A Charge Collection Study with Dedicated RD50 Charge Multiplication Sensors

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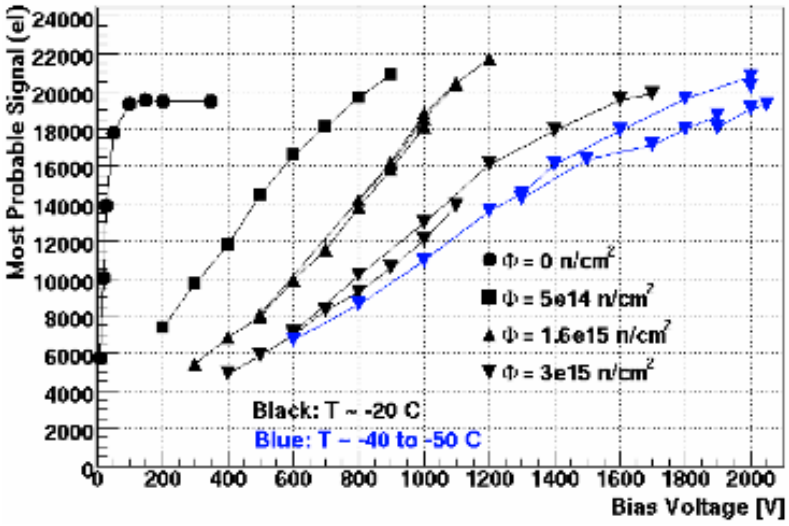
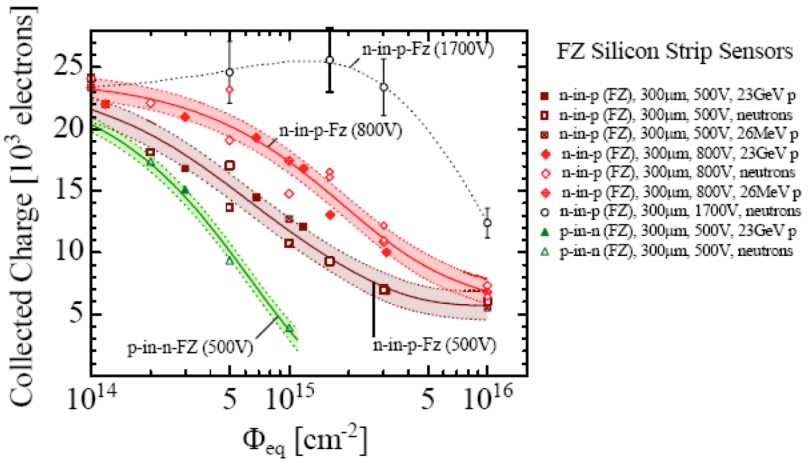
Charge Multiplication

- At high fluences and bias voltages, charge multiplication of the signal in the detector has been observed
- Signal is multiplied through the process of impact ionization
- Impact ionization in silicon begins when the electric field reaches 10-15 V/μm
- Charge multiplication can be beneficial for sensors, leading to higher signal
- Same process that is responsible for charge multiplication also leads to increased noise and lower breakdown voltage



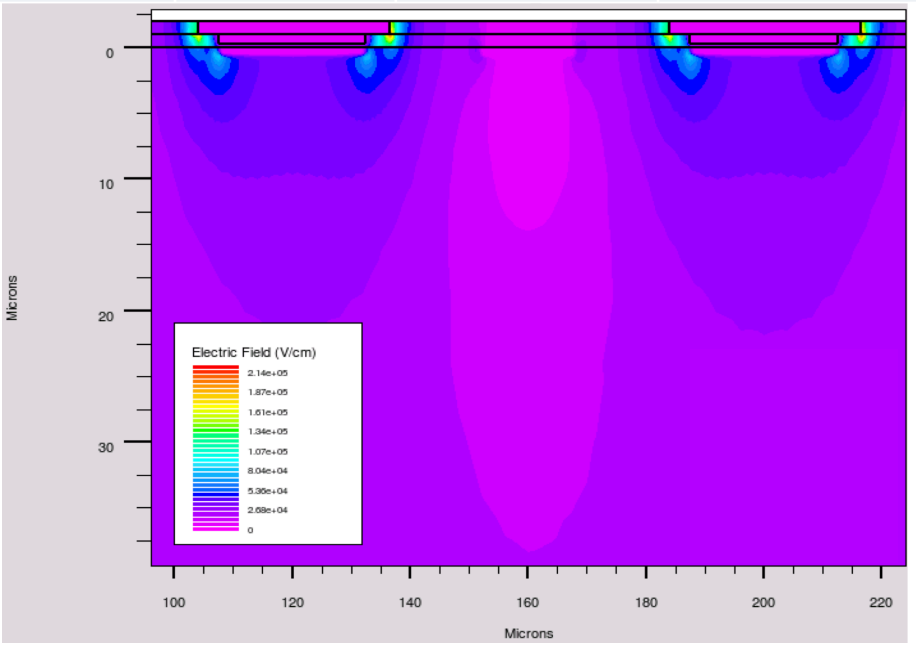
[I. Mandic, 12th RD50 workshop, 2008]



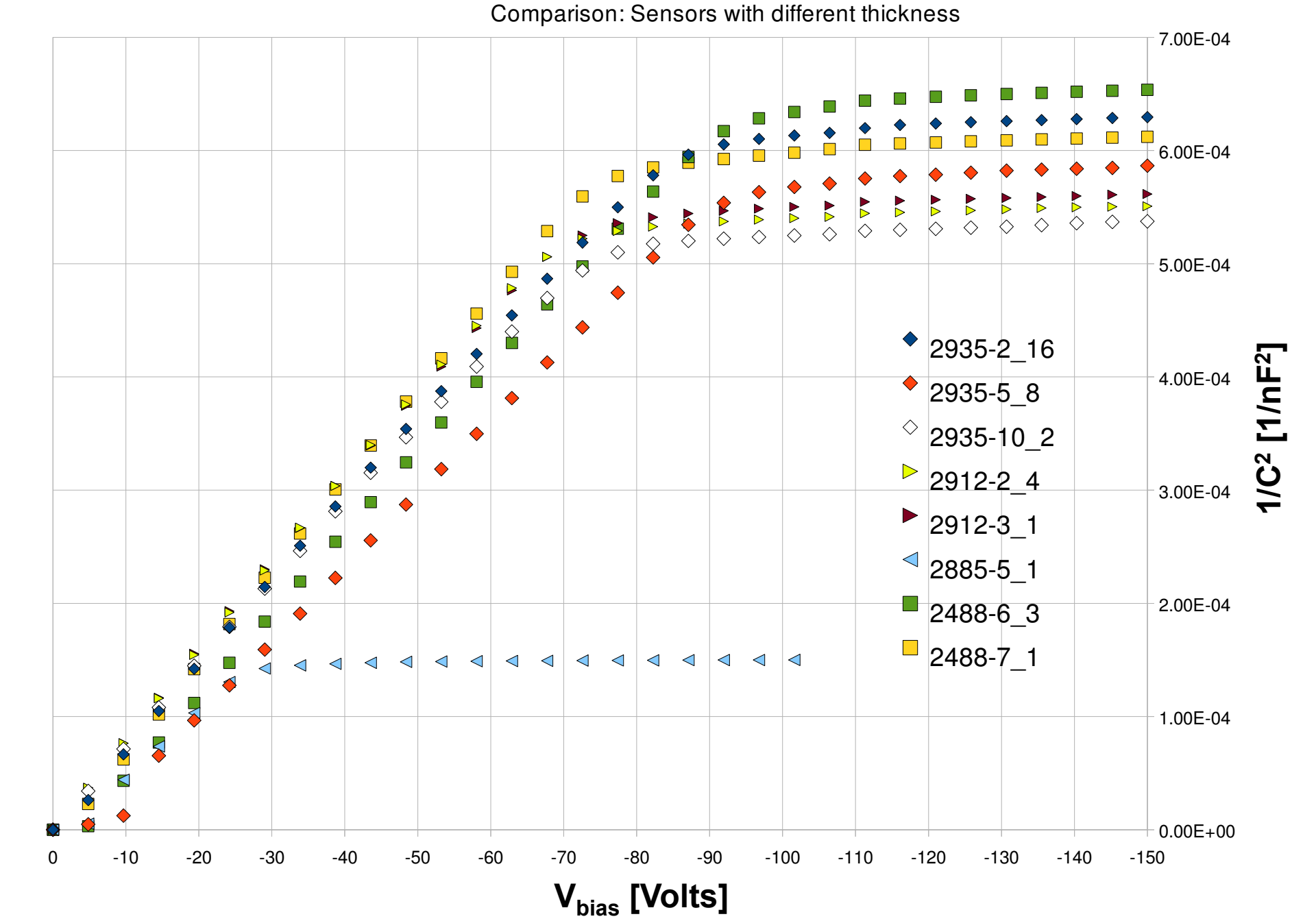
Charge Multiplication Detectors

- 1 cm x 1 cm, n-in-p FZ strip detectors developed by MICRON
- Detectors aim to enhance the electric field near the readout strips
- Sensors of various strip width and pitch were produced, as well as sensors with floating and biased intermediate strips between readout strips
- 5 type of wafers were produced: standard, double diff. time, double implant energy, thick and thin
- IV, CV, C interstrip, and CCE measurements have been carried out

