Recent Results of CERN RD39 Collaboration on Development of Radiation Hard Si Detectors Operated at Low to Cryogenic Temperatures

Zheng Li

On behalf of CERN RD 39 Collaboration

This research was supported by the U.S. Department of Energy: Contract No. DE-AC02 -98CH10886 and it is within the frame work of CERN RD39 Collaboration

Outline

1. The CID (Current-Injected-Diode) Concept and Principle
2. Test Results of CID Strip Detectors
3. CID Application for LHC Beam-Loss-Monitor
4. Summary

Trapping effect on CCE in LHC Upgrade

$$Q = Q_0 \cdot CCE = Q_0 \cdot \frac{w}{d} \cdot \frac{\tau_t}{t_{dr}}(1 - e^{-t_{dr}/\tau_t})$$

Trapping term

Depletion term

For fluence 10^{16} n/cm^2, the trapping term CCE_t is a limiting factor of detector operation !

For sLHC fluences :

$$Q \cong 80 \text{ e's}/\mu\text{m} \cdot v_{dr} \cdot \tau_t \equiv 80 \cdot d_t \text{ (e's)}$$

$d_t = v_{dr} \cdot \tau_t$ is the trapping distance

Effect of Trapping on CCE in SLHC

TRAPPING

$$\tau_t = \frac{1}{\sigma v_{th} N_{t,empty}}$$

The thermal velocity $v_{th} \approx 10^7$ cm/s

10^{16} cm^{-2} irradiation produces $N_{t,empty} \approx 3\text{-}5 \times 10^{16}$ cm^{-3} with $\sigma \approx 10^{-14}$ cm^2

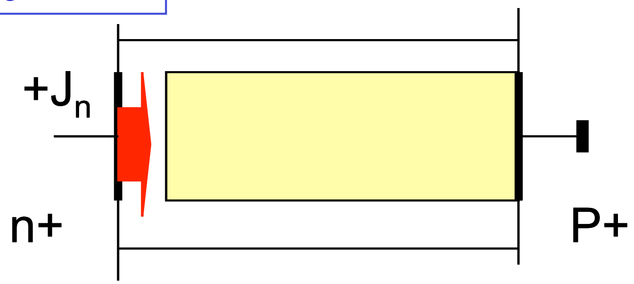
On average (e and h) it gives a $\tau_t \approx 0.2$ ns!

Even in highest E-field (Saturation velocity, 10^7 cm/s), carrier drifts only 20-30 μm before it gets trapped regardless whether the detector is fully depleted or not !

In S-LHC conditions, about 90% of the volume of d=300μm detector is dead space if $N_{t,empty}$ is not reduced!

The CID Concept and Principle (CERN RD 39 Collaboration)

Carrier injection

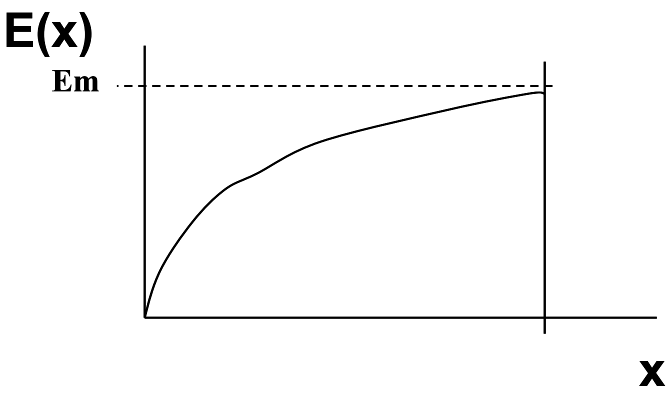


$J_n = en\mu E$

divJ=0

$divE=n_{tr}$

E(x=0) = 0
(SCLC: Space Charge Limited Current mode)



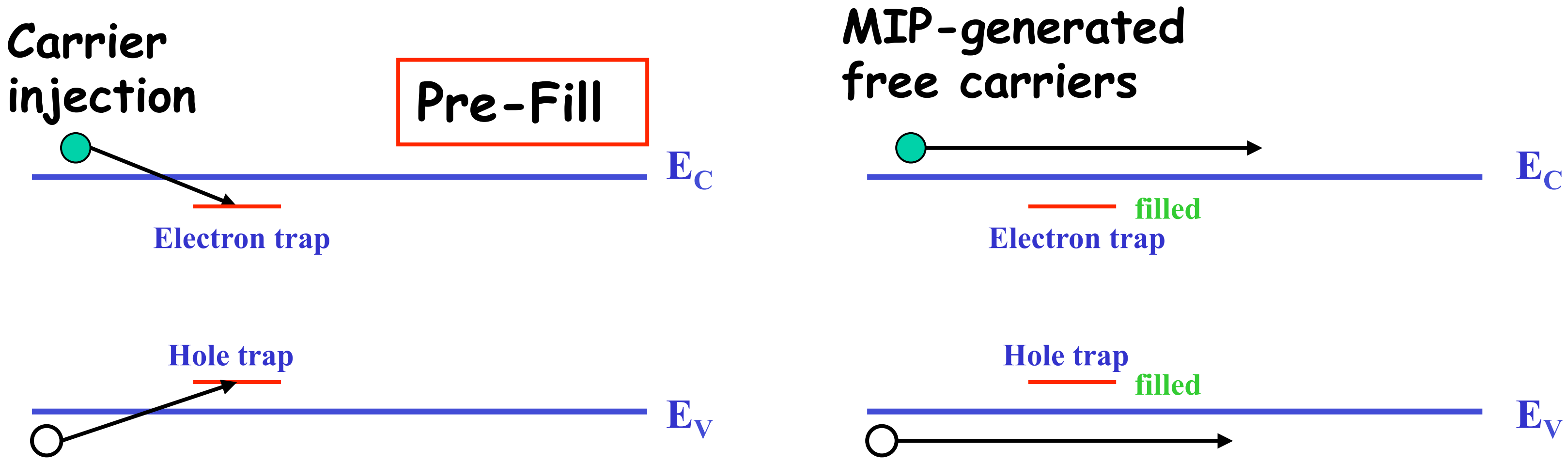
$$E(x) = \frac{3}{2}\frac{V}{d}\cdot\sqrt{\frac{x}{d}} \qquad E_m = \frac{3}{2}\cdot\frac{V}{d}$$

The key advantage:

The shape of E(x) is ***not affected*** by fluence, **and virtual full depletion**

