Irradiation studies of the ATLAS Pixel Electronics.

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Outline

The talk will focus on two studies performed on the electronics of the pixel detector:

- The irradiation of bare FE-1Is conducted in March 2002.
- The irradiation of single pixel chip assemblies conducted at the begining of May 2002.

Irradiation of bare FE-1I chips

The irradiation of the bare FE-1I chips was performed at the 88” cyclotron located at LBL.
The aim was to:

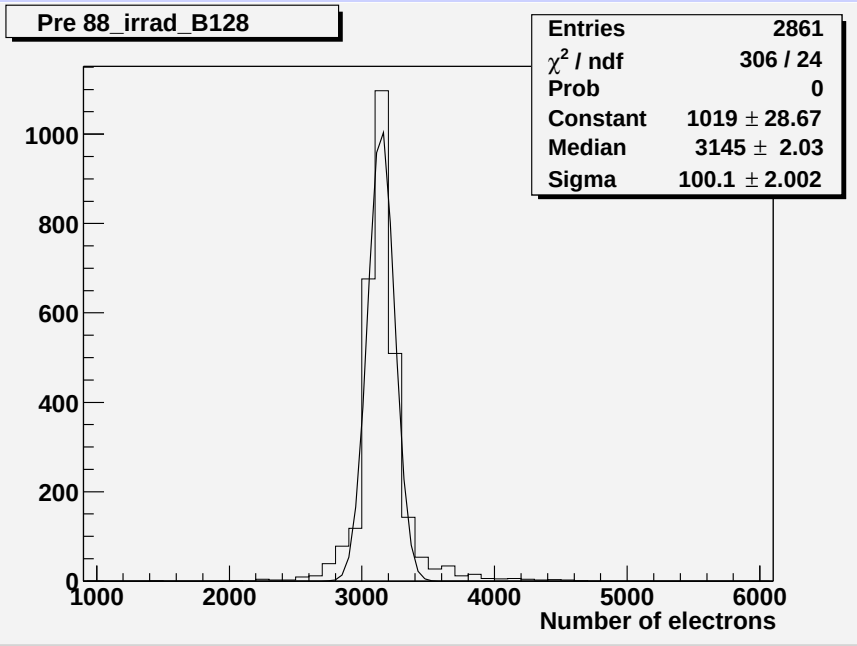
- Study the performance of the chip as a function of dose under realistic LHC operating conditions.
- To evaluate the radiation tolerance of the chip.

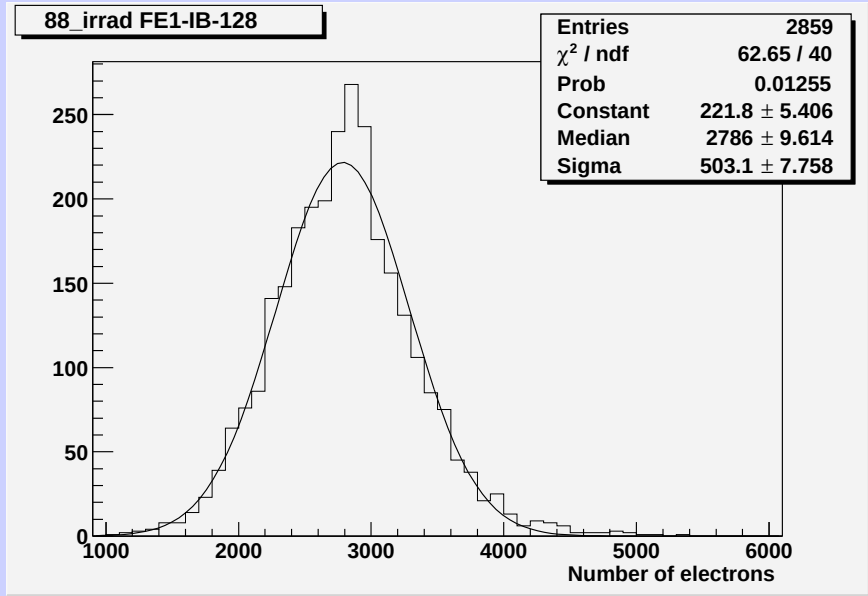
To achieve this:

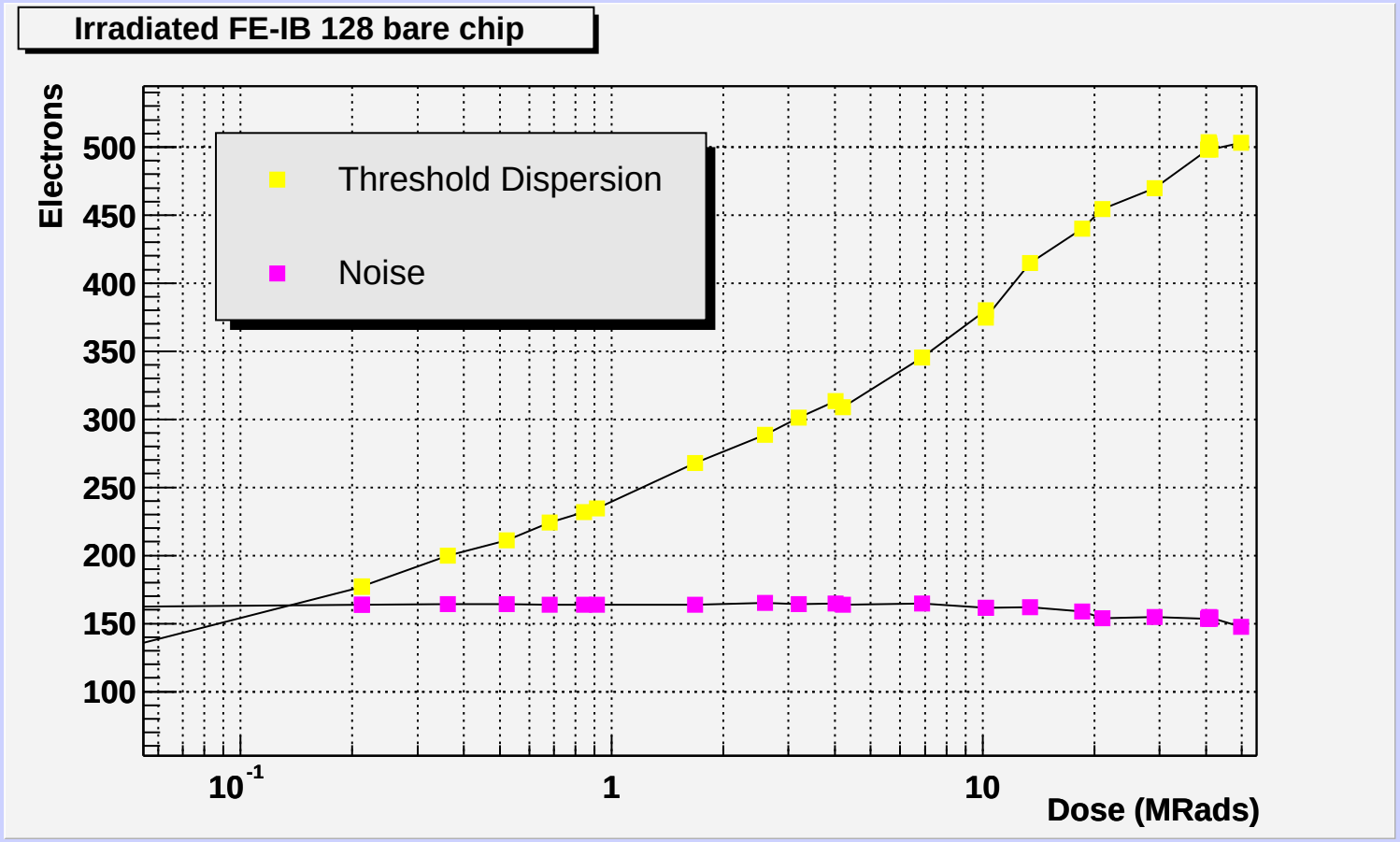
- Two bare chips, FE-1A (210) and FE-1B (128) were irradiated upto a dose of $\approx$ 50Mrads.
- Throughout the whole irradiation the bare chips were kept at a temperature 7C and powered.
- The program followed was loosely based on the ATLAS procedure to evaluate radiation tolerance of electronics.

