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Study and characterization of Low Gain Avalanche Diodes

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INFN Torino (Italy)

Outline

- Hamamatsu 50&80µm Production:

  - IV and CV measurements;

- CNM 50µm production:

  - Test of UFSDs production for CTPPS experiments;

Hamamatsu LGADs

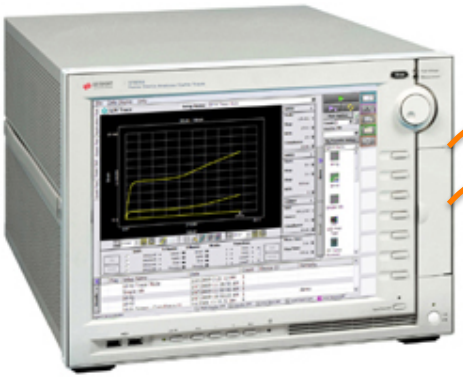
- Two different Thickness: 50µm and 80µm;
- 4 gain layer doses implantation (A/B/C/D)
  Dose A < Dose B < Dose C < Dose D
- Single pad sensors;
- Sensors active area ~1mm^2

Thickness	Doping implant	Sensor Name
50µm	A	ECX20840_Single_80-A_STD
		ECX20840_Single_80-A_GR
		ECX20840_Single_80-A_GBGR
	B	ECX20840_Single_80-B_STD
		ECX20840_Single_80-B_GR
		ECX20840_Single_80-B_GBGR
	C	ECX20840_Single_80-C_STD
		ECX20840_Single_80-C_GR
		ECX20840_Single_80-C_GBGR
	D	ECX20840_Single_80-D_STD
		ECX20840_Single_80-D_GR
		ECX20840_Single_80-D_GBGR

Thickness	Doping implant	Sensor Name
80µm	A	ECX20840_Single_80-A_STD
		ECX20840_Single_80-A_GR
		ECX20840_Single_80-A_GBGR
	B	ECX20840_Single_80-B_STD
		ECX20840_Single_80-B_GR
		ECX20840_Single_80-B_GBGR
	C	ECX20840_Single_80-C_STD
		ECX20840_Single_80-C_GR
		ECX20840_Single_80-C_GBGR
	D	ECX20840_Single_80-D_STD
		ECX20840_Single_80-D_GR
		ECX20840_Single_80-D_GBGR

IV measurements (laboratory setup)

Keysight
B1505A Power Device Analyzer / Curve Tracer

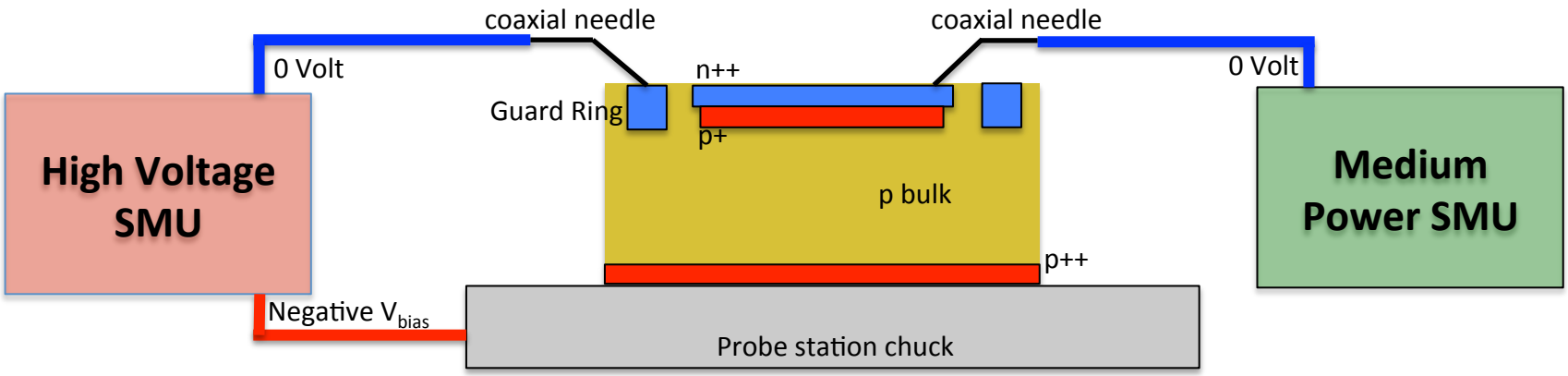


Probe station

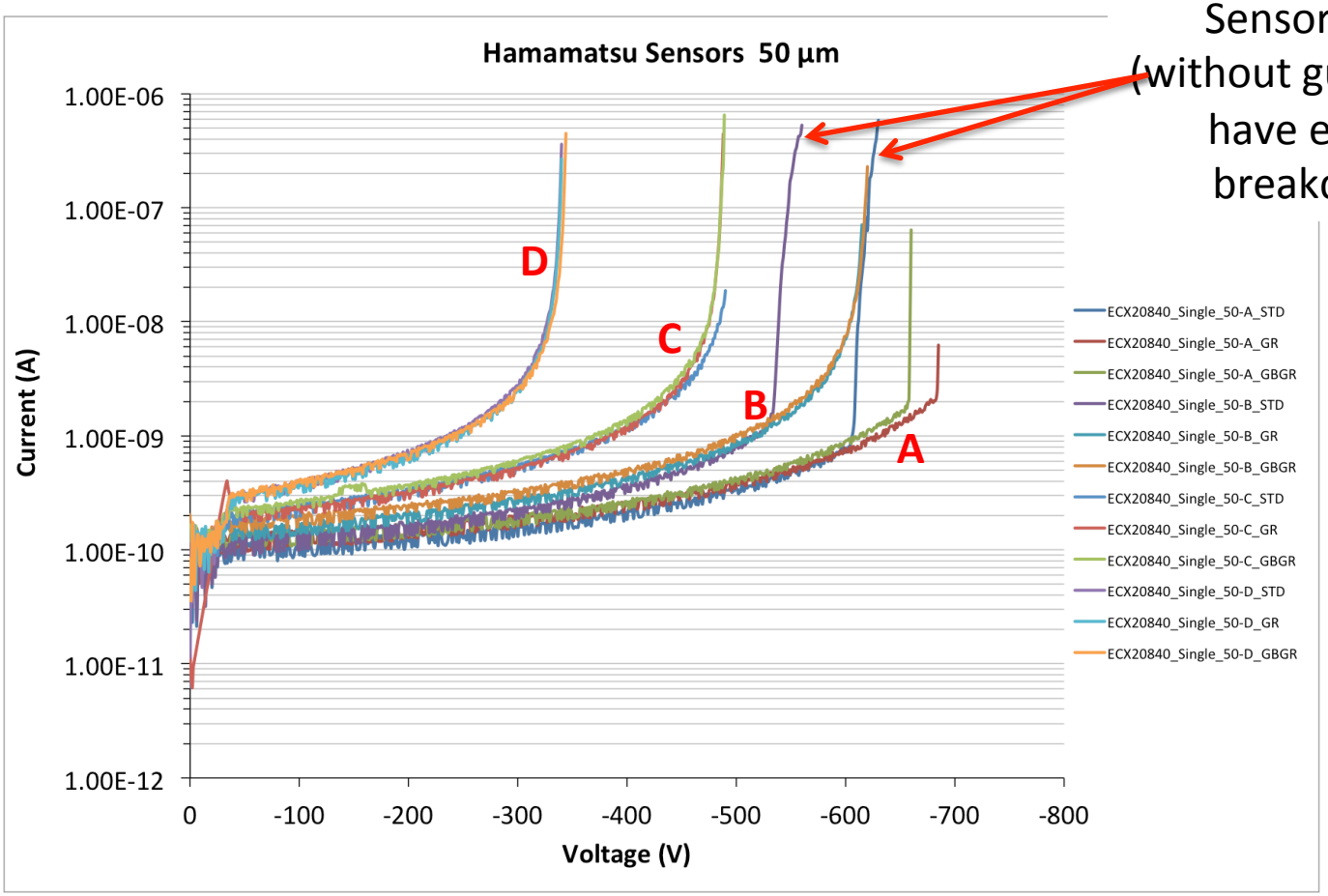
The electric contacts was made with coaxial needles

