35th RD50 Workshop Radiation hard semiconductor devices

Institut de Física d'Altes Energies

Safety and stability on LGADs

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•Detector Design

Requirements

What do we need to built a long running detector that work for several years?

{ *Performance* *Stability* *Efficiency* *Safety* }

Performance

- Time resolution <80psec per hit
- S/N of at least 5σ (10mV threshold for ~1.8mV noise)

Efficiency

- Hit efficiency of at least 90%
- Sufficient available efficiency headroom

Stability

- Low or no auto triggering (false events) wrt the application
- Less than 1% auto trigger rate with respect to the actual event rate

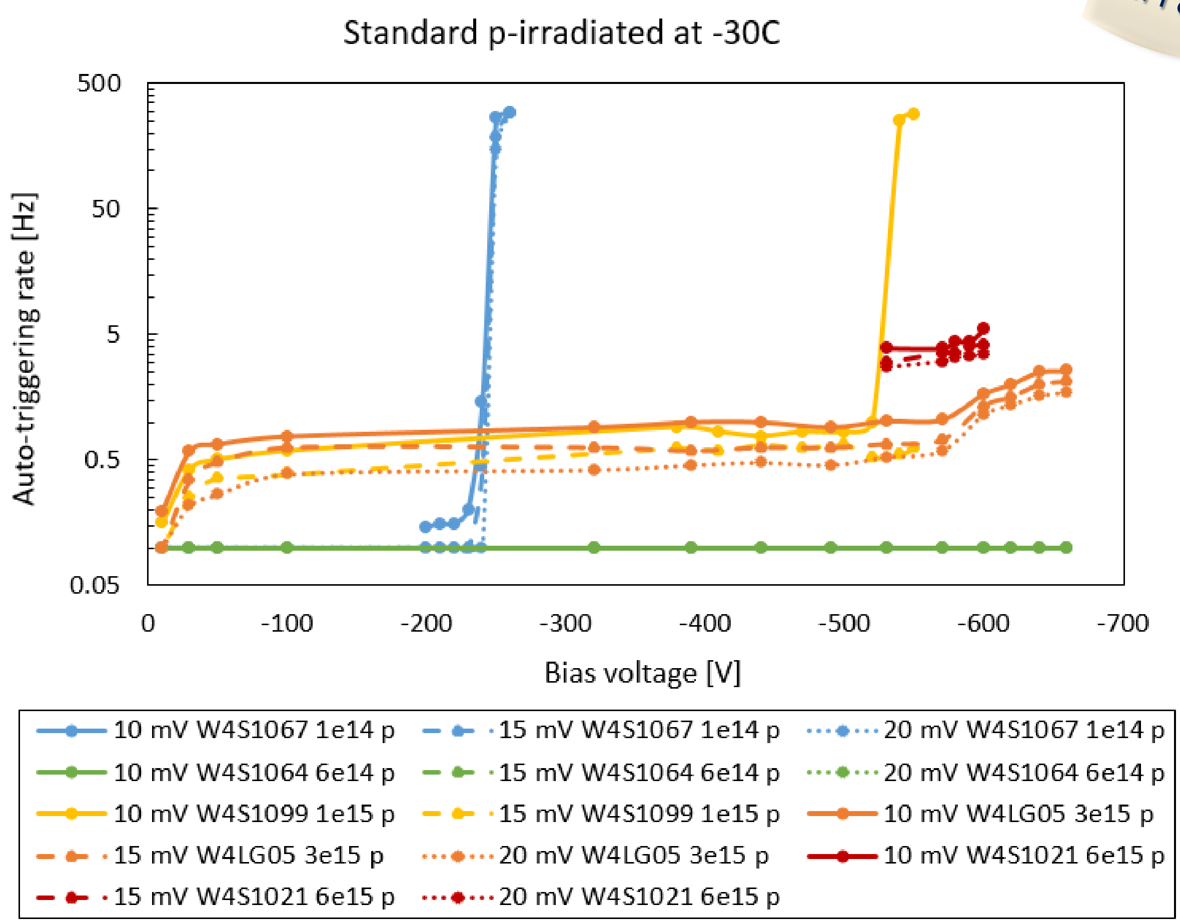
Safety

- Operate in mean field less than 15 V/μm → 750V max stable point for 50μm
- Sensor not in breakdown → Either dV/dI< 10 or current multiplier <2

