TOPIX: the first prototype of pixel readout for PANDA experiment

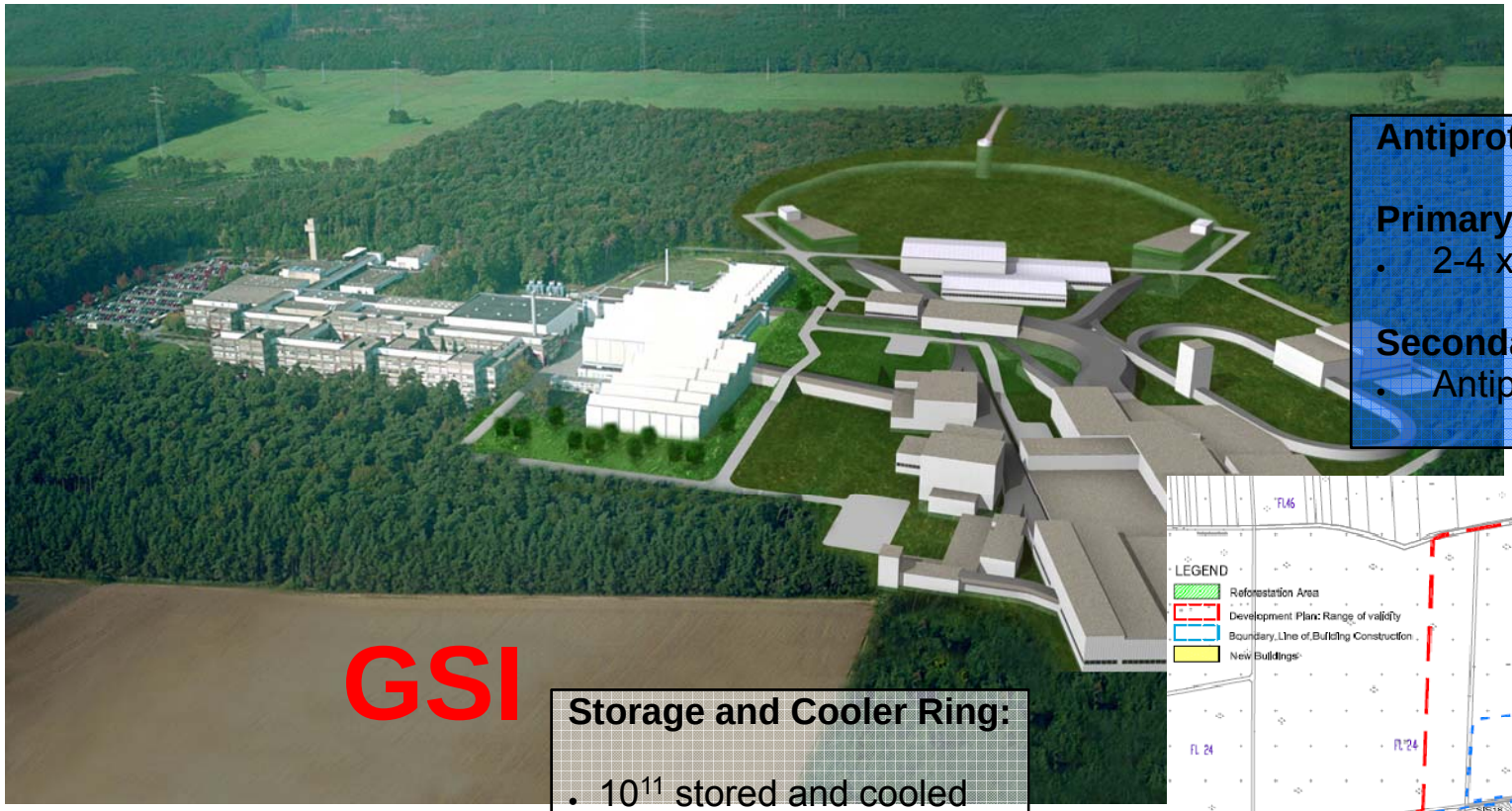
Calvo D.[1], De Remigis P. [1], Martoiu S.[1,2], Rivetti A.[1], Wheadon R.[1]
1: INFN – Sezione di Torino
2: Universita' di Torino, Dipartimento Fisica Sperimentale

Outline

- Introduction
- TOPIX
- Electrical functionality
- Radiation damage test
  - TID test at higher dose rate
  - TID test at lower dose rate
  - Neutron test
- Conclusion

Introduction

FAIR
Facility for Antiproton and Ion Research

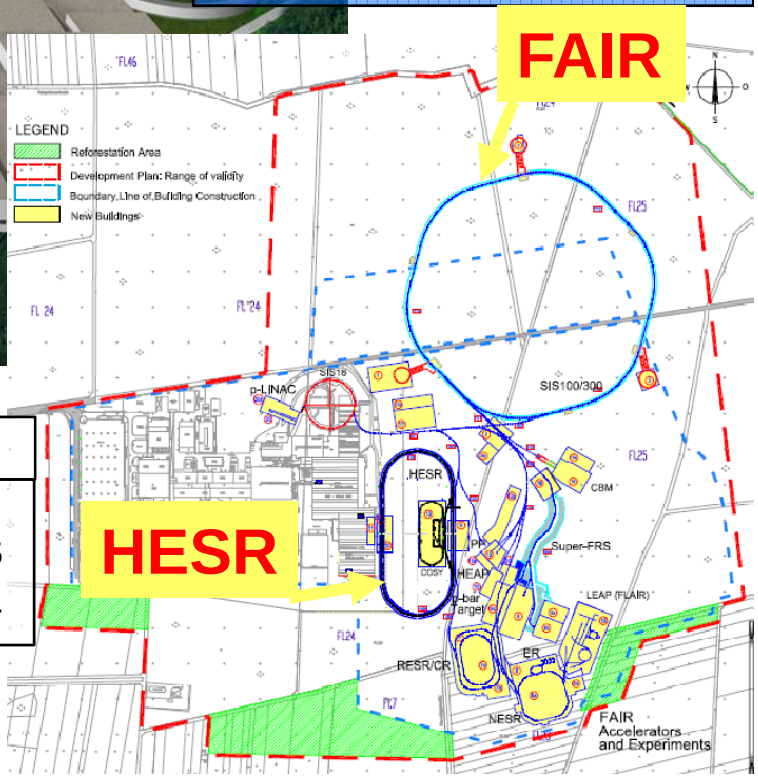


Antiproton relevant aspects:

Primary Beam:
- 2-4 x10^{13}/s 30 GeV protons

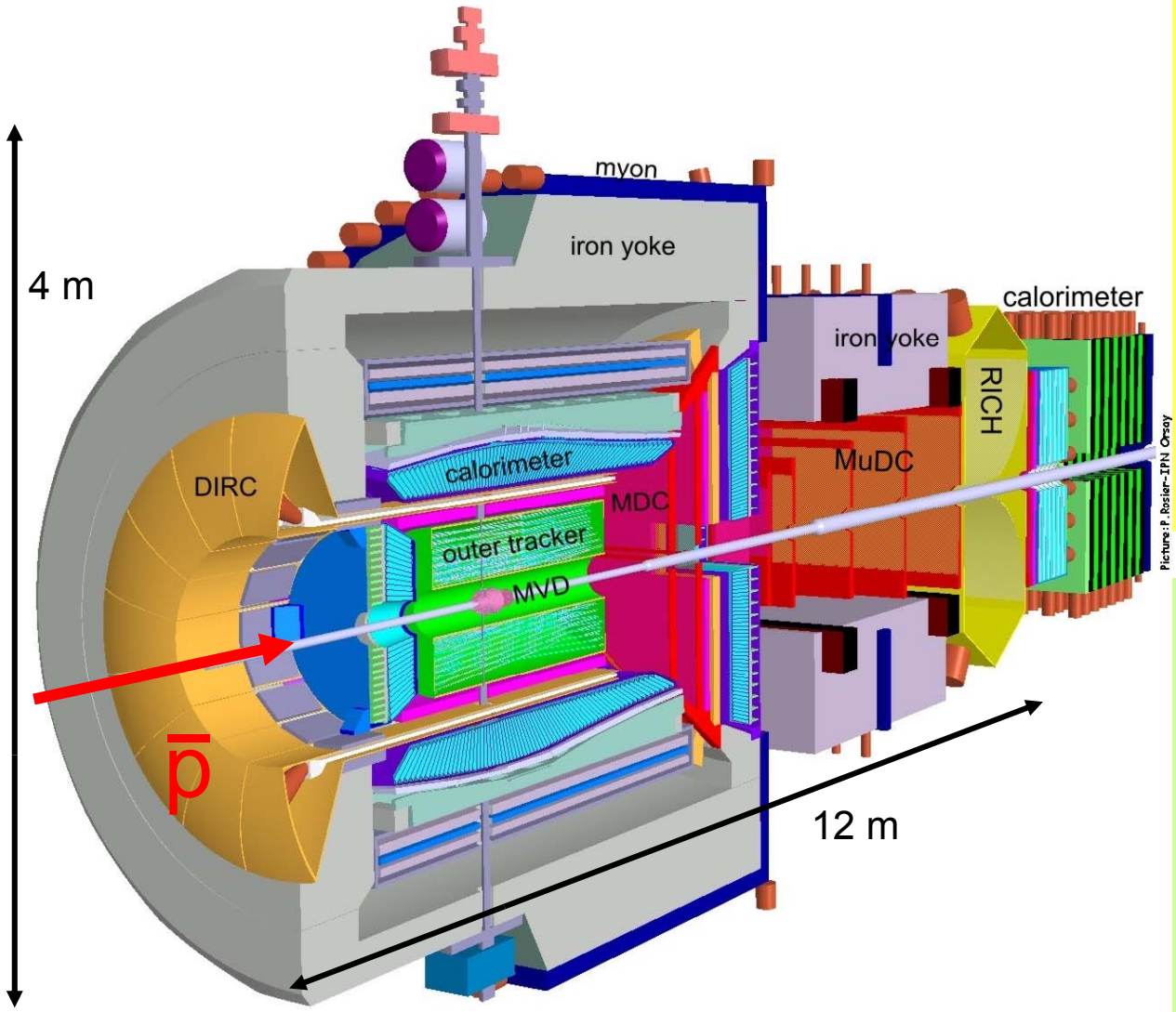
Secondary Beam:
- Antiprotons 1 x 10^{7} /s

Storage and Cooler Ring:
- 10^{11} stored and cooled 1.5-15 GeV antiprotons



Cooling: electron/stochastic		
Antiproton Pmax = 15 GeV/c		
High resol. Mode: L =	10^{31} cm^{-2} s^{-1}	$\delta p/p < 10^{-5}$
High lum. Mode: L =	$2 \cdot 10^{32}$ cm^{-2} s^{-1}	$\delta p/p < 10^{-4}$

