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Characterization, time resolution and proton hardness of IHEP-NDL LGAD sensors

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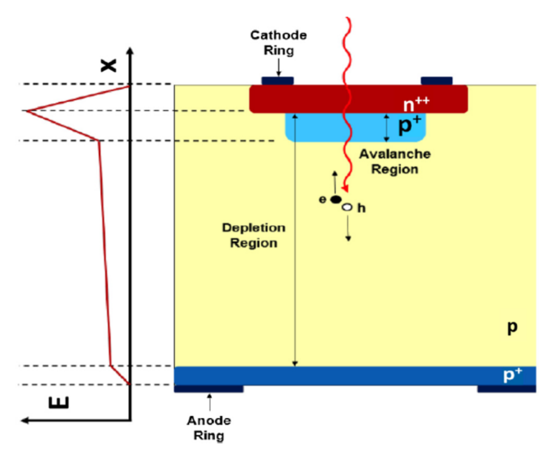
Introduction

- Why timing and LGAD?

Future particle physics experiments can benefit from high-precision timing information in many aspects of 4D tracking, pile-up rejection, particle identification.

A High-Granularity Timing Detector (HGTD) is proposed and being developed for the ATLAS Phase-II upgrade, to mitigate the pile-up effects in High-Luminosity LHC (HL-LHC). **Low gain avalanche diode (LGAD)** is the best candidate for HGTD and 4D detector.



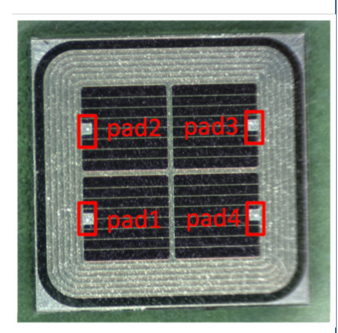
LGAD structure

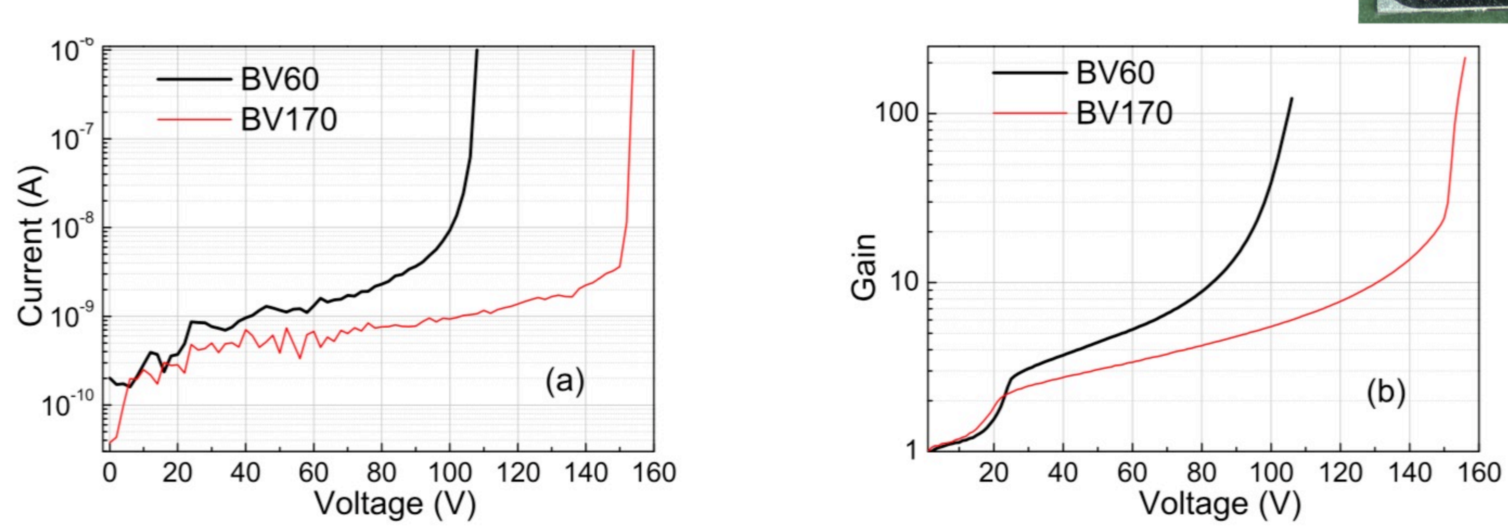
- Why irradiation hard?

