DRD3

Low Gain Avalanche Detectors with deep Carbon implantation

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WG3/WP3 - Extreme fluence and radiation damage characterization

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Motivation

- Low gain avalanche detectors with 30ps temporal resolution designed by IHEP are chosen as a part of HGTD for HL-LHC.These detectors (denoted as W0) are:
  - Carbonated.
  - Different implantation depth for gain layer and Carbon.
  - High thermal load for Carbon.
- Growing need for enhanced radiation hardness in detectors:
  - to meet higher requirements, we have investigated devices utilizing a deep carbon implantation layer.

Table 7.1: Key numbers relating the detector challenges at the different accelerators.

Parameter	Unit	LHC	HL-LHC	HE-LHC	FCC-hh
Total number of pp collisions	10^{16}	2.6	26	91	324
Charged part. flux at 2.5 cm, est.(FLUKA)	$\mathrm{GHz\,cm^{-2}}$	0.1	0.7	2.7	8.4 (10)
1 MeV-neq fluence at 2.5 cm, est.(FLUKA)	$10^{16}\,\mathrm{cm}^{-2}$	0.4	3.9	16.8	84.3 (60)
Total ionising dose at 2.5 cm, est.(FLUKA)	MGy	1.3	13	54	270 (300)
$dE/d\eta\|_{\eta=5}$ [331]	GeV	316	316	427	765
$dP/d\eta\|_{\eta=5}$	kW	0.04	0.2	1.0	4.0
90% $\mathrm{b\bar{b}}$ $p_T^b > 30$ GeV/c [332]	$\|\eta\|<$	3	3	3.3	4.5
VBF jet peak [332]	$\|\eta\|$	3.4	3.4	3.7	4.4
90% VBF jets [332]	$\|\eta\|<$	4.5	4.5	5.0	6.0
90% $\mathrm{H} \rightarrow 4l$ [332]	$\|\eta\|<$	3.8	3.8	4.1	4.8