Modules

- High Voltage SMU: Max Range (±3000V, ±4mA);
  Min Range (200V, 1nA);
- Medium Power SMU: Max Range (±100V, ±100mA);
  Min Range (0,5V, 1nA);



I-V Measurements (50µm)

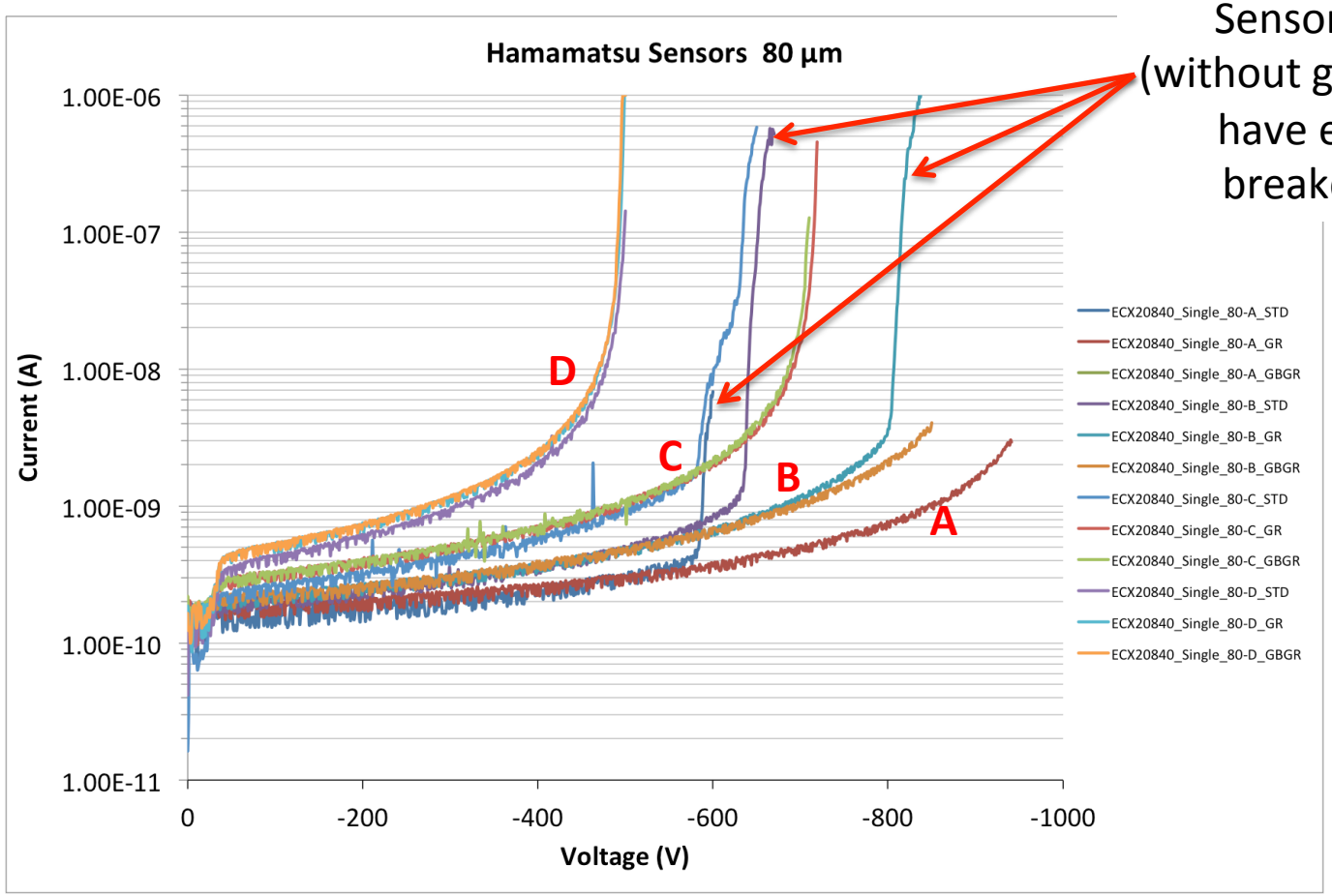


Sensors STD (without guard ring) have earlier breakdown

Gain dose A → $V_{breakdown}$ ~ 650V
Gain dose B → $V_{breakdown}$ ~ 600V
Gain dose C → $V_{breakdown}$ ~ 450V
Gain dose D → $V_{breakdown}$ ~ 300V

Leakage current is hundreds of pA

I-V Measurements (80µm)

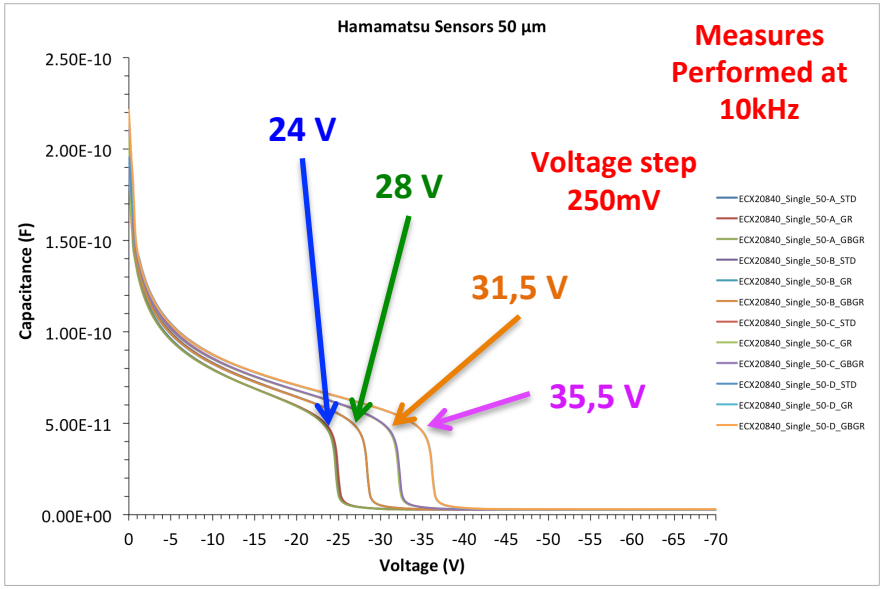


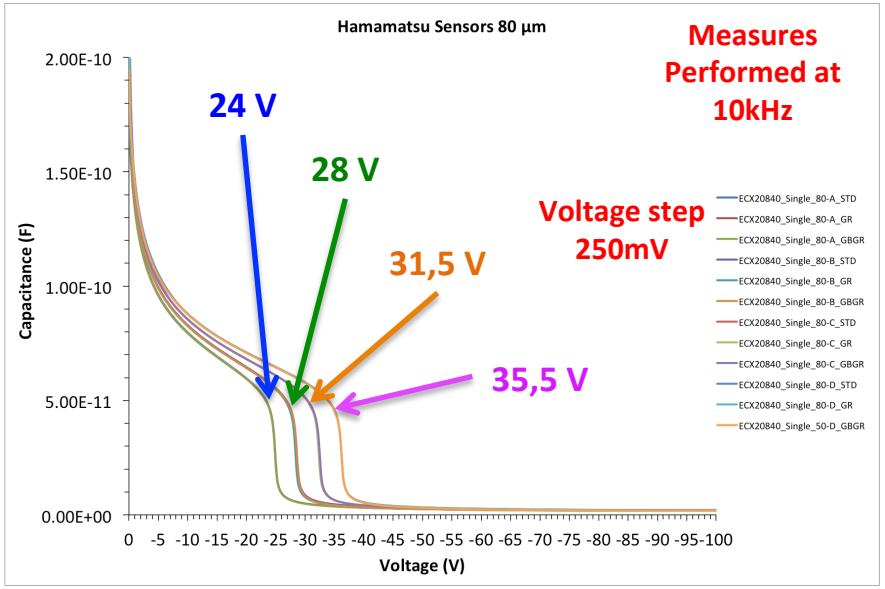
Sensors STD (without guard ring) have earlier breakdown

