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Sezione di Torino

A 64-channel wide dynamic range charge measurement ASIC for strip and pixel ionization detectors

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Outline

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- Application: hadrontherapy
- 1st generation ASIC architecture
- Test results
- 2nd generation ASIC
- Test results
- Conclusions

Hadrontherapy

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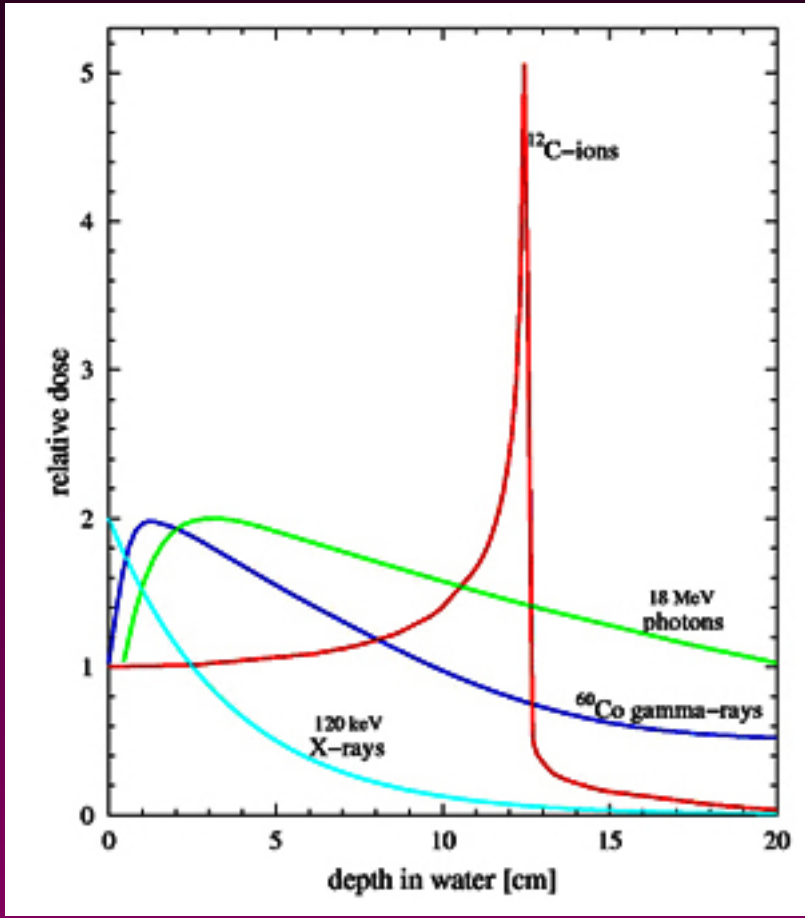

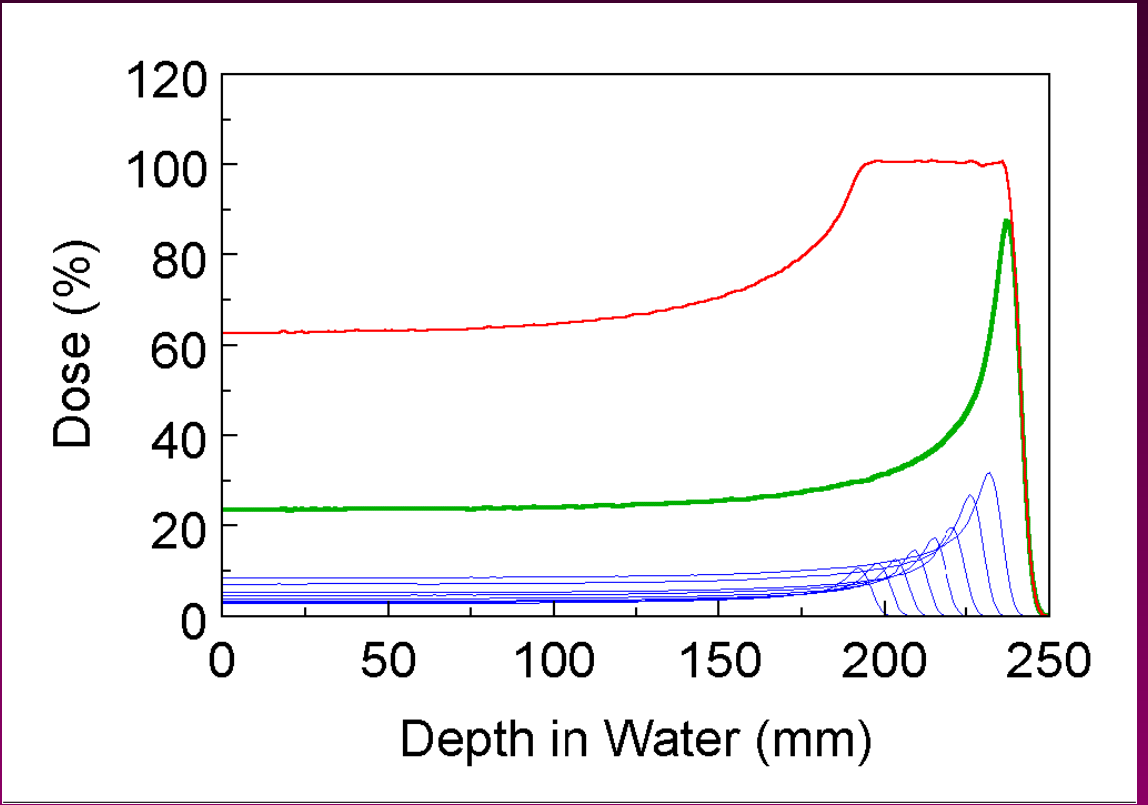

Applications

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Two applications :

- beam calibration : a stack of strip segmented ionization detectors interleaved by passive material is used to measure the beam profile before treatment
- beam monitoring : a pixel ionization chamber is used to monitor the hadron beam during patient irradiation

- Both the dose deposited by the beam on the target tissue and the dose on the surrounding tissues has to be measured.
- A very dynamic range, of the order of 10^3, is required

The detectors

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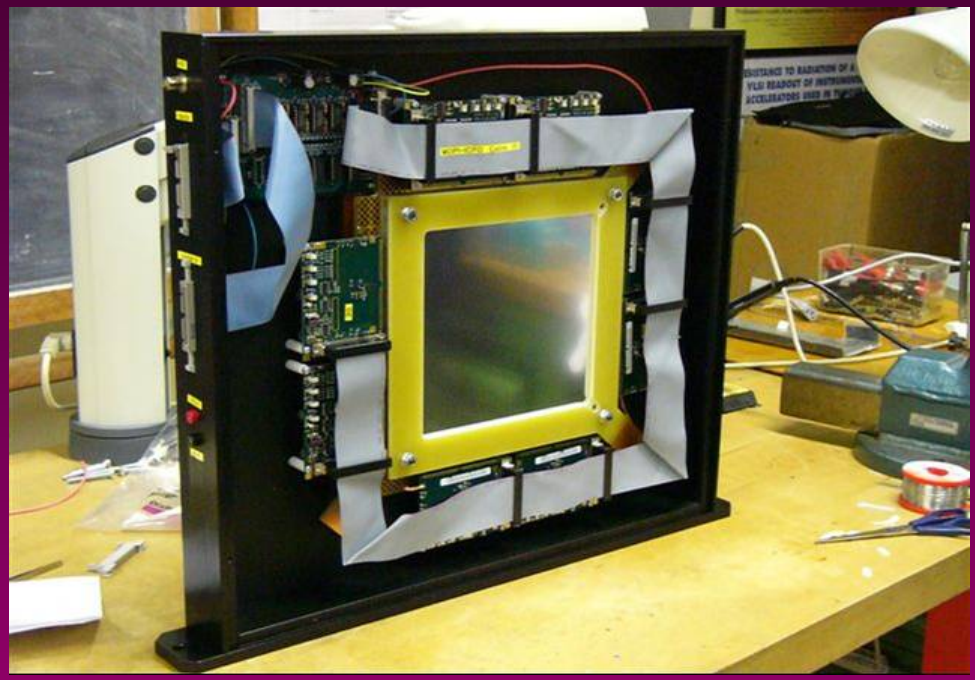
The strip detector
(“Magic Cube”)

The pixel detector



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Architecture

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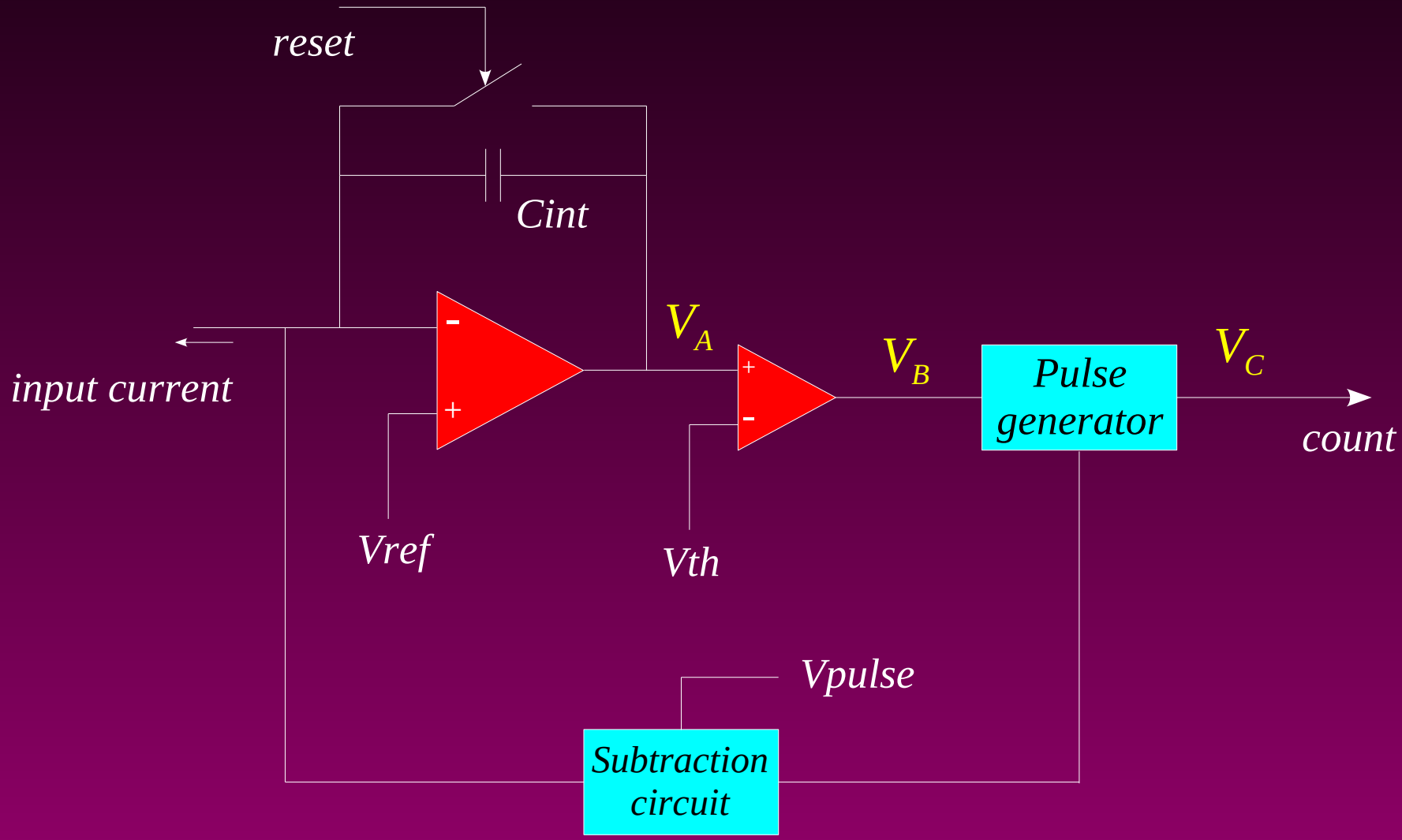
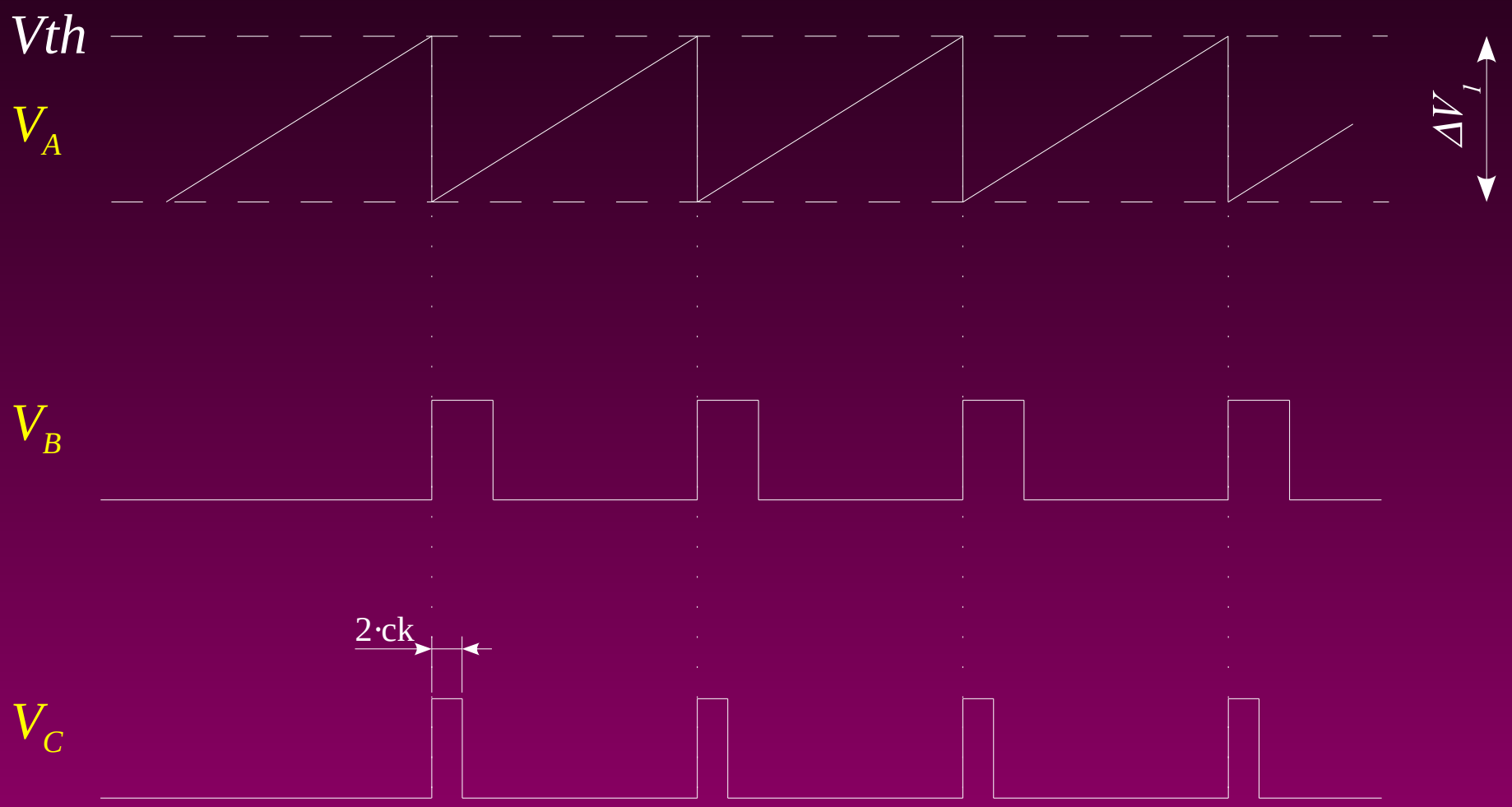


Waveforms

Sezione di Torino



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Charge subtraction

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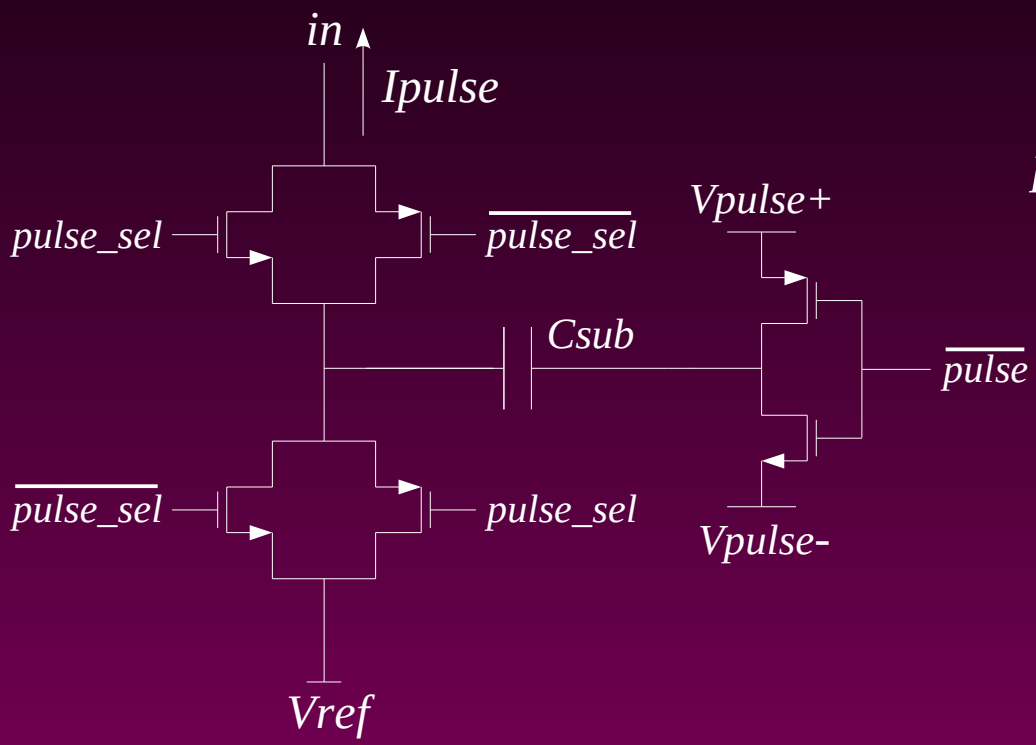