Roadmap of IHEP sensors

IHEP_IMEv1
2020

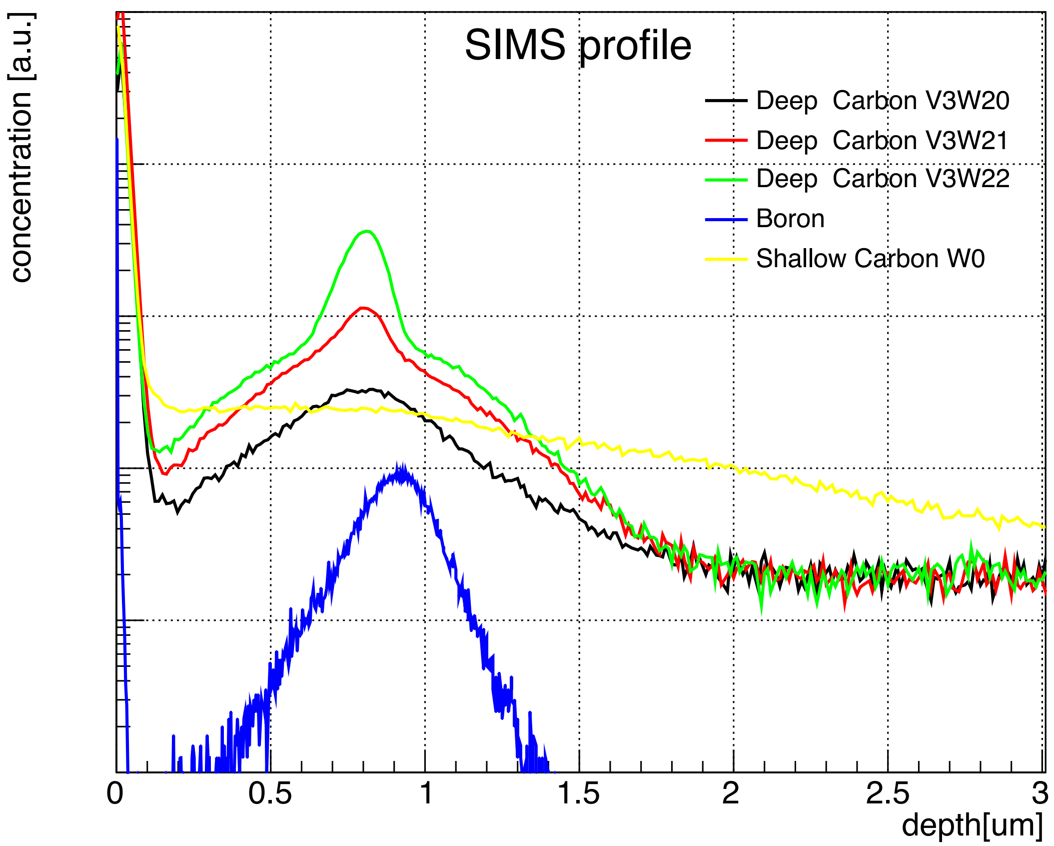
IHEP_IMEv2
2021-2022

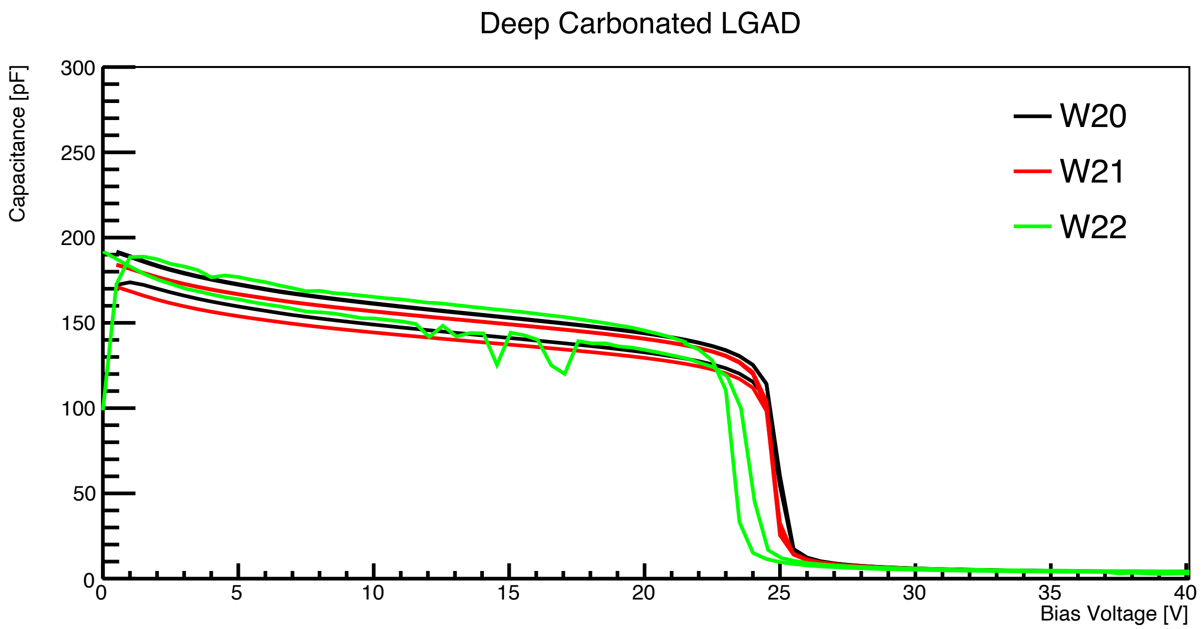
IHEP_IMEv3
2022-

IHEP_IMEv3 LGAD deigns

Sensor		Diffuse	C dose(a.u.)	
W15		CHBL	0.5	Different B dose
W16 W17	**W16Q1**	CHBL	0.2	Interpolate v2w7 to minimize the C factor.