PANDA: a Multi Purpose Detector



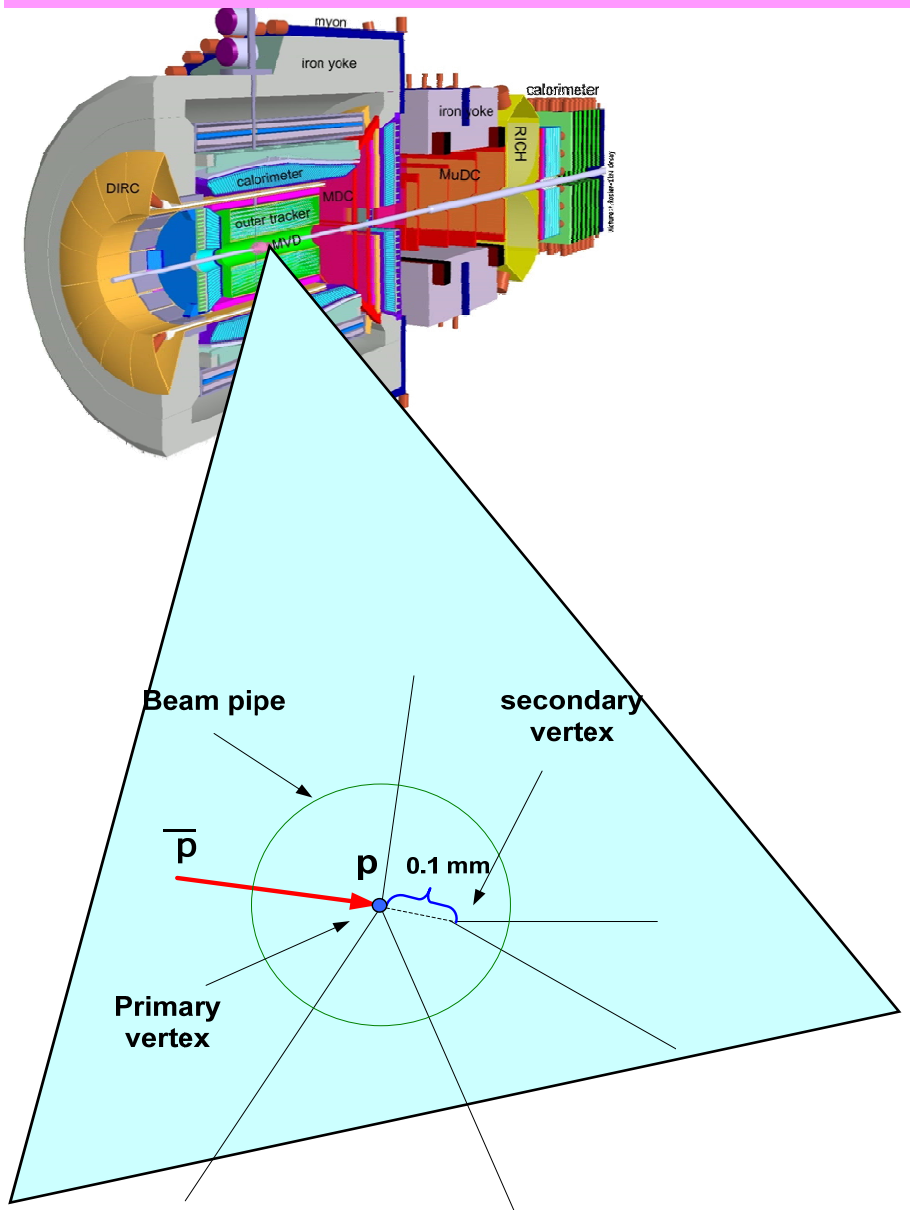
Antiproton physics program:

- **charmonium spectroscopy**
- **search for hybrids and glueballs**
- **search for modifications of mesons properties in the nuclear medium**
- **γ-ray spectroscopy of single and double hypernuclei**

Features of the apparatus

- **nearly 4π solid angle**
- **high rate capability (1×10^7 annihilations/s)**
- **good PID (γ, e, μ, π, K, p)**
- **momentum resolution (~1%)**
- **vertex info for D,K^0_S,Λ**

Micro-Vertex-Detector



- **good spatial resolution in r-phi for the momentum measurement of soft pions from D* decays**
- **good spatial resolution especially in z for D-Tagging**
- **good time resolution with 'DC' beam (10^7 events/s)**
- **triggerless readout due to the absence of a first level hardware trigger**
- **discrimination among particles by the energy loss measurements**
- **low material due to low momentum particles (some hundreds of MeV/c)**
- **fluence of 3-4 $\cdot 10^{13}$ n_{eq}/cm^2 for year (half year data taking) for pbar-p at 15 GeV/c**

The custom pixel detector – basic features

standard hybrid technology

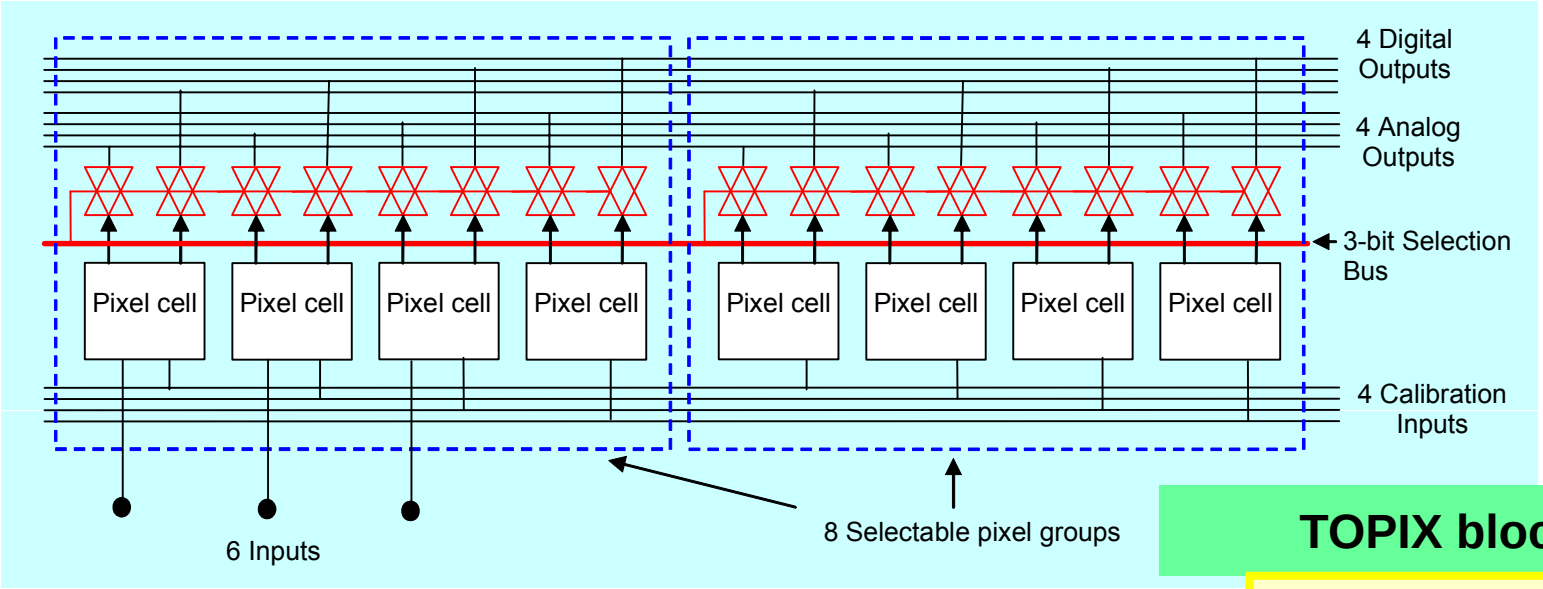
pixel FEE developed with the 130 nm CMOS technology

pixel sensors realized with epitaxial silicon material

- ~ 8 million pixels arranged in 2 barrels and 5 forward disks
- pixel size: 100 μm x 100 μm
- data rate: 60 Gbit/sec (data load: 50 bit/pixel)
- Time over Threshold measurement (like ATLAS)
- large dynamic range: 160 fC
- time stamp: rms 6 ns @ 50 MHz
- triggerless readout
- target power consumption: <200 mW/chip

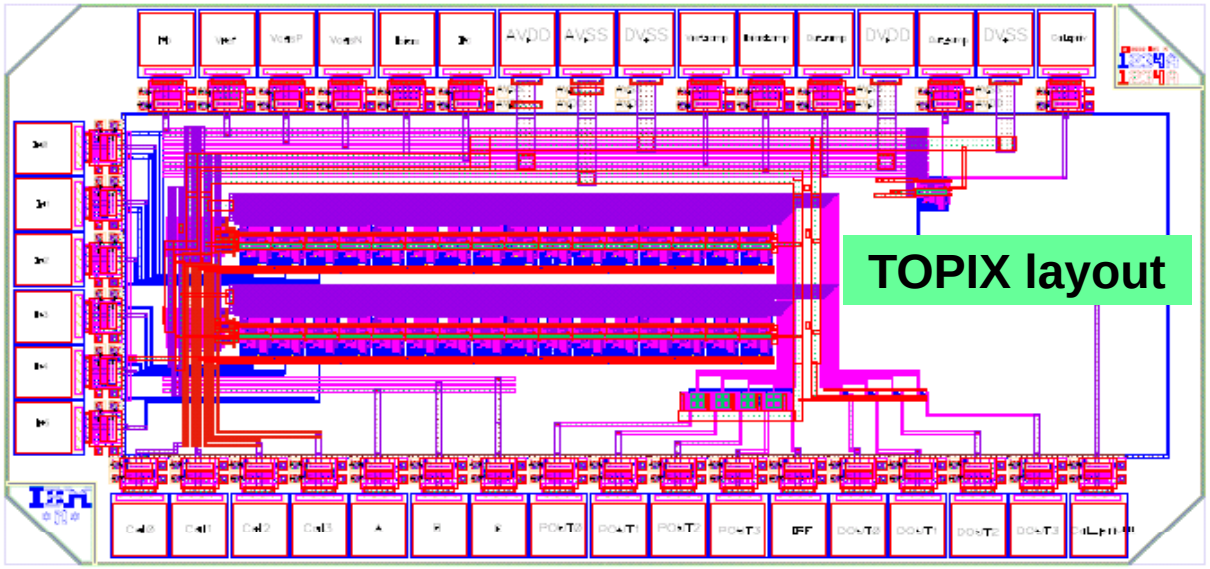
TOPIX

TOPIX – first prototype of pixel readout



Size: 2x1mm²

TOPIX block diagram



32 cells (8 selectable groups) with preamplifier and discriminator

No bump bonding pads

4 Calibration Input Lines

4 Multiplexed Digital Outputs

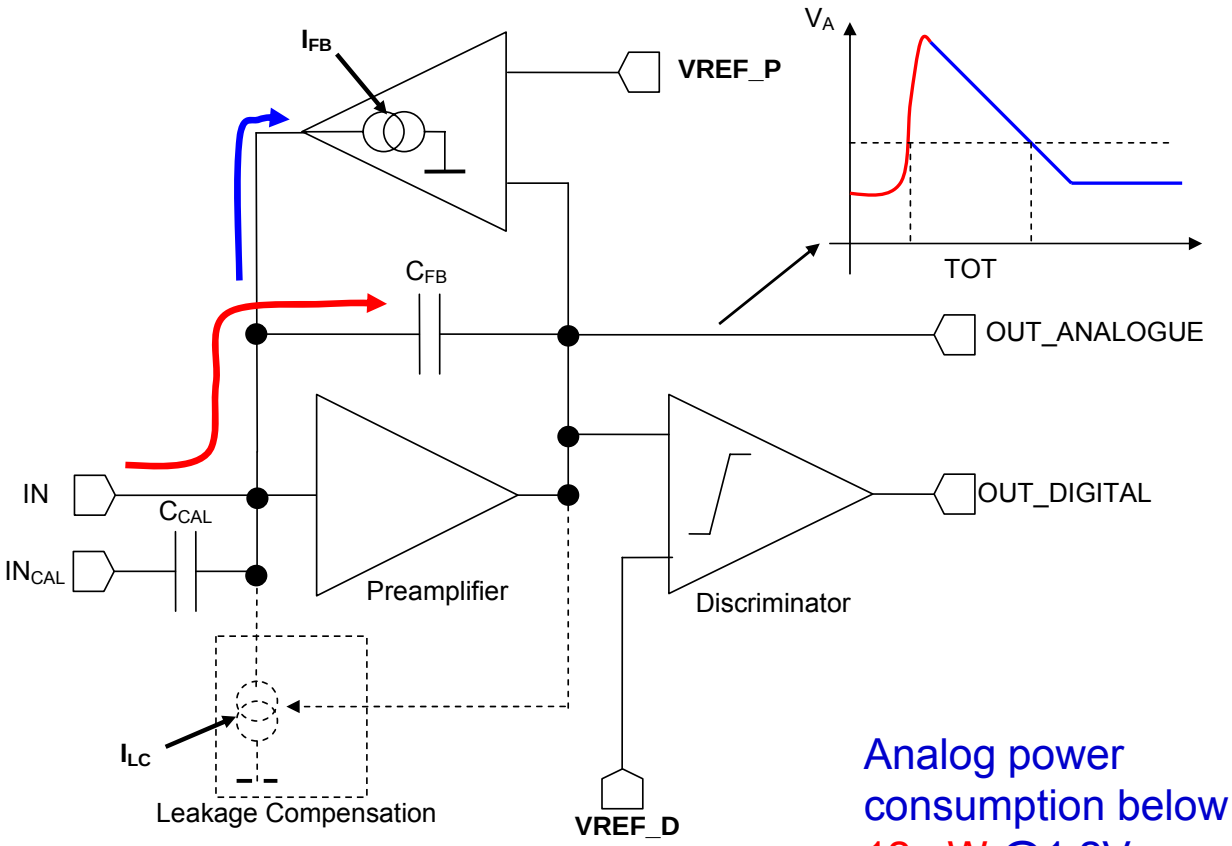
4 Multiplexed Analog Outputs

6 Input Lines to connect sensors

Pixel cell schematic

Preamplifier features:

