Current Injected Detectors (CID) for very harsh radiation environment

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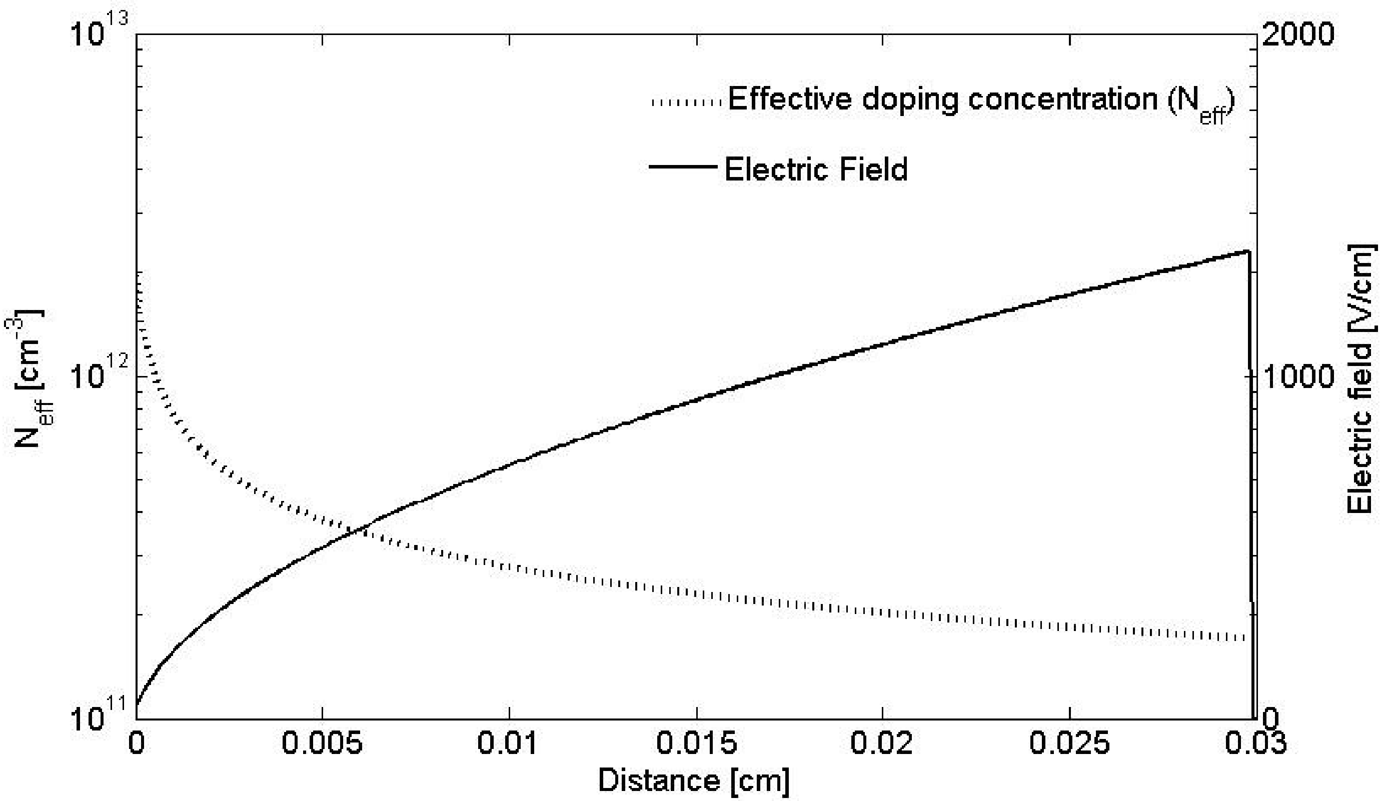
http://www.hip.fi/research/cms/tracker/RD39/php/home.php

- Short introduction on operation principle of Charge Injected Detector (CID)
- CID performance with test beams
- Future directions and applications

Charge Injected Detector (CID) –Operational Principle

The electric field is controlled by charge injection, i.e. charge is trapped but not detrapped at "low" temperature

$$\tau_{trapping} = \frac{1}{\sigma_{e,h} v_{th} N_t} \qquad \tau_{detrapping} = \frac{1}{\sigma_{e,h} v_{th} e^{\frac{-E_t}{kT}}}$$

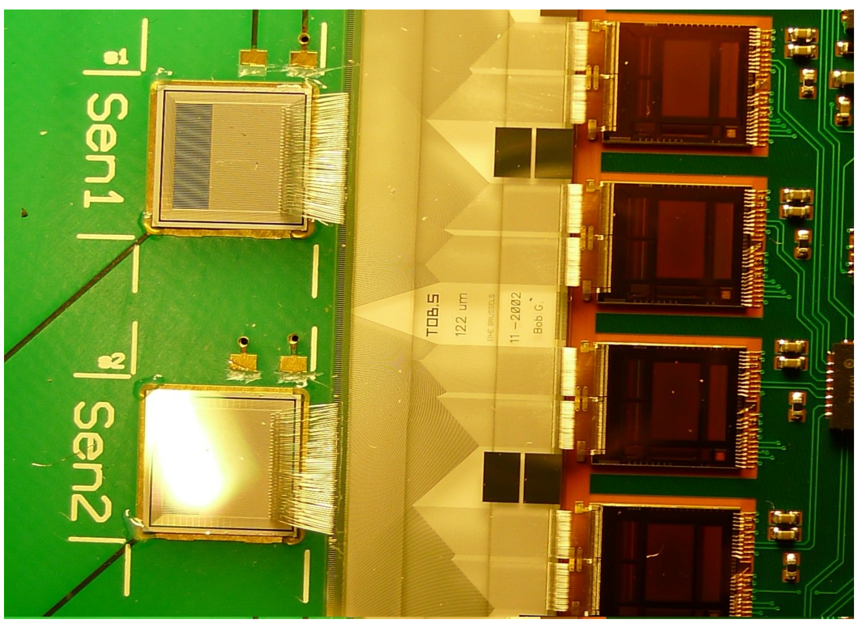


Electric field is <u>extended through entire bulk</u> regardless of irradiation fluence.