	W16Q2		0.3	
	W16Q3		0.4	
	W16Q4		0.5	
	W17Q1		0.6	
	W17Q2		0.7	
	W17Q3		0.8	
	W17Q4		0.9	
W18		CMBL	0.5, 0.8, 1, 2	Change c thermal load
W20 w21 w22		CHBL	0.2	Different C Depth
		CHBL	0.5	
		CHBL	1	

Doping profiles and Vgl





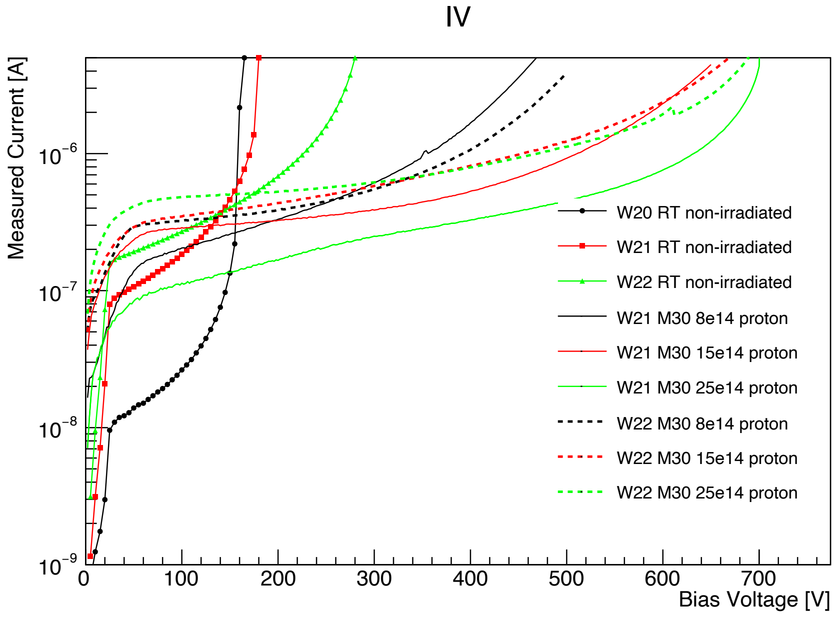
Wafer	W20	W21	W22
Vgl (V)	24.8	24.6 (-0.8%)	23.3 (-6%)