- Active feedback acts as a discharge current source → constant trailing-edge slope → TOT measurement (ATLAS style)
- Feedback capacitor is discharged at the input → large dynamic range
- DC compensation circuit drains the leakage current from the detector

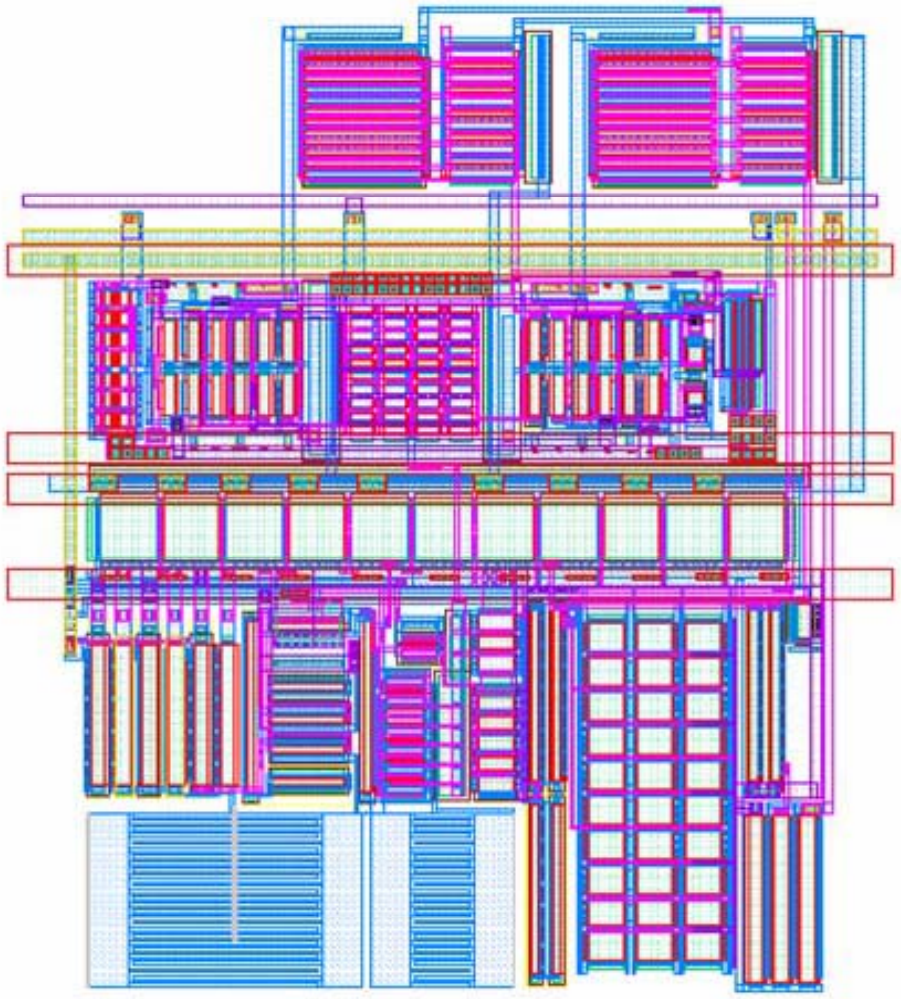


Analog power consumption below 12 μW @1.2V

Discriminator features:

- Folded cascode topology for low voltage operation
- High gain with reasonable high GBW product

Single pixel cell



Discriminator

(12.8 x 48 μm²)

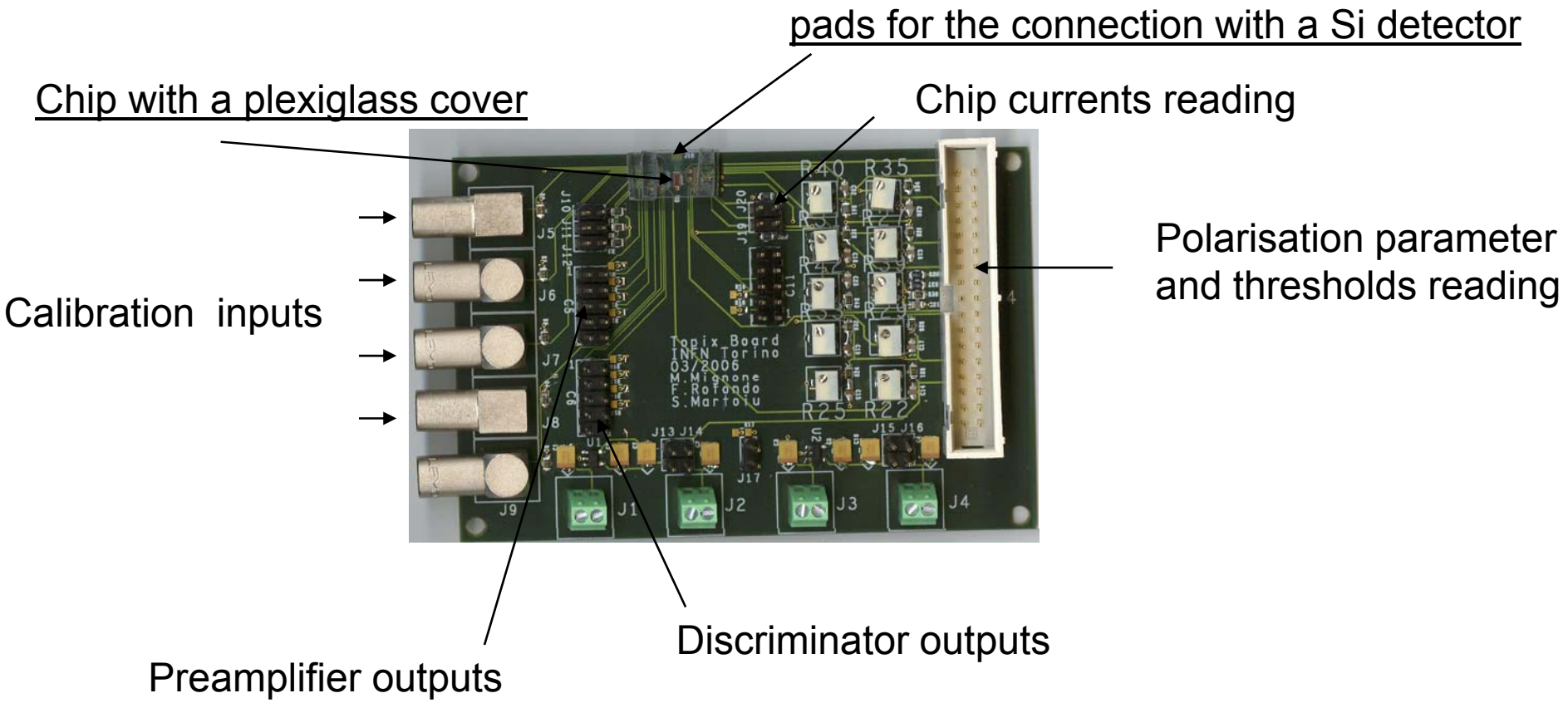
Preamplifier

(37 x 51 μm²)

- the size of the layout has been obtained with conservative design rules
- absence of enclosed structures to study the foreseen radiation tolerance of the 130 nm CMOS technology

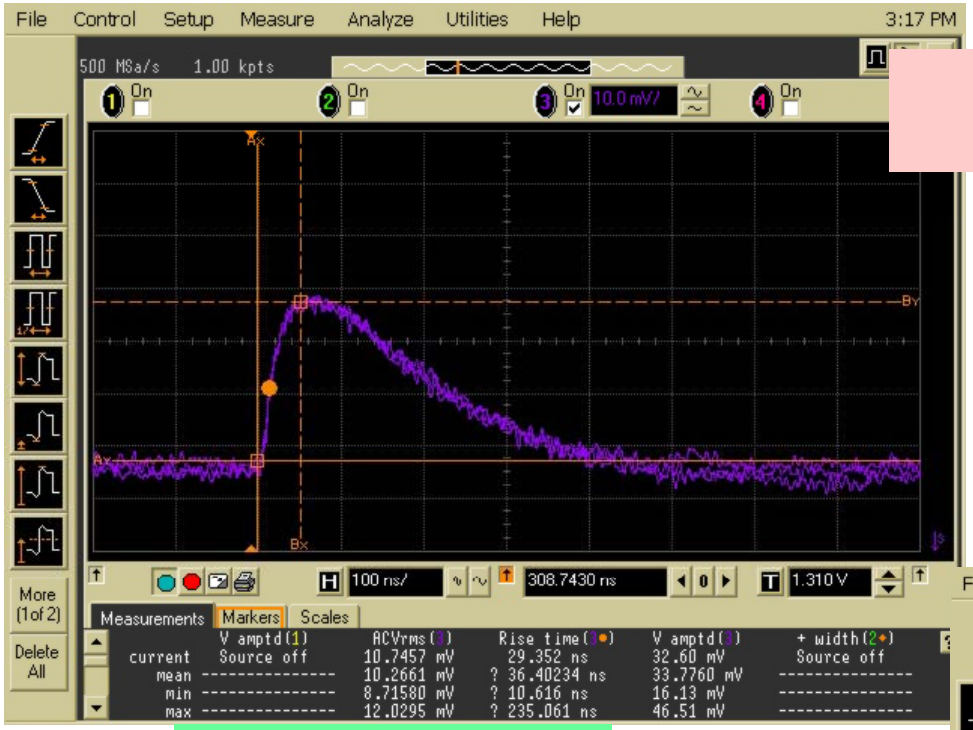
Experimental setup: the test board and the chip

