Update on IHEP RD50 activities

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On behalf of IHEP RD50 Group

中国科学院高能物理研究所

CERN

35th RD50 Workshop

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Outline

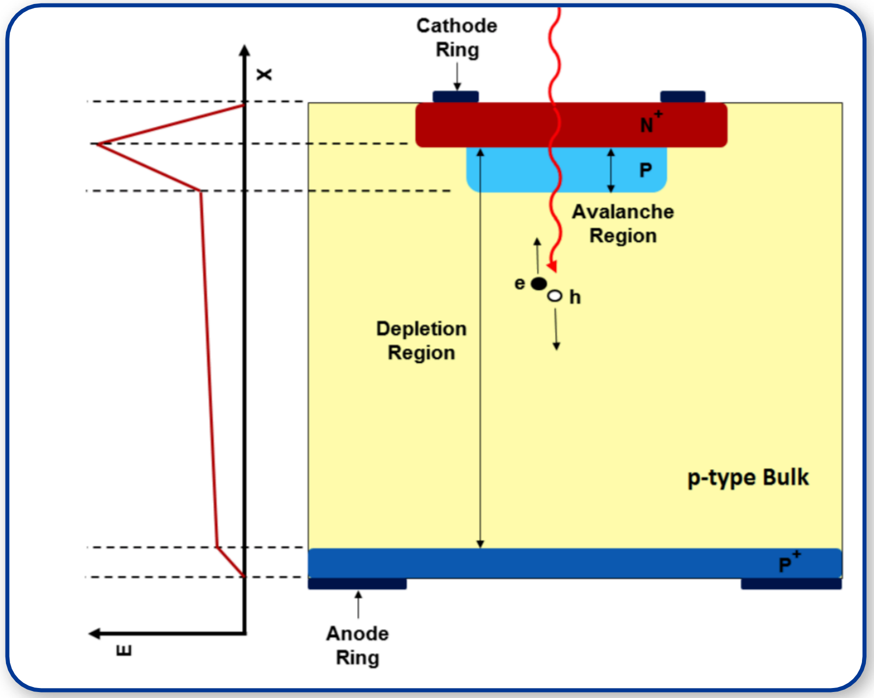
- LGAD Sensor Development
- Proton Irradiation at CIAE
- TCT and Beta source test
- TCAD irradiation modeling
- TRACS development

LGAD Sensor Development Status

Zhijun Liang, et al.

LGAD Development in China

- LGAD sensor with epitaxial layer wafer
  - Collaboration with Beijing Normal University Novel Device Laboratory (NDL)
  - Lower resistivity in epitaxial layer (300 Ω.cm)



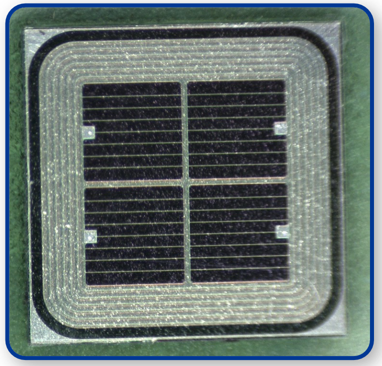
- "High resistance wafer" + "low resistance" bonded wafer
  - Collaboration with Tsinghua University
  - High resistance wafer (> 10k Ω.cm)

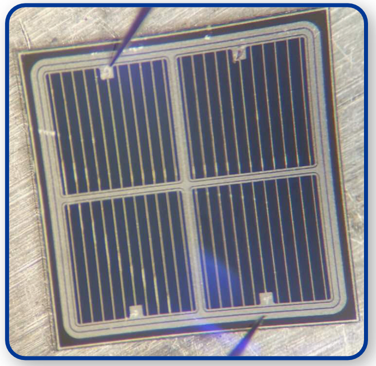
IHEP-NDL Sensor Design

- 6 guard ring: BV170, BV60
  (floating, no metal contact)

- 2 guard ring: Type 9#, 10#
  (with metal contact, can be grounded)
- Higher breakdown voltage (VBD) with new guard ring design

New !



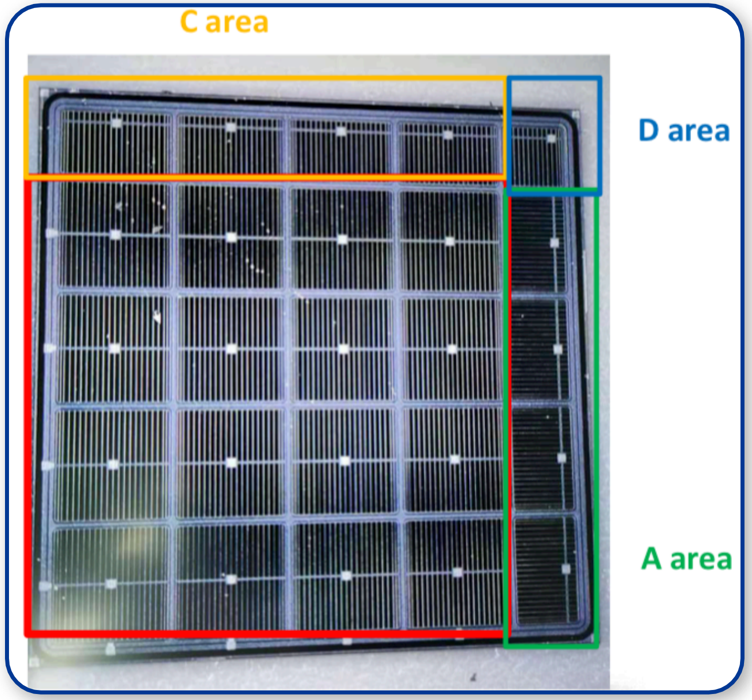


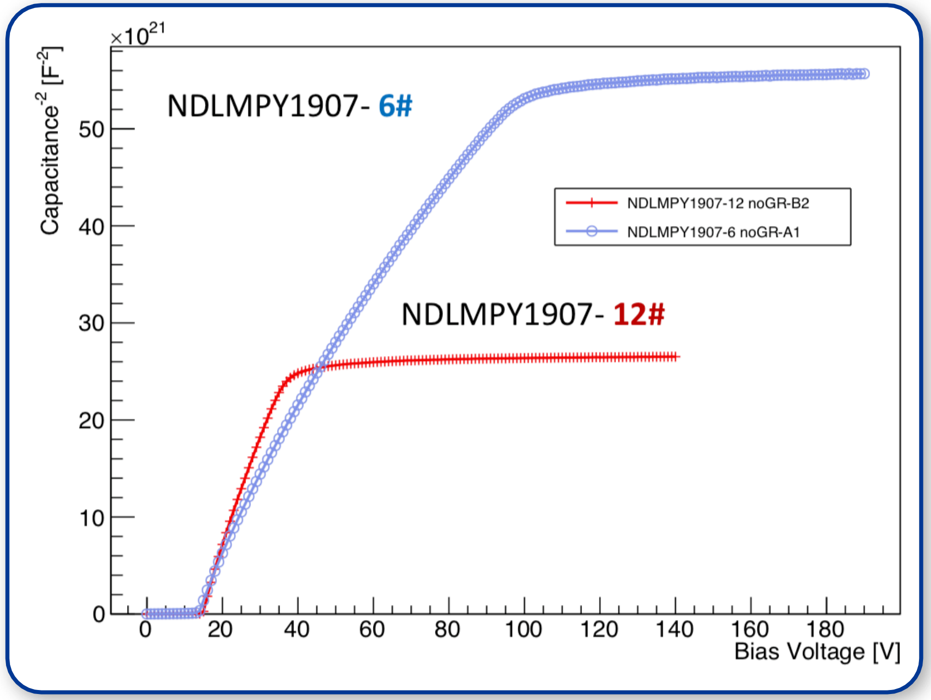
	VBD	$V_{Depleted}$	Layout	Wafer	Gain
Type 13# (BV170)	~165V	~100V	6GR	100Ω.cm	40
Type 12#(BV60)	~95V	~40V	6GR	300Ω.cm	40
Type 10#	~300V	~40V	2GR	300Ω.cm	80
Type 9#	~250V	~40V	2GR	300Ω.cm	80

NDL 5x5 sensors

- Two types of NDL 5x5 sensors fabricated in September 2019

	VBD	$V_{Depleted}$	Layout	Epi layer(33μm) resistance	Gain
NDL 5x5 6#	~250V	~120V	2 guard ring	100Ω.cm	10~20
NDL 5x5 12#	~235V	35V	2 guard ring	300Ω.cm	10~20





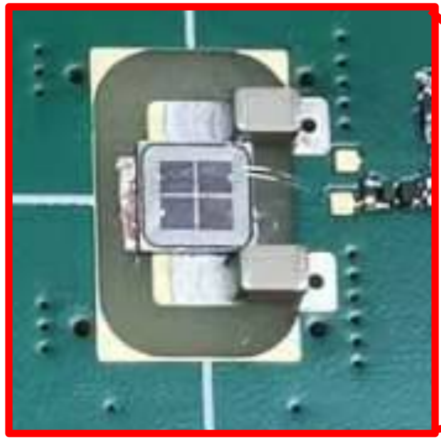
Laser and Beta source test

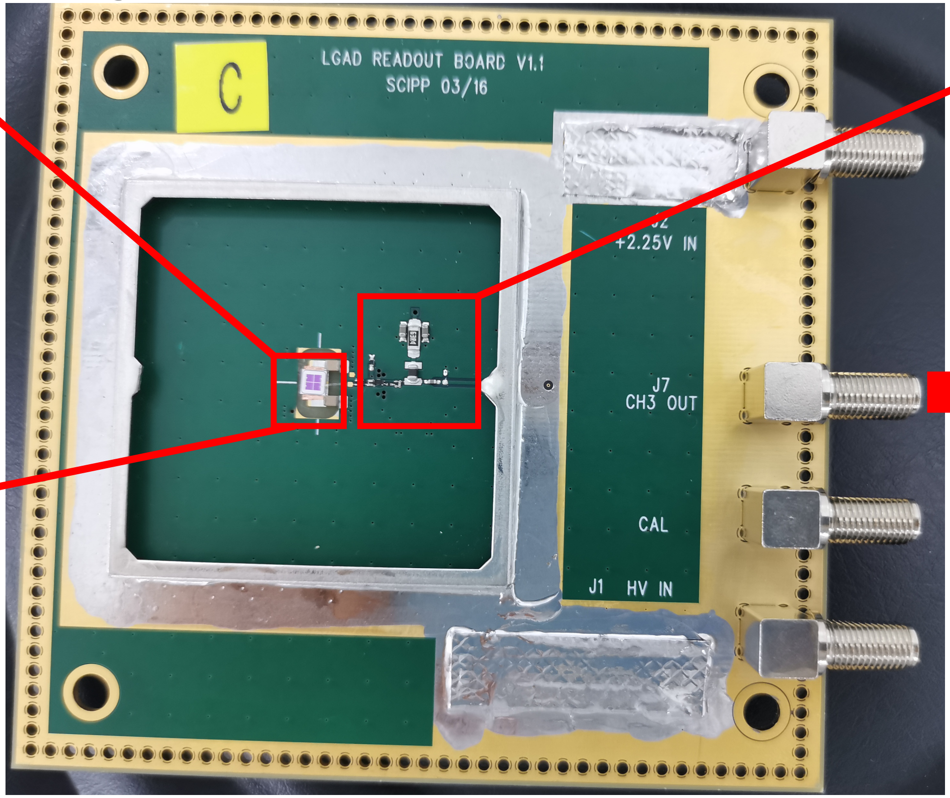
Yuzhen Yang, et al.