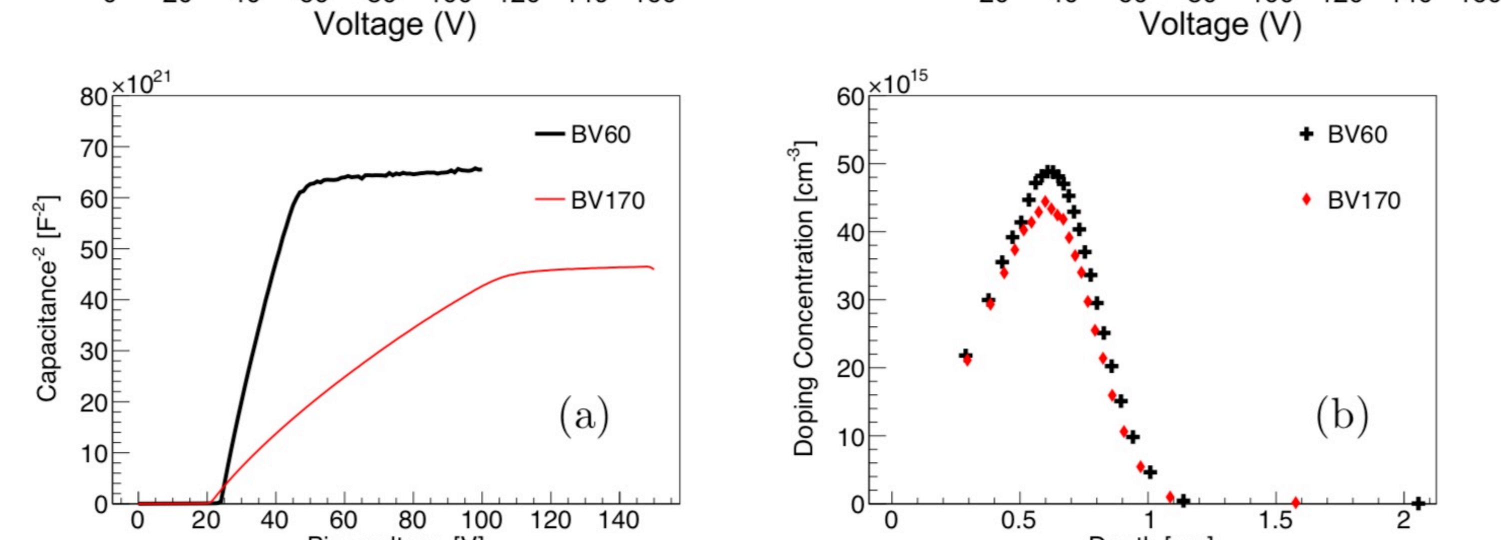
- The silicon detectors in high energy collider HL-LHC will be exposed in high hadron fluences. Radiation-resistant detectors play a key role in the flavor physics of CEPC. Higher radiation level damaging the time resolution of the detector is becoming a serious problem.

IHEP-NDL LGAD sensor

- LGAD sensor developed by the Beijing Normal University Novel Device Laboratory (NDL) cooperated with IHEP.
- n-on-p type with different volume resistivity: BV60 and BV170.
- 2x2 pads, pad size 1.3x1.3mm^2, total size 3.2x3.2mm^2.
- The physics thickness is 300um, epitaxial layer is 33um.
- Current-voltage (I-V) and capacity-voltage(C-V) curves are measured at room temperature.