- TOPIX size: 2 mm x 1 mm
- board size: ~60 mm x ~90 mm



Electrical functionality

Preamp response

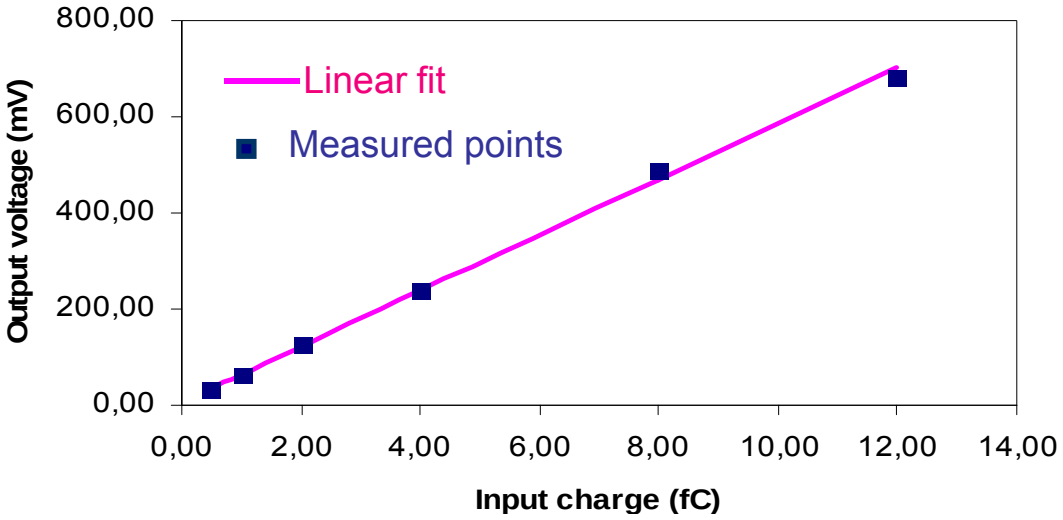


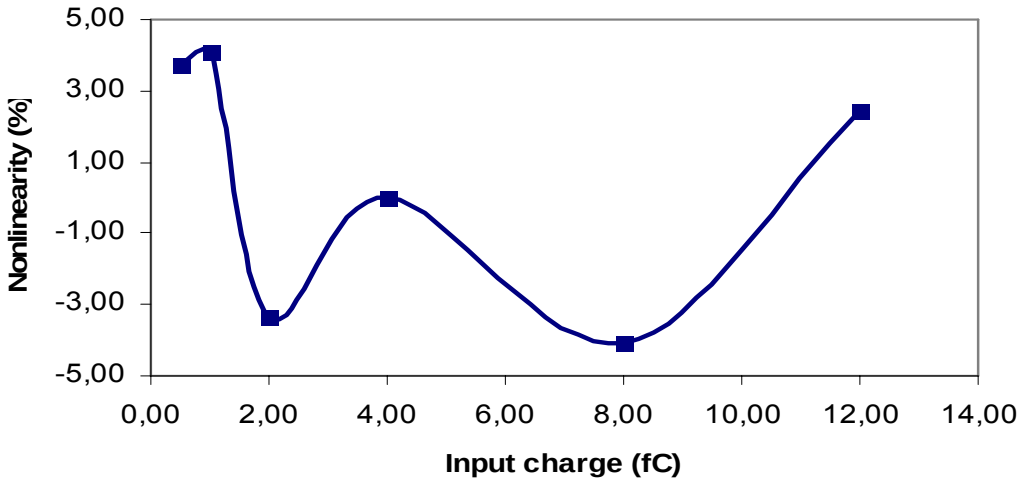
ENC: 98 rms electrons@0pF

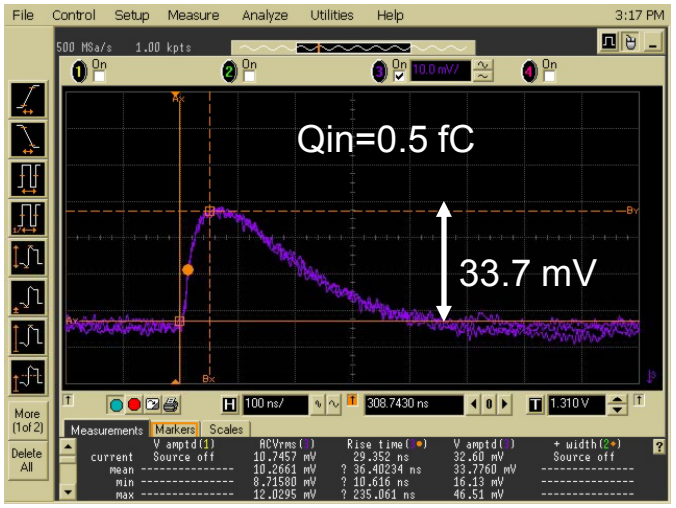
Input charge: 0.5 fC

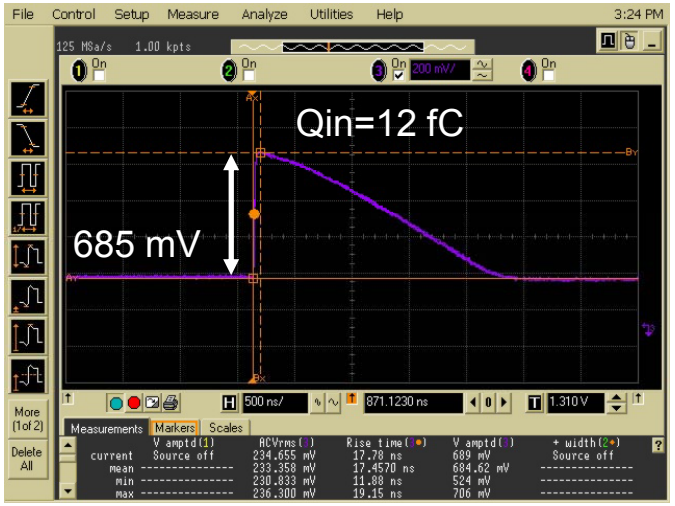
Input charge: 8 fC

Preamplifier linearity





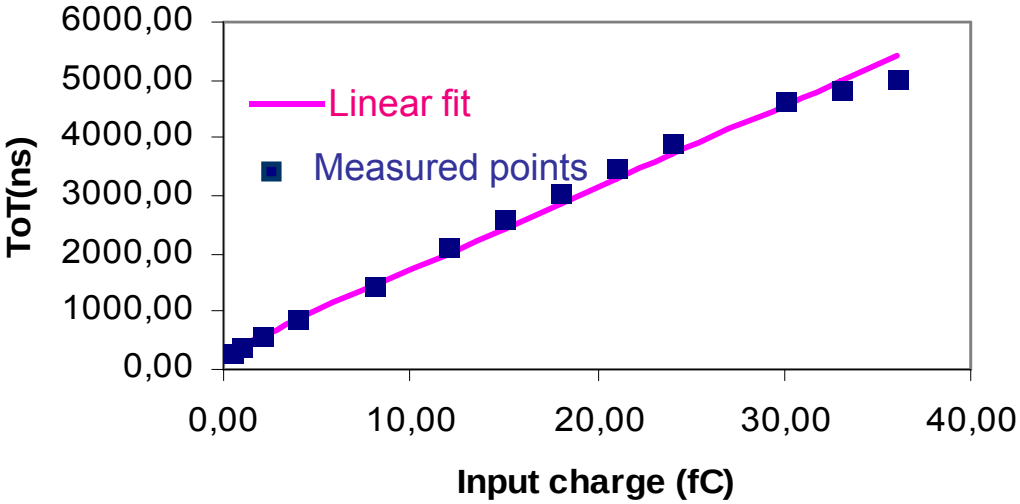


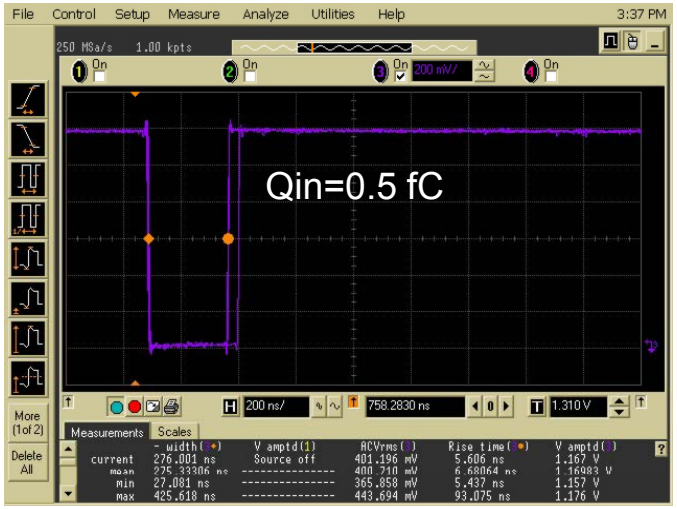


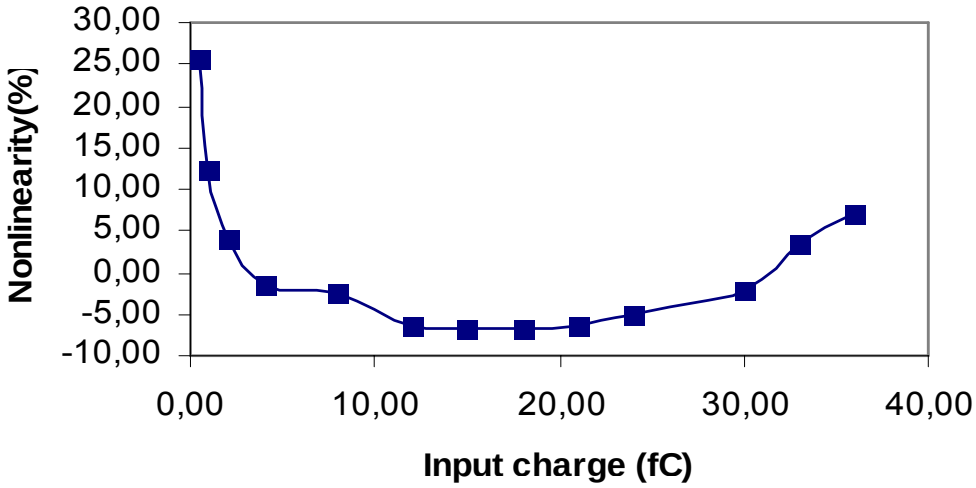
The preamplier saturates at 12 fC, but….