Operating point defined as 10% below breakdown

•Auto-trigger studies

Auto-trigger Frequency



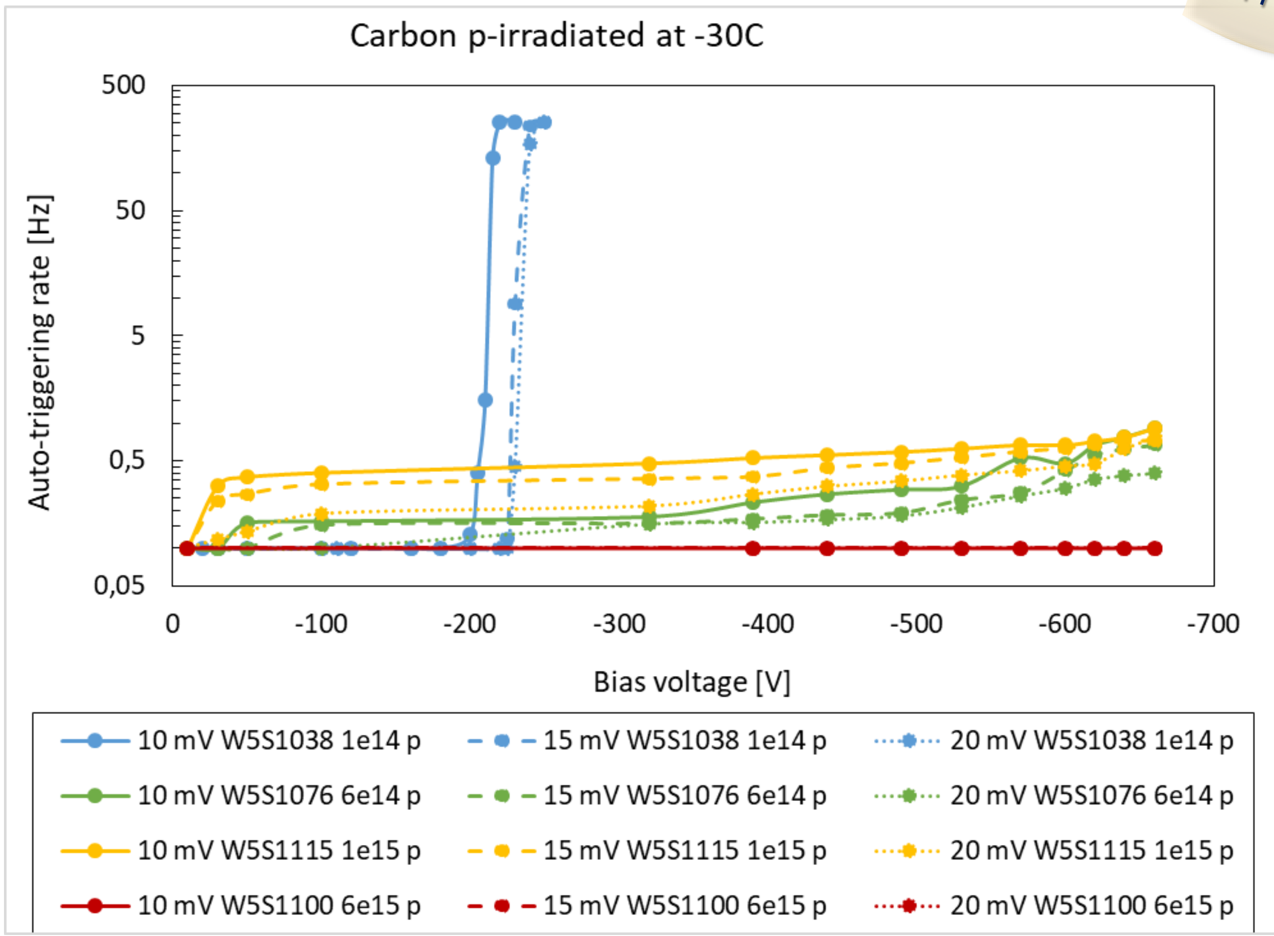
p irradiated

- < 1000 events fro each point
- Three temperatures (-10°C, -20°C and – 30°C)
- Three thresholds (10,15 and 20 mV)

•Auto-trigger studies

Auto-trigger Frequency

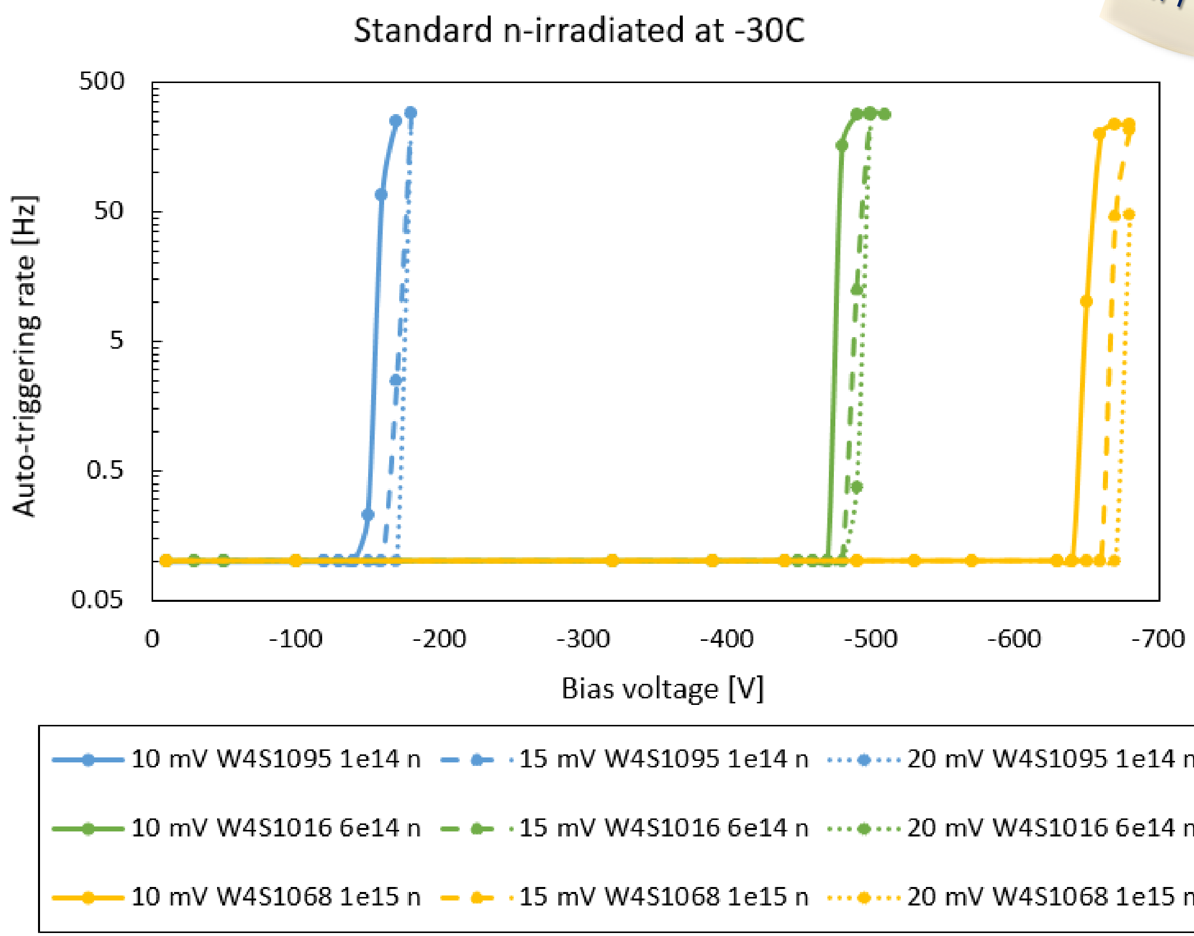
p irradiated



- < 1000 events fro each point
- Three temperatures (-10°C, -20°C and – 30°C)
- Three thresholds (10,15 and 20 mV)