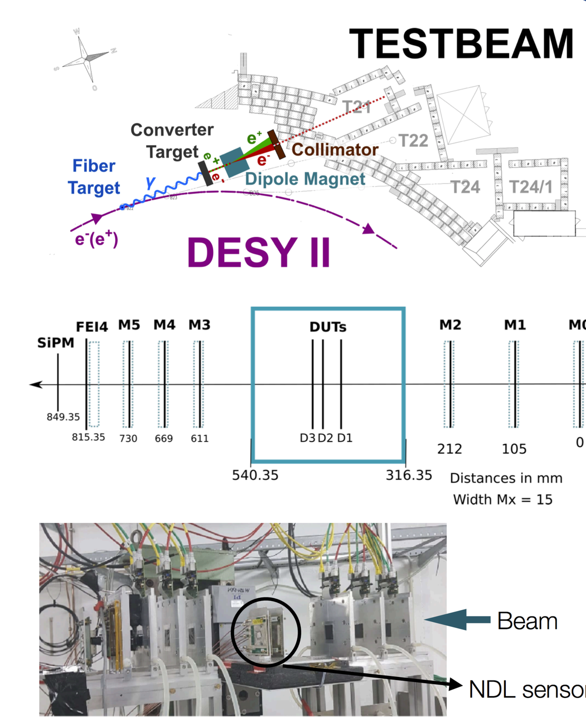






Test Beam

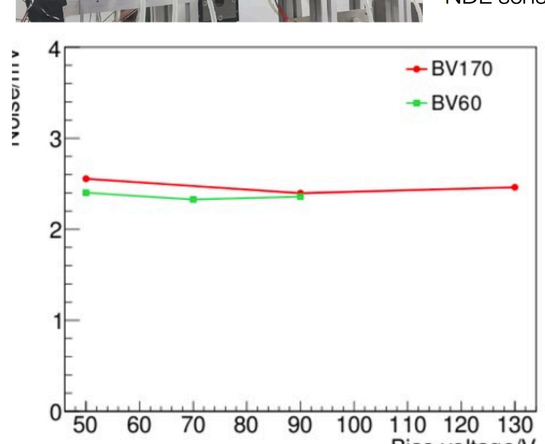
- Desy test beam facility
- Electron/positron beams: 5GeV
- The hit positions from beam are recorded with 6 mimosa plates with 18.5um x 18.5um unit pixel size
- DUT: NDL sensor
- Time resolution needs to be obtained by combining different measurements
- Calculation method.

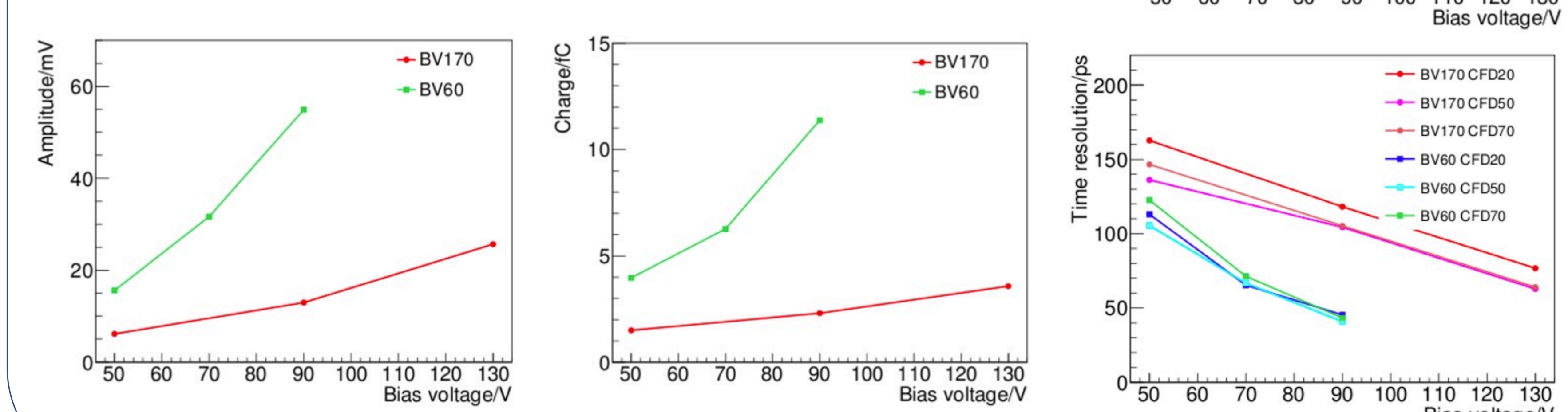


$$\sigma_1=\sqrt{\frac{\sigma_{21}^2+\sigma_{13}^2-\sigma_{32}^2}{2}},\quad \delta_1=\frac{\sqrt{(\sigma_{21}\delta_{21})^2+(\sigma_{13}\delta_{13})^2+(\sigma_{32}\delta_{32})^2}}{2\sigma_1},$$

$$\sigma_2=\sqrt{\frac{\sigma_{21}^2-\sigma_{13}^2+\sigma_{32}^2}{2}},\quad \delta_2=\frac{\sqrt{(\sigma_{21}\delta_{21})^2+(\sigma_{13}\delta_{13})^2+(\sigma_{32}\delta_{32})^2}}{2\sigma_2},$$