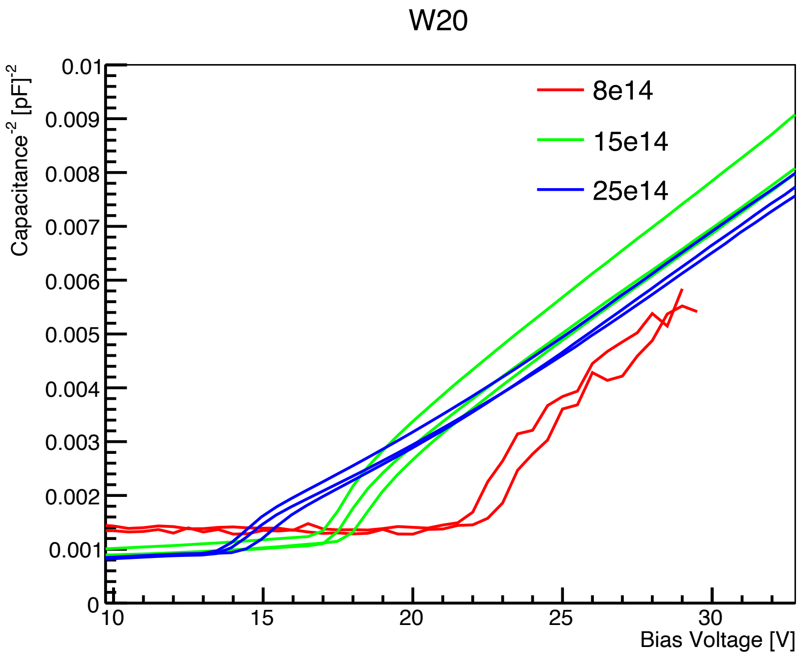
- Carbon and Boron are implanted with very close depth.
- 3 deep carbonated wafers differ only in carbon dose.
- Gain layer deactivated with increasing carbon density, up to 6%.