•Auto-trigger studies

Auto-trigger Frequency



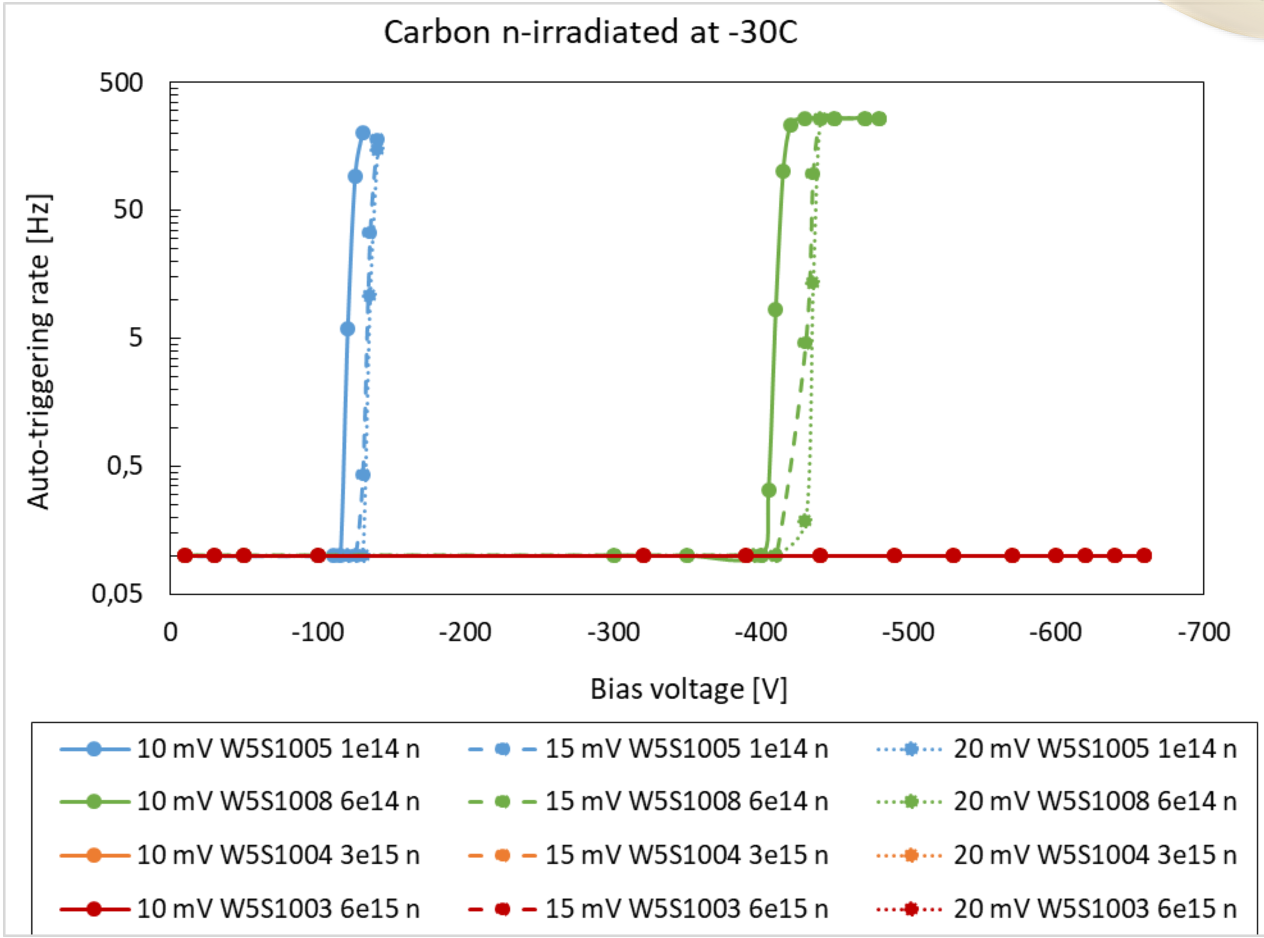
n irradiated

- < 1000 events fro each point
- Three temperatures (-10°C, -20°C and – 30°C)
- Three thresholds (10,15 and 20 mV)

•Auto-trigger studies

Auto-trigger Frequency

n irradiated

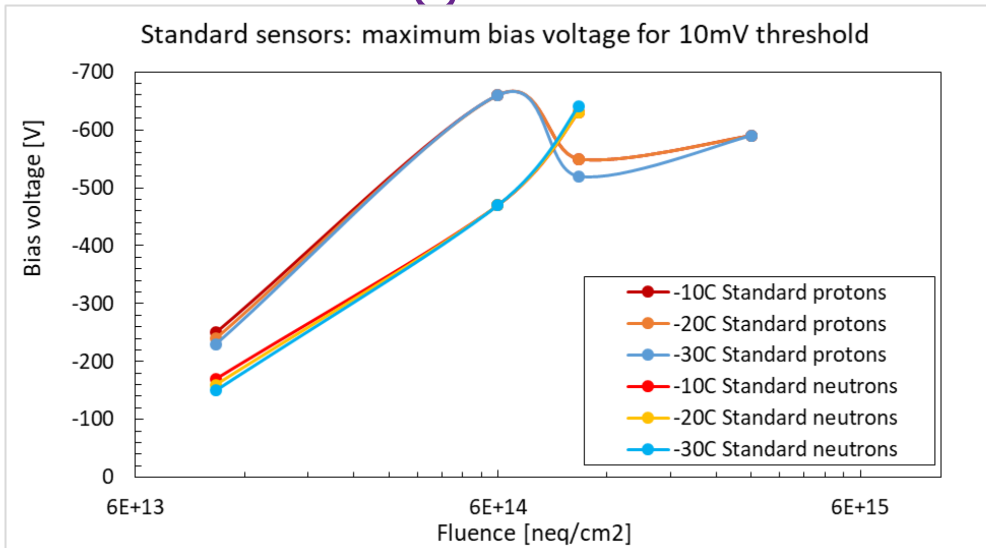


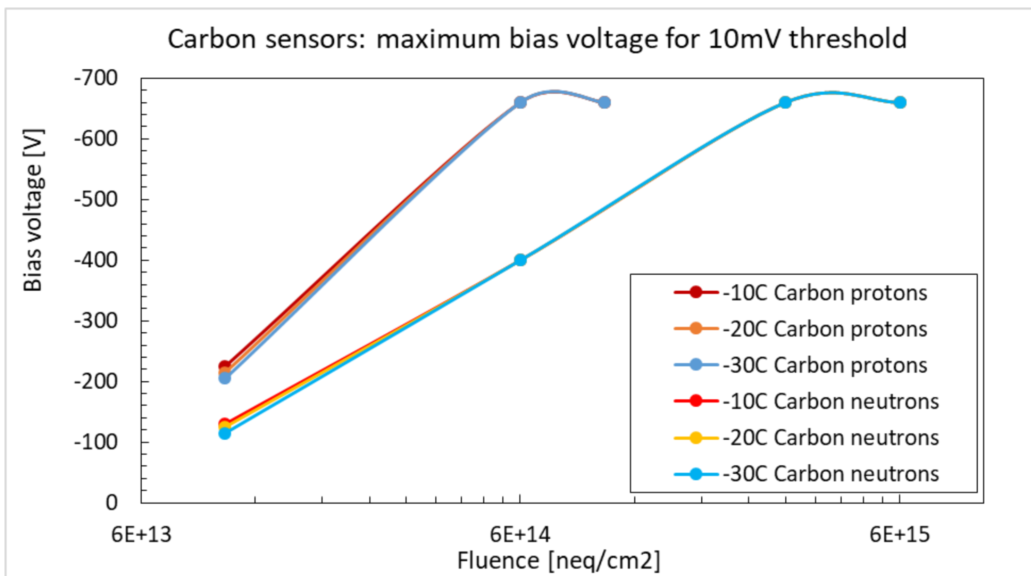
- < 1000 events fro each point
- Three temperatures (-10°C, -20°C and – 30°C)
- Three thresholds (10,15 and 20 mV)