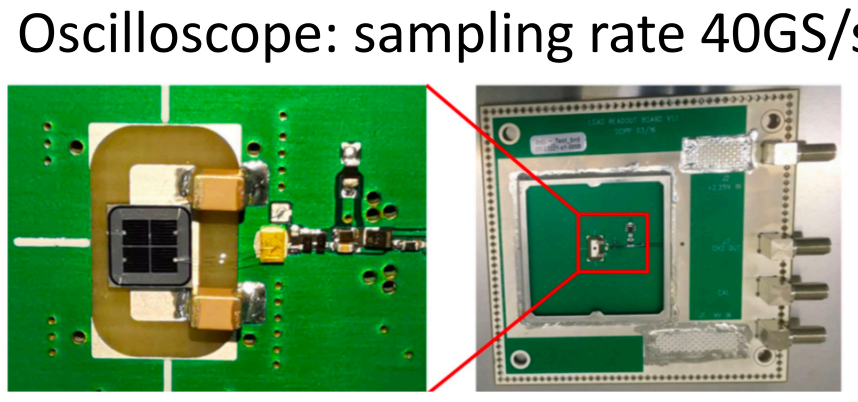
$$\sigma_3=\sqrt{\frac{-\sigma_{21}^2+\sigma_{13}^2+\sigma_{32}^2}{2}}\quad \delta_3=\frac{\sqrt{(\sigma_{21}\delta_{21})^2+(\sigma_{13}\delta_{13})^2+(\sigma_{32}\delta_{32})^2}}{2\sigma_3}$$

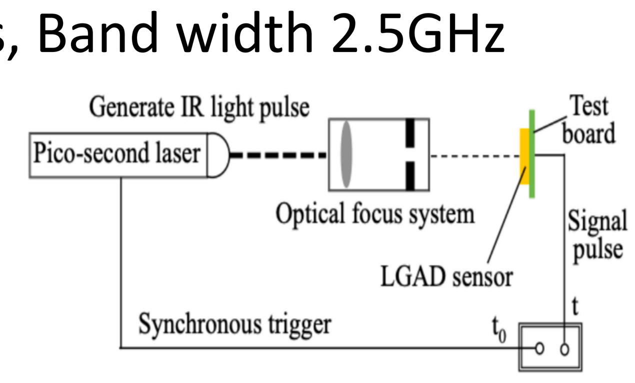




Laser test for time resolution

- Detector read-out board developed by UC Santa Cruzz
- Double-side conductive tape to mount the LGAD on test board
- Aluminum wire connecting LGAD to input amplifier on test board
- Laser testing system:
  - Picosecond laser: wave length 1064 nm, pulse width7.5 ps
  - Oscilloscope: sampling rate 40GS/s, Band width 2.5GHz