Gain dose A → $V_{breakdown}$ > 900V
Gain dose B → $V_{breakdown}$ > 800V
Gain dose C → $V_{breakdown}$ ~ 650V
Gain dose D → $V_{breakdown}$ ~ 400V

Leakage current is hundreds of pA

C-V Measurements

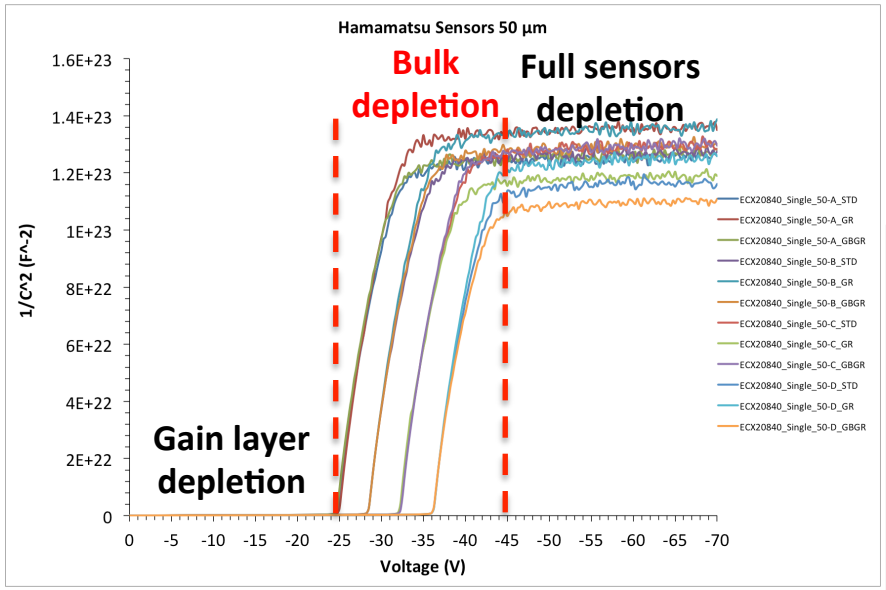


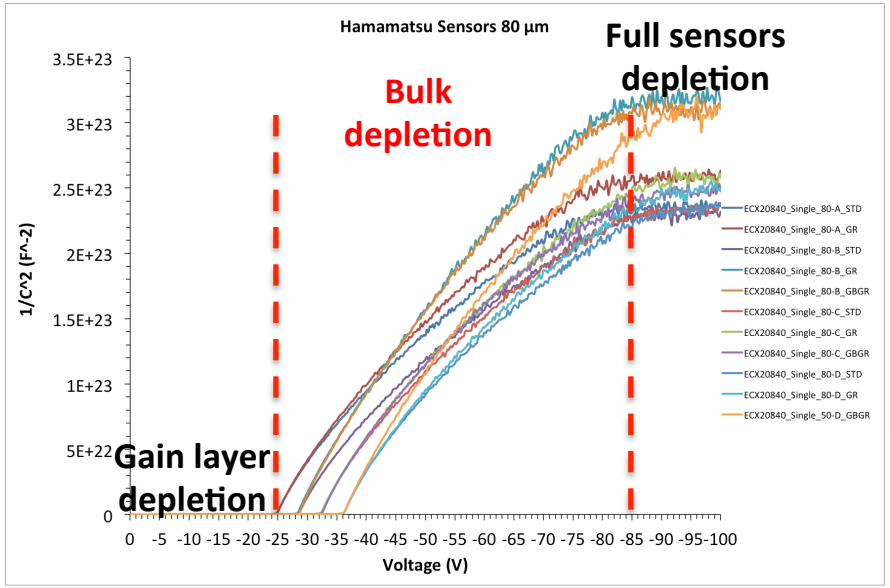


RESULTS & CONSIDERATIONS:

- Same Depletion Voltages of gain layer for 50µm and 80µm thickness;
  - Dose A = ~24 Volt
  - Dose B = ~28 Volt
  - Dose C = ~31,5 Volt
  - Dose D = ~35,5 Volt
- Expected same Doping profile for 50µm and 80µm thickness;
- Uniformity of the gain dose implant (Very good overlap of the CV curves about sensors with same gain implant);

$1/C^2$-V Curves





RESULTS & CONSIDERATIONS:

- Sensors Voltage Depletion varies with the gain layer doping:
  between 35 V and 45 V for 50µm thickness;
  between 80 V and 90 V for 80µm thickness;
- Bulk depletion of 80µm sensors is slower in voltage compared to 50µm sensors;
  Expected an higher bulk resistivity for 50µm sensors than 80µm ones;
- Voltage necessary to deplete the p-bulk:
  ~ 10 for the 50µm thickness sensors;
  ~ 55 for the 80µm thickness sensors;

$1/C^2$-V Curves considerations

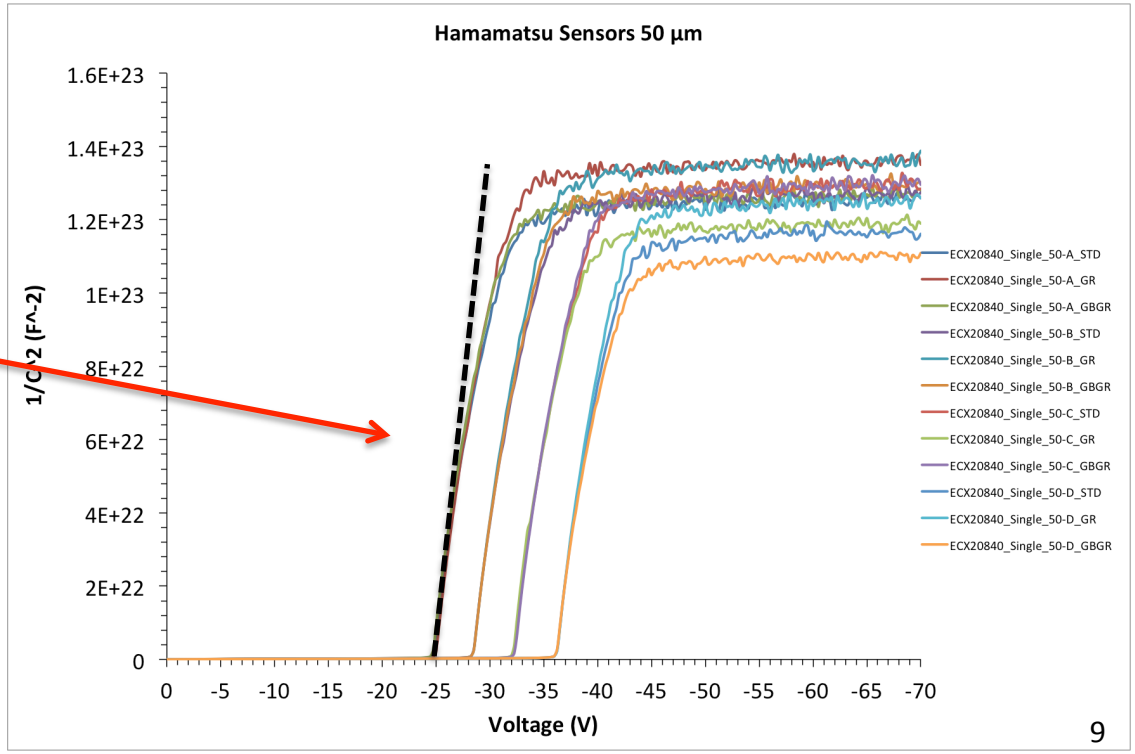
It is expected a linear dependency between $1/C^2$ and the V_{bias} It isn't the case of the HPK sensors

$$\frac{1}{C^2} = \frac{2}{N_A q \varepsilon} \frac{1}{A} V_{Bias} \Longrightarrow \frac{\partial(1/C^2)}{\partial V} = \underbrace{\frac{2}{N_A q \varepsilon} \frac{1}{A}}_{\text{Constant slope}} - \underbrace{\frac{2}{N_A q \varepsilon} \frac{1}{A^2} V_{Bias} \frac{\partial A}{\partial V}}_{\text{Correction factor}}$$