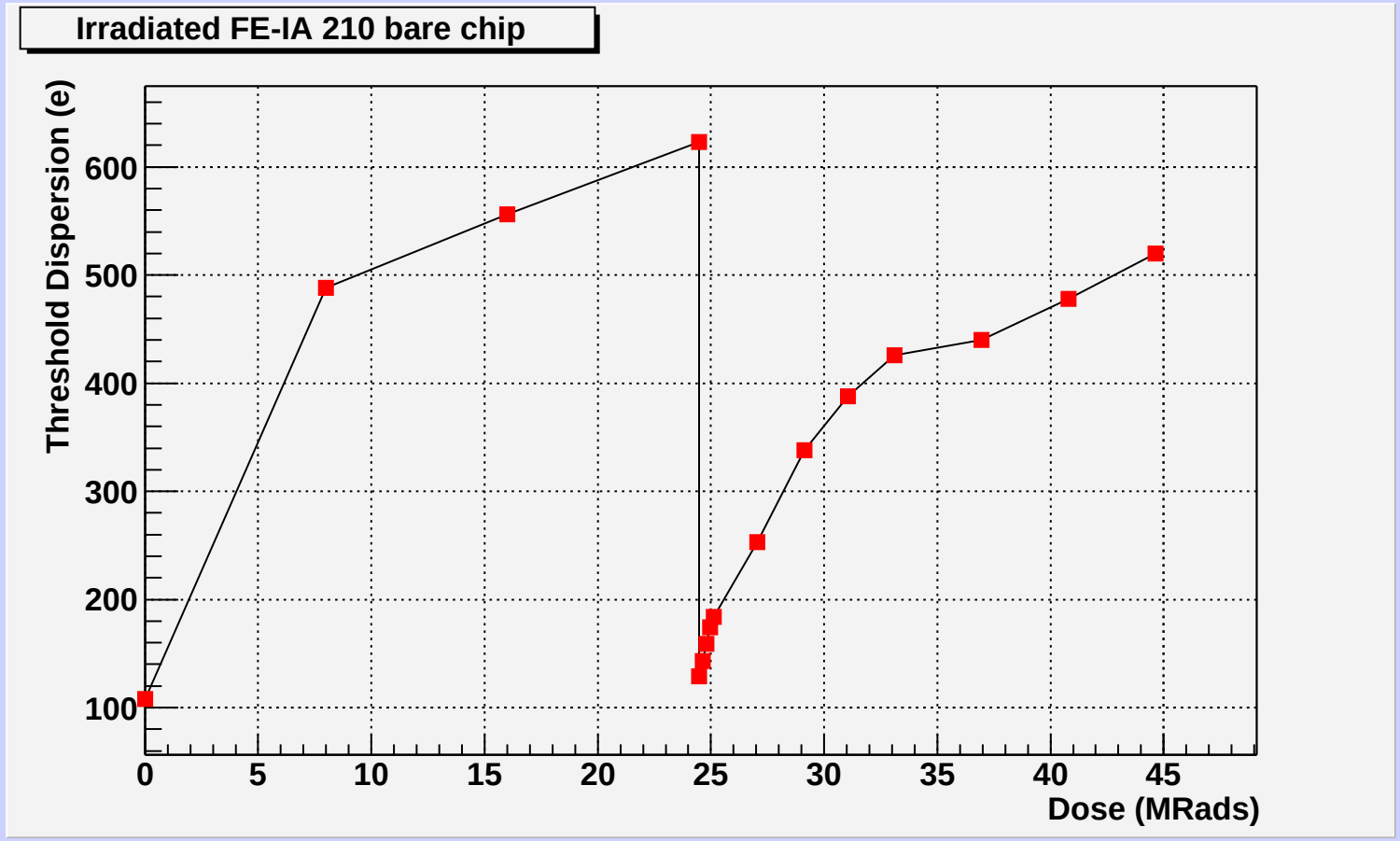
The ATLAS procedure to evaluate the radiation tolerance of CMOS electronics is composed of the following steps:

- Eleven Devices will be tested
- Electrical Measurements Performed
- Irradiation upto RTC (Radiation Tolerance Criteria)
- Annealing for 168 hours at 20C with electrical measurements at the 24th and 168th hour mark.
- Low Radiation Dose Rate Simulation: 168 hours at 100C
- Electrical Measurements


Pre 88_irrad_B128
Entries 2861
χ^2 / ndf 306 / 24
Prob 0
Constant 1019 ± 28.67
Median 3145 ± 2.03
Sigma 100.1 ± 2.002
1000
800
600
400
200
0
1000
2000
3000
4000
5000
6000
Number of electrons


88_irrad FE1-IB-128
Entries 2859
χ^2 / ndf 62.65 / 40
Prob 0.01255
Constant 221.8 ± 5.406
Median 2786 ± 9.614
Sigma 503.1 ± 7.758
250
200
150
100
50
0
1000
2000
3000
4000
5000
6000
Number of electrons


Irradiated FE-IB 128 bare chip
Electrons
500
450
400
350
300
250
200
150
100
Threshold Dispersion
Noise
10^{-1}
1
10
Dose (MRads)


Irradiated FE-IA 210 bare chip
Threshold Dispersion (e)
100
200
300
400
500
600
0
5
10
15
20
25
30
35
40
45
Dose (MRads)

The Irradiation of single pixel chip assemblies

Bump bonded single pixel chip assemblies were irradiated at the Proton Synchroton at CERN to:

- To simulate the operation of the pixel detector in the harsh radiation environment that will be present during the operation of the LHC.
- To understand any degradation in the performance with respect to radiation dose.
- To evaluate the different types of chips(FEI-1A/FEI-1B), bump vendors(AMS/IZM) and sensor vendors(CIS/Tesla) available to the ATLAS pixel community.

To achieve this:

- Eight bump bonded assemblies were irradiated to study every possible combination.
- The average dose recieved by each assembly was 2.2×10^{15} protons/cm^2 $\approx$ 1.1×10^{15} 1MeV neutron equivalent dose.
- All assemblies were kept at -10C and were powered throughout the irradiation period.

- Threshold scans, TOT calibrations, leakage currents scans and SEU measurements were conducted periodically during the irradiation.
- Post irradiation measurements were also conducted after the assemblies were annealed to simulate the expected temperature history of the pixel detector during 10 years of operation in the ATLAS detector.

Results to be presented today will only include the post irradiation measurements for a single chip assembly with the following characteristics $\rightarrow$ FE-1B/IZM/CIS.

Post Irradiation Measurements

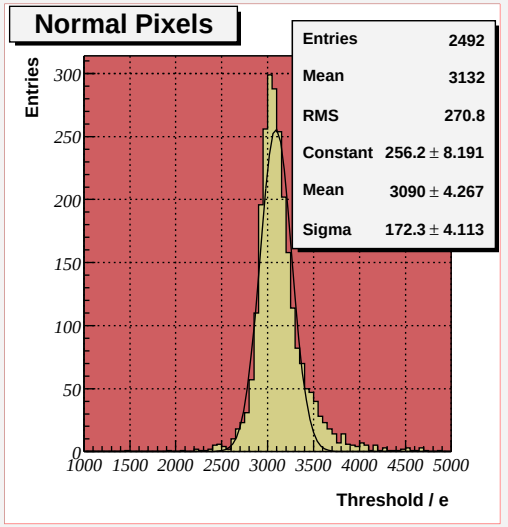
The post irradiation measurements included the following:

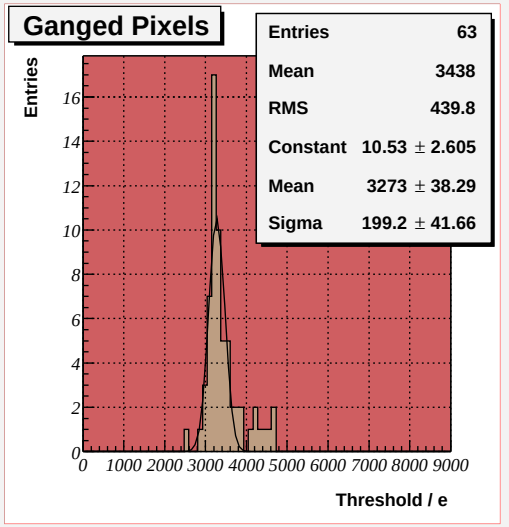
- **Threshold Scans**: Performed to measure the threshold and the noise of each pixel composing the assembly under different conditions.
- **Leakage Current Scans**: Performed to measure the leakage current of each pixel composing the assembly under different conditions.

