

Radiation hardness studies of the Shashlyk DCS parts:

Gamma and neutrons hardness of ADC microchips and temperature sensors

Forward Spectrometer Calorimeter

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Why we need it

To know a real voltage on PMT cathode we need to modify Cockcroft-Walton generators at “shashlyk” with voltage feedback => Easy way: to add ADC chip with the serial interface (DACs DAC7512 with SPI are already used in every generator).

All other CW components have been tested for radiation hardness*. It is necessary to make the similar tests before ADC using.

**LHCb Calorimeters, Technical Design Report, CERN/LHCC/2000-0036, 6 Sept. 2000*

**Design of PMT base for the LHCb electromagnetic calorimeter:*

<http://indico.cern.ch/event/414850/contributions/995205/attachments/846448/1178118/note2.pdf>

Radiation resistant requirements

Gamma rays:

< 0.03 Gy/hour (behind FSC, at the maximum luminosity)

~130 Gy/year (integral dose for 6 months with beam in the year)

Neutrons:

~ $3 \cdot 10^{10}$ neutrons per cm^2 per year (at the maximum frequency of intersections equal $2 \cdot 10^7$ per second and $1 \cdot 10^{-4}$ neutron per intersection)

$3 \cdot 10^{11}$ neutrons per cm^2 per 10 years

Reference values of the neutrons and the gamma dose for radiation test should be **10^{12} neutrons per cm^2 and <1000 Gy**

Radiation sources

1) Gamma rays irradiation (mean energy 1.25MeV): container with radioactive isotope ^{60}Co with activity $\sim 5 \cdot 10^{12}$ Bq allows to get a dose rate from 20 to 0.005 Gy per hour depending on the distance from source (special room PANDA-RS at IHEP, Protvino).

2) Neutrons irradiation (hadrons with energy $< 20\text{MeV}$): beam absorber at booster U-1.5 of accelerator complex U-70 (IHEP, Protvino). Depending on booster mode $2.0 \cdot 10^{11}$ to $9.0 \cdot 10^{11}$ protons could be accelerated for one cycle. Proton beams that are non-injected to ring accelerator U-70 are dumped into the beam absorber (steel cube 2.8m). In the end of the channel that goes to the beam dump there is a special area $\sim 15 \text{ m}^2$ where we could put test setup. To obtain the desired neutrons number for radiation tests the ADC samples were put on the calculated distance from target (steel blocks) in front of beam absorber.

ADC requirements. Samples

- Serial interface (SPI)
 - 12-bit resolution
 - Availability and low price (1512 chips for the whole detector)
 - Small package (preferably sot-23)
- } DACs (DAC7512) on CW-generators

Selected serial ADC samples:

- 1) AD7476ARTZ (Analog Devices): 12-bit, sot-23, 4\$, 0.6um*
 - 2) AD7478AARMZ (Analog Devices): 8-bit, msop-8, 1\$, 0.6um*
 - 3) ADS7886SBDBVT (Texas Instruments): 12-bit, sot-23, 2\$, ??
 - 4) ADC121S021CIMF (Texas Instruments): 12-bit, sot-23, 2\$, ??
 - 5) MAX11665AUT (Maxim Intergrated): 12-bit, sot-23, 2\$, 0.18um**
- 1), 3), 4) and 5) have the identical pin mapping