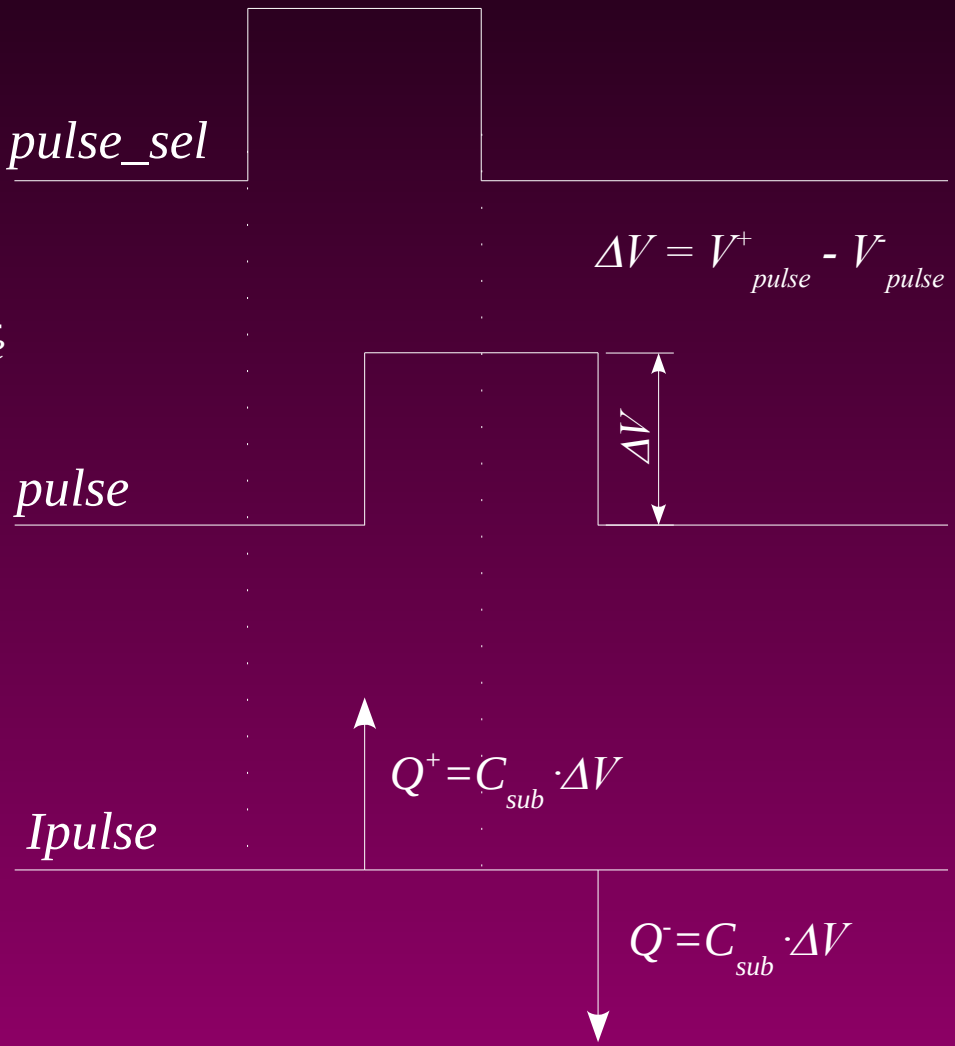

$$f = \frac{Iin}{Q} = \frac{Iin}{C_{sub} \cdot \Delta V}$$

ASIC architecture

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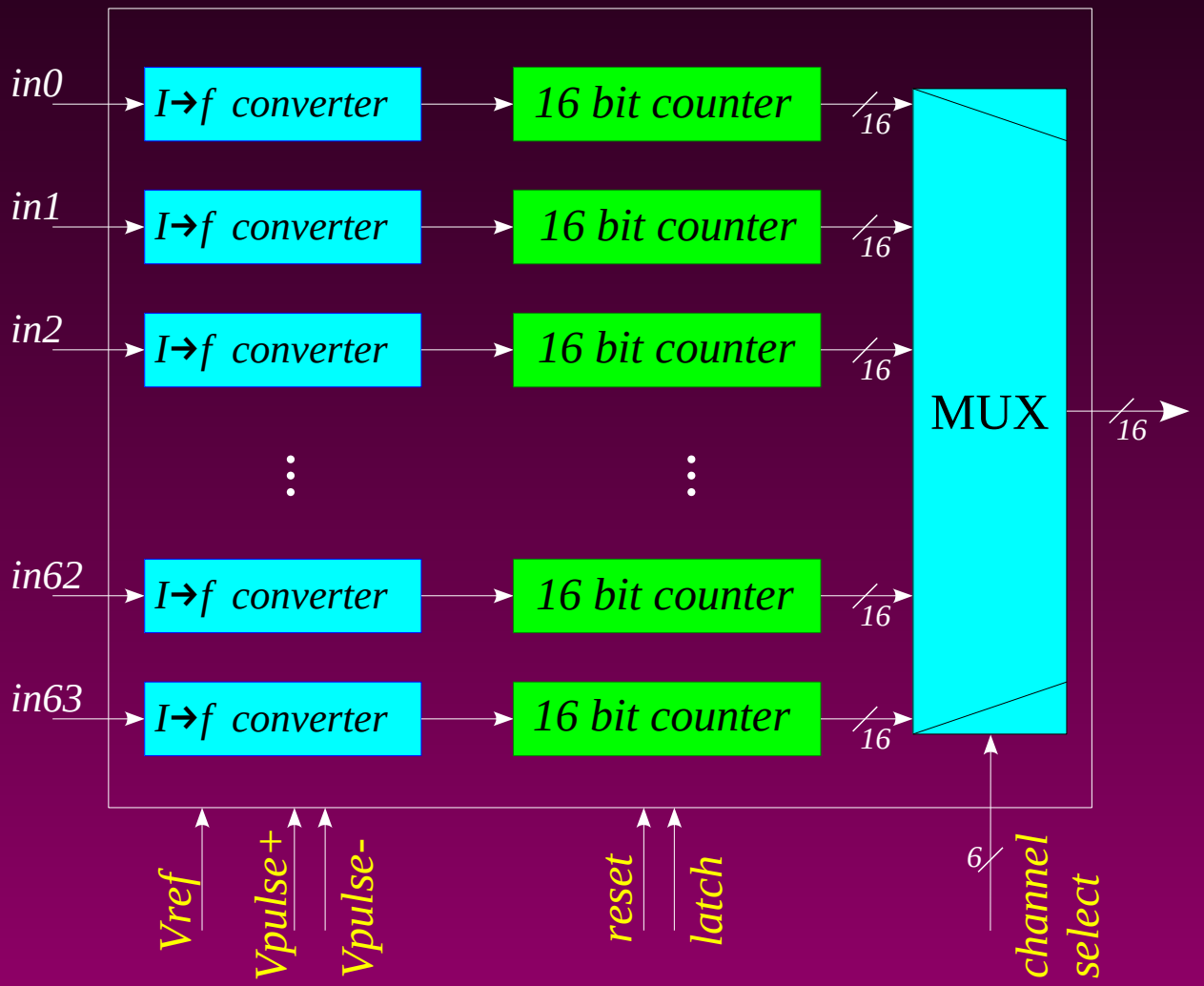
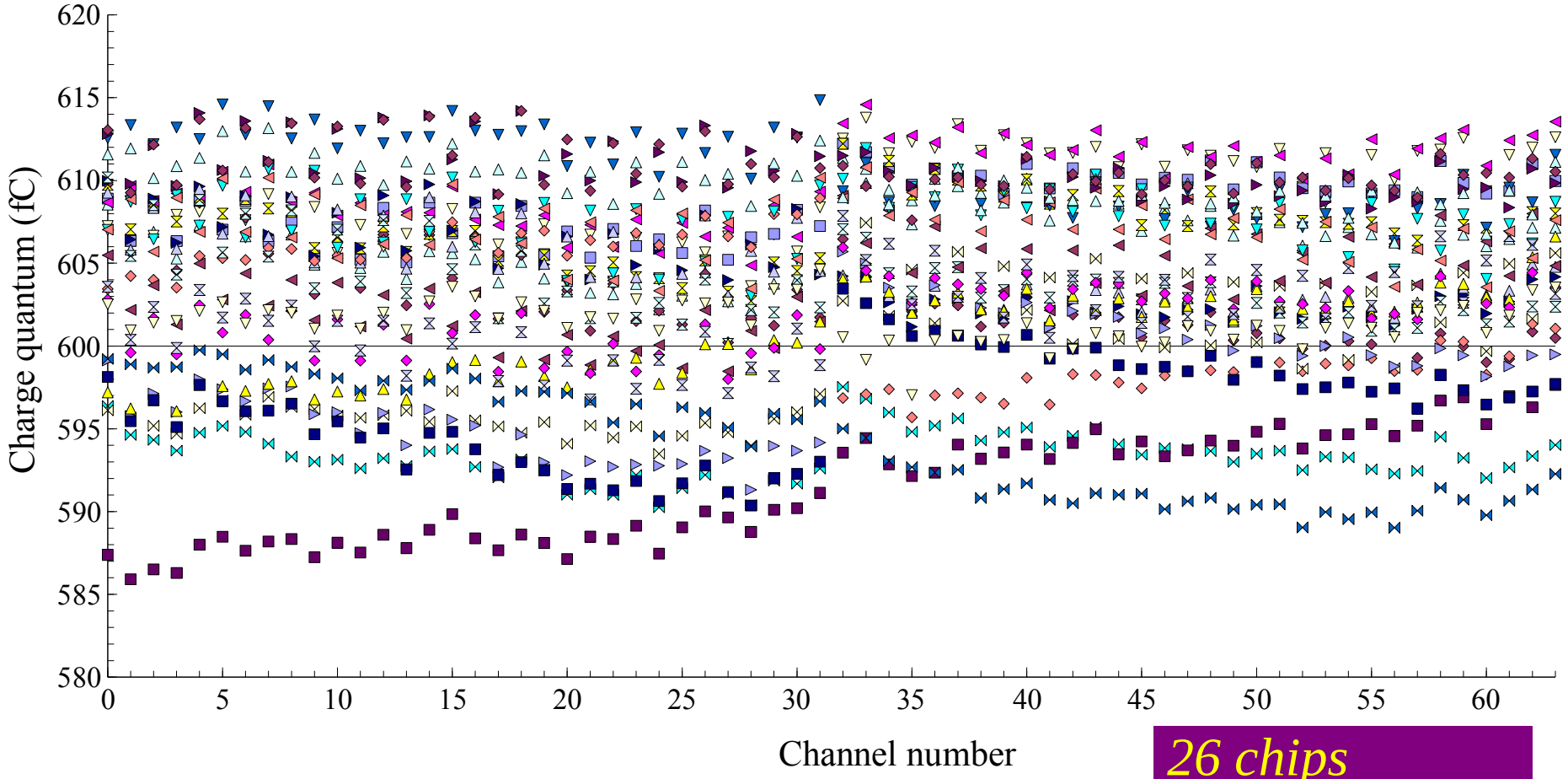


Charge quantum @ 600fC

Sezione di Torino



26 chips
Itest = 49.96 nA
ΔV = 3 V

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Distribution @ 600fC

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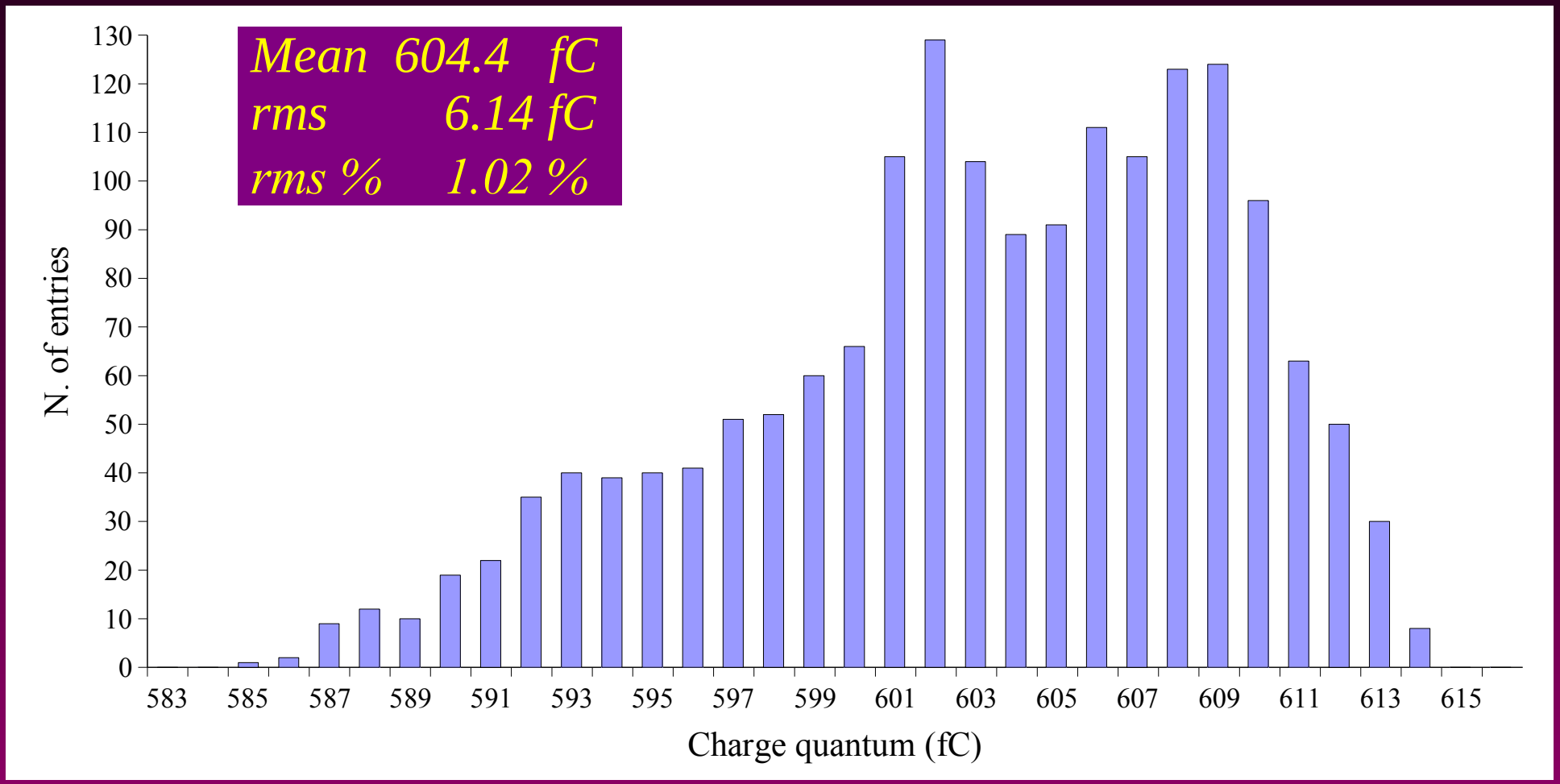
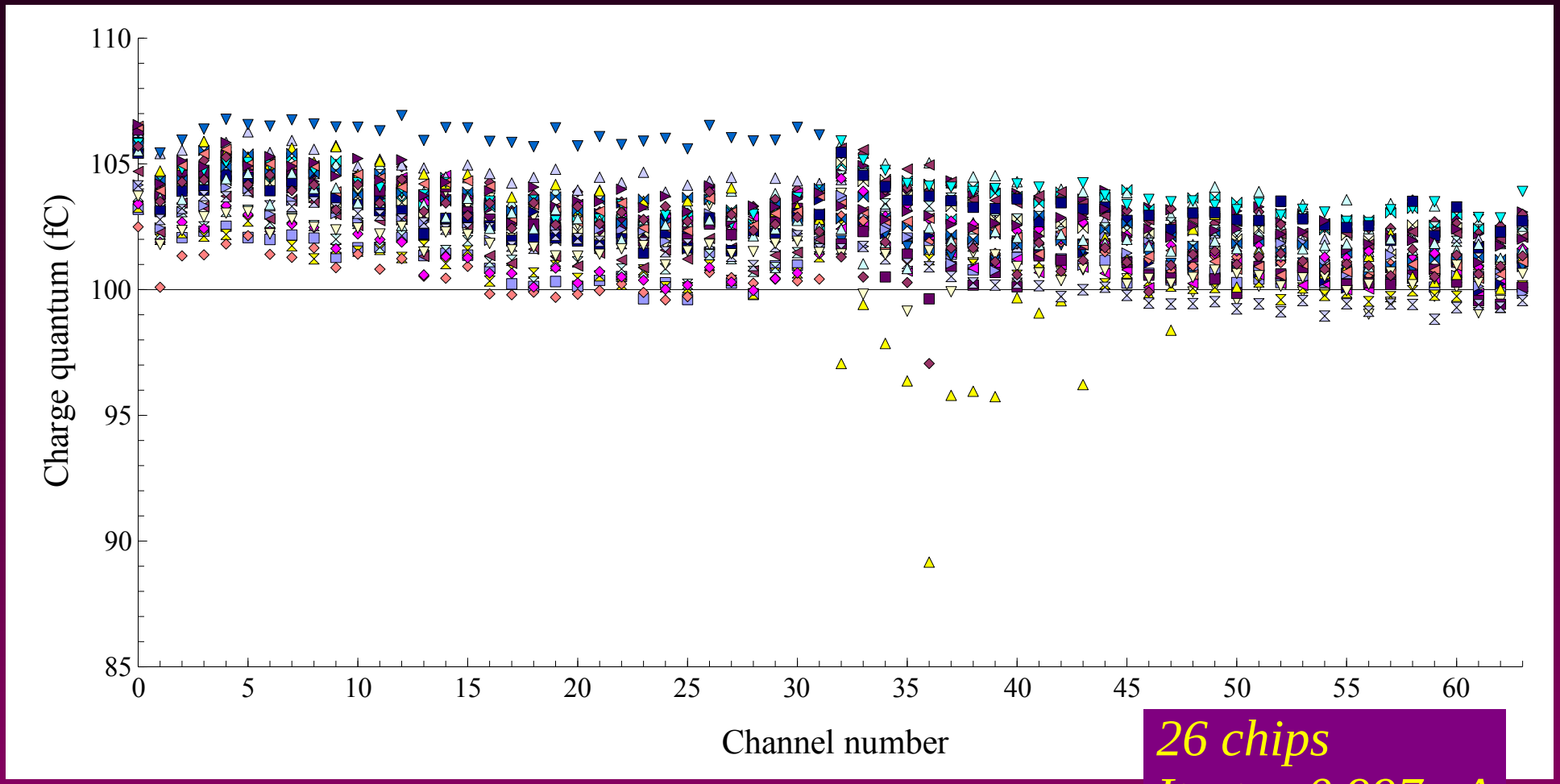


Charge quantum @ 100 fC



26 chips
Itest = 0.997 nA
ΔV = 500 mV

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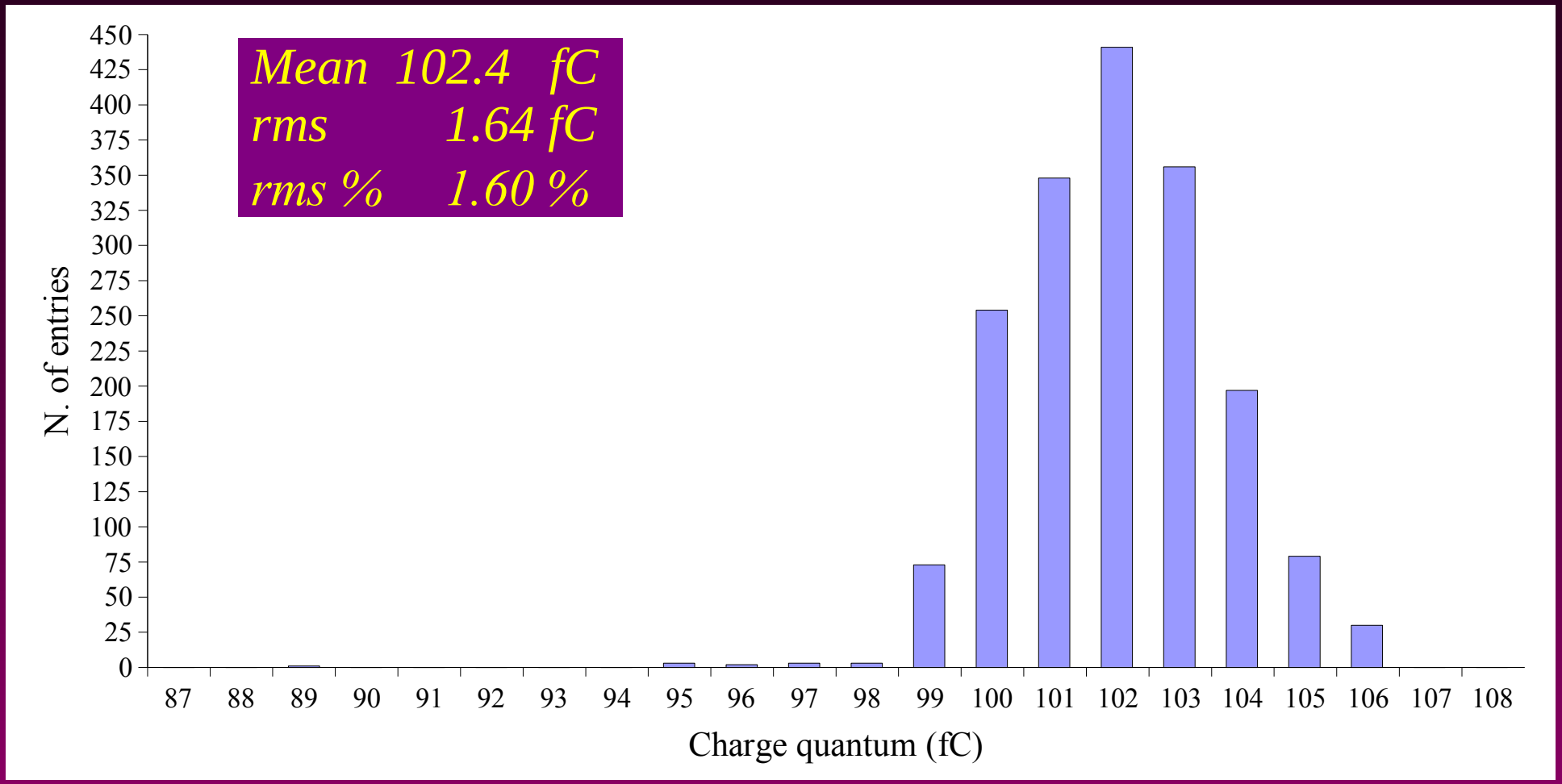
Charge quantum – 4a