Pre-filling of traps by carrier injection

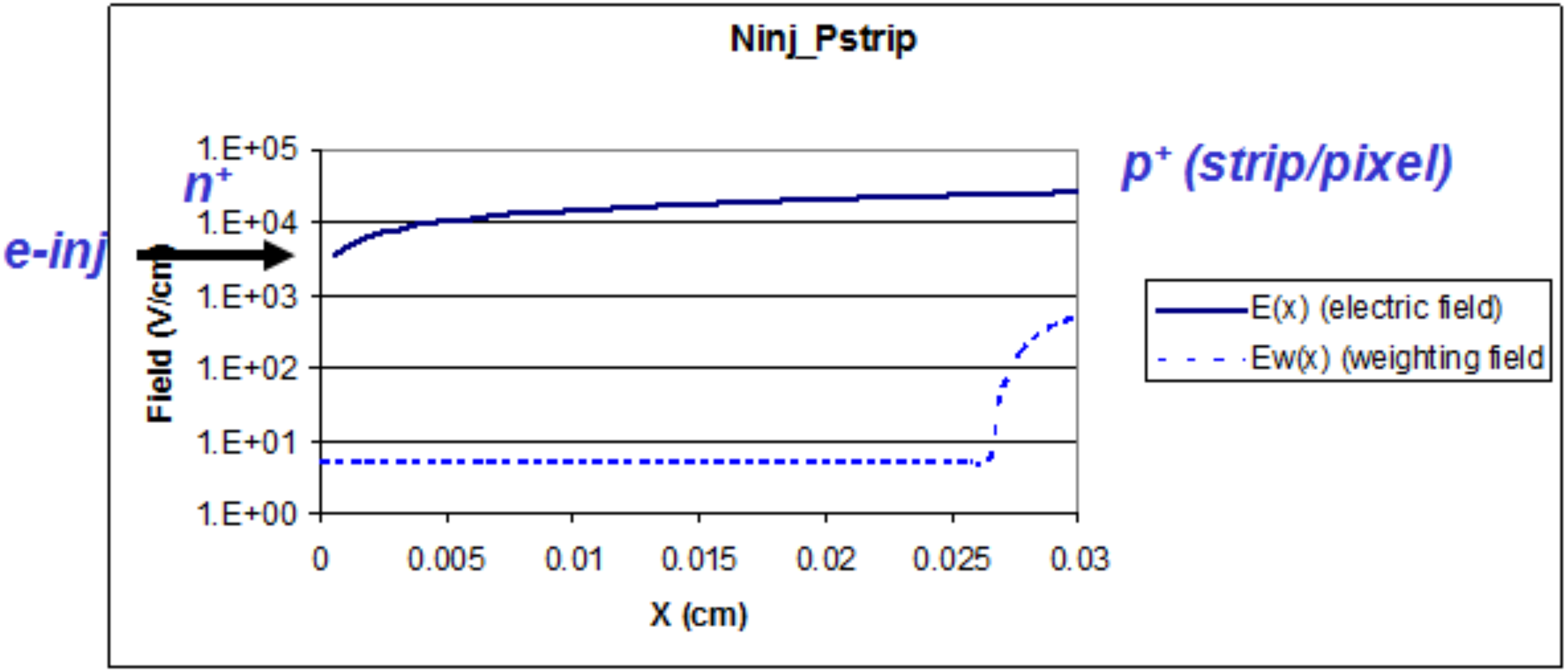
Carrier injection can also pre-fill the traps to make them inactive

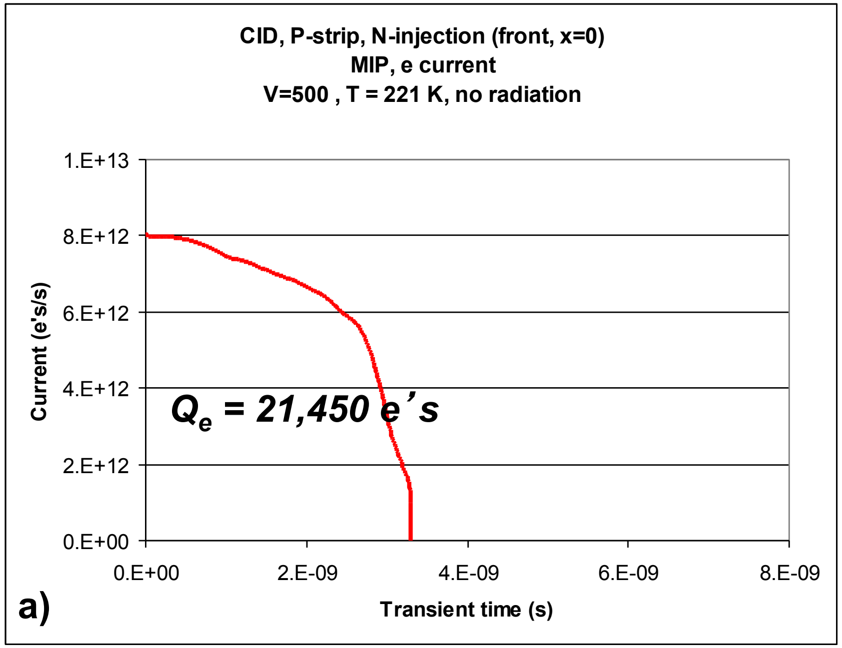


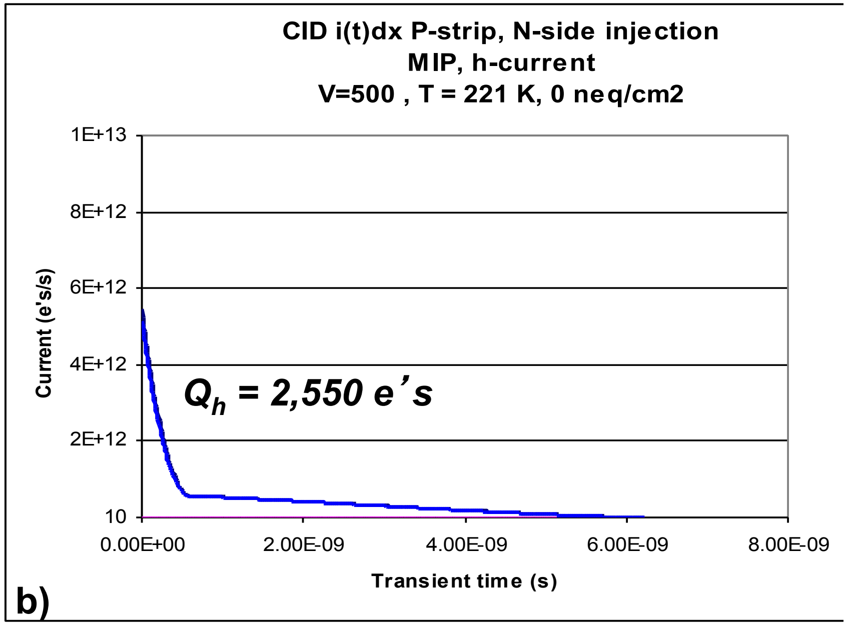
$$N_{t,empty} \searrow \longrightarrow \tau_t \nearrow \longrightarrow Q \nearrow$$

CID Simulation

V = 500 V, T = 221 K







No radiation

Q = 24,000 e's

(89.4% by electrons)

CID Simulation

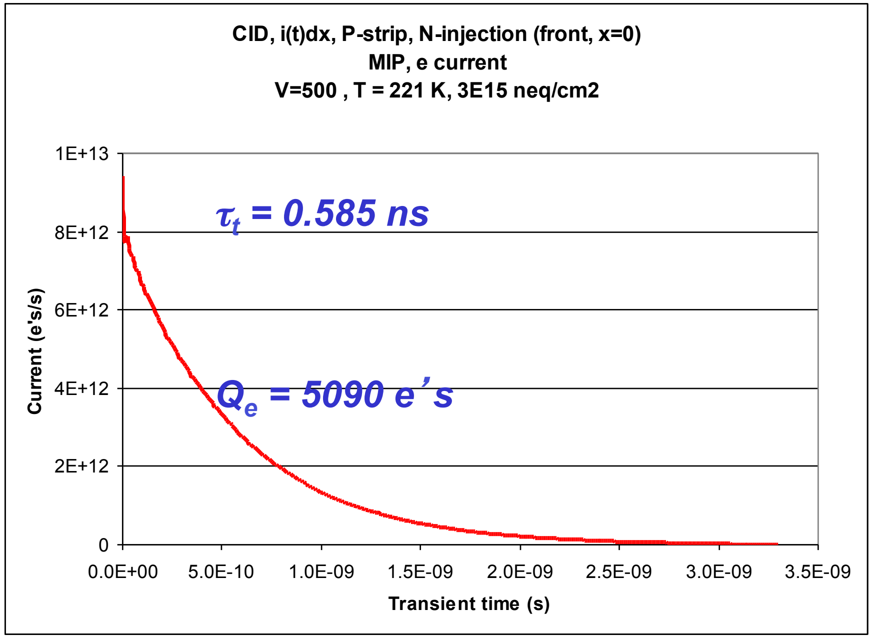
V = 500 V, T = 221 K

Standard Strip Detector

$3x10^{15}$ n_{eq}/cm^2

Q = 6110 e's

(83% by electrons)