Wafer	Thickness (µm)	Type	Resisivity (kΩ cm)
2935-2 2935-5 2935-8	305±15	Standard	13
2935-10	305±15	Standard w/ double diffusion time	13
2912-2 2912-3	300±15	Standard w/ double implant energy	10-13
2488-6 2488-7	675±30	Standard thick	8
2885-5	150±10	Standard thin	10

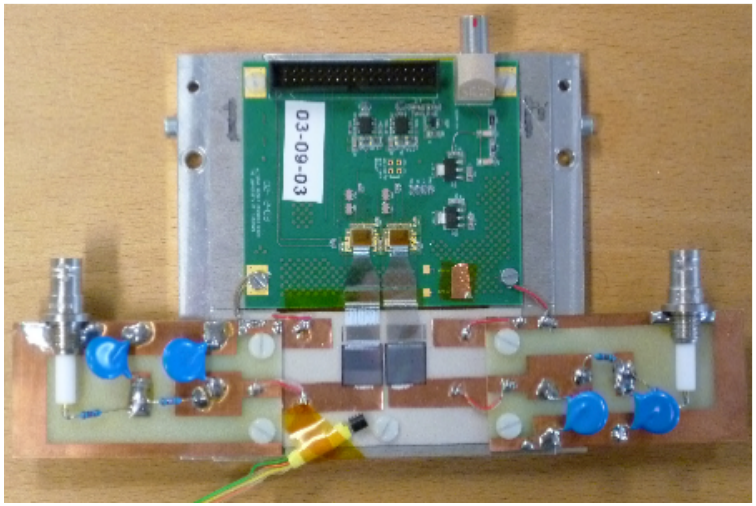


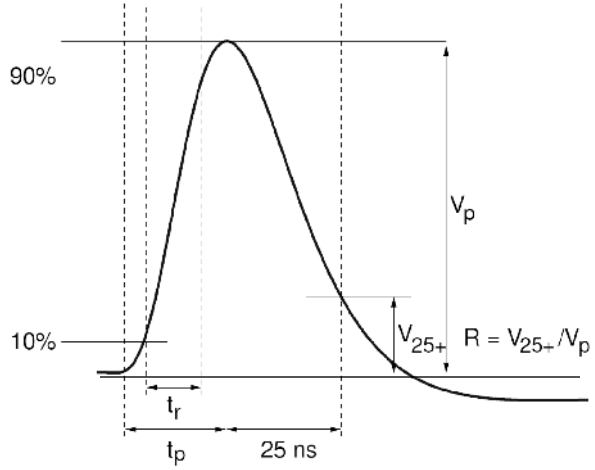
[L. Atlan, 20th RD50 workshop, 2012]


Comparison: Sensors with different thickness
7.00E-04
6.00E-04
5.00E-04
4.00E-04
3.00E-04
2.00E-04
1.00E-04
0.00E+00
1/C² [1/nF²]
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
V bias [Volts]
2935-2_16
2935-5_8
2935-10_2
2912-2_4
2912-3_1
2885-5_1
2488-6_3
2488-7_1

ALIBAVA Readout System

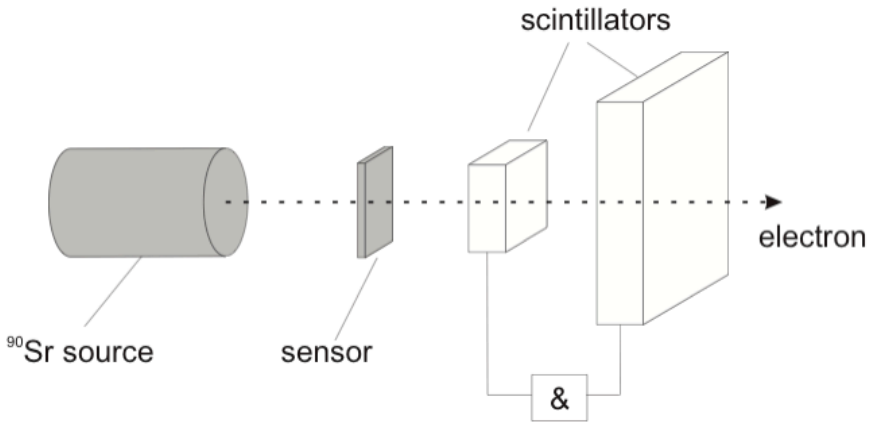
- Charge collection measurements are done through the ALIBAVA readout system
- The daughterboard carries 2 analog front-end ASIC (Beetle) chips, which perform amplification and shaping of the signal
- The analog signal is sent to the motherboard, controlled by an FPGA, and converted into digital counts using a 10-bit ADC (Analogue to Digital Converter)
- The raw data is sent to a PC from the motherboard using a USB connection, and analyzed by custom software based off the ROOT framework

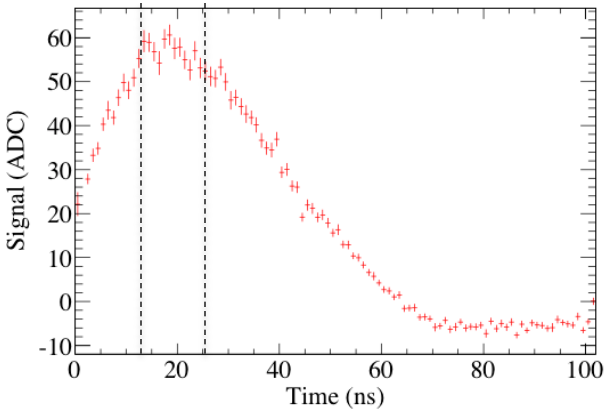


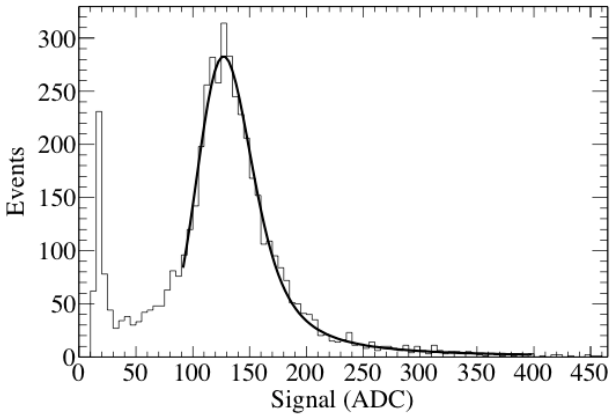


Beta Source Measurements

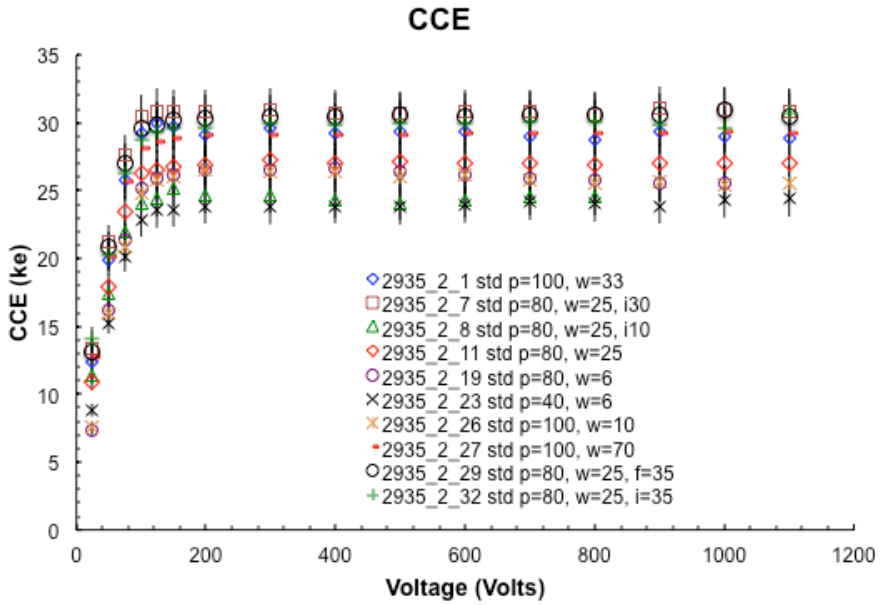
- MIPs from a ^{90}Sr source are used to perform charge collection measurements
- Time between trigger signal and edge of a 10 MHz clock is measured by the ALIBAVA TDC
- For each event, channel with largest SNR is chosen, and mean is calculated for each 1 ns time bin
- Only events in 10 ns window around max are considered
- Resulting spectrum is fitted with a convolution of a Gaussian and Landau distribution to determine MPV