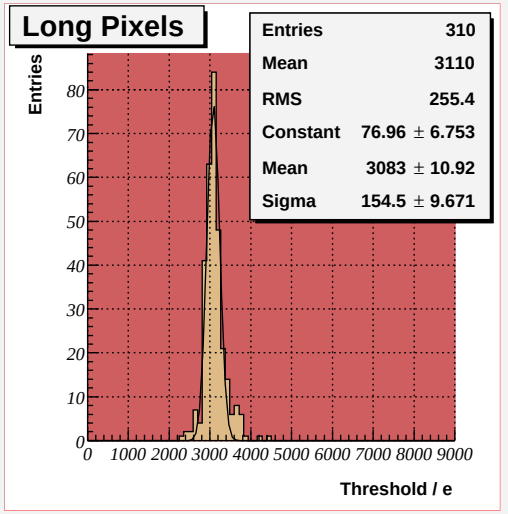
- **Cross Talk Scans**: Performed to measure the cross talk between pixels. The number of hits registered by a pixel is measured when its adjacent neighbours are injected with a large amount of charge (150Ke per pair).
- **Time Walk** Performed to study the pulse height slewing of the front-end and timestamping circuitry in FE-I1.

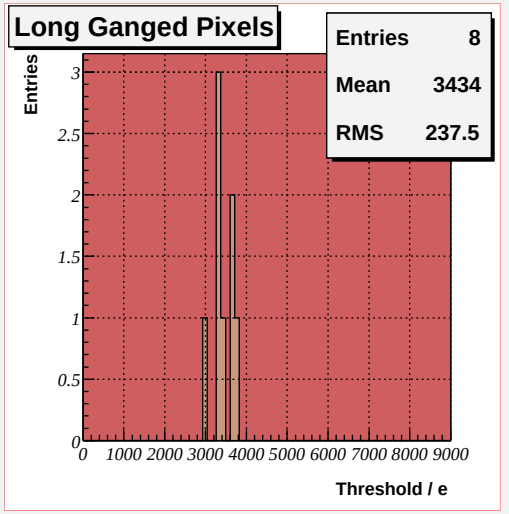
Post Irradiation Results:Threshold

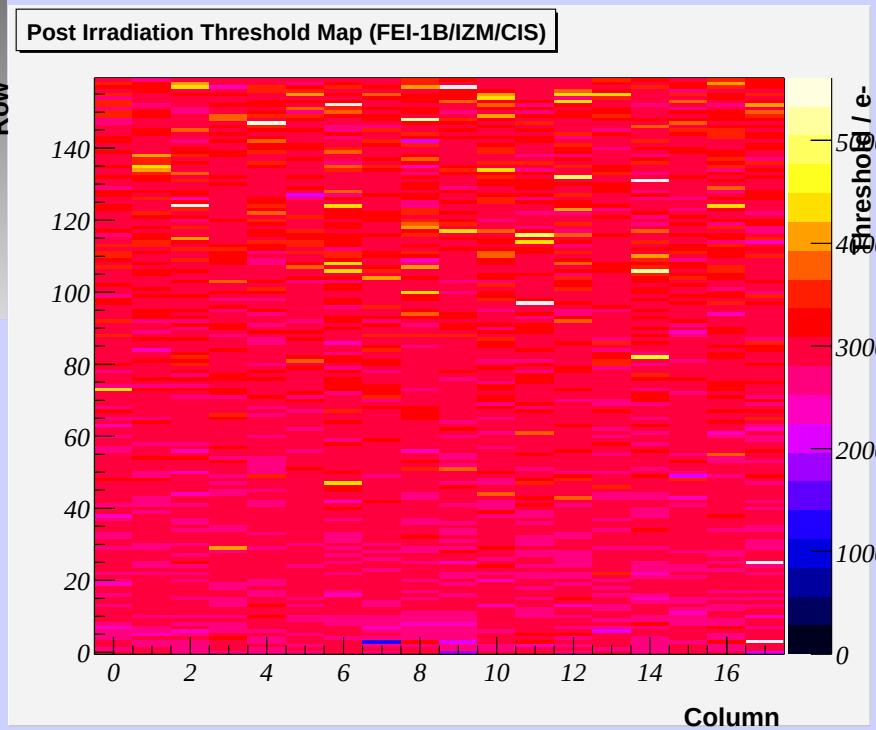
Post Irradiation Threshold Distributions FE-IB/IZM/CIS

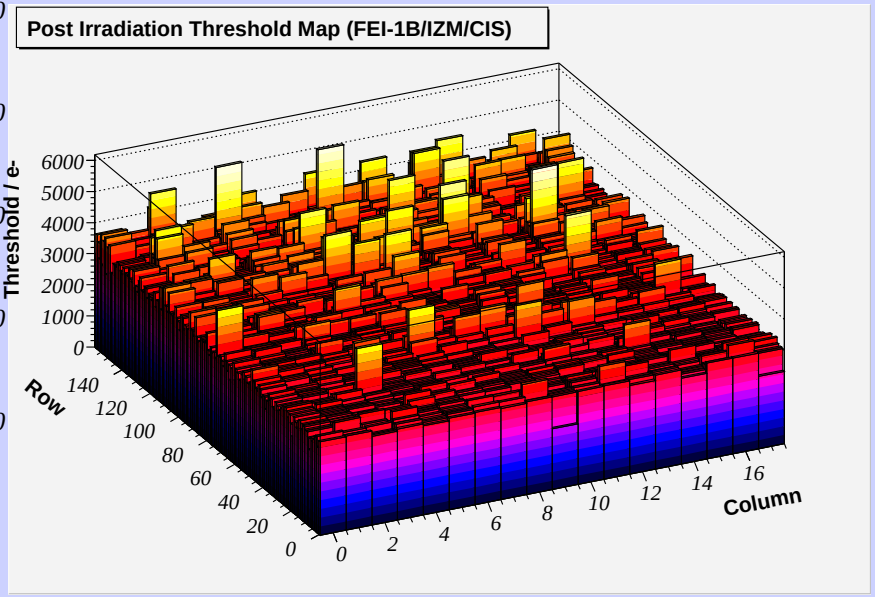






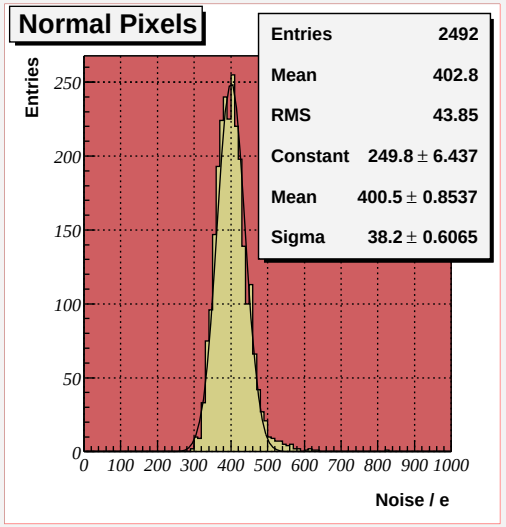


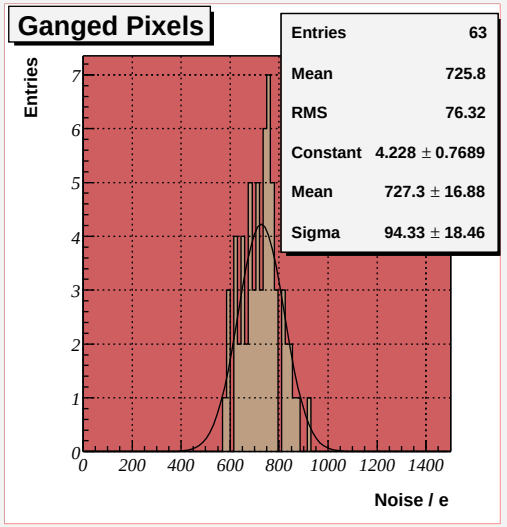

Post Irradiation Threshold Map (FEI-1B/IZM/CIS)
Row
Column
Threshold / e-
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
1000
2000
3000
4000
5000