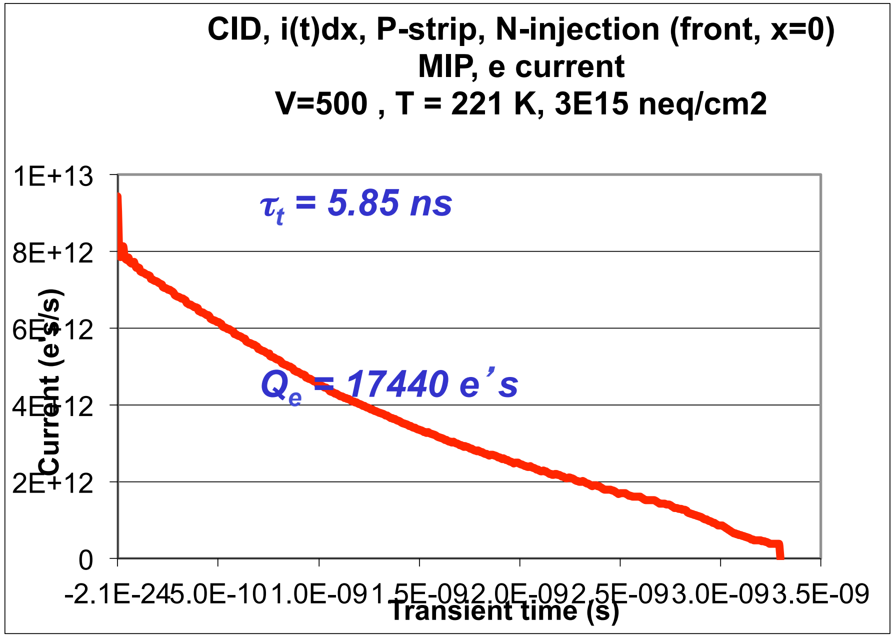


CID Strip Detector

$3x10^{15}$ n_{eq}/cm^2

Q = 18360 e's

(94% by electrons)



CID Simulation

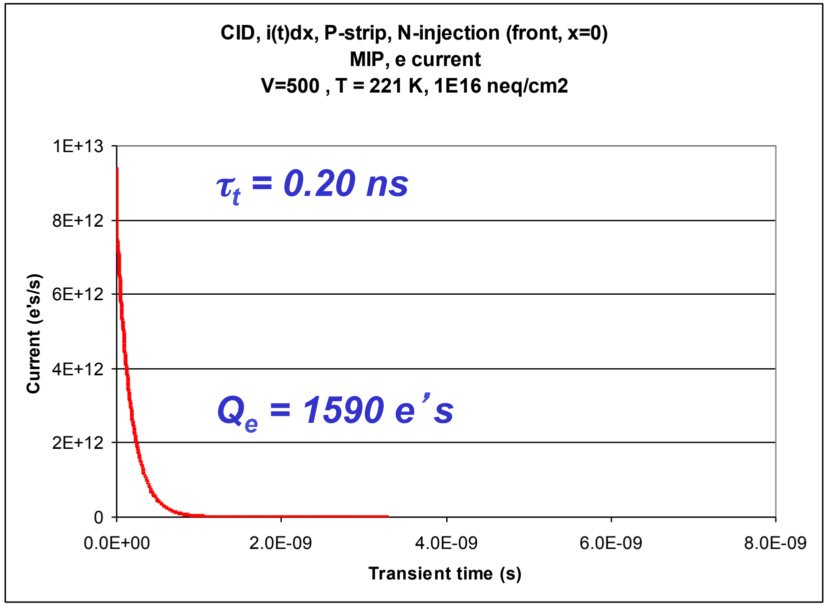
V = 500 V, T = 221 K

Standard Strip Detector

$1x10^{16}$ n_{eq}/cm^2

Q = 2140 e's

(74% by electrons)