Electric field is proportional to square of distance E(x)~√x

Detector is "fully depleted" at <u>any bias or irradiation fluence</u>

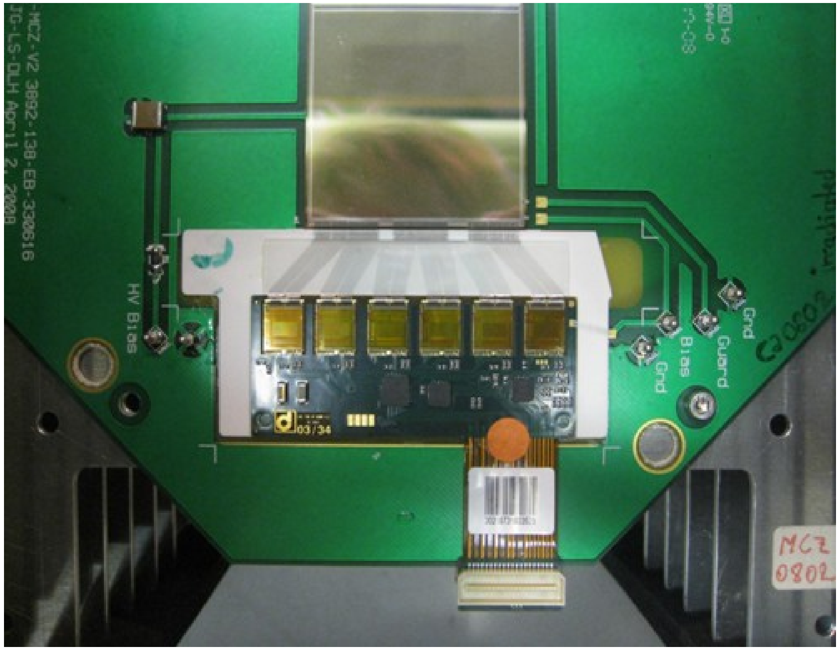
Test Beam set up

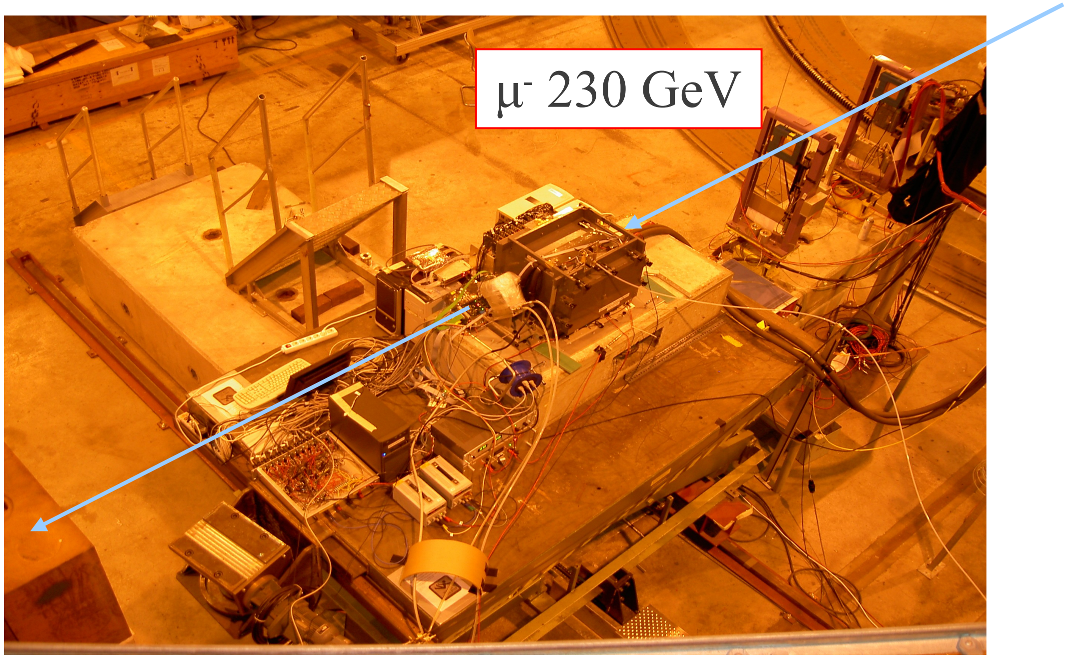


- CMS readout and DAQ
- Operated at CERN H2 area and FNAL
- Nominal resolution 4μm, 10 reference planes, effective area 4×4 cm^2 .
- Detector module can be cooled ≈-53^{0}C by Peltier elements
- Test beam setup gradually developed since past ≈10yrs

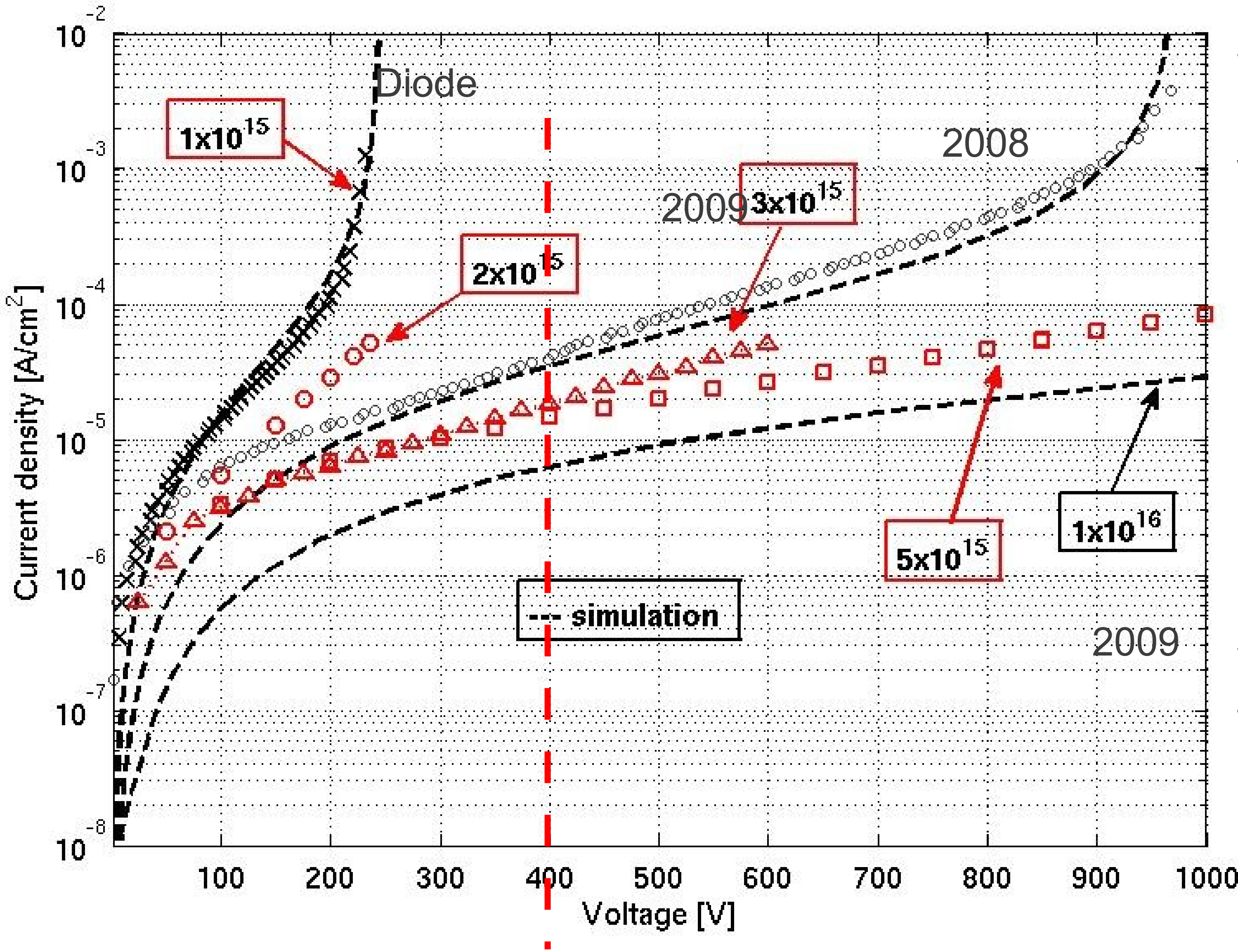
Test Beam experiment on CID detectors 2008-2011