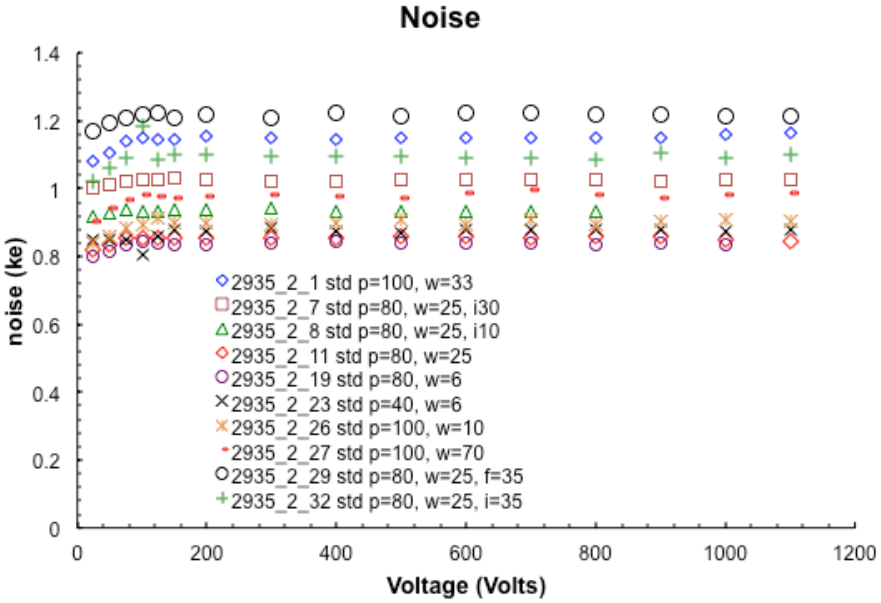


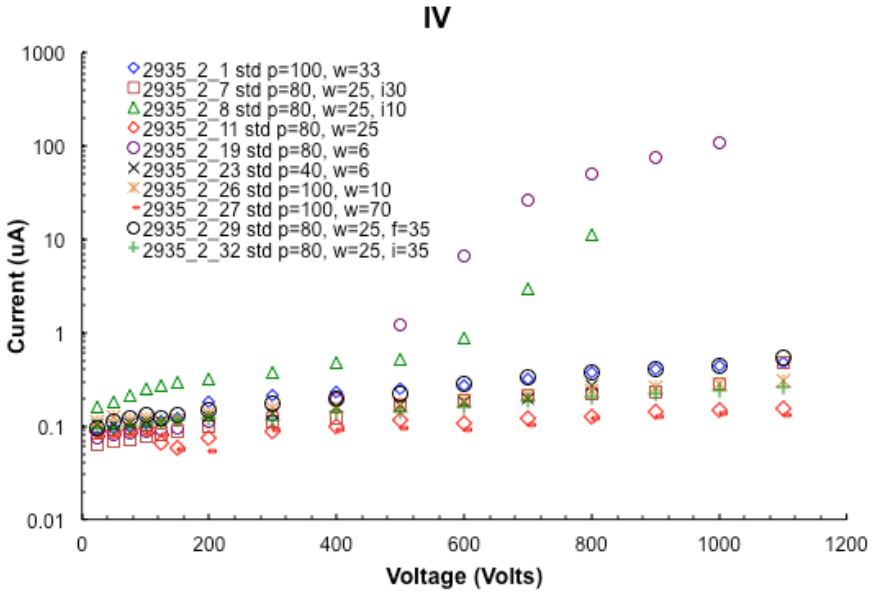


Unirradiated Results

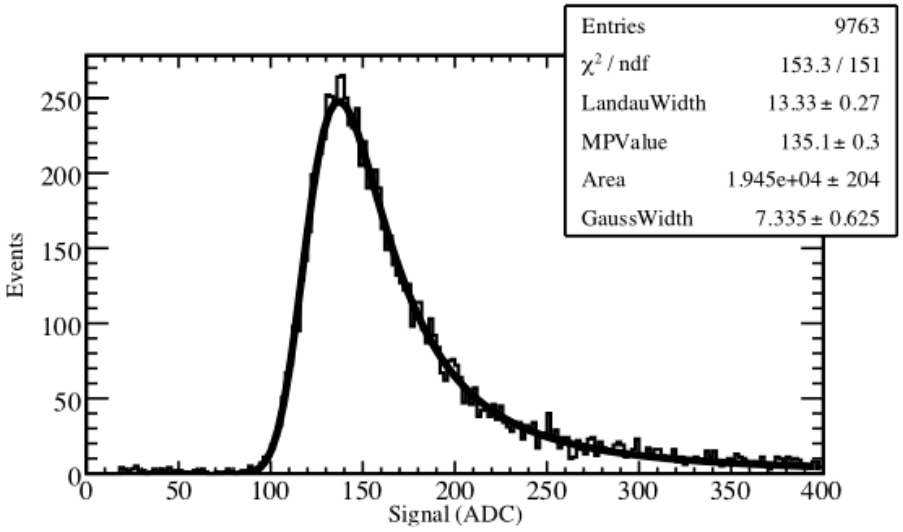


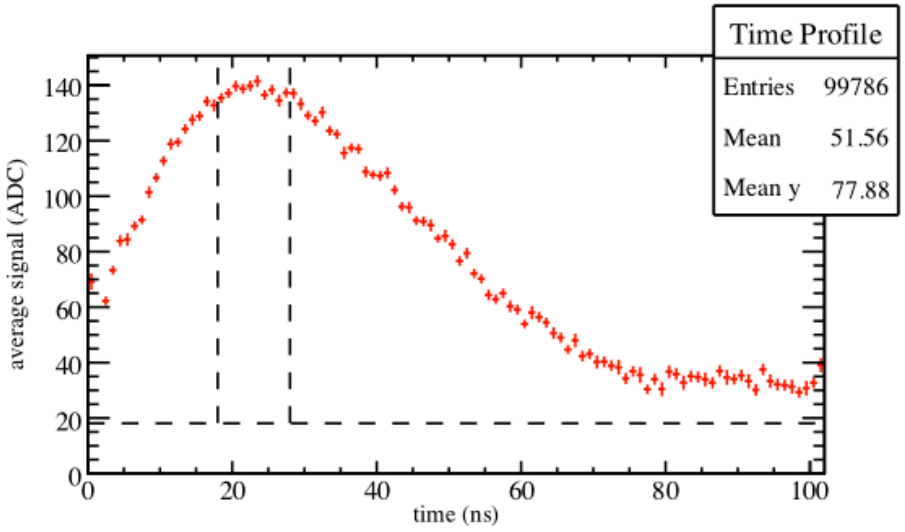
- Full depletion reached at 100-125V
- No charge multiplication observed up to 1100V on any sensor
- Large spread of collected charge for sensors from a given wafer, no clear correlation on geometry
- Most sensors show no breakdown up to 1100V