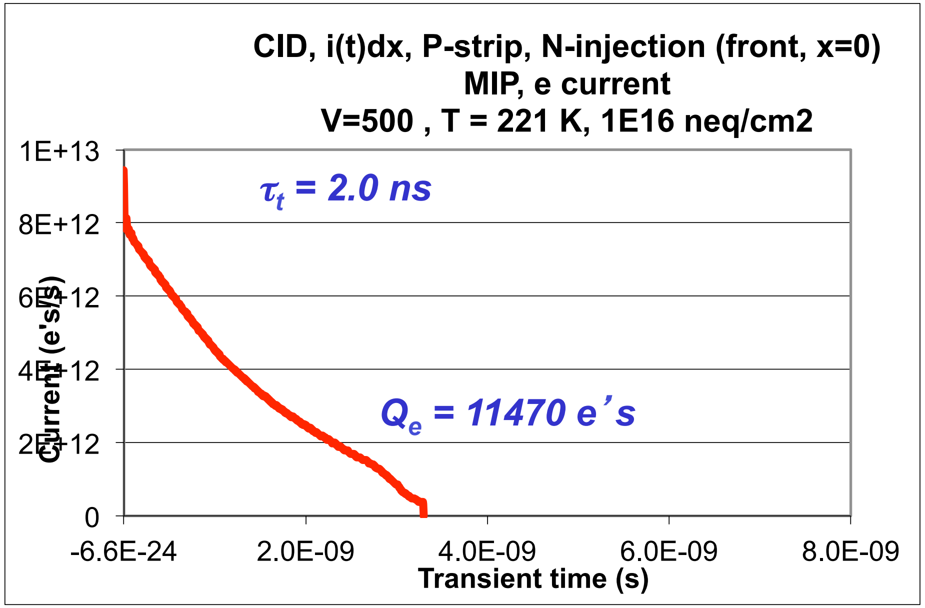


CID Strip Detector

$1x10^{16}$ n_{eq}/cm^2

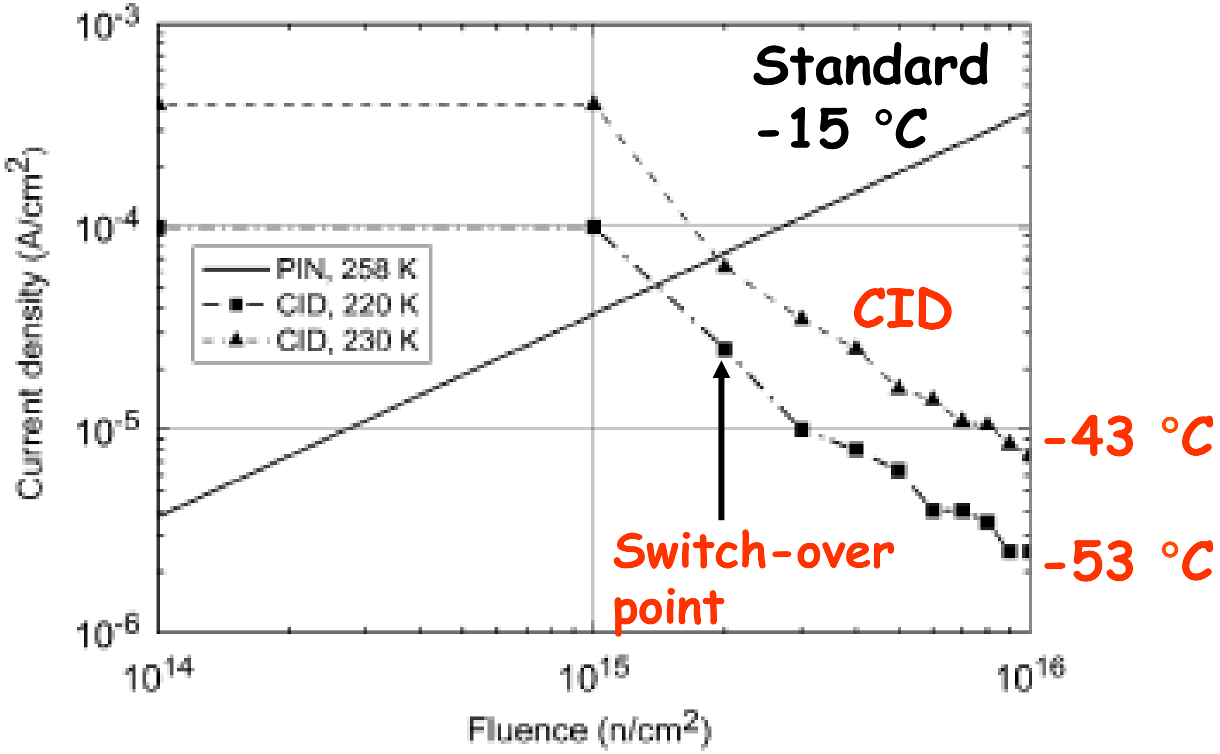
Q = 12020 e's

(94% by electrons)

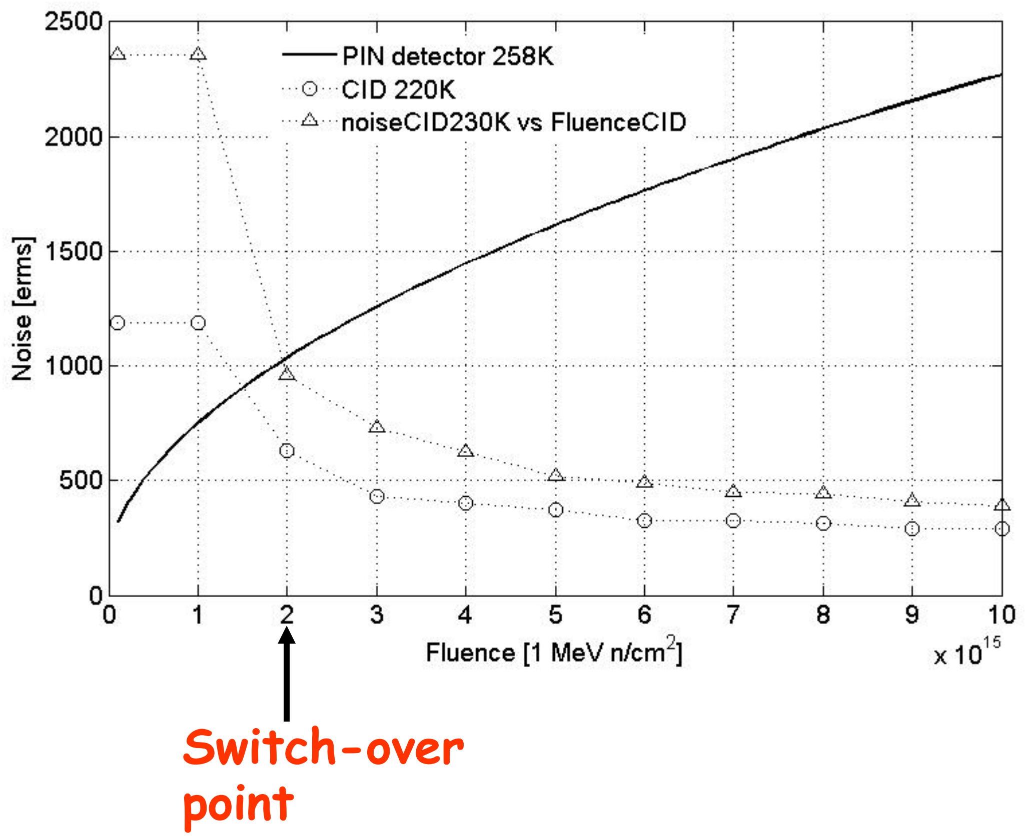


Current comparisons

Switch over point from standard reverse bias to CID (forward) is $2x10^{15}$ n_{eq}/cm^2



Simulation of noise performance of CID detector versus normal detector operation.