•Auto-trigger studies

Maximum Voltage

n & p irradiated

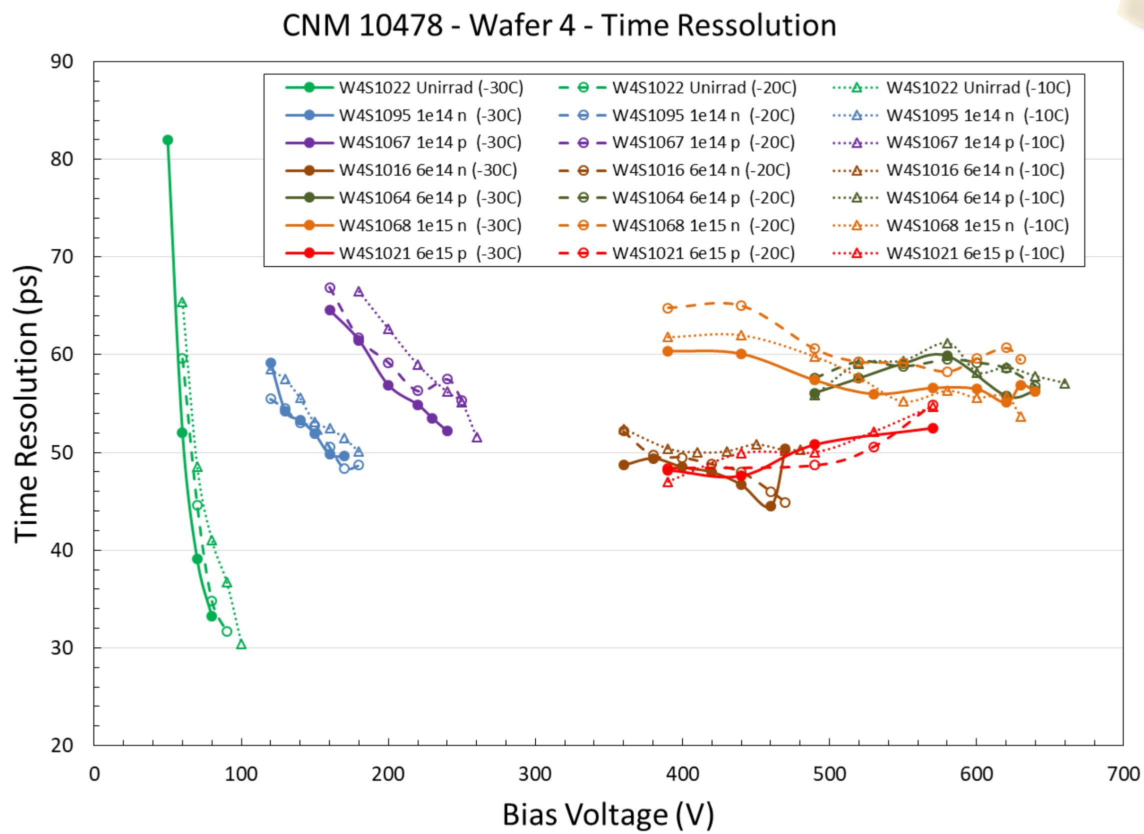




•Time resolution

Standard Boron

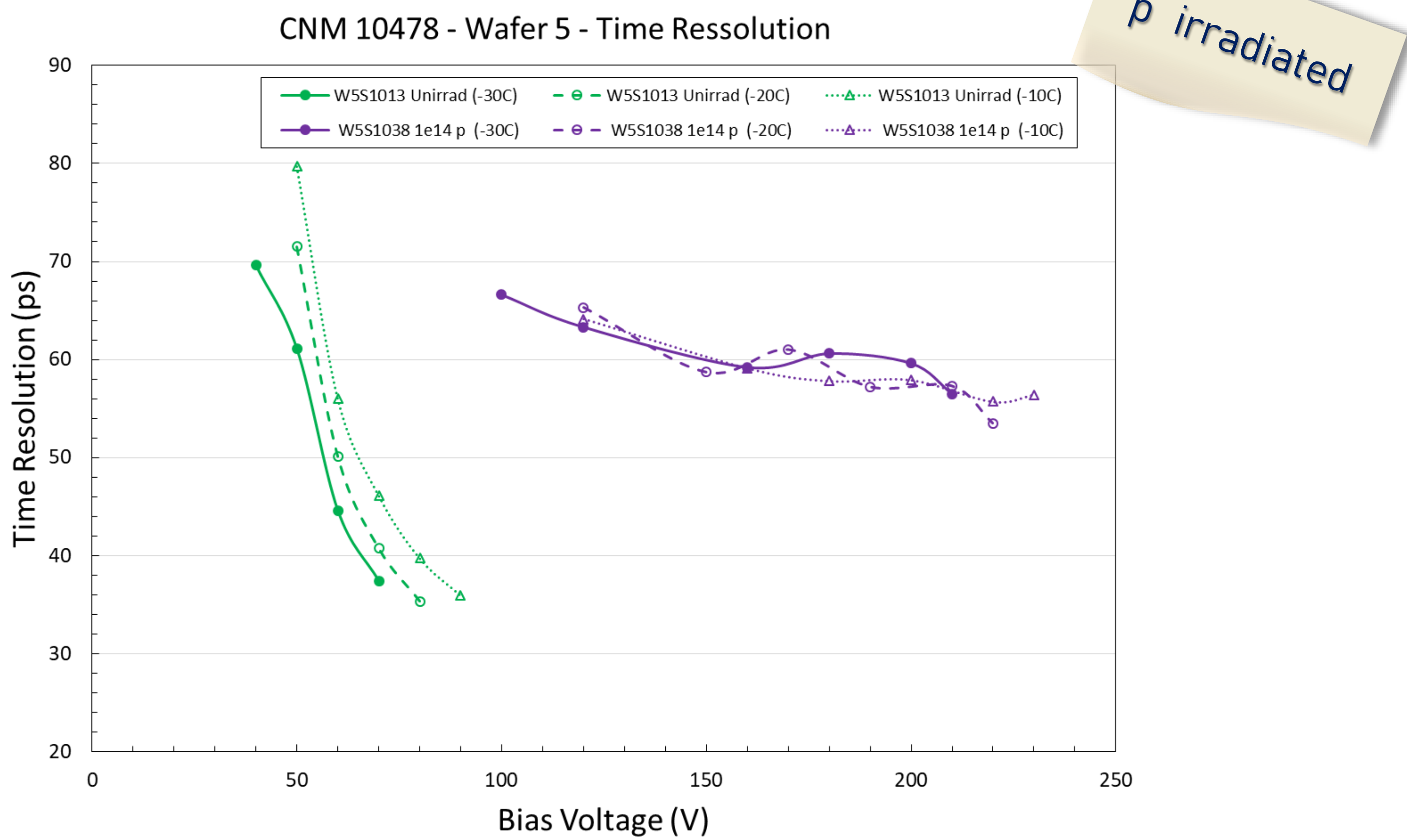
p + n irradiated



- < 5000 events fro each point
- CFD @ 20% for un-irradiated and @ 50% for all irradiated to compare with test beam
- CFD percentage has been optimized separately for each point, time resolution ~ 1-2 psec better if optimized value used
- Three temperatures (-10°C, -20°C and – 30°C)

•Time resolution

Carbon implanted



- 20% CFD for un-irradiated, 50% CFD for irradiated
- Maximum voltage set by self-triggering at 10mV threshold
- Amplitude cuts at 10mv < p_{max} < 200mV
- Measurements on the rest of the samples ongoing