- Sensors investigated
  - $2\times10^{15}\ n_{eq}/cm^2\ n^+/p^-/p^+$ MCz-Si
  - $5\times10^{15}\ n_{eq}/cm^2\ p^+/n^-/n^+$ MCz-Si (in 2008 $3\times10^{15}\ n_{eq}/cm^2\ p^+/n^-/n^+$ MCz-Si)





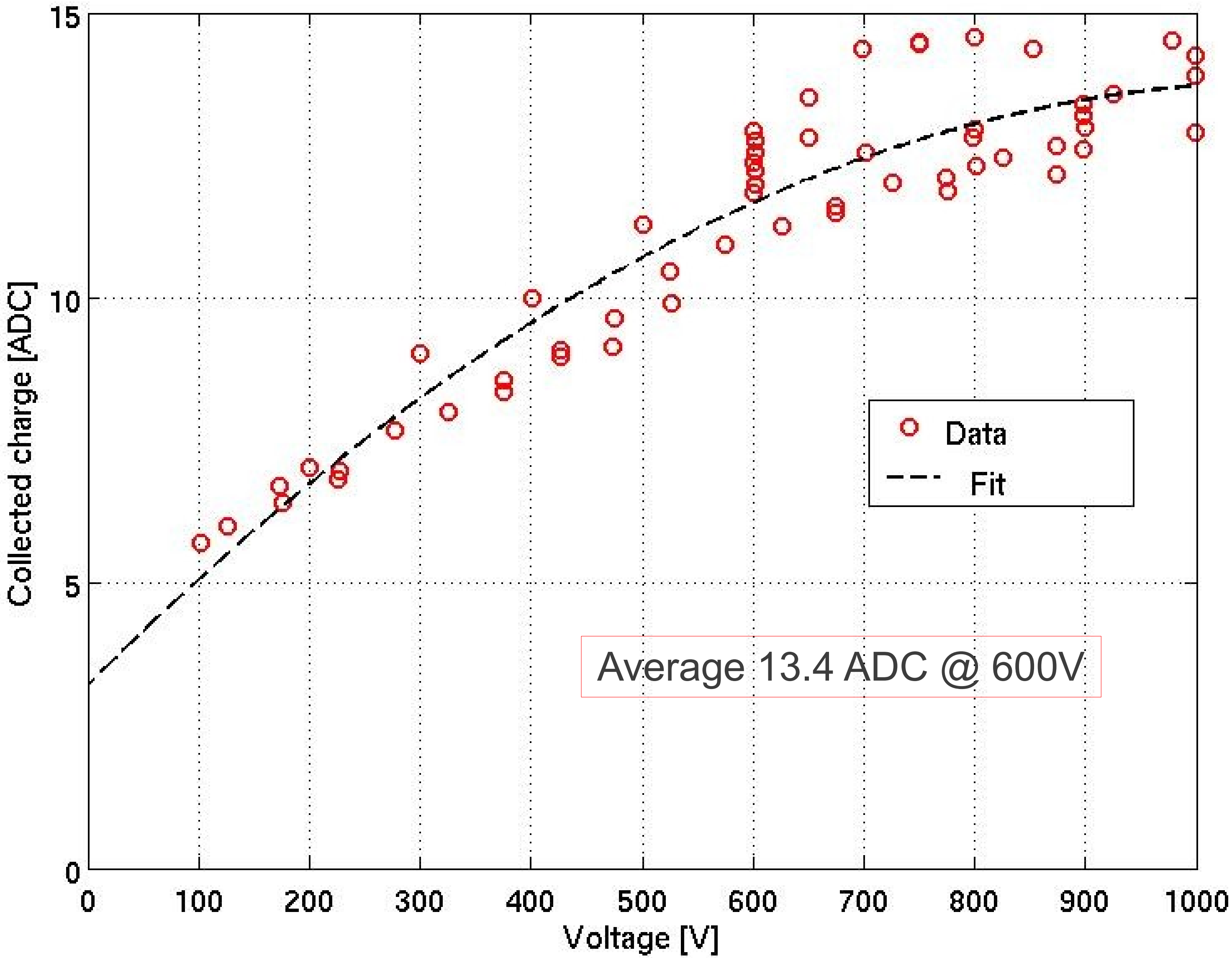
IV characteristics



When V_{frw} is increased, at some point all deep levels will be filled
>sharp current increase

