The performance of IHEP-NDL and IHEP-IME LGAD sensors after neutron irradiation

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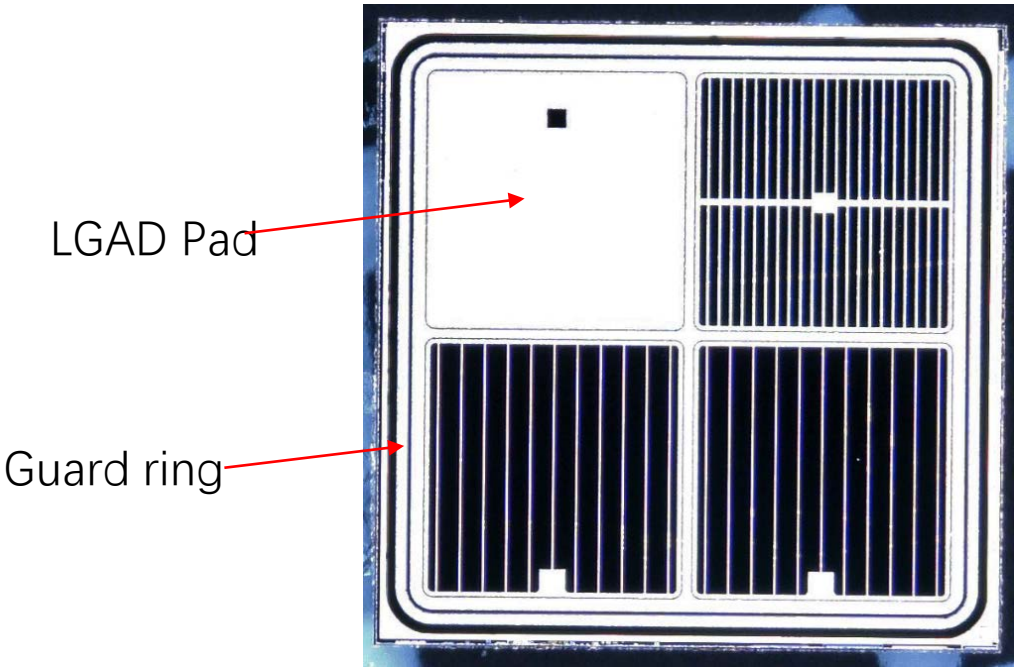
1. IHEP-NDL LGAD sensor

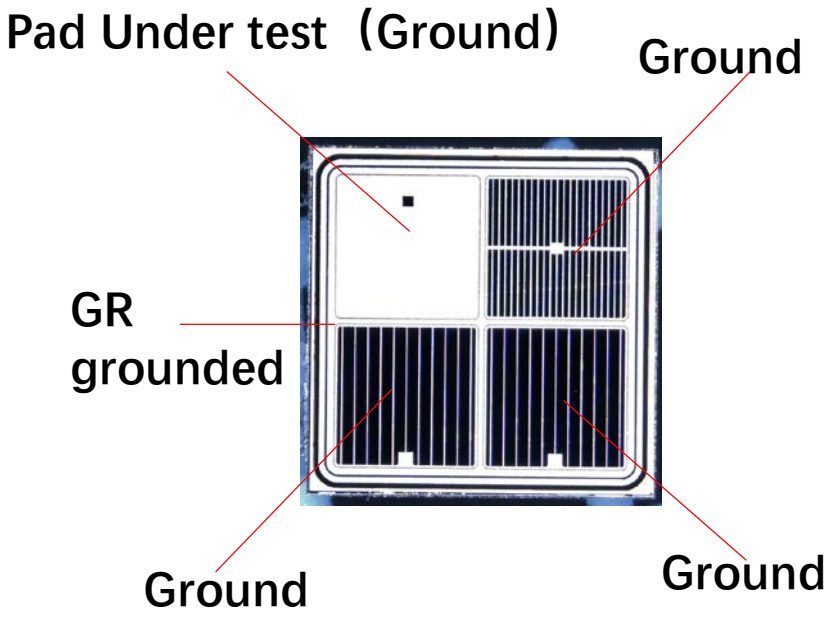


IHEP-NDLv3-B14

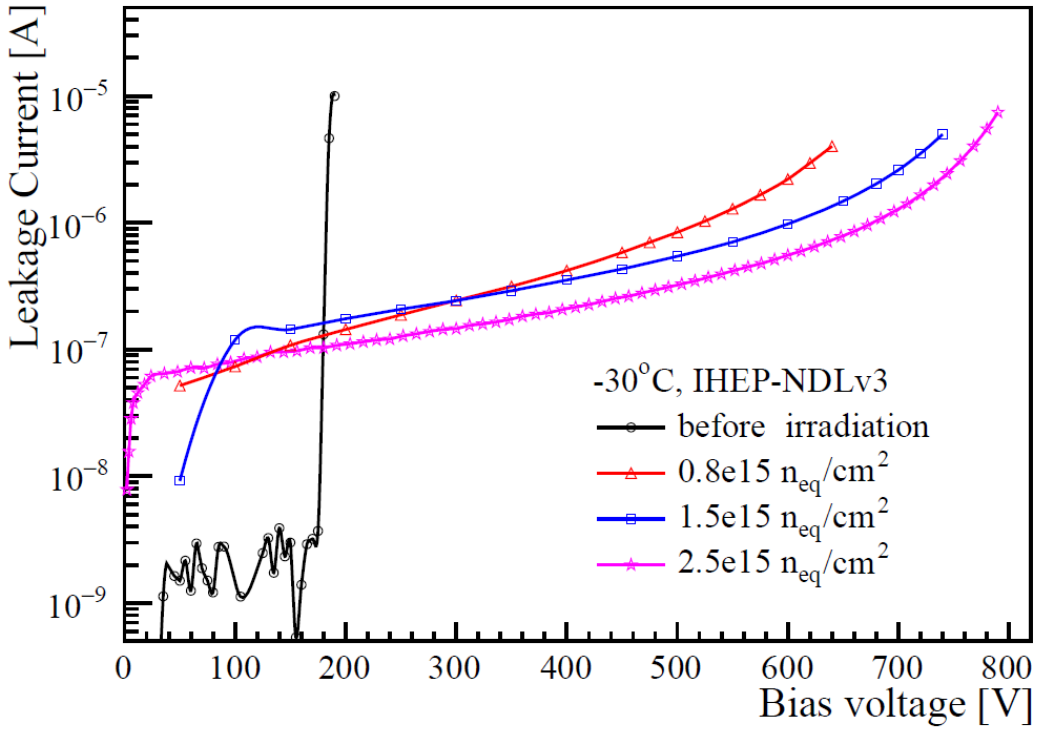
- Fabricated on 6 inch wafer
- Active layer 50μm
- 2×2 arrays
- single pad size 1.3×1.3 mm^2
- Epitaxial layer 350Ω·m

- **IHEP-NDLv3 LGAD sensors were irradiated with neutron by JSI**
- **Fluence: 0.8e15，1.5e15，2.5e15 n_{eq}/cm^2**