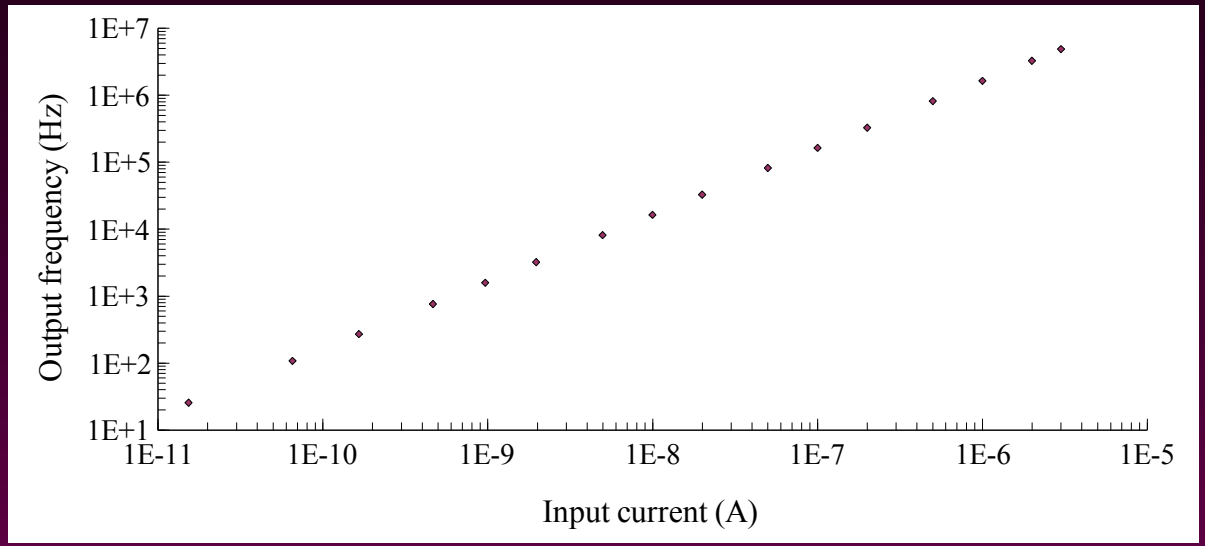
Sezione di Torino

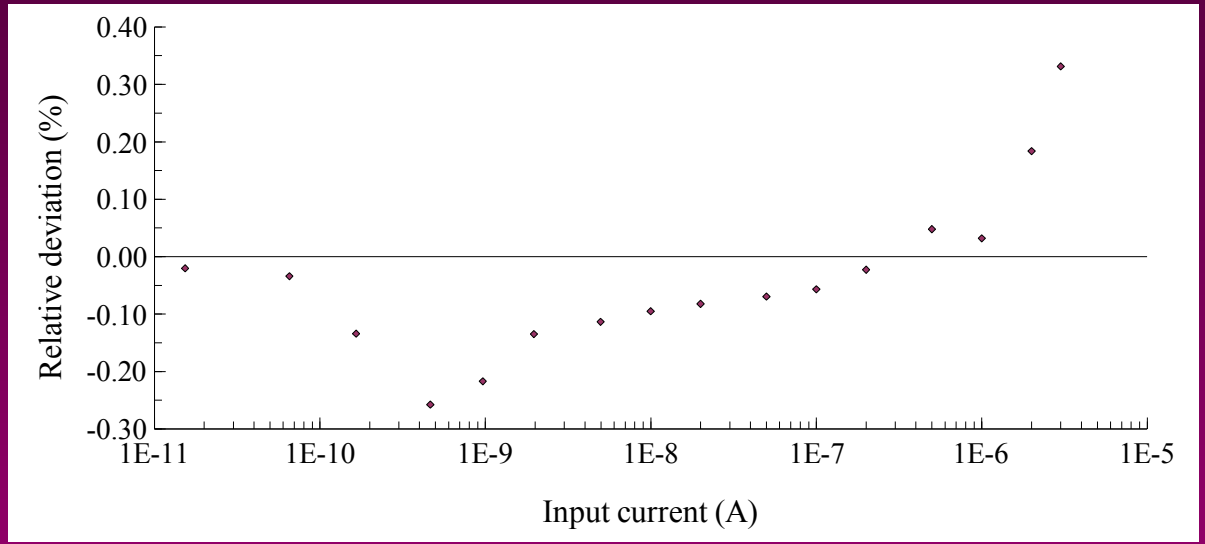


Linearity – 1a

Sezione di Torino

Chip n. 2
Channel n. 1
$\Delta V = 3$ V
Qc = 610.1 fC
Input range :
50 pA ÷ 3 μA





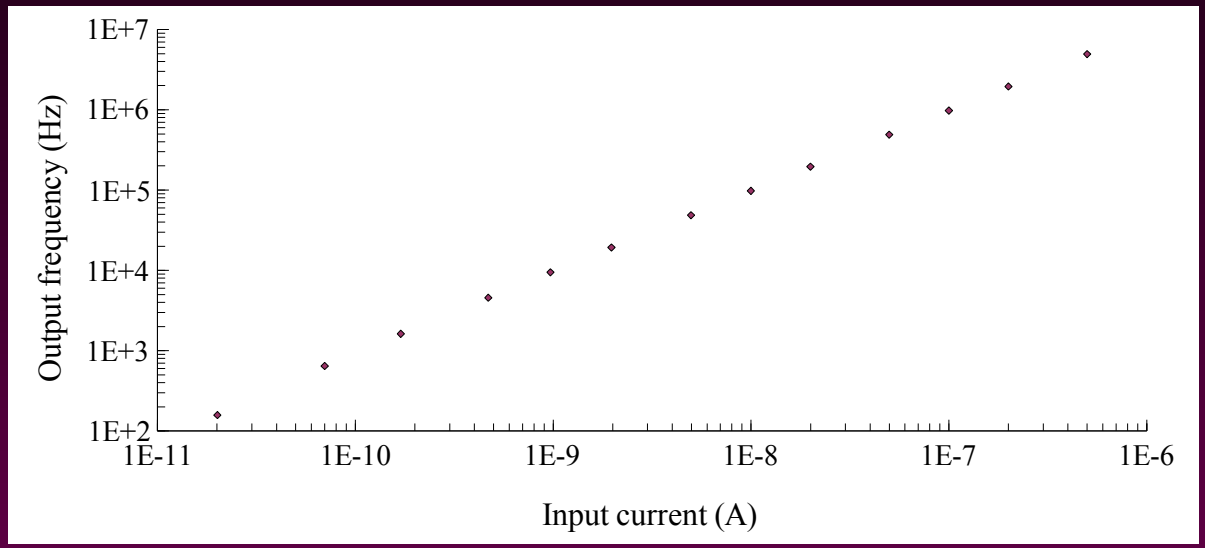
The relative deviation is better than .6 %

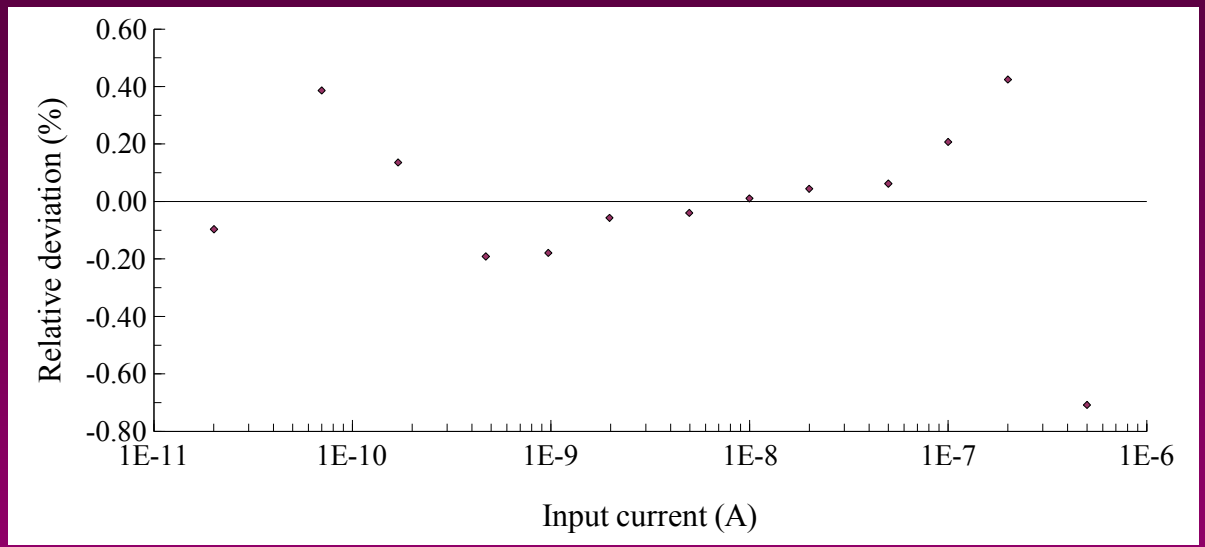
Linearity – 2a

Sezione di Torino

Chip n. 2
Channel n. 1
$\Delta V = 500$ mV
Qc = 102.2 fC
Input range :
50 pA ÷ 500 nA

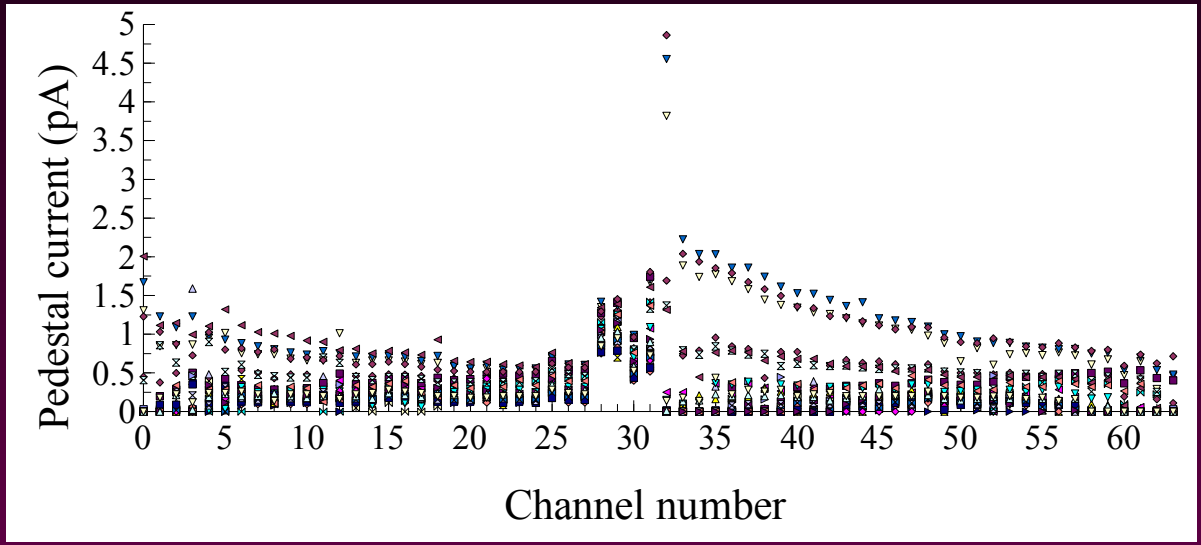
The relative deviation is better than 1 %

