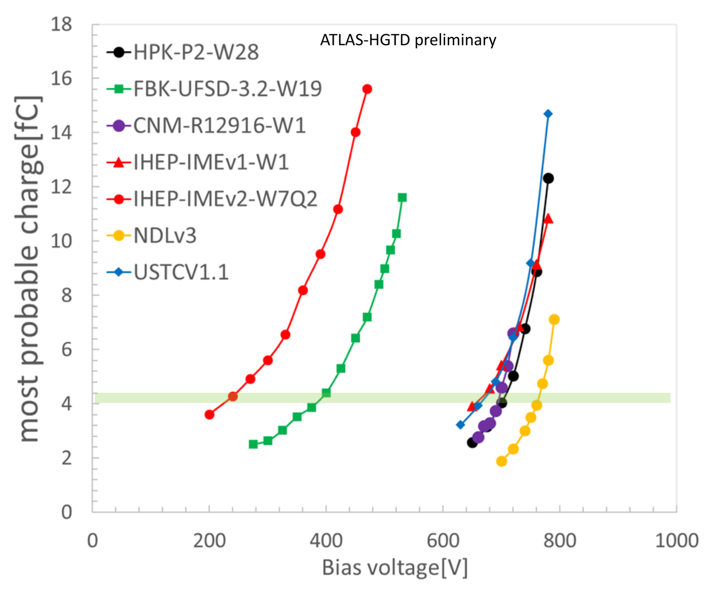


Figure 8 (left): Time resolution results of different vendors LGAD. (right): Collected charges of different vendors LGAD

Summary

Comparing with HPK, FBK, CNM, NDL, and USTC Sensors, IHEP-IMEv2 W7Q2 have the best radiation hardness until now:

- Smallest acceptor removal factor
- Lowest bias voltage for 30-50 ps time resolution
- Lowest bias voltage for 4 fC Charge Collection
- Reach HGTD specifications for 2.5e15 with < 450 V
- Survived in the test beam several days with many millions of events at operational voltage

Reference

[1] ATLAS Collaboration, Technical Design Report: A High-Granularity Timing Detector for the ATLAS Phase-II Upgrade.
[2] R. Pinacho, Carbon in silicon: Modeling of diffusion and clustering mechanisms.