The $1/C^2$ slope is decreasing with V_{bias};

There is a relationship between the parallel plate capacitor area and the V_{bias};

The correction factor is therefore negative and increase with V_{bias};



On the $1/C^2$ slope (1)

The slope of $1/C^2$ tell us if the sensors active area is getting larger or smaller as a function of depletion depth

<u>Increasing steepness:</u>

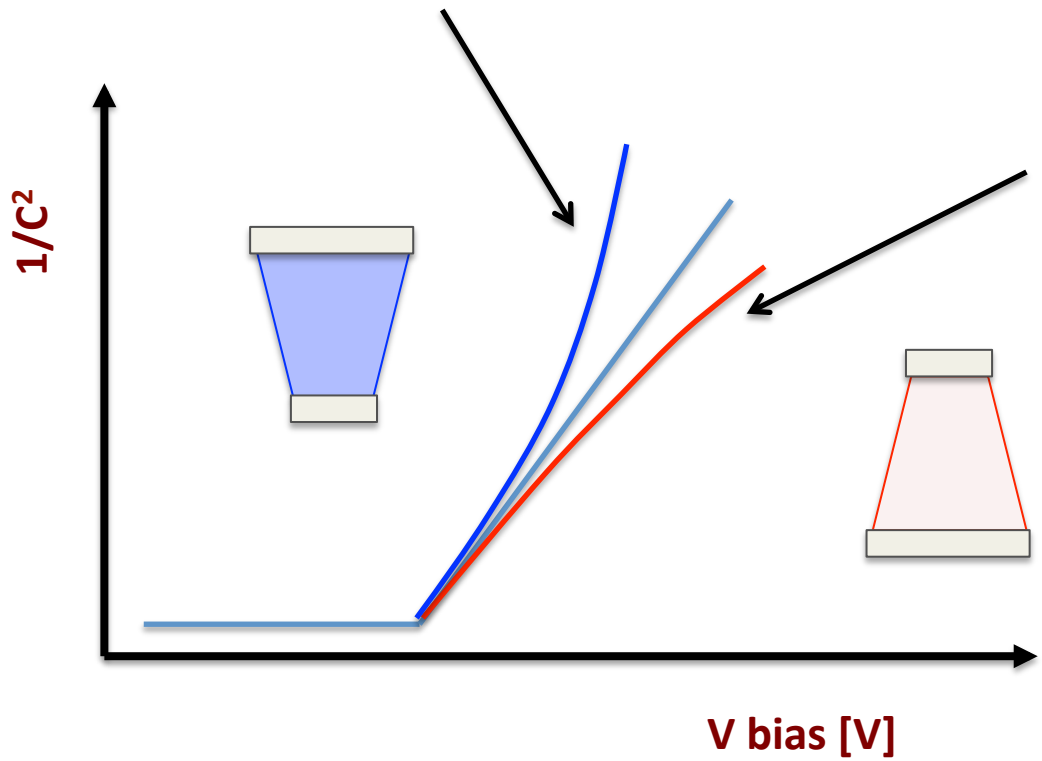
The area is decreasing as a function of V_{bias}

$$\frac{\partial A}{\partial V} < 0$$

<u>Decreasing steepness:</u>

The area is increasing as a function of V_{bias}

$$\frac{\partial A}{\partial V} > 0$$

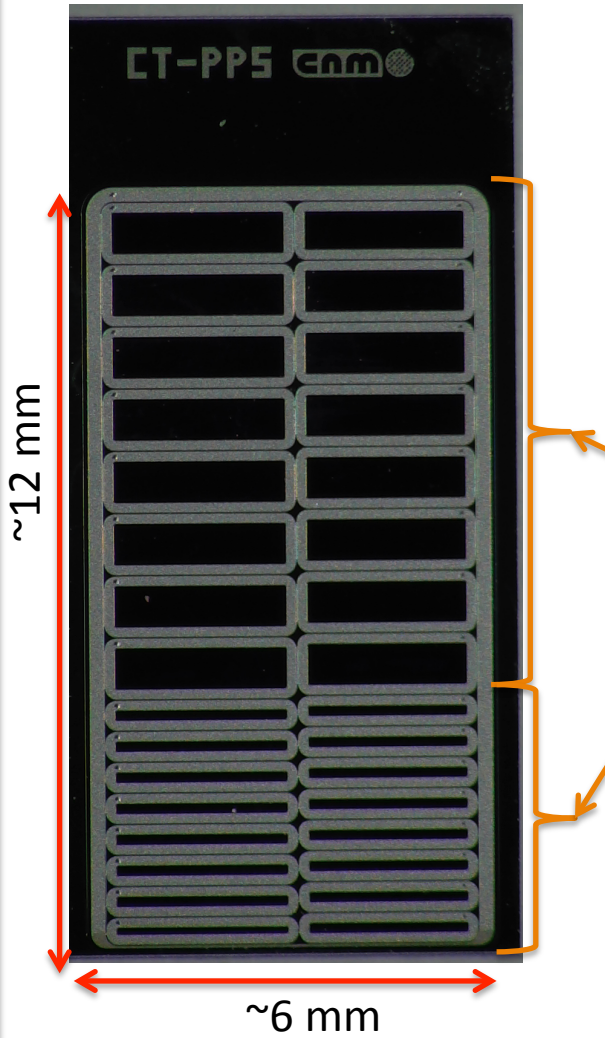


CONCLUSION

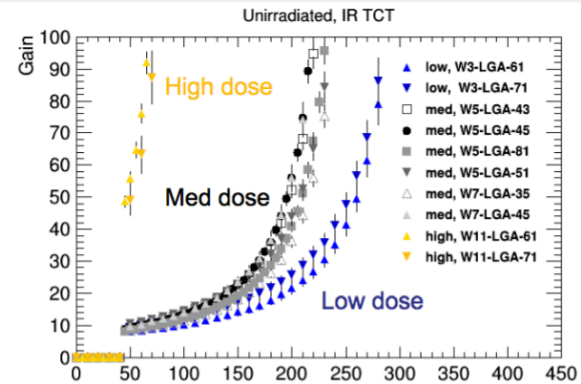
Since in the measurement of the HPK diode the $1/C^2$ slope is decreasing, the area of the depleted area is increasing with thickness

UFSD, CTPPS sensors (50µm CNM production)

CTPPS sensors (*CNM 50 µm Run 9088*)
n side

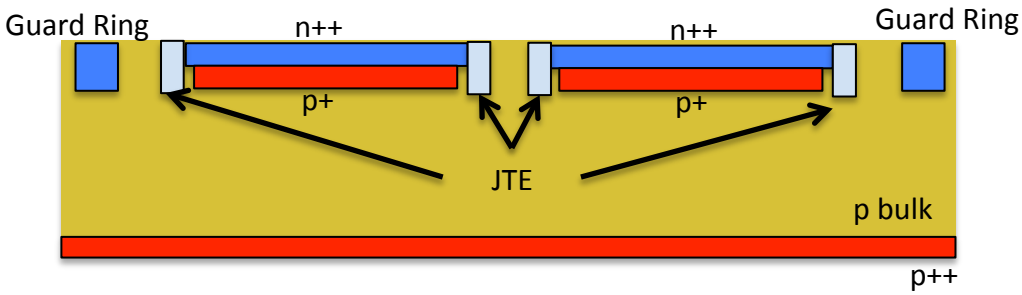


- 3 gain layer dose implants
  $1{,}8 \cdot 10^{13} cm^{-2}$ (Low gain)
  $1{,}9 \cdot 10^{13} cm^{-2}$ (Medium gain)
  $2{,}0 \cdot 10^{13} cm^{-2}$ (High gain)