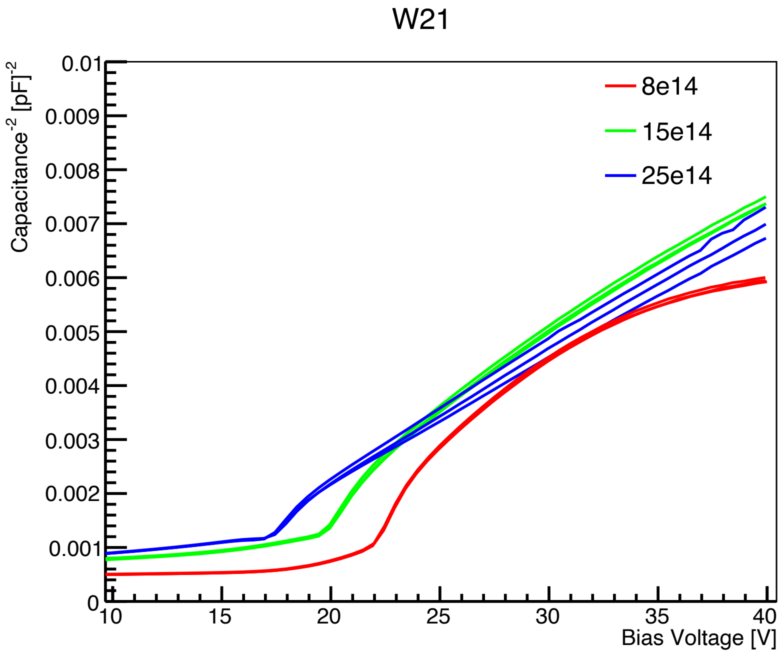
Radiation resistance 1

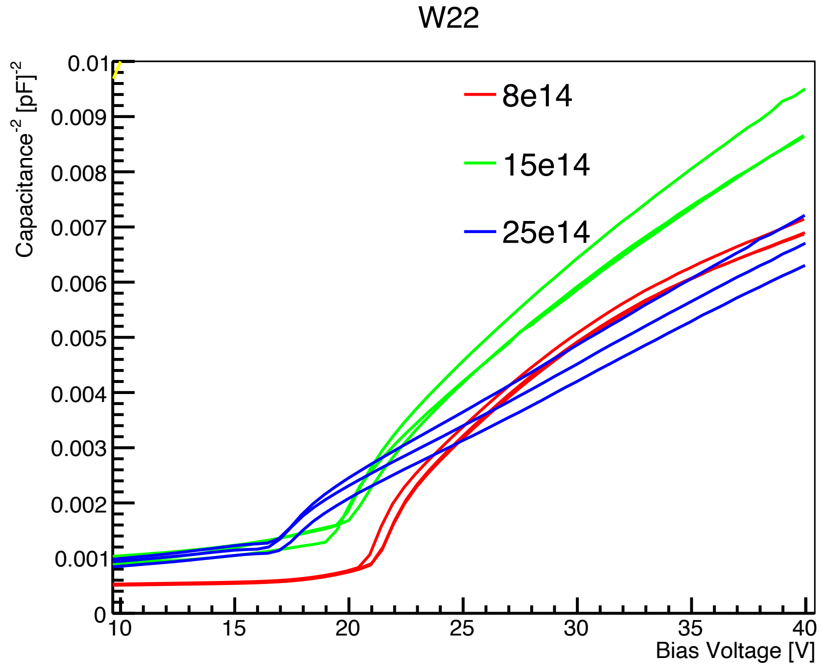
- 80MeV proton irradiation at China Spallation Neutron Source (csns) up to $2.5e15\ n_{eq}/cm^2$.
- Measure c-factor with CV scan.

Wafer	W20	W21	W22	W0
C (1e-16cm2) proton	2.48	1.63	1.44	3.11
C (1e-16cm2) neutron (JSI)	-	-	-	1.06



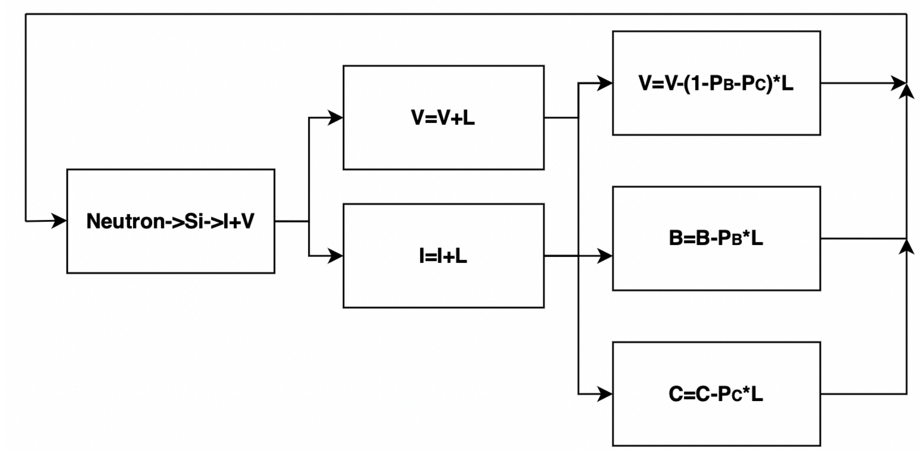




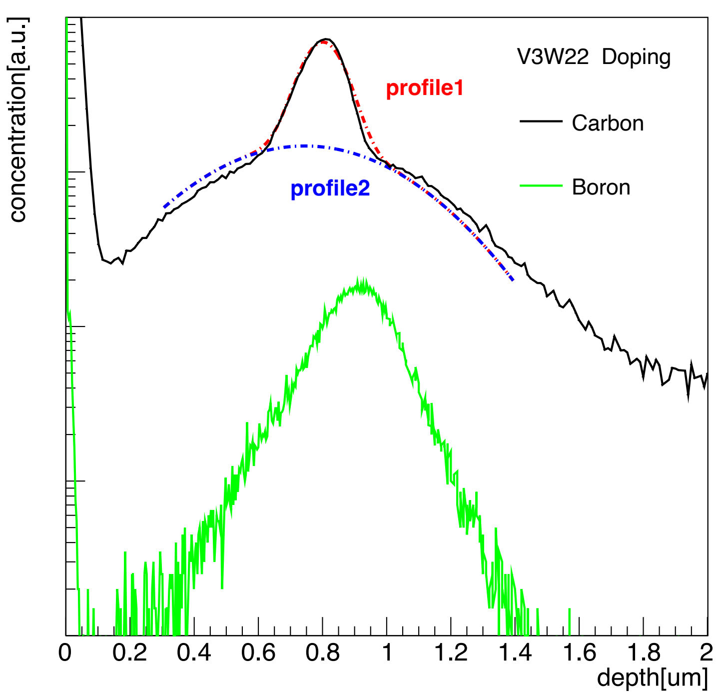


Radiation resistance 2

- Modeling c factors
  - 1.Assume carbon with profile1 protects boron.
  - 2.Only carbon with profile 2 affects.