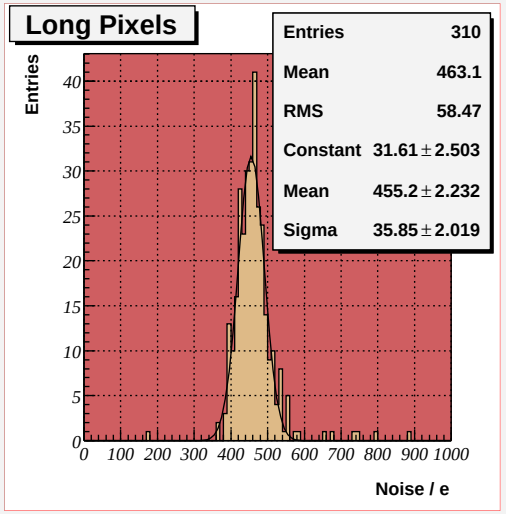

Post Irradiation Threshold Map (FEI-1B/IZM/CIS)
Threshold / e-
Row
Column
0
1000
2000
3000
4000
5000
6000
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16

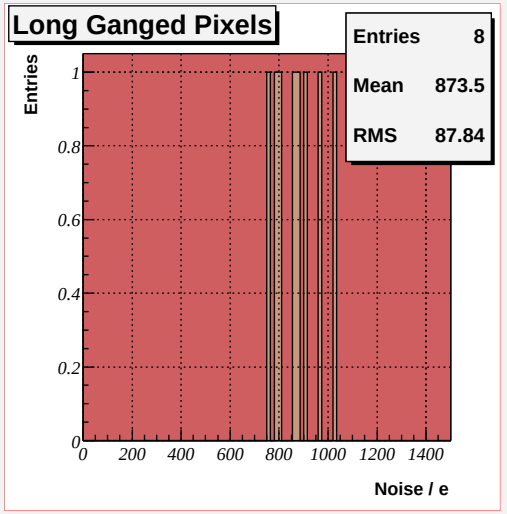
Post Irradiation Results:Noise

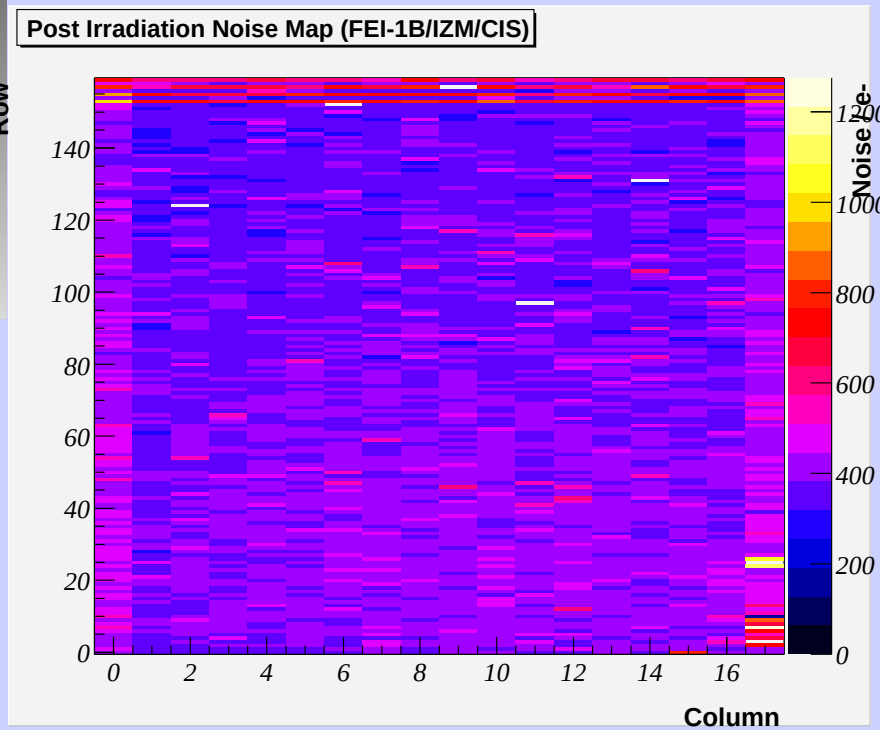
Post Irradiation Noise Distributions FE-IB/IZM/CIS