2. IHEP-NDLv3 I-V test



All pads and GR are grounded
to avoid early breakdown



Leakage current 4pads+GR

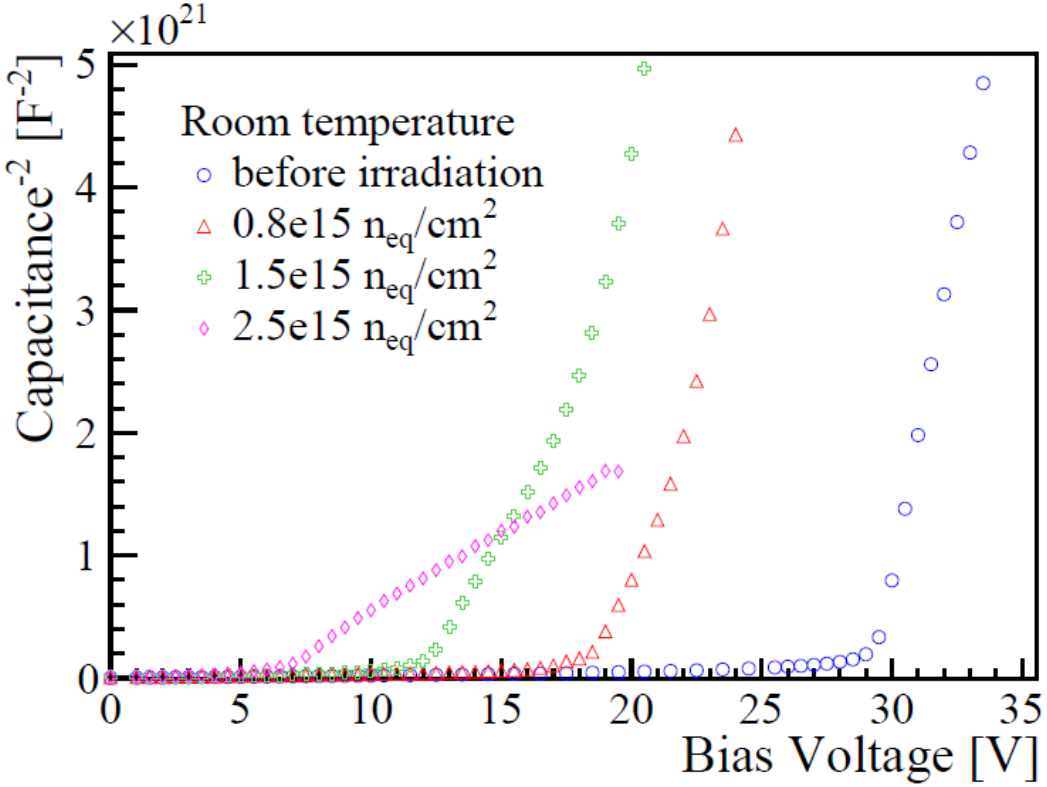
Leakage current @ Before irradiation

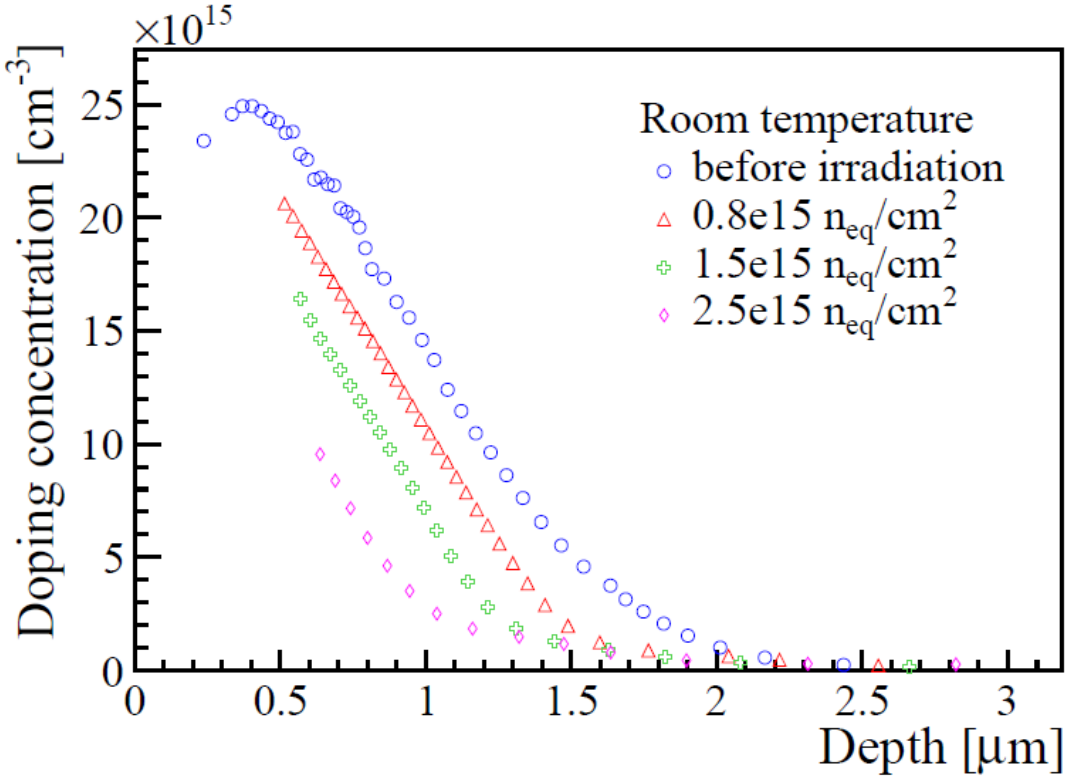
Leakage current ~2nA

Leakage current @ 2.5e15n_{eq}/cm^2

Leakage current 3.4 μA (50μA/cm^2) at 760V → lower than HGTD requirement(125uA/cm^2).

2. IHEP-NDLv3 C-V test

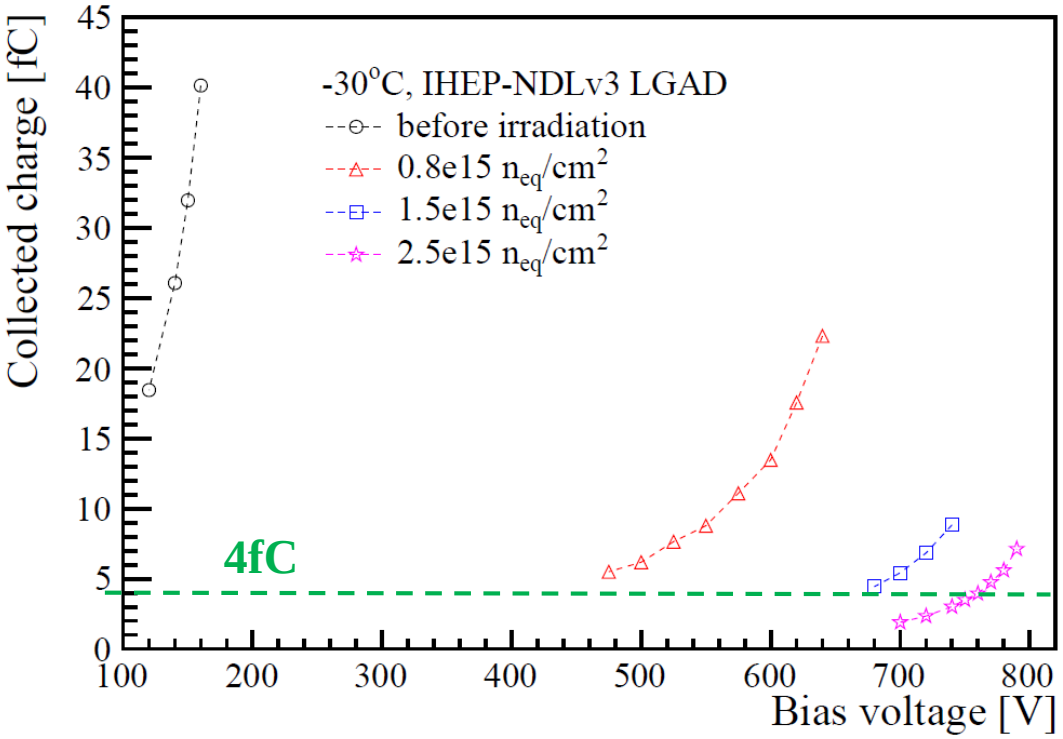


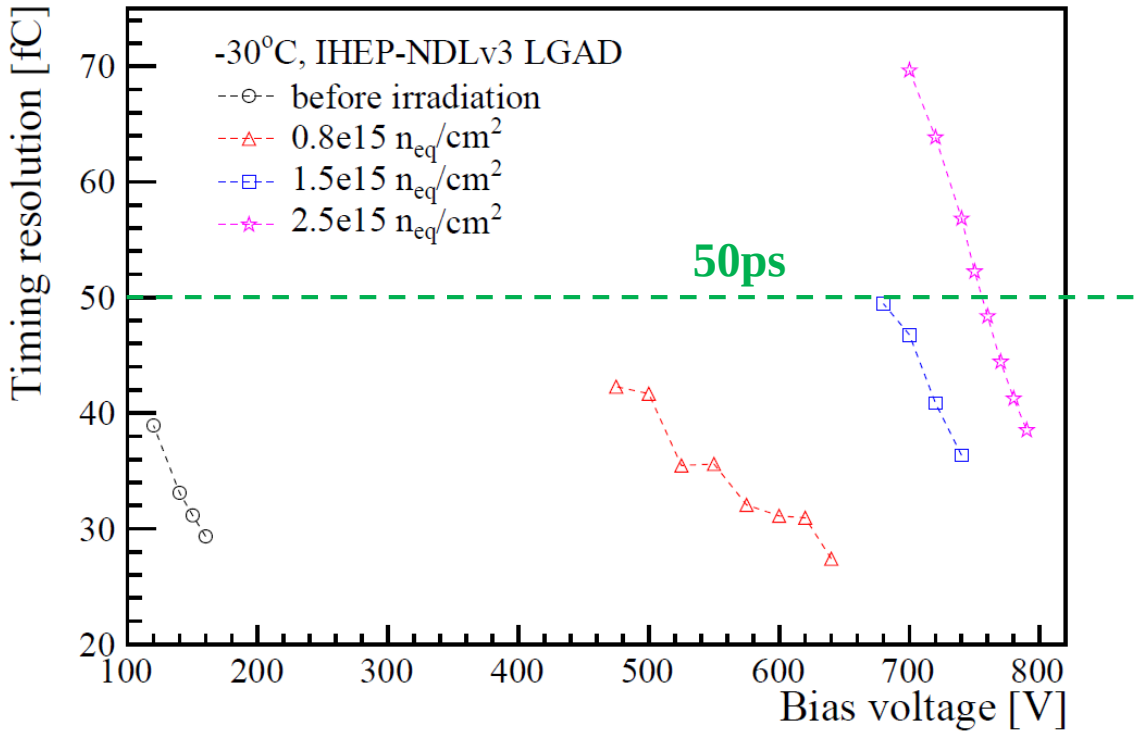


V_{GL} decreases
30V(before irradiation)-> 18V (0.8e15n_{eq}/cm^2)
-> 12V (1.5e15n_{eq}/cm^2)-> 7V (2.5e15n_{eq}/cm^2)