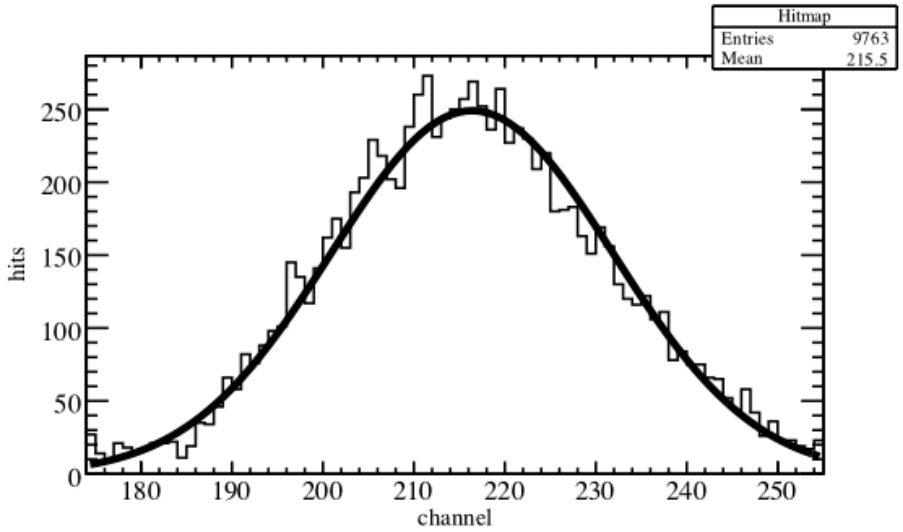


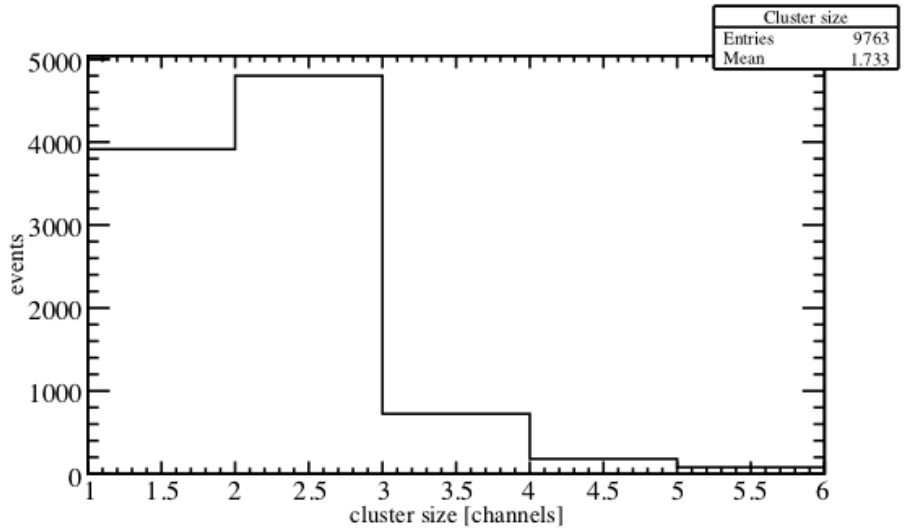


2935-2-27, 200V, CCE (ke) = 29.14 ± 1.61









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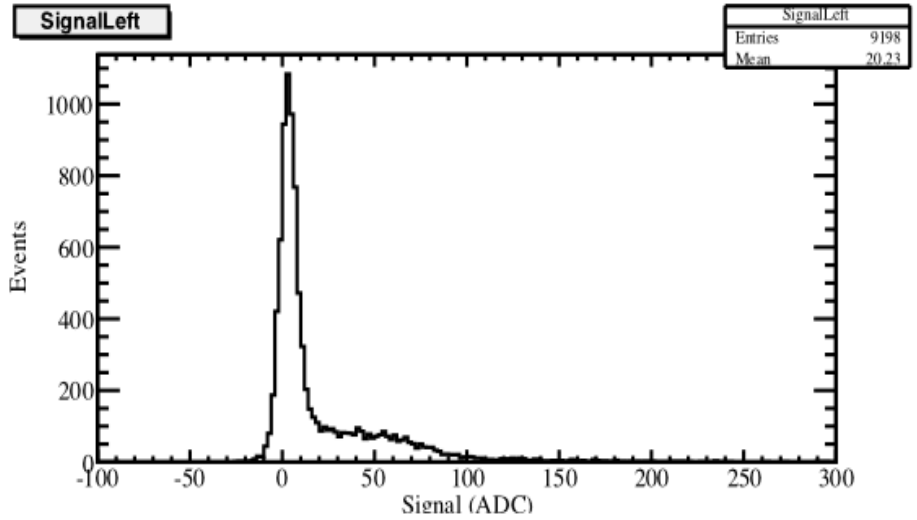
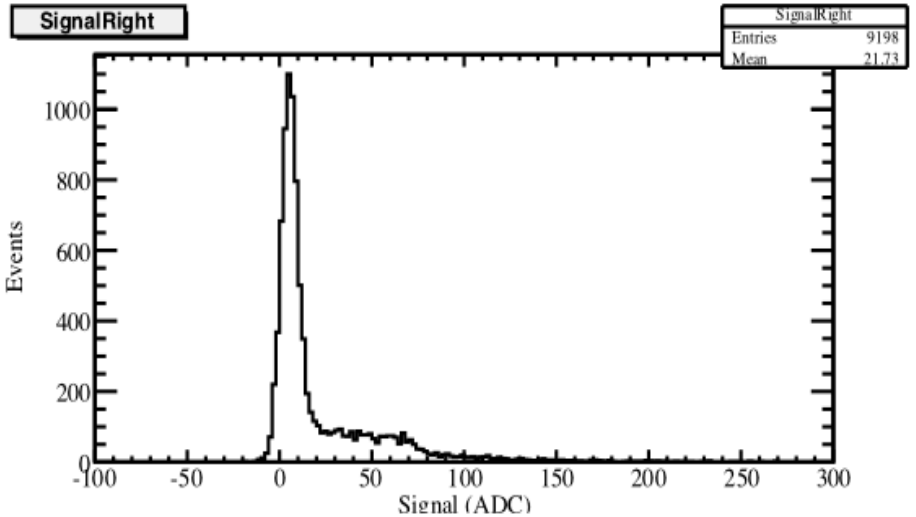
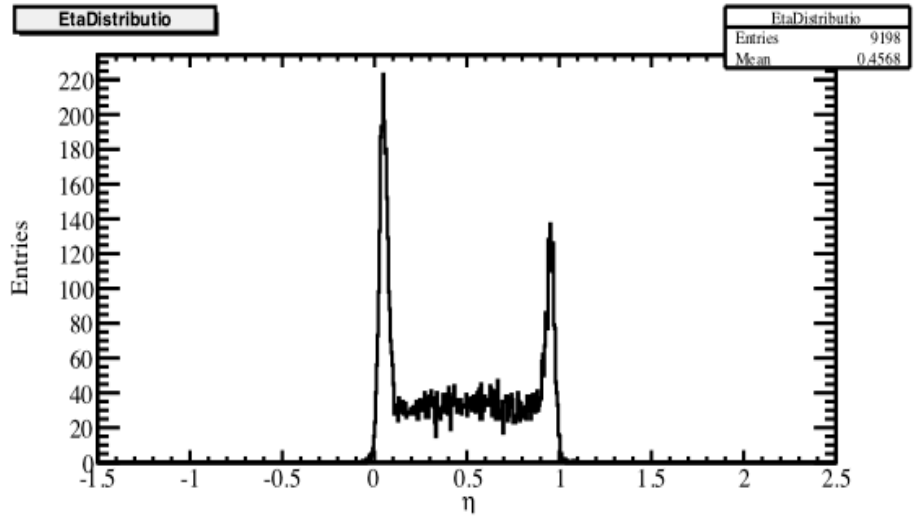
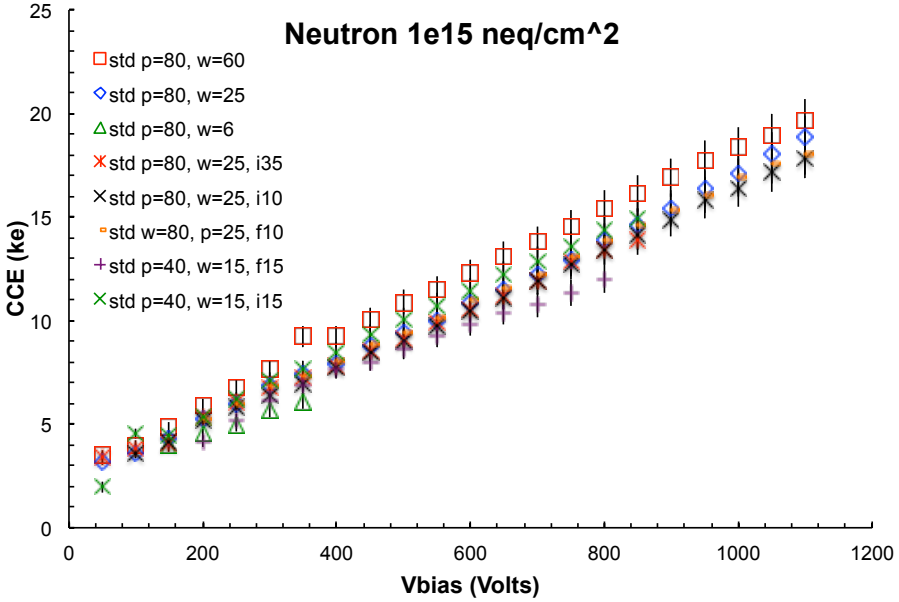