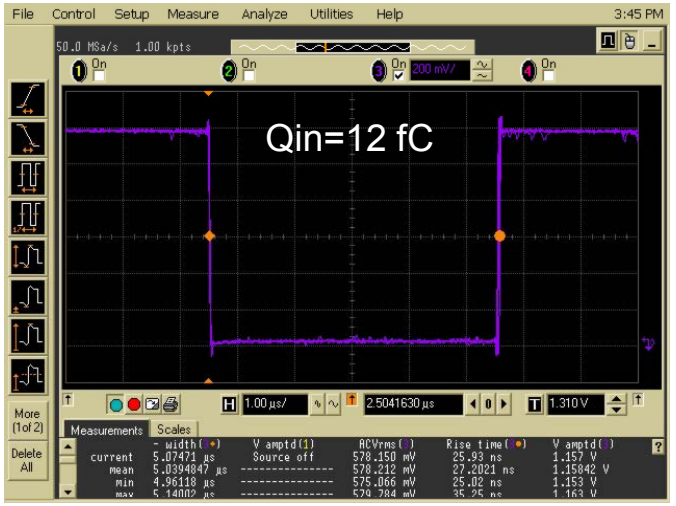
ToT linearity

….the ToT preserves good linearity at least up to 40 fC



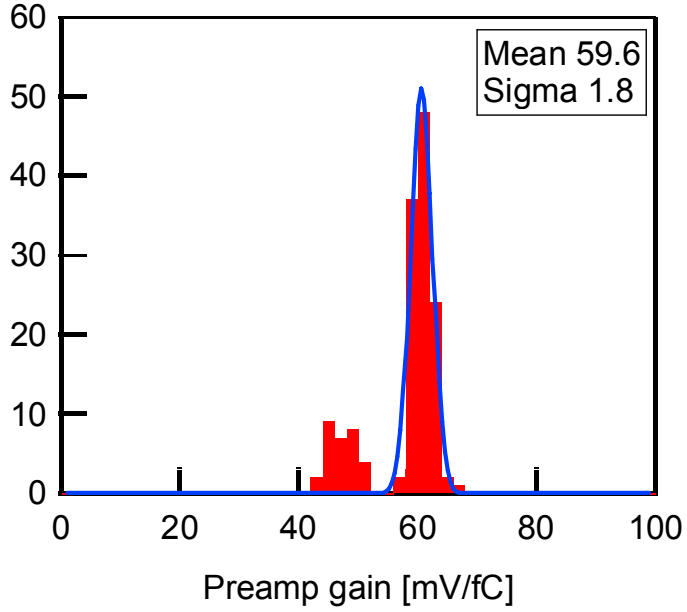


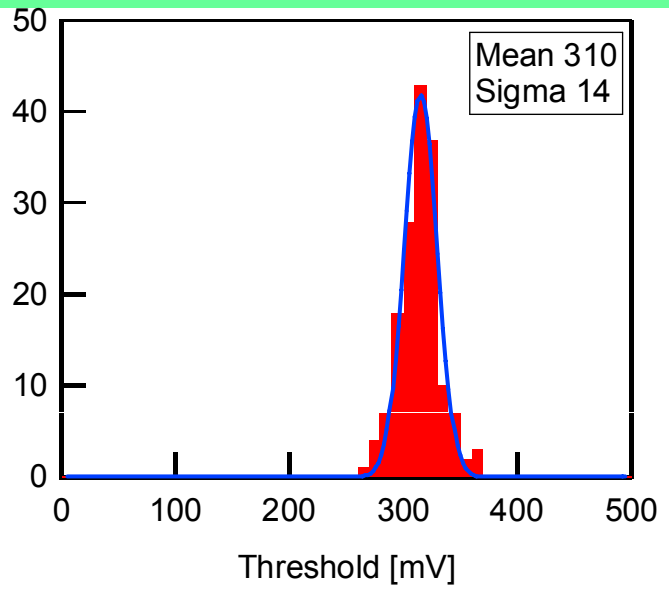


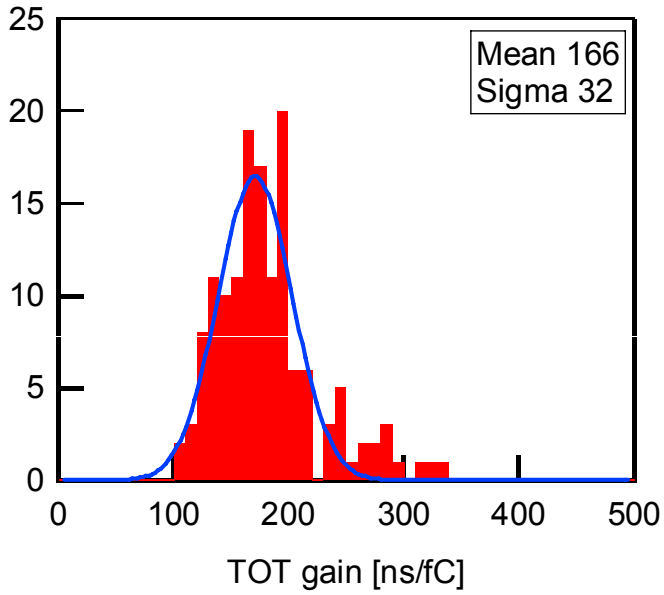


Distributions for more important parameters

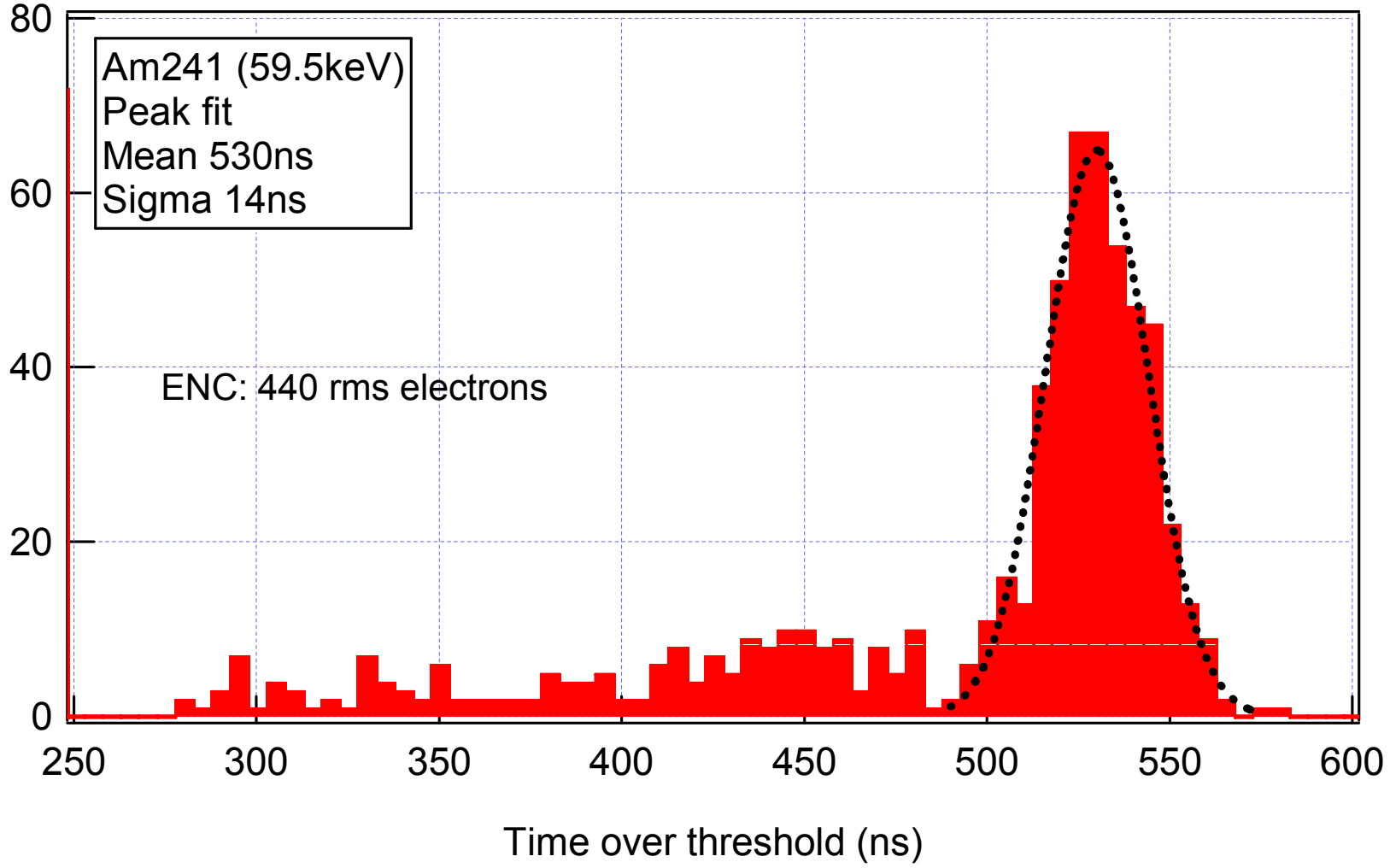
• threshold, preamplifier and ToT gain distributions for 144 pixel cells (with and without pads)







Preliminary result with a ^{241}Am source



TOPIX was connected with wire bonding to a pixel sensor
(of size: 400 x 400 μm^2 , 200 μm thickness) provided by IRST

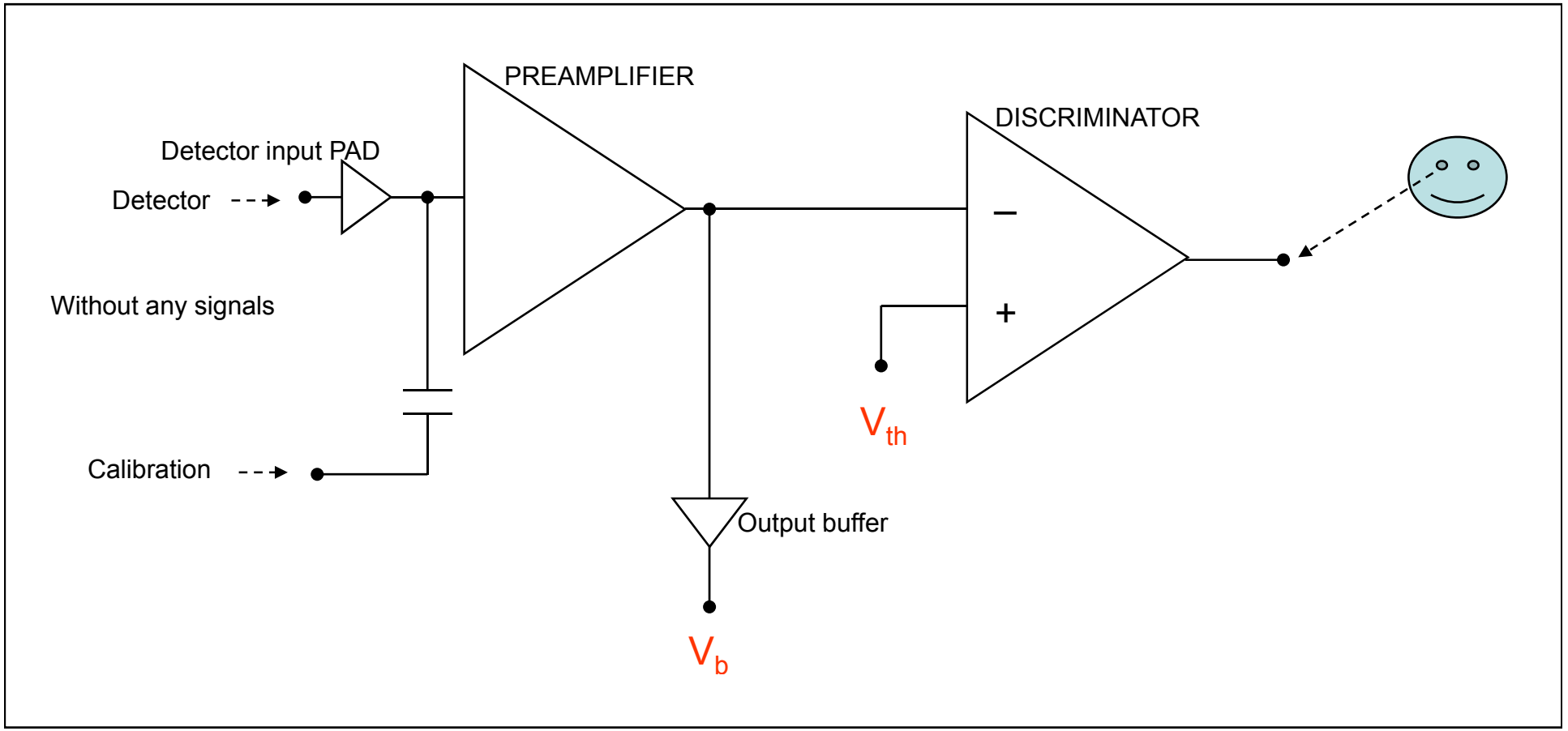
Radiation damage tests

Radiation damage tests

- Total Ionizing Dose (TID)
  - X rays at different dose rate
    - » X ray source at disposal at CERN thanks to Federico Faccio
    - » X ray source at disposal at the University of Piemonte Orientale thanks to Luciano Ramello
- Displacement damage:
  - neutrons at INFN-Laboratori Nazionali of Legnaro

Parameters to measure…

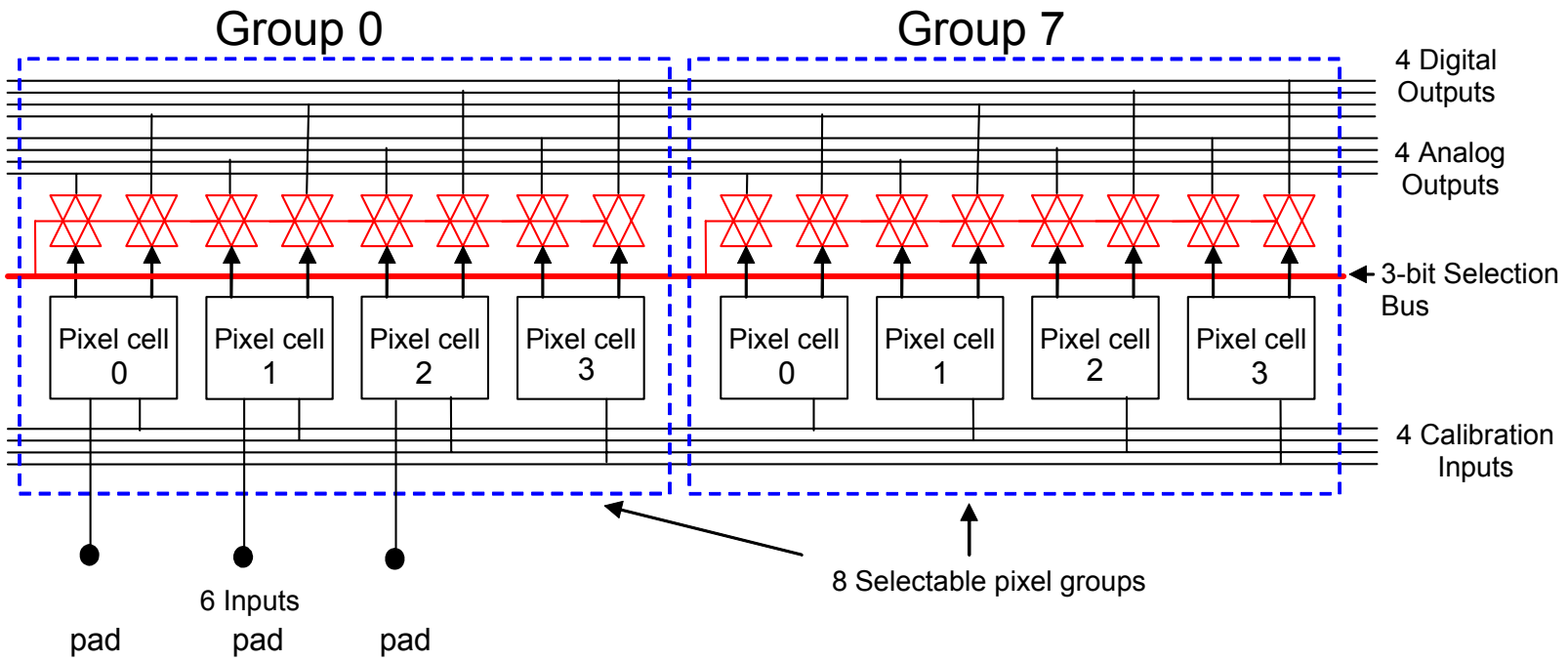
- power consumption of the chip
- the baseline voltage at the preamplifier output (V_b) of the pixel cell
- the threshold voltage with the discriminator output in transition (V_{th}) of the pixel cell



…parameters to measure

- the gain of the preamplifier fitting 5 calibration inputs (1, 3, 4, 8, 12 fC)
- the Time Over Threshold gain, fitting 5 calibrations inputs (1, 3, 4, 8, 12 fC)

to check any possible difference, both pixel cells have been studied selecting a pixel cell respectively in the group 0 (with pad) and in the group 7 (without pad)