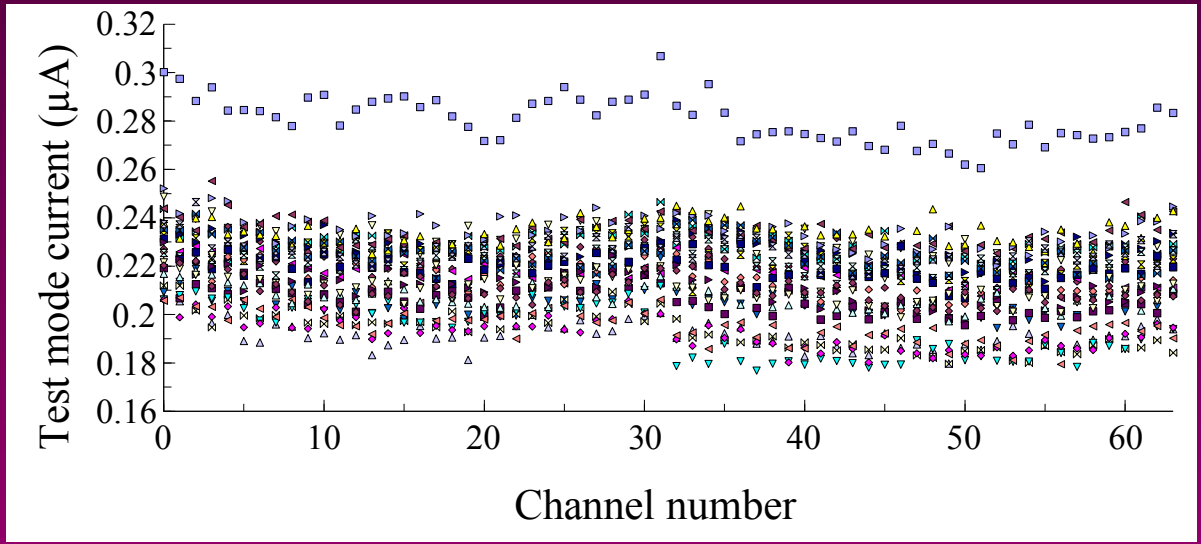




Pedestals & test mode

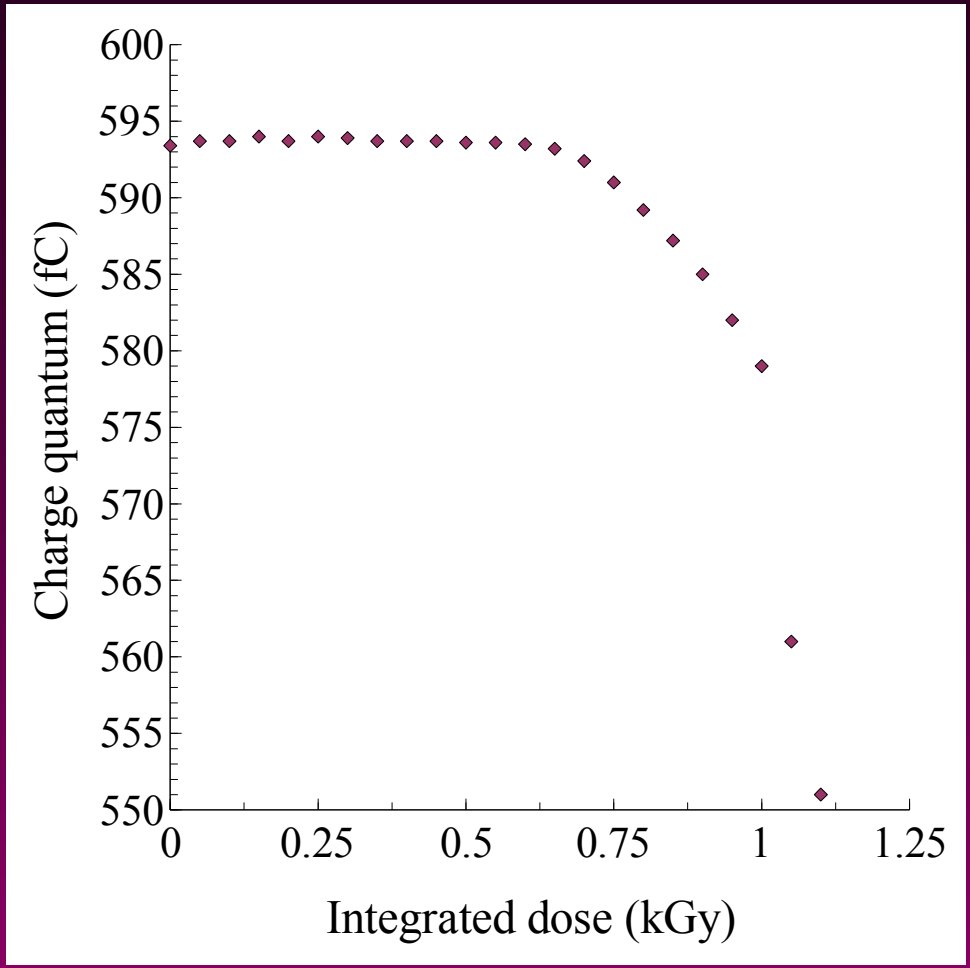
Sezione di Torino

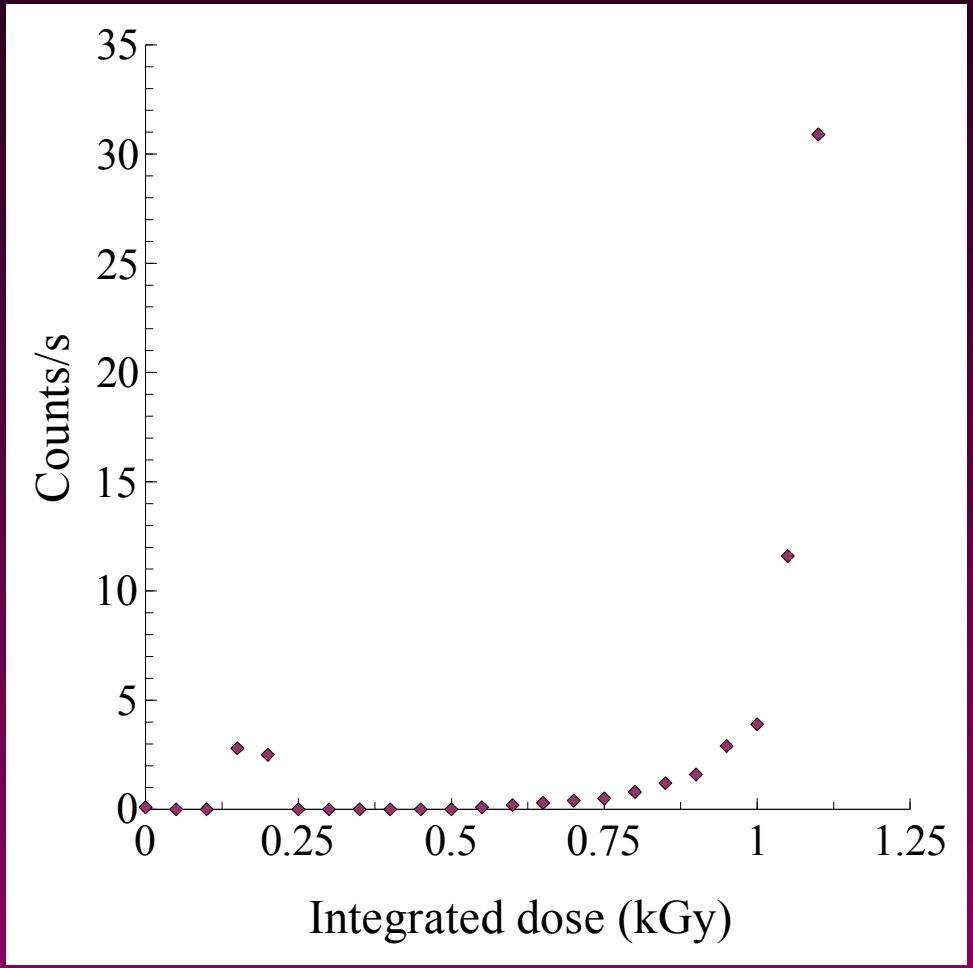




Radiation Tolerance

Sezione di Torino





Application

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New ASIC

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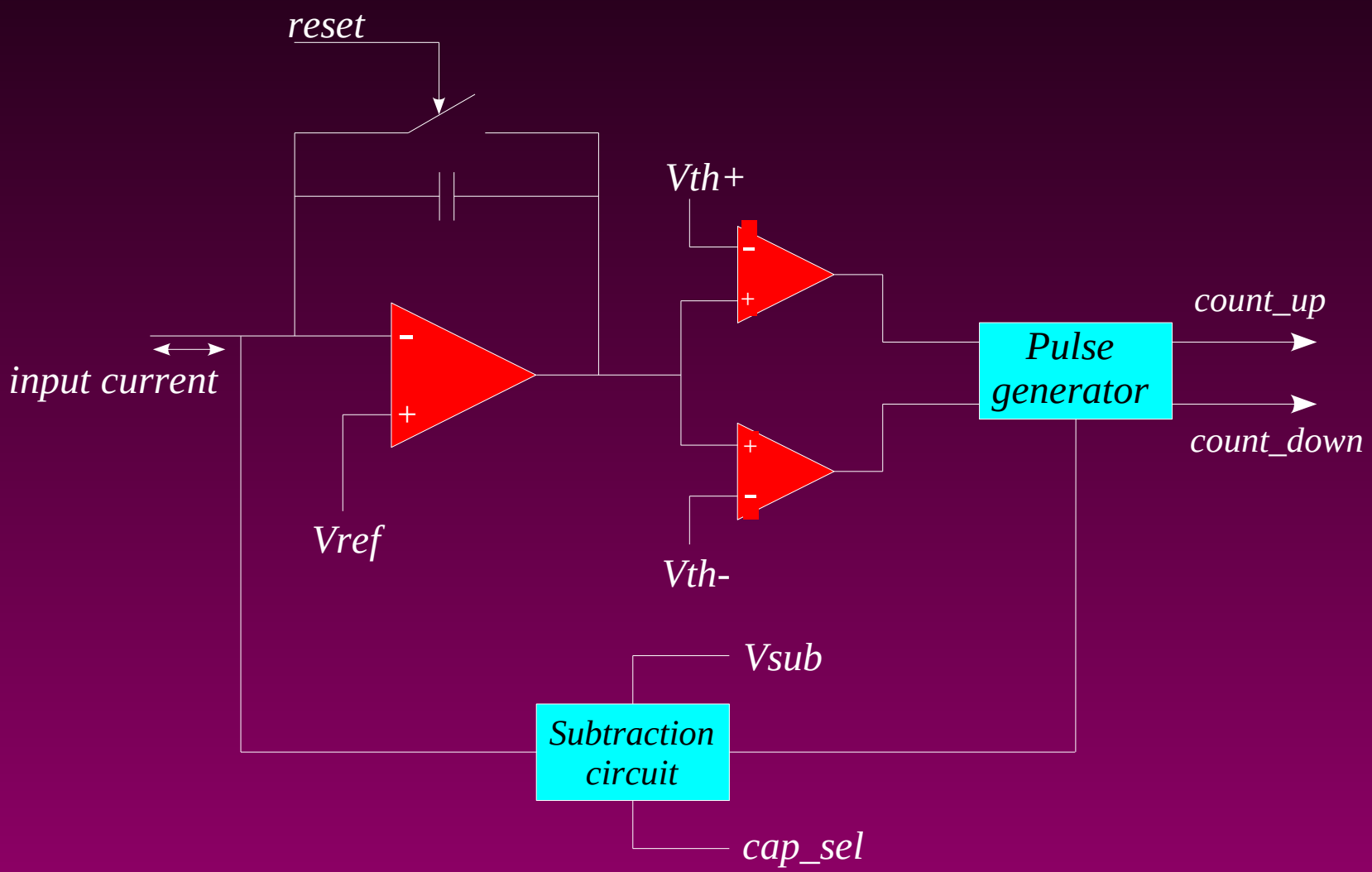
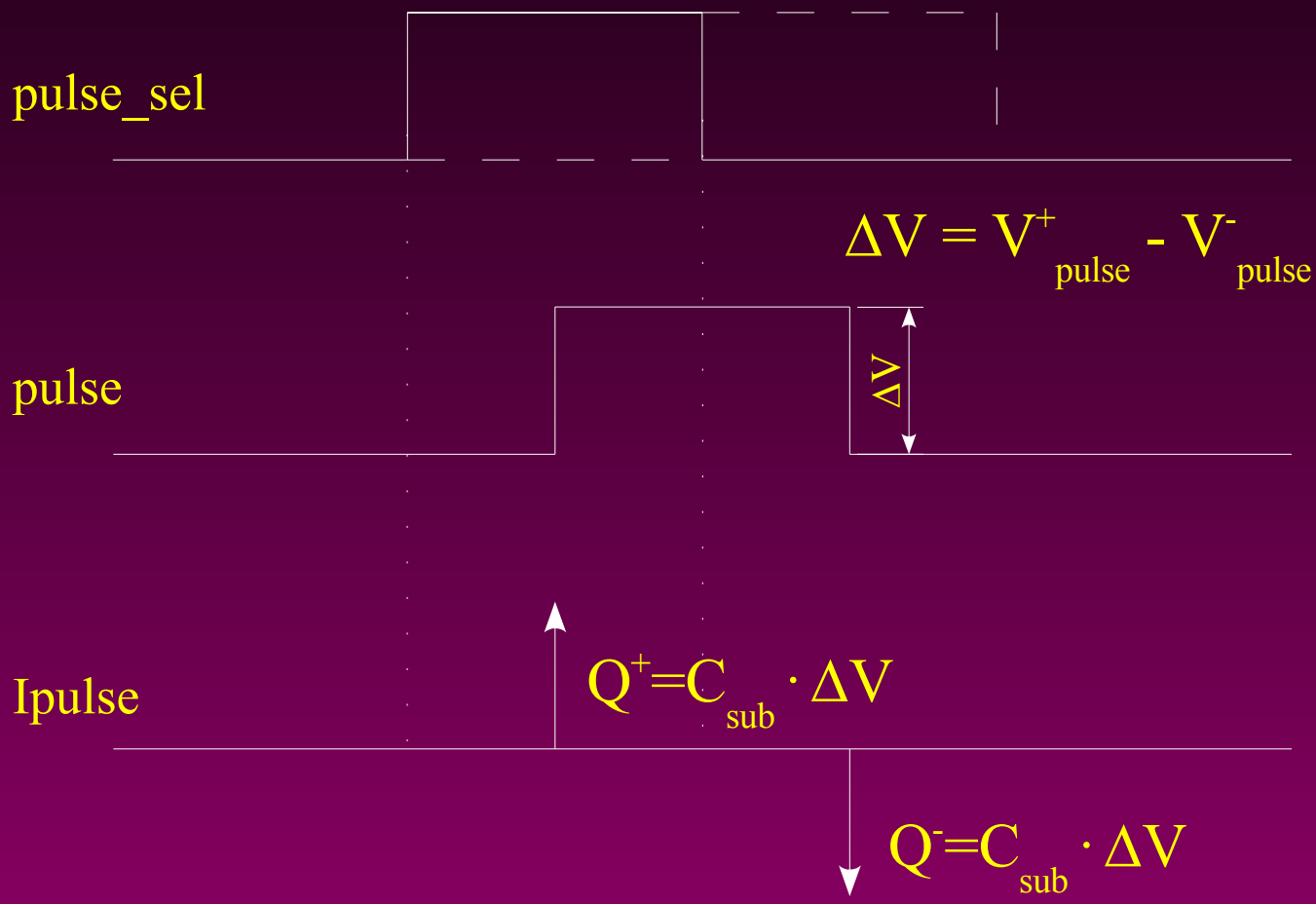


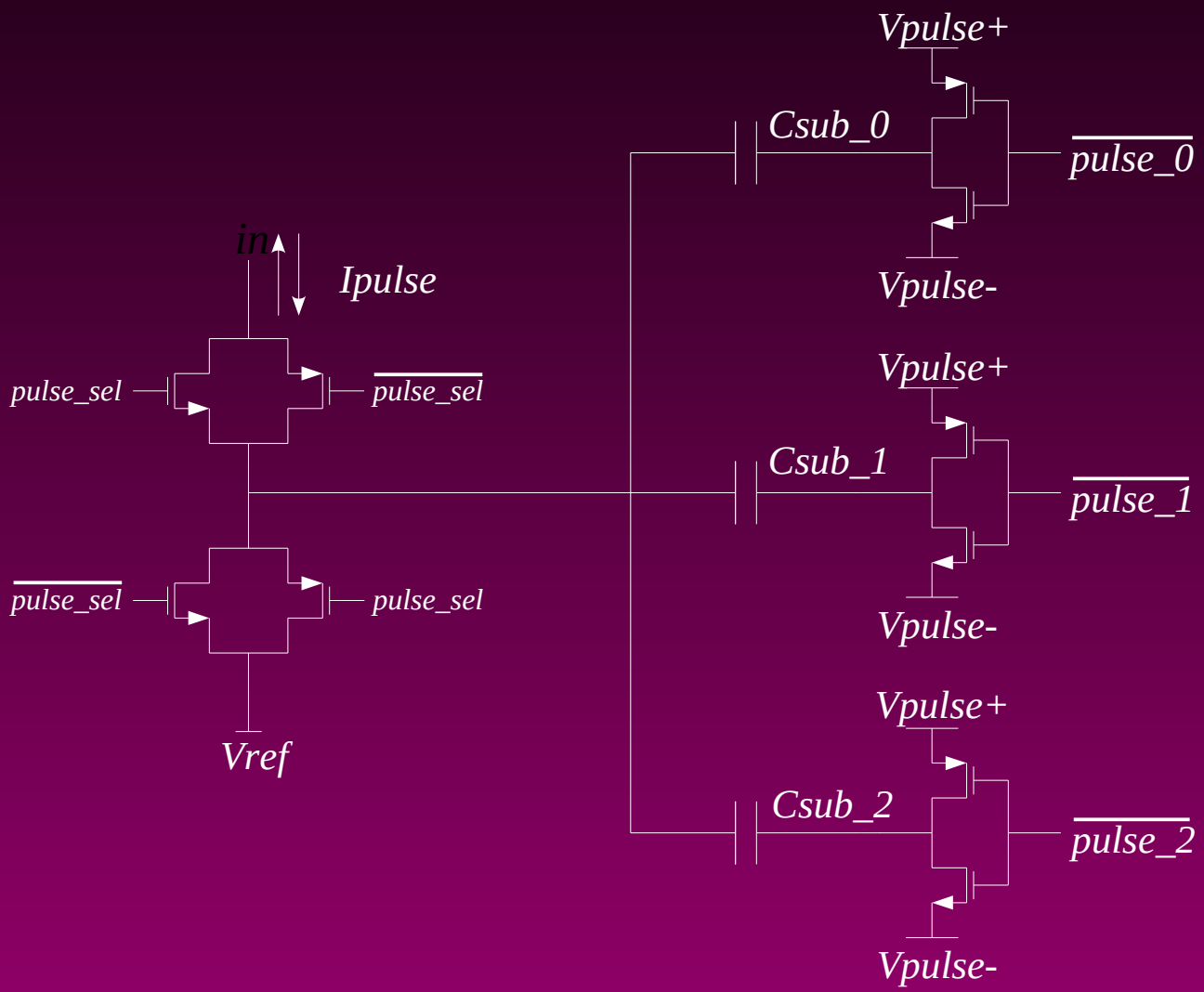
Waveforms

Sezione di Torino



Subtraction scheme

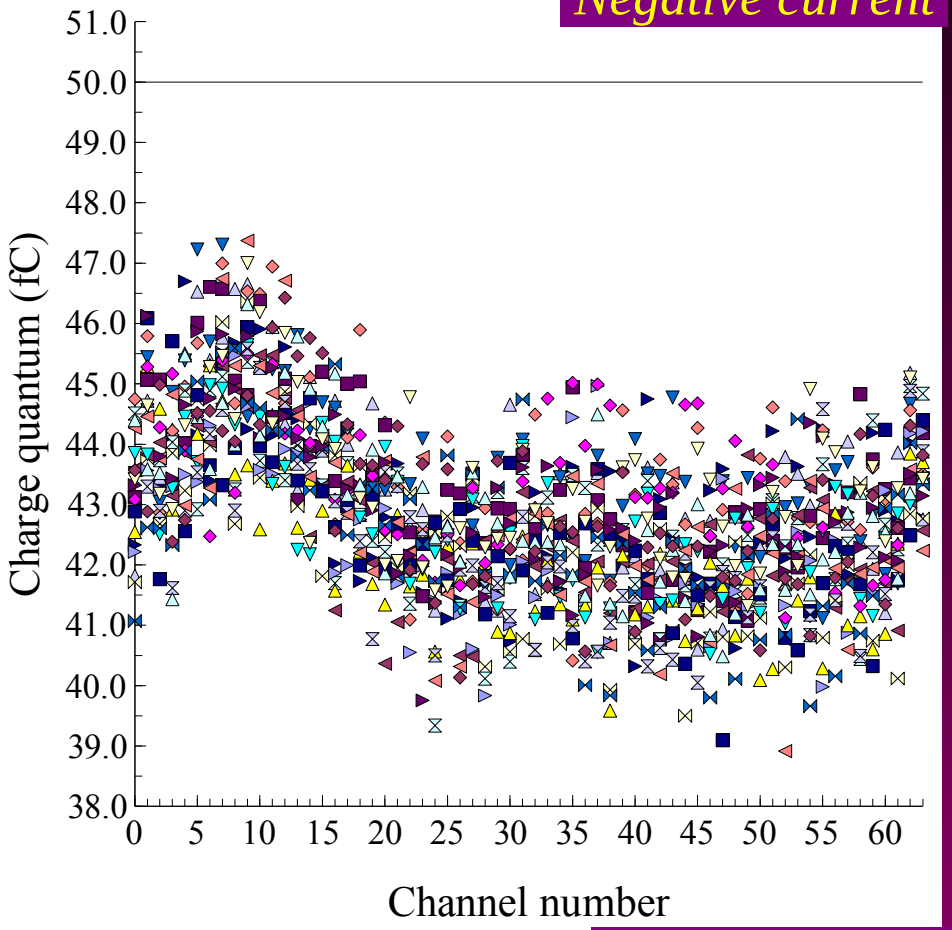
Sezione di Torino



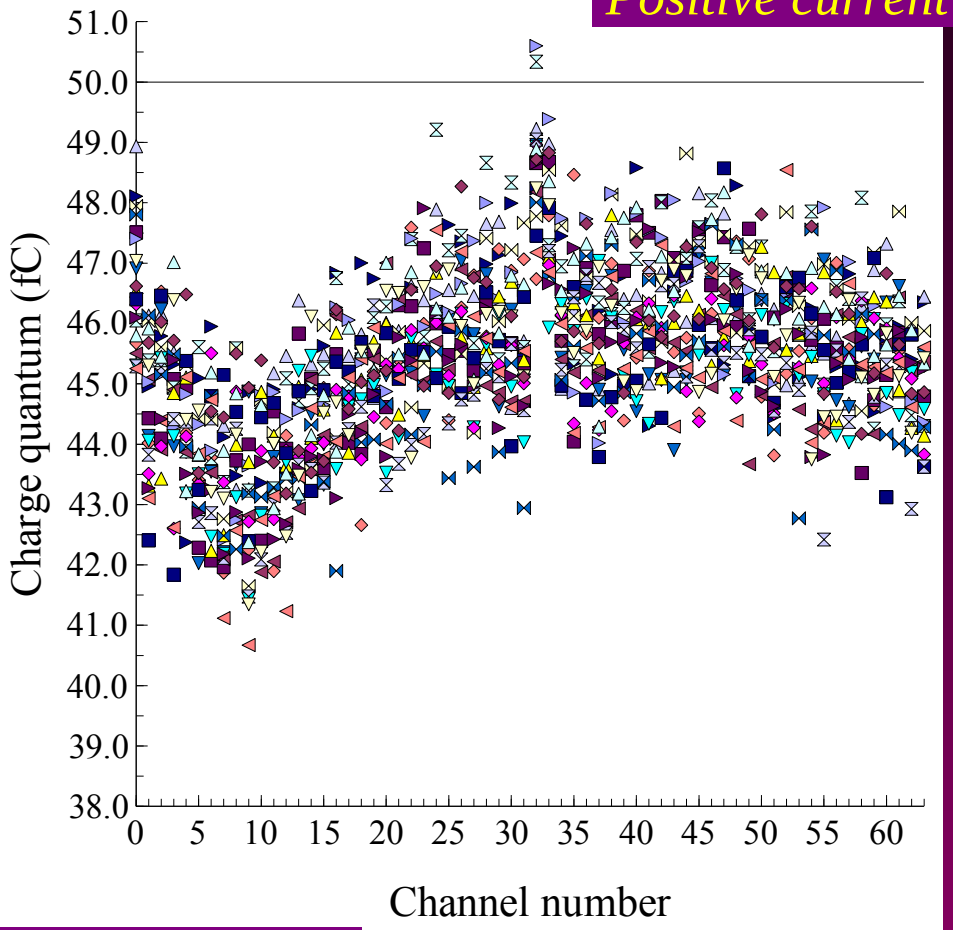
Charge quantum @ 50fC

Sezione di Torino

Negative current



Positive current



20 chips *ΔV = 1 V*

Itest = 100 nA *capsel = 001*

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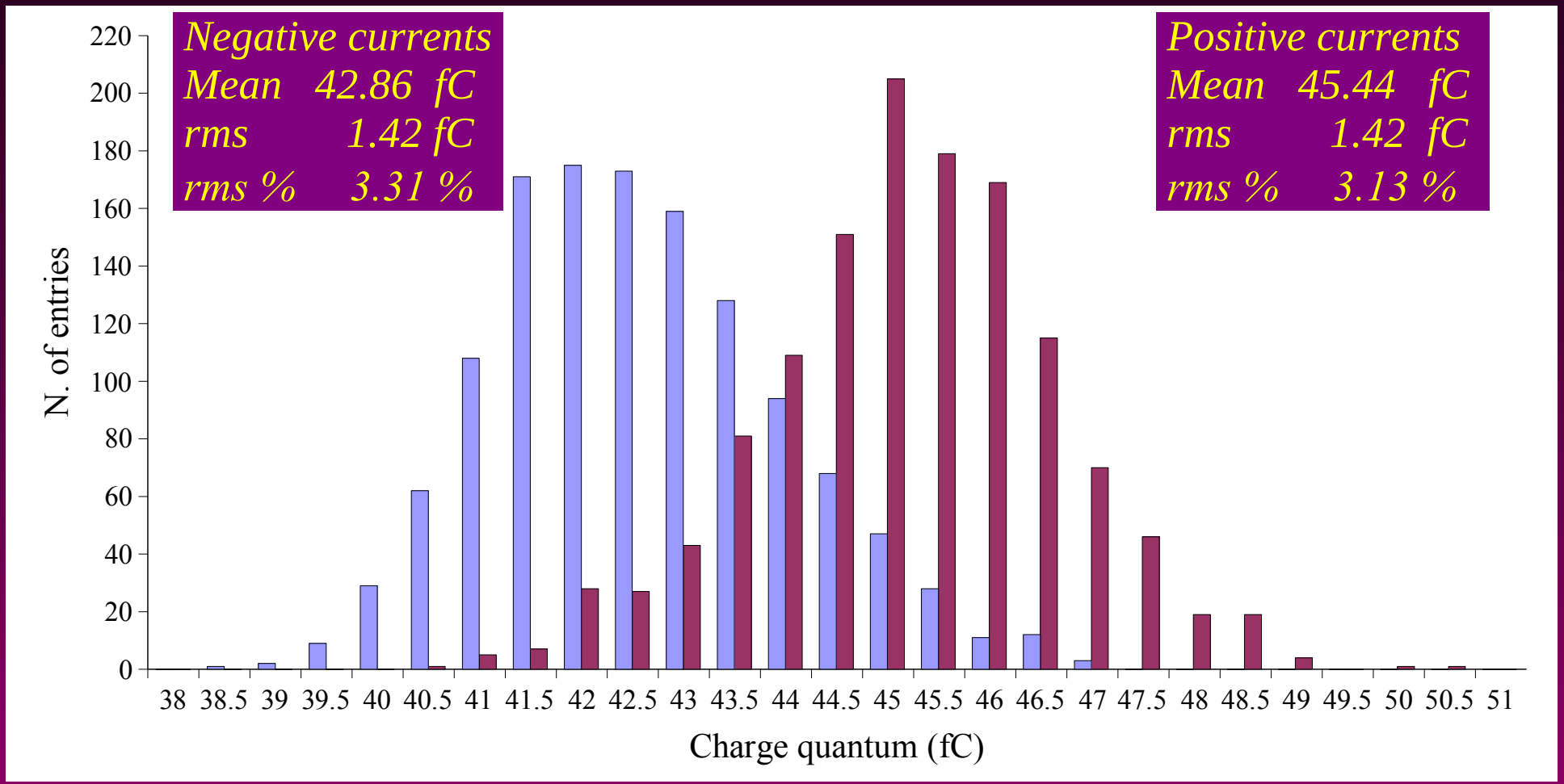
Distribution @ 50fC