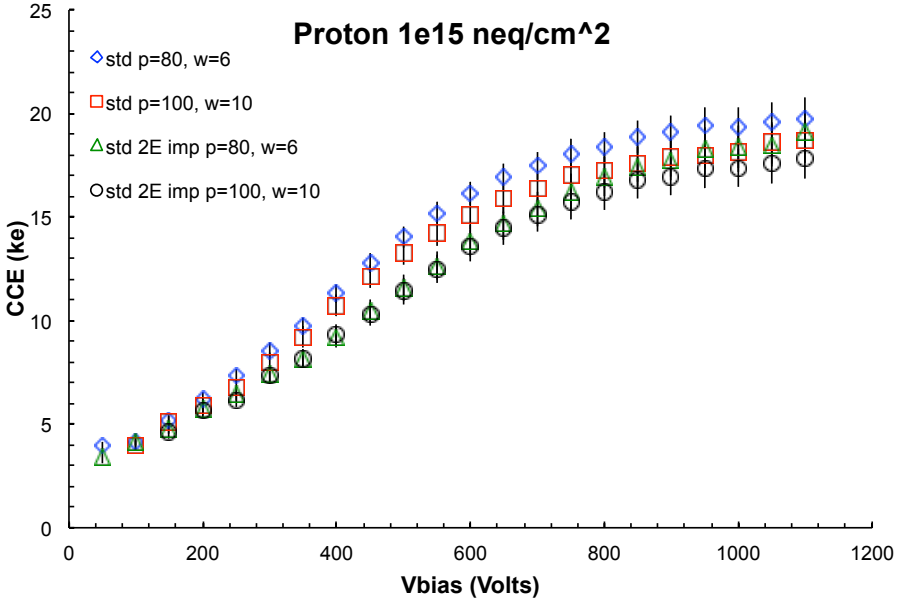


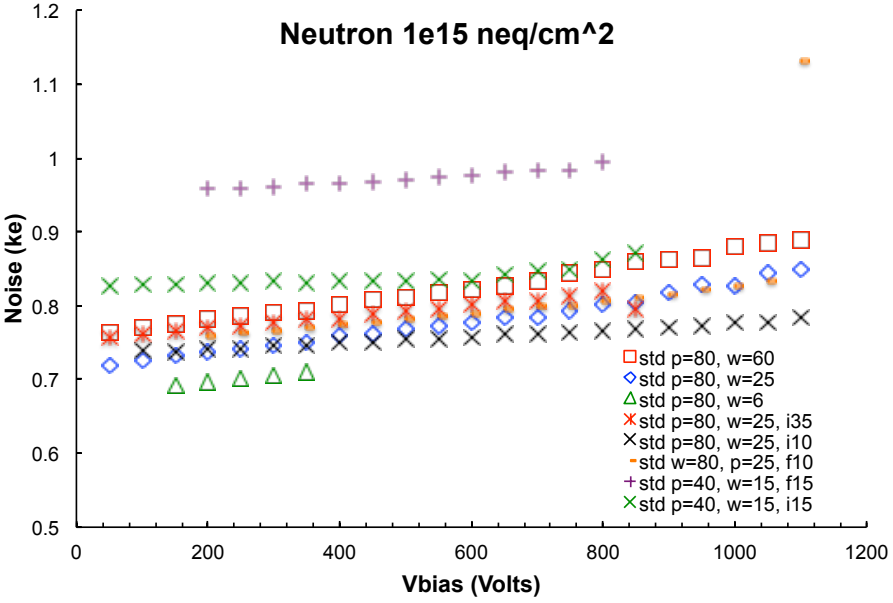


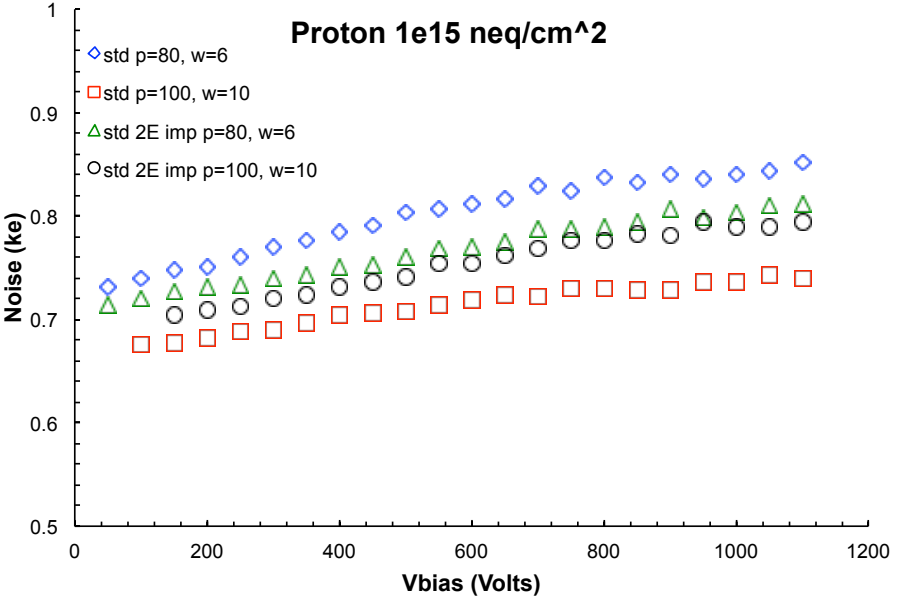
- Cluster distribution has too many 2-Hit clusters
- Sharp peaks around 0 and 1 of the η distribution with a flat area in-between
- Signal on neighbors not as expected (superposition of two separate distributions?)
- Asymmetry present in η distribution