Laser and Beta source test: readout board

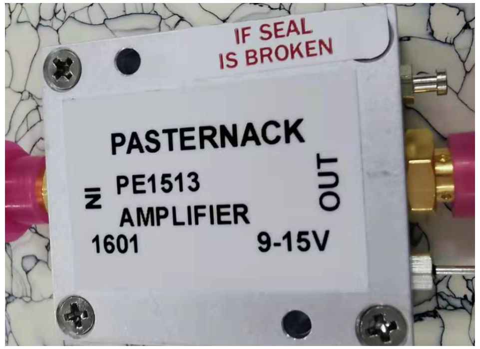
- LGAD readout boards with trans-impedance first stage amplifier (designed by UCSC)
- Voltage second stage amplifiers: PE1513

first stage amplifier





- sensor attached to test board using double-side conductive tape
- amplifier input coupled to metallization layer via wire bonds



output to oscilloscope

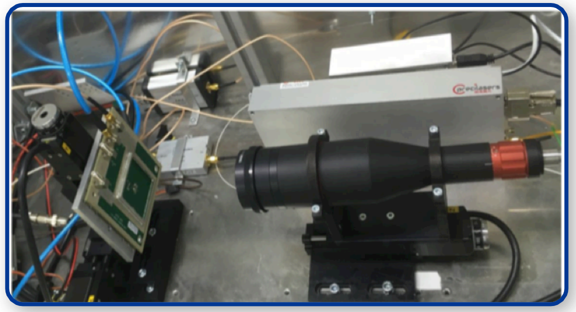
second stage amplifiers

- Gain ~10
- 2GHz Bandwidth

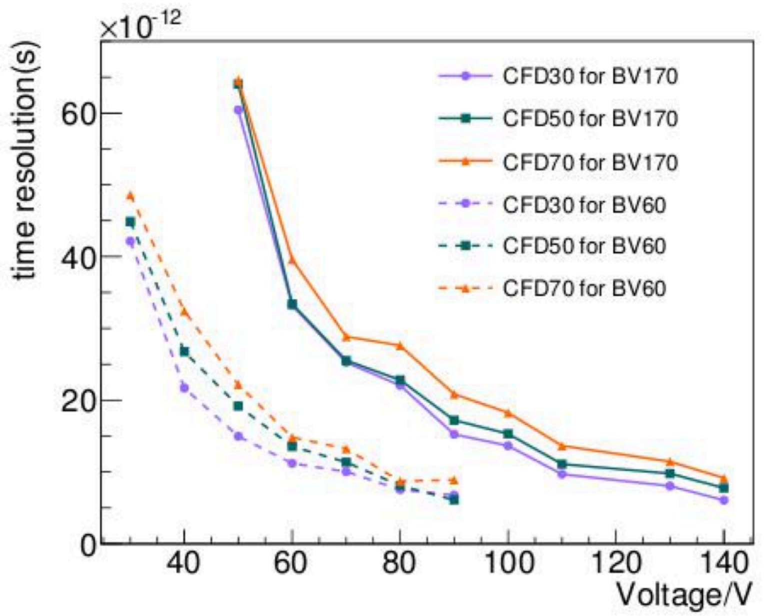
Laser test for NDL LGAD Sensor

- Time resolution of LGAD sensor

$$\sigma_t^2 = \sigma_{TDC}^2 + \sigma_{Time\ Walk}^2 + \sigma_{Landau\ Noise}^2 + \sigma_{Signal\ distortion}^2 + \sigma_{Jitter}^2$$

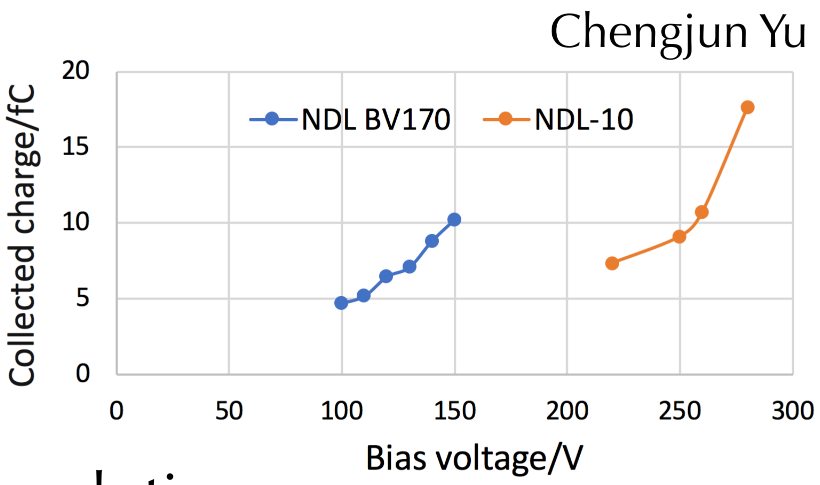


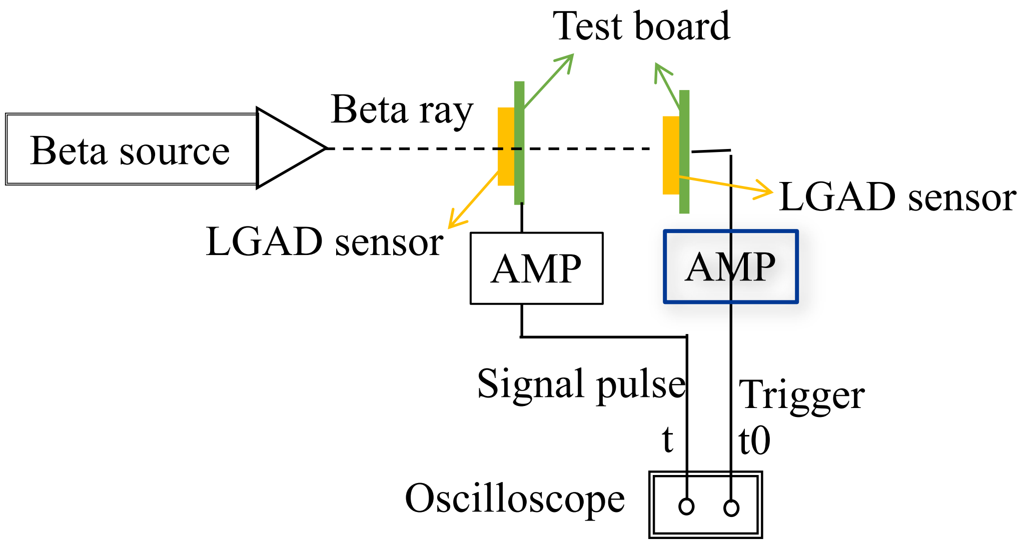
- Time resolution test system using pico-second laser
  - Laser pulse width: 7ps
  - Wavelength: 1064nm
  - Frequency: 20MHz
- Evaluate the jitter contribution
  - Less than 10ps at room temperature
  - Laser power larger than MIP
  - Next: irradiated sensor at low temperature



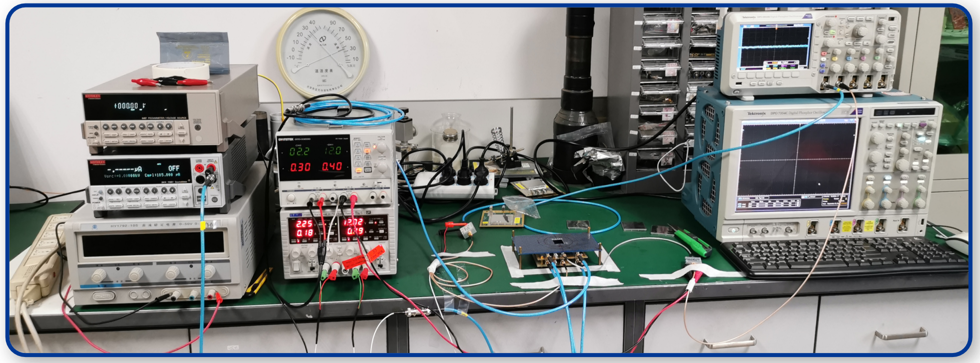
Beta source test for NDL sensor

- Collected charge



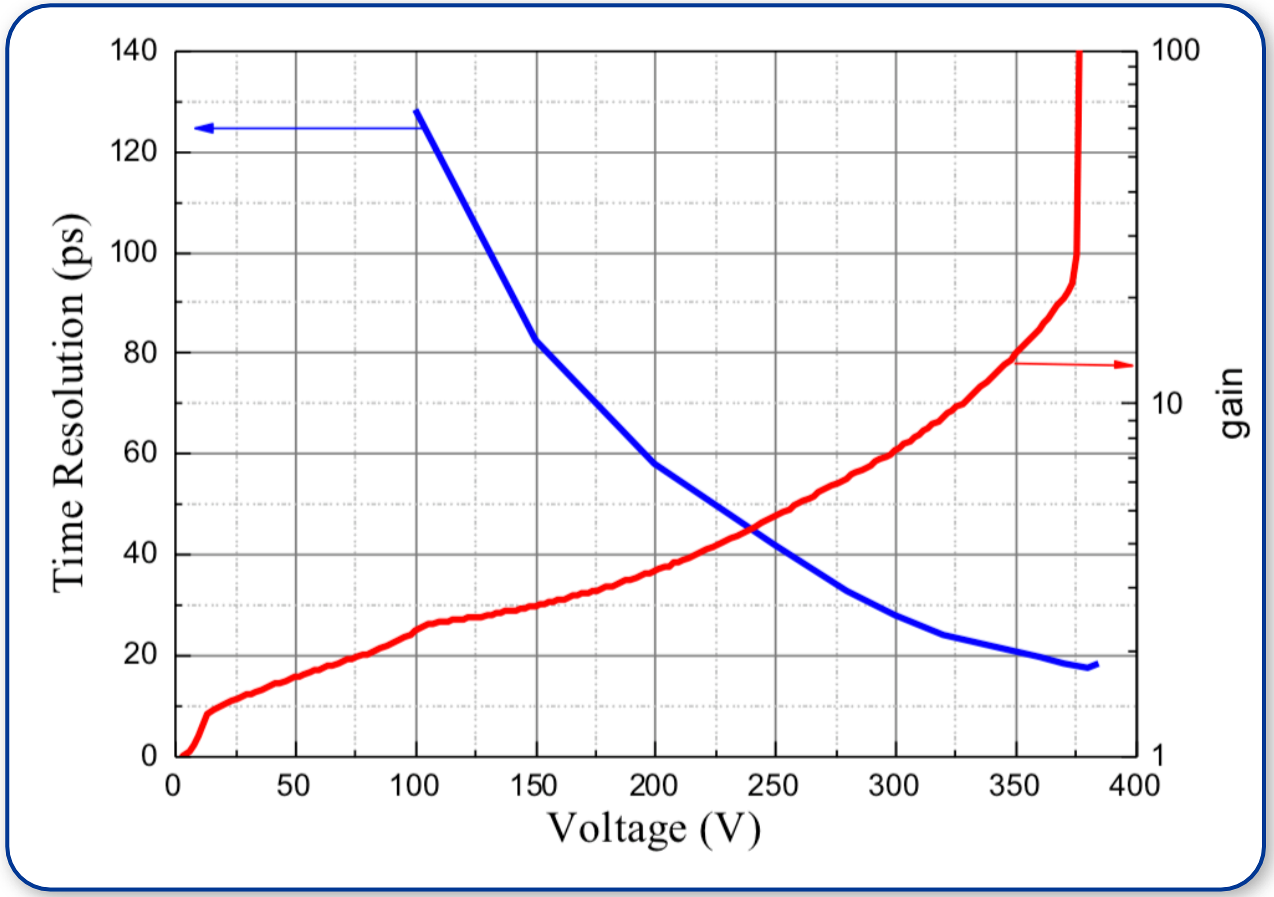


- Time resolution
  - Using two LGAD sensor coincidence as trigger
  - commission on the way
  - Next: test time resolution at room and low temperature



Time resolution vs. gain in 5x5 NDL LGAD

- Pico-second laser measurement
  - The power of the laser is reduced to simulate MIP
  - Jitter term can reach 20ps in this laser tests
    - Note: Landau term can not be evaluated in laser test

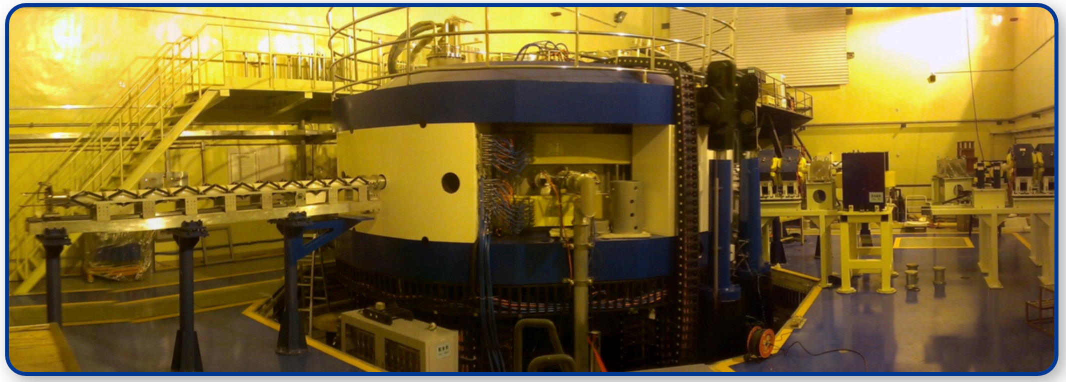


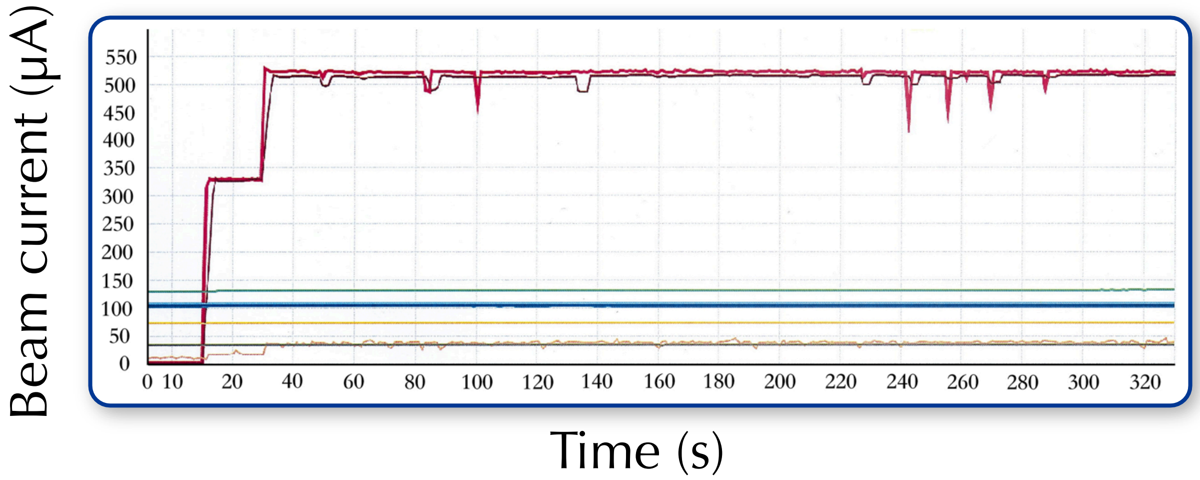
CIAE Irradiation Campaign

Yuhang Tan, et al.