• Stable operation points and efficiency

Definitions

- Perform measurements with radioactive ^{90}Sr source
- Define stable operation points satisfying the following conditions:

Current multiplier <2 for each point

Mean field inside sensor < 15 V/μm

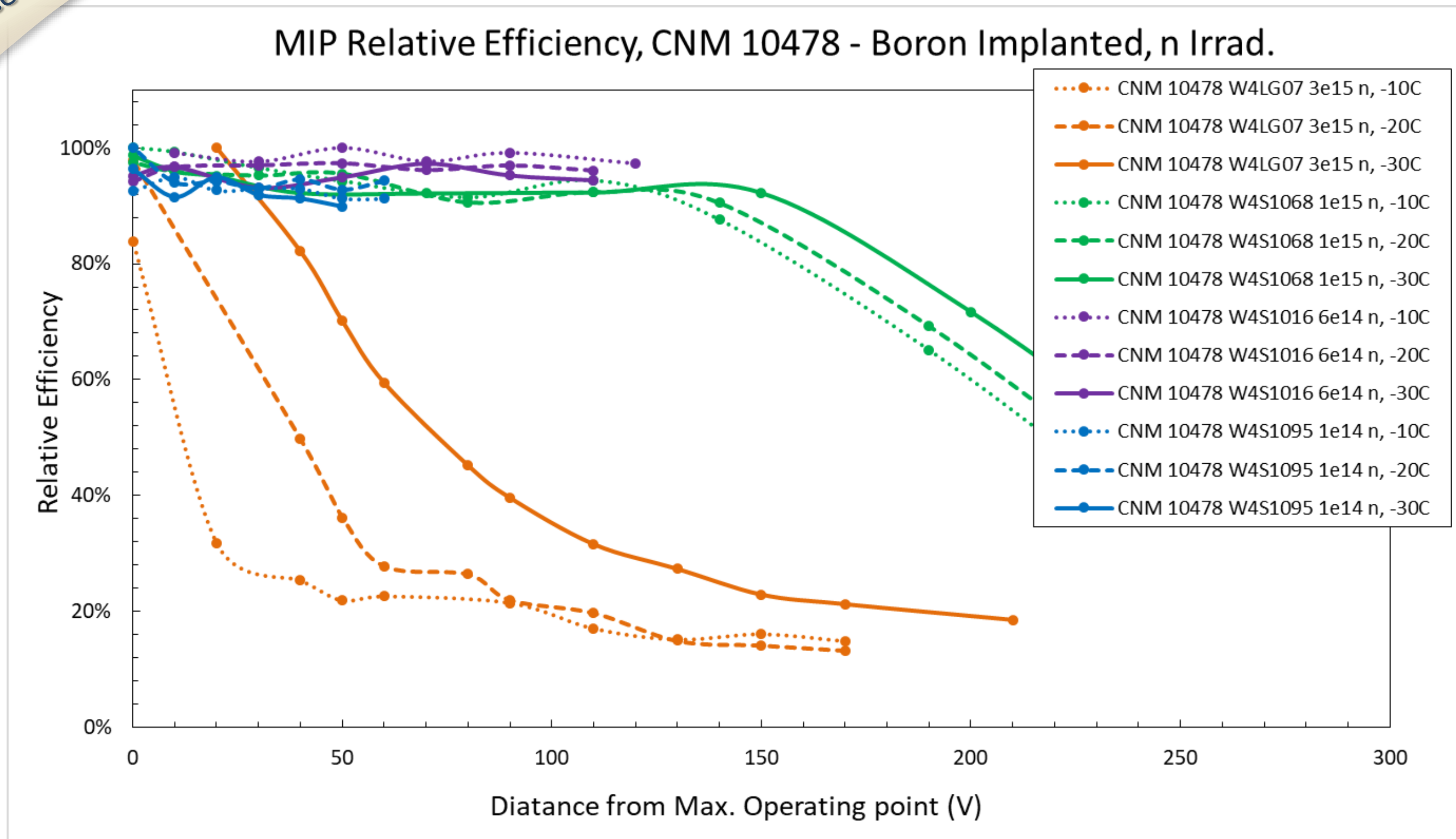
Autro-trigger rate < 1% of source trigger

- Repast measurements for -10°C, -20°C & -30°C without changing setup
- Record for each voltage point time between consecutive triggers for 5k events
- Fit with exponential radioactive law and extract mean trigger period per point
- Define as 100% efficient point with highest rate
- Calculate the relative efficiency of all other points in all temperatures using as reference the most efficient point