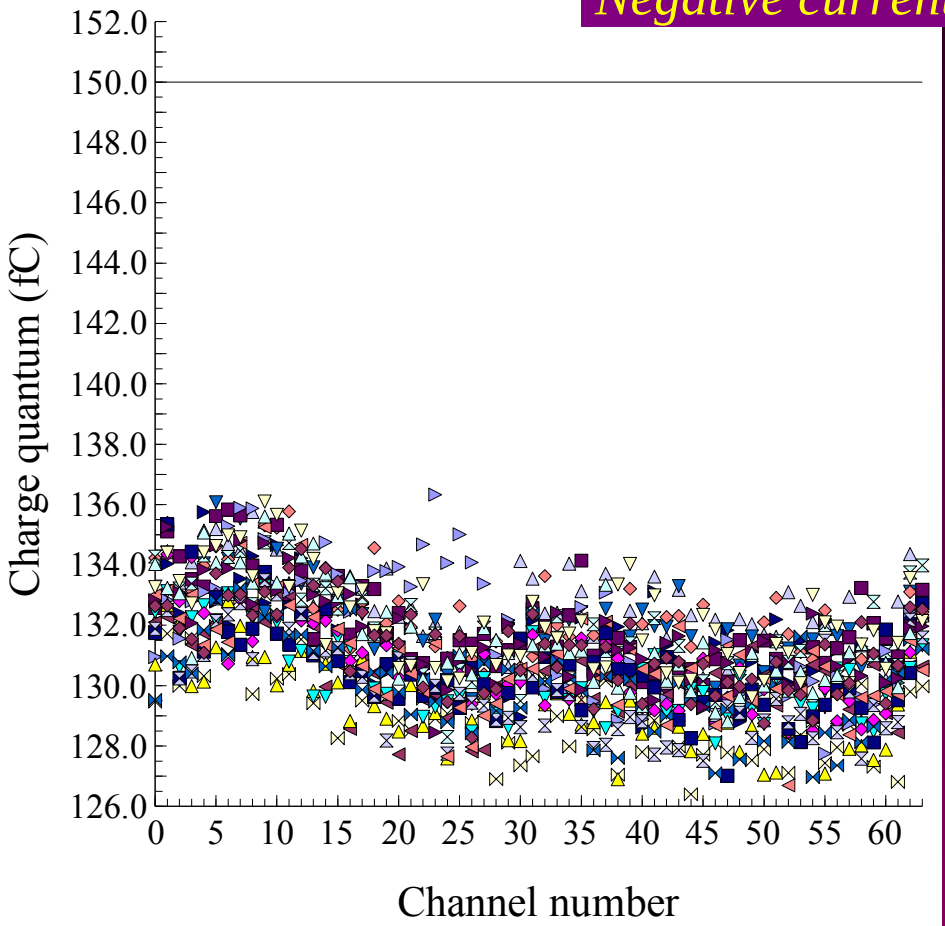
Sezione di Torino



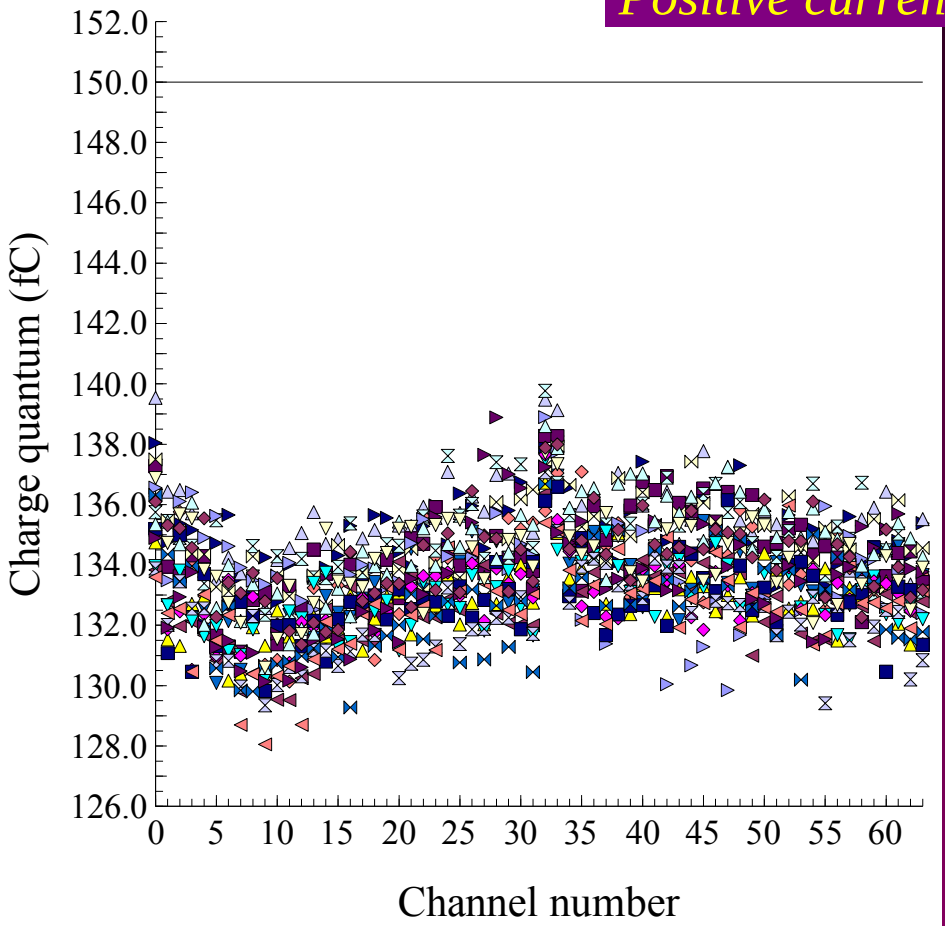
Charge quantum @ 150fC

Sezione di Torino

Negative current



Positive current



20 chips *ΔV = 1 V*

Itest = 100 nA *capsel = 011*

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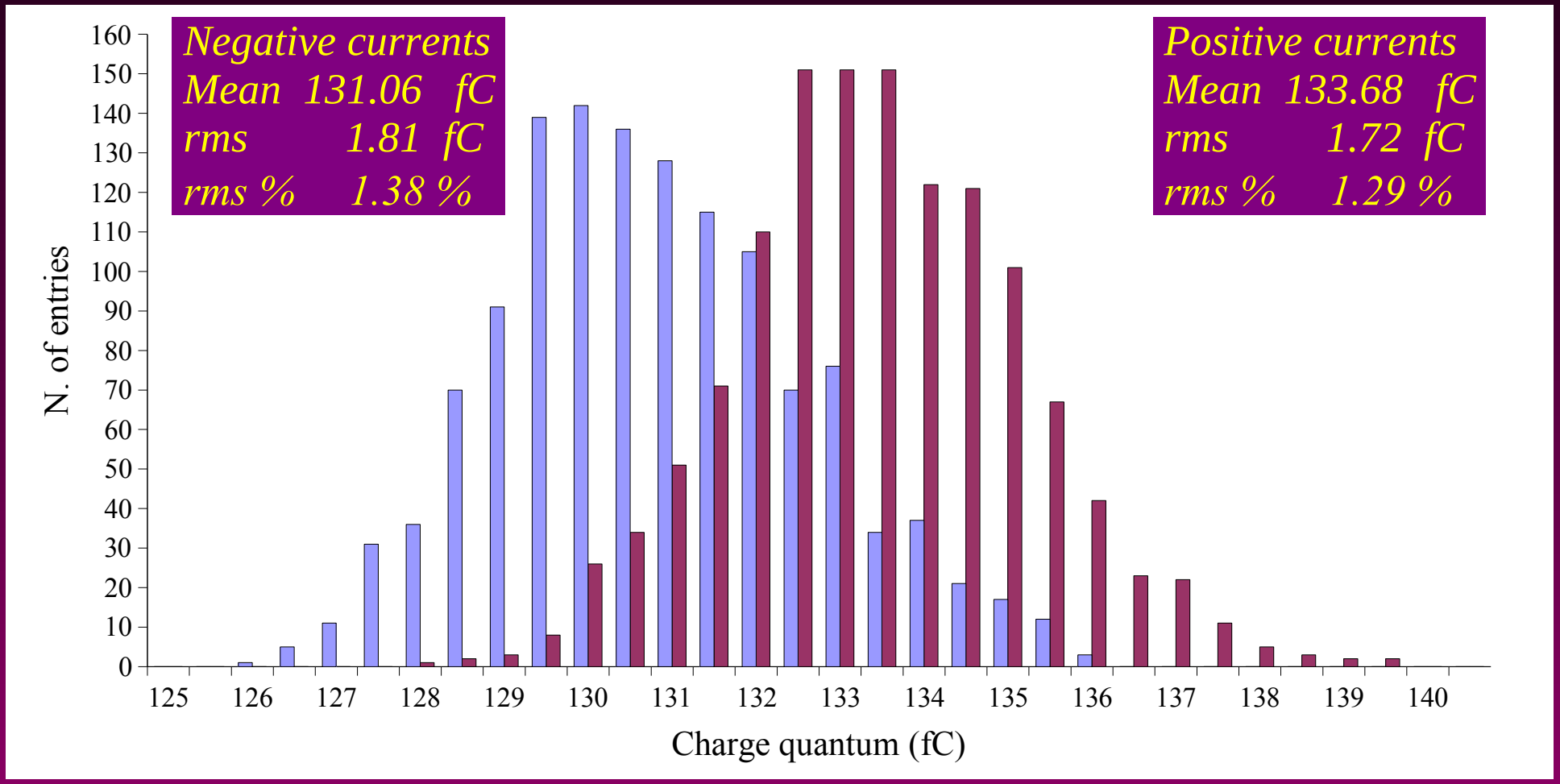
Distribution @ 150fC

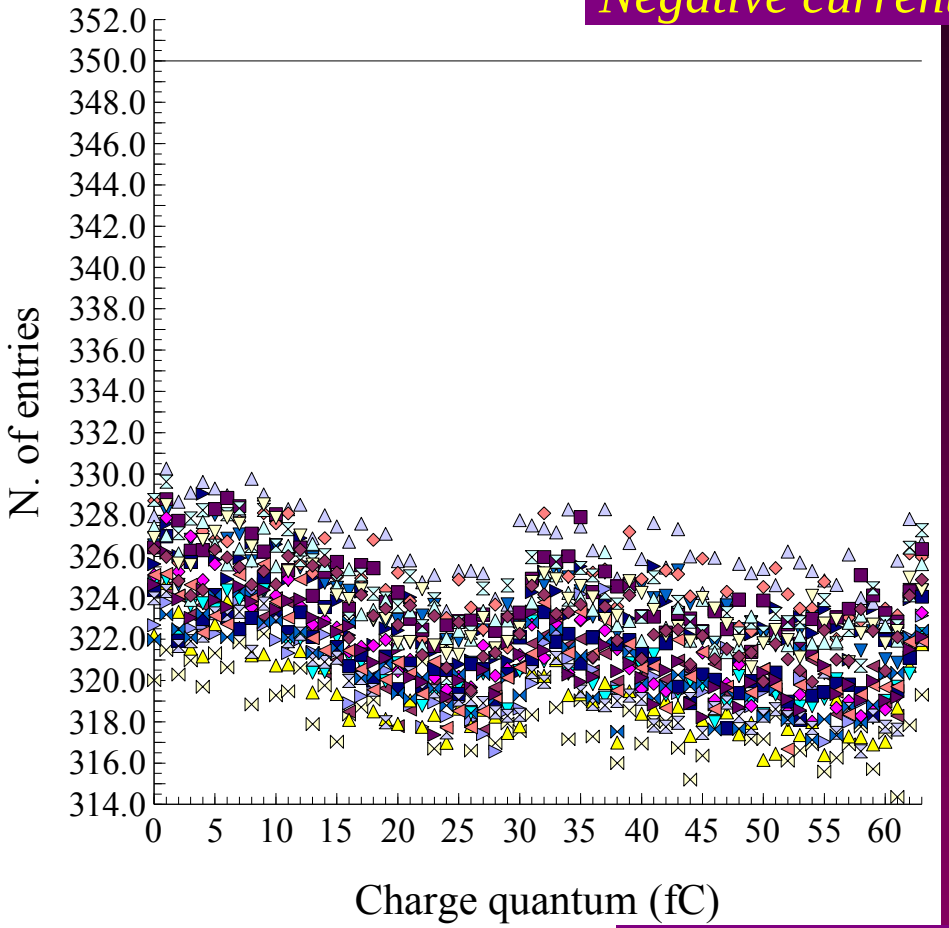
Sezione di Torino



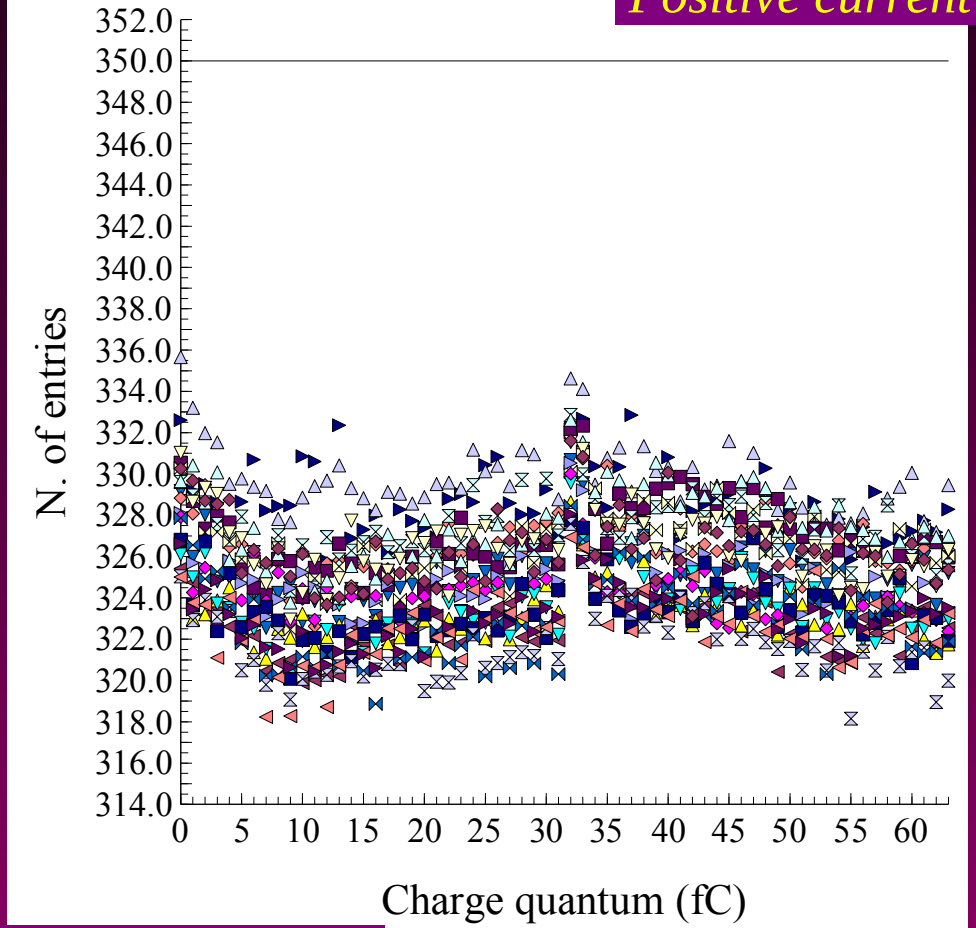
Charge quantum @ 350fC

Sezione di Torino

Negative current



Positive current



20 chips *ΔV = 1 V*

Itest = 100 nA *capsel = 111*

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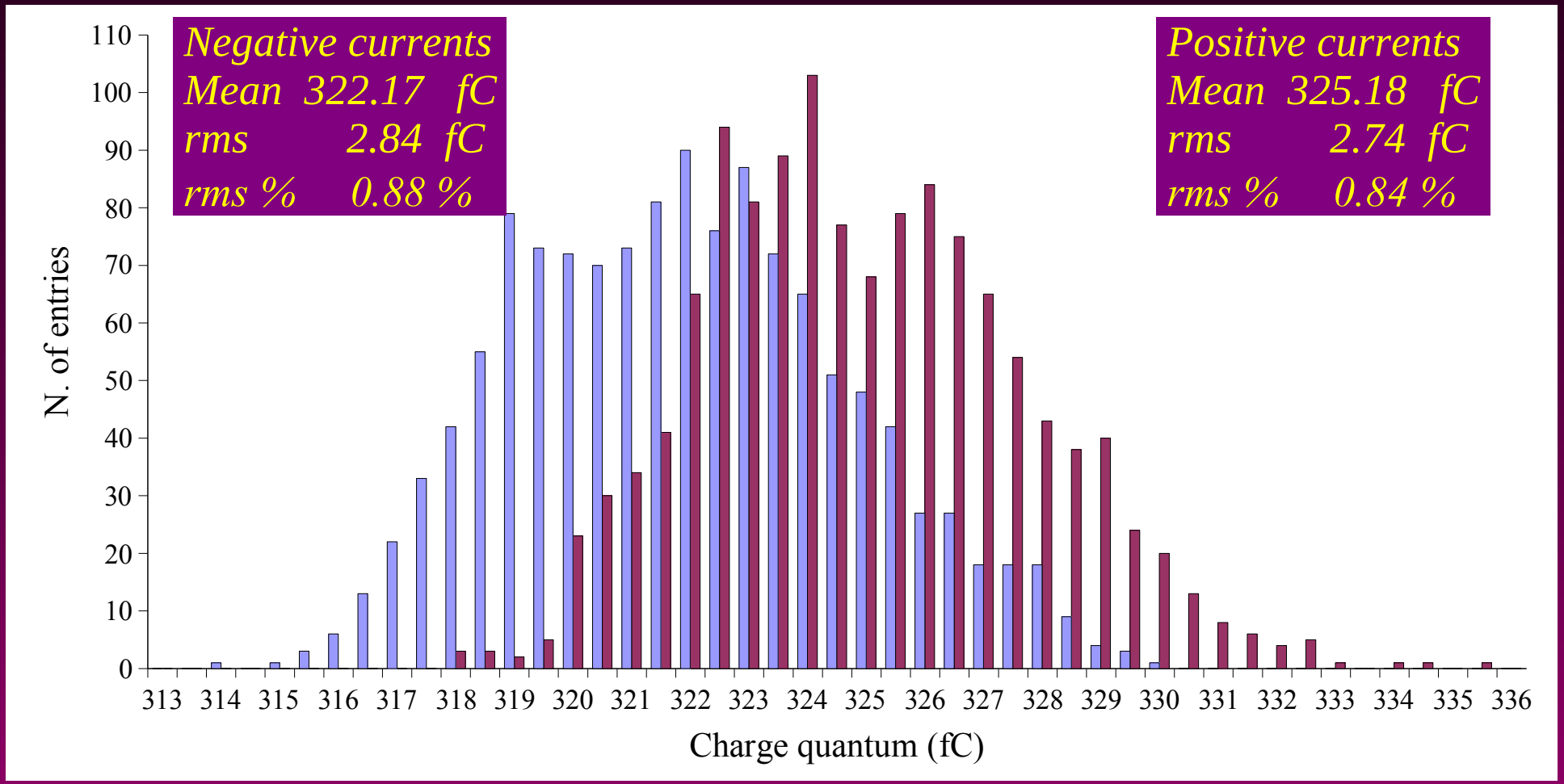
Charge quantum @ 350fC

Sezione di Torino



Charge quantum

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	Negative input current			Positive input current		
Q_{th} (fC)	Q_{meas} (fC)	r.m.s (fC)	r.m.s (%)	Q_{meas} (fC)	r.m.s (fC)	r.m.s (%)
50	42.86	1.42	3.31	45.44	1.42	3.13
100	86.84	1.67	1.92	89.42	1.50	1.68
150	131.06	1.81	1.38	133.68	1.72	1.29
200	189.39	2.07	1.09	192.20	1.92	1.00
250	233.89	2.47	1.06	236.71	2.16	0.91
300	277.70	2.65	0.95	280.65	2.43	0.87
350	322.17	2.84	0.88	325.18	2.74	0.84