Proton irradiation facilities in China

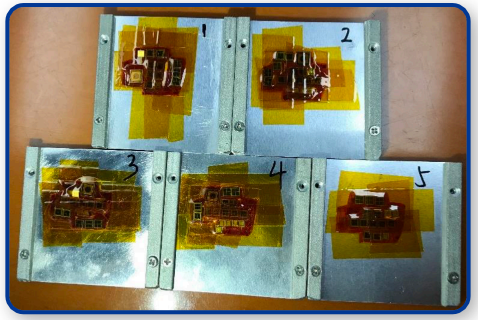
- China Institute of Atomic Energy (CIAE) in Beijing
- 100 MeV proton synchrotron
  - Beam energy: 20 –100 MeV
  - Beam current: 1pA – 200μA
  - Experiment terminal: 5





CIAE irradiation campaign

- Irradiation was carried out on July 9
- 5 fluence points were chosen: 7E14, 1E15, 2E15, 3E15, 4.5E15
- 18 HPK, 4 CNM , 55 IHEP-NDL
- Beam current: 100nA (~1-2%)
- Beam area: 2.5cm X 2.5cm
- Temperature: below 0C



Experiment device:

Thermocouple:
temperature measurement

Graphite:absorbing protons

Al foil: keep the temperature

Test beam status:
exist or not

Beam direction

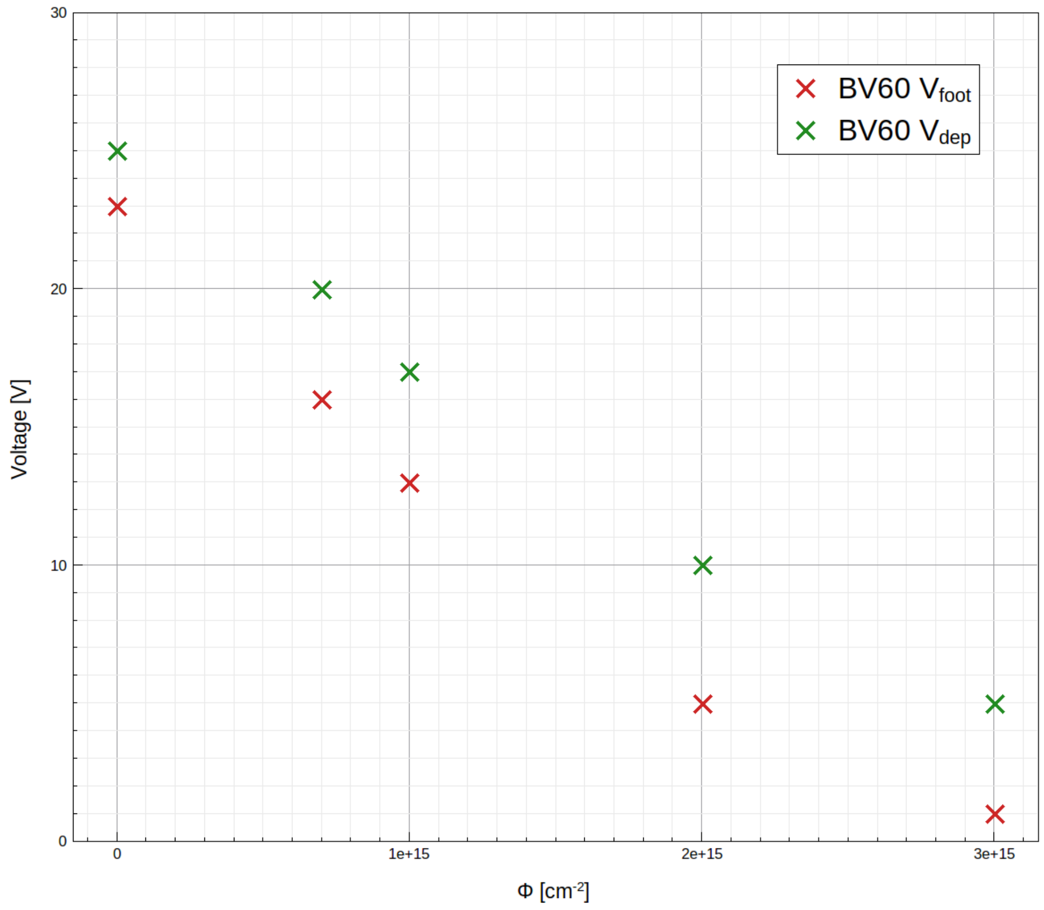
Sensor

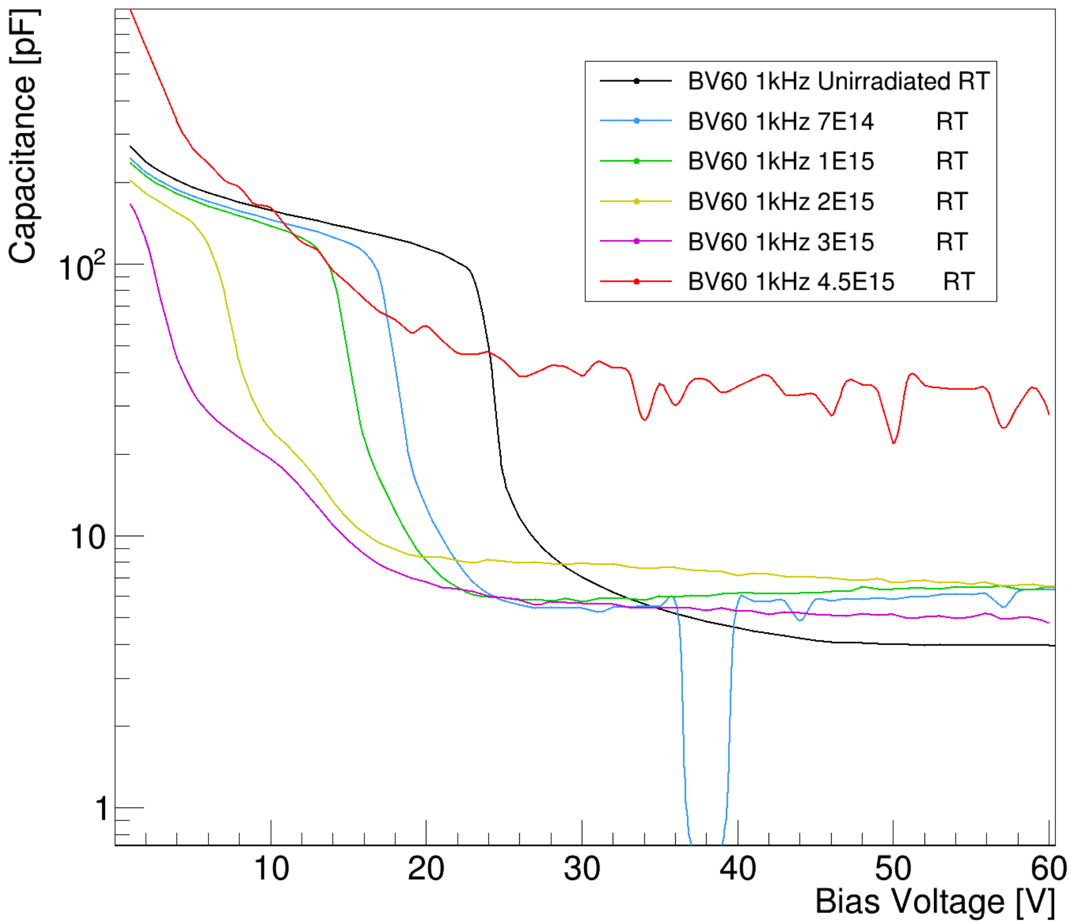
Refrigeration device: keep the sensor below 0C

Temperature test: the surface is frost, and the temperature up to 2C throughout the test

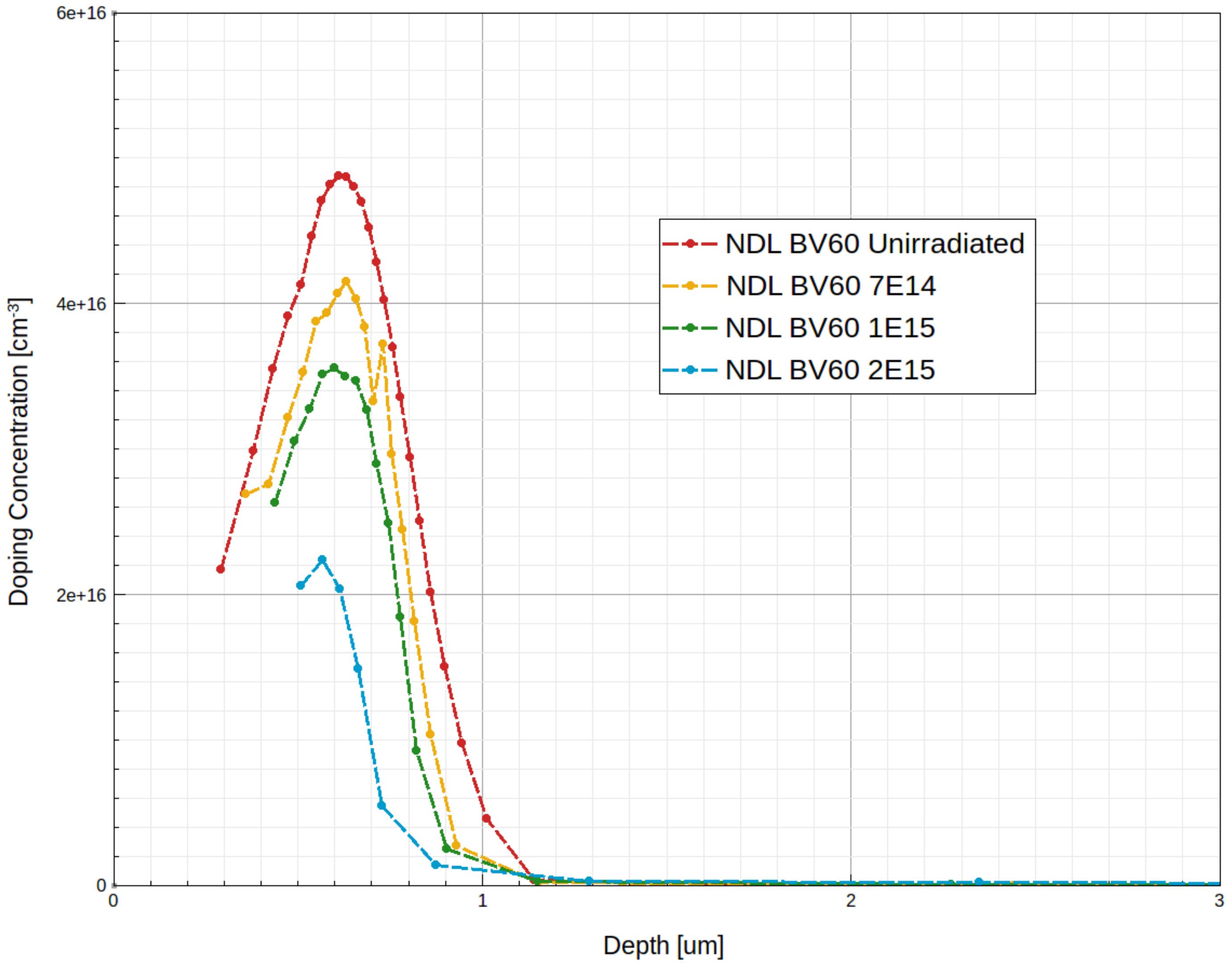
First Results of CIAE irradiation: NDL sensors