**Reliability report:*

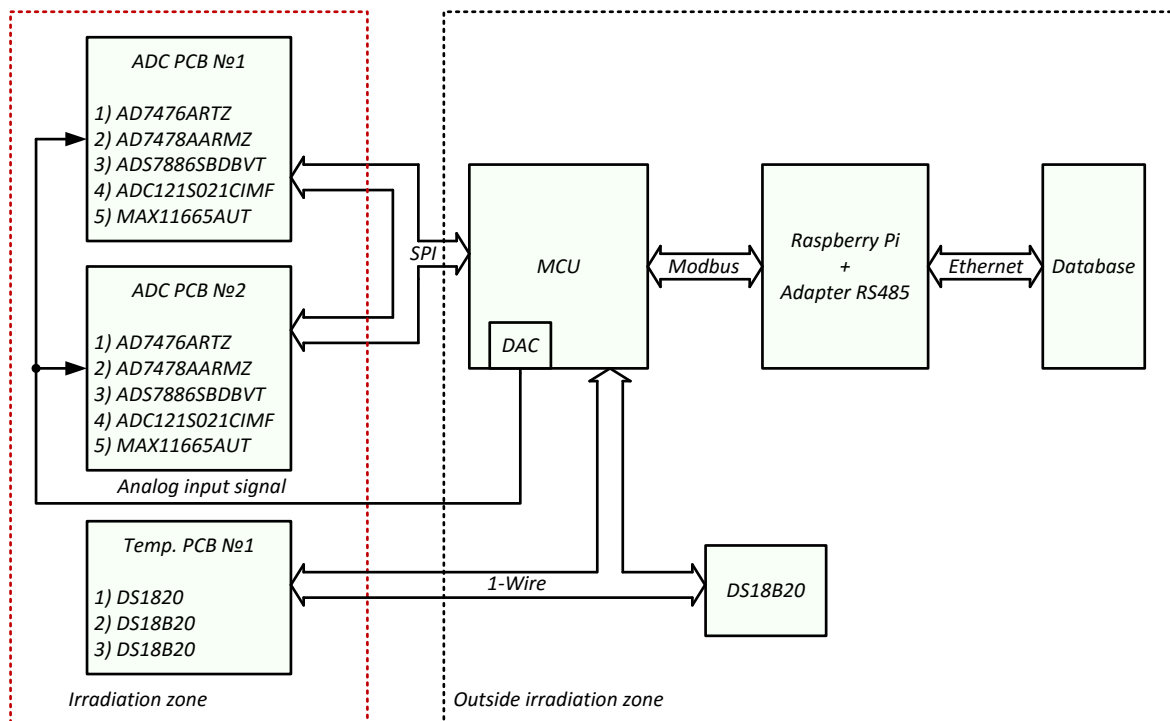
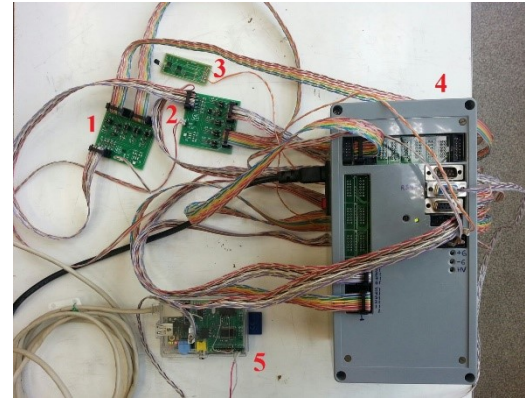
http://www.analog.com/media/en/pcn/ADI_PCN_10_0184_Rev_A_RQR02620.pdf

***Reliability report:*

http://www.analog.com/media/en/pcn/ADI_PCN_10_0184_Rev_A_RQR02620.pdf

Test setup: elements

- 1 – First board with ADC chips ADC PCB1
- 2 – Second board with ADC chips ADC PCB2
- 3 - Temperature sensors
- 4 - Microcontroller unit (MCU)
- 5 - Single-board computer Raspberry Pi (RPi)



- This system was made for FSC DCS (in particular for CW-control) and was used in radiation tests.

- DAC increments analog input signal for all ADC from 0 to 3.22V every 80.5mV per 10 seconds.

12-bit resolution means: from 0 to 4000 counts every 100 counts per 10 seconds.

- Continuously monitoring to estimate changes during irradiation time.

Gamma test. Stability: ADC on input analog signal 3,22V (4000 Counts)

Time period 0-8 hours – without irradiation

Time period 8-208 hours – irradiation 2.7 Gy/h:

Integral dose = 292 Gy: first changes in ADC;

Integral dose = 540 Gy: significant changes in ADC,
ADC1,2,6,7 (Analog Devices) are totally damaged.