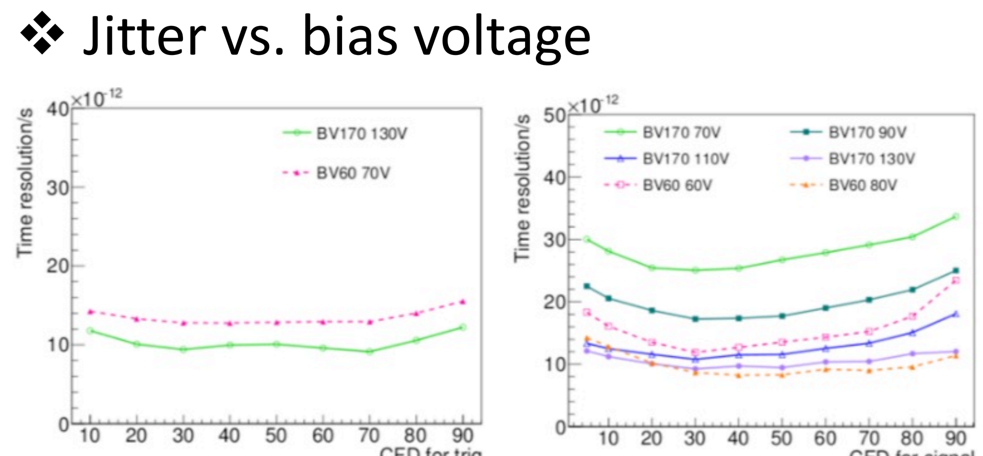




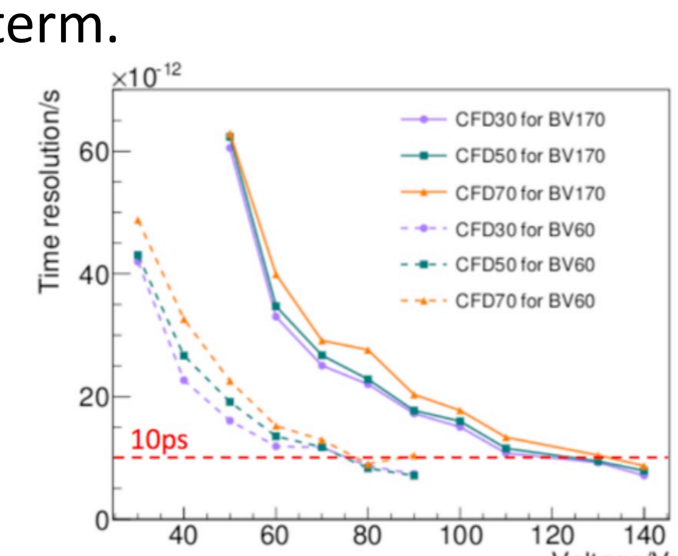
- Time resolution expression of LGAD sensor: $\sigma_t^2 = \sigma_{TDC}^2 + \sigma_{Time\ Walk}^2 + \sigma_{Landau\ Noise}^2 + \sigma_{Signal\ distortion}^2 + \sigma_{Jitter}^2$

For the time resolution test by laser, the first 4 terms are small enough to neglect, and the test is effect of jitter term.