A simple monte carlo scheme

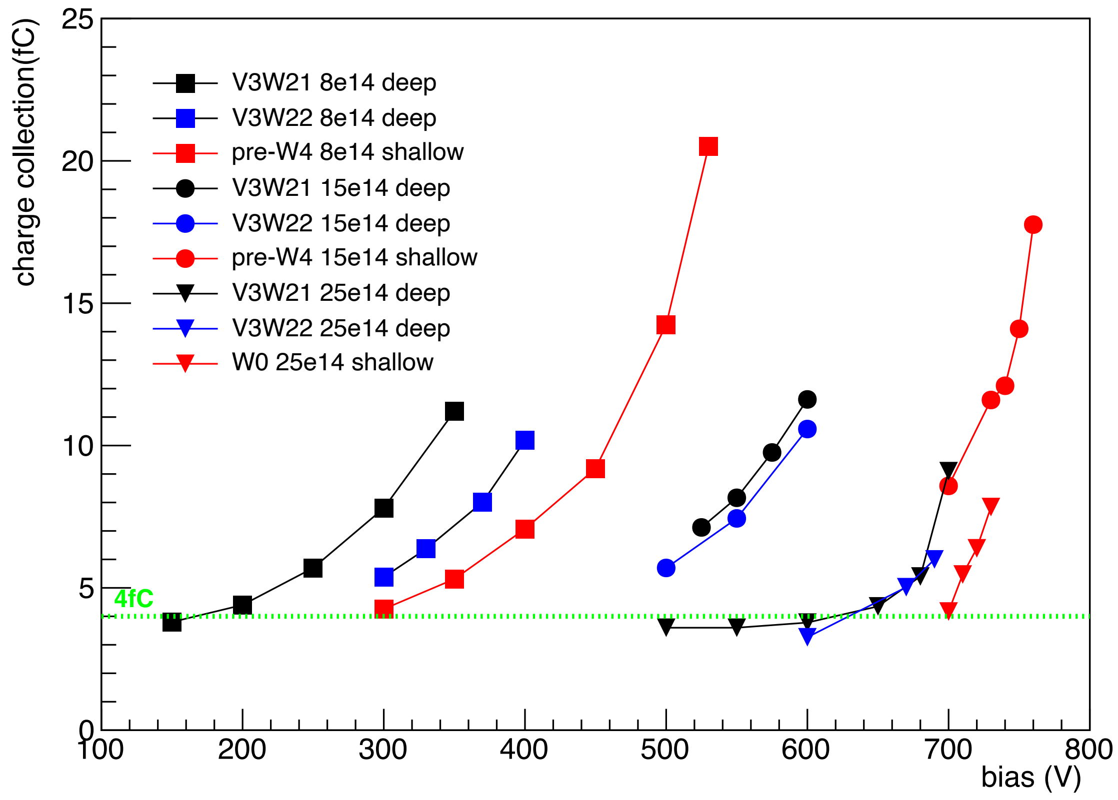


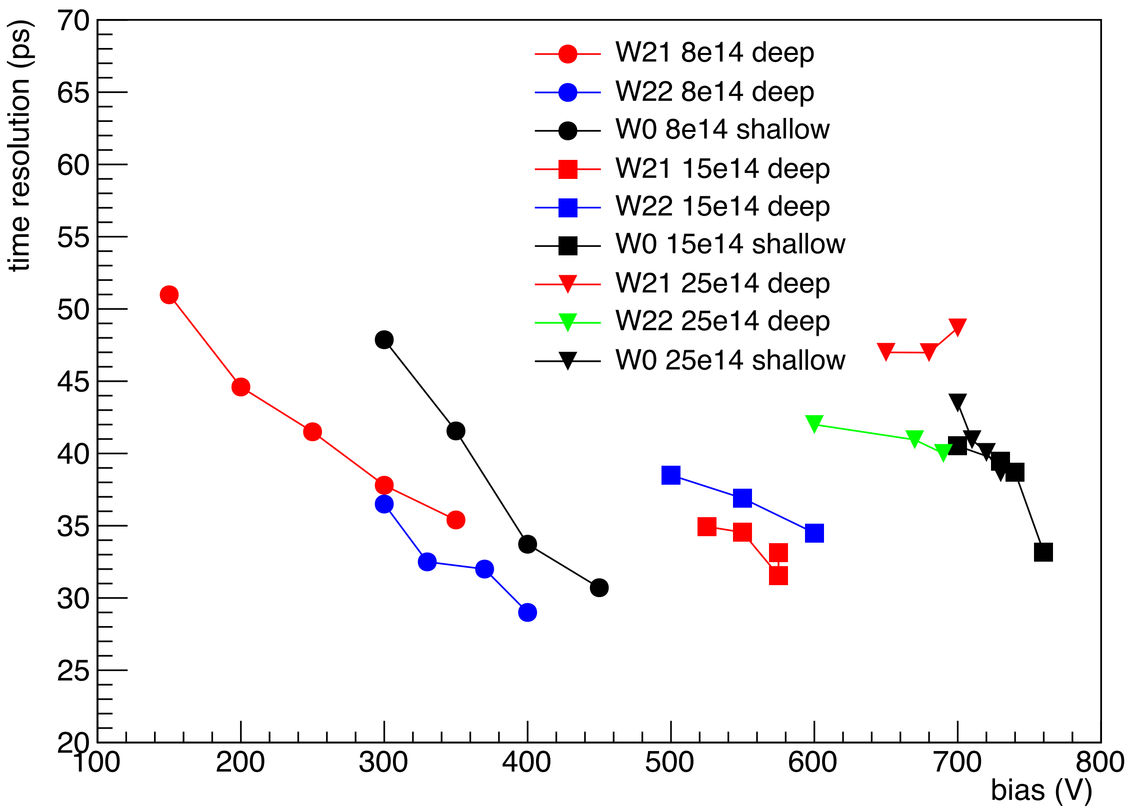
Wafer	W20	W21	W22	W0
C (1e-16cm2) proton	2.48	1.63	1.44	3.11
C (1e-16cm2) netron	-	-	-	1.06
C (neutron) Assumption 1	1.18	0.74	0.50	-
C (neutron) Assumption 2		0.82	0.70	
Ratio (proton / neutron)	2.10	2.20	2.88	2.93
		1.99	2.06	

- Ratio of proton c-factor and neutron c-factor derived from modeling: between 2 and 3.
- Improvement in radiation hardness compared with shallow carbonated LGAD (W0).

Radiation resistance 3

- Charge collection and time resolution:
  - A comparison with pre-W4, both much improvement especially at lower irradiation dose.
  - W22 shows slightly smaller c value, it’s charge collection is not better than W21.