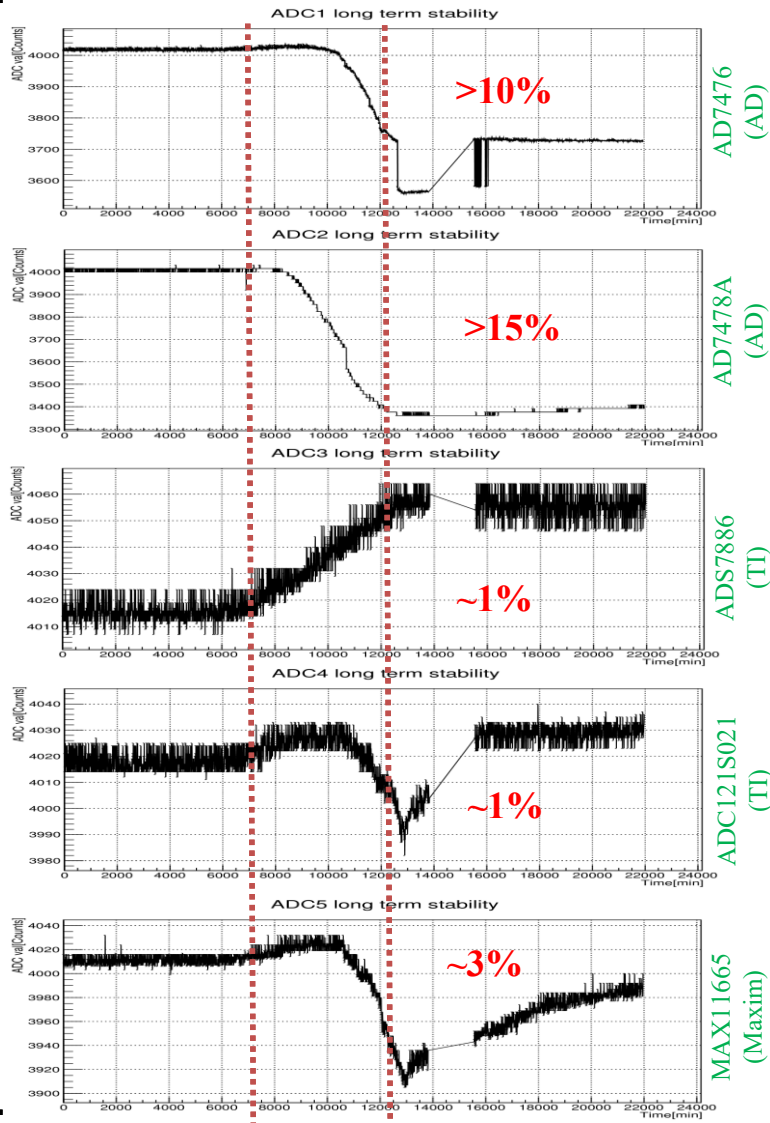
Time period 208-366 hours – without radiation, recovering:

ADC1,2,6,7 (Analog Devices) were not recovered.

(linear zones on graphs at recovering period: no data because of network problems)

Gamma test. Stability: ADC on input analog signal 3.22V (4000 Counts)