- Depleted voltage and foot voltage vs. fluence

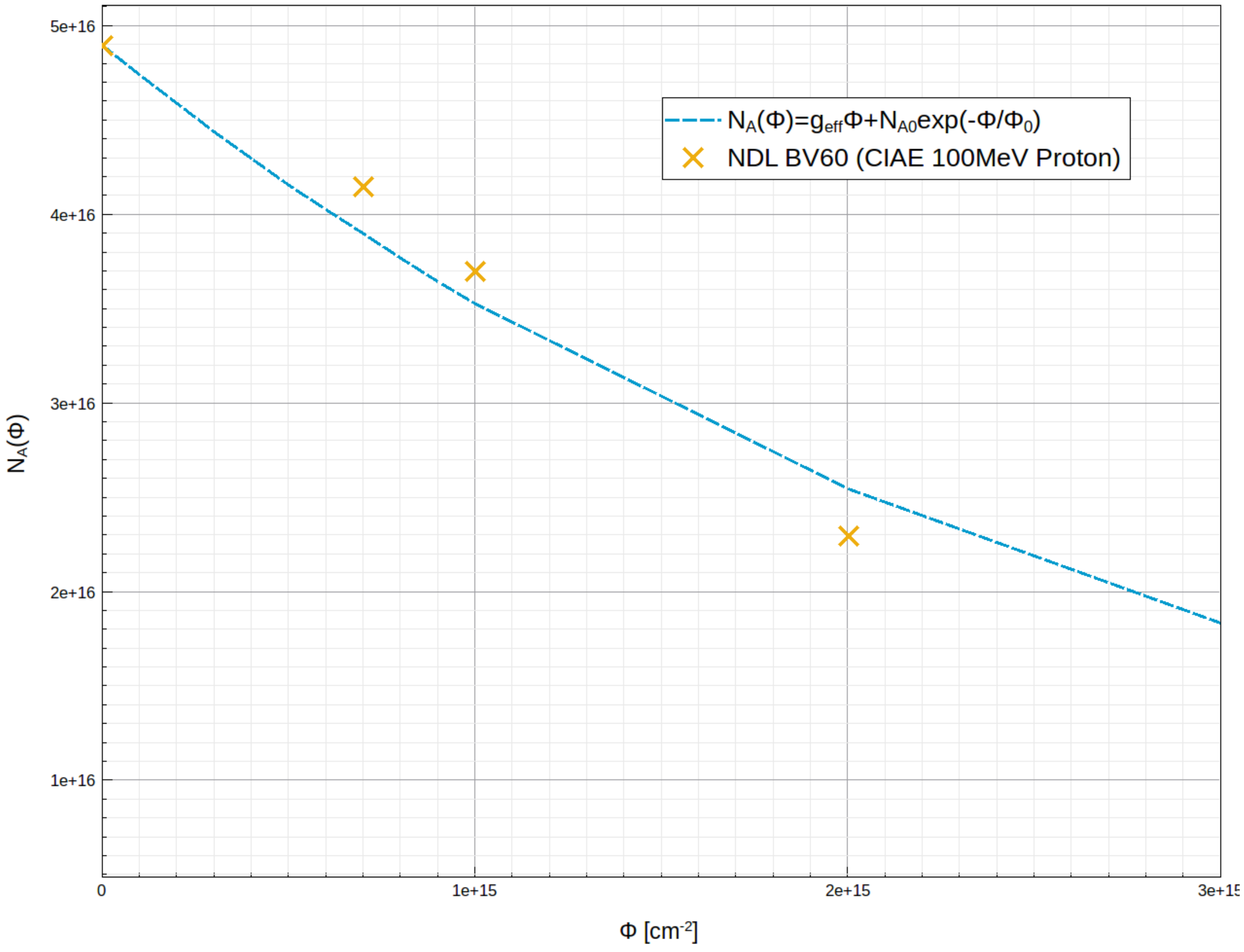




Doping profile vs. Fluence



Acceptor removal effect

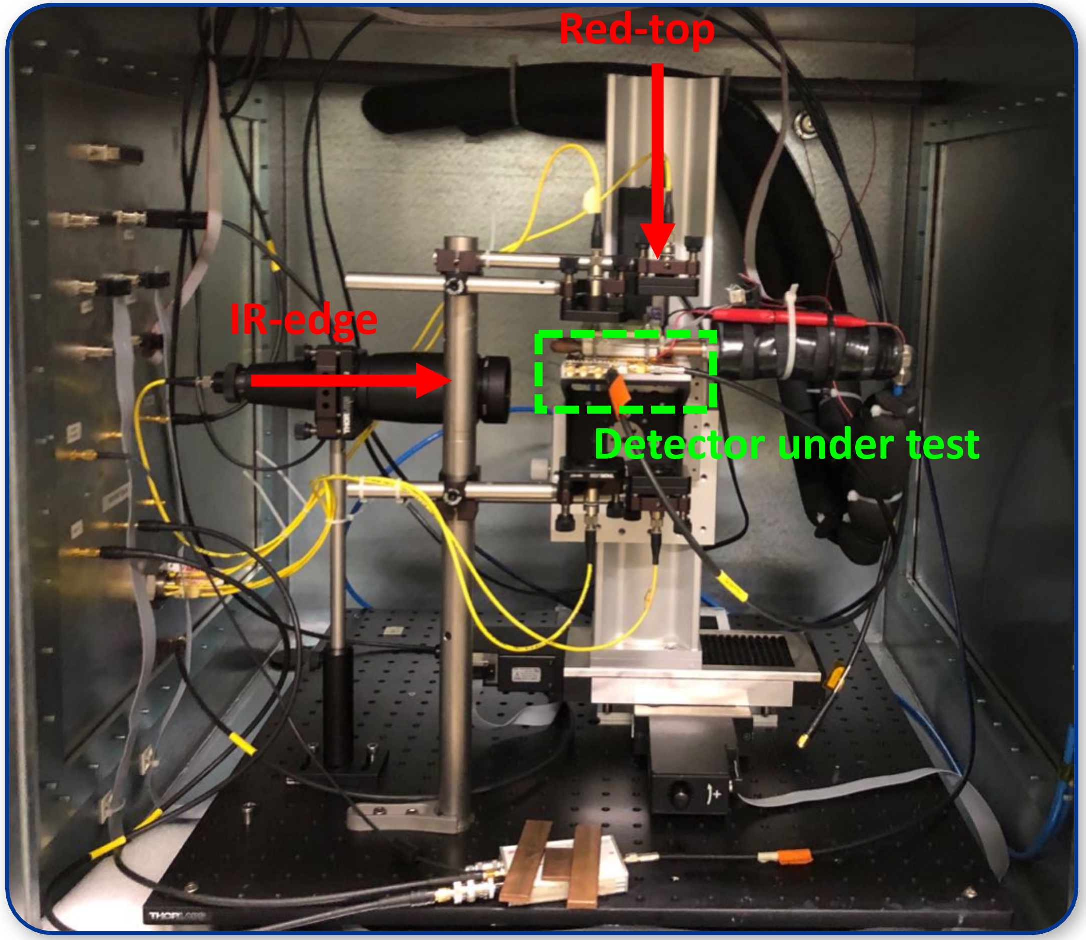


TCT Measurement

Suyu Xiao, et. al

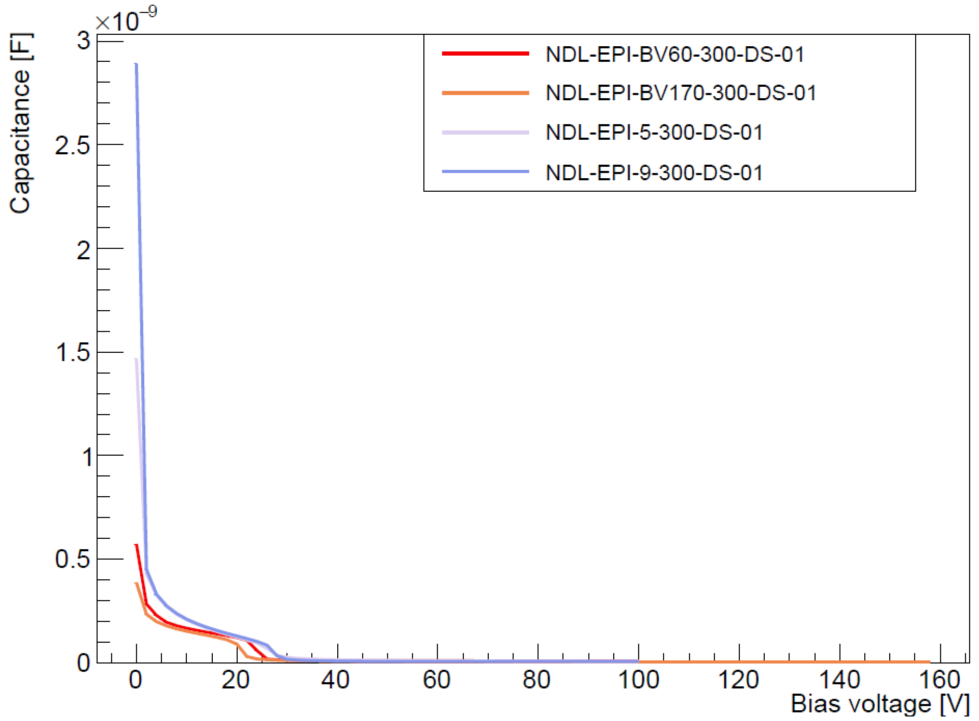
TCT Setup at CERN

- 664nm for Red laser
- 1064nm for IR laser
- ~4µm spatial resolution

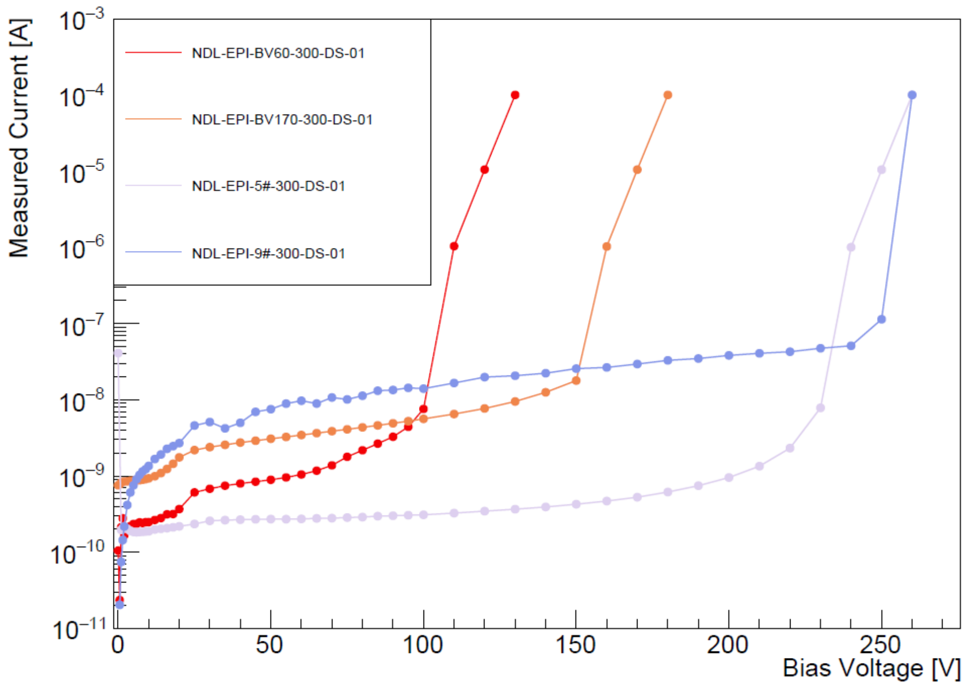


CV and IV measurement of NDL BV170

CV curve of BV170



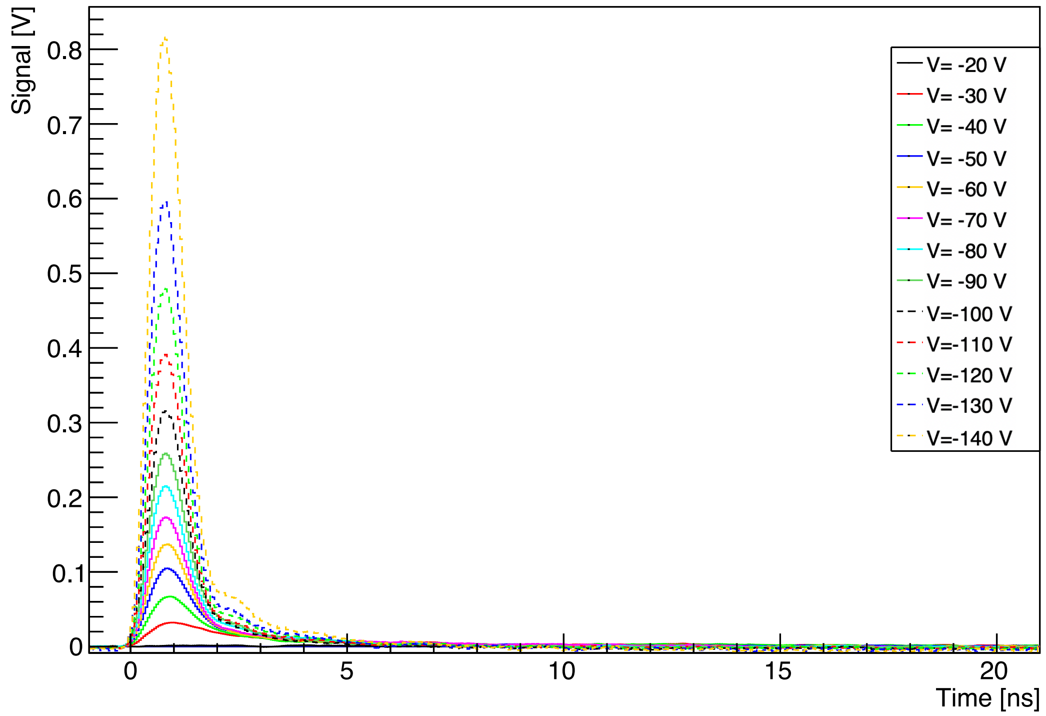
IV curve of BV170



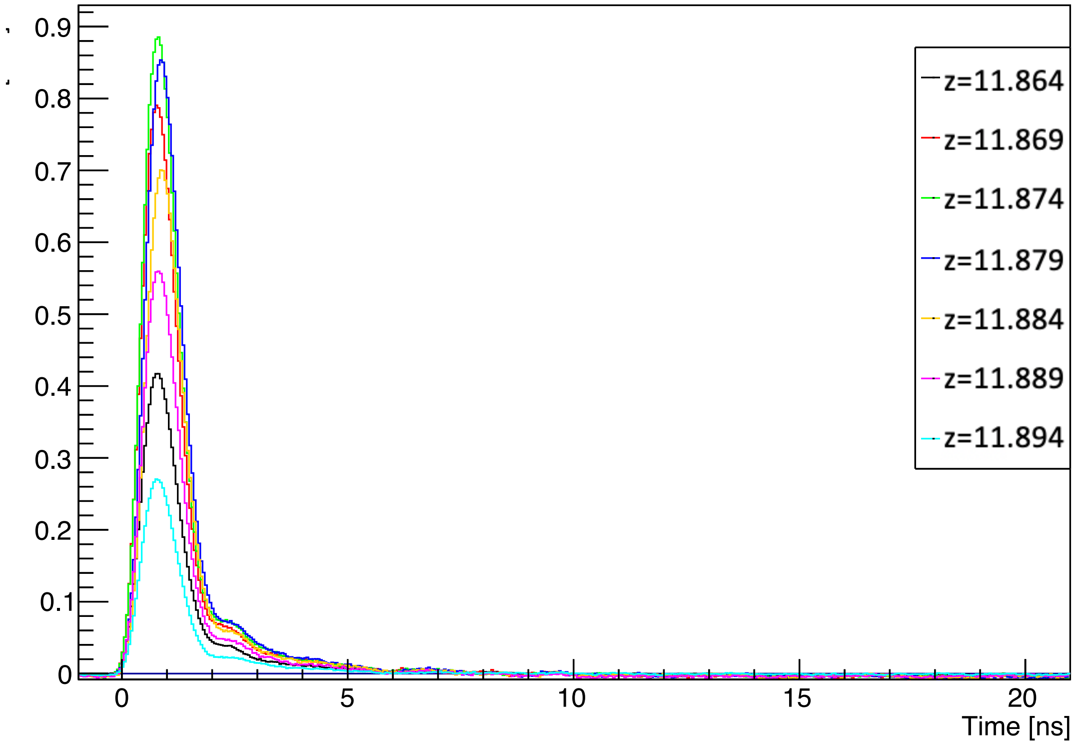
- BV170 depleted at 105V, breakdown at 155V.

NDL BV170-05 IR-edge 2.65mm

- Waveform at different V_{bias}



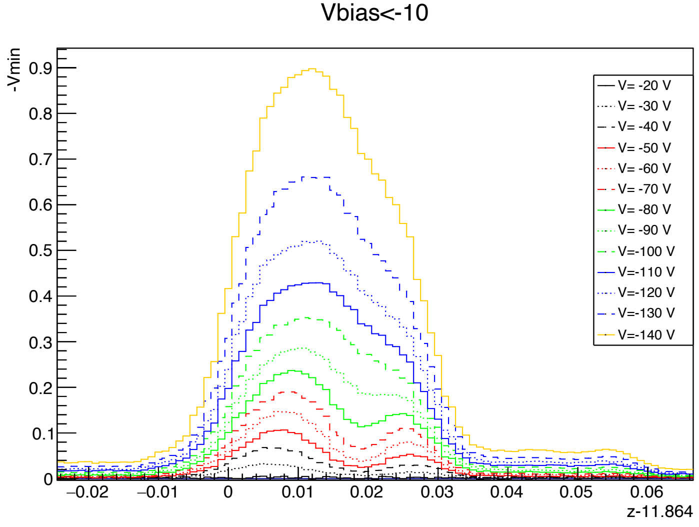
- Current at different depth



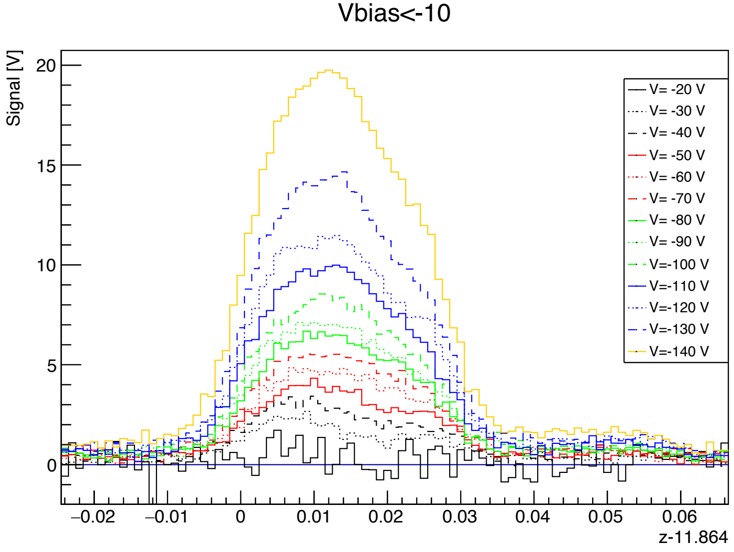
- Do voltage scan on BV170 from 20V to 140V. Obvious signal appears from 30V.