Irradiated Detectors

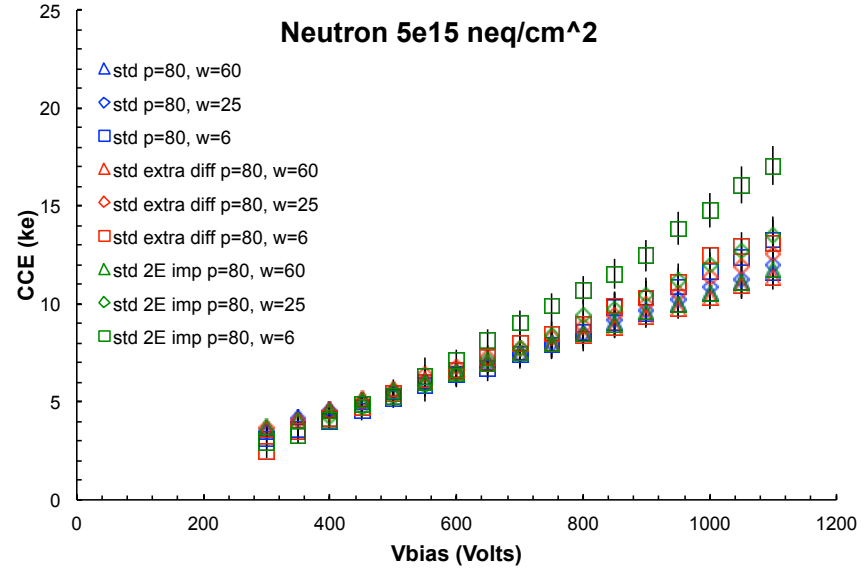


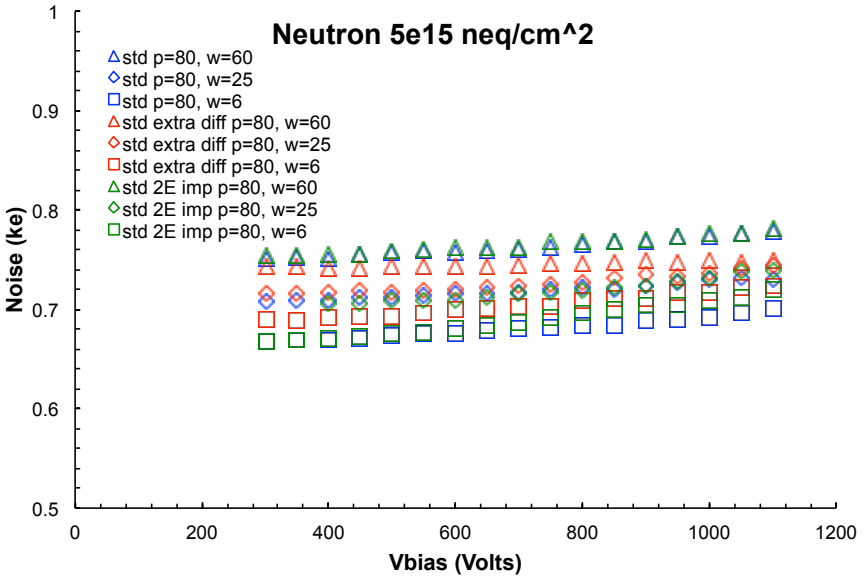


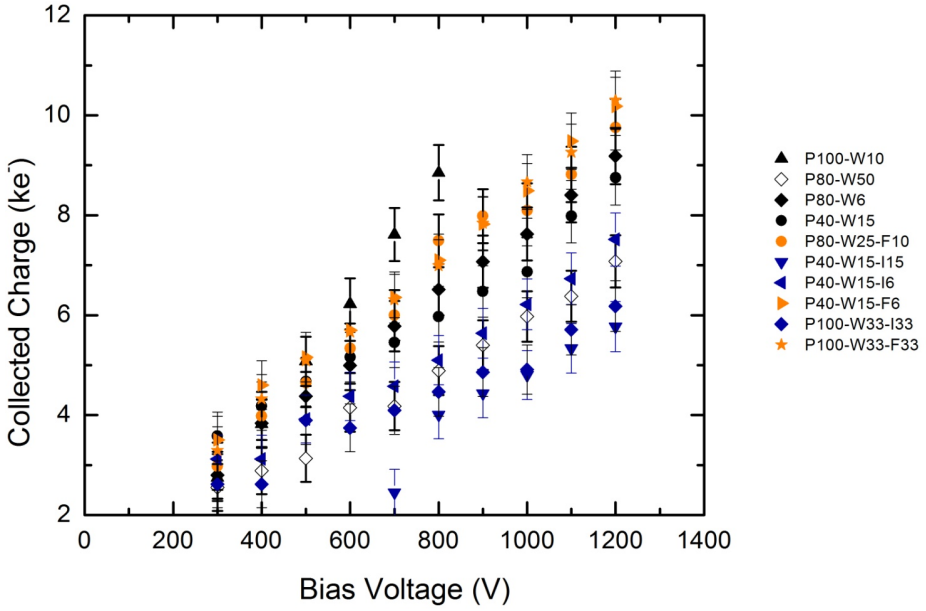




Irradiated Detectors



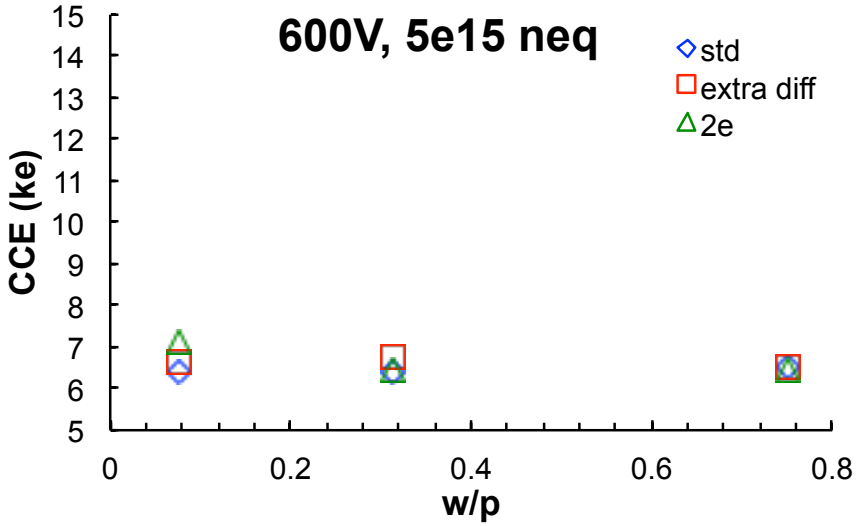


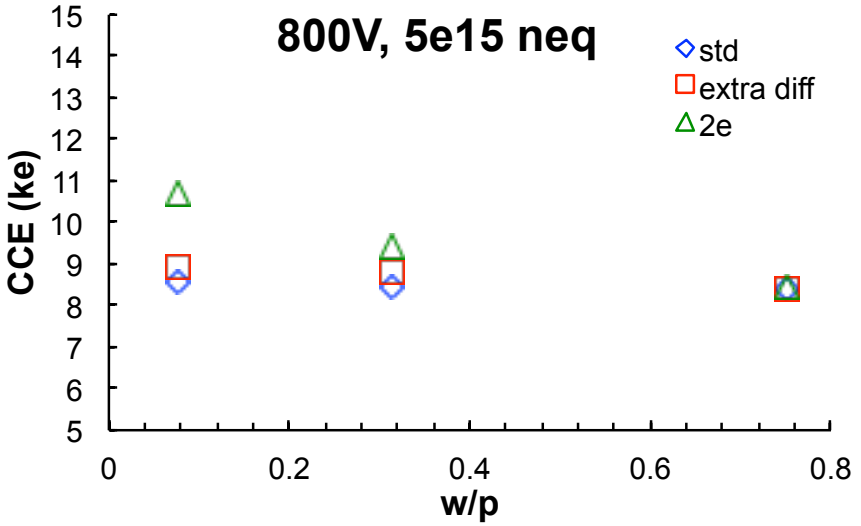


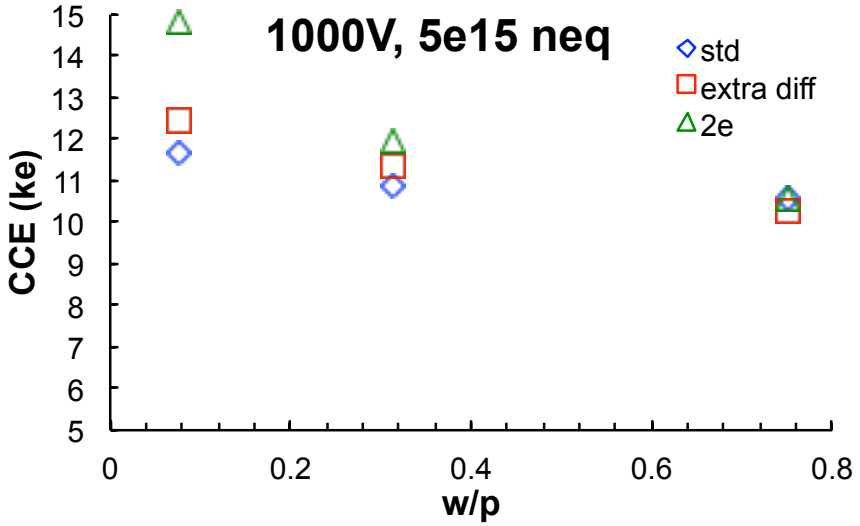
[G. Casse, 9th RESMDD, Florence 10 Oct 2012]

- One sensor (2E imp w/p=6/80) shows clear signs of CM past 600V with no significant increase in noise
- Detectors with floating intermediate strips increase charge compared to no intermediate strip detectors
- Detectors with biased intermediate strips decrease charge compared to no intermediate strip detectors

Irradiated Detectors







- CM only seen at V_{bias} > 600V
- Both Extr. Diff. and 2E imp. Show signs of CM with respect to standard wafer
- Lower w/p ratio leads to more pronounced multiplication (as expected)

Summary

• The RD50 collaboration is investigating charge multiplication sensors as a viable option for radiation hard detectors

• This study focuses on MICRON strip detectors of various geometries

• No CM observed at 1e15 n_{eq}/cm^2 for both proton and neutron irradiated samples

• At 5e15 n_{eq}/cm^2 one sensor (w/p=6/80 2E imp) shows pronounced signs of CM without a corresponding increase in the noise

• Detectors with floating intermediate strips tend to enhance charge collection while detectors with a biased intermediate strip tend to decrease charge collection

• Sensors with Double Diff. and Double Imp. Energy show enhanced charge for V_{bias}>600V at 5e15 n_{eq}/cm^2, with lower w/p leading to more charge

Acknowledgements

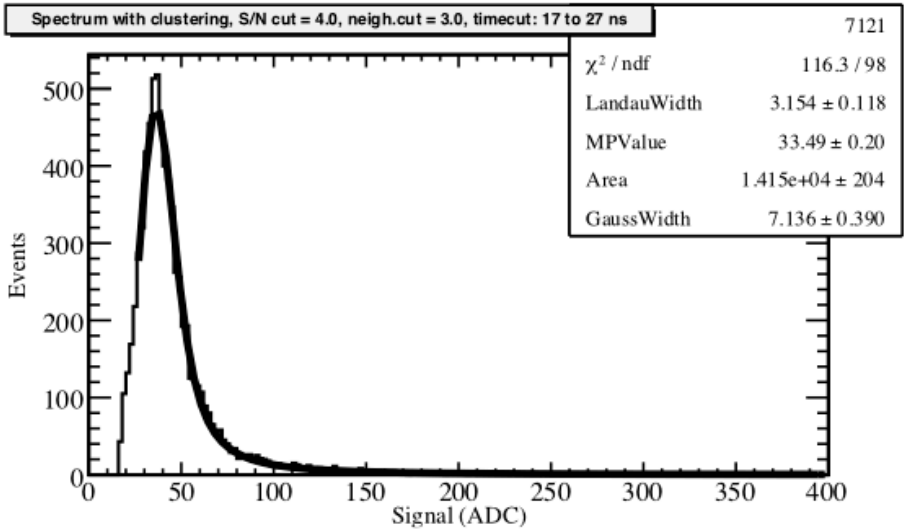
We would like to thank the irradiation teams and Ljubljana and Karlsruhe

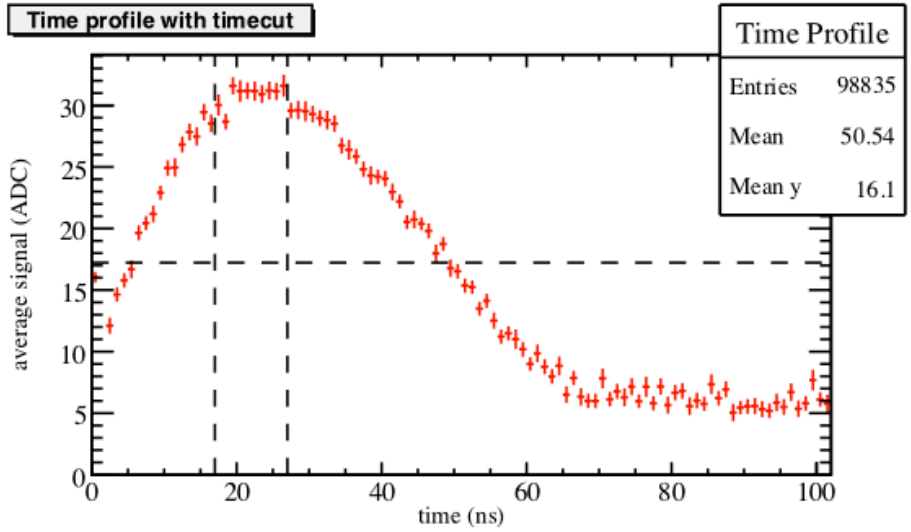
Discussions with Gianluigi Casse from Liverpool