Doping concentration reduced by ~2.5 times

2. IHEP-NDLv3 Collected Charge & Timing Resolution





Collected charge

39fC @before irradiation

4fC @ 760V 2.5e15n_{eq}/cm^2

Timing Resolution

28ps @ before irradiation

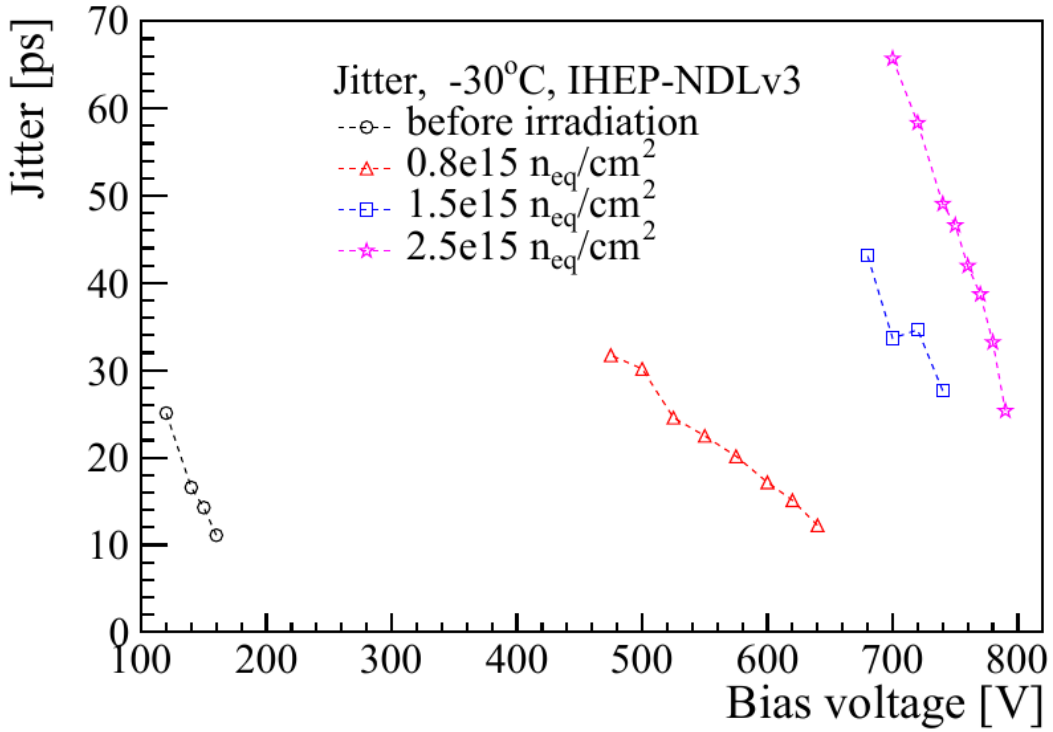
50ps @ 755V 2.5e15n_{eq}/cm^2

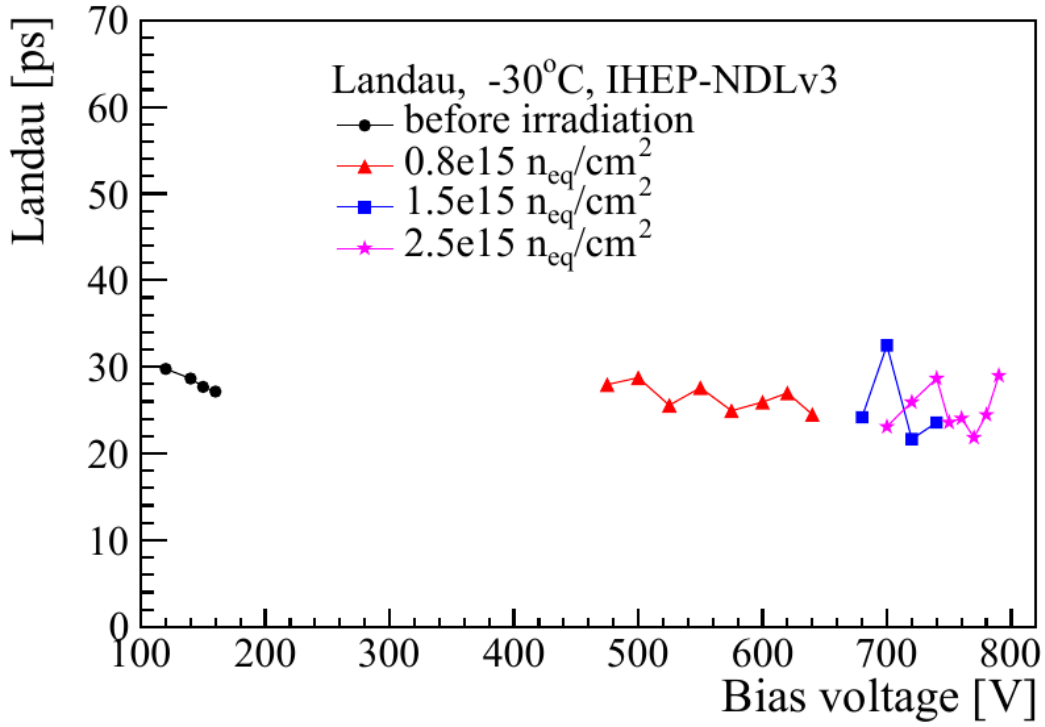
2. IHEP-NDLv3 Jitter & Landau contributions in the timing resolution

$$\sigma_{\text{Jitter}} = \frac{N}{\mathrm{d}V/\mathrm{d}t} \approx t_{\text{rise}} / \left(\frac{S}{N}\right)$$

mitigated by the CFD method

$$\sigma_t^2 = \sigma_{\text{TimeWalk}}^2 + \sigma_{\text{Landau}}^2 + \sigma_{\text{Jitter}}^2$$





Fluence ↑ → Gain ↓ → S/N ↓ → Jitter ↑

Landau no significant change
stable at 20-30ps

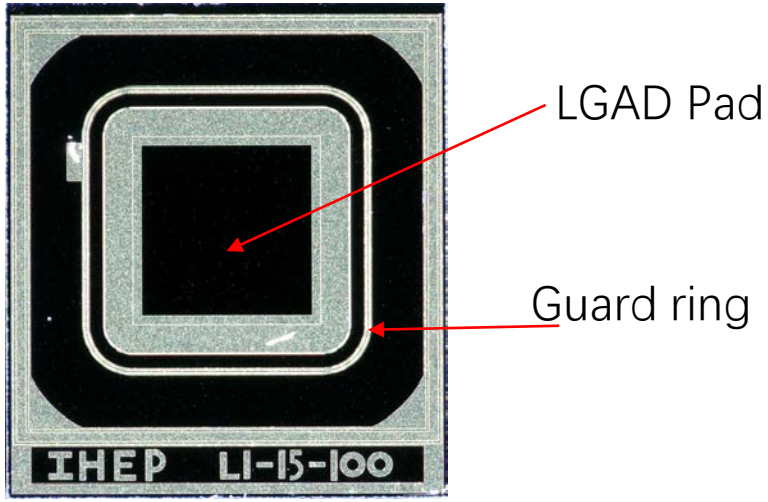
3. Summary of IHEP-NDLv3

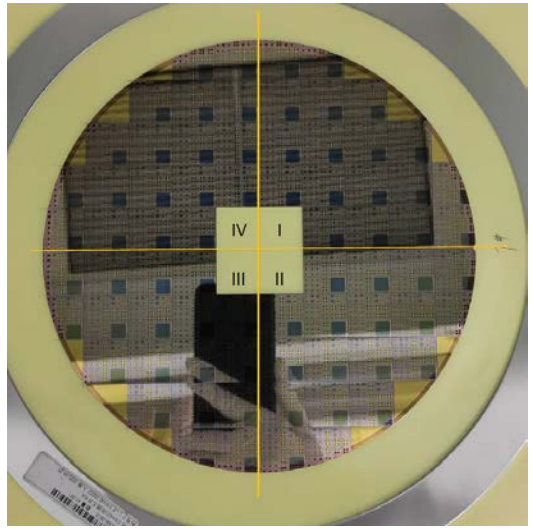
NDLv3 LGAD @ 2.5e15n_{eq}/cm^2

- Collected charge can reach 4fC at 760V.
- Time Resolution can be better than 50ps at 760V.
- Landau contribution stable at 20-30ps