- 7 depths are chosen to compare current(50μm a point, 300μm in total, 7 point). ~100μm from the top achieves the maximum current, then decreasing slowly.

NDL BV170-05 IR-edge 2.65mm

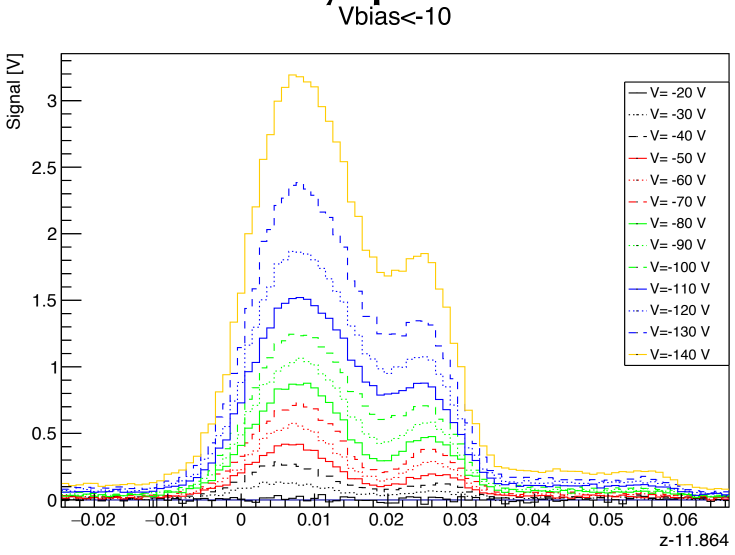
- Pulse Height at different depth



- Charge collection in 20ns



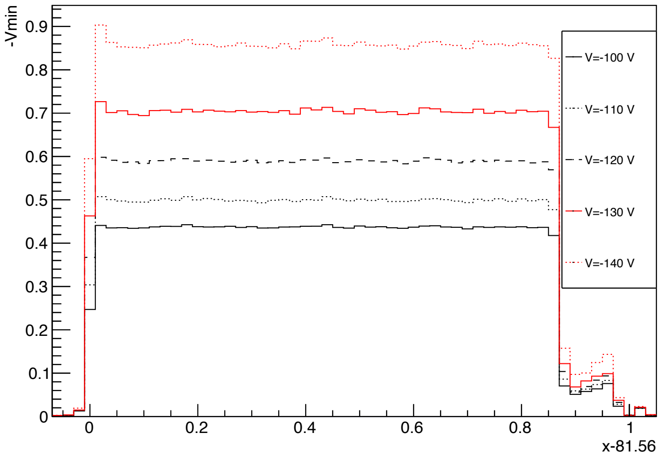
- Velocity profile



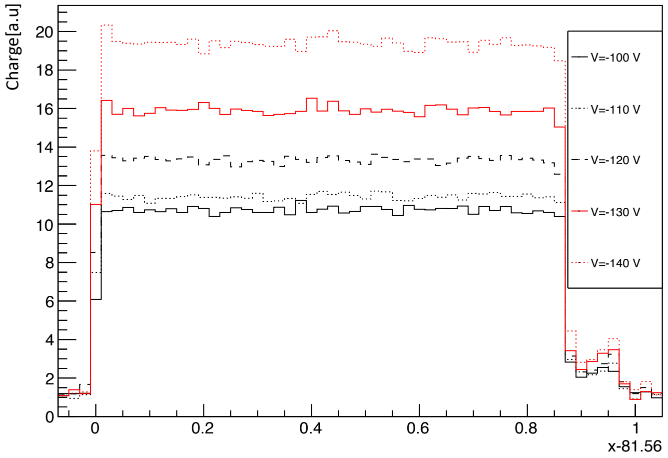
- A second peak in velocity is shown for LGAD near the bottom before irradiation, caused by the electric field from the diffusion of holes from the p+ region into the p bulk region.

NDL BV170-05 Red-top 2.95mm

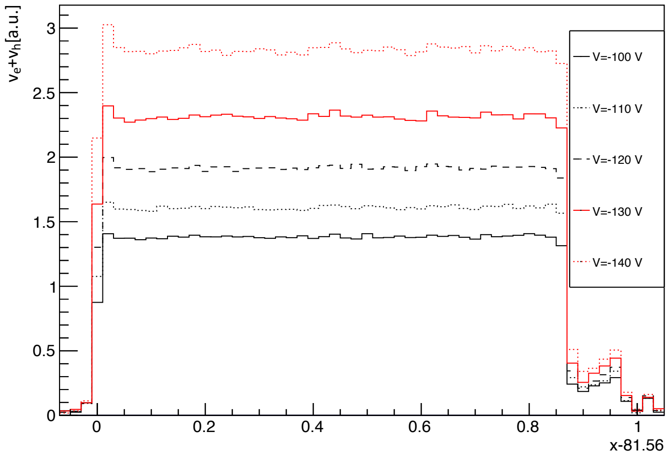
- Pulse Height at different depth

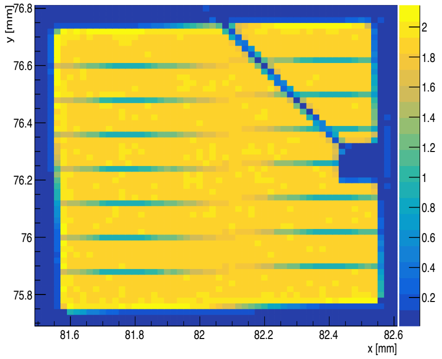


- Charge collection in 20ns



- Velocity profile





- Good spatial uniformity can be seen from the top scan.