•Relative efficiency – n Irradiated

CNM 10478, Wafer 4, Standard boron

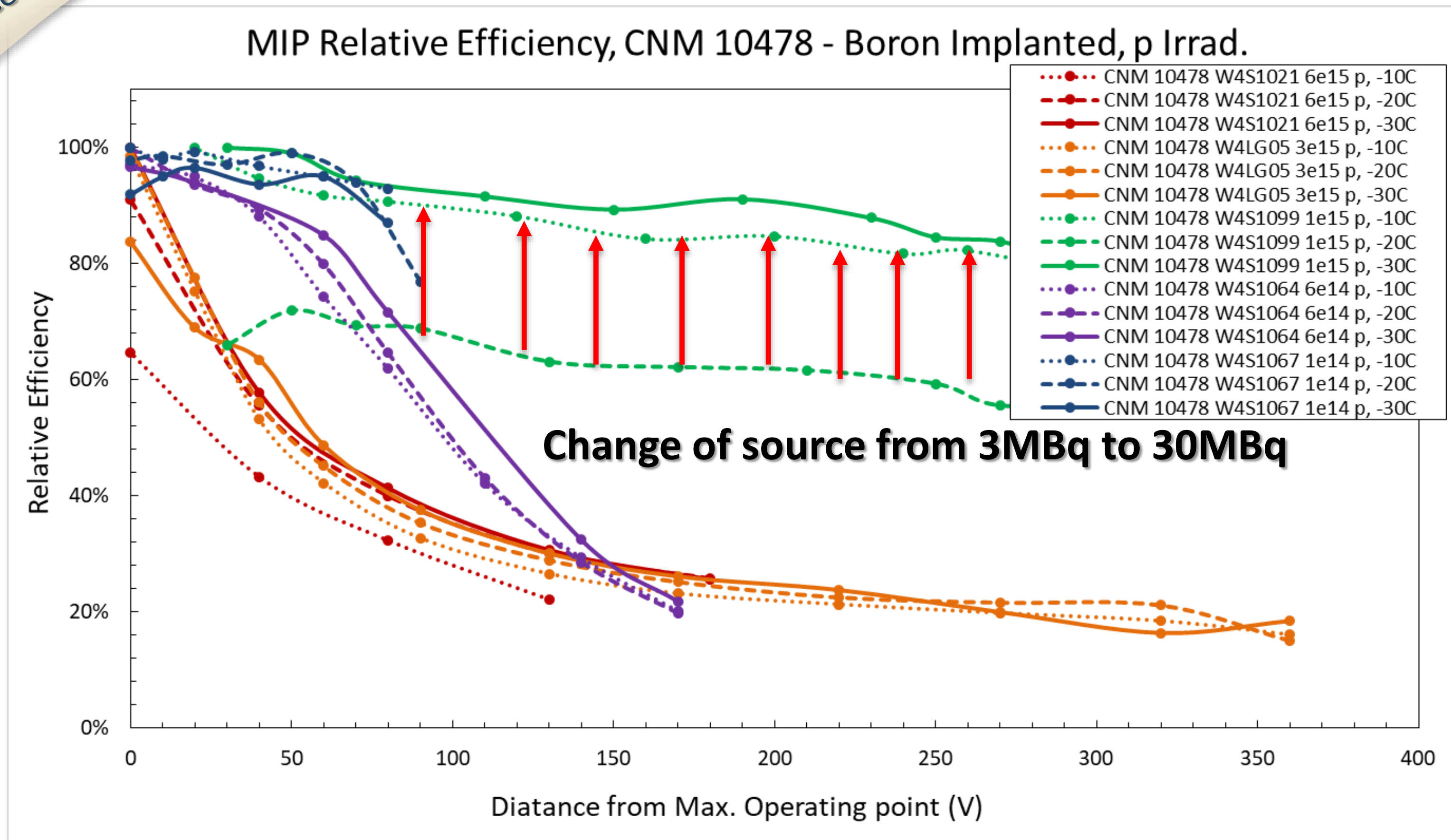
^{90}Sr source data



•Relative efficiency – p Irradiated

CNM 10478, Wafer 4, Standard boron

^{90}Sr source data

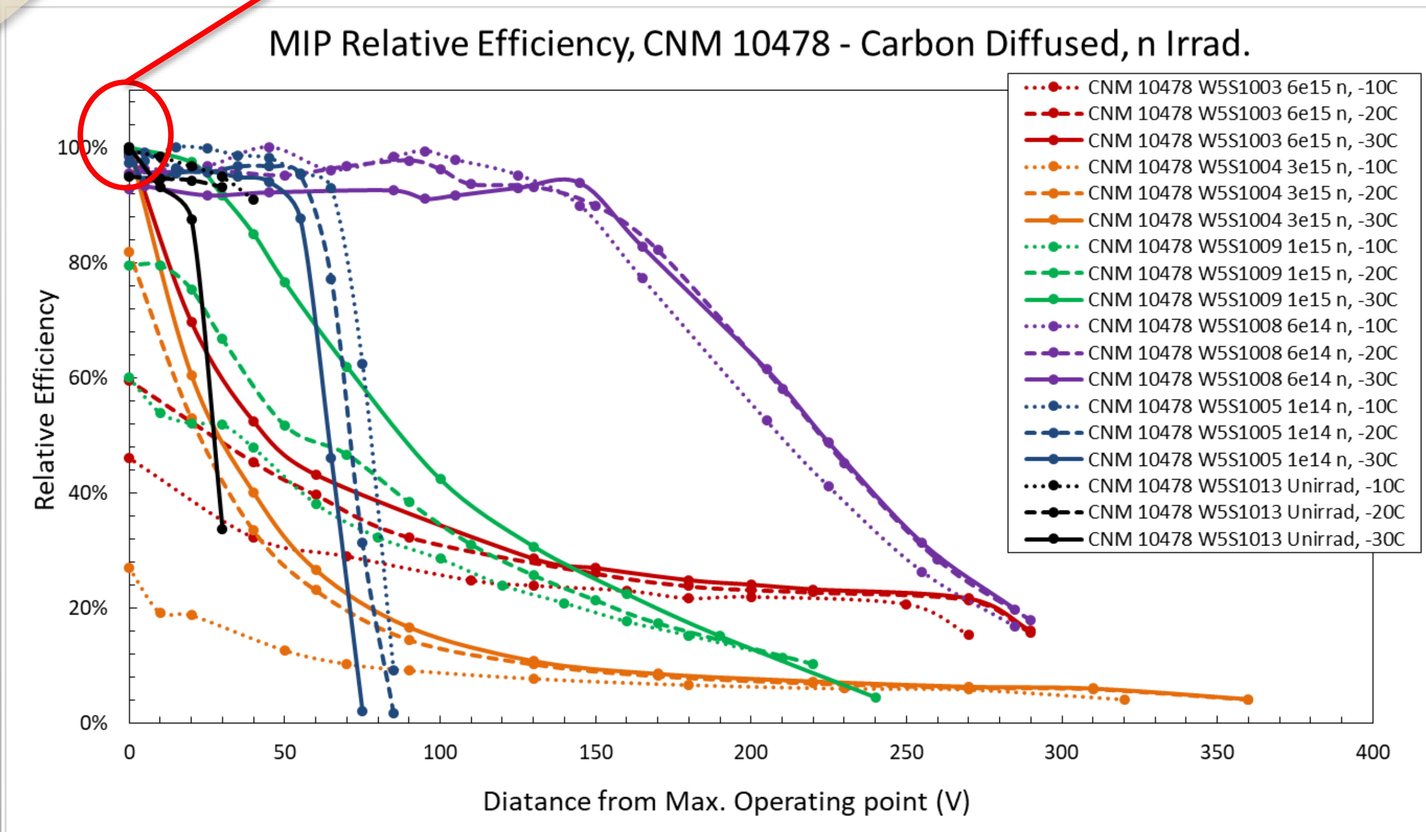


•Relative efficiency – n Irradiated

CNM 10478, Wafer 5, Carbon Implanted

^{90}Sr source data

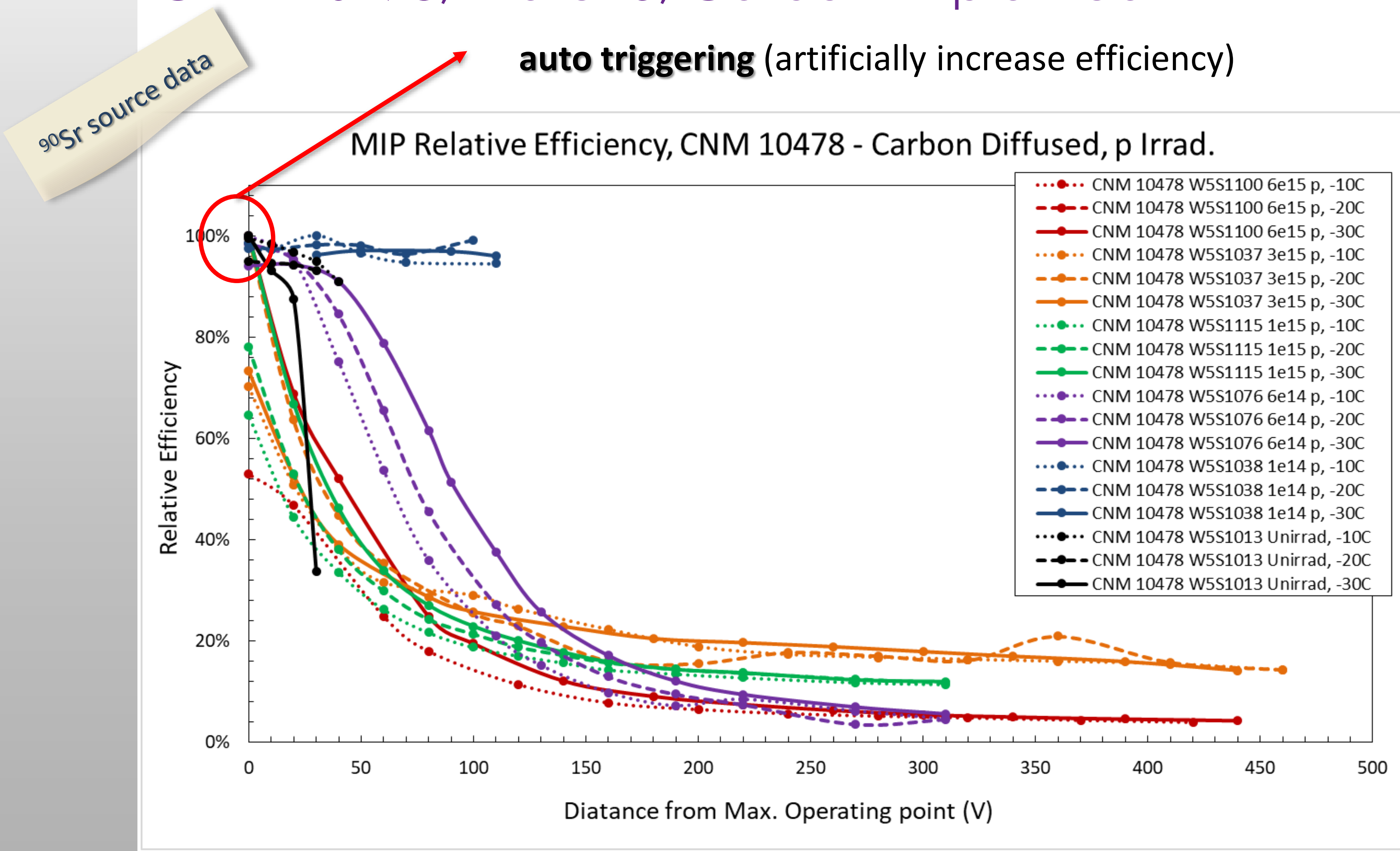
auto triggering (artificially increase efficiency)



•Inter-pad distance studies

CNM 10478, Wafer 5, Carbon Implanted

auto triggering (artificially increase efficiency)



•Damaged sensor list

2018 - 19 CNM Unrecoverable sensors

Run	Wafer	Structure	Rad. Fluence	Species	GR Grounded	Discharge marks	Annealing	Conditions	
10478	W4	S1017	3e15	n	no	Pad	0 min	Pion beam	*April Test Beam*
10478	W4	S1025	3e15	p	no	Pad	0 min	IVs on probe	
10478	W4	S1058	1e15	p	no	Pad	0 min	Pion beam	