	HGTD requirement	IHEP-NDLv3	
CC	4 fC	4fC @760V 7fC@790V	√
Timing	70 ps	50ps @755V	√
Leakage current	125 μA/cm^2	50 μA/cm^2 @760V	√

4. IHEP-IME LGAD sensors





8 inch wafer

wafer	Phosphorus Energy	Carbon
W1	Low	+
W7	Low	-
W8	high	-

IHEP-IMEv1-W1/W7/W8

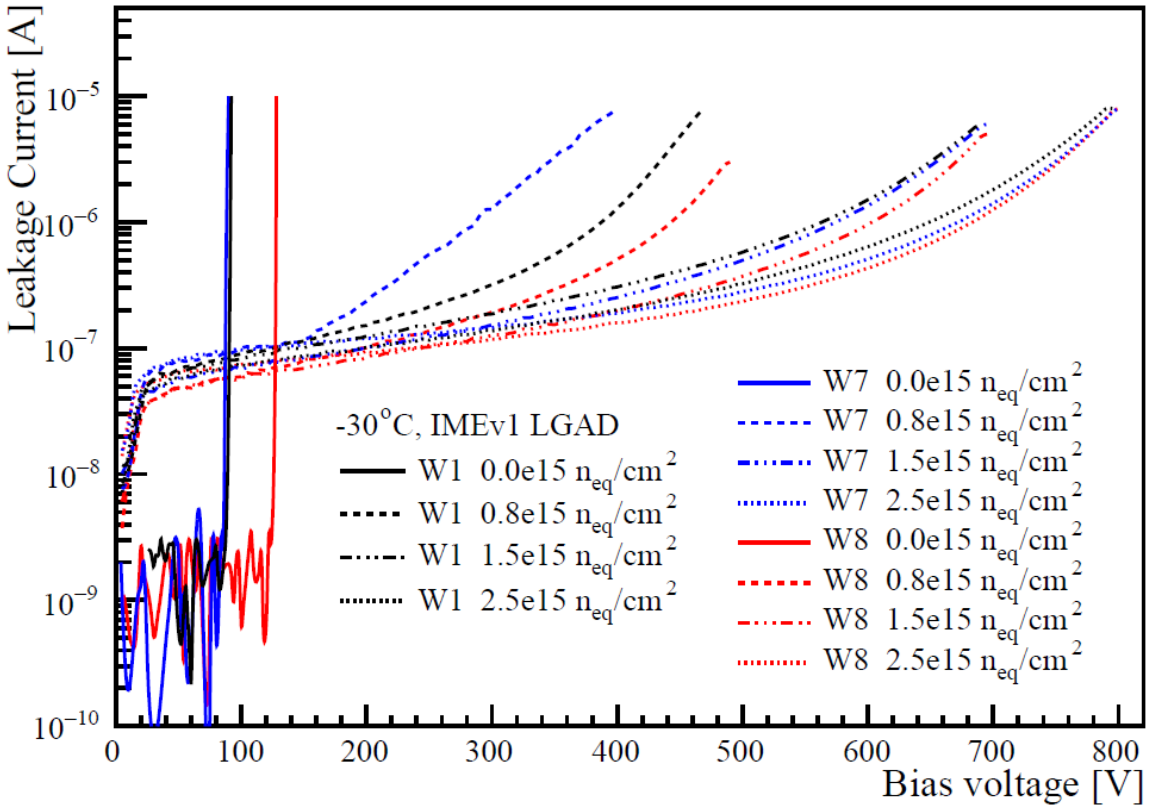
- Fabricated on 8 inch wafer
- Active layer 50μm
- Epitaxial layer 1000Ω·m
- single pad / 2x2 / 5x5
- single pad size 1.3×1.3 mm^2
- single pad sensor is the test object in this slides

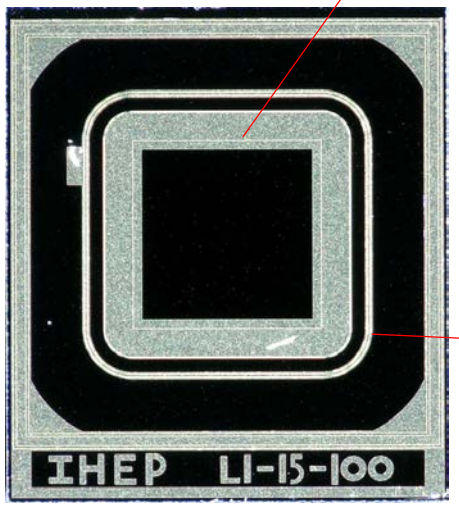
- **W1, W7** and **W8** have the same P+ doping in design.
- **W1 has carbon implantation**.
- **W8** has higher N+ energy implantation.

➢ **IHEP-IMEv1 sensors were irradiated with neutron by JSI**

➢ **Fluence: 0.8e15，1.5e15，2.5e15 n_{eq}/cm^2**

5. IHEP-IMEv1 I-V test





Pad Under test (Ground)