Linearity @ 150 fC - 1

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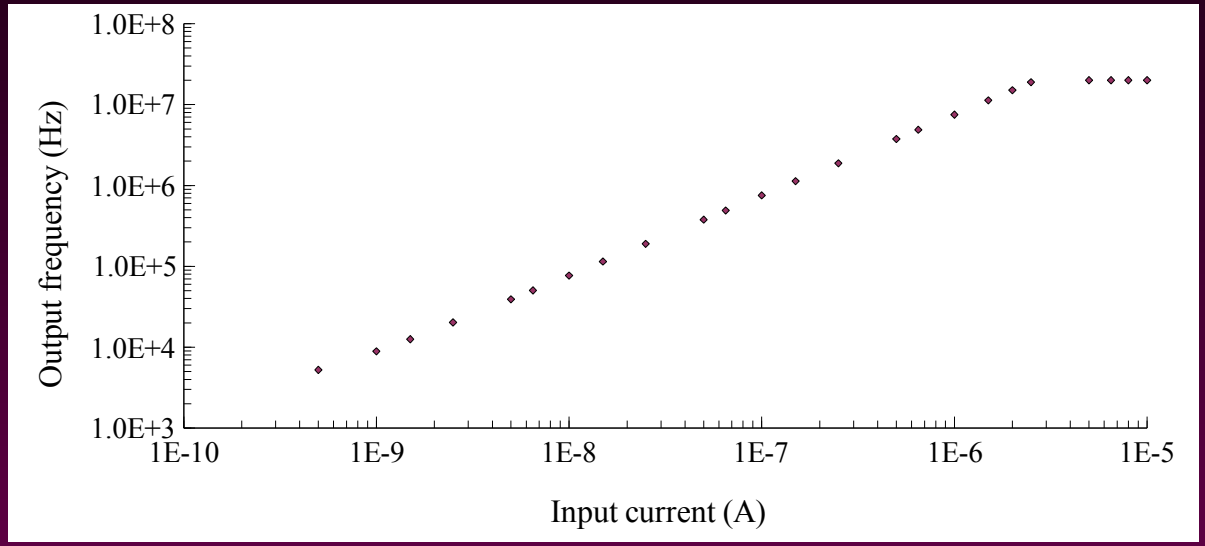
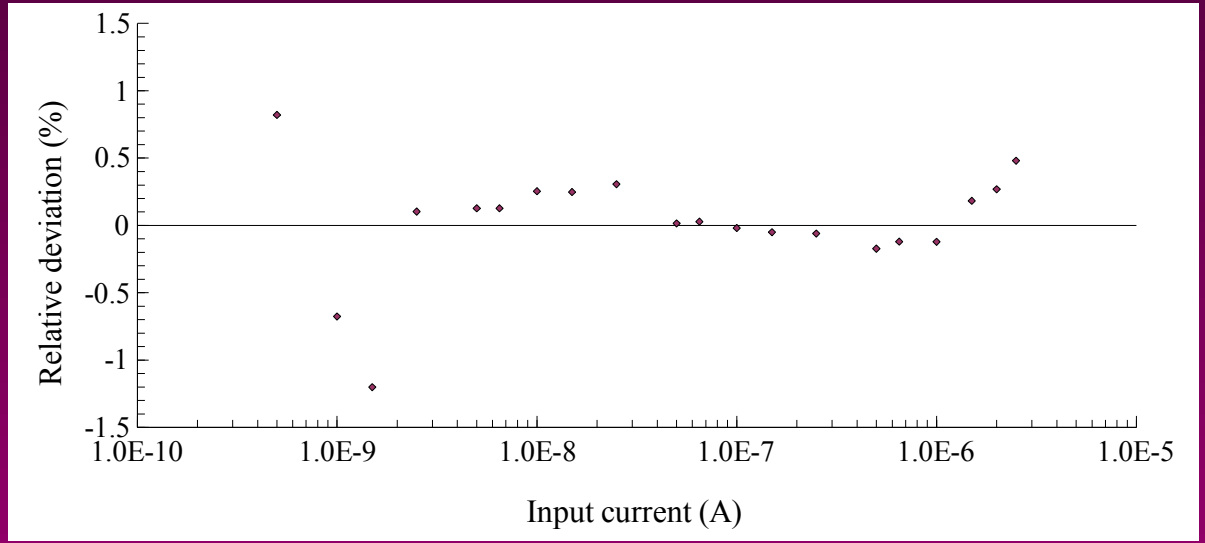
Chip n. 1
Channel n. 15
Negative currents
Qc = 132.98 fC
Input range :
500 pA ÷ 2.5 μA



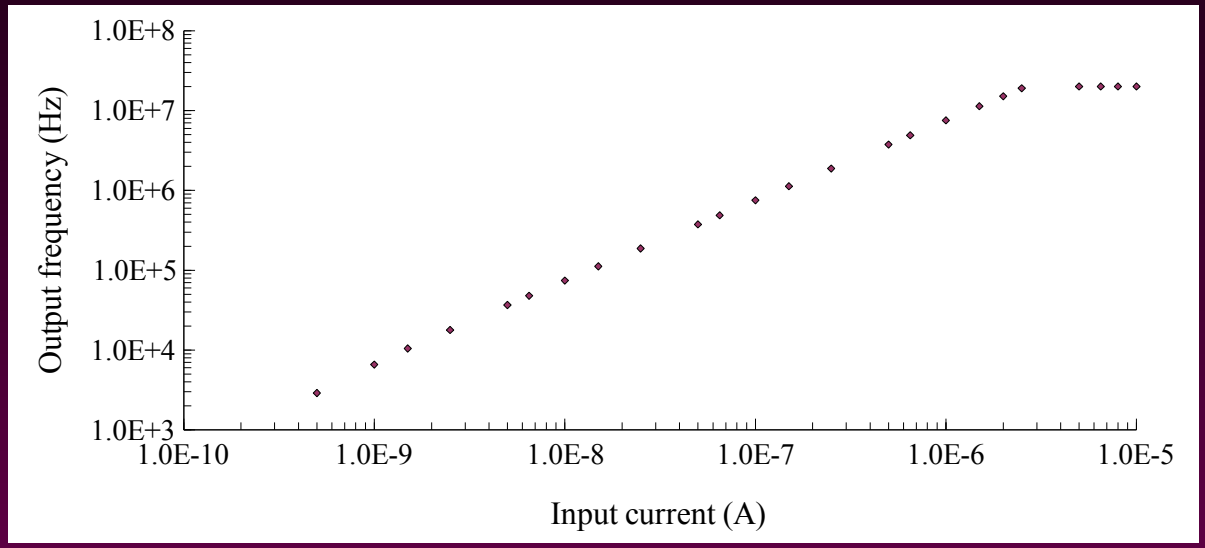
The relative deviation is around 2%

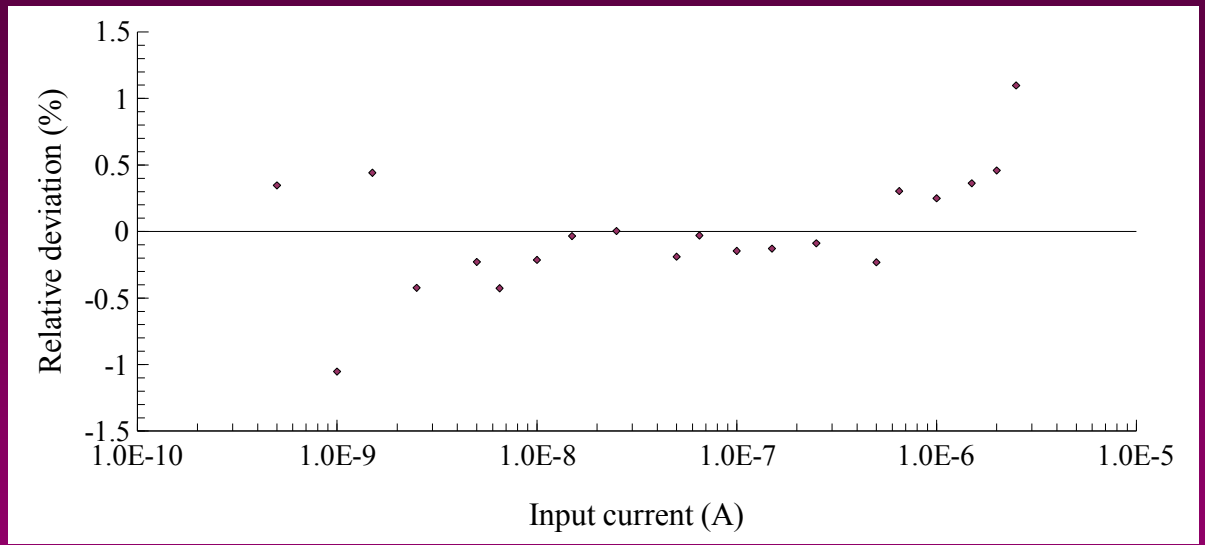


Linearity @ 150 fC - 2

Sezione di Torino

Chip n. 1
Channel n. 15
Positive currents
Qc = 132.80 fC
Input range :
500 pA ÷ 2.5 μA



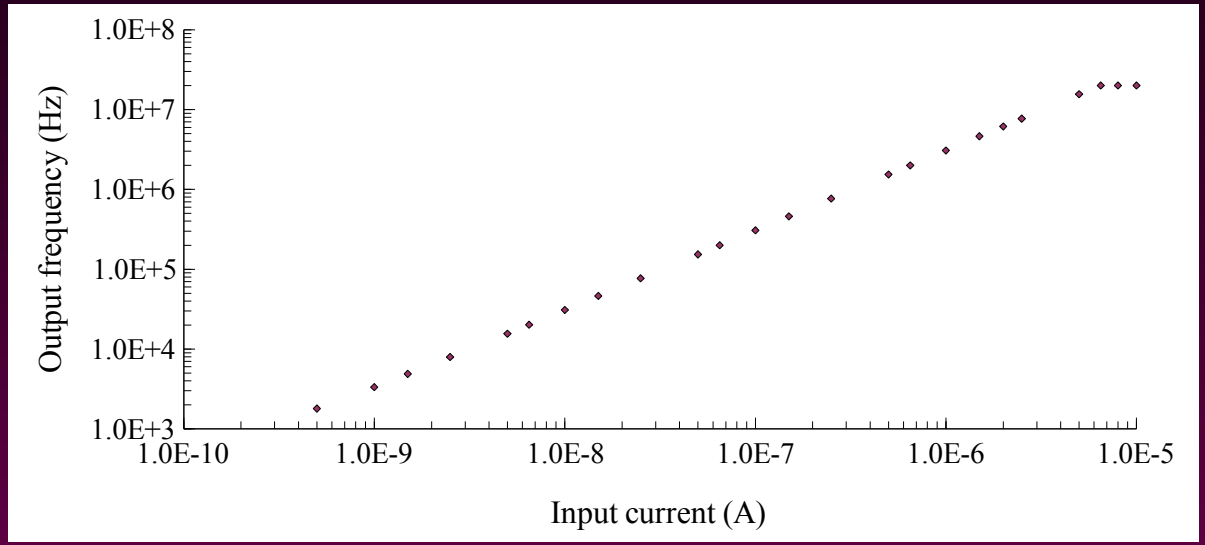


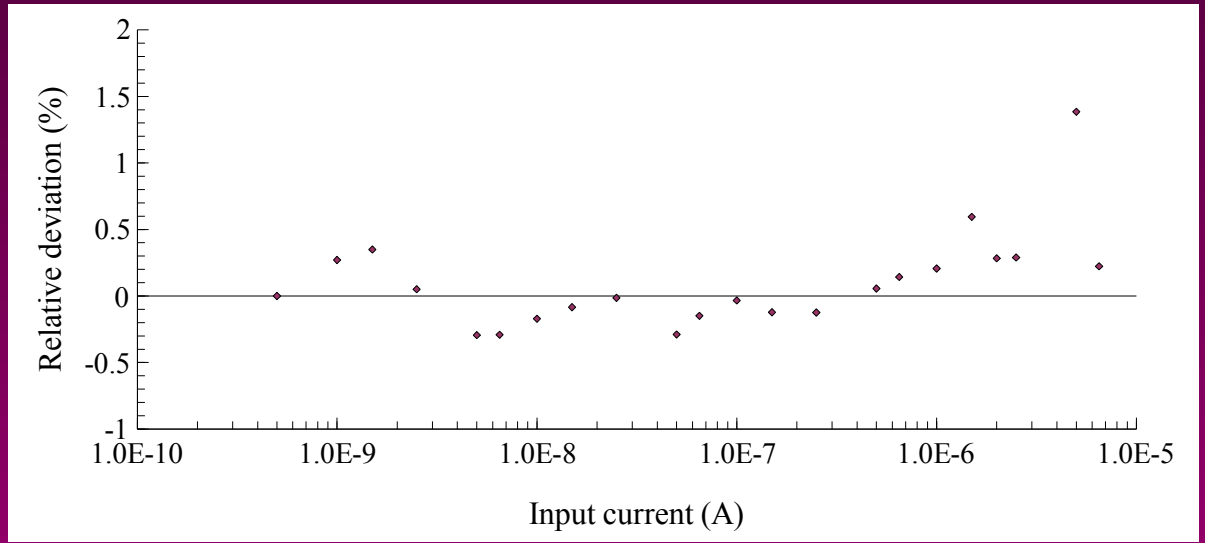
The relative deviation is around 2.2 %

Linearity @350 fC - 1

Sezione di Torino

Chip n. 1
Channel n. 15
Negative currents
Qc = 325.73 fC
Input range :
500 pA ÷ 6.5 μA



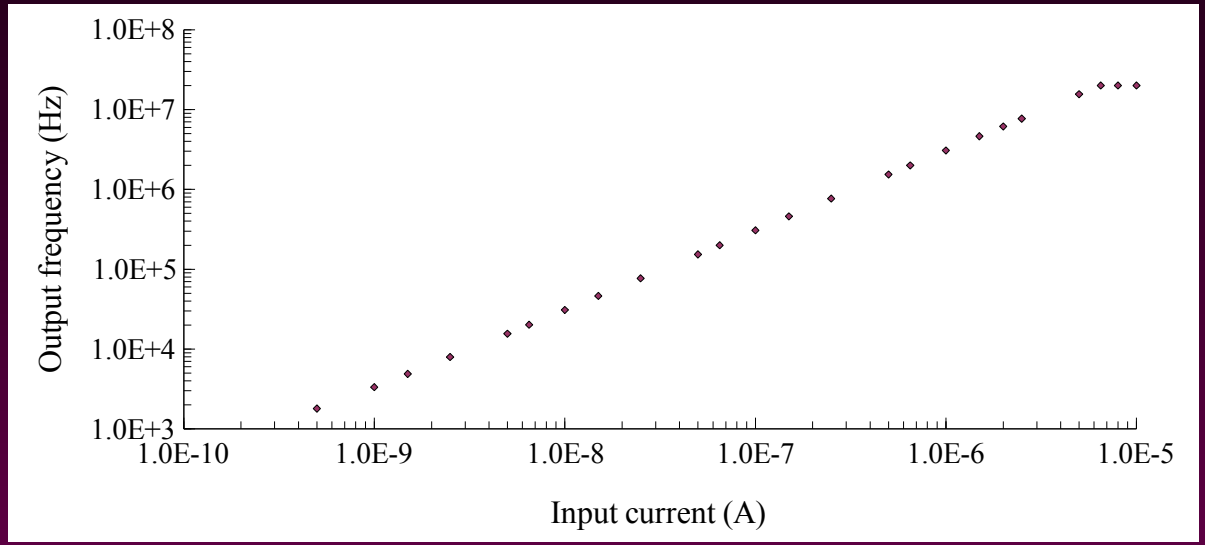


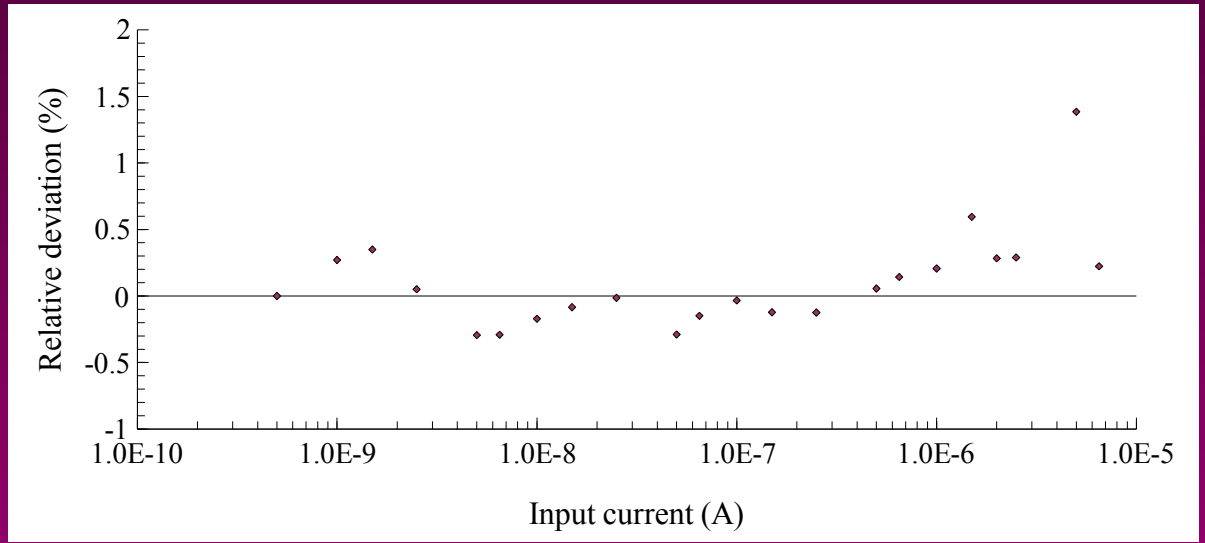
The relative deviation is below 1.7 %

Linearity – 350 fC - 2

Sezione di Torino

Chip n. 1
Channel n. 15
Positive currents
Qc = 325.86 fC
Input range :
500 pA ÷ 6.5 μA





The relative deviation is around 2.5 %

Pedestal

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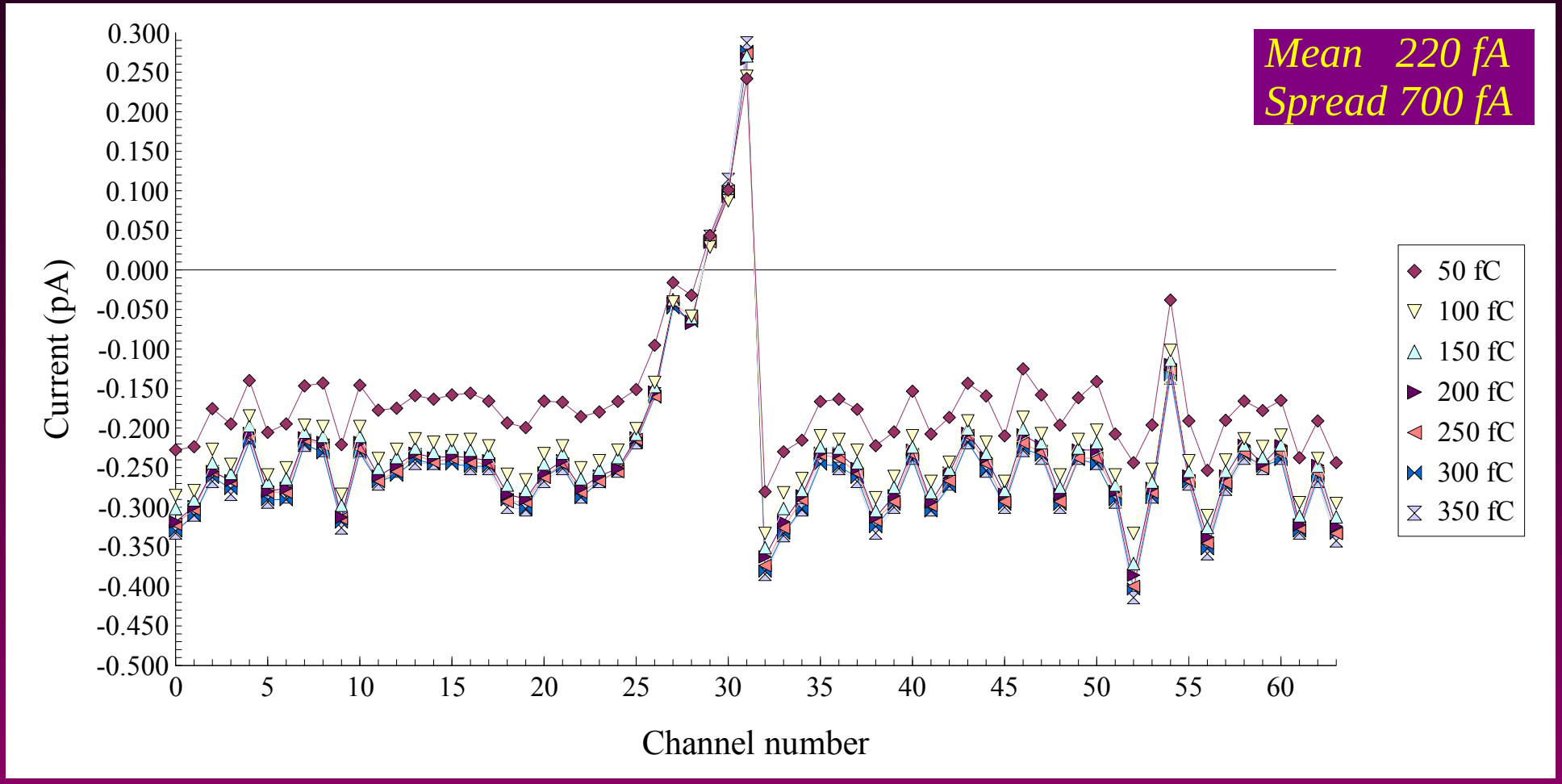