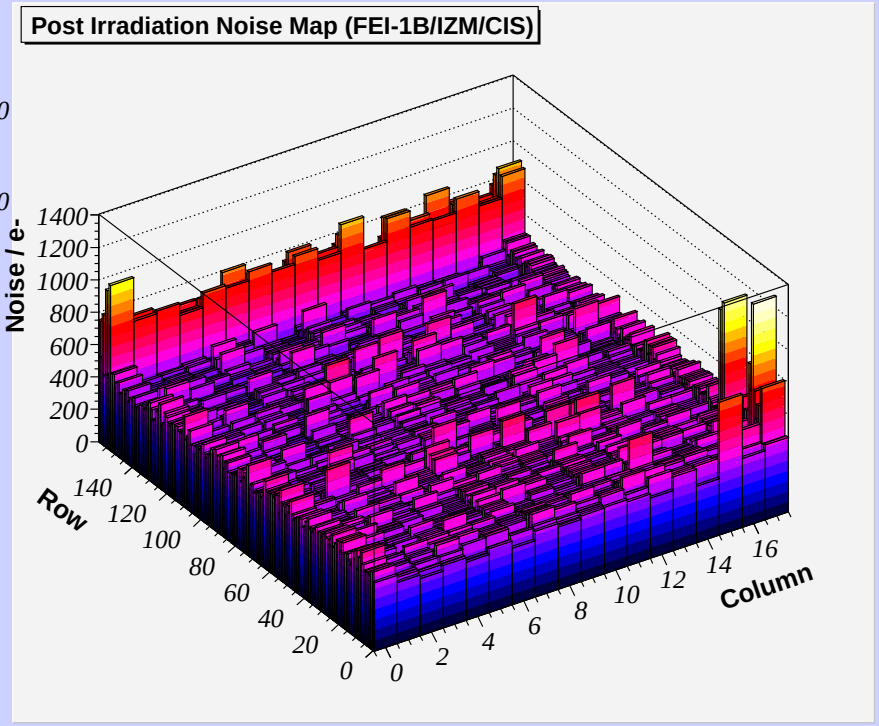




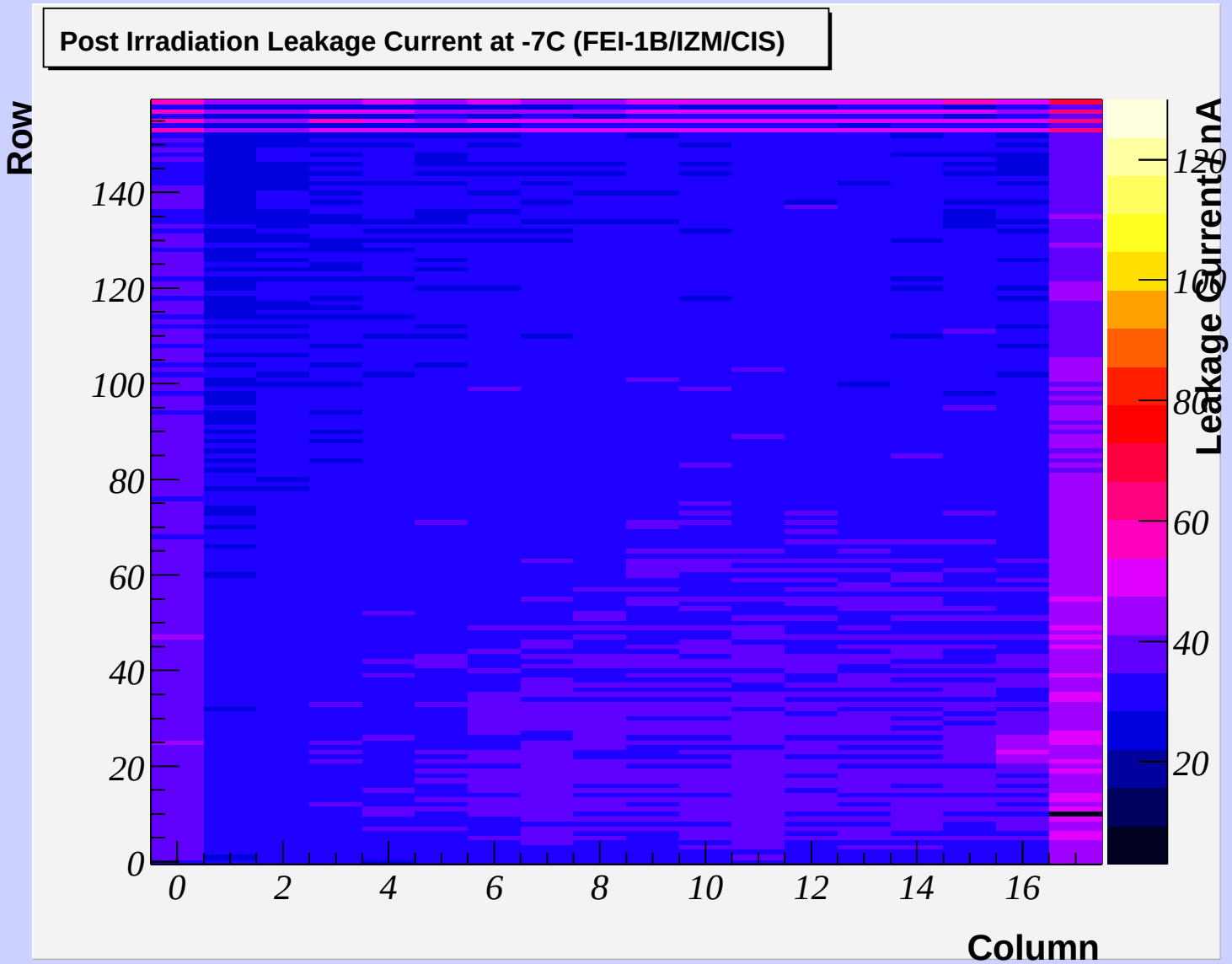


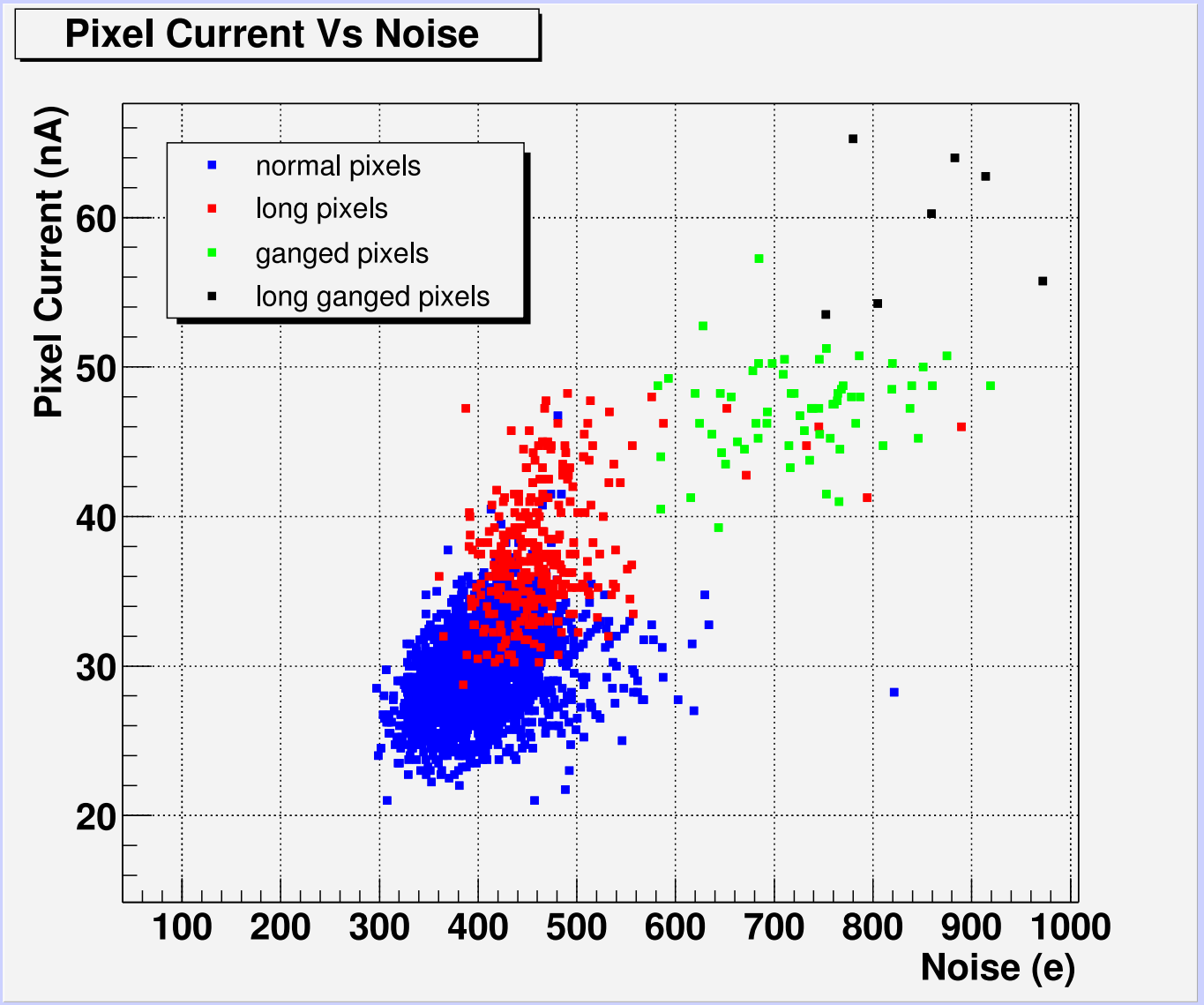


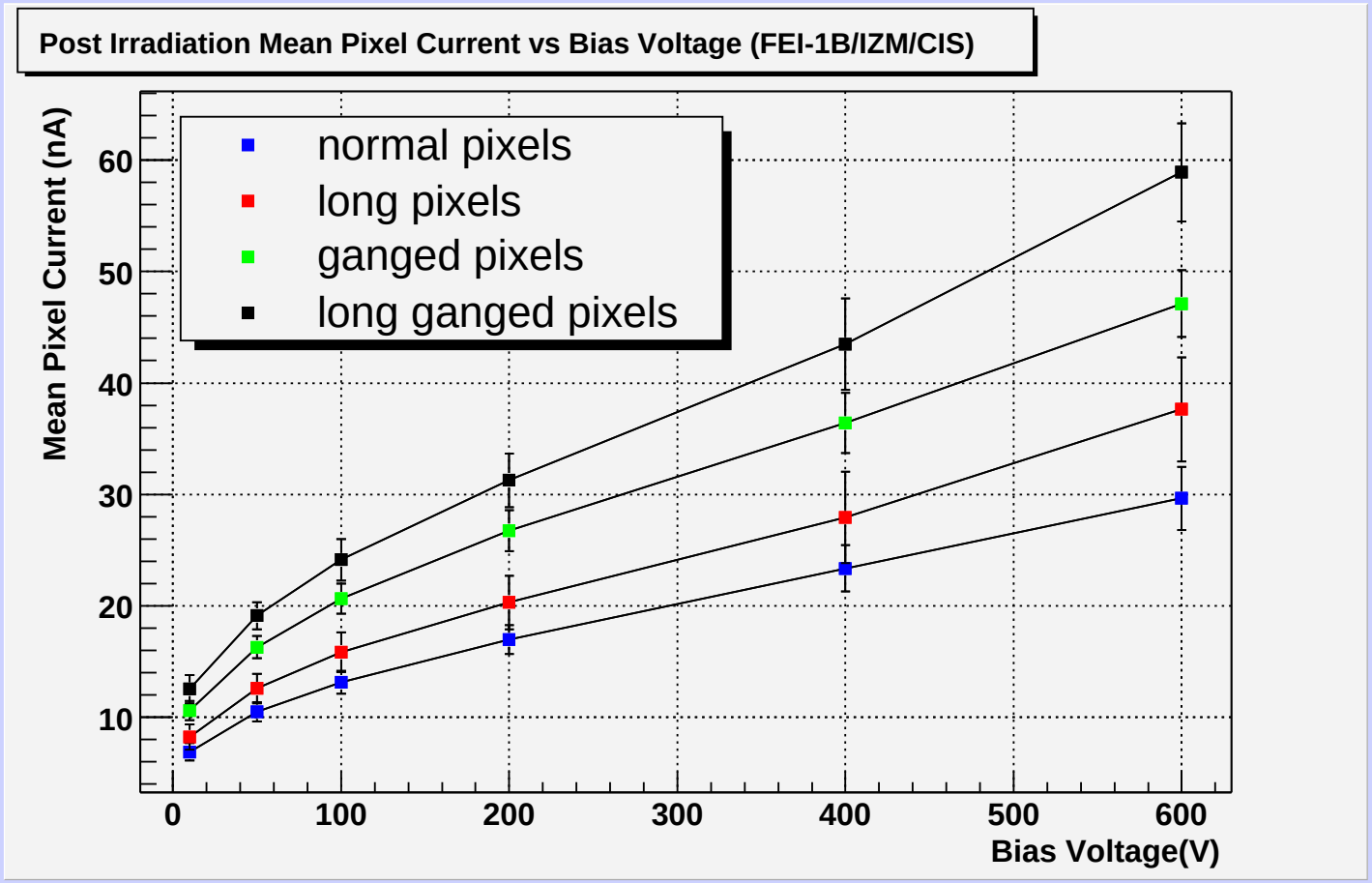

Post Irradiation Noise Map (FEI-1B/IZM/CIS)
Row
Column
Noise / e-
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
0
200
400
600
800
1000
1200