GR grounded

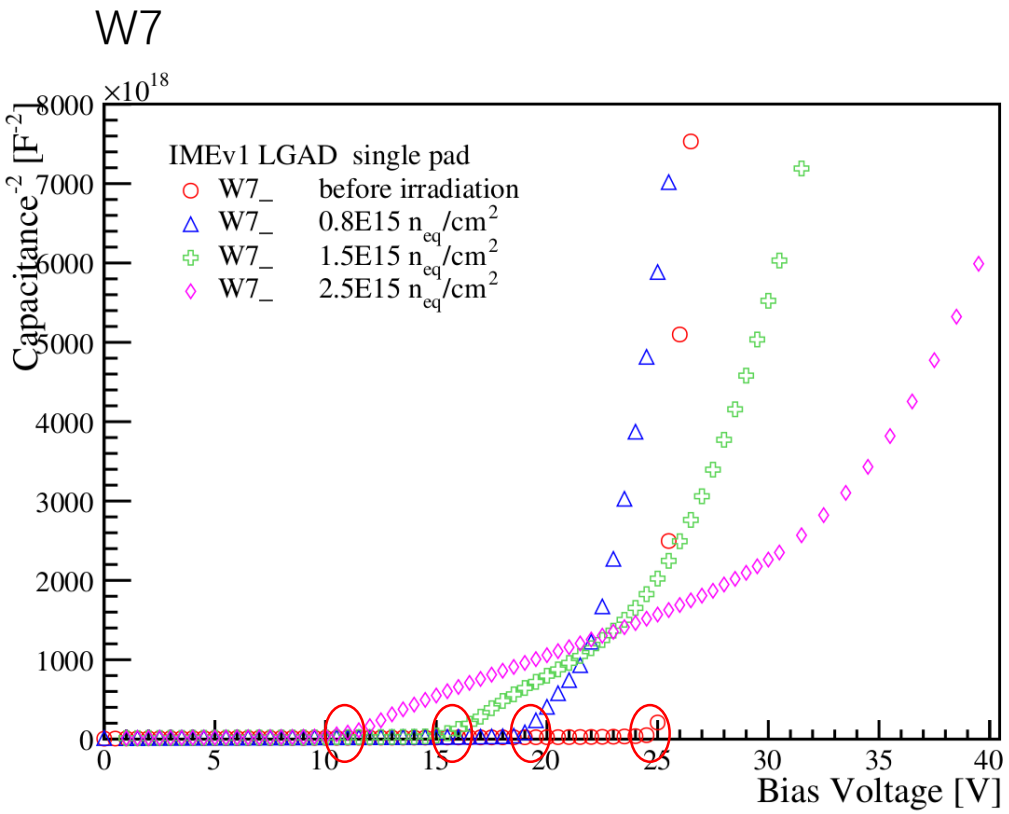
Before irradiation @ -30℃

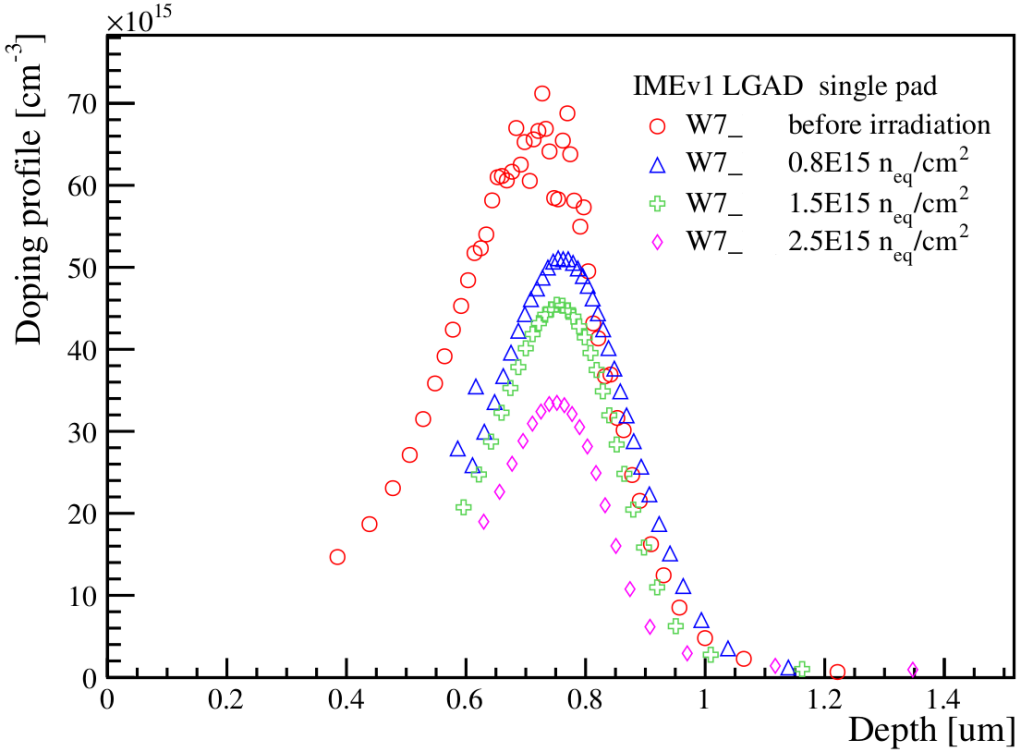
- Single pad current ~2nA
- W1 W7 breakdown at ~80V
- W8 breakdown at ~120V

2.5e15n_{eq}/cm^2 @ -30℃

- W1>W7>W8 ,
- W1 (carbon implantation) slightly higher current
- W1 ~60 μA/cm^2 at 650V (4fC)
- Lower than HGTD requirement (125 μA/cm^2)

5. IHEP-IMEv1 C-V test



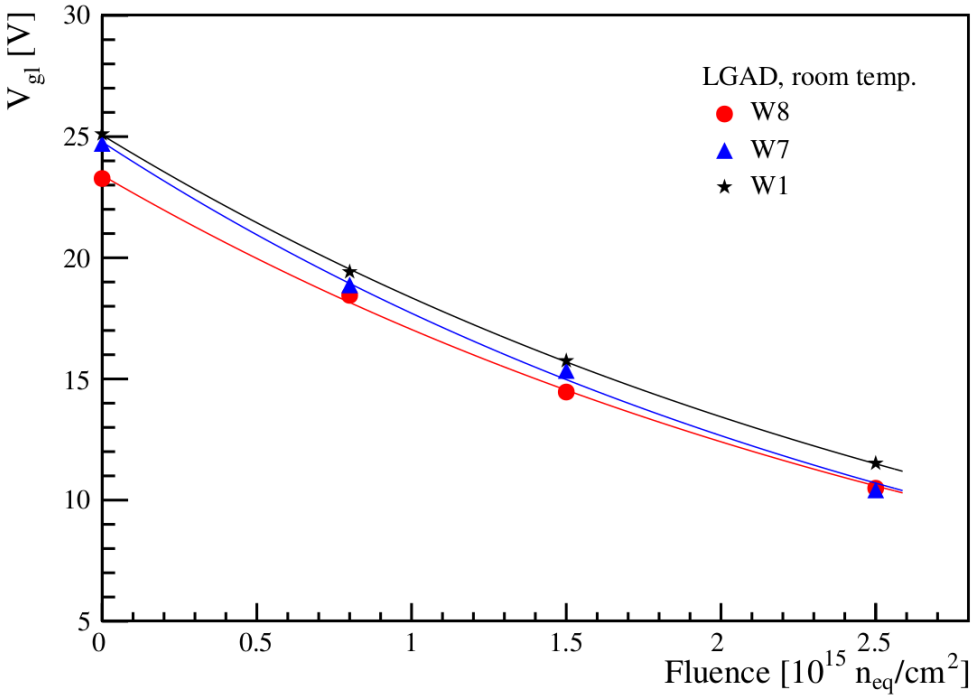


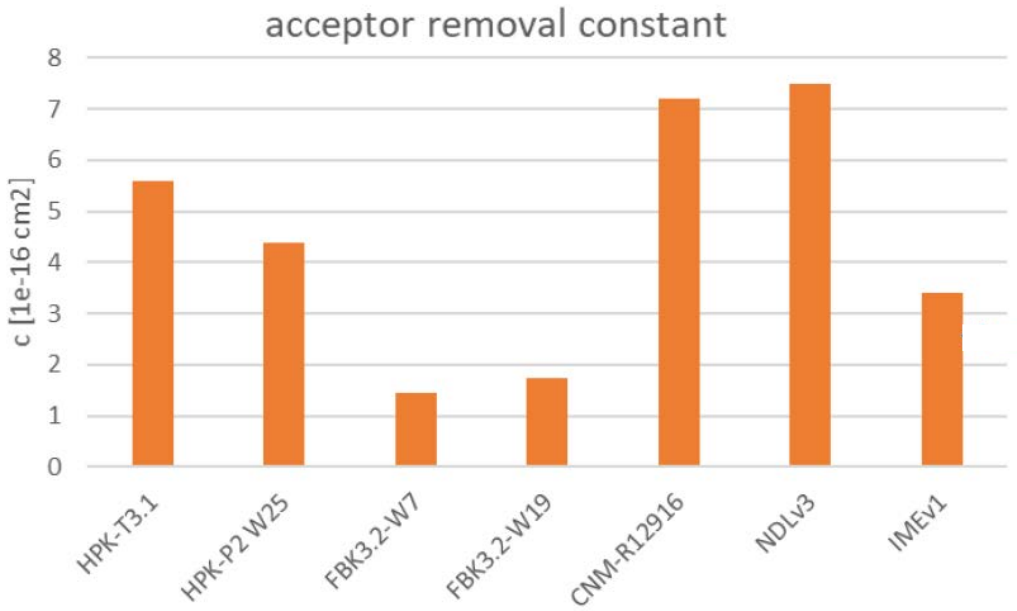
V_{GL} decreased with irradiation fluence
24.7V(before irradiation)-> 18.9V (0.8e15)
-> 15.4V (1.5e15)-> 10.4V (2.5e15)