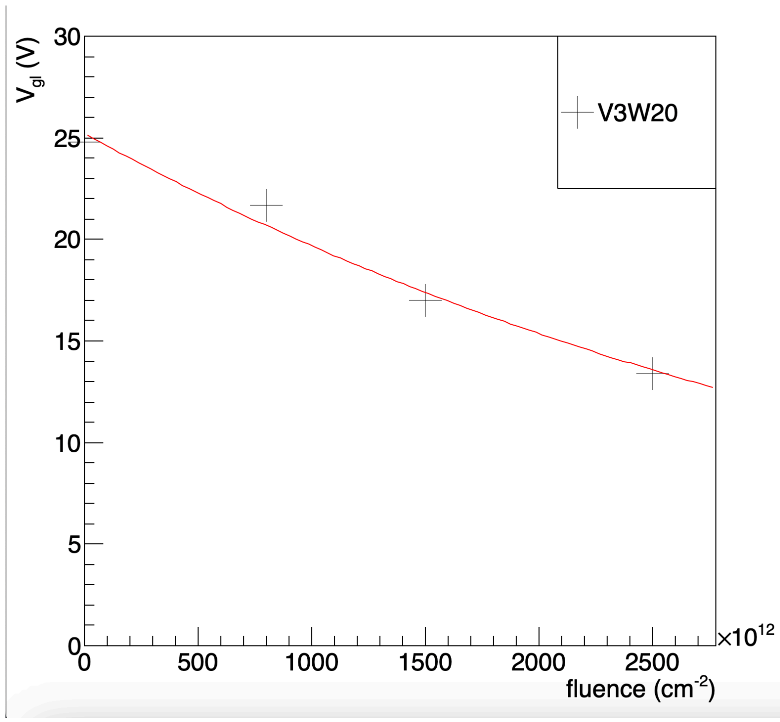


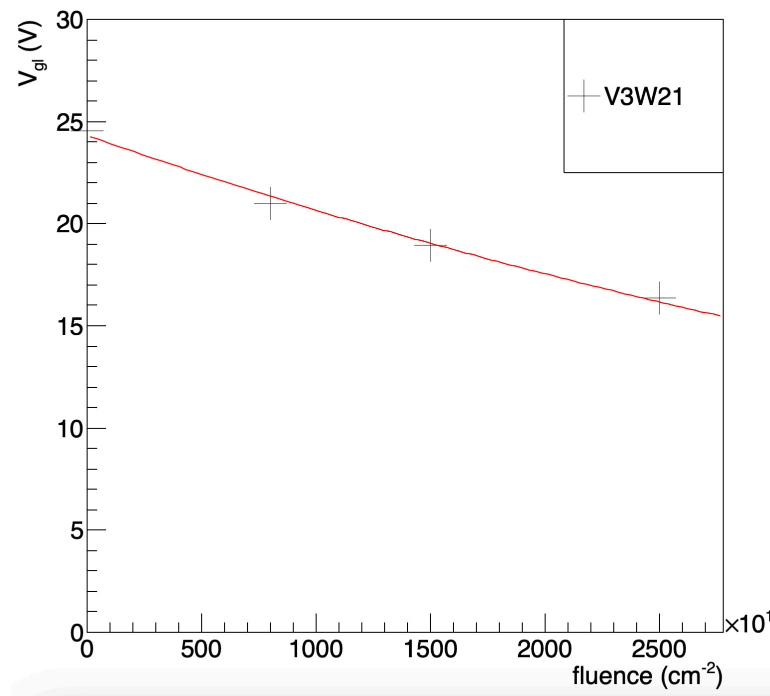
Summary

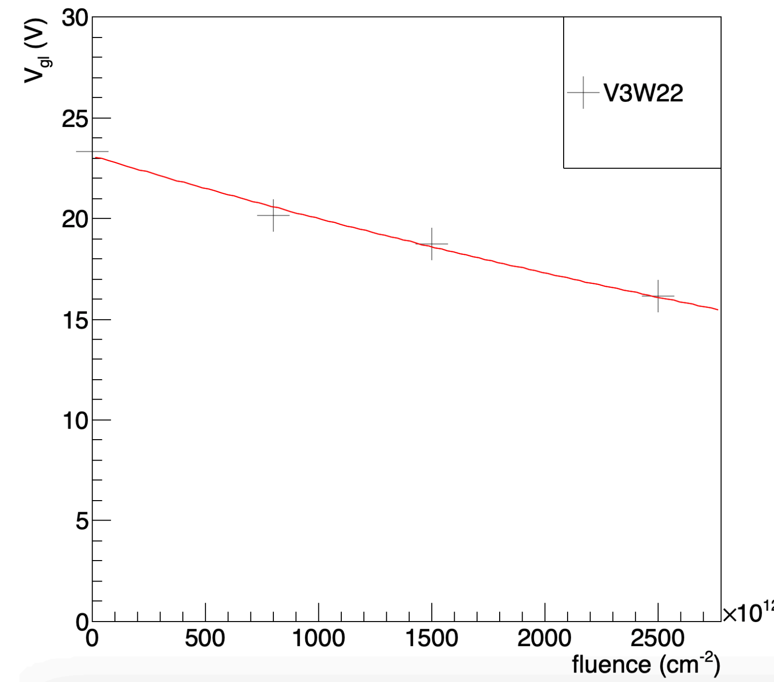
- LGAD devices with Boron and Carbon implanted with same depth is designed by IHEP.
  - Common features:
    - All wafers utilize the same gain layer design.
    - The carbon annealing process involves a high thermal load to create a wide active profile.
  - Among all recipes with different Carbon energy and dose, the deep-implanted design with moderate dose exhibits best performance.
  - Challenges:
    - The carbon profile is limited by anneal temperature.
    - Gain layer acceptors become deactivated as carbon density increases.
    - High leakage current are inevitable issue worsening with gain layer carbon density.