10478	W4	S1102	6e15	n	no	Pad	0 min	Pion beam	
10478	W5	S1036	6e14	p	yes	GR	0 min	Pion beam	*June Test Beam*
10478	W5	S1075	3e35	p	yes	GR	0 min	Pion beam	
10478	W5	S1117P	6e14	p	yes	GR	0 min	Pion beam	
10478	W4	LG08	3e15	n	yes	Pad	0 min	IVs on card	***Lab Measurement***
10924	W6	S1028	1e14	p	yes	none	0 min	Pion beam	*September Test Beam*
10924	W6	S1026	1e15	p	yes	GR	0 min	Pion beam	
10924	W6	S1025	3e15	p	yes	GR	0 min	Pion beam	
10924	W4	S1020	6e15	n	yes	Pad - GR	0 min	IVs on probe	***Lab Measurement***
10478	W5	S1100	6e15	p	yes	?/?	0 min	β measurement	

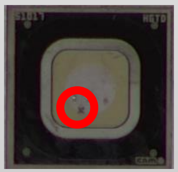
Dead sensors sent back to manufactures for investigation

•Damaged sensor list

Visual inspection

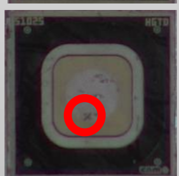
Normal

W4S1017



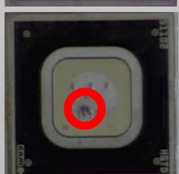
April 2018, 120GeV pion beam
Rate issues @ 620V, -30°C, N_2
(neutrons 3e15 n_{eq}/cm^2)