Doping concentration reduced by ~2 times
6.7e16->5.1e16->4.6e16->3.4e16

5. IHEP-IMEv1 Vgl & acceptor removal constant

V_{gl} vs. fluence

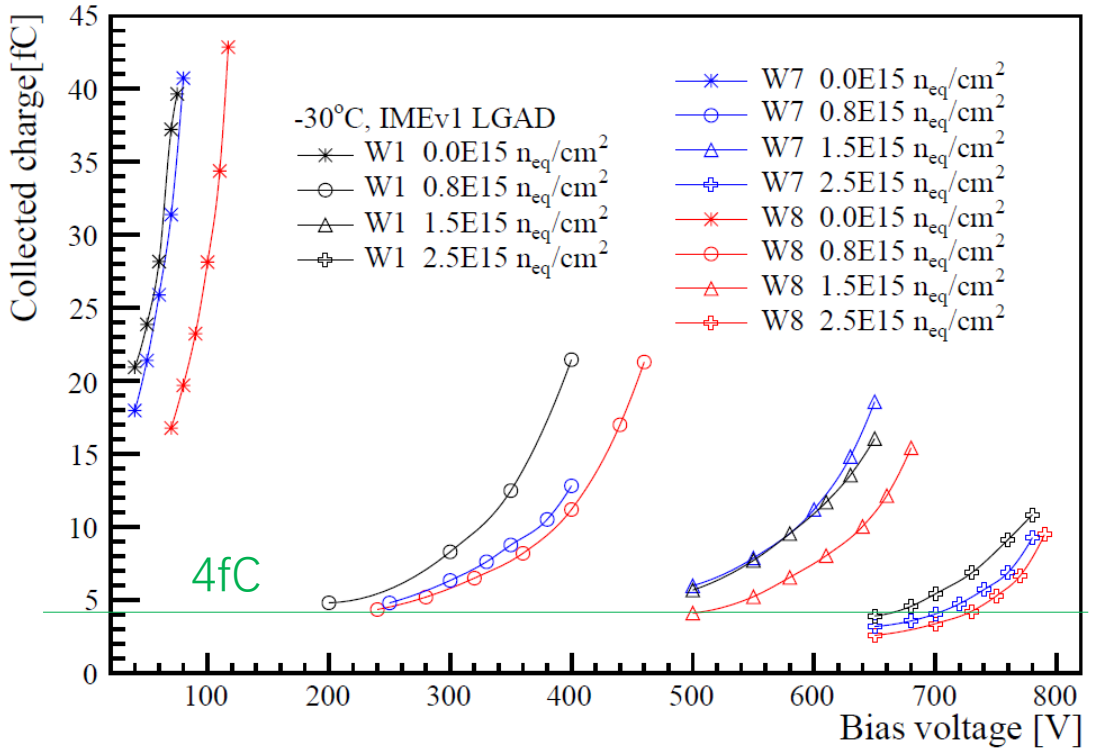


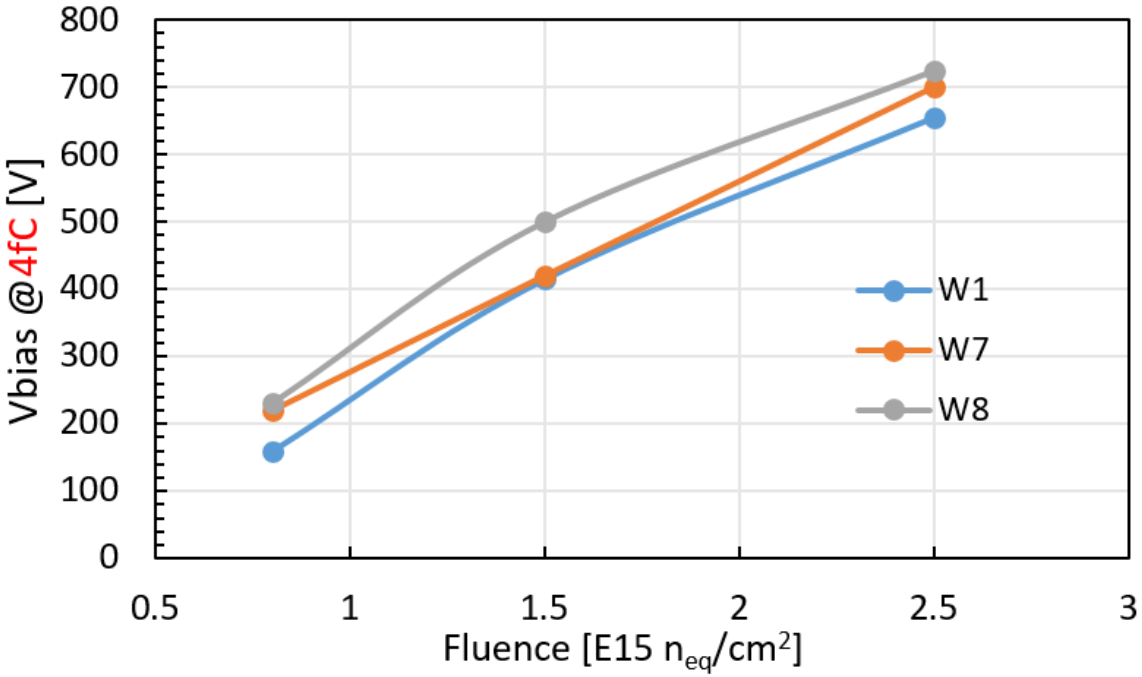


	c [cm^2]
W8	3.17E-16
W7	3.36E-16
W1	3.12E-16

Compared with NDLv3,
IMEv1 has a smaller removal constant

5. IHEP-IMEv1 Collected charge





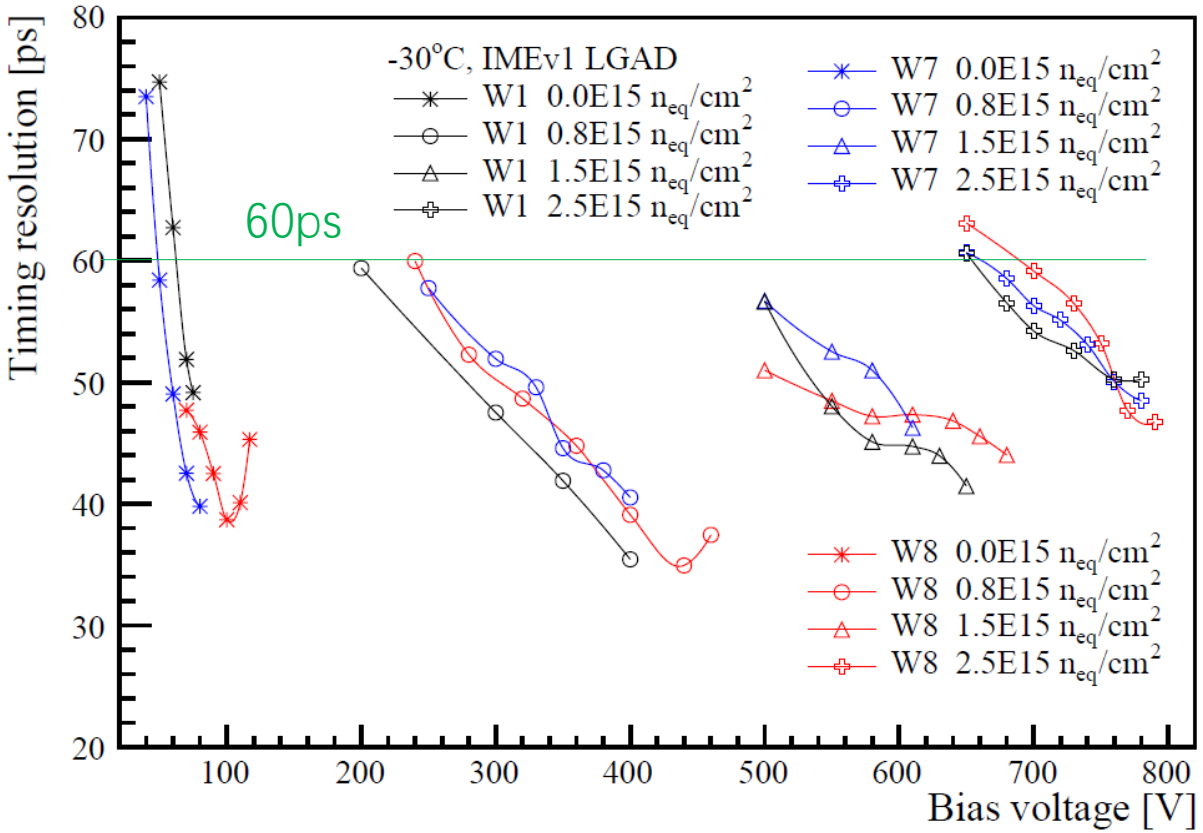
Collected charge:

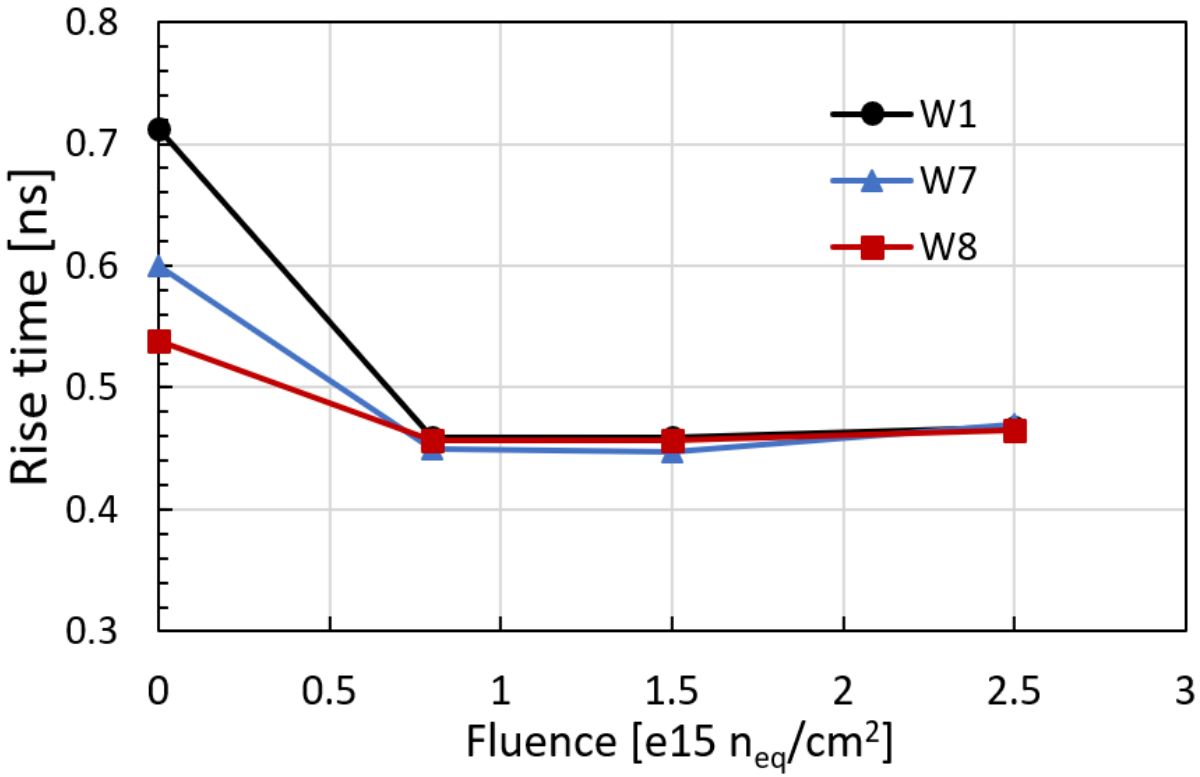
- All reached **4fC** @ 2.5E15(660V, 700V, 730V)
- W1 > W7 > W8

Voltage @4fC vs. Fluence

W1 (carbon implantation) has higher collected charge and lower working voltage

5. IHEP-IMEv1 Timing resolution





Timing resolution:

- All reached **60ps** @2.5E15 (655V, 660V, 680V)
- W8 has a better timing resolution

Rise time:

- Before irradiation, W8 has the fastest rising edge
- After irradiation, three wafers have almost the same rise time(0.45-0.47ns)
- At higher voltage, electrons reach saturation drift velocity

6. Summary

IHEP-NDLv3 LGAD @ 2.5e15n_{eq}/cm^2

- Collected charge can reach 4fC at 760V.
- Time Resolution can be better than 50ps at 760V.

IHEP-IMEv1 LGAD @ 2.5e15n_{eq}/cm^2

- All three wafers （W1/W7/W8） reaches 4fC
- W1 (carbon implantation) has higher collected charge
- All reached 50ps

@ 2.5e15	HGTD requirement	IHEP-NDLv3		IHEP-IMEv1	
Collected charge	4 fC	4fC @760V 7fC@790V	√	4fC @660V 11fC @ 780V	√
Timing	70 ps	50ps @755V	√	50ps @760V	√
Leakage current	125 μA/cm^2	50 μA/cm^2 @760V	√	60 μA/cm^2 @650V	√

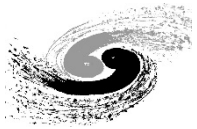
7. Future plan

IHEP-NDLv4 next run

- Higher P+ doping
- Full size 15x15
- Will be ready by July 2021

IHEP-IMEv2 run

- Higher carbon doping
- Full size 15x15
- Production is completed and preliminary testing
- 10+ good full size sensor each wafer



Thank you !