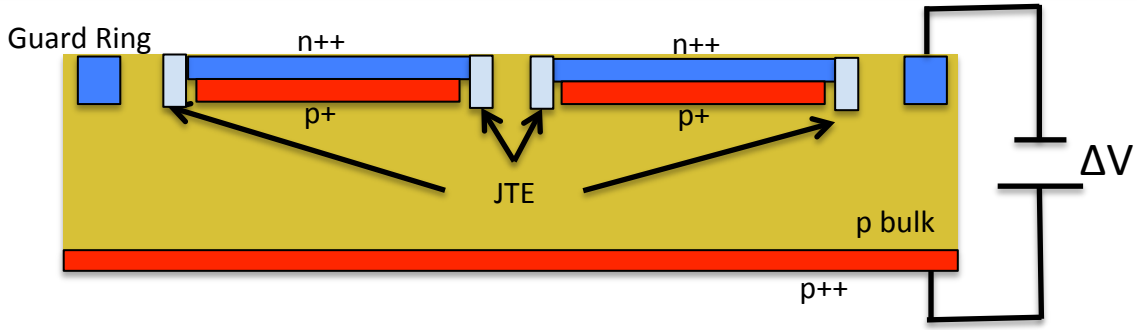


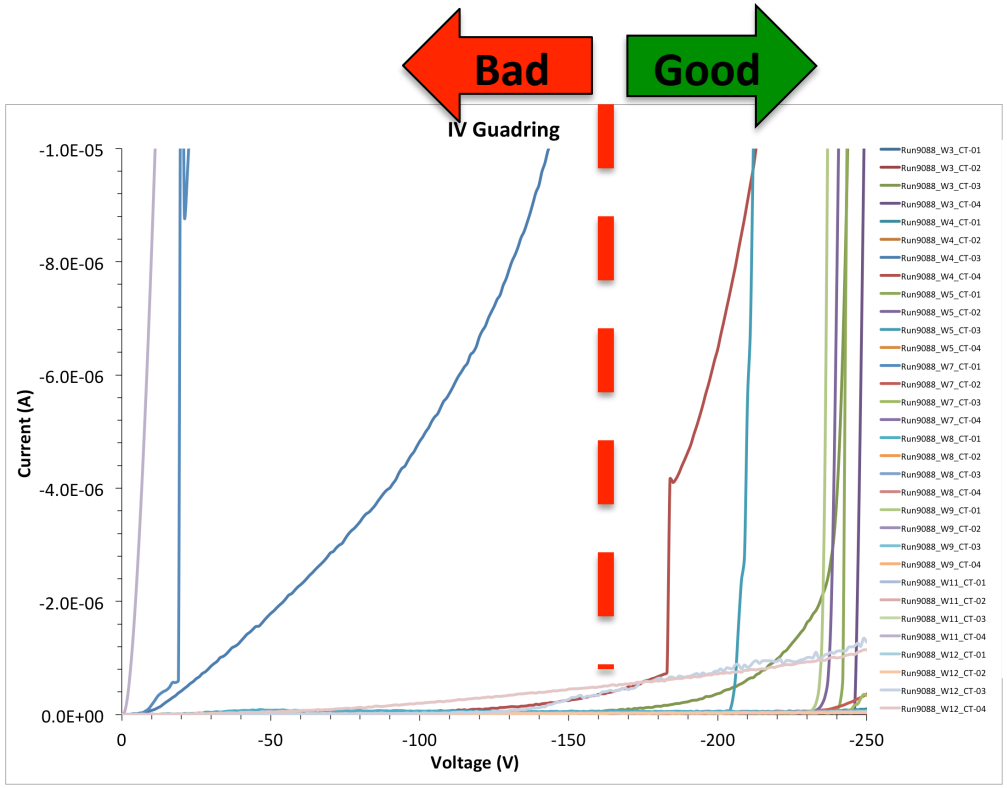
Gain and time resolution of 50µm LGADs before and after irradiation.
Joern Lange, 29th RD50 Workshop, CERN

- Two Groups of pads:
  Small pads (#16) → Active area = 1,5 mm^2
  Big pads (#16) → Active area = 3 mm^2
- Pads surrounded by a Guard Ring;
- Each pads is surrounded by a JTE;



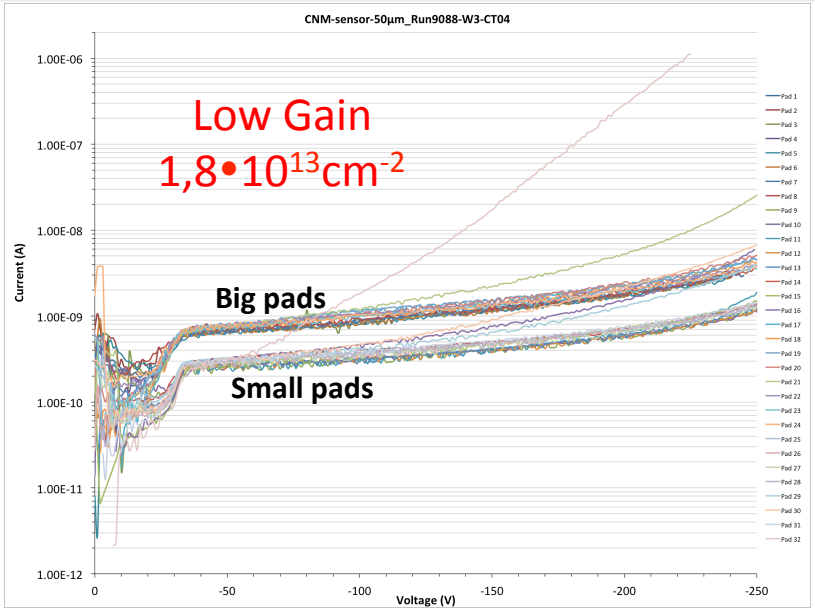
CTPPS sensors, Guard Ring Current

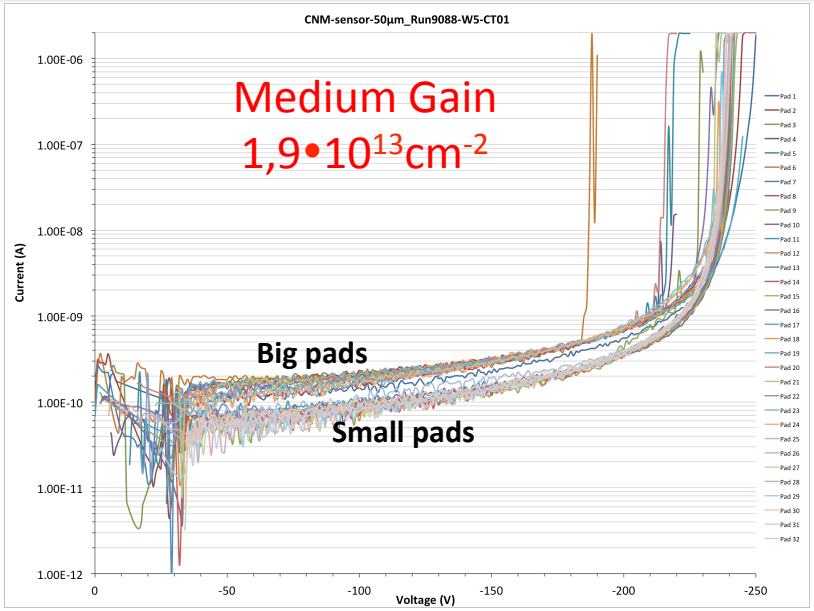


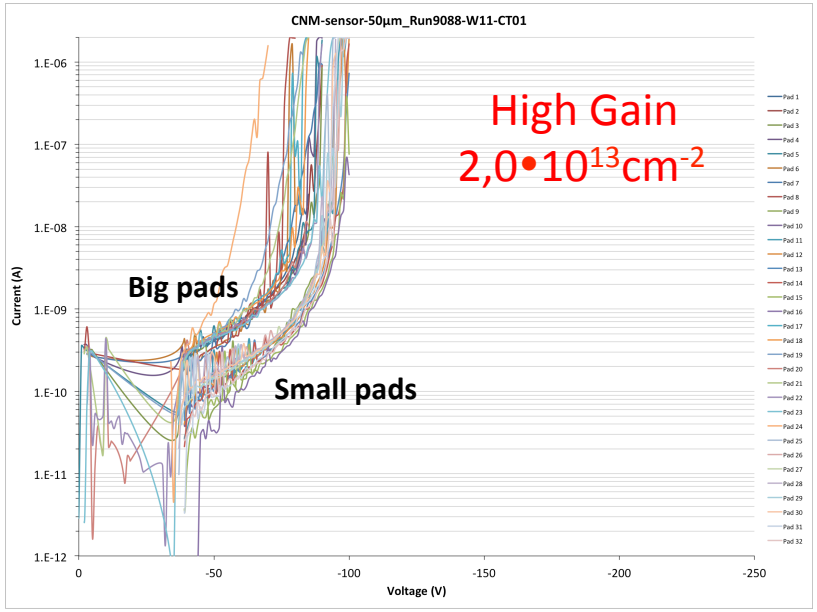


- $I_{guardring}$ allows to select good sensors;
- Good sensors → $V_{breakdown}$ > 150V (*150V is the voltage necessary to saturation the free charge drift velocity in 50μm silicon sensors*);
- Most of the sensors have a V_{BD} above 200V;