With given V_{frw} e.g. 400V the *current decreases with respect of irradiation*

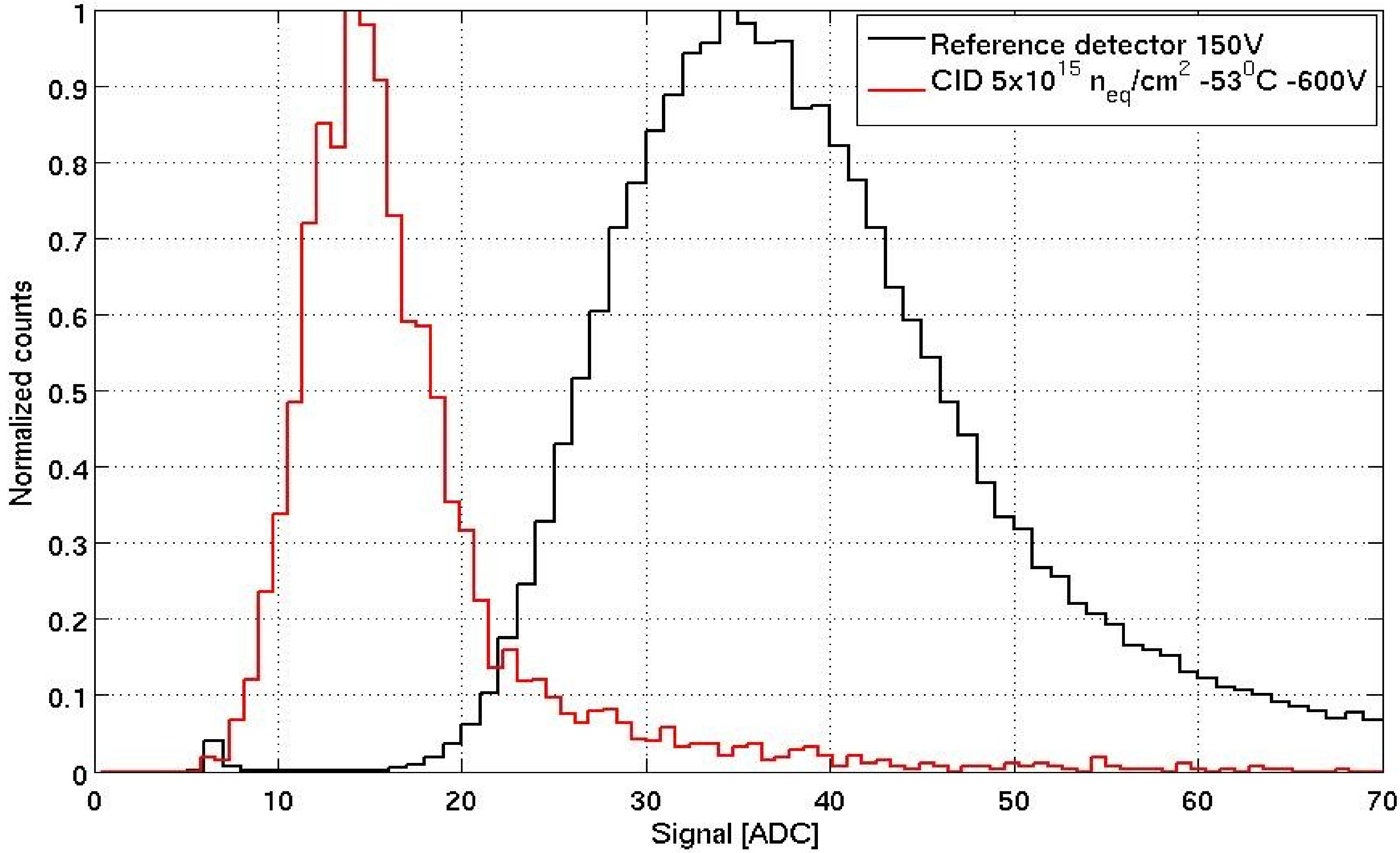
5×10^{15} n_{eq}/cm^2 results -Collected charge vs V CID mode