ADC PCB №1



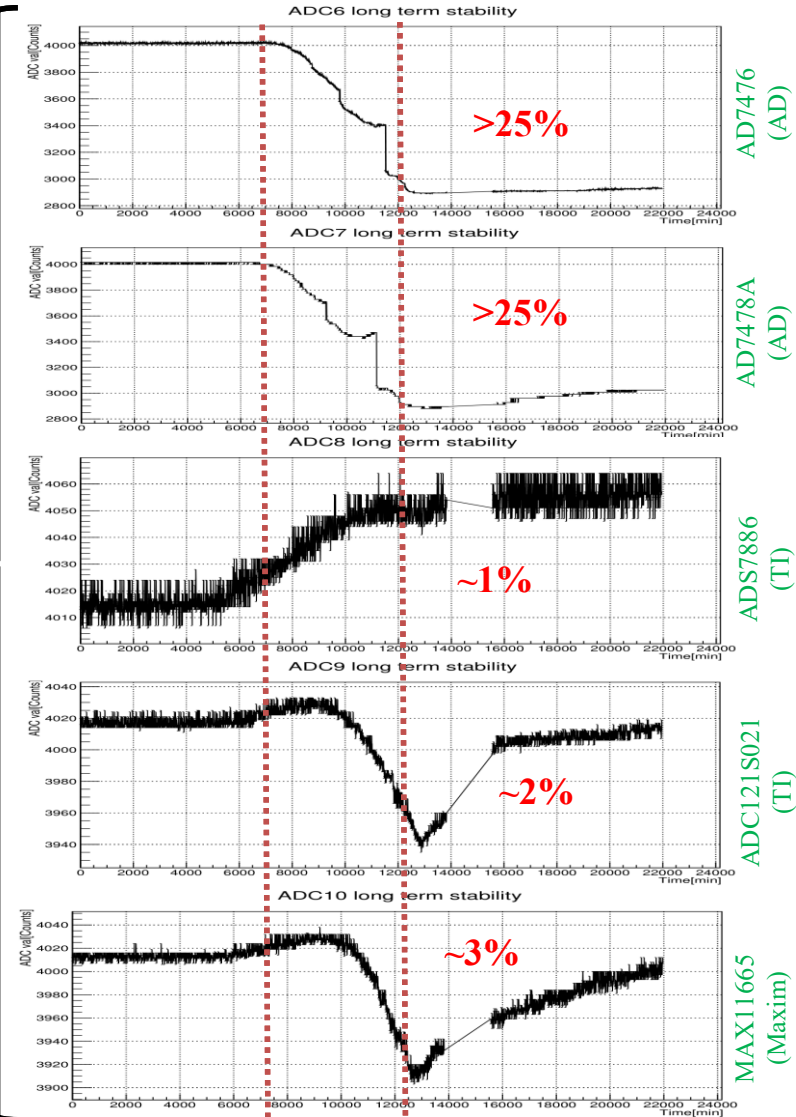
2.7 Gy/h

292 Gy

540 Gy

recovering

ADC PCB №2



2.7 Gy/h

292 Gy

540 Gy

recovering

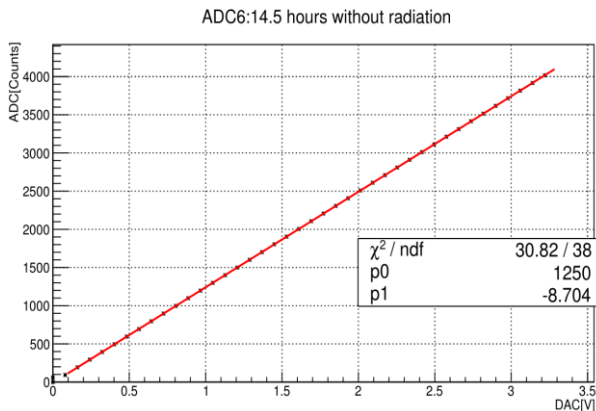
Gamma test.

The similar effects on both PCBs for all input analog steps =>
next slides show results only for one PCB.

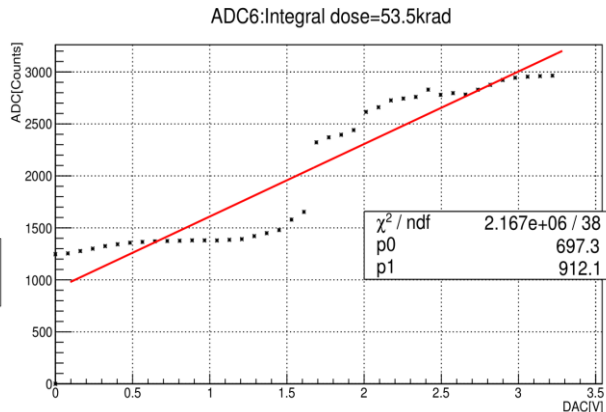
Gamma test: ADC6=AD7476ARTZ (Analog Devices)

ADC outputs [counts] depending on input analog signal 0 to 3.22V every 80.5mV (every 100 counts).

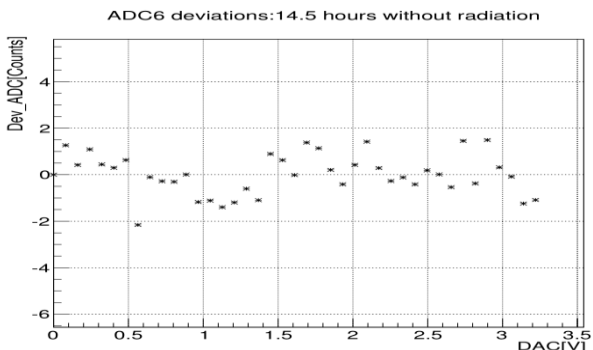
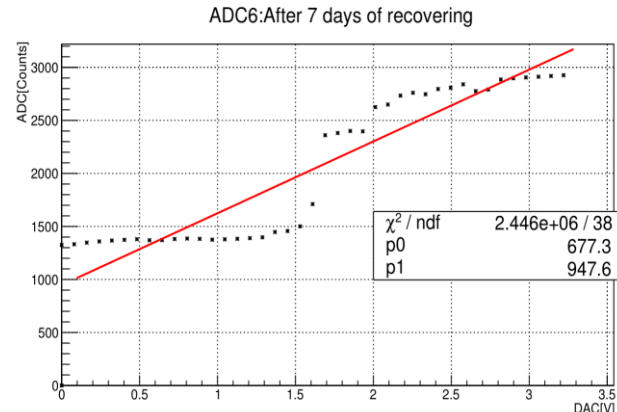
Mean values
for the 14 hours
without radiation