TID test at high dose rate

TID test and Annealing phase

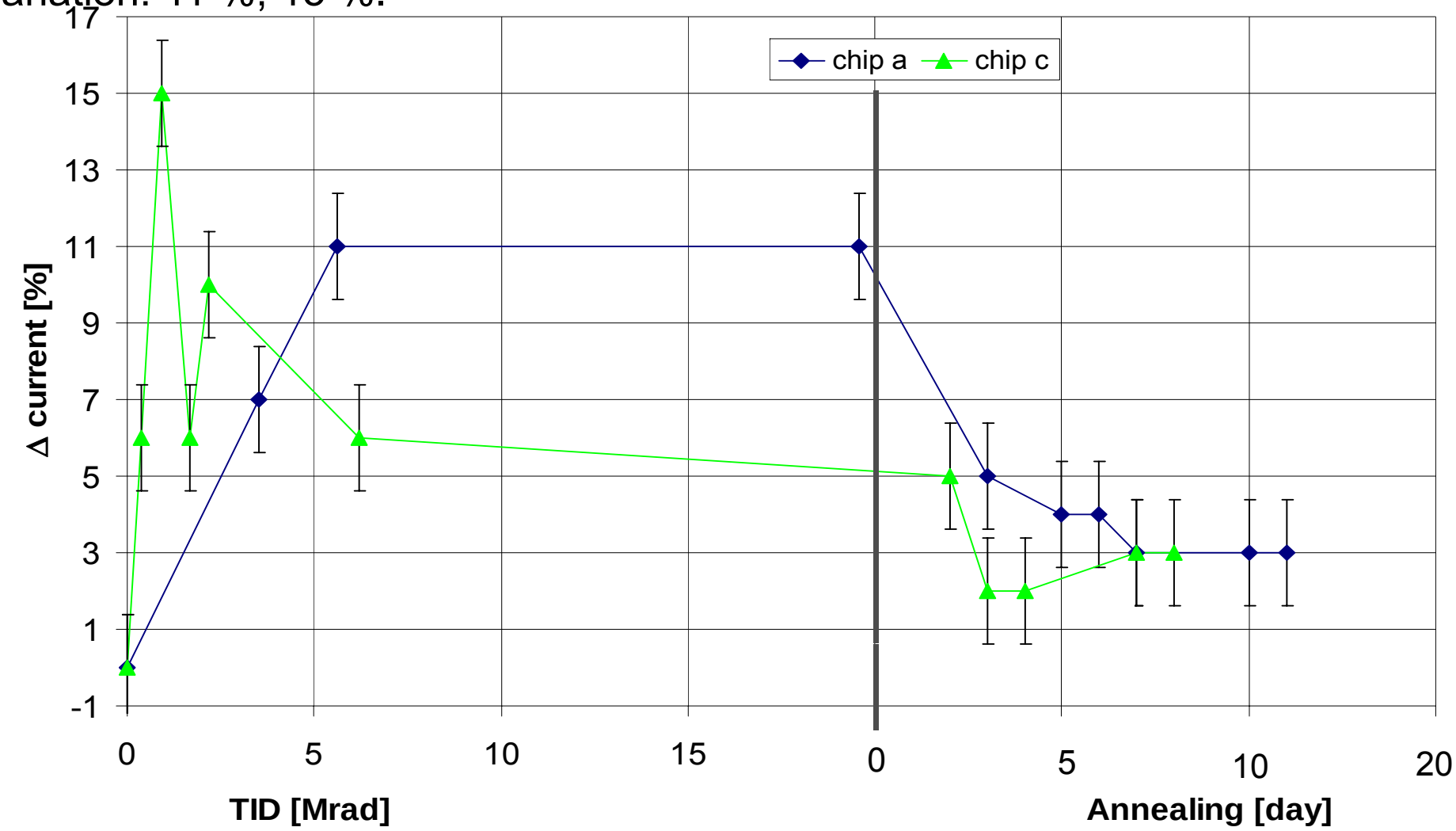
PRE-TID : 4 chip has been characterized before the TID test

TID measurements : the parameters for the 4 chips have been measured at each TID, at Tlab of 25°C ± 2.5° C. For each chip the final dose has been obtained in about 1 day

Chip	Dose rate (rad/s)	Measurement points (Mrad)	Annealing at 25°C (days)	Annealing at 100°C (days)
a	400	3.5, 5.6, 19.5	4	7
b	100	0.330, 0.771, 6.2	3	7
c	100	0.358, 0.941, 1.7, 2.2, 6.2	1	7
d	100	0.179, 0.358, 5.1	2	7

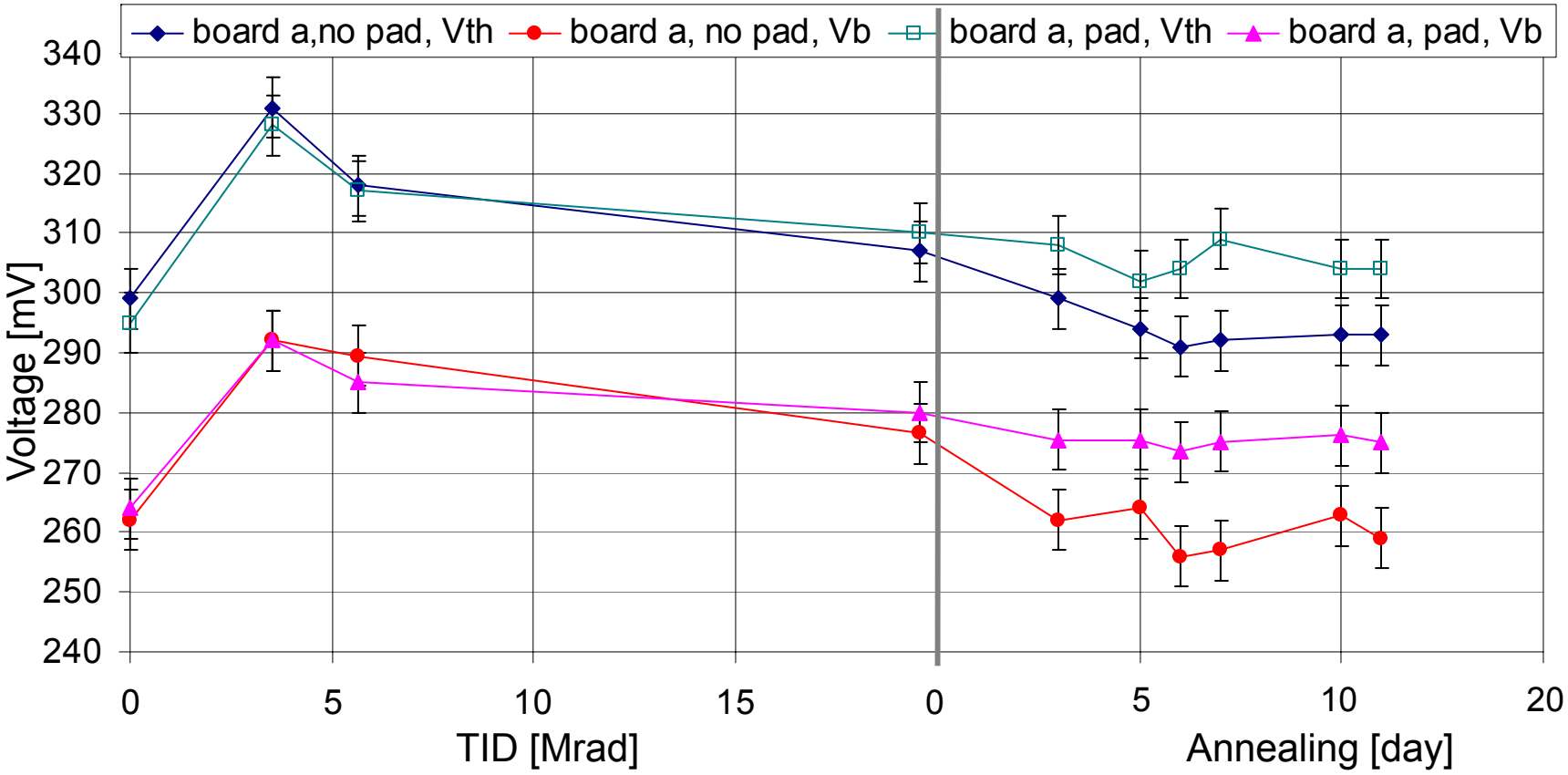
Results

Chip a and c - Leakage current [%] as a function of TID and Annealing. The PRE-TID currents (a: 2.99 mA, c: 3.17 mA) are the reference values. Max. variation: 11 %, 15 %.



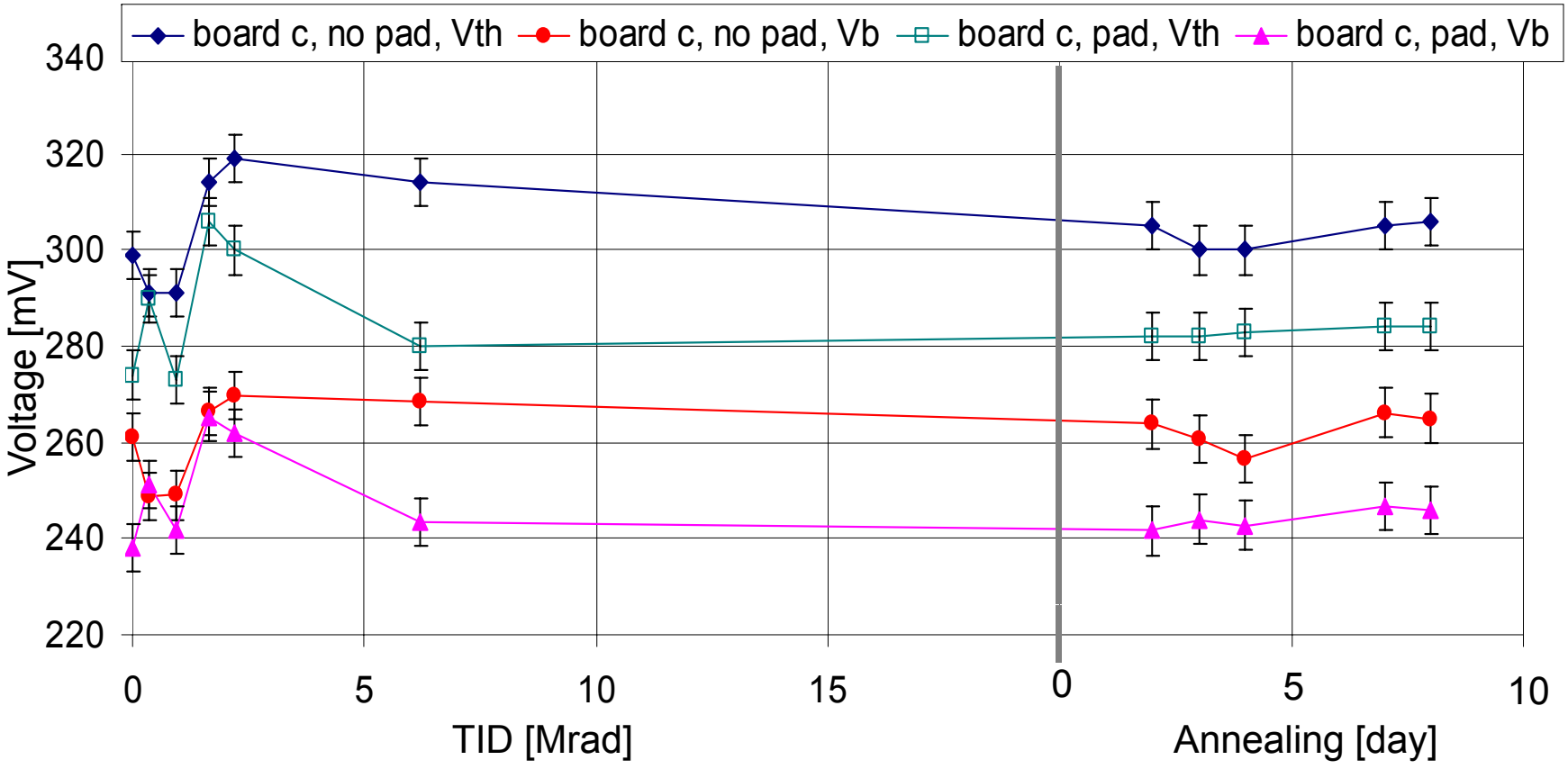
Results

chip a – threshold voltage (Vth) and baseline voltage (Vb) for both pixel cells with pad and without pad (no pad) as a function of TID and Annealing; max. variation within 11%