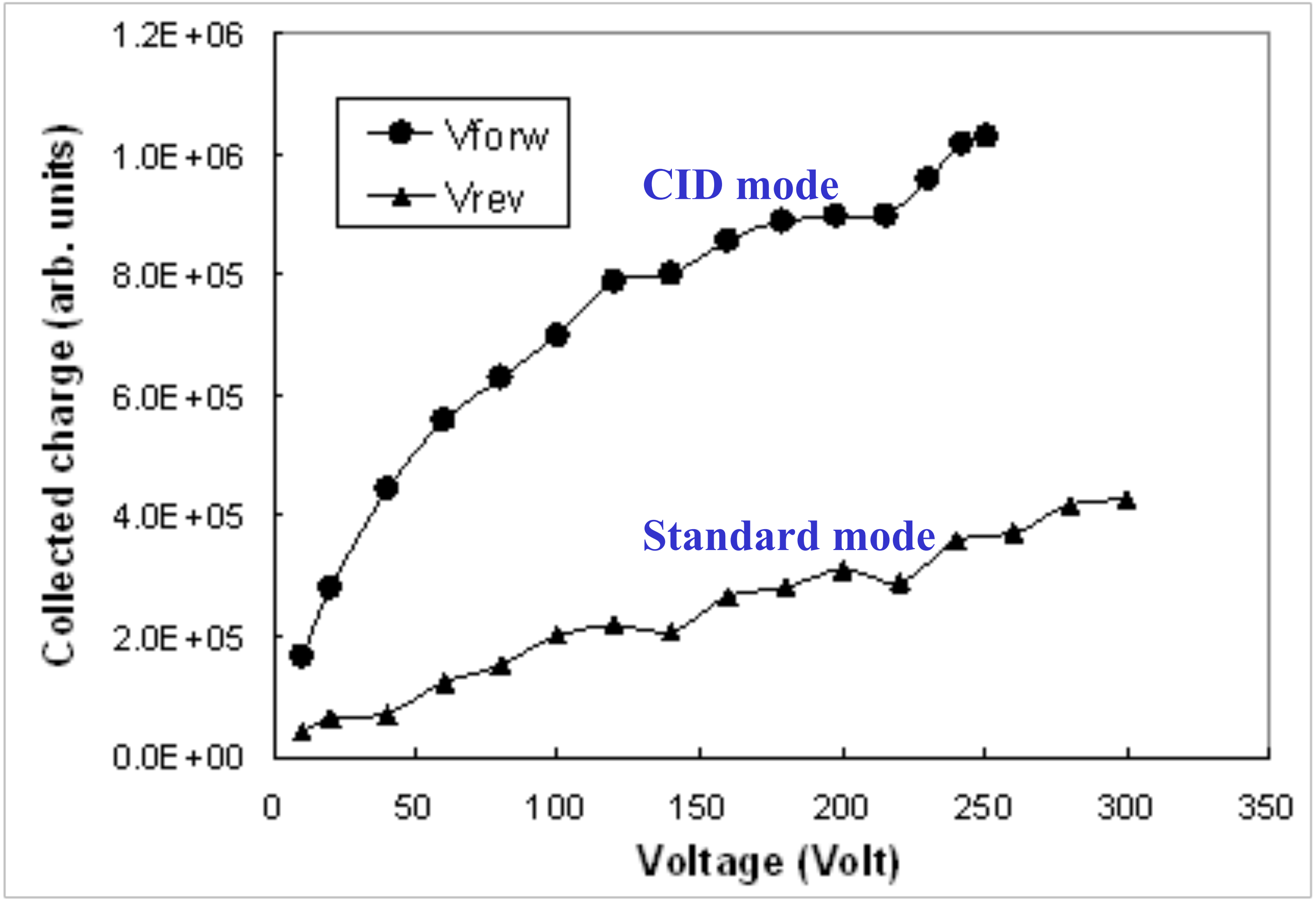


The simulation has been made according to the strip detector design of CERN ATLAS experiment: pitch 80 µm, strip length 6 cm and read-out shaping time 25 ns , PIN is biased to the full depletion and the temperature is 258 K. The bias for CID is 200V. As it can be seen, at fluence 2×10^{15} n_{eq}/cm^2 the CID noise becomes lower than in PIN detector.

Zheng Li May 24, 2012

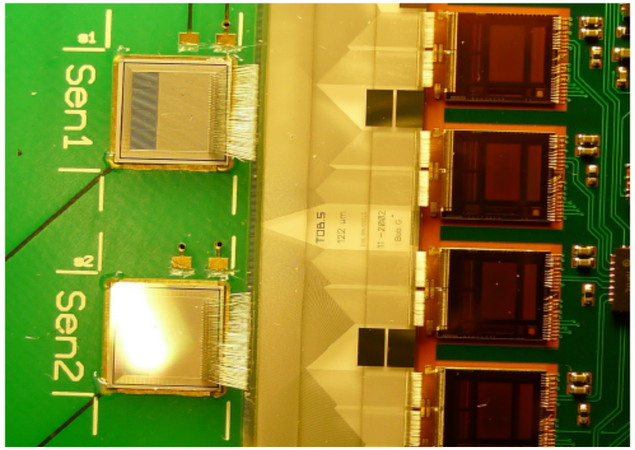
Test Results of CID Detectors

$\Phi_n = 1\times10^{15}$ cm^{-2}, T = 180 K, MIPs (1050 nm laser)



Test Results of CID Strip Detectors

Test Beam set up



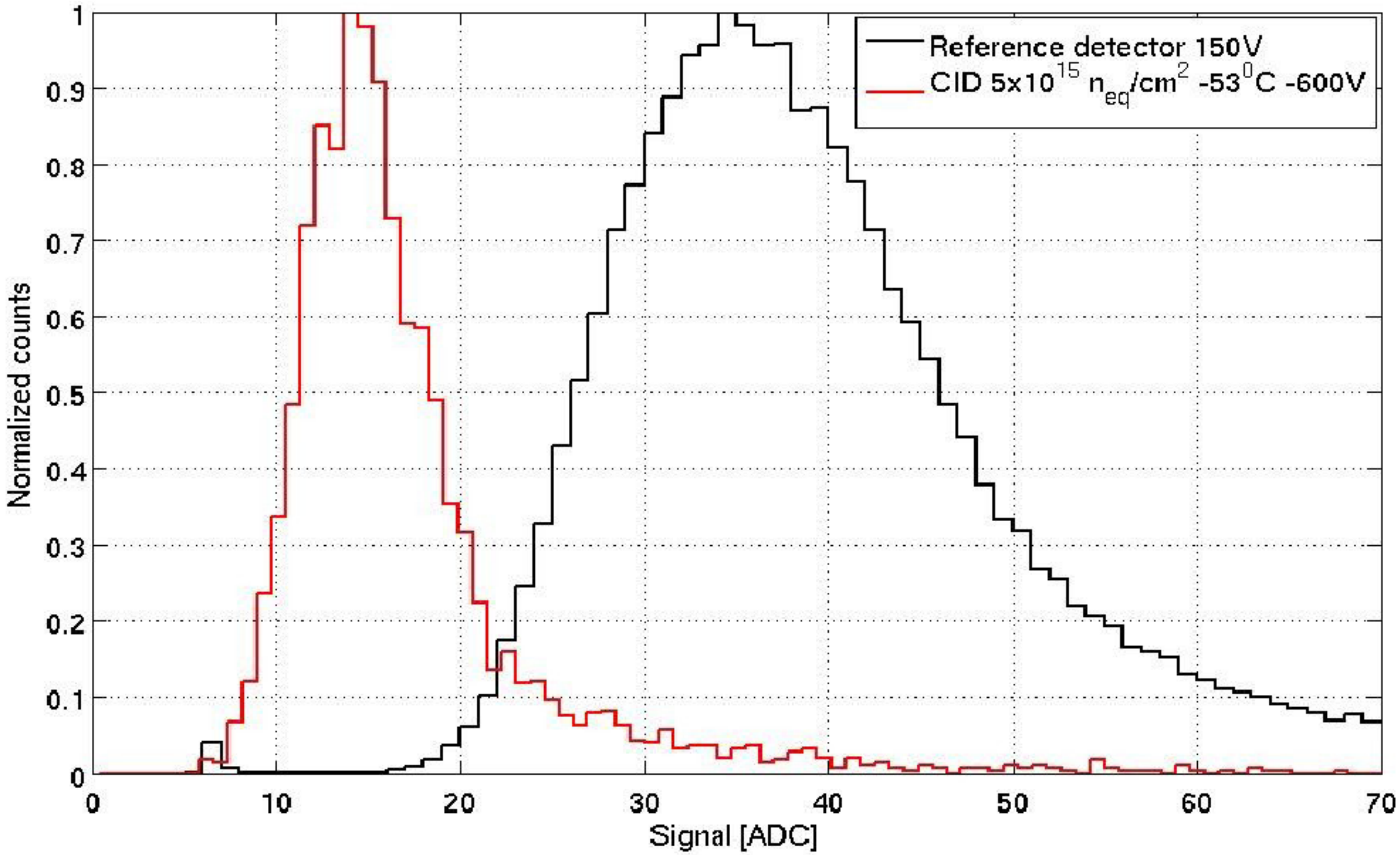
- CMS readout and DAQ
- Operated at CERN H2 area and FNAL
- Nominal resolution 4μm, 10 reference planes, effective area 4×4 cm^2 .
- Detector module can be cooled ≈-53^{0}C by Peltier elements
- Test beam setup gradually developed since past ≈10yrs