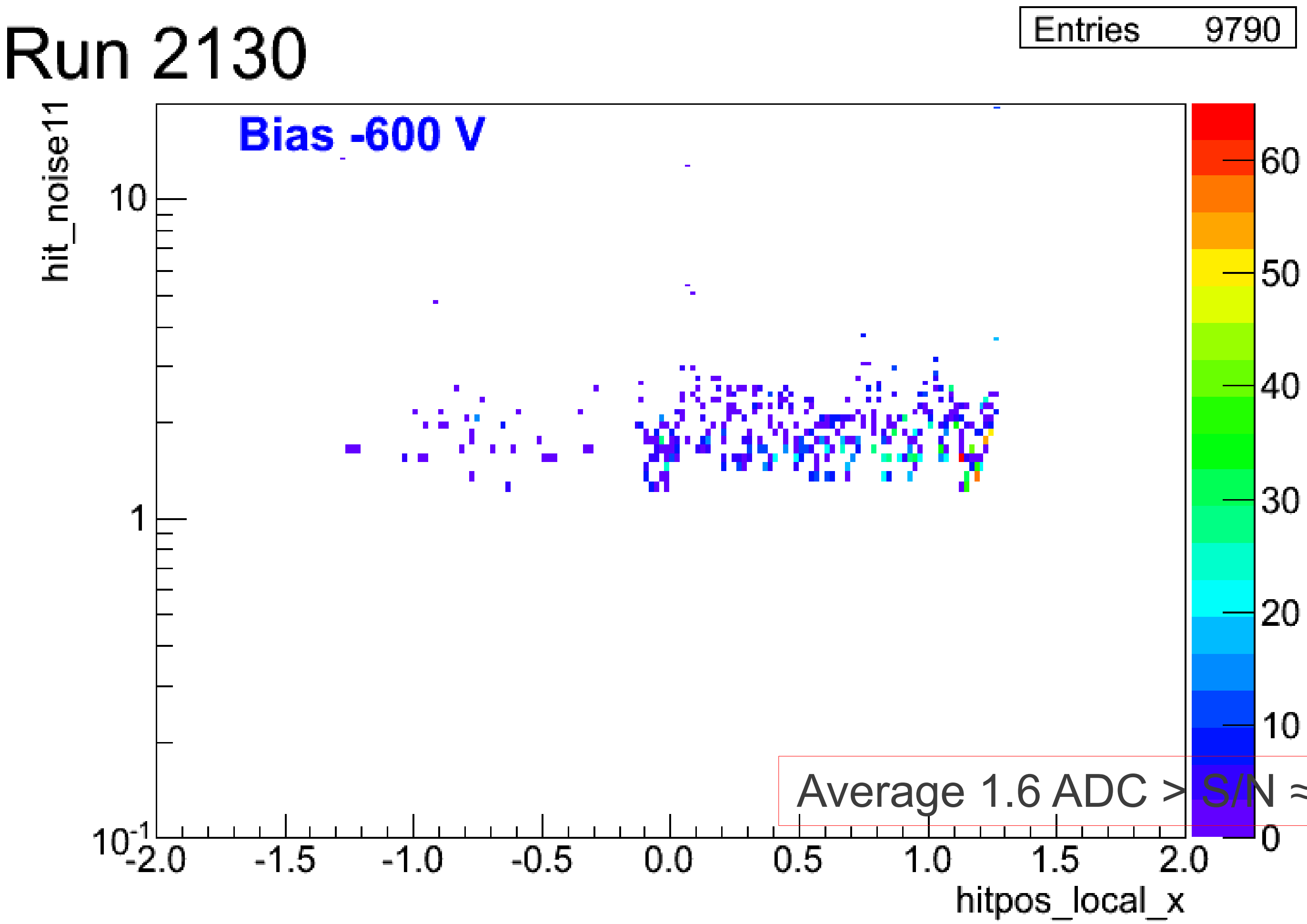
Full charge ≈ 40 ADC

1 ADC ≈ 600e$^-$

$5\times10^{15}\ n_{eq}/cm^2$ results -Collected charge vs non-irrad



$5\times10^{15}\ n_{eq}/cm^2$ results -Noise



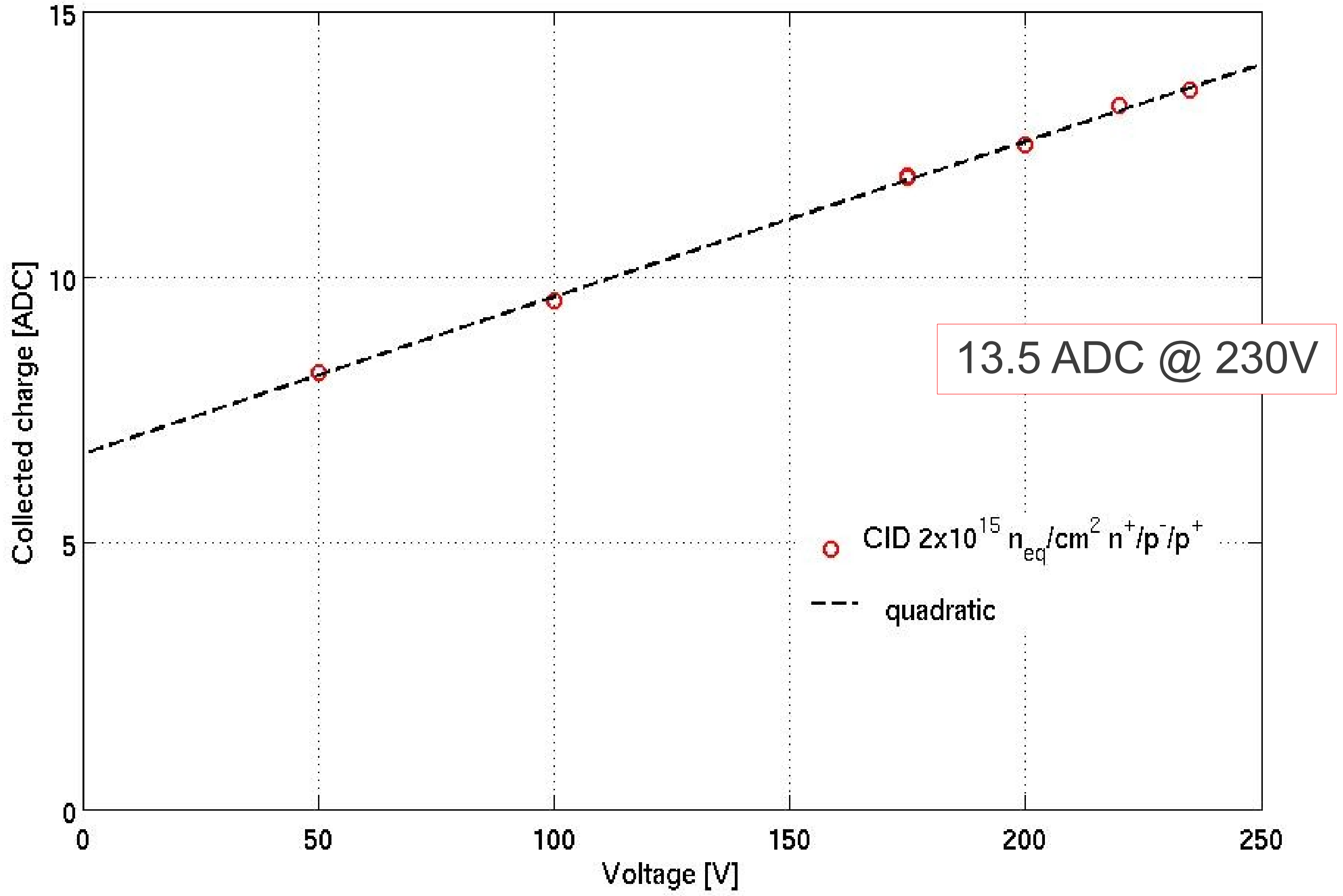
Average 1.6 ADC > S/N ≈ 8

With our setup we record 1.4-1.6 ADC noise from non-irradiated strip sensors with 10cm strip length.

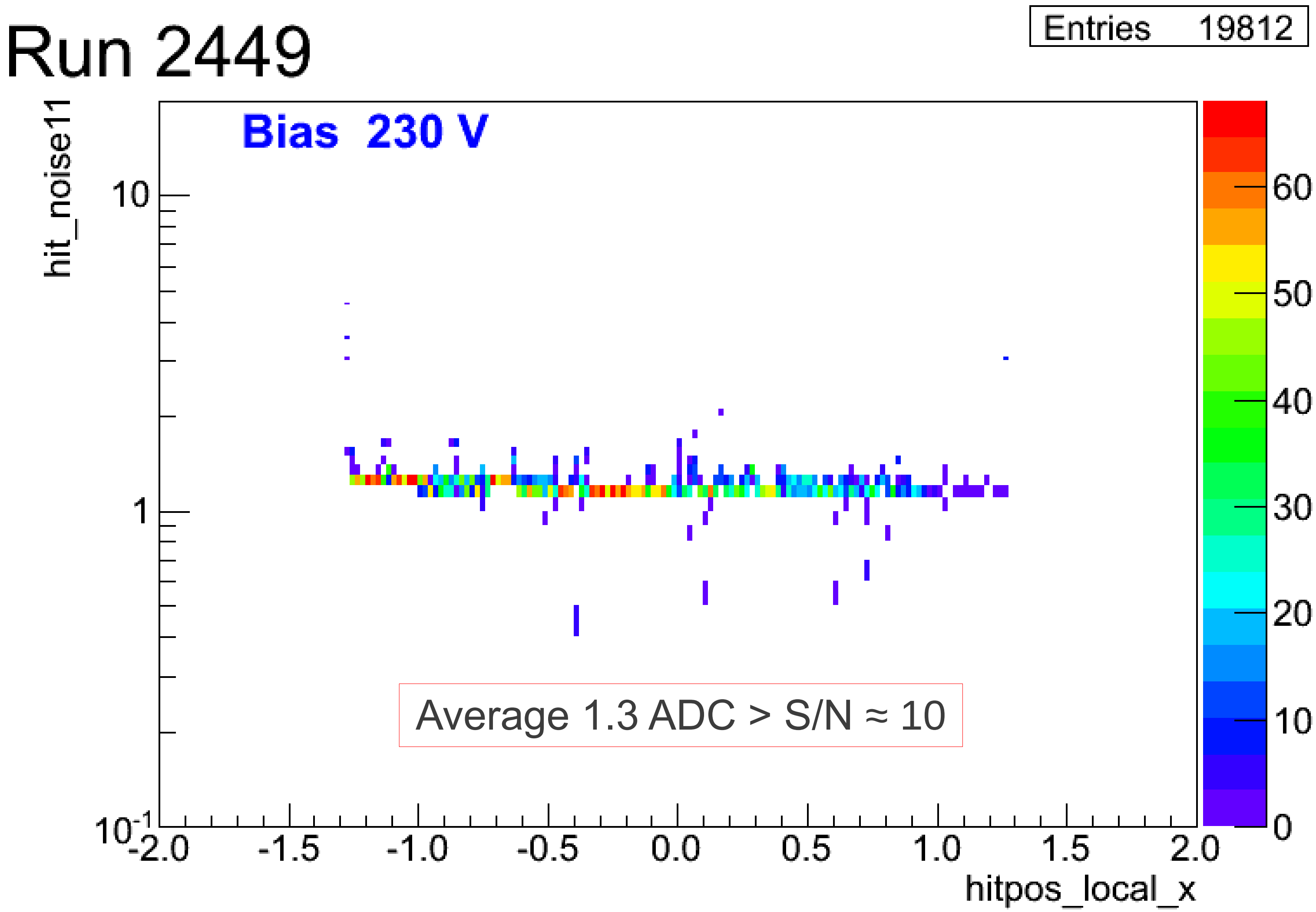
1cm strip length minisensor produces ≈0.6-0.8 ADC noise