Comparison

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Technology	CMOS 0.8 µm	CMOS 0.35 µm
Die size	6x7 mm^2	5.4x4.5 mm^2
N. of channels	64	64
Cint	600 fF	600fF
Q_{min}	100 fC	50 fC
Q_{max}	1 pC	1.155 pC
Csub	200 fF	50 fF → 300 fF
N. of bit of the counter	16	32
Input current	unipolar	bipolar
Max clock frequency	20 MHz	100 MHz
Max I-f converter frequency	5 MHz	20 MHz

Conclusions

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- A 64-channel ASIC for the readout of strip and pixel ionization detectors has been designed in a 0.8 µm CMOS technology and tested.
- The charge balancing integration technique allows for a dynamic range in excess of 10^3 with a nonlinearity of less than 1%
- The ASIC is currently used in a commercial product in the framework of a technology transfer program
- A 2nd generation ASIC in 0.35 µm technology with bipolar input capability and improved performances has been designed and tested

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Spare slides

History of the Tera ASICs

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- Tera 01 : first prototype with 14 channels in CMOS 1.2 μm (1996)
- Tera 02-03 : 64 channels chips with asynchronous logic and 20/16 bits counters in CMOS 0.8 μm (1997-98)
- Tera 04 : 64 channels chip with synchronous logic and 16 bit counter (1999) - *not working...* :-(
- Tera 05-06 : same as version 4 after bug correction and mass production for IBA (2000-02)
- Tera 07 : upgrade with bipolar input capability and digital charge quantum selection in CMOS 0.35 μm (2004-05)

Temperature variation

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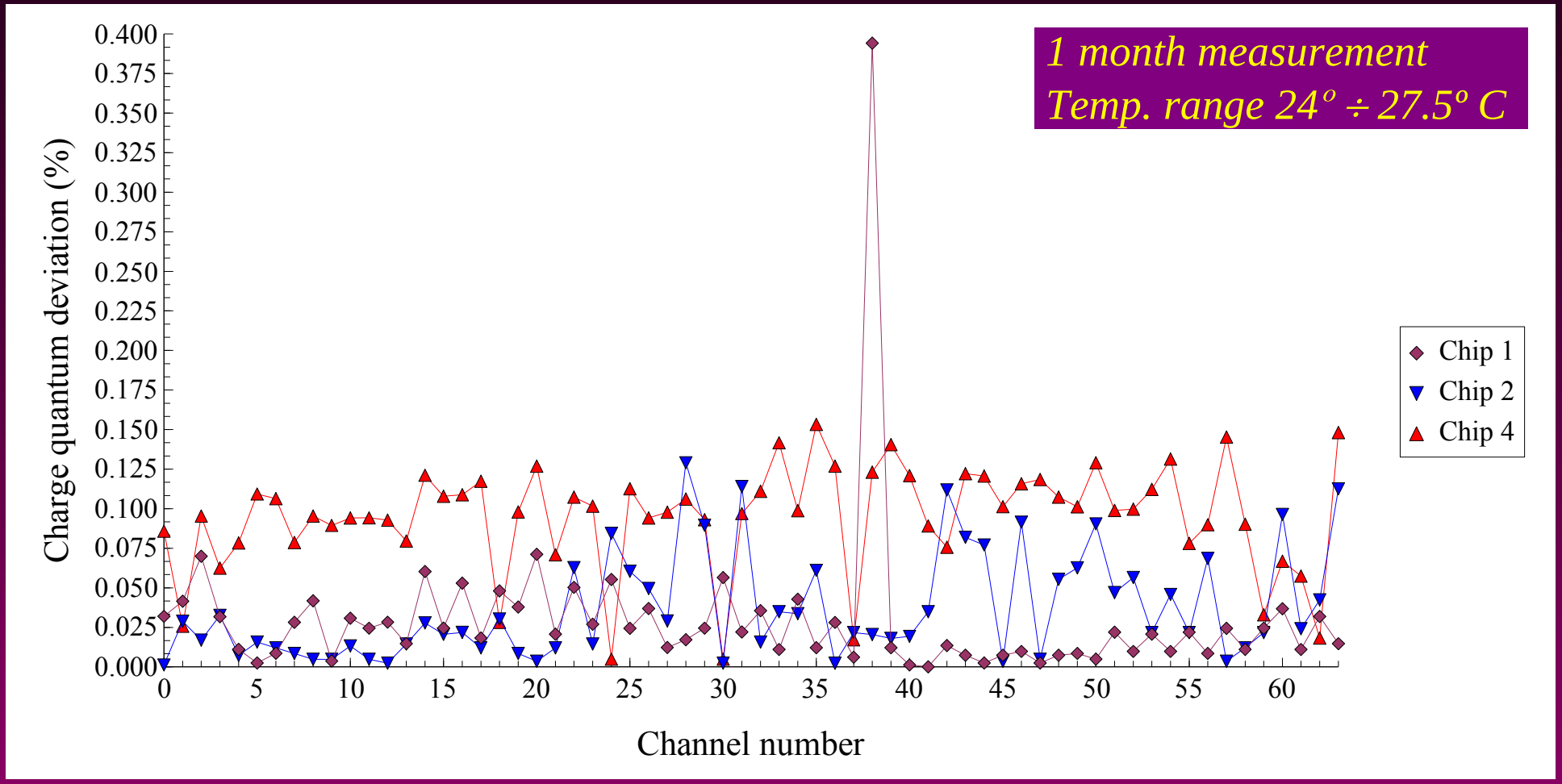

Charge quantum @ 100fC

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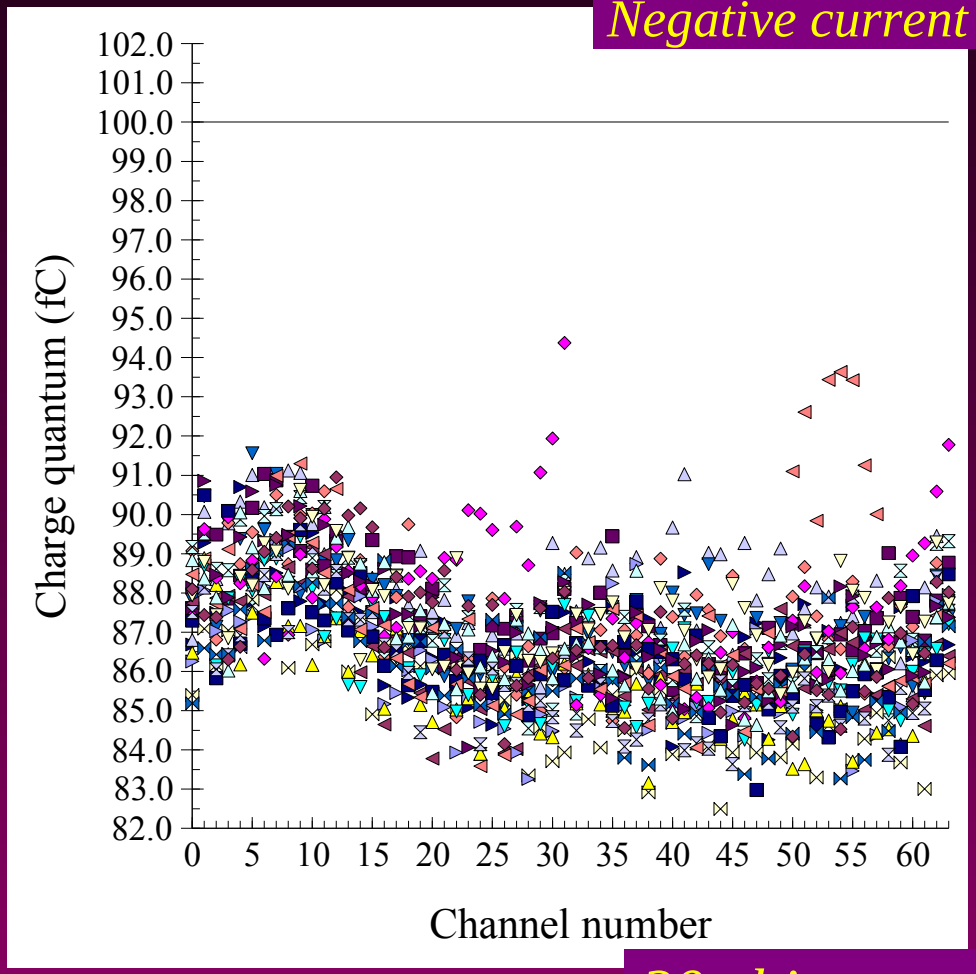
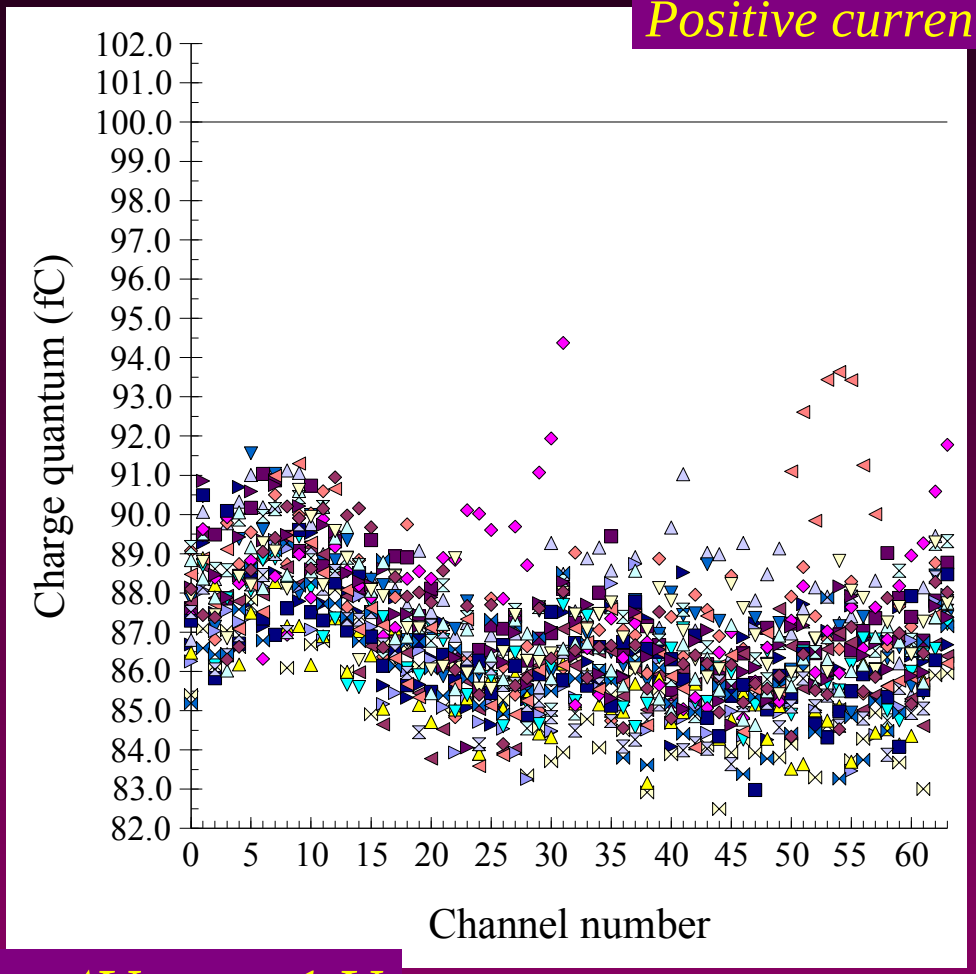
Negative current



Positive current



20 chips *ΔV = 1 V*
Itest = 100 nA *capsel = 010*

Distribution @ 100fC

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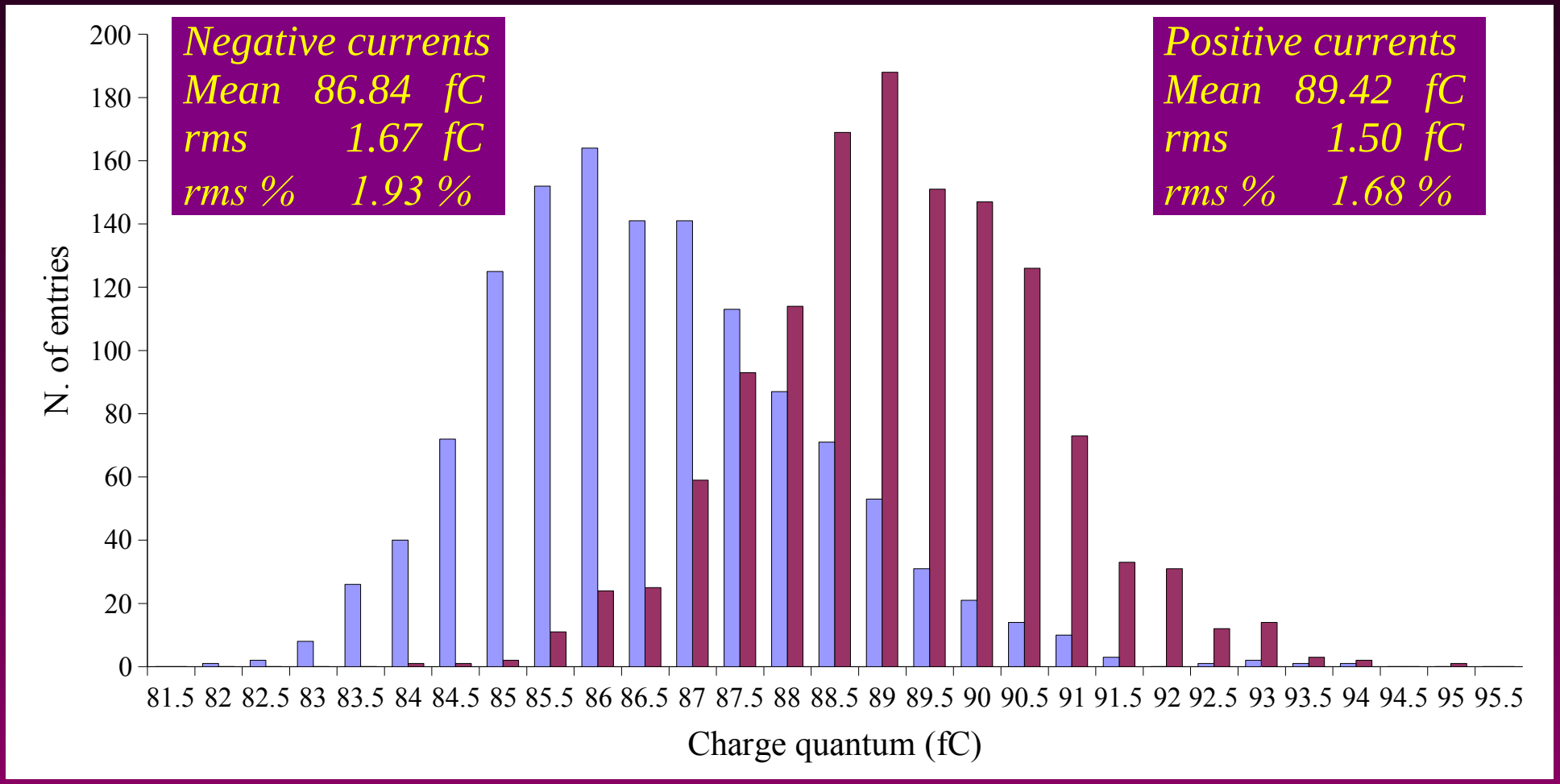
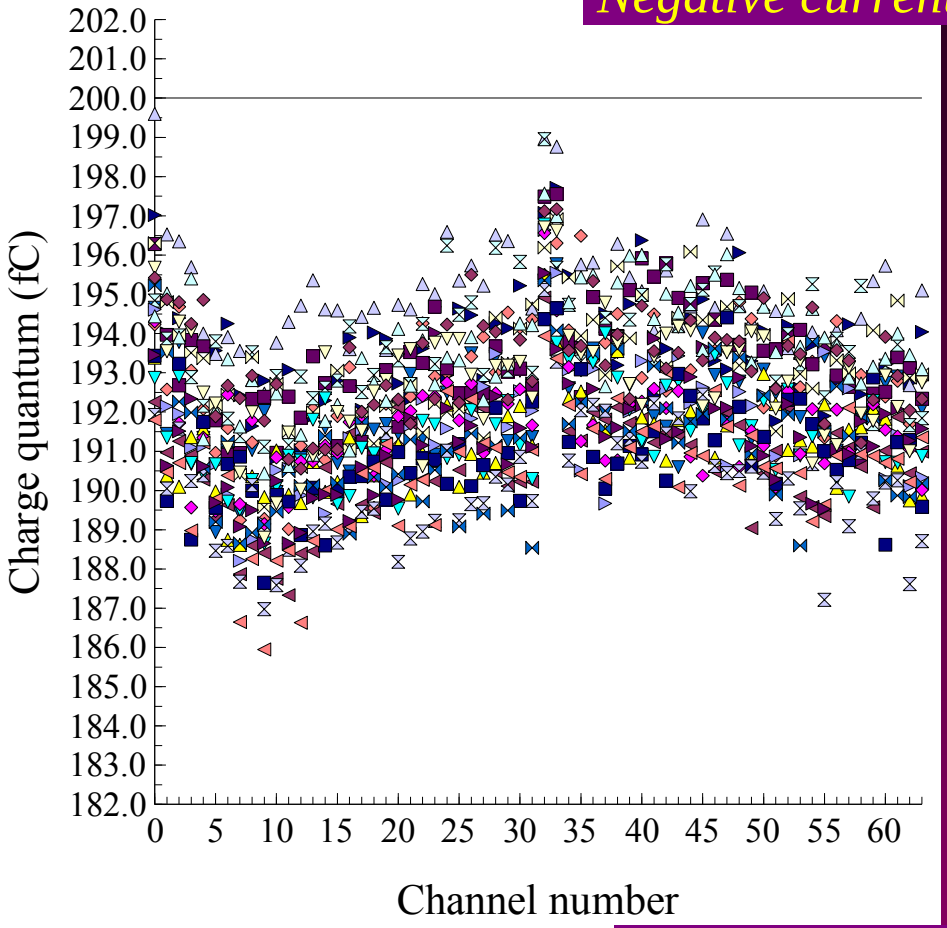