TCT Measurement Plan

- Irradiated samples with different fluences are needed.
  Following 3 fluences will be irradiated with neutron at Ljubljana.
  - 1e14
  - 1e15
  - 2.5e15

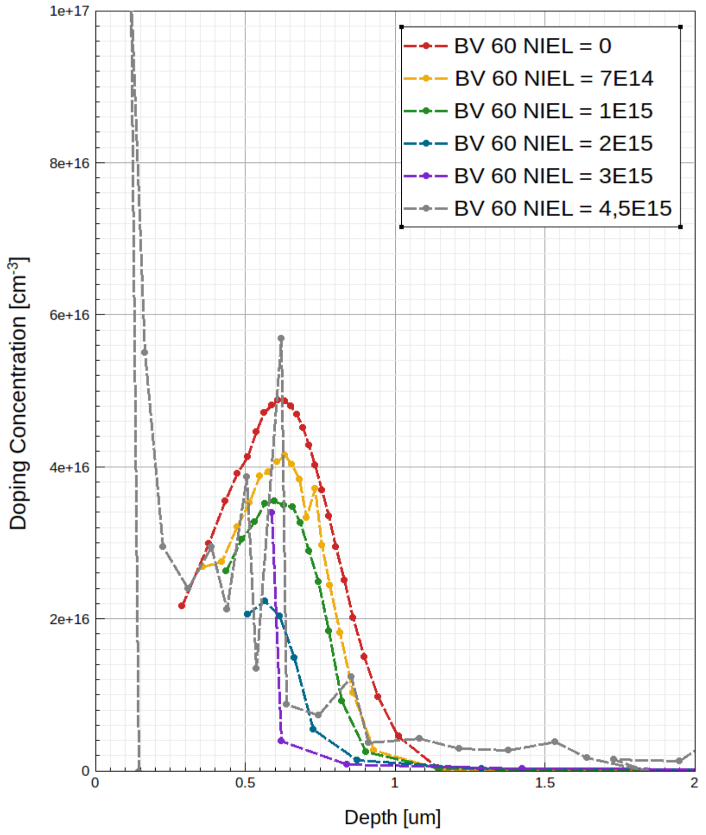
Irradiation Modeling with TCAD

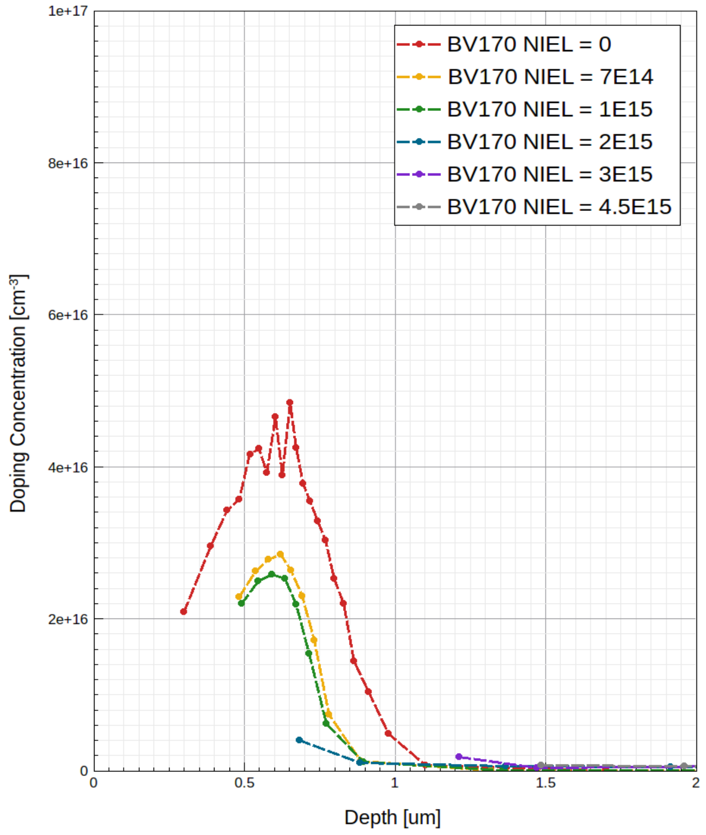
Tao Yang

Acceptor Removal Measurements

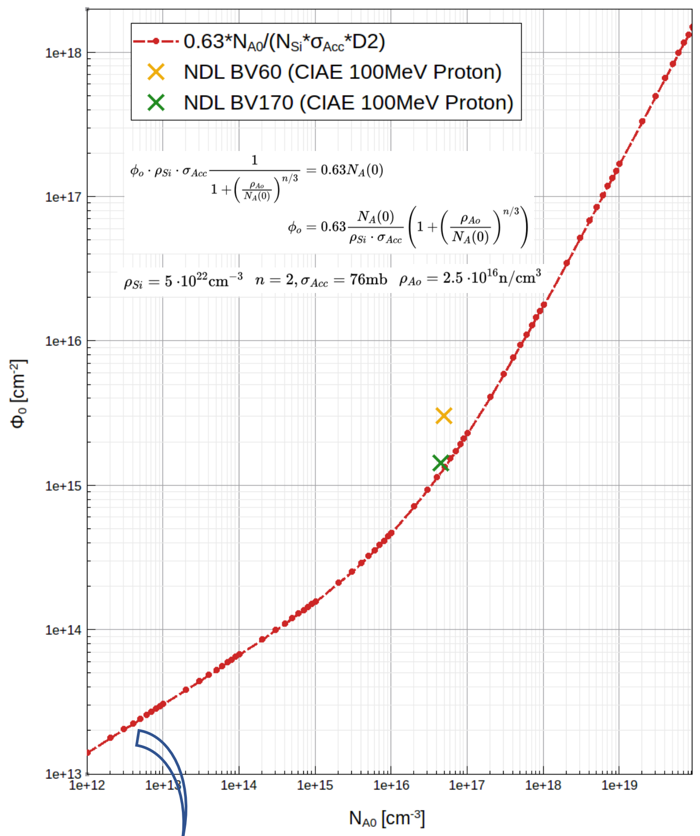
- Doping profile extracted from CV measurements
  - Temperature: 22 ℃
  - Frequency: 1kHz

the number of initial acceptor atoms deactivated by radiation is given by the product of the fluence ϕ_o





Doping profile extracted from CV for BV60(left) and BV170(right) in various fluence.



Radiation resistance

Ref: Ferrero M , Arcidiacono R , Barozzi M , et al. Radiation resistant LGAD design[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2019, 919:16-26.

Acceptor Removal Simulation in TCAD

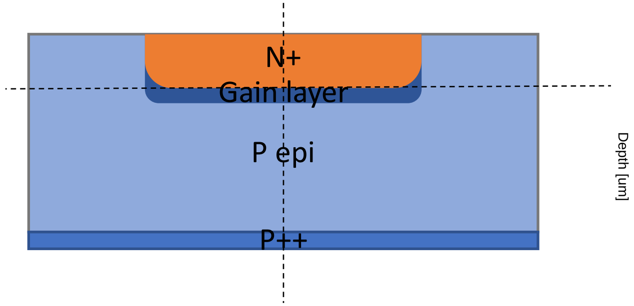
- Effective acceptor

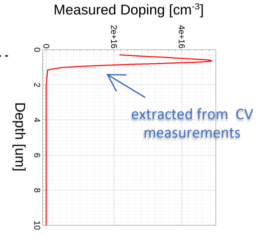
$$N_A(\phi) = g_{eff}\phi + N_A(0)e^{-c\phi}$$

$\rho_A(0)(\rho_A(\phi))$ the initial (after a fluence ϕ) acceptor density [cm^{-3}]

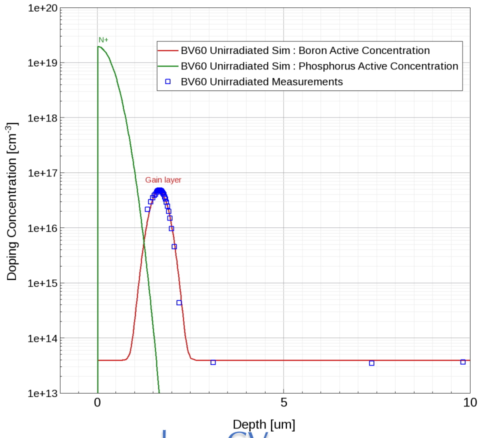
$g_{eff} = 0.02\,[\mathrm{cm}^{-1}]$

$\phi_o = 1/c$ is the fluence needed to reduce the initial doping density to 1/e of its initial value.

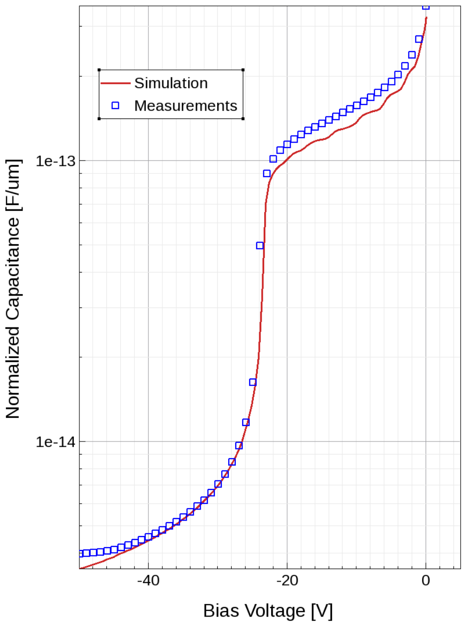




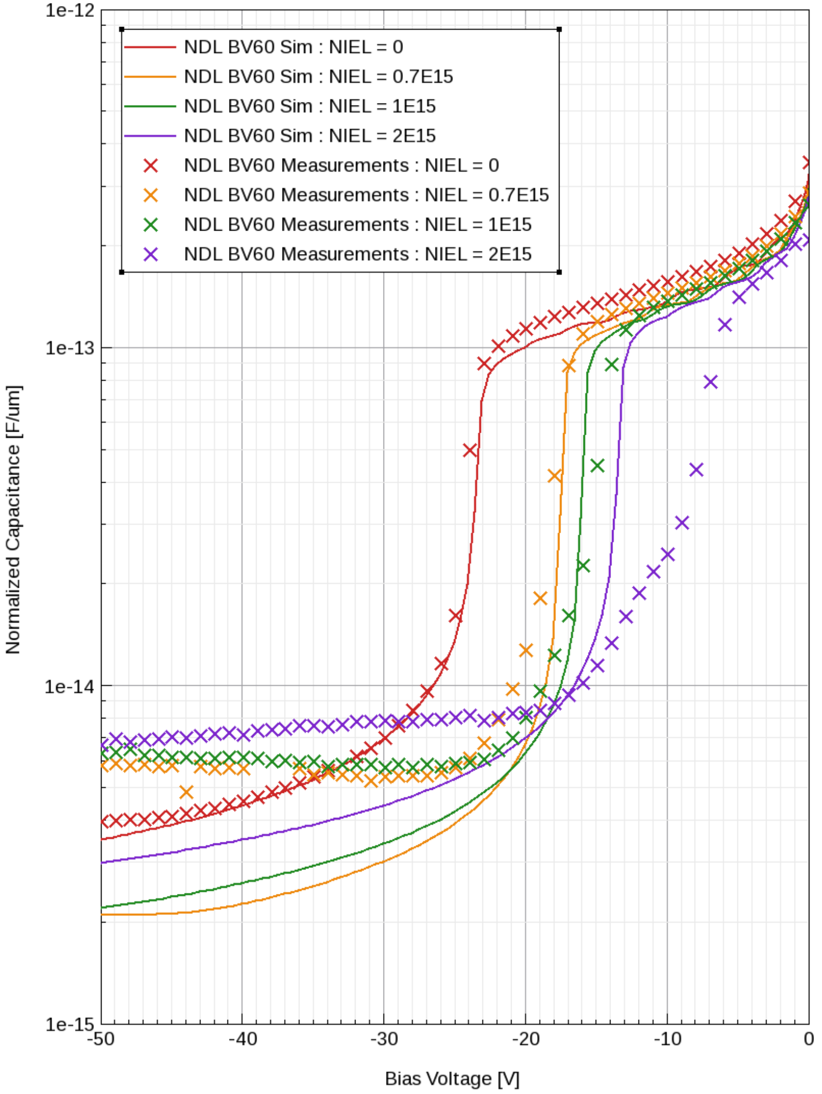
doping depth calibration



reproduce CV



couple with acceptor removal model



Next for TCAD simulation on LGAD:

- Couple with Deep energy levels(DLs) to reproduce radiation effect on IV, CCE and gain.
- Refine acceptor removal model work with DLs to Extended to cover temperature dependence of the bulk-damage related effects from room temperature down to -30 °C

TRACS Development for LGAD

Ryuta Kiuchi

TRACS Development for LGAD Sensors

- TRACS [1] is developed for a fast simulator tool of transient currents in silicon detectors
  - Ramo's theorem for calculating the transient current
  - FEniCS solver for Laplace/Poisson equations
  - Multi-threading
- Its lightweight and efficient implementation supports the fitting functionality to extract detector parameters
- Development has been started aiming for simulating LGAD sensors to deduce and compare parameters of LGADs both of non-irradiated and irradiated one.