Post Irradiation Noise Map (FEI-1B/IZM/CIS)
Noise / e-
Row
Column
0
200
400
600
800
1000
1200
1400
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16

Post Irradiation Results:Leakage Current



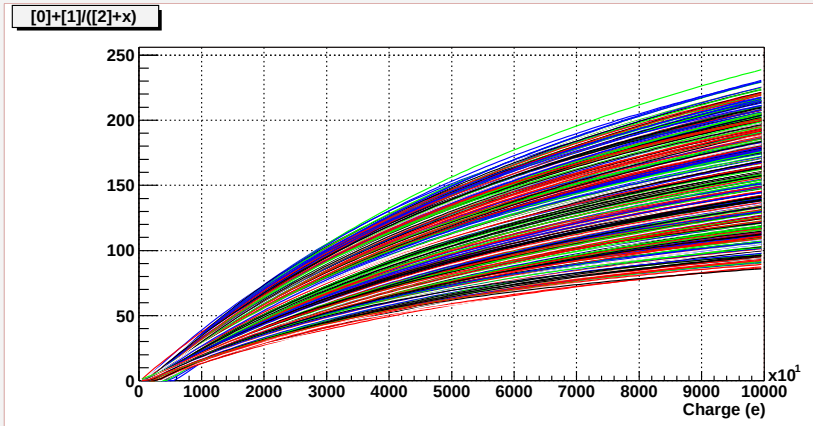

Pixel Current Vs Noise
normal pixels
long pixels
ganged pixels
long ganged pixels
Pixel Current (nA)
20
30
40
50
60
100
200
300
400
500
600
700
800
900
1000
Noise (e)


Post Irradiation Mean Pixel Current vs Bias Voltage (FEI-1B/IZM/CIS)
normal pixels
long pixels
ganged pixels
long ganged pixels
Mean Pixel Current (nA)
10
20
30
40
50
60
0
100
200
300
400
500
600
Bias Voltage(V)