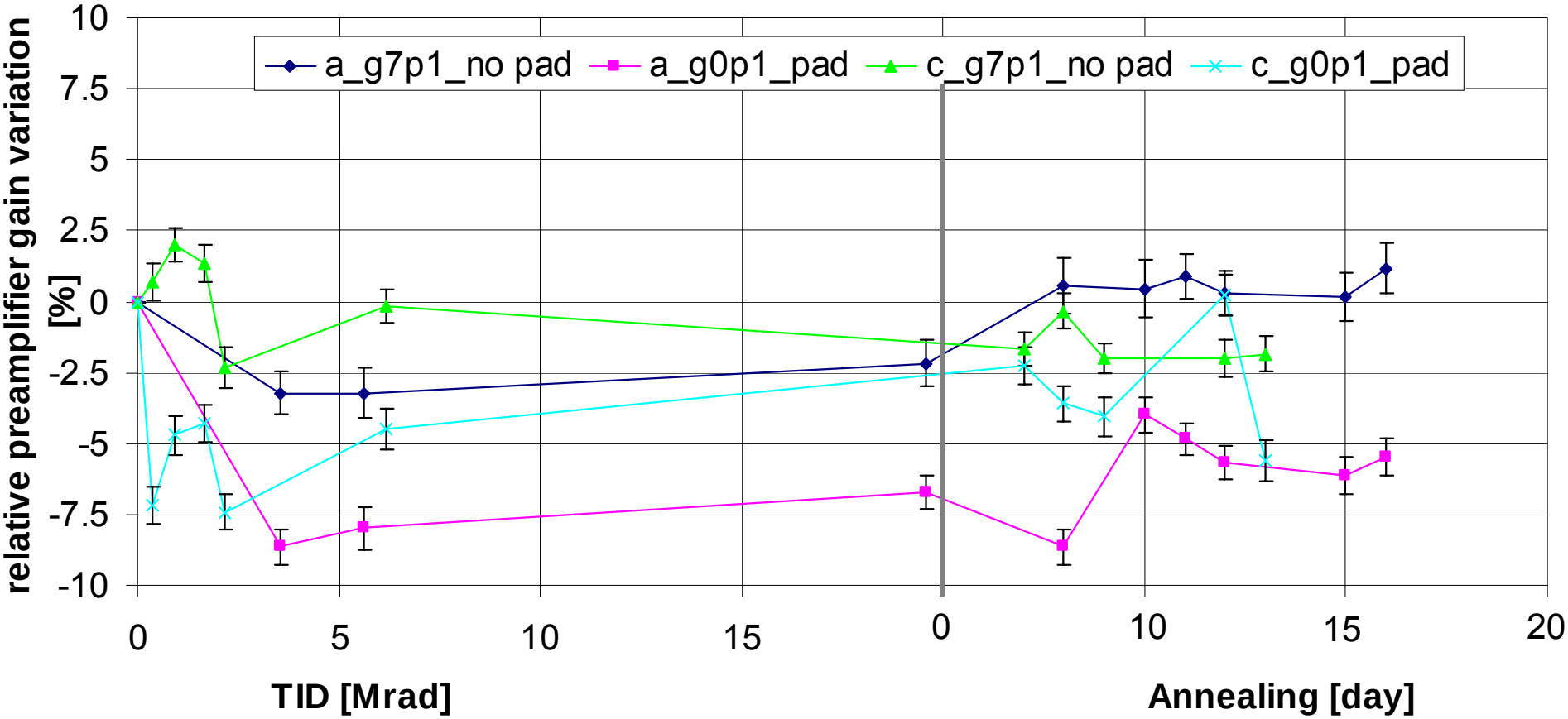
Results

chip c – threshold voltage (Vth) and baseline voltage (Vb) for both pixel cells with pad and without pad (no pad) as a function of TID and Annealing; max. variation within 11% (pad) and within 7 % (no pad)



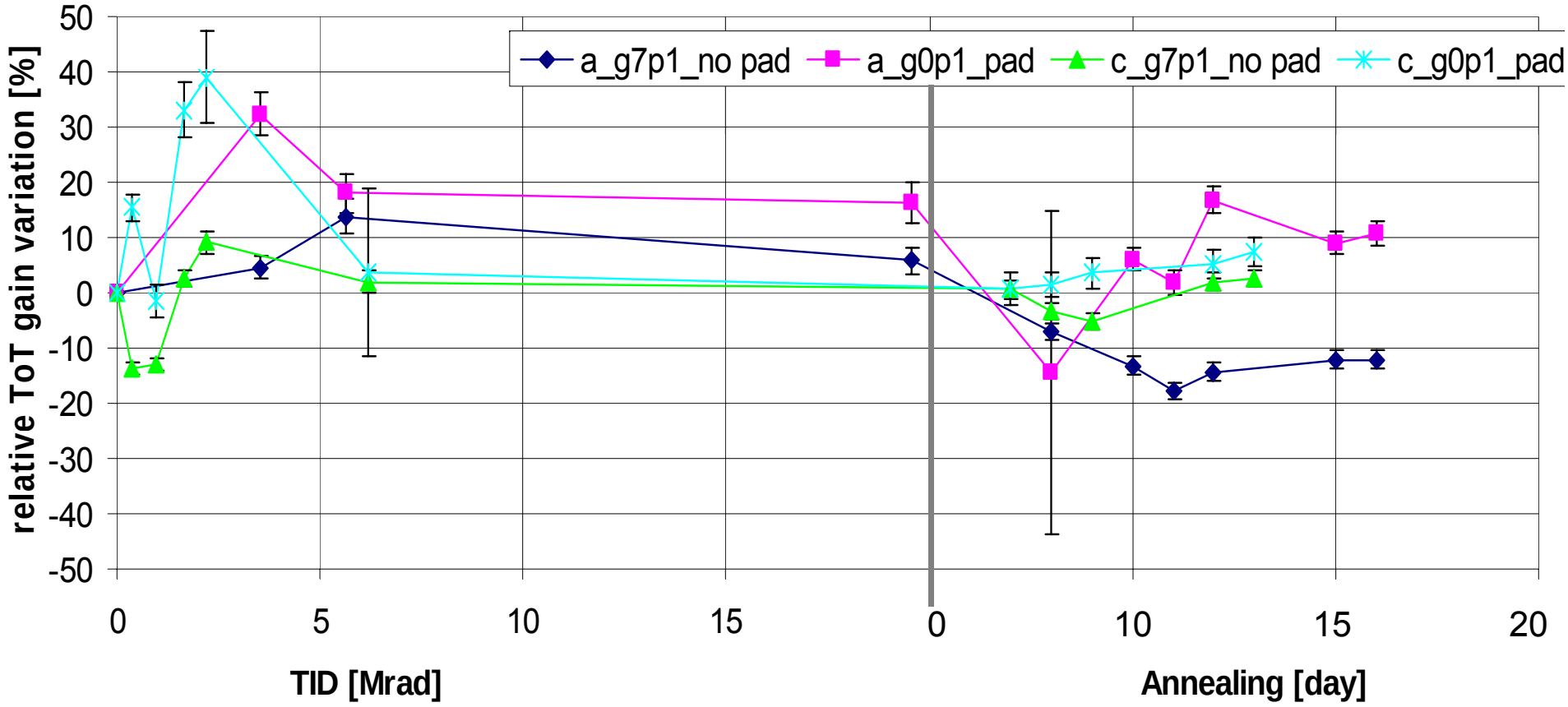
Results

chip a and c – relative preamplifier gain varation for pixel cells with and without pad; the max variation are less than 9 % and 3 % respectively



Results

chip a and c – relative TOT gain variation for pixel cells with and without pad; this plot involves the digital part of the pixel cell; max. variation within 39 % and 18 % respectively.



TID test at low dose rate

TID test at low dose rate

PRE-TID : 1 chip has been characterized before the TID test

TID measurements :

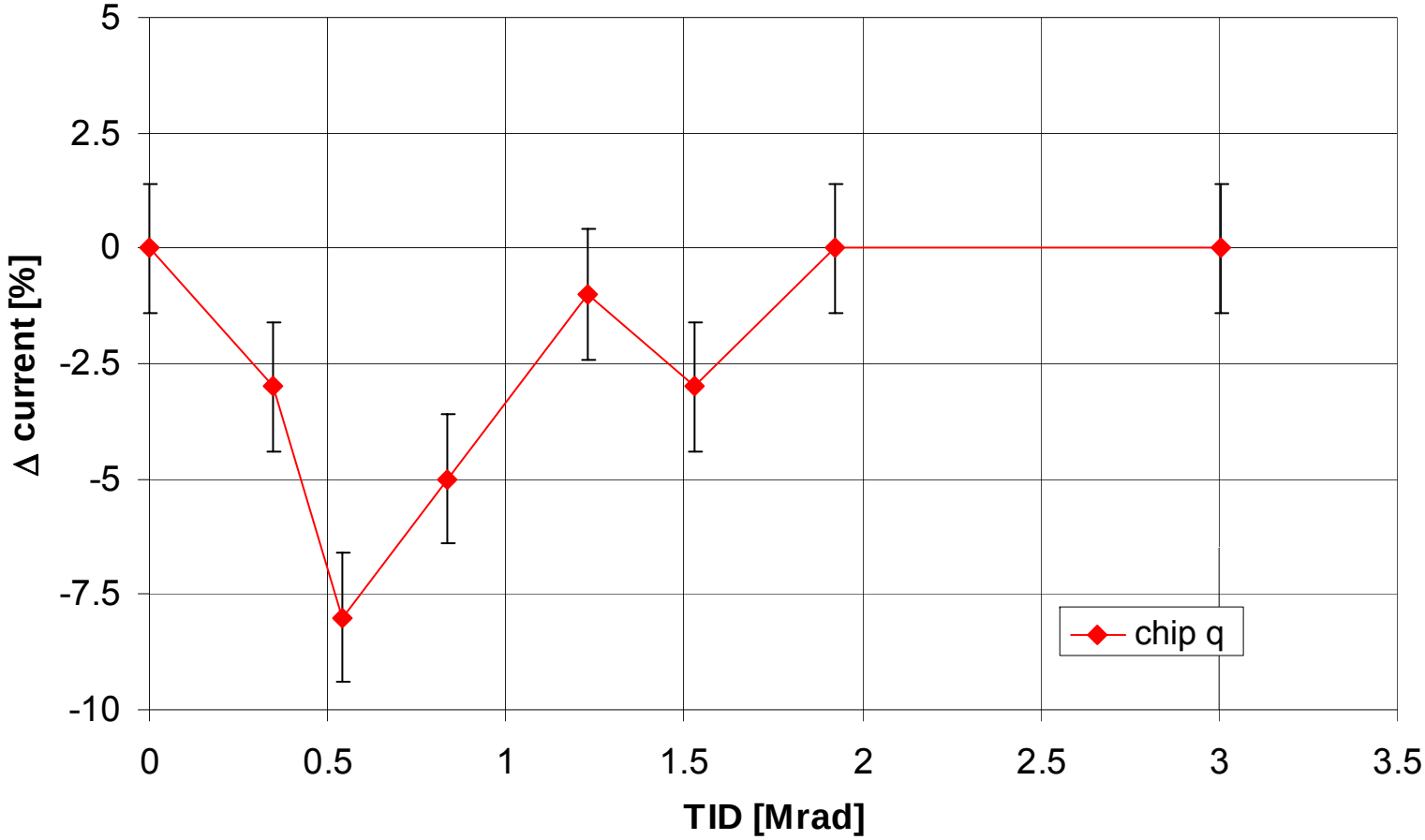
- the dose rate was 1.1 rad/s
- the final dose has been obtained in about 5 weeks
- the parameters for this chip have been measured at each TID, at Tlab of 25°C ± 2.5° C

Chip	Dose rate [rad/s]	Measurement point [Mrad]
q	1.1	0.345, 0.542, 0.838, 1.232, 1.527, 1.922, 3.006