[1] J. Calvo, P. de Castro, A. Díez González-Pardo, M. Fernández García, M. Moll, U. Senica, I. Vila, Nucl. Instrum. Meth. A 917 (2019) 77.

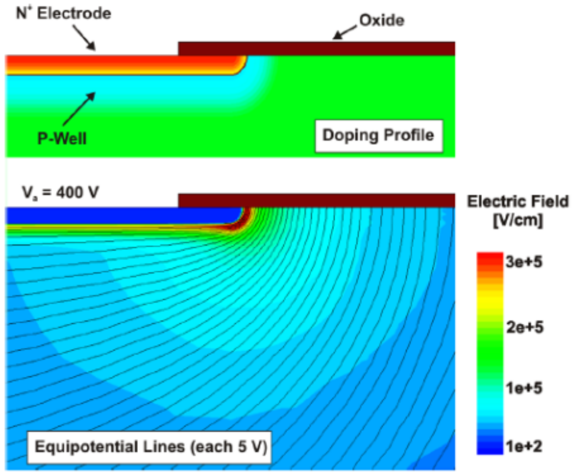
Doping Profile

- Avalanche region in LGADs is reproduced
  - Neff parameters to set the effective doping profile
  - Simple Gaussian shape is assumed

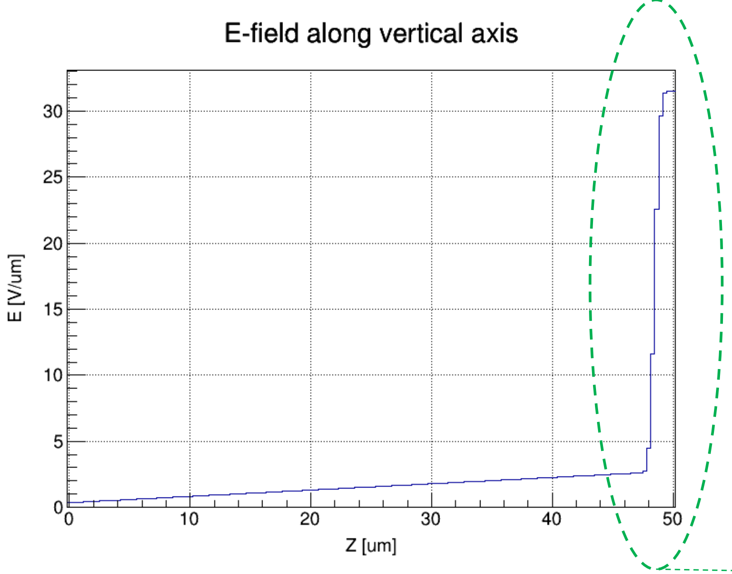
Doping profile set in the TRACS simulation

↕

Doping profile deduced from CV measurements



Schematic view of electric field and doping profile in LGAD [2]

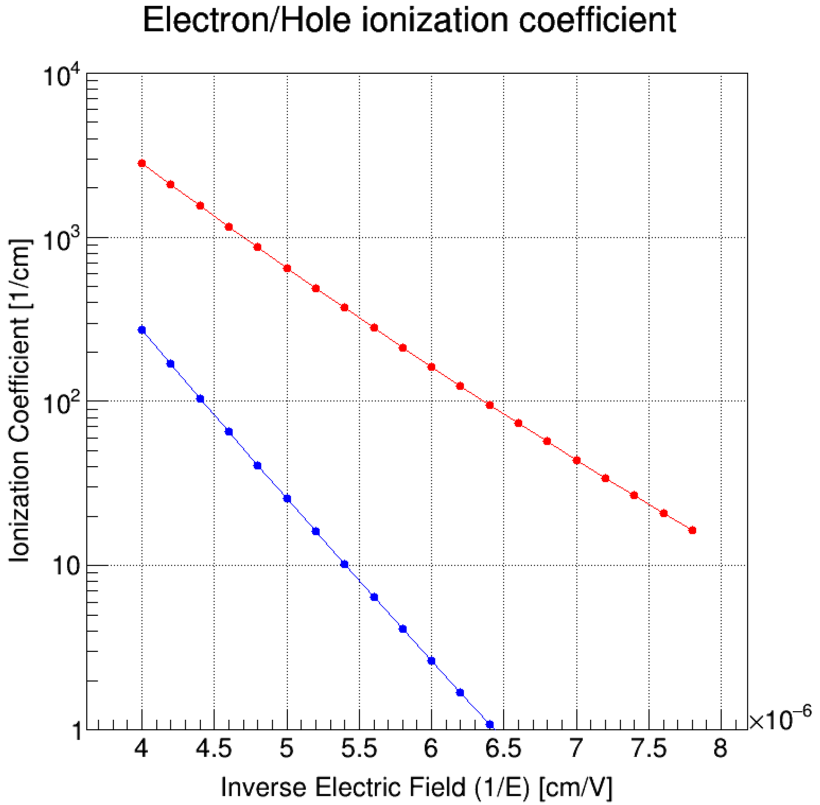


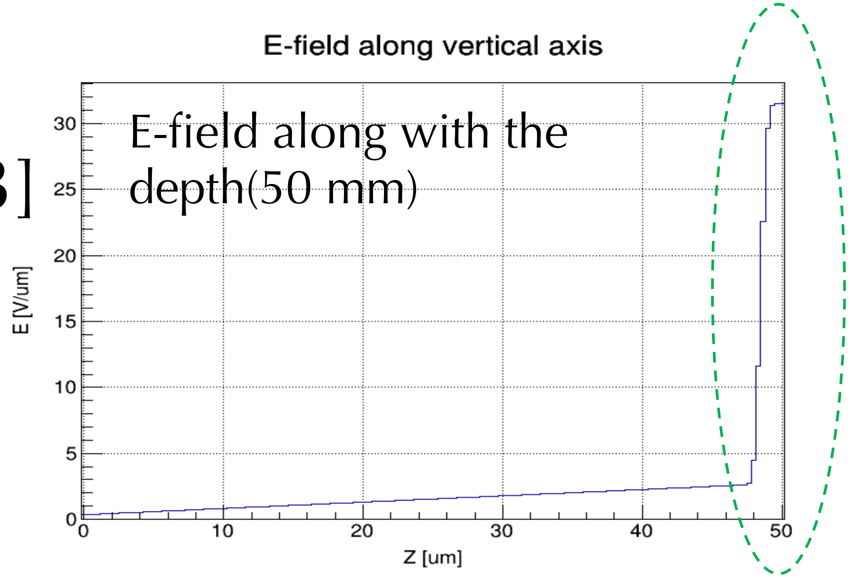
High electric field at "gain layer" in LGAD

[2] Pablo Fernández-Martínez, D. Flores, S. Hidalgo, V. Greco, A. Merlos, G. Pellegrini, D. Quirion, Nucl. Instrum. Meth. A 821 (2016) 93.

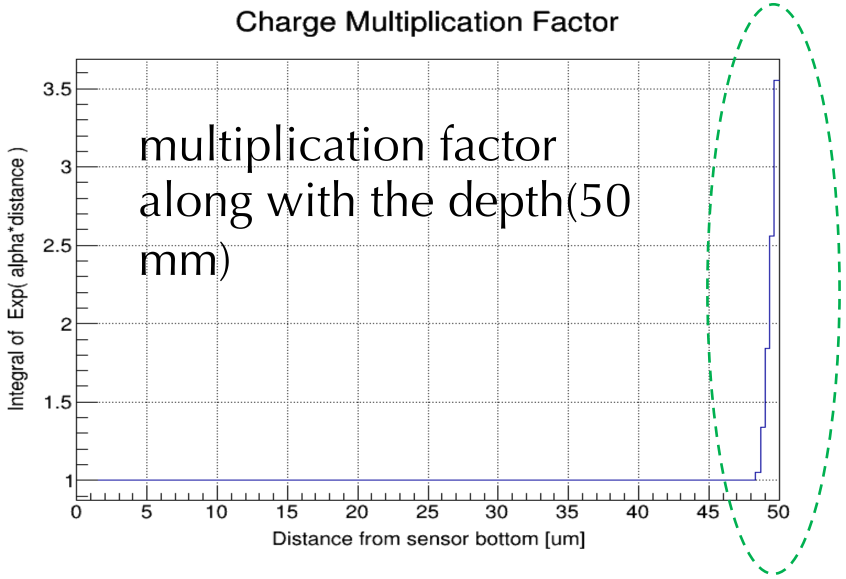
Impact Ionization Effect

- Adopt the impact ionization analytical model [3]



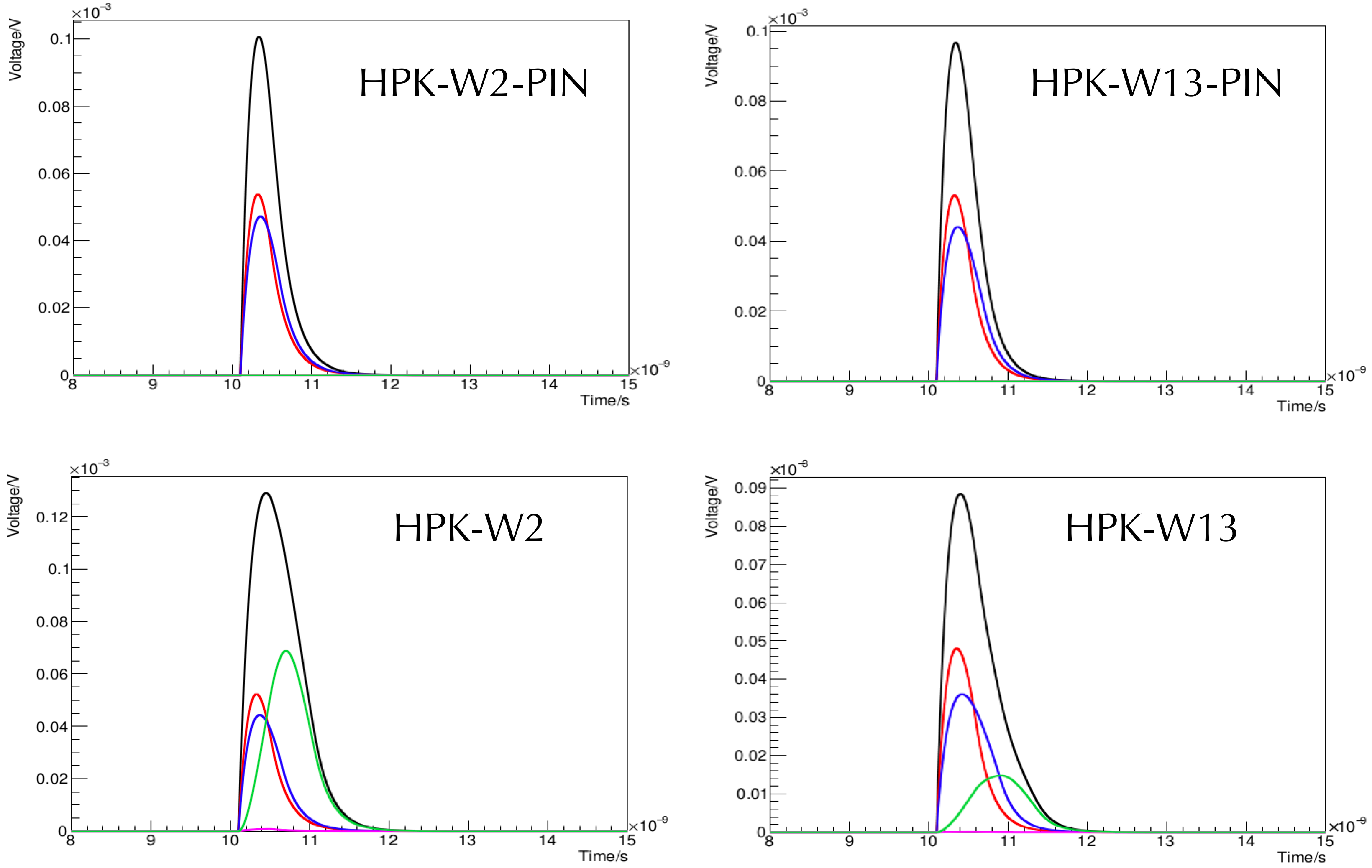


“gain layer” in LGAD



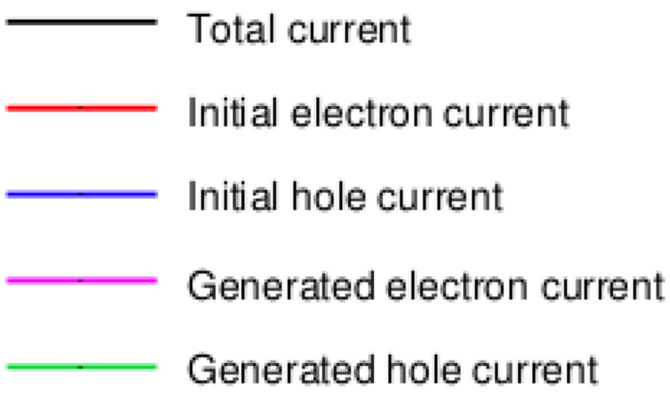
[3] M. Valdinoci, D. Ventura, M. C. Vecchi, M. Rudan, G. Baccarani, F. Illien, A. Stricker, L. Zullino, "Impact-ionization in silicon at large operating temperature", SISPAD '99, Sept. 6-8, 1999, Kyoto, Japan.