Test Beam experiment on CID detectors 2008-2011

- Sensors investigated
  - 2×10^{15} n_{eq}/cm^2 $n^+/p^-/p^+$ MCz-Si
  - 5×10^{15} n_{eq}/cm^2 $p^+/n^-/n^+$ MCz-Si (in 2008 3×10^{15} n_{eq}/cm^2 $p^+/n^-/n^+$ MCz-Si)

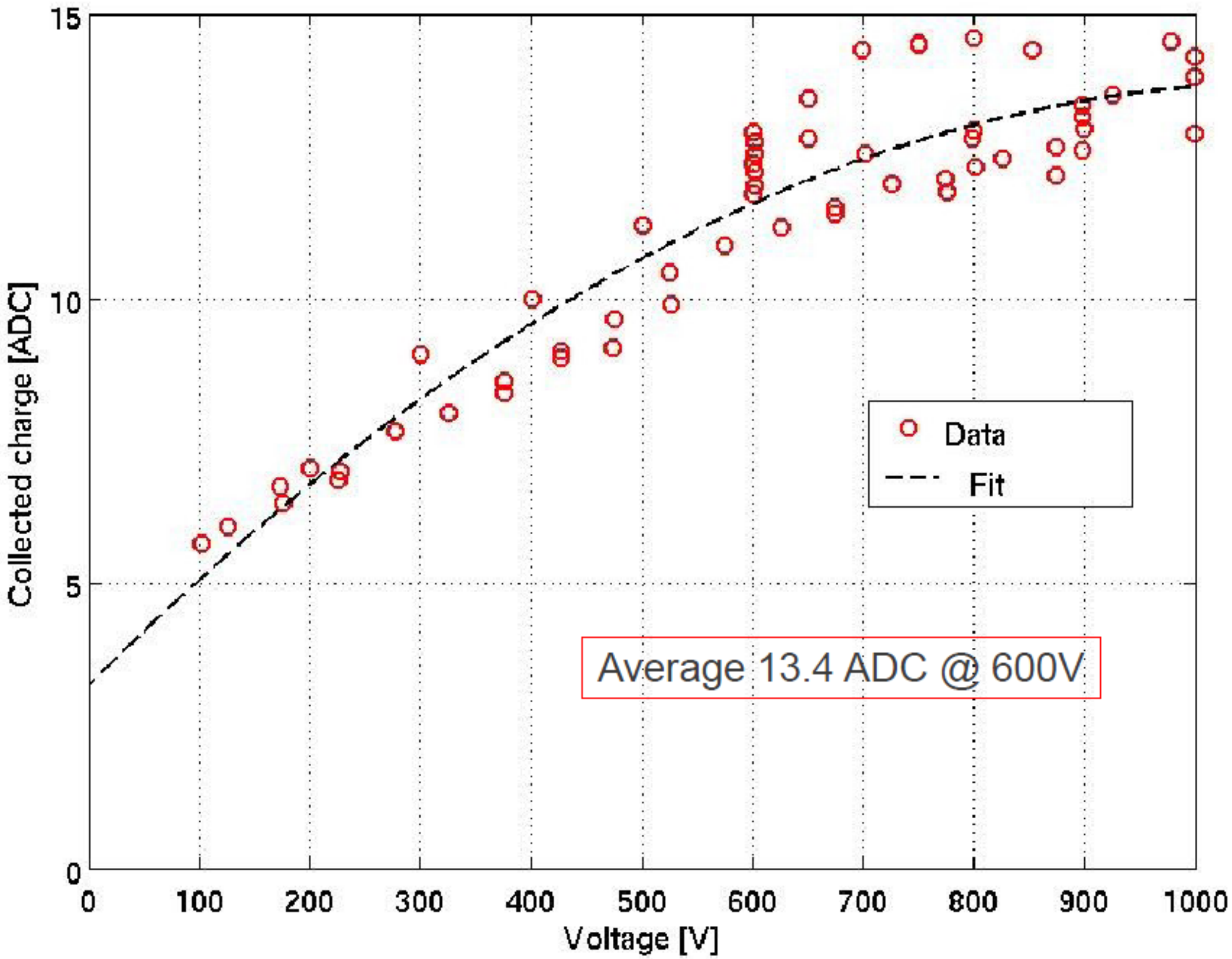
Test Results of CID Strip Detectors

5×10^{15} n_{eq}/cm^2 results -Collected charge vs non-irrad



Test Results of CID Strip Detectors

5×10^{15} n_{eq}/cm^2 results -Collected charge vs V CID mode

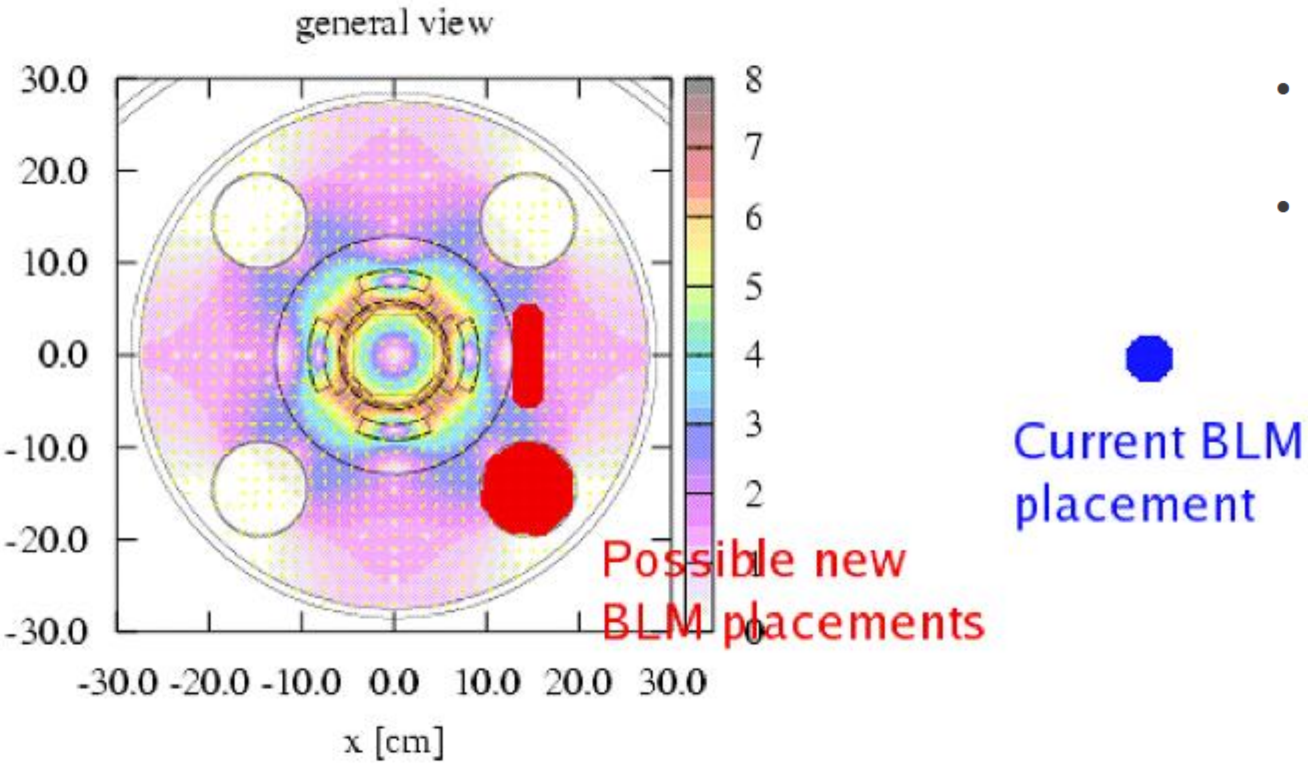


Full charge ≈ 40 ADC

1 ADC ≈ 600e^-

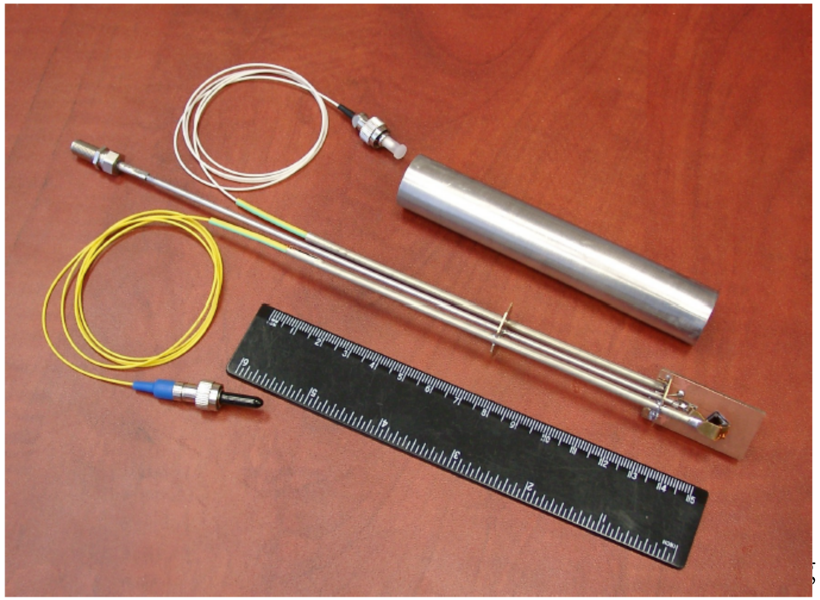
CID Application for LHC Beam-Loss-Monitor

- LHC upgrade will require BLM to be located inside of LHe cryostat.
- BLM will receive radiation load comparable with S-LHC pixel sensors
- At 1.8K radiation defects will trap >50% of signal
- Polarization makes normal reverse bias operation impossible