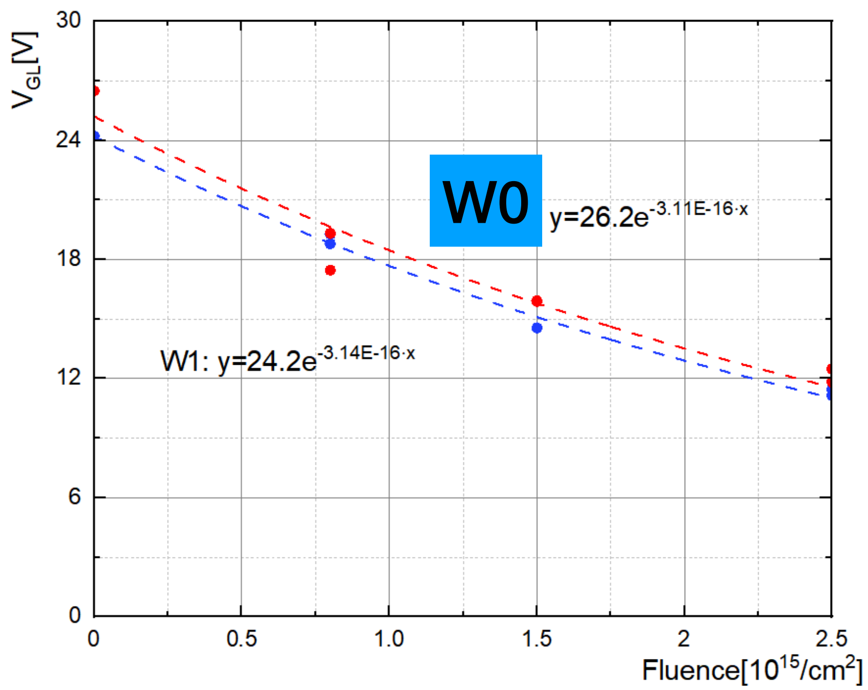
Backup

- CV curve

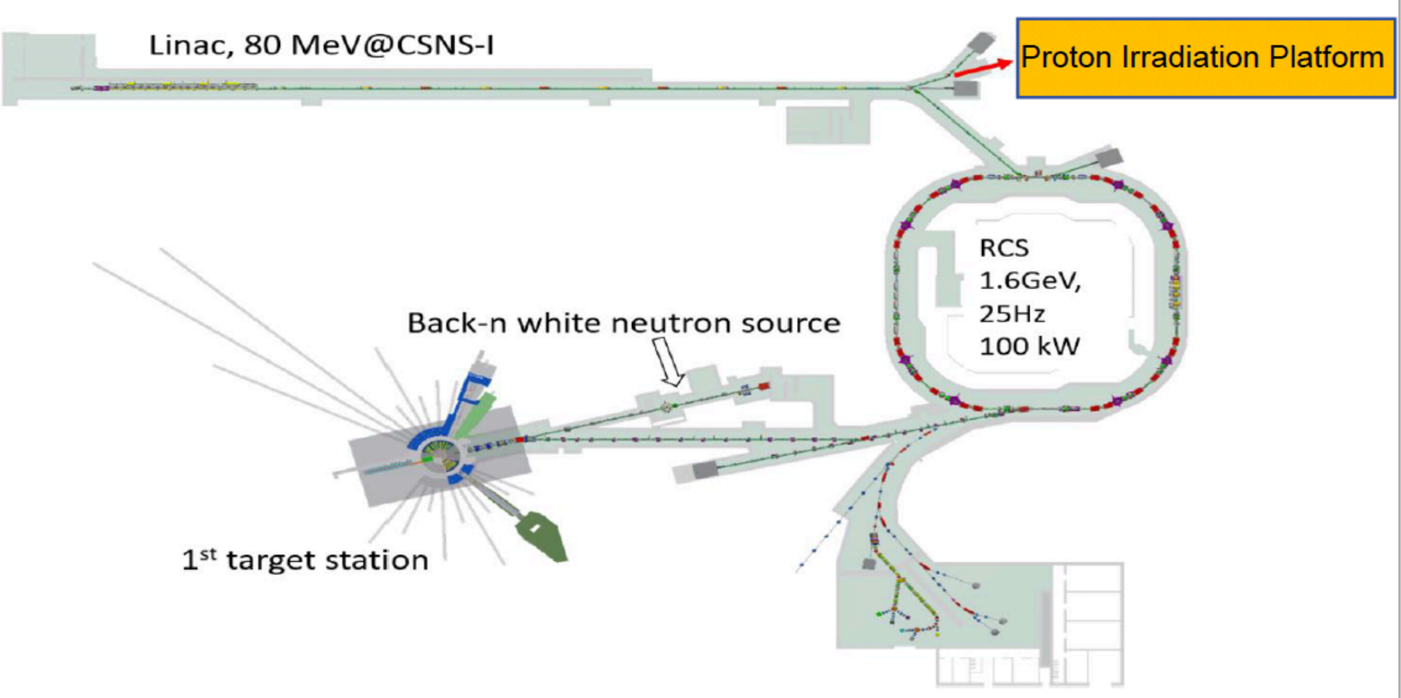








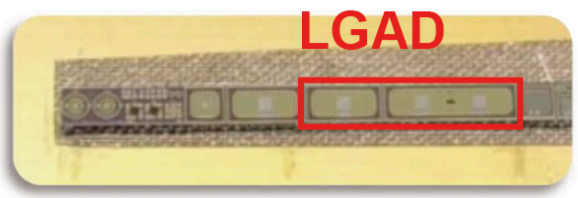
About CSNS



Facility	Proton energy (MeV)	Proton flux $(p \cdot cm^{-2} \cdot s^{-1})$	Beam spot size (cm)
CSNS APEP	10—80	10^7—10^{10}	1×1—5×5

- Beam Energy: 80MeV
- Beam Size: $20 \times 20mm^2$

Irradiation setup



Proton beam spot