Annealing : not performed

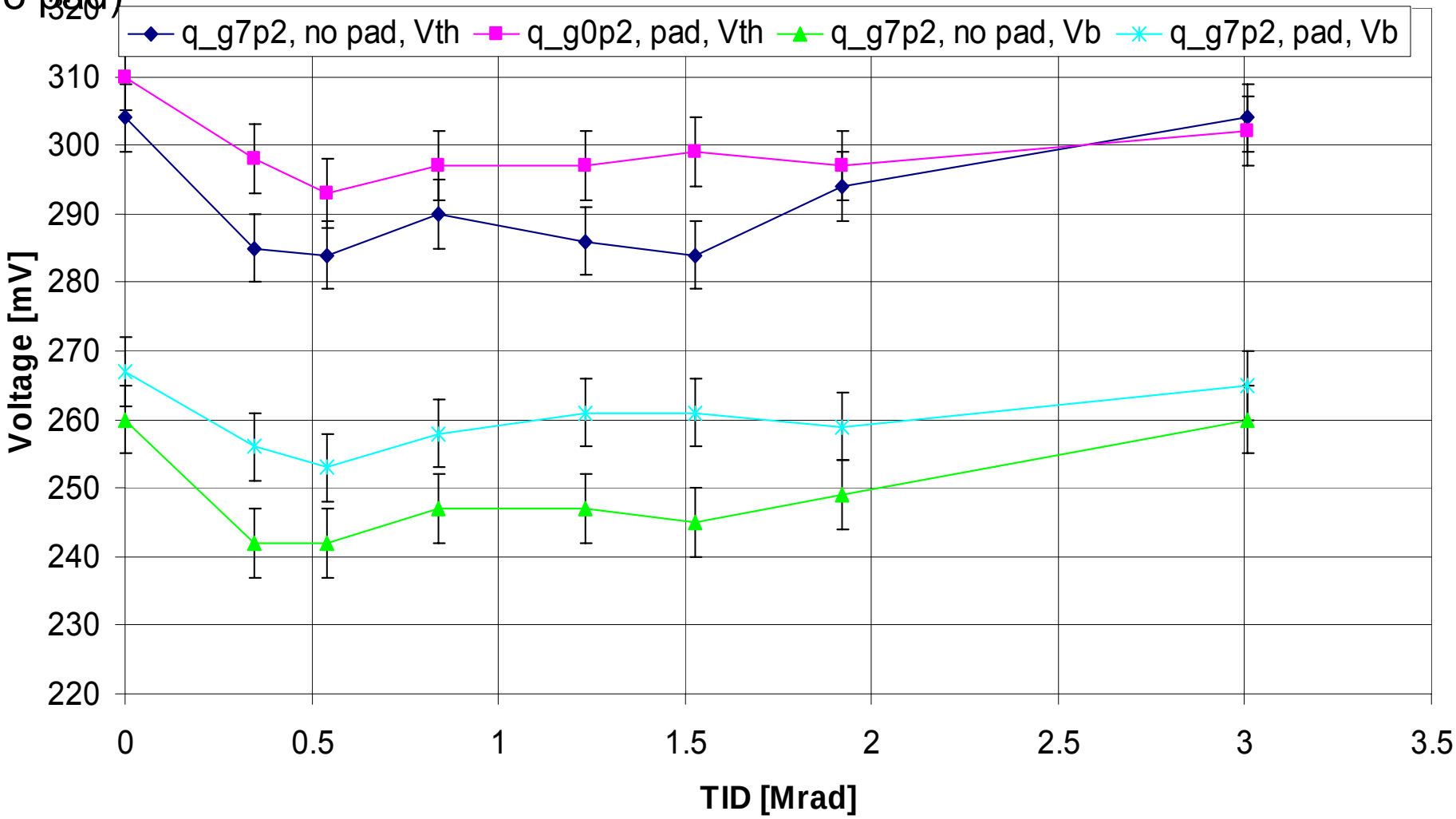
Results

chip q – leakage current, the pre-TID current (3.26 mA) is the reference value; max. variation within 8 %



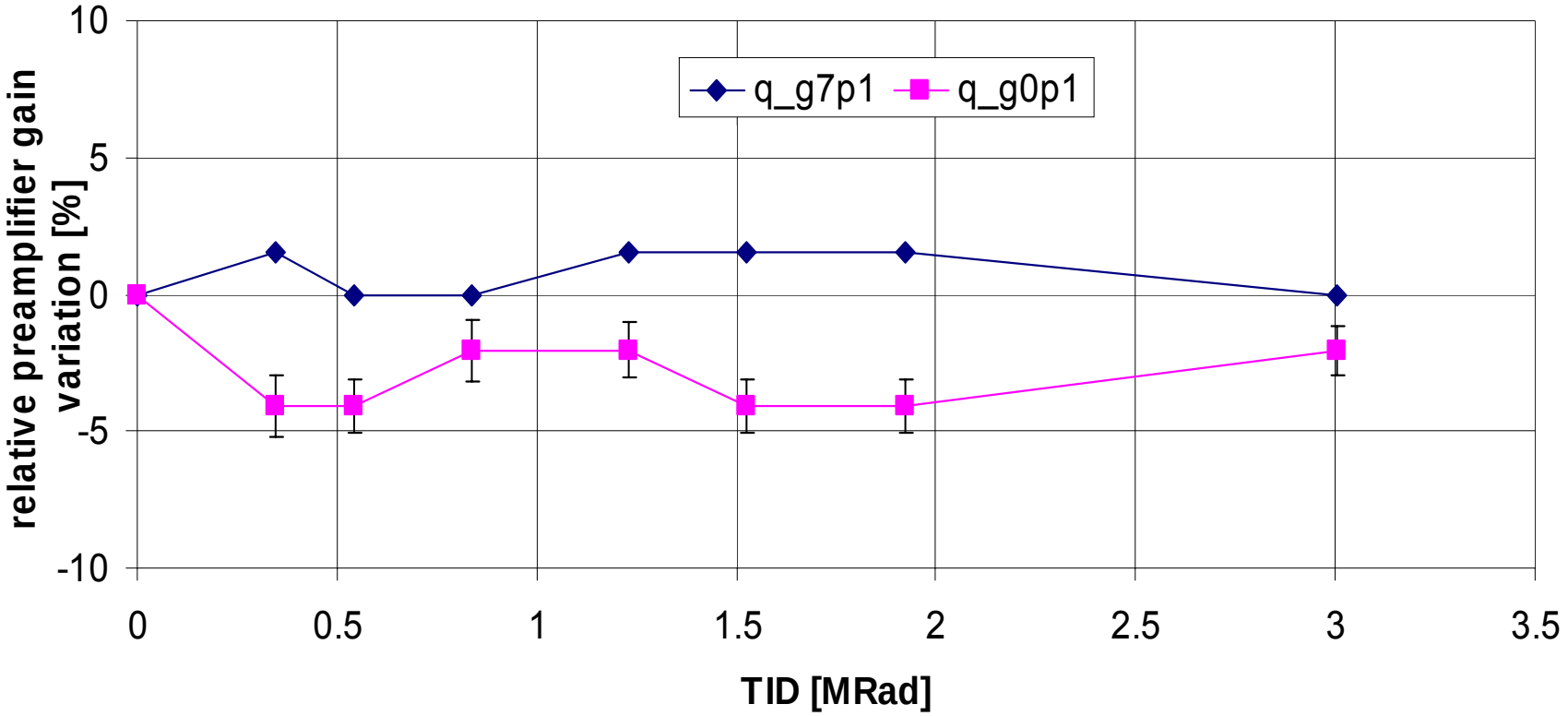
TID test – low dose rate

chip q – threshold voltage (Vth) and baseline voltage (Vb) for both pixel cells with pad and without pad (no pad); max. variation within 6.7 % (pad) and 5.5 % (no pad)



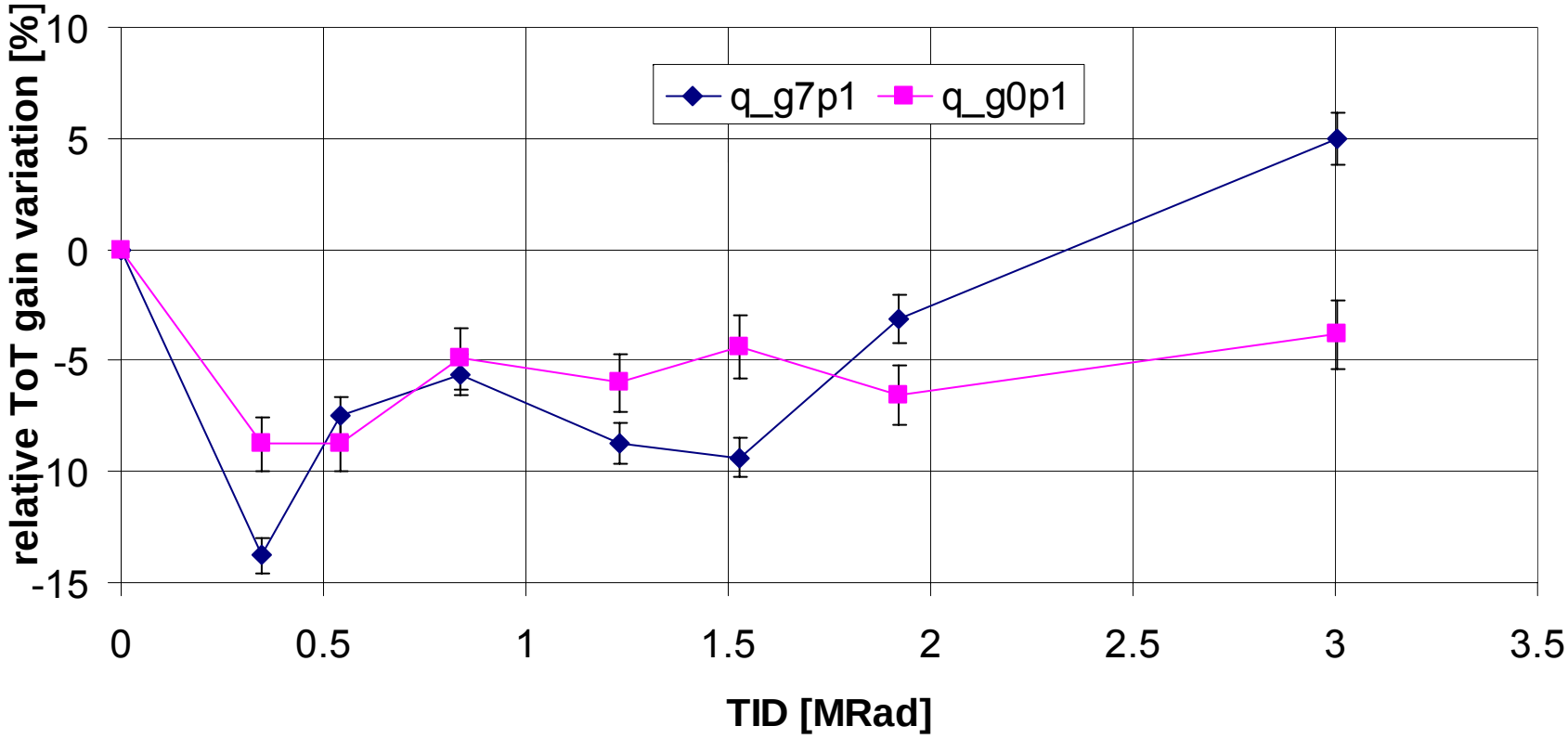
TID test – low dose rate

chip q - relative preamplifier gain variation for pixel cells with and without pad (q_g0p2 and q_g7p2); the max. variation is ~ 4% and 1.5 % respectively



TID test – low dose rate

chip q - relative ToT gain variation for pixel cells with and without pad (q_g0p2 and q_g7p2); the max. variation is ~ 9 % and 14 % respectively



Neutron test

Neutron test

- The neutron test has been performed in INFN LNL using the reaction deuteron-Be at the CN Van der Graaf
- 2 chips were exposed to a neutron flux
- The total flux of 3.6 ($\pm$1.6)10^{14}n (1MeVeq)/cm^2 was compatible to the Panda lifetime (10 years: ~3-4·10^{14}n (1MeV$_{eq}$)/cm^2)
- Both chips are working
- No significant changing was observed on main parameters (power dissipation, thresholds, preamplifier gain, ToT gain…): < 1%

Conclusion

Conclusions

• the first prototype (TOPIX) for pixel readout in PANDA has been realized with the 130 nm CMOS technology, without enclosed structures: ToT measurement is implemented

• a TID test has been performed on different TOPIX chips with X ray up to a final value of ~ 20 Mrad, followed by annealing measurements; a TID test with low dose rate (1 order of magniture higher of that expected in PANDA experiment) has been performed too up to ~ 3 Mrad. The leakage current, threshold and baseline, preamplifier gain and Tot gain variations are sistematically lower in the second test

• a neutron test has been performed: no significant variations have been observed in the more important parameters of TOPIX

• Does the 130 nm CMOS technology seem suitable for the PANDA needs, also without enclosing layout ? Probably yes, but…further damage test on the future second prototype including digital circuits have to be performed