- Jitter vs. bias voltage

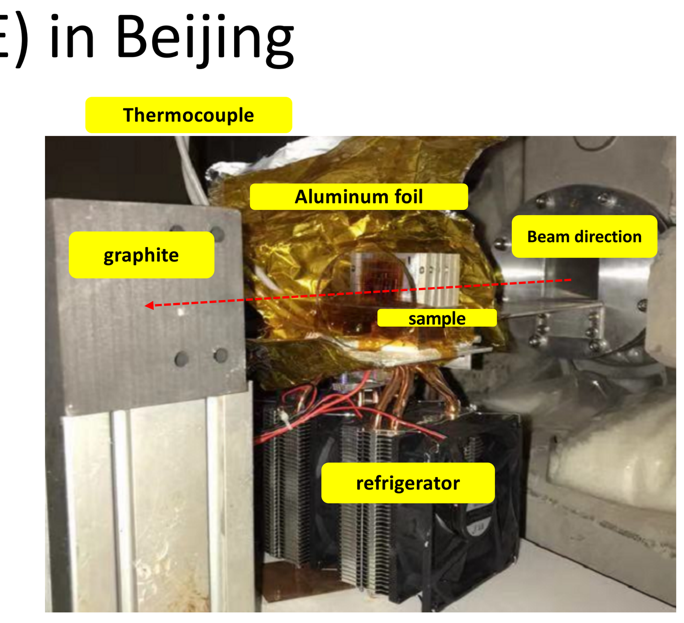


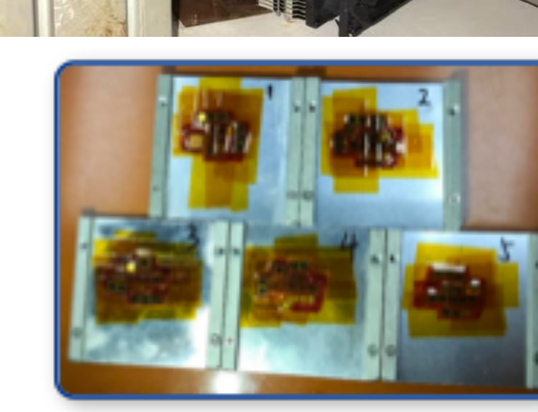
Jitter affected by CFD fraction



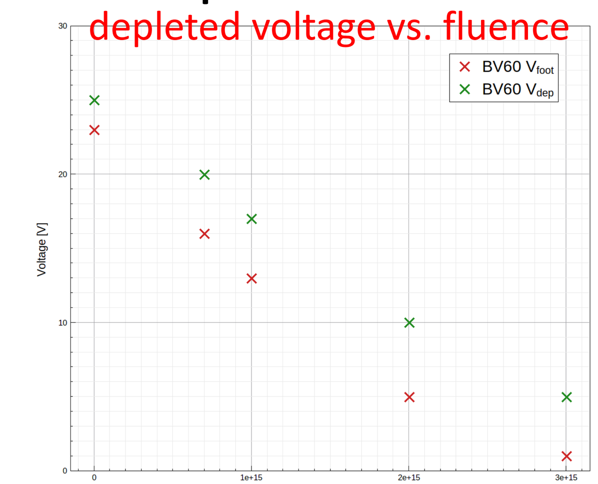
Proton irradiation hardness

- China Institute of Atomic Energy (CIAE) in Beijing
- 100 MeV proton synchrotron
- Irradiation was carried out on July 9
- 5 fluence points were chosen: 7E14, 1E15, 2E15, 3E15, 4.5E15
- sensor: 18 HPK, 4 CNM , 55 IHEP-NDL
- Beam current: 100nA (~1-2%)
- Beam area: 2.5cm X 2.5cm
- Temperature: below 0°C

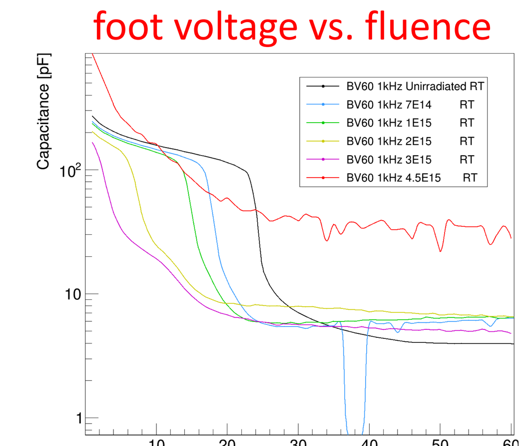




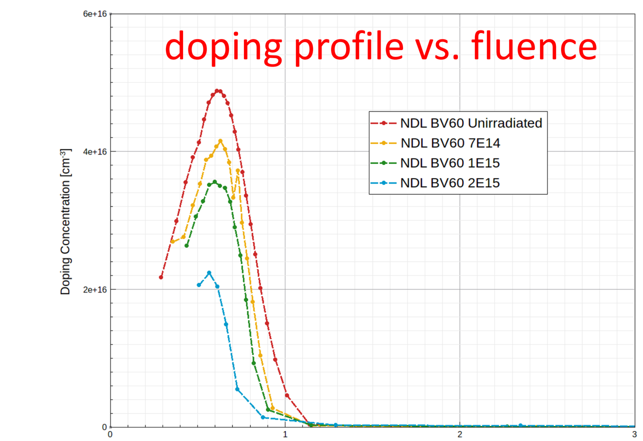
depleted voltage vs. fluence



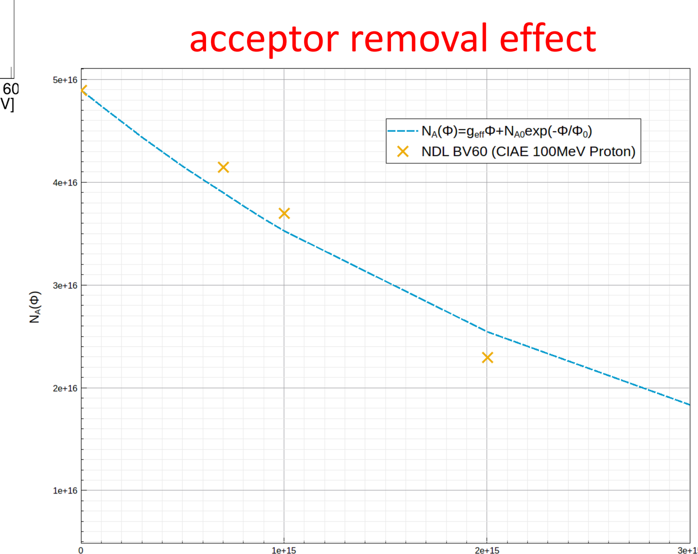
foot voltage vs. fluence



doping profile vs. fluence



acceptor removal effect



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