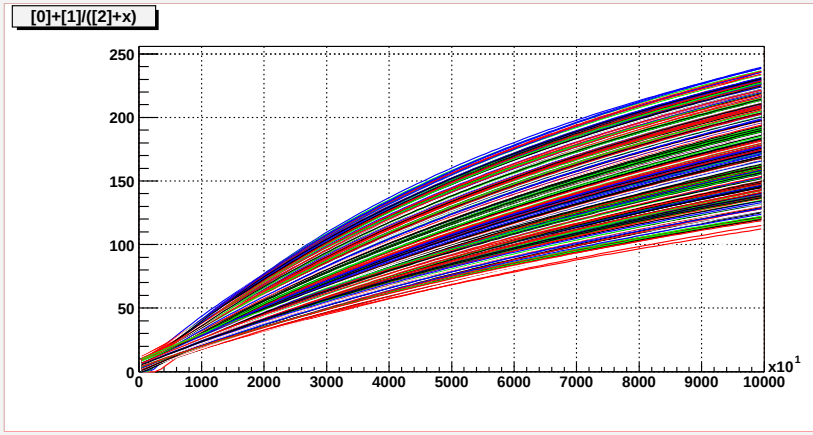
Post Irradiation Results:TOT dispersion

FEI-1B/IZM/CIS Post Irradiation TOT calibration

Clo Calibration Fit Results

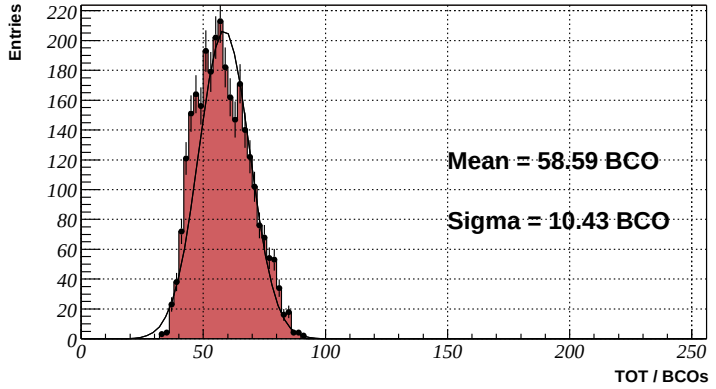


Chi Calibration Fit Results

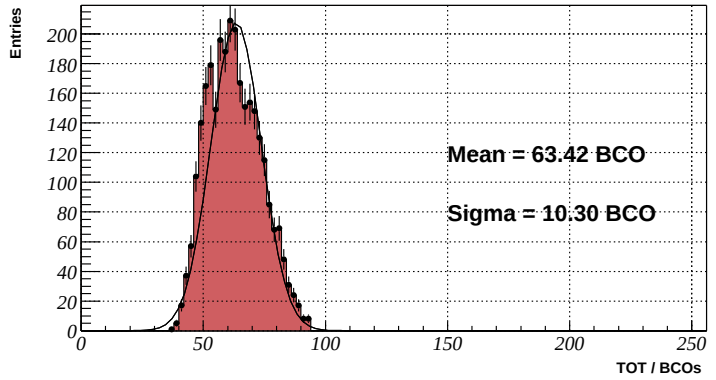


FEI-1B/IZM/CIS Post Irradiation TOT calibration

Clo Calibration Fits at 25Ke



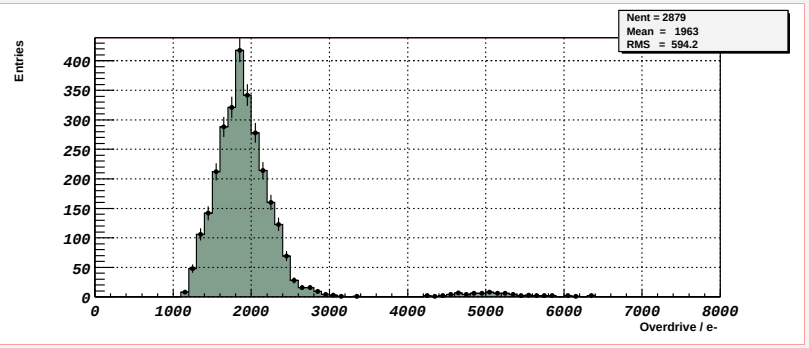
Chi Calibration Fits at 25Ke

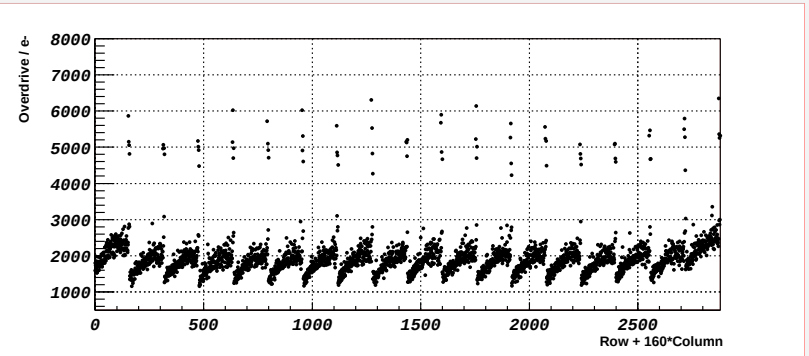


Post Irradiation Results:Timewalk

IZM_B: Overdrive for 20ns Timewalk from 50ke-

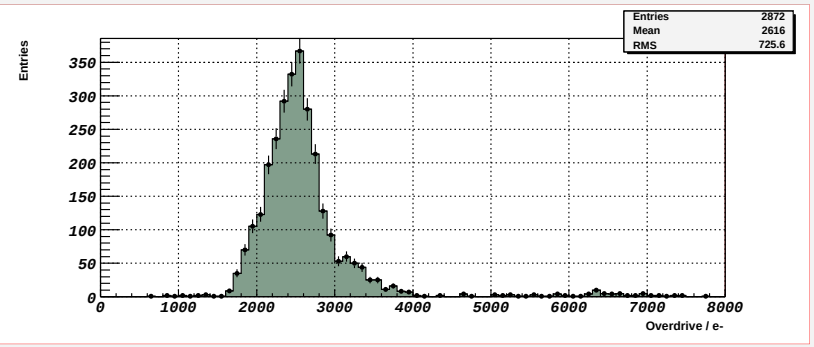
Config A, PICT, VCC=5.1V, VEE=-5.1V

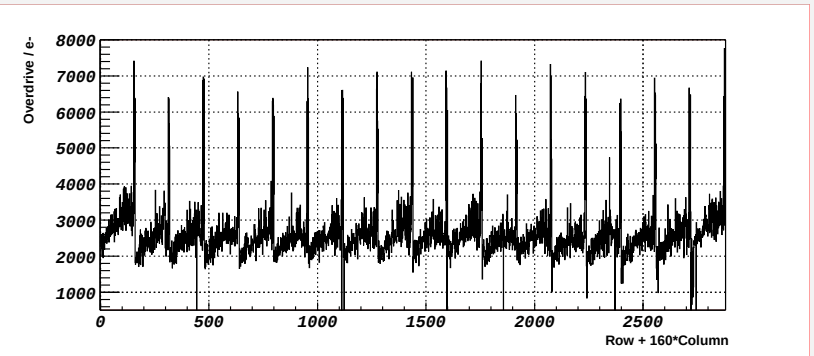


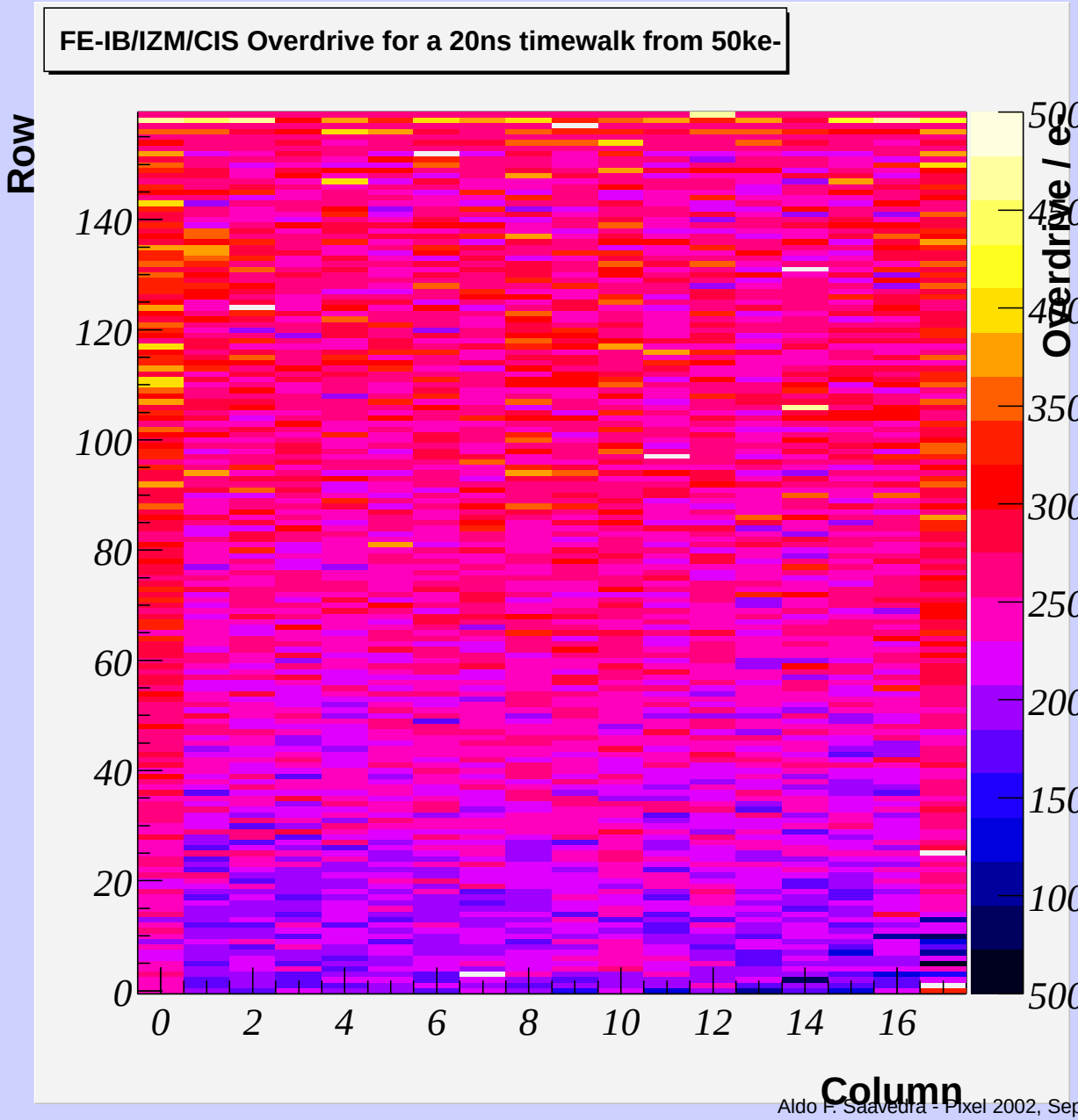


IZM_B: Overdrive for 20ns Timewalk from 50ke-

Config A, Mod_TPCC0, VCC=5.1V, VEE=-5.1V, IF=255

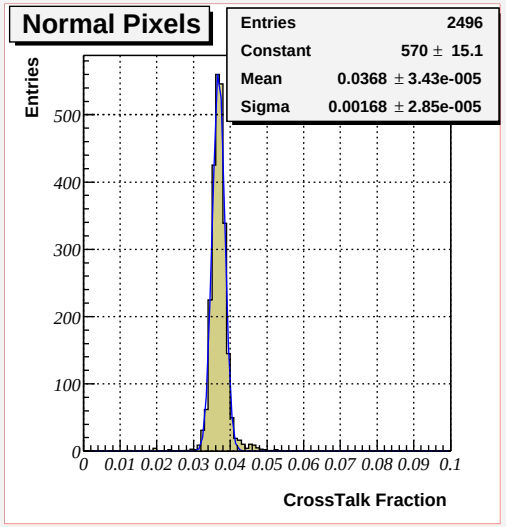


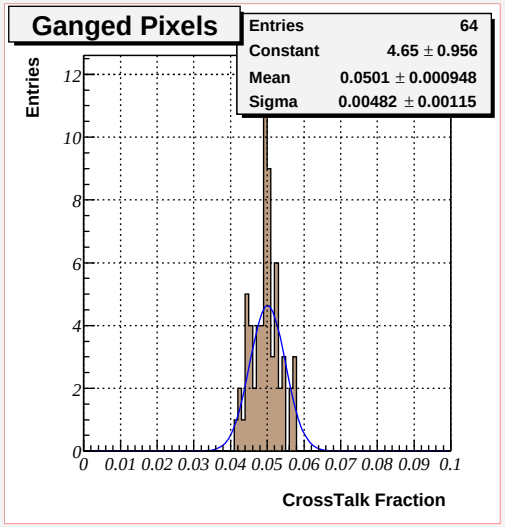


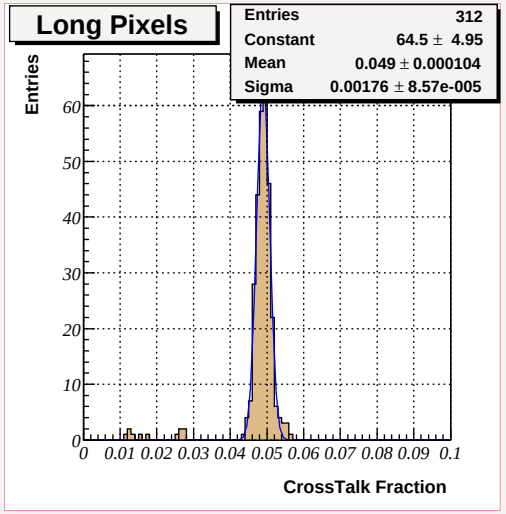

FE-IB/IZM/CIS Overdrive for a 20ns timewalk from 50ke-
Row
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
Column
Overdrive / e
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