1 ADC ≈ $600e^-$

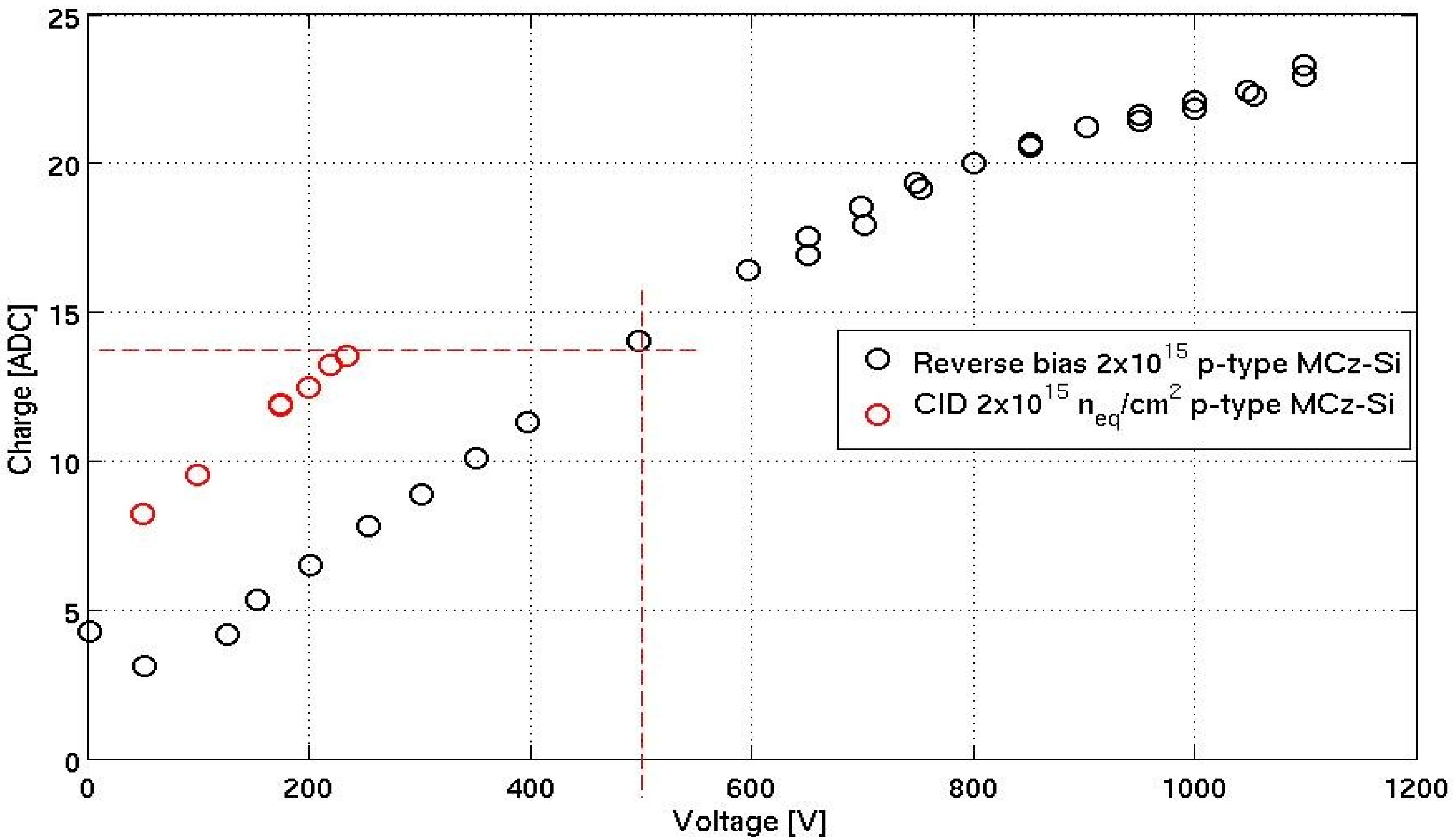
2×10^{15} n_{eq}/cm^2 results -Collected Charge CID mode



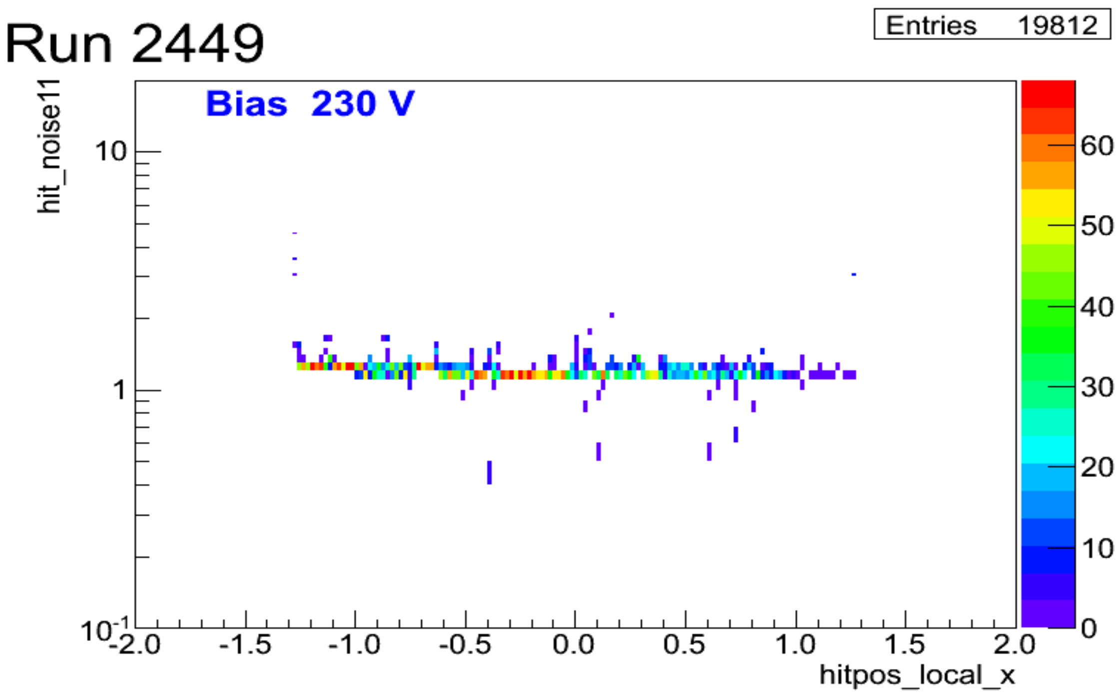
$2\times10^{15}\ n_{eq}/cm^2$ results -Noise