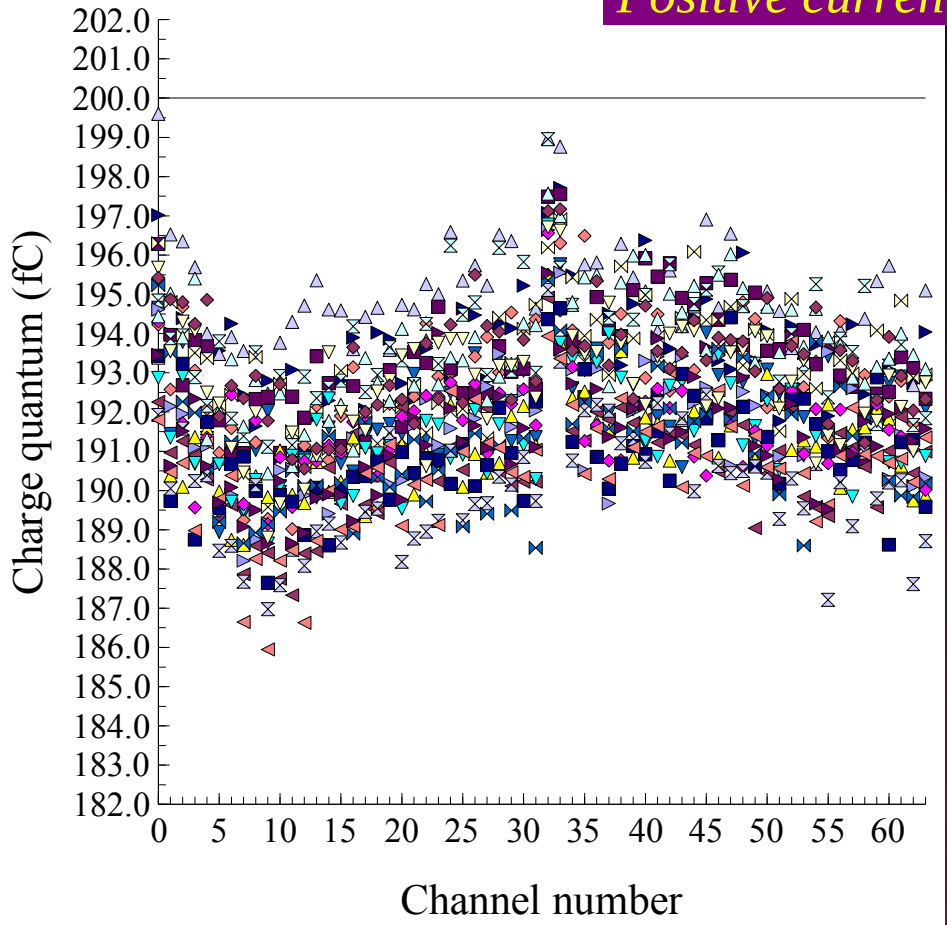
Charge quantum @ 200fC

Sezione di Torino

Negative current



Positive current

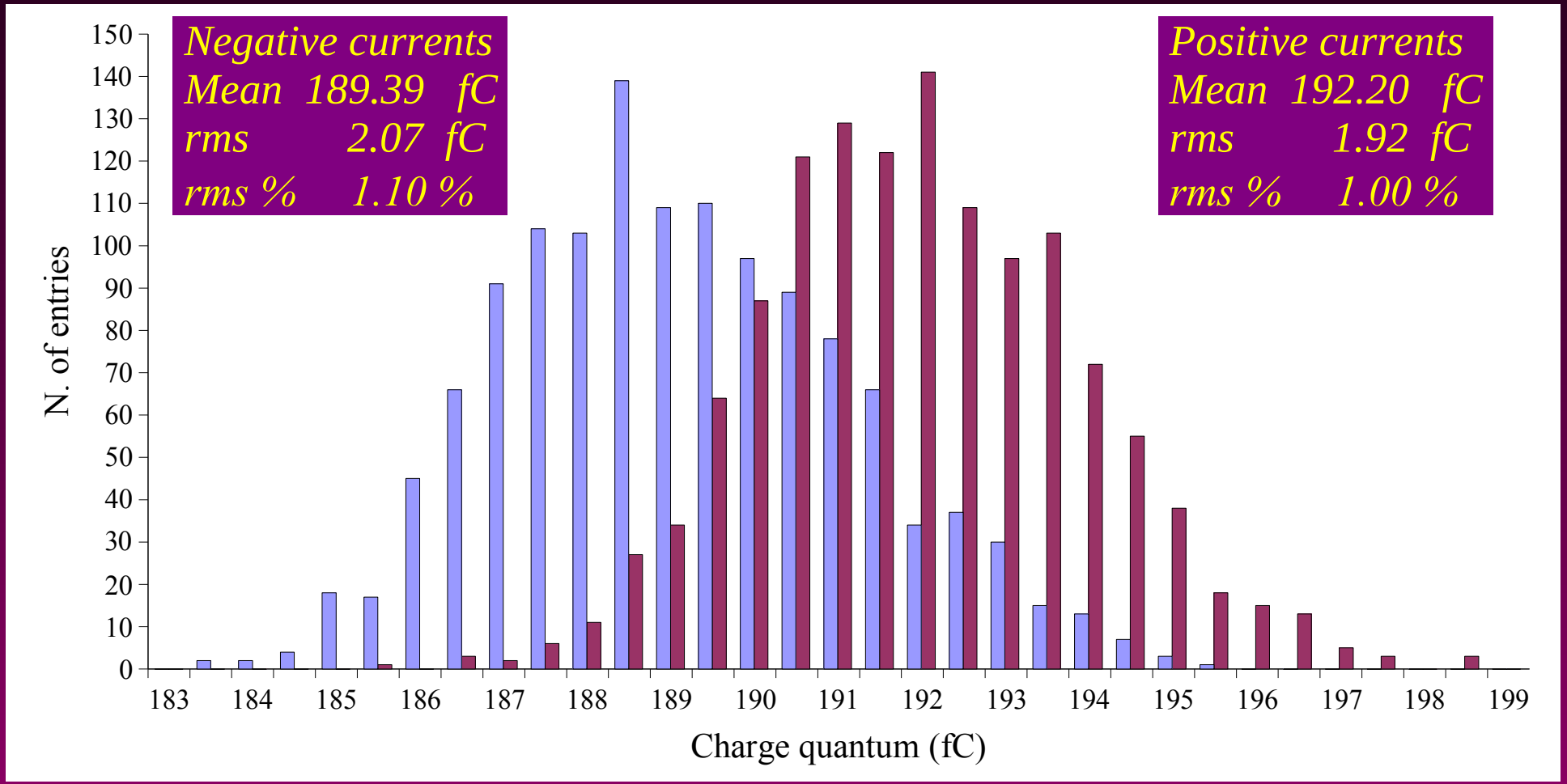


20 chips *ΔV = 1 V*

Itest = 100 nA *capsel = 100*

Distribution @ 200fC

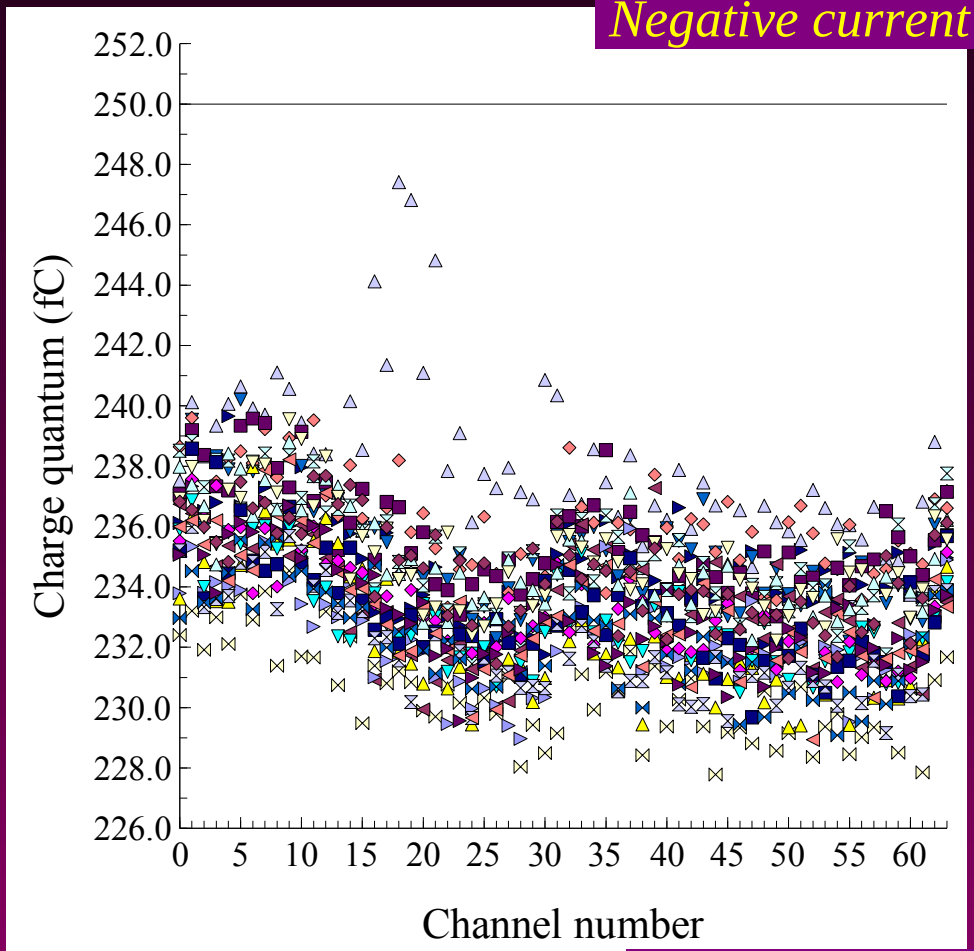
Sezione di Torino



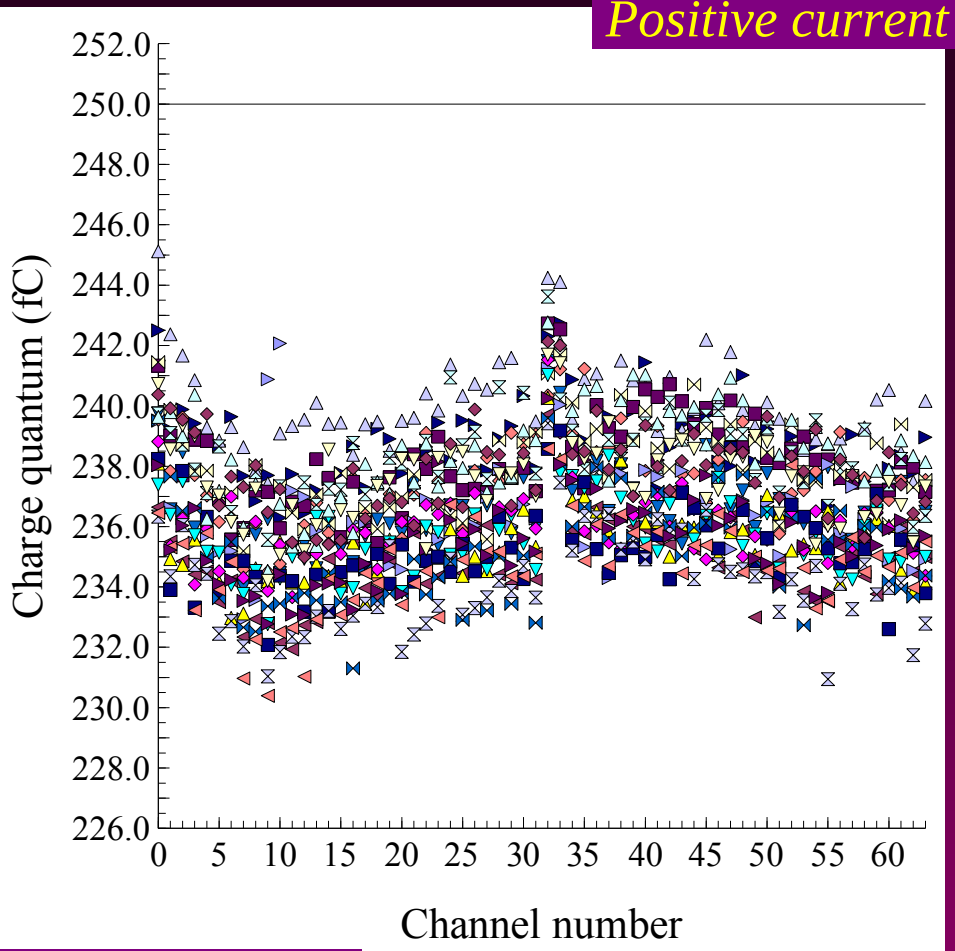
Charge quantum @ 250fC

Sezione di Torino

Negative current



Positive current



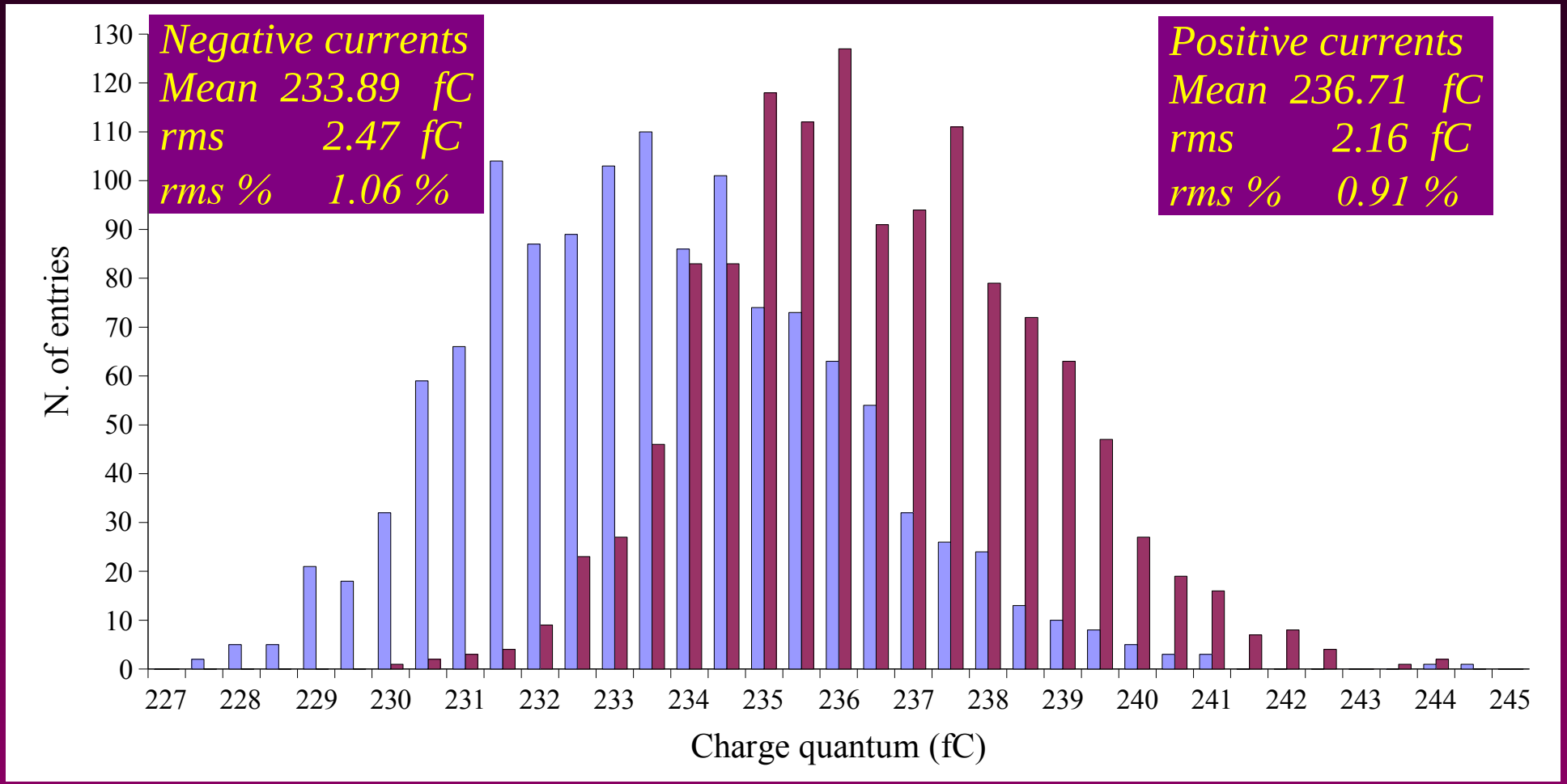
20 chips *ΔV = 1 V*

Itest = 100 nA *capsel = 101*

Gianni Mazza

Distribution @ 250fC

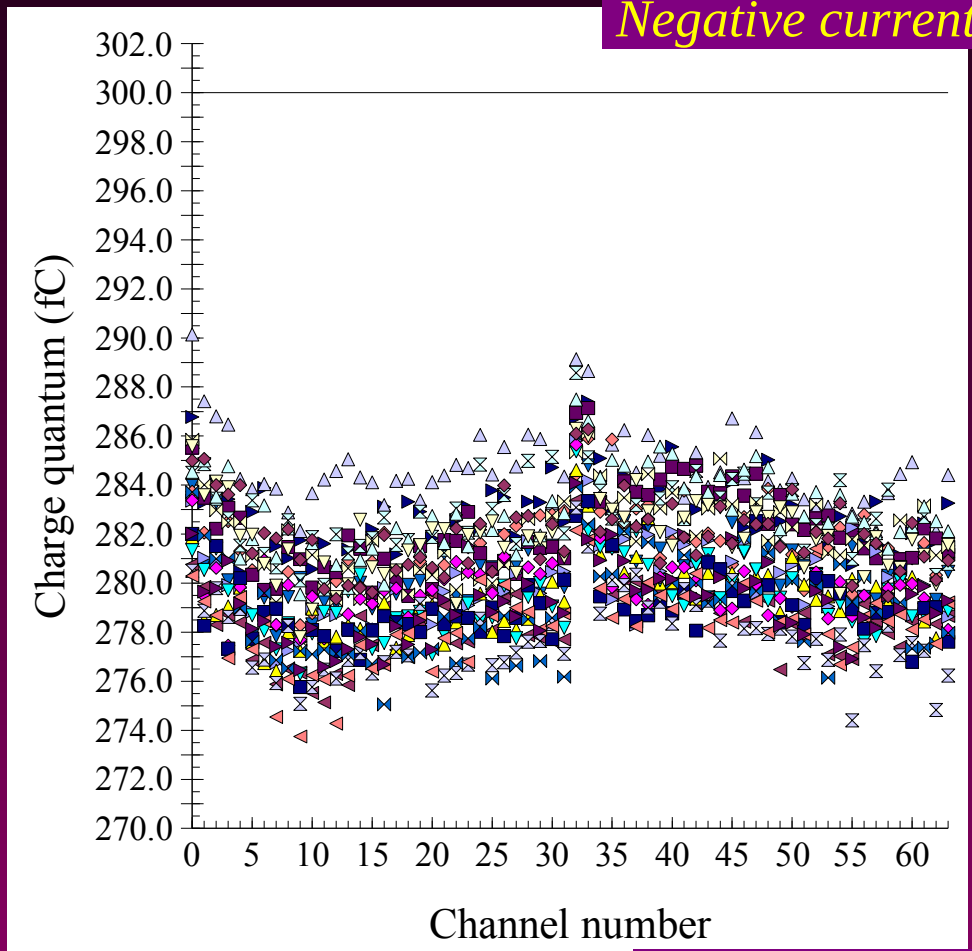
Sezione di Torino



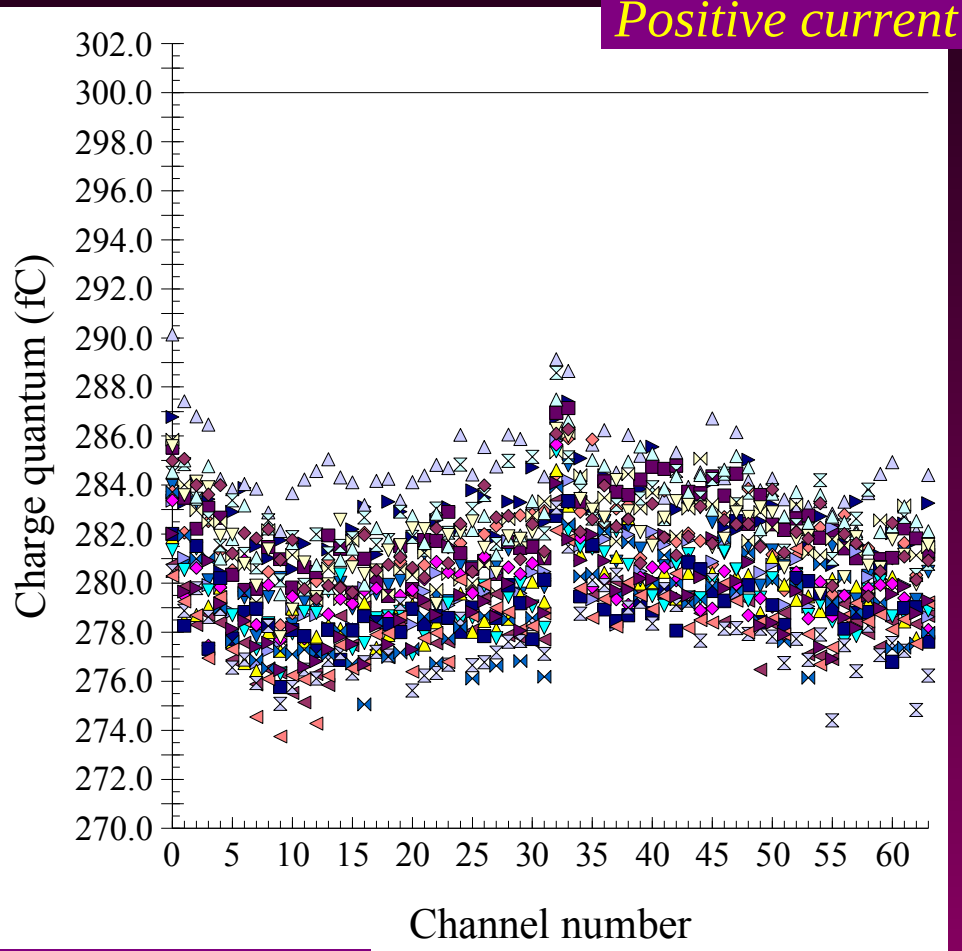
Charge quantum @ 300fC

Sezione di Torino

Negative current



Positive current



20 chips *ΔV = 1 V*

Itest = 100 nA *capsel = 110*

Charge quantum @ 300fC

Sezione di Torino