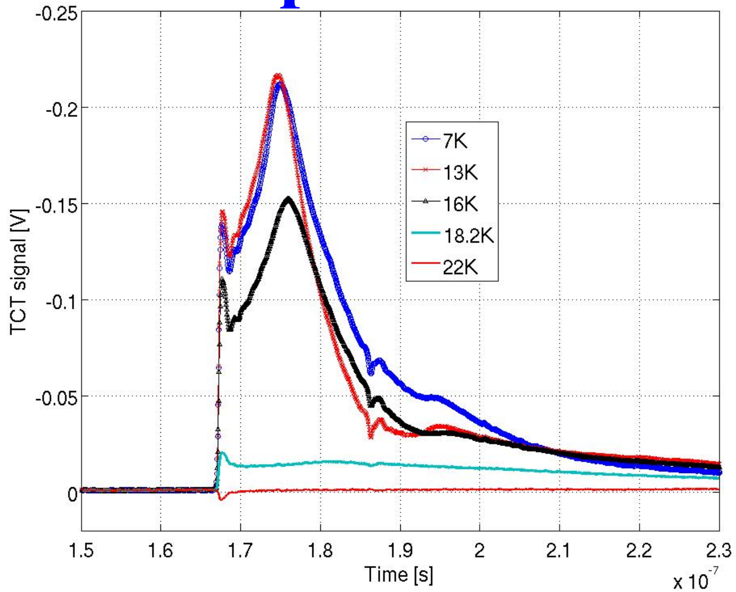
Laser Tests for LHC Beam-Loss-Monitor

Detector arrangement



Crogenic TCT at CERN with ps laser

Preliminary TCT data
CID operated at <25K



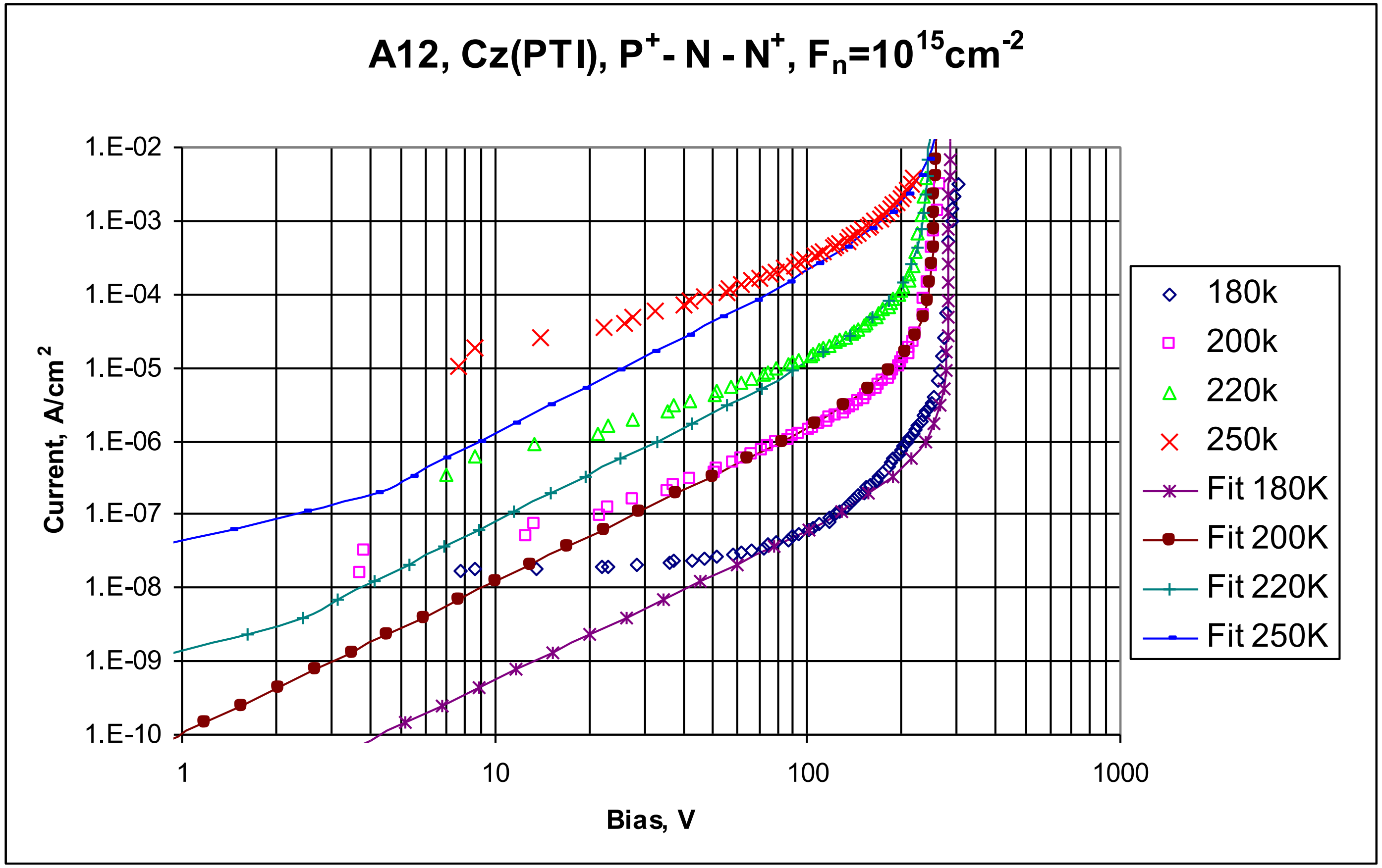
Summary

1. Segmented CID detectors have been modeled to have advantages in having low depletion voltage and trapping

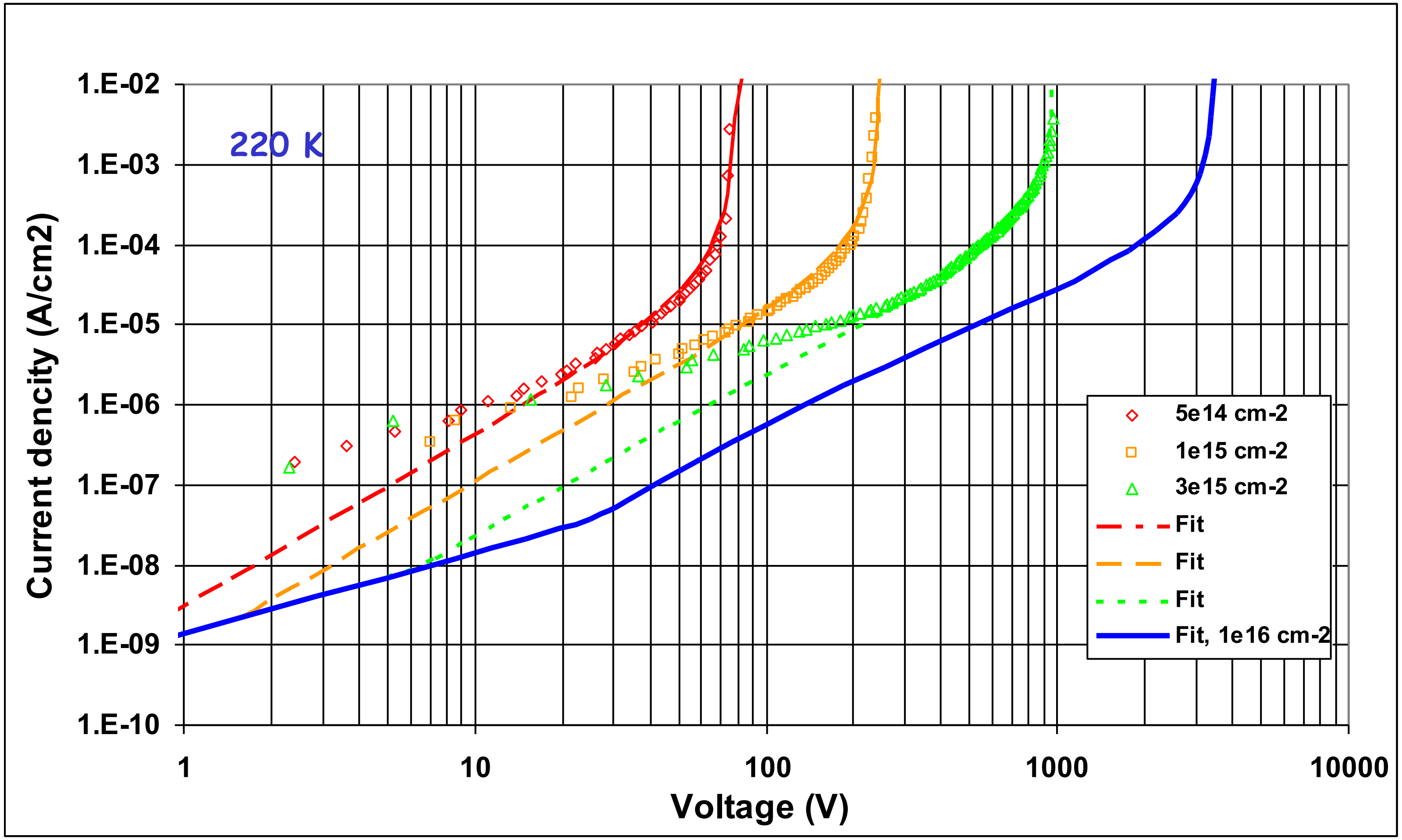
2. CID strp detectors have been beam-tested to be much more rad-hard than the standard ones up to $5 \times 10^{15}\ n_{eq}/cm^2$

3. Tests (ps-laser, beam) are underway for the application of CID detectors as the beam-loss-monitor for the LHC Upgrate

I-V characteristics of CID



I-V characteristics of CID



Main advantages CID over standard PN detectors

1. **The detectors are always fully depleted**

2. **The electric field profile does not change with fluence**

3. **Much lower bias voltage is needed**