Simulated Transient Current



Upper panels: PIN sensor
(=wo Gain layer)

Lower panels : LGAD sensor
(= w Gain layer)

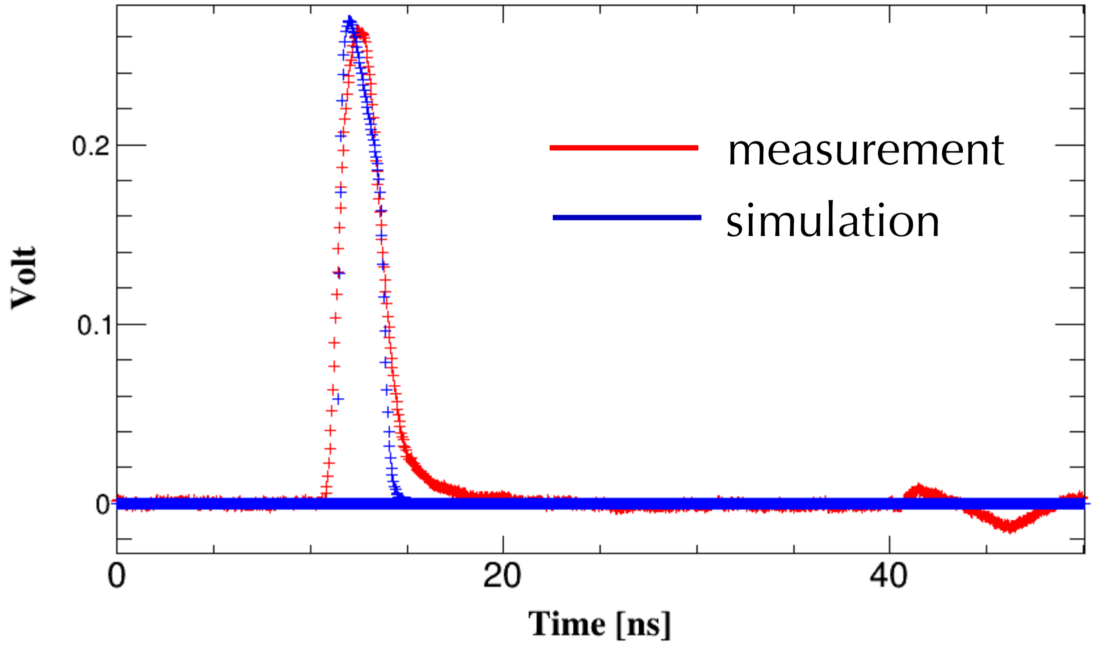


IR-Top configuration

Status

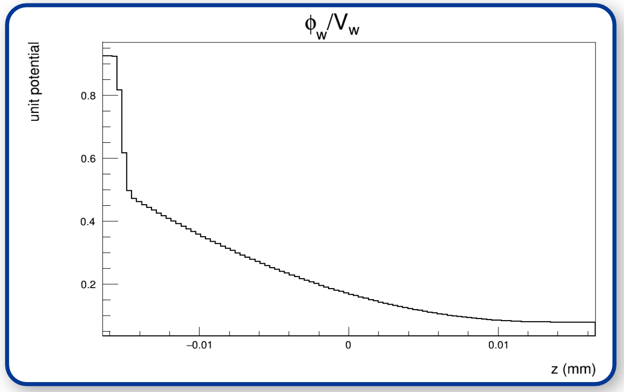
- Comparison with the measurement has been just began
  - Right figure shows an example of HPK W13 LGAD , Red-Top TCT
  - May need to tune the response function ?
  - Need further investigations

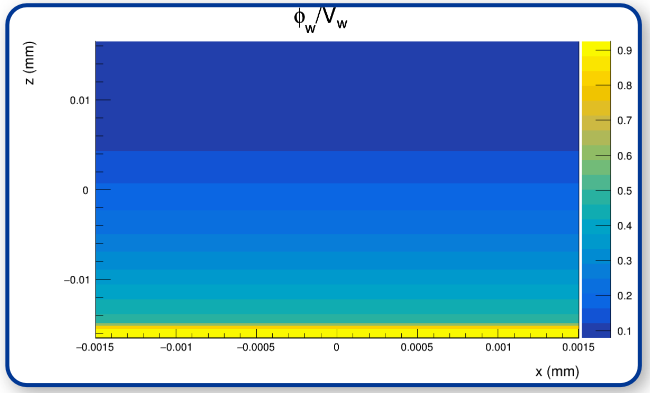
- What's next ?
  - Simulate the irradiated sensors
  - ...
  - Any suggestions/comments are highly appreciated !

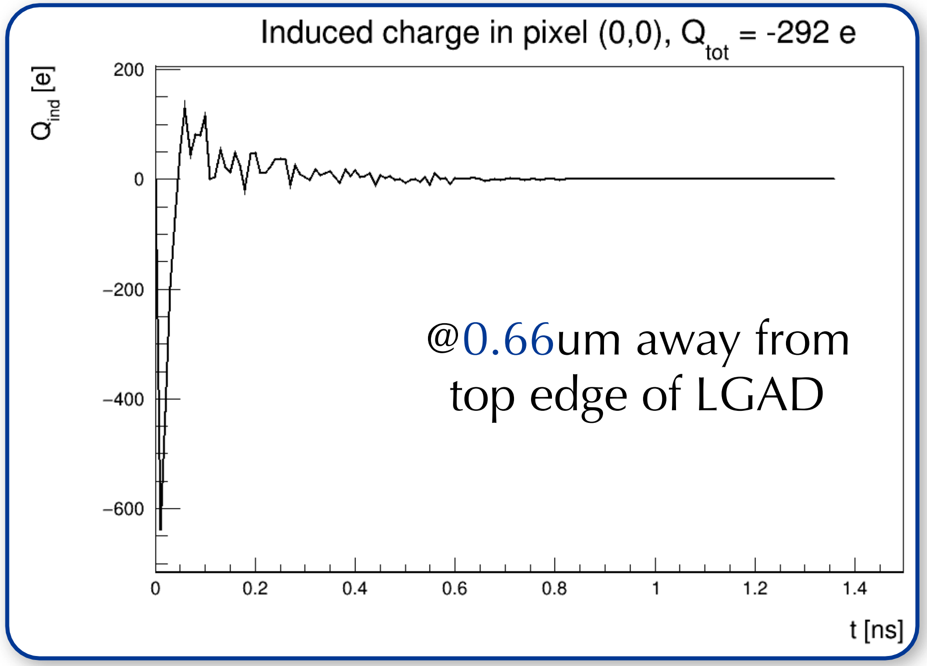


Allpix2 simulation

- LGAD
  - Size: 2um * 1.04mm * 33um
  - Material: Silicon
  - Support:
    - Size: 2um * 1.04mm
    - Thickness: 30um
    - Material: Aluminium
- Source
  - Particle: gamma
  - Energy: 5.4keV
- Weighting potential field
  - 2D: x z plane
  - Volt: -50V





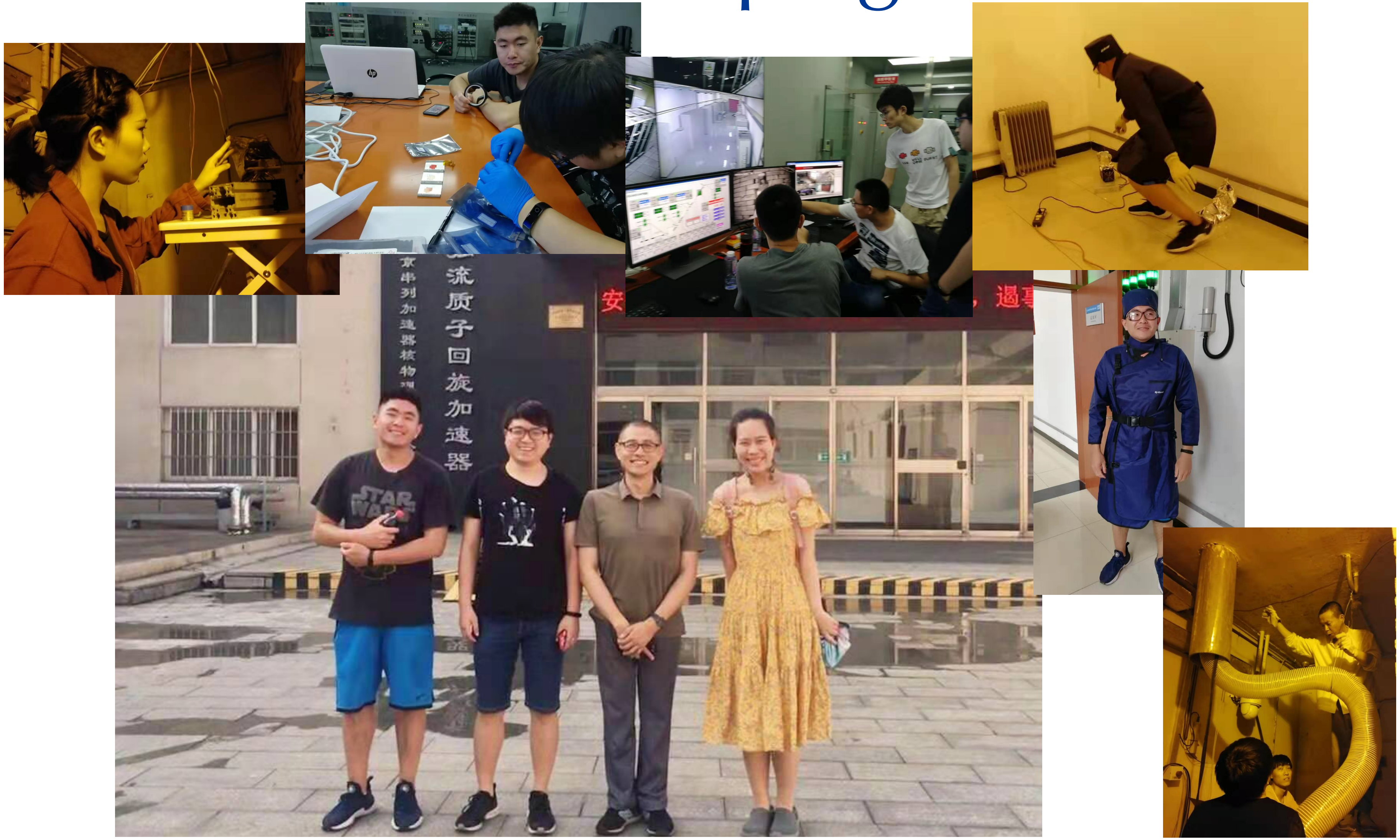


Summary

- There batches of LGAD sensor has been made in China with promising test results, including IV, CV, TCT, Beta sources.
- The first proton irradiation at CIAE has been done successfully with on-going tests and TCAD irradiation modeling
- TRACS with LGAD feature has been implemented along with Allpix2 investigation.

Stay tuned for more RD50 related activities from IHEP !

CIAE Irradiation Campaign – Thanks all!



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