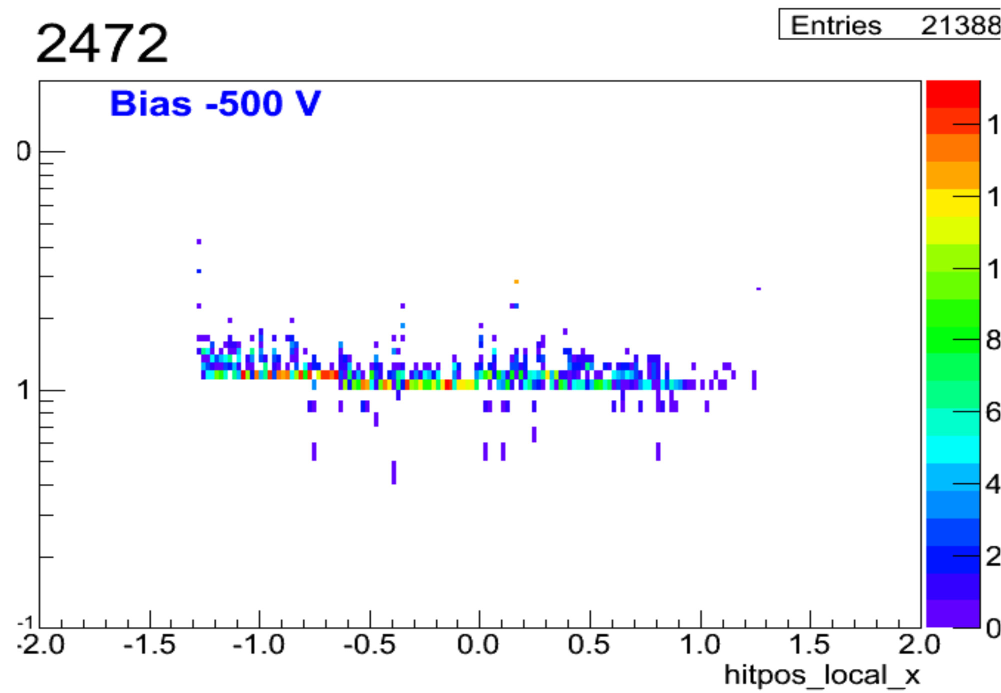


Comparison of CID vs reverse bias -Collected charge



Comparison of CID vs reverse bias -Noise





CID

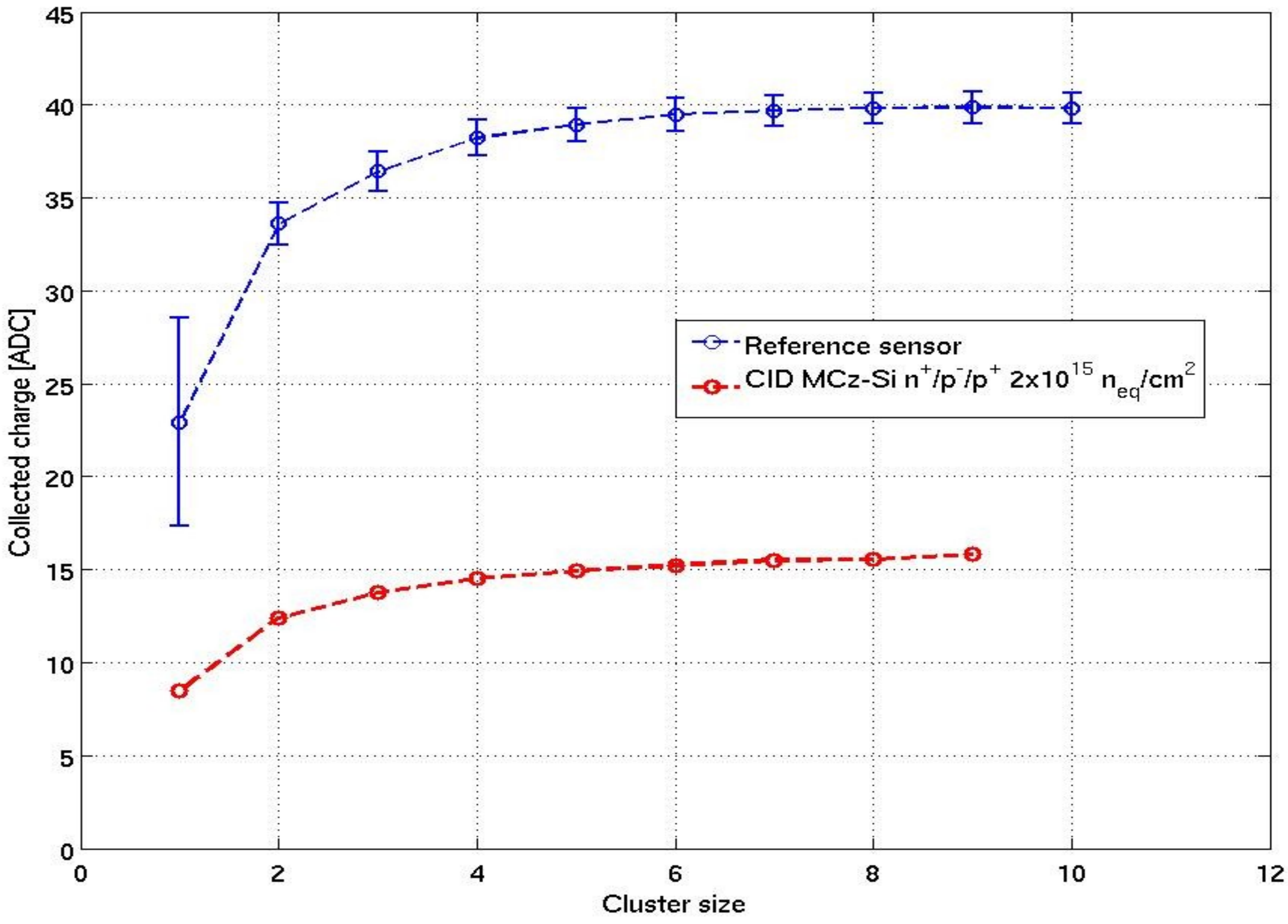
Reverse bias

Average 1.3 ADC > S/N ≈ 10

Average 1.1 ADC > S/N ≈ 12

Same detector module (CMS APV25) operated as CID and normal reverse bias. Both measurements resulted in same collected charge. This is still feasible at 2×10^{15} n_{eq}/cm^2 fluence, but higher because trapping kills reverse biased detector.