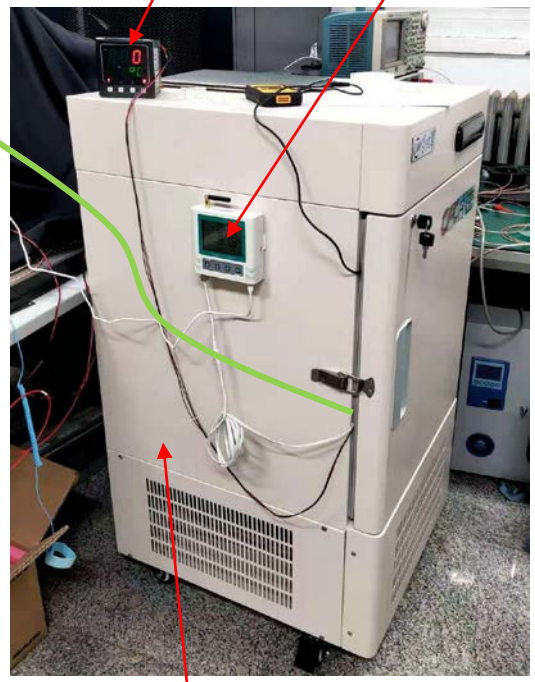
1. Low Temperature Beta Setup at IHEP

Air compressor

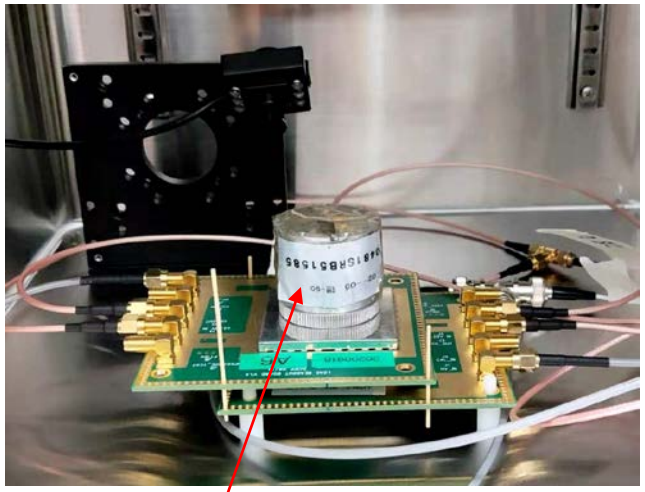
Air dryer

Flowmeter

Temperature Humidity

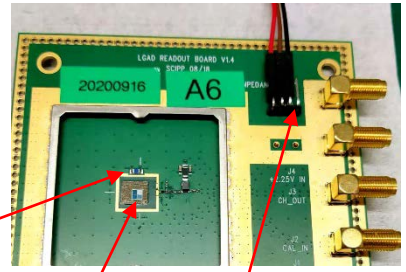


Low-temperature chamber



Beta source

Temperature converter



Temperature sensor PT100

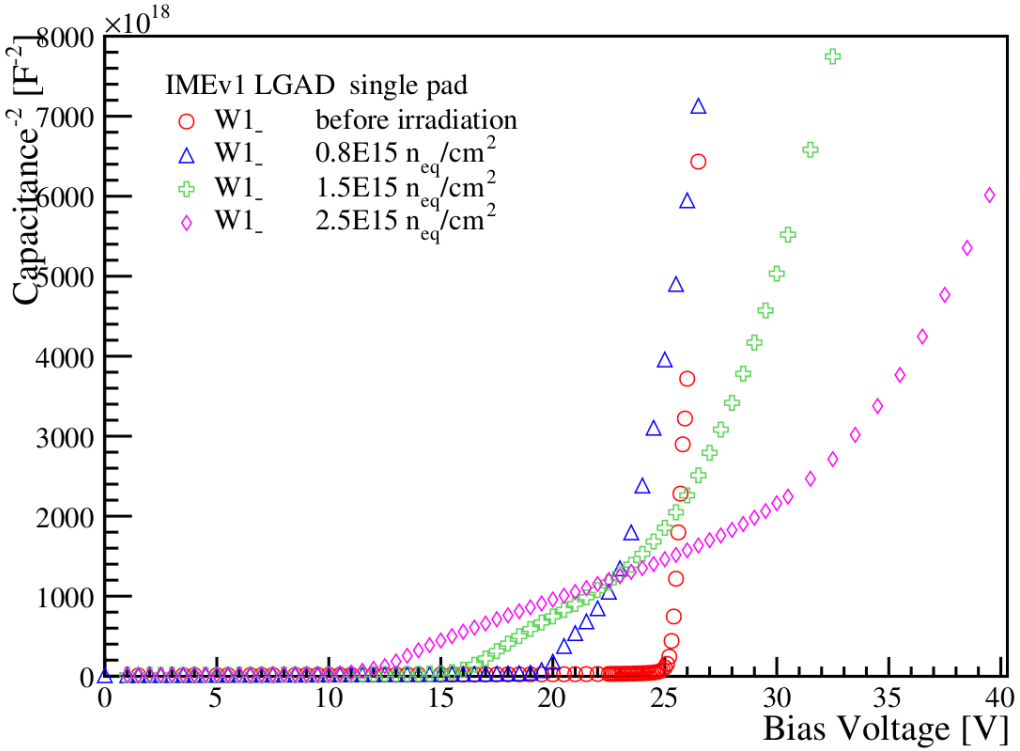
PT100 interface

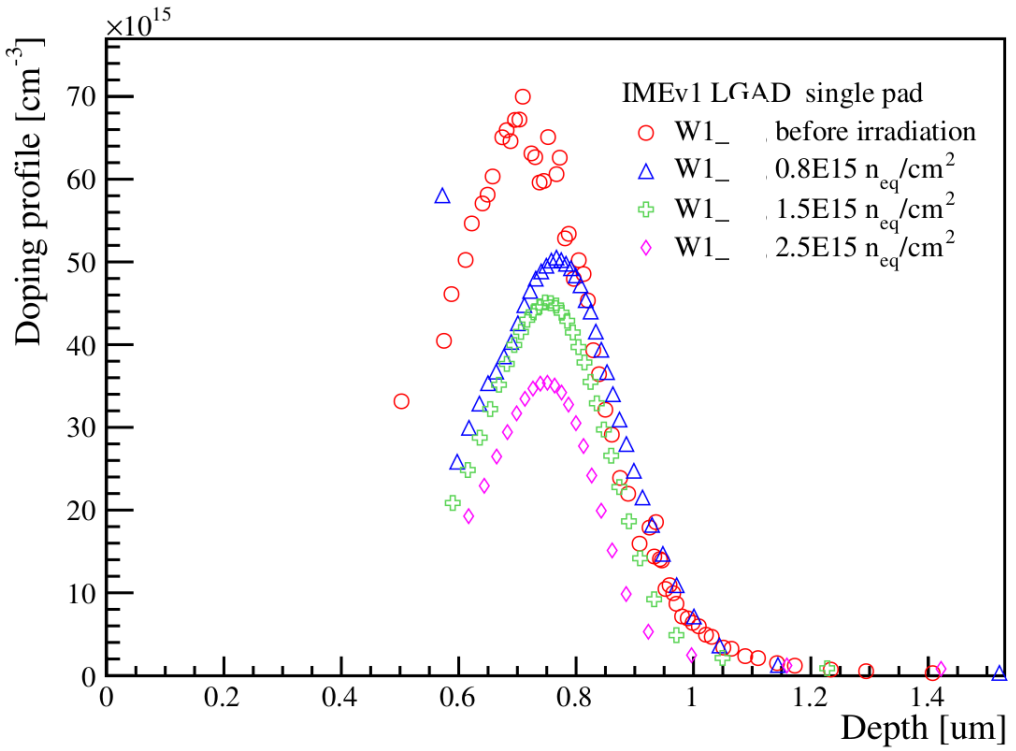
LGAD sensor

Temperature -30±2°C
Humidity < 10%

2. CV test

W1__single pad



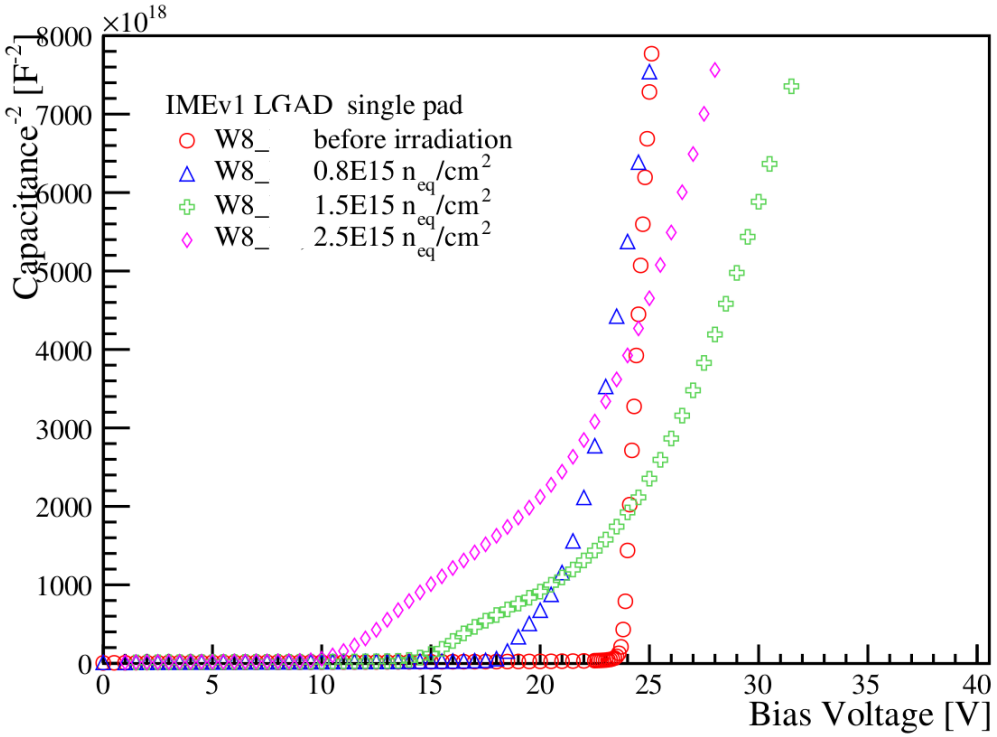


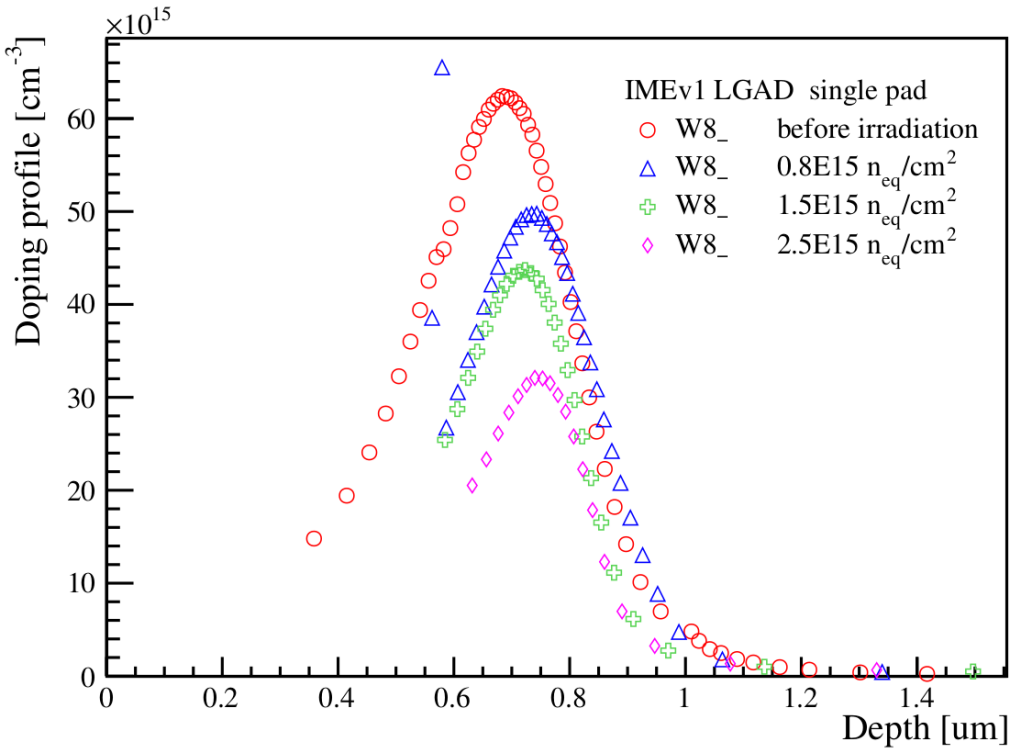
Vgl
25->19->15.5->11

Doping peak
6.64e16->4.97e16->4.50e16->3.56e16

3. CV test

W8__single pad





Vgl
24->18->14.5->10.5

Doping peak
6.26e16->4.97e16->4.42e16->3.25e16