CTPPS sensors, Pads leakage Current



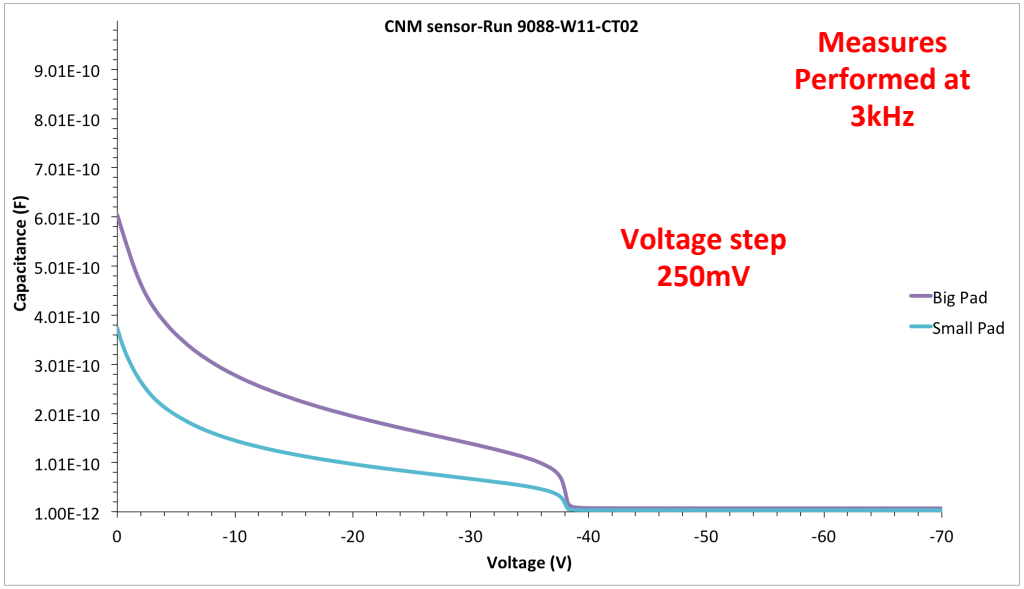


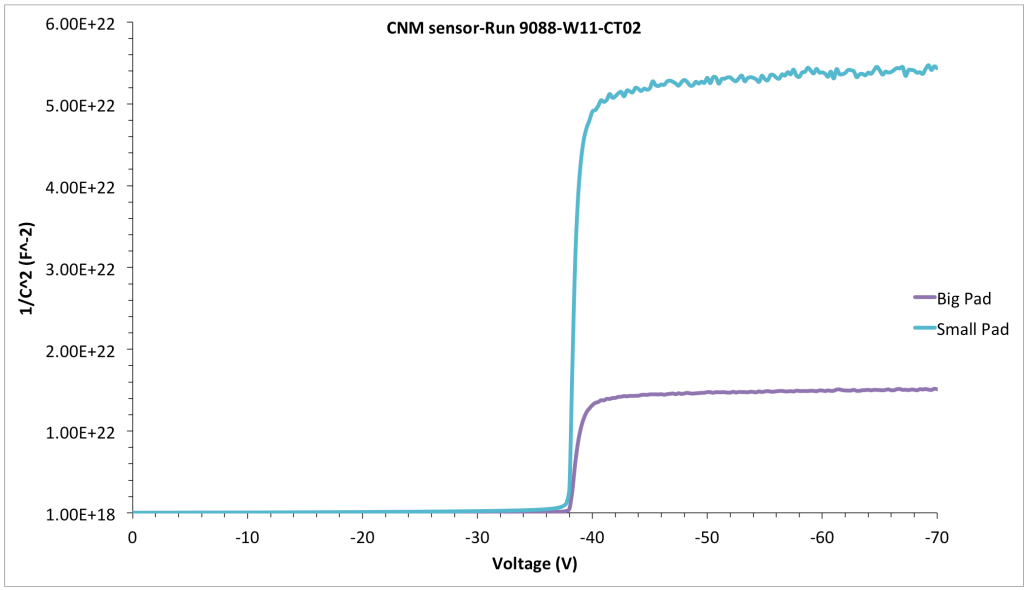


Gain	$V_{brakdown}$
Low	> 250 V
Medium	~ 250 V
High	~ 75 V

Sensors chosen to install in CTPPS are the medium and low gain ones

CTPPS sensors, CV measures (High gain)

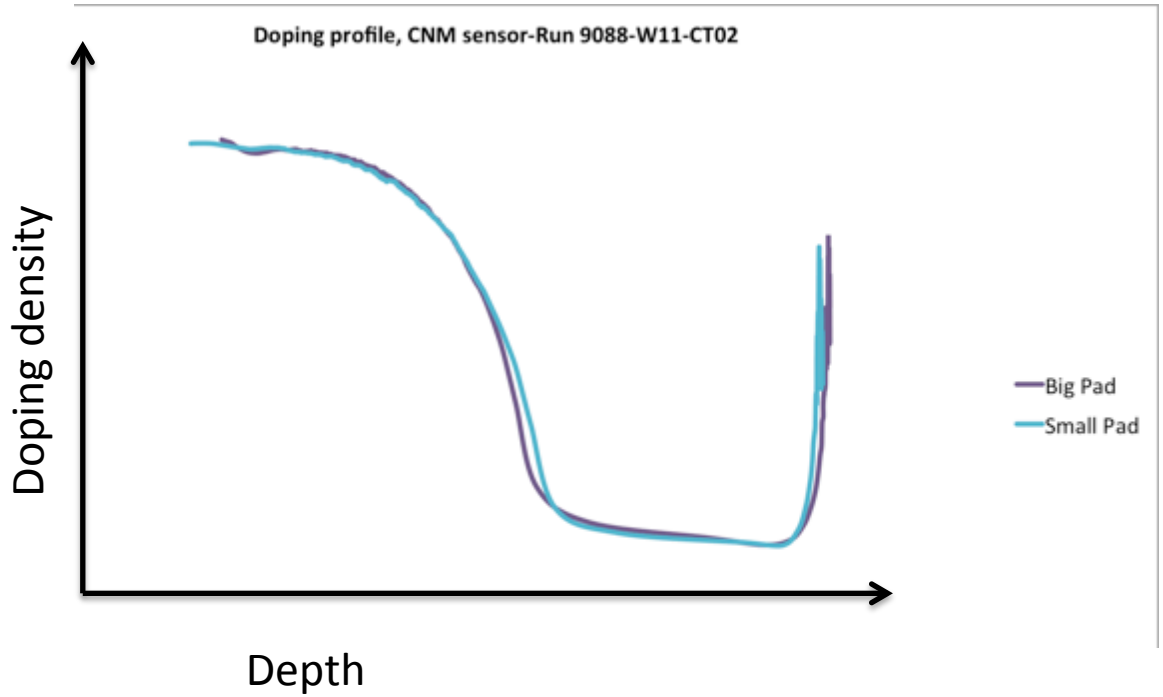




HIGH GAIN

- Gain Layer Voltage depletion ~ 37 V;
- Full Depletion Voltage ~ 41 V; (Only 4 V are necessary to deplete the p-bulk);
- Pad Capacitance:
  $C_{Big\ Pad} = 8{,}2$ pF
  $C_{Small\ Pad} = 4{,}1$ pF