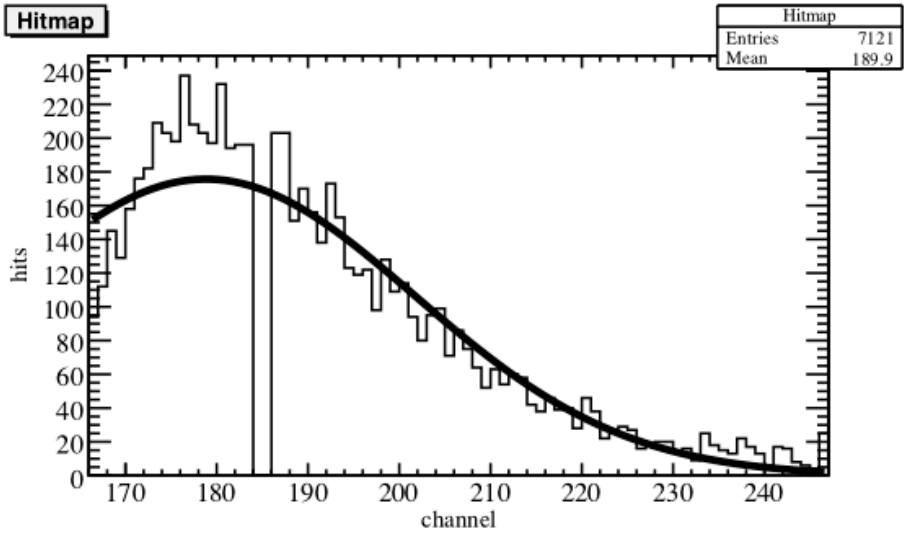
The RD50 community as a whole

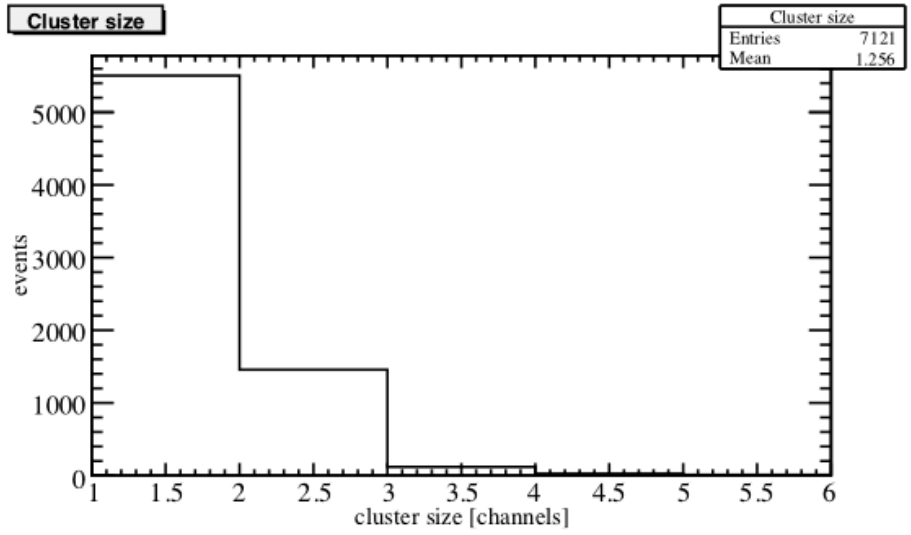
BACKUP SLIDES

3D_S2, 20V

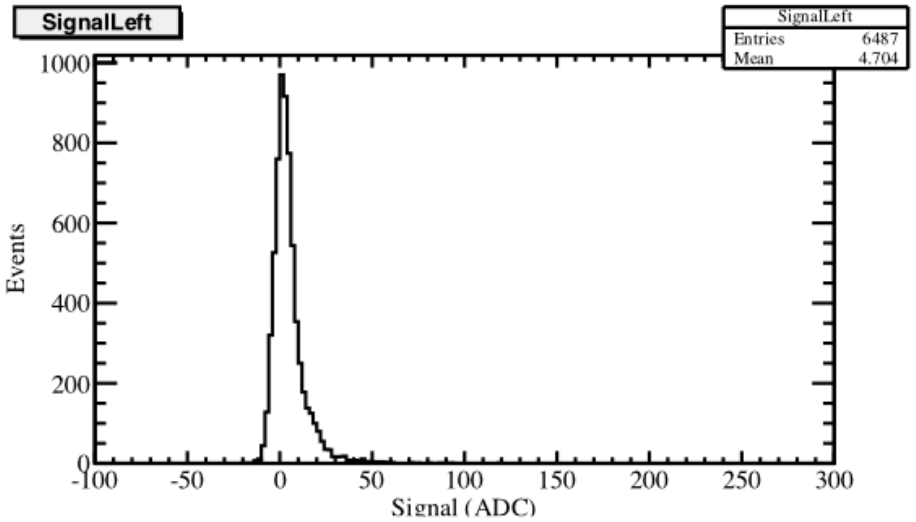

Spectrum with clustering, S/N cut = 4.0, neigh.cut = 3.0, timecut: 17 to 27 ns
7121
χ² / ndf 116.3 / 98
LandauWidth 3.154 ± 0.118
MPValue 33.49 ± 0.20
Area 1.415e+04 ± 204
GaussWidth 7.136 ± 0.390
Events
Signal (ADC)

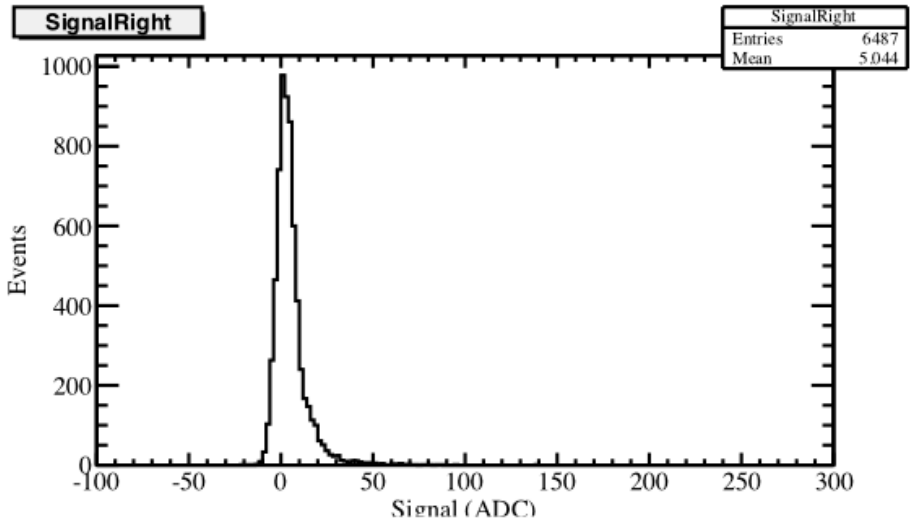

Time profile with timecut
Time Profile
Entries 98835
Mean 50.54
Mean y 16.1
average signal (ADC)
time (ns)

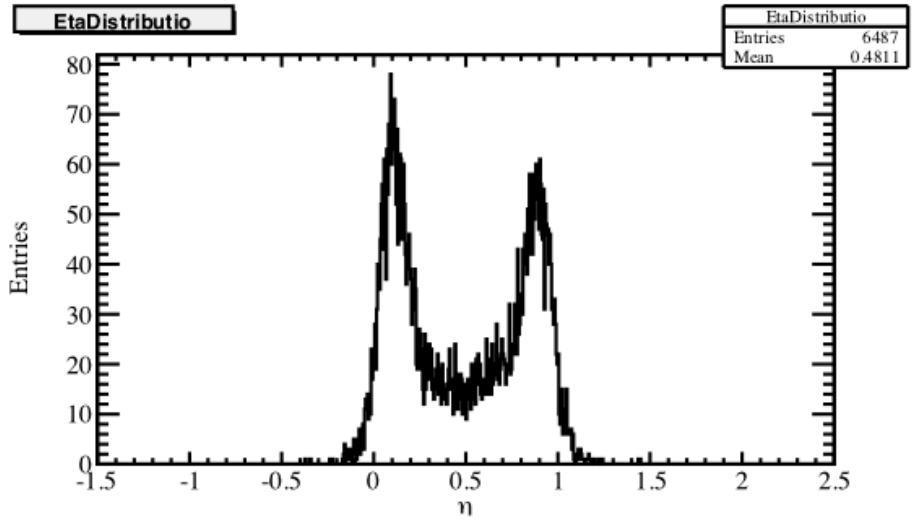

Hitmap
Hitmap
Entries 7121
Mean 189.9
hits
channel


Cluster size
Cluster size
Entries 7121
Mean 1.256
events
cluster size [channels]