W4S1025



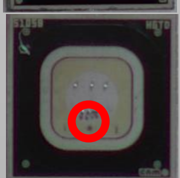
April 2018, died during IVs
Dielectric discharge @ 720V
-30°C, N_2
(protons 3e15 n_{eq}/cm^2)

W4S1102



April 2018, 120GeV pion beam ,Rate issues @ 620V
-30°C, N_2
(neutrons 6e15 n_{eq}/cm^2)

W4S1058

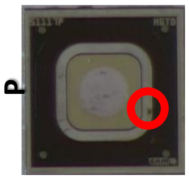


April 2018, 120GeV pion beam, Rate issues @ 580V
-20°C, N_2 / **-30°C completed**
(protons 1e15 n_{eq}/cm^2)

GR not grounded – Pad Discharge

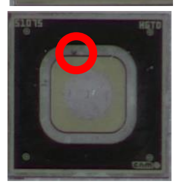
Carbon

W5S1117 P



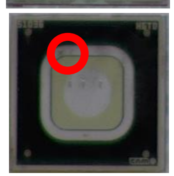
June 2018, 120GeV pion beam, Rate issues @ 620V, -30°C, N_2
(protons 6e14 n_{eq}/cm^2)

W5S1075



June 2018, 120GeV pion beam,
Rate issues @ 600V, -30°C, N_2
(protons 3e15 n_{eq}/cm^2)

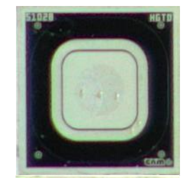
W5S1036



Died during alignment
June 2018, 120GeV pion beam
Rate issues @ 600V, -30°C, N_2
(protons 6e14 n_{eq}/cm^2)

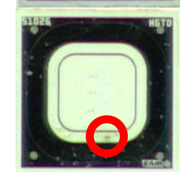
Gallium

W6S1028



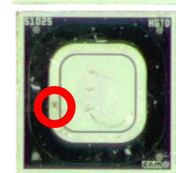
September 2018, data taking
Rate issues @ 220V
-20°C, N_2 / **-30°C completed**
(protons 1e14 n_{eq}/cm^2)

W6S1026



September 2018, data taking
Rate issues @ 590V
-20°C, N_2 / **-30°C completed**
(protons 1e15 n_{eq}/cm^2)

W6S1025



September 2018, data taking
Rate issues @ 590V -30°C, N_2
(protons 3e15 n_{eq}/cm^2)

GR grounded – GR Discharge

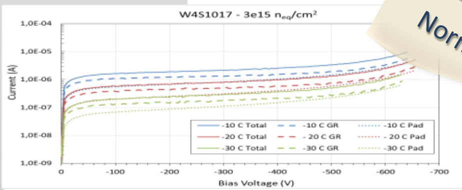
•Damaged sensor list

Visual inspection

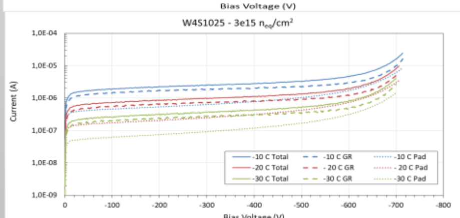
Where they really bad sensors?? – <u>not according to their IVs</u>

Normal

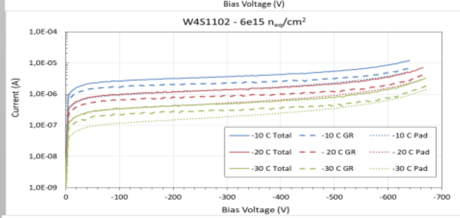
W4S1017



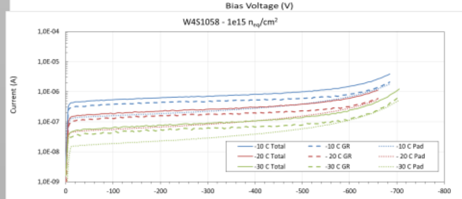
W4S1025



W4S1102

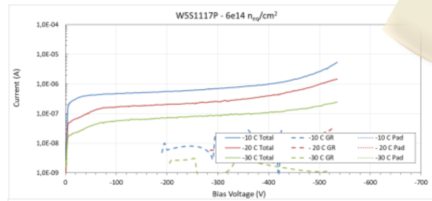


W4S1058

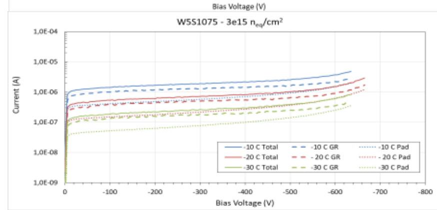


Carbon

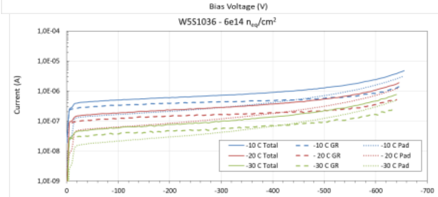
W5S1117P



W5S1075

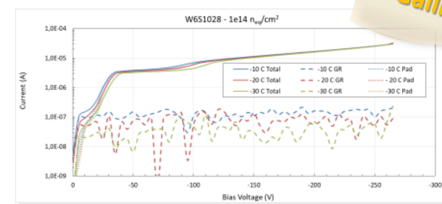


W5S1036

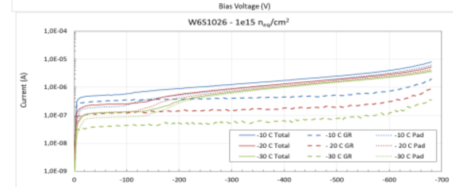


Gallium

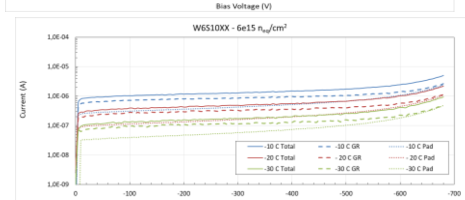
W6S1028



W6S1026



W6S1025



•Conclusions

Head room and efficiency

- We can achieve ~100% efficiency for Carbon+Boron and Boron only for up to 1e15 at neutron irradiation
- For proton irradiation we achieve 100% efficiency at 1e15 only for boron only sensors
- It seems that boron only at 3e15 neutron is close to a 100%, more study is needed
- Boron only sensors provide larger headroom at 100% efficiency that boron + carbon combination
- Proton irradiation is more damaging than neutrons if correct scaling factors are applied, reality is somewhere in the middle
- In best case scenario (boron at 3e15 neutrons) no safety factor is present