CTPPS sensors, doping profile (High gain)



RESULTS & CONSIDERATIONS:

- No effective active area correction in these measurements;
- Implant width peaks at the n++ /p+ junction, depth is about 3-4µm;
- p-bulk doping concentration ~10^{12};

Conclusions

- Guard Ring: measurements from HPK devices suggest that the presence of the guard ring is helpful to prevent earlier Breakdown

- Segmented LGAD structures:

  We have successfully tested multipad structures from CNM.
  Large statistics show that it is possible to have segmented silicon sensors with internal gain. The characteristics that we find important are:

  1. The leakage current in each pad should be low, otherwise it will cause a breakdown due to the internal gain
  ==> Small pads are less prone to breakdown due to internal gain;
  ==> Large pads are often in breakdown before reaching good operation voltage

  2. Multipad sensors where the pads are isolated from each other by an edge protection are more reliable, with large number of pads well behaving

References

- M. Carulla et al. , First 50µm thick LGAD fabrication at CNM, 28th RD50 Workshop, Torino, (June 7th, 2016);

- G. Pellegrini et al. , Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications, NIMA 765 (2014) 24;

- J.Lange et al. , Study of Ggain and time resolution of 50µm LGADs before and after irradiation, 29th RD50 Workshop, CERN (November 22th, 2017);

Acknowledgements

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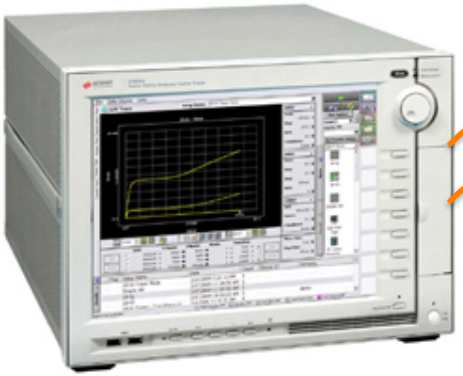
- INFN - Gruppo V
- Horizon 2020, grant UFSD669529
- Horizon 2020, grant INFRAIA
- Ministero degli Affari Esteri, Italy,MAE, “Progetti di Grande Rilevanza Scientifica”
- U.S. Department of Energy grant number DE-SC0010107
- RD50, CERN

Backup

CV measurements (laboratory setup)

Keysight
B1505A Power Device Analyzer / Curve Tracer

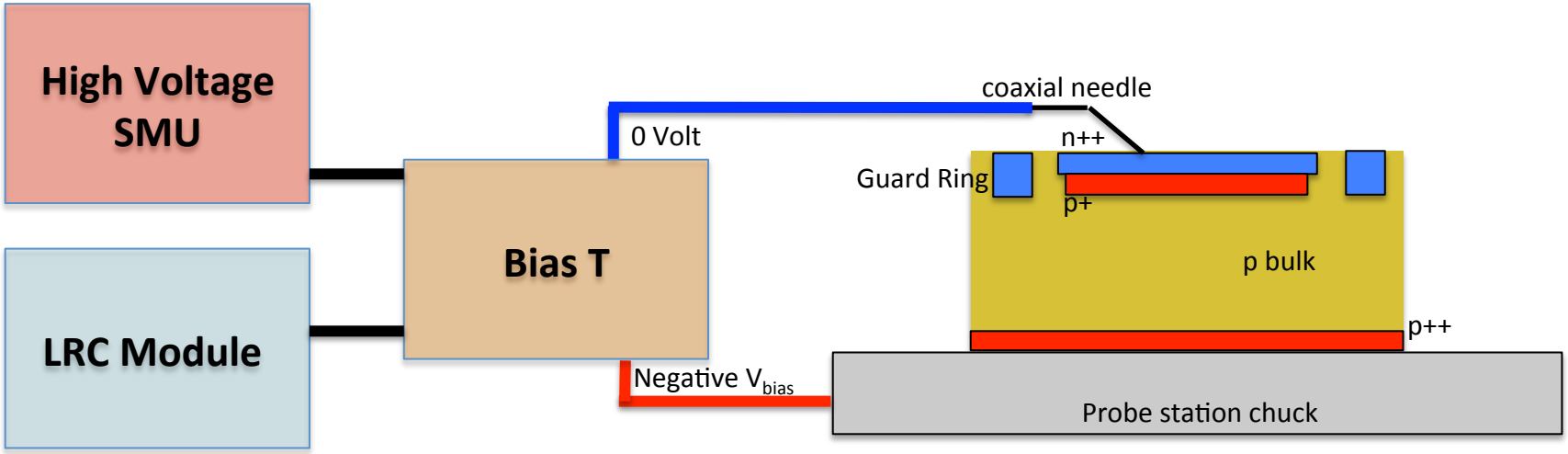


Probe station

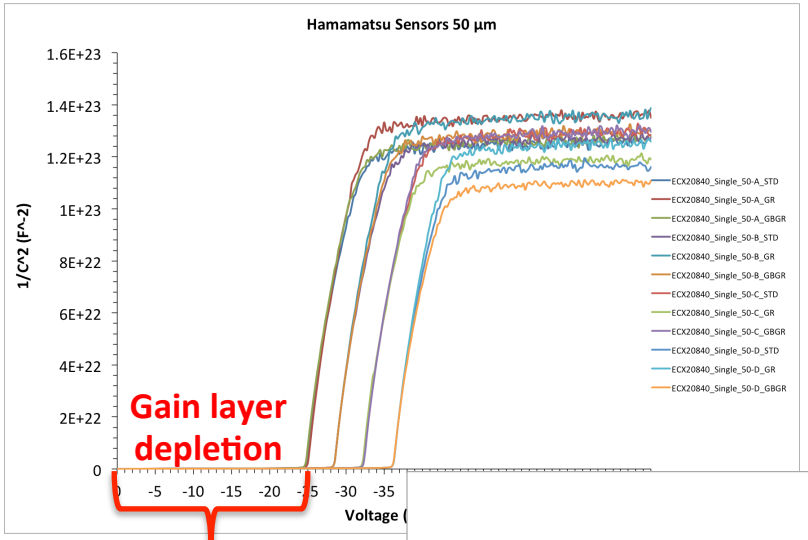
The electric contacts was made with coaxial needles