3D_S2, 20V

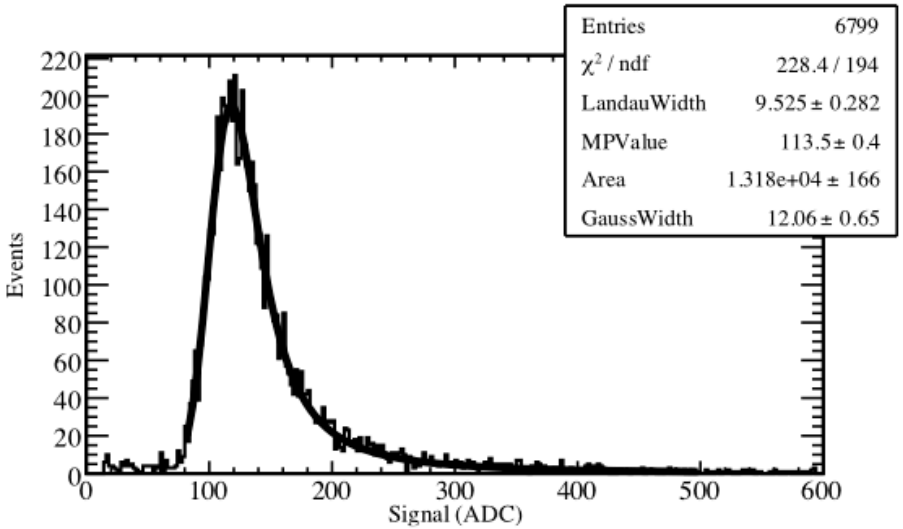


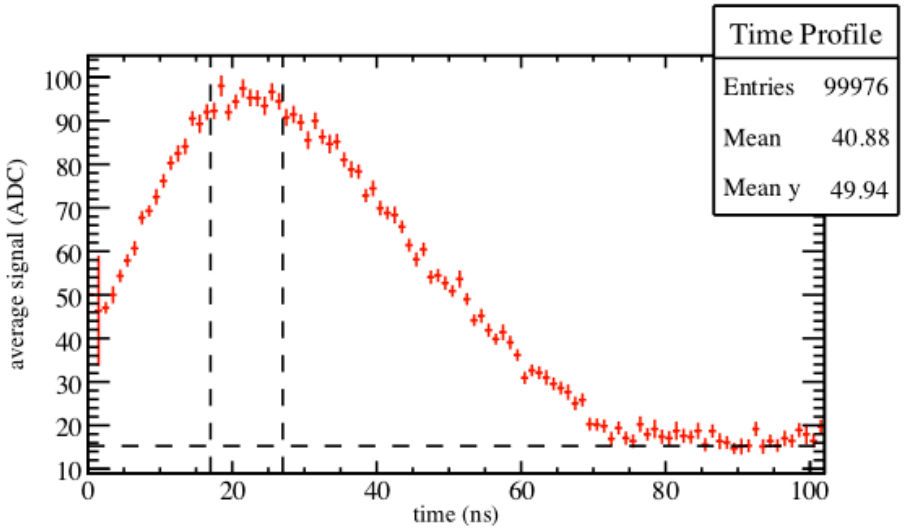


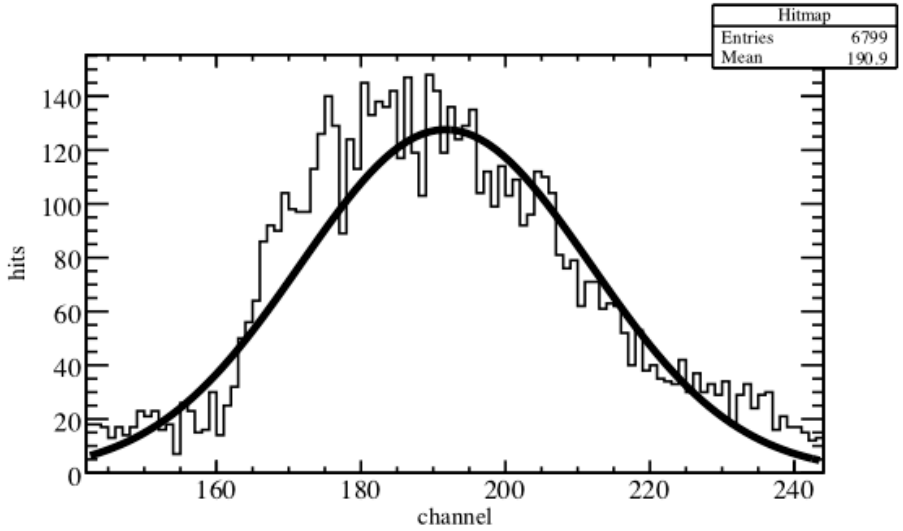


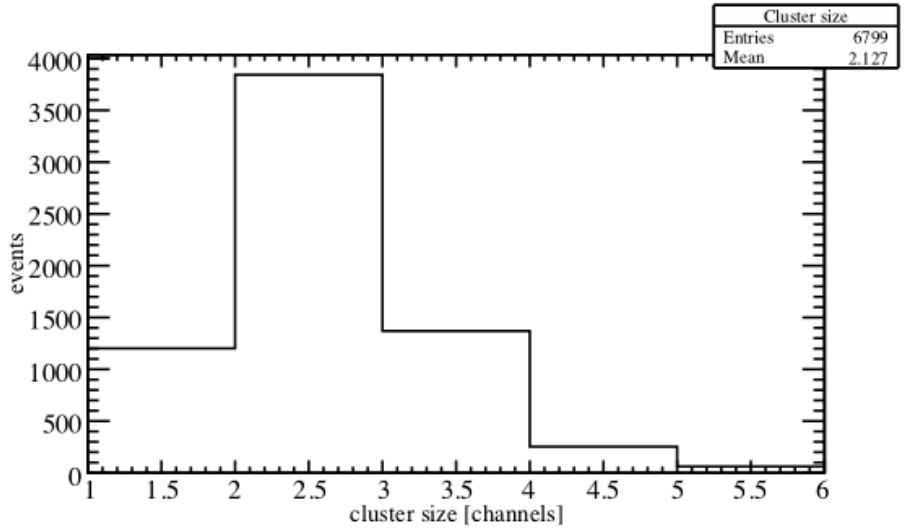
- Cluster distribution looks as expected
- Small asymmetry evident in the η distribution (possibly from the way the ASIC reads charge out from left to right, issues with the ALIBAVA firmware, or some other unknown cause)

W53-BZ4A-P4, 200V, CCE (ke) = 24.19 ± 1.33









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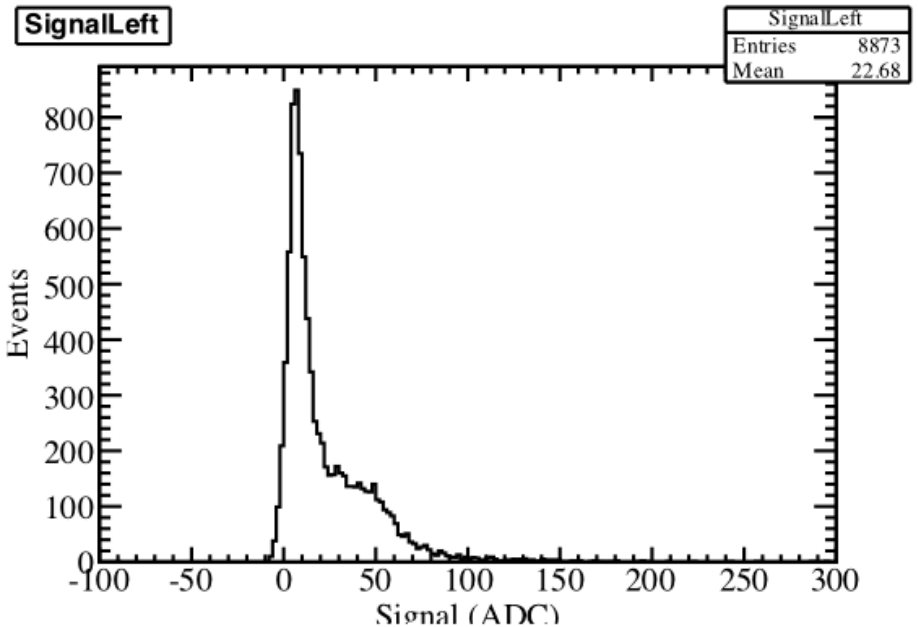

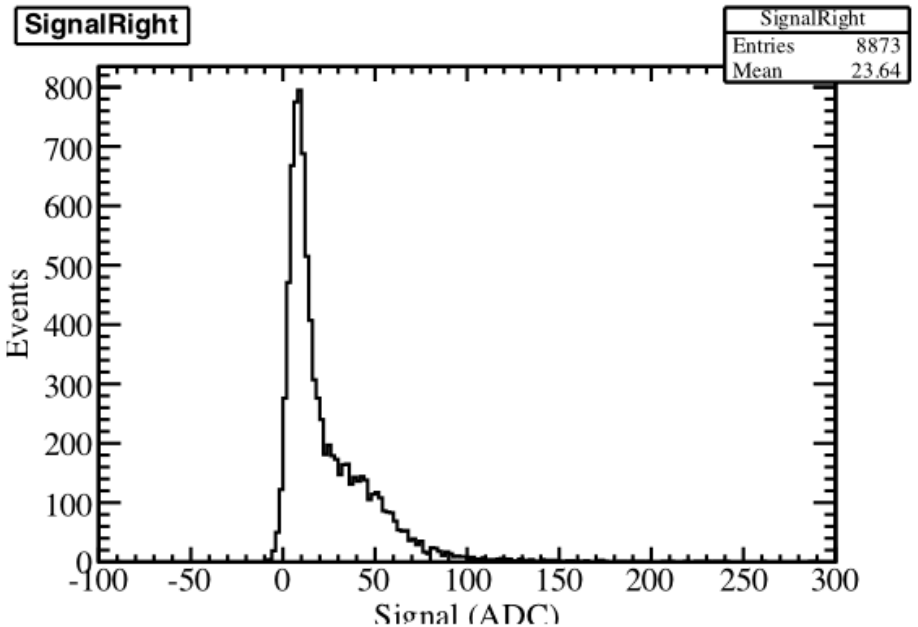

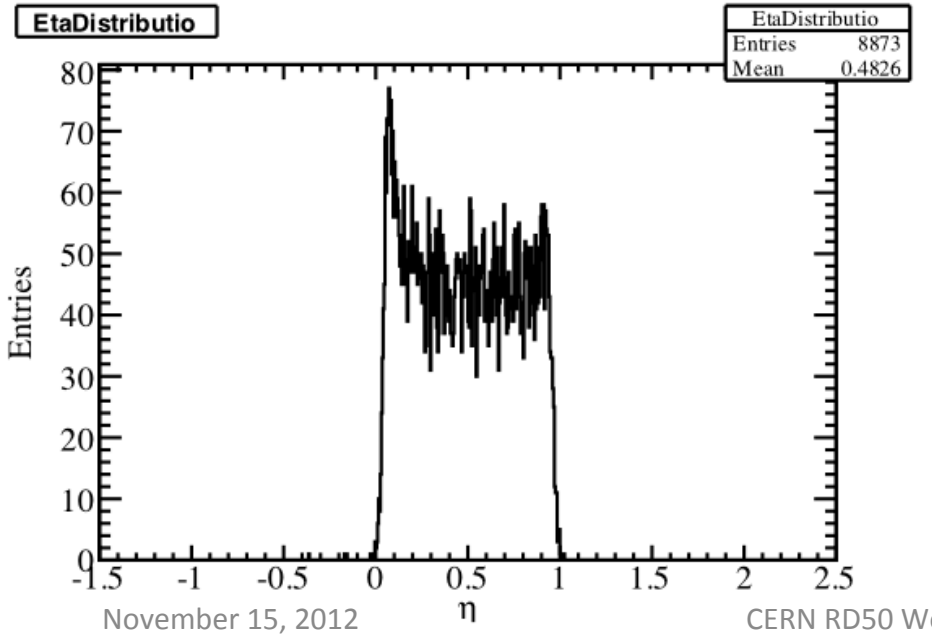

- Cluster distribution dominated by 2-Hit and 3-Hit clusters
- η distribution makes no sense!
- Hidden distribution more evident on neighbor's signals
- This detector used to calibrate our daughter boards (part of the reason we see too high of a signal on some MICRON sensors?)