Mean values
for the last 20 hours at 2.7 Gy/h
Integral dose close to 540 Gy



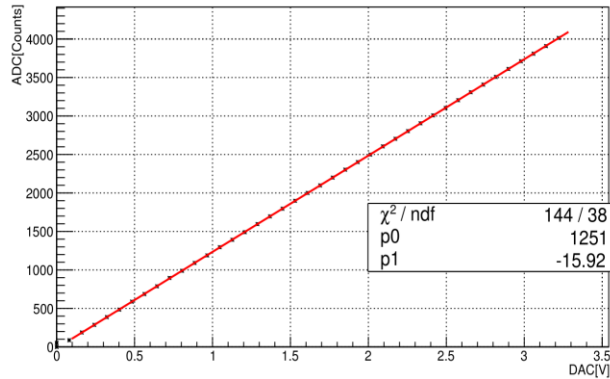
Mean values
for the last 20 hours
recovering



Gamma test: ADC7=AD7478AARMZ (Analog Devices)

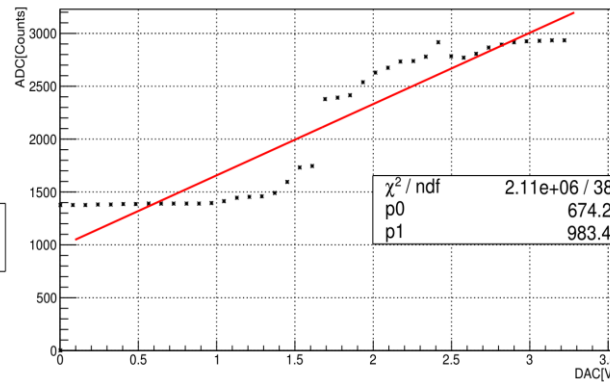
Mean values
for the 14 hours
without radiation

ADC7:14.5 hours without radiation



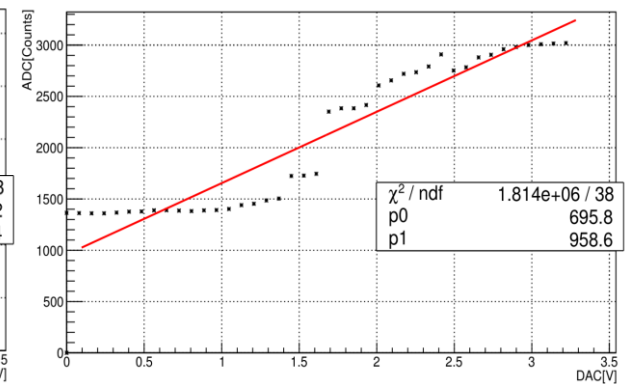
Mean values
for the last 20 hours at 2.7 Gy/h
Integral dose close to 540 Gy

ADC7: Integral dose=53.5krad

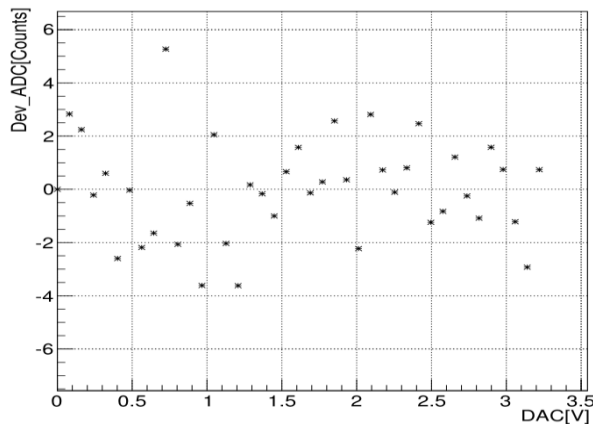


Mean values
for the last 20 hours
recovering

ADC7: After 7 days of recovering



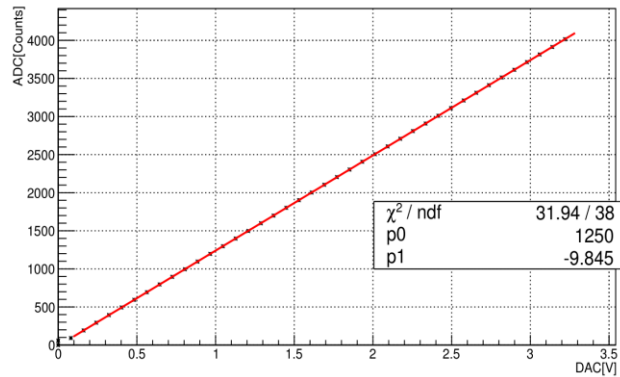
ADC7 deviations: 14.5 hours without radiation



Gamma test: ADC8=ADS7886SBDBVT (Texas Instruments)