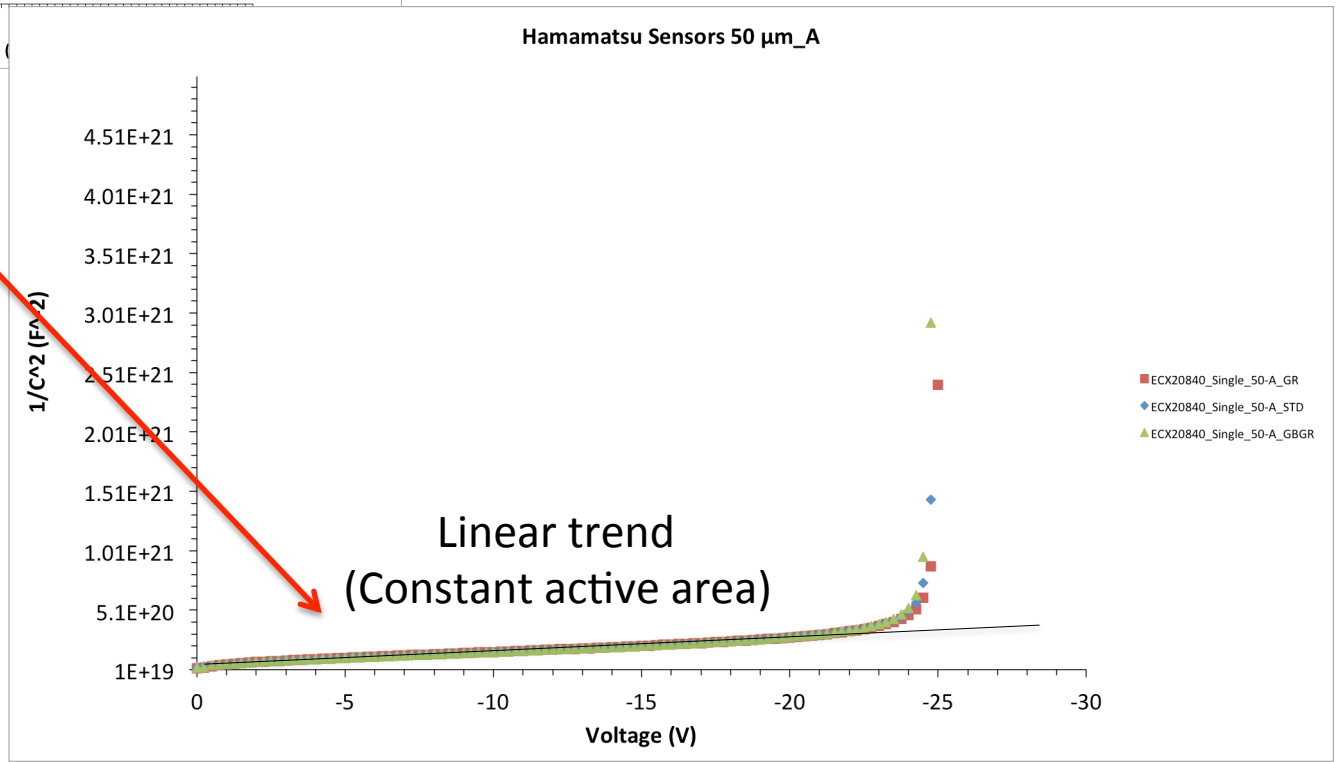
Modules

- High Voltage SMU: Max Range (±3000V, ±4mA);
  Min Range (200V, 1nA);
- LRC Module;



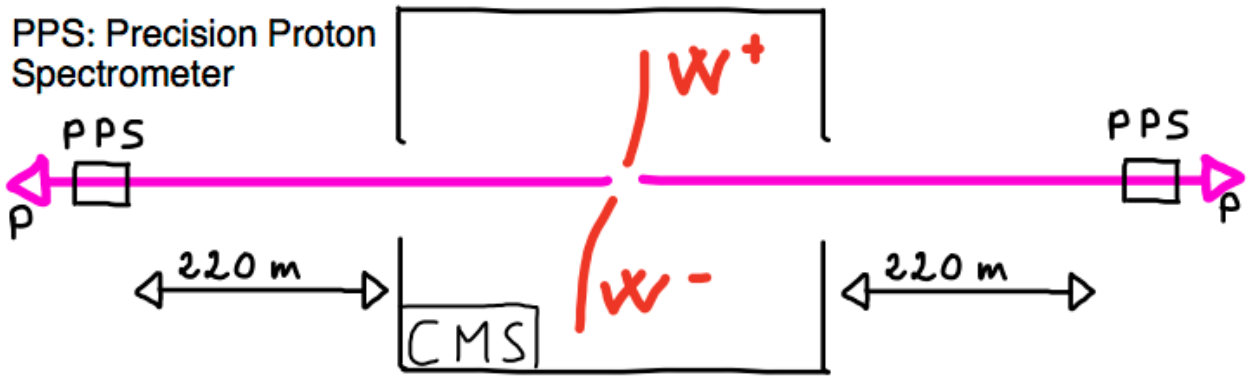
$1/C^2$-V Curves considerations



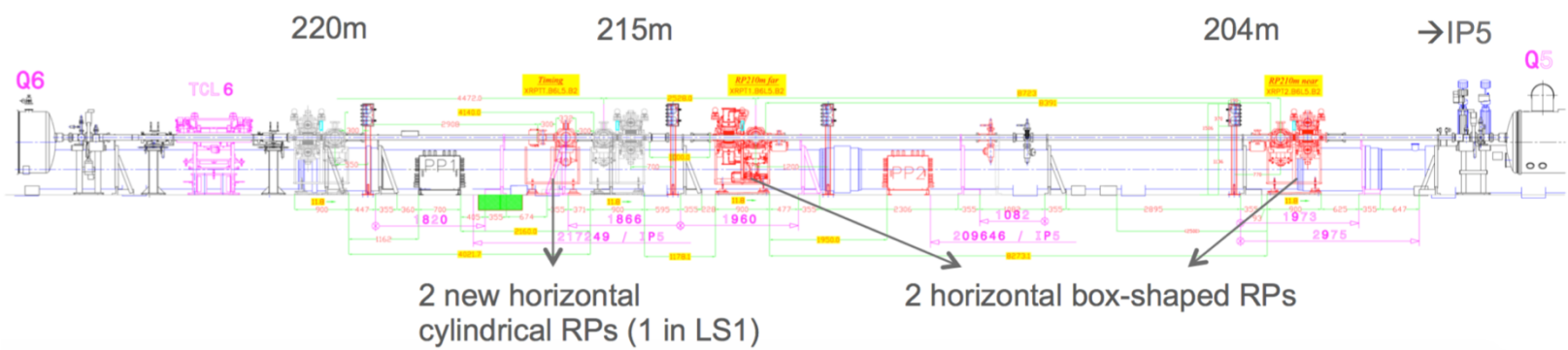


CT-PPS: CMS TOTEM Precision Proton Spectrometer

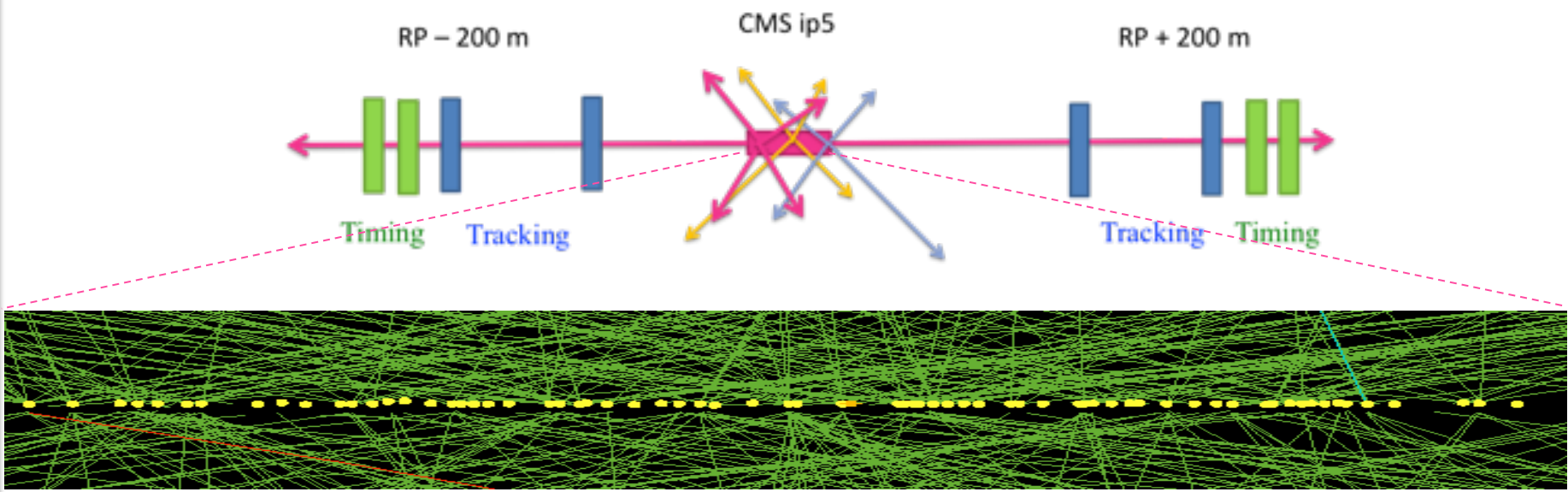
A proton spectrometer to study central exclusive production at the LHC



CT-PPS consists a silicon tracking system to measure the position and direction of the protons, and a set of timing counters to measure their arrival time



Timing for CT-PPS – Why?



PILEUP!

At each bunch crossing there will be many interactions (up to 50 in 2016-2018)

A precision of ~20 ps on the arrival time of each proton

will determine the vertex position with a precision of ~4.2 mm

'z-by-timing' resolution $\Delta z = c\,\Delta(t1-t2)/2$