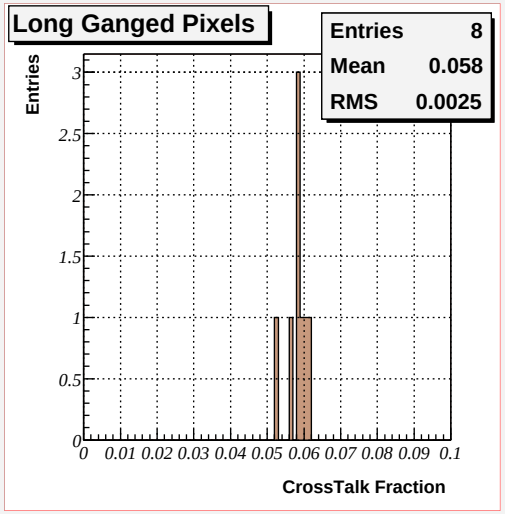
Post Irradiation Results:Cross Talk

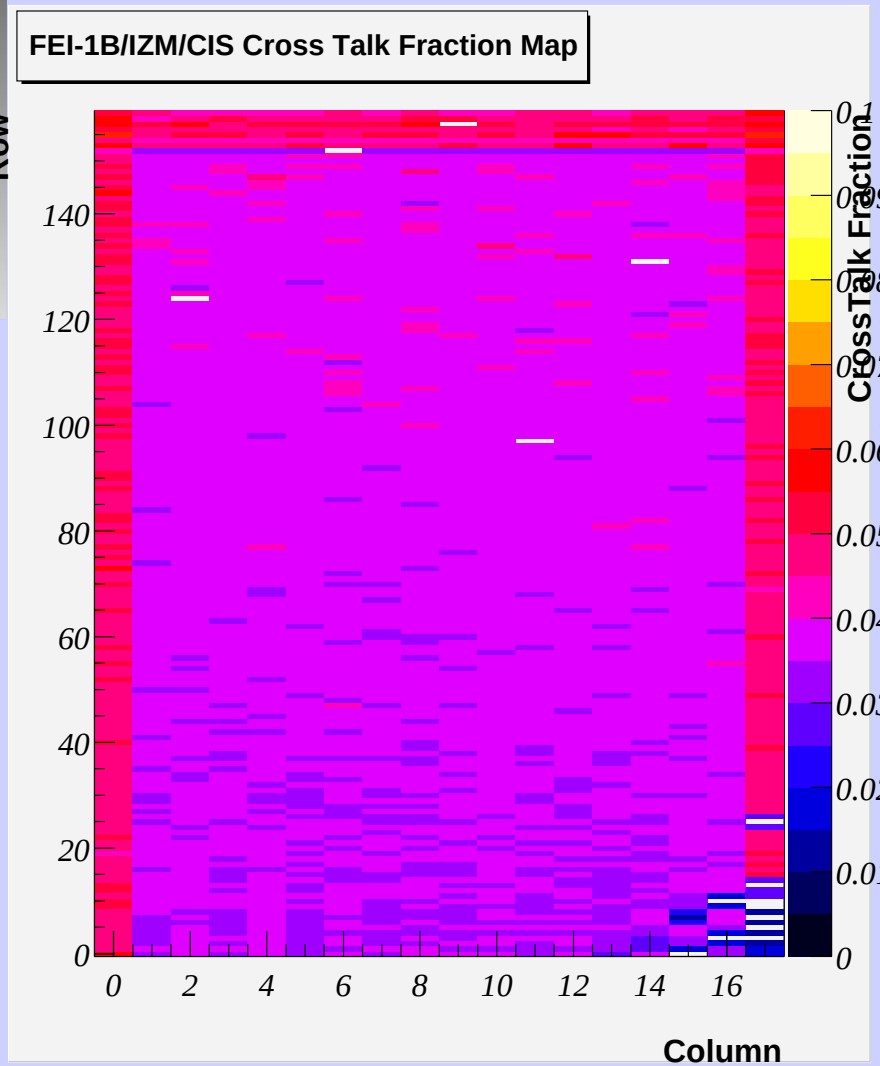
Post Irradiation XTalk Distributions FE-IB/IZM/CIS

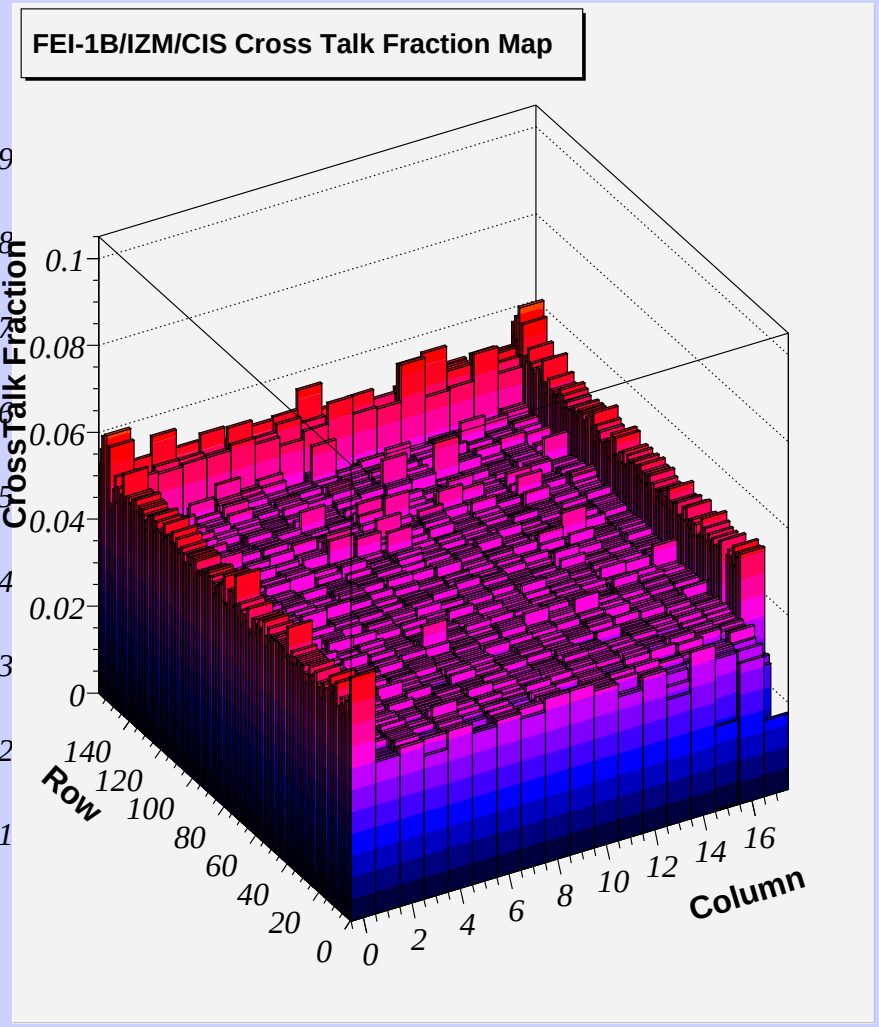









FEI-1B/IZM/CIS Cross Talk Fraction Map
Row
Column
CrossTalk Fraction
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1


FEI-1B/IZM/CIS Cross Talk Fraction Map
CrossTalk Fraction
0
0.02
0.04
0.06
0.08
0.1
Row
0
20
40
60
80
100
120
140
Column
0
2
4
6
8
10
12
14
16

Conclusion

- All the single pixel chip assemblies operated properly during the irradiation.
- The post irradiation measurements show that the chip meets all of our requirements but there are areas that need improving.
- The current threshold tunning is marginally adequate at the moment but it will be improved in the next generation.
- The current timewalk of 2000e is barely acceptable. For example setting a threshold of 3Ke means that all the charges above 5Ke will be within 20ns. We are aiming for a timewalk of 1000e.