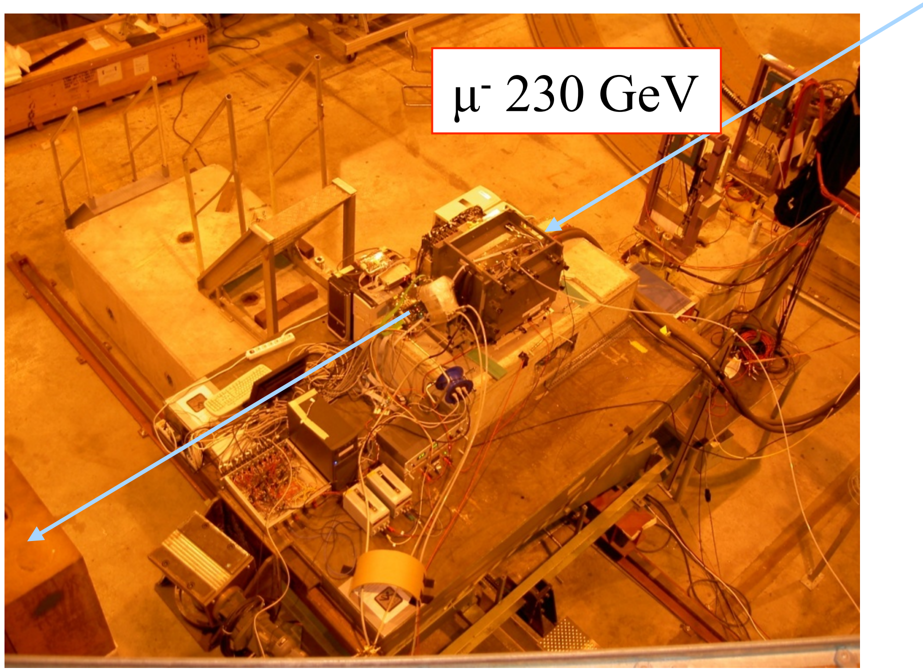
4. **The higher the radiation fluence, the lower the operation current at given bias and temperature**

5. **The operation bias range increases with fluence**

6. **No breakdown problem due to self-adjusted electric field by space charge limited current feedback effect**

7. **Simple detector processing technology (single-sided planar technology)**
8. **Injection can also be used to deactivate trapping centers --- CCE ↑**

Characterization of CID strip detectors –Segmented detectors



- Test beam with 225 GeV/c muon beam at CERN H2.
- MCz-Si strip detector irradiated $3\times10^{15} n_{eq}/cm^2$.
- 768 channels attached to APV25 read-out
- CID detector placed in external cold box capable to cool down to -54°C while module is operational.
- Data acquisition with modified XDAQ. Analysis with CMSSW.

- 8 reference planes.
- Resolution ~4μm.
- About 25000 events in 20min.