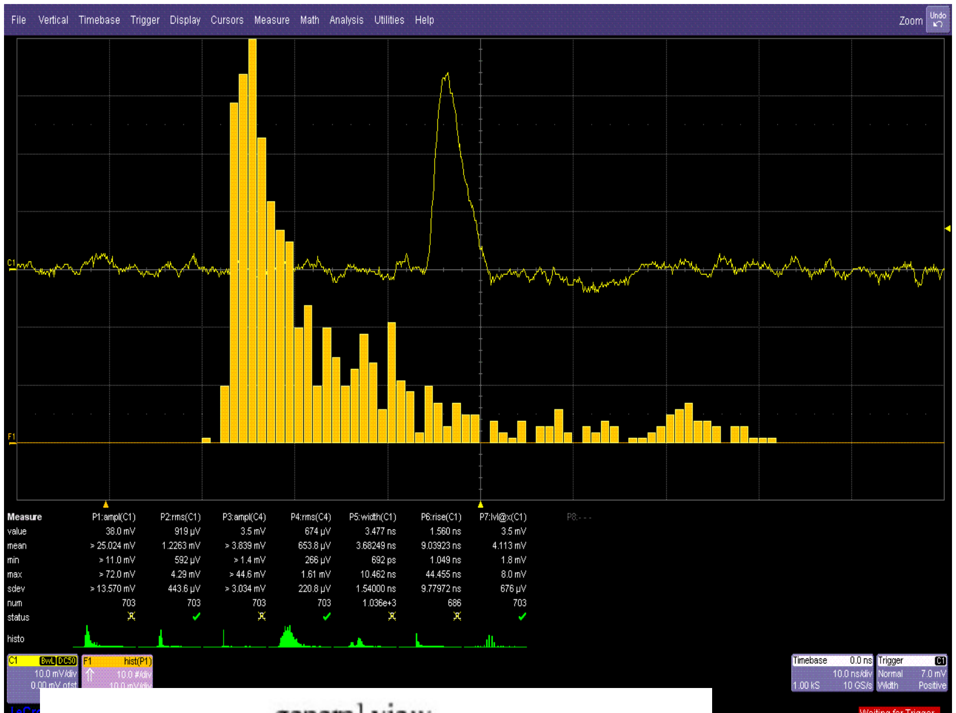
Cluster size

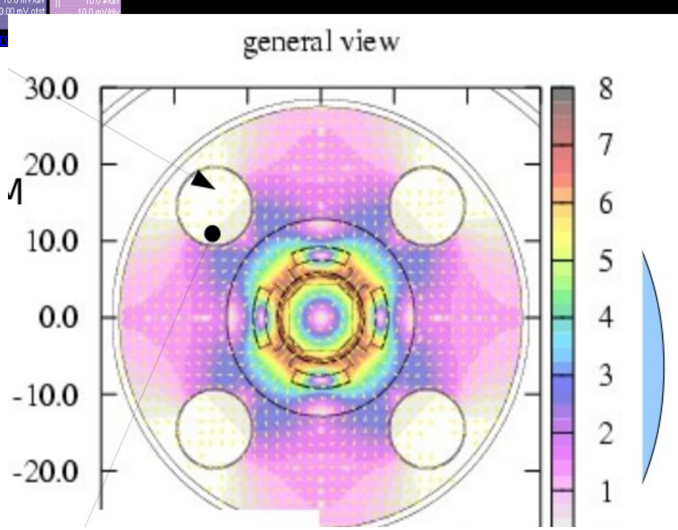


HPK reference sensor
average of 8 planes
bias 150V

CID bias 230V
$2\times10^{15}\ n_{eq}/cm^2$

Possible applications -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

Summary

- CID detectors are operational at -50^0C. That's feasible with CO_2 cooling
- n and p-type full size CID detectors were beam tested in 2009.
- 2×10^{15} n_{eq}/cm^2 and 5×10^{15} n_{eq}/cm^2 irradiated CID detectors show ≈ 35% charge collection efficiency.
- S/N were 8 and 10.
- Measurements were done at -50^0C.
- One needs 2× reverse bias in n on p sensor to gain same CCE.
- Average noise (1.6ADC) of a 5×10^{15} n_{eq}/cm^2 irradiated CID is about $960e^-$ at -50^0C/600V. Injected forward current is about 20µA for 4cm × 4cm sensor at this operating point.

Publications on CID detectors

- Current injected detectors (CID) - a new approach for detector operation in very high radiation environment, Eremin, V.; Ilyashenko, I.; Verbitskaya, E.; Egorov, N.; Golubkov, S.; Konkov, K.; Sidorov, A.; Li, Z.; Smith, K.M.; Niinikoski, T.; Härkönen, J.; Nuclear Science Symposium Conference Record, 2004 IEEE Volume 3, October 2004, Pages 2003 - 2006.

- V. Eremin, J. Härkönen, P. Luukka, Z. Li, E. Verbitskaya, S. Väyrynen and I. Kassamakov, The operation and performance of Current Injected Detector (CID), Nuclear Instruments and Methods in Physics Research Section A 581 (2007) 356-360.

- V. Eremin, J. Härkönen, Z. Li and E. Verbitskaya, Current injected detectors at super-LHC program, Nuclear Instruments and Methods in Physics Research Section A 583 (2007) 91-98.

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- E. Tuominen et al., Recent progress in CERN RD39: radiation hard cryogenic silicon detectors for applications in LHC experiments and their future upgrades, IEEE Transactions on Nuclear Science 56 (2009) 2119-2123.

- J. Härkönen, V. Eremin, P. Luukka, S. Czellar, T. Mäenpää, A. Dierlamm, M. Frey, Z. Li, M.J. Kortelainen, T. Lampén, H. Moilanen, E. Tuovinen, E. Verbitskaya, E. Tuominen, Test beam results of a heavily irradiated Current Injected Detector (CID), Nuclear Instruments and Methods in Physics Research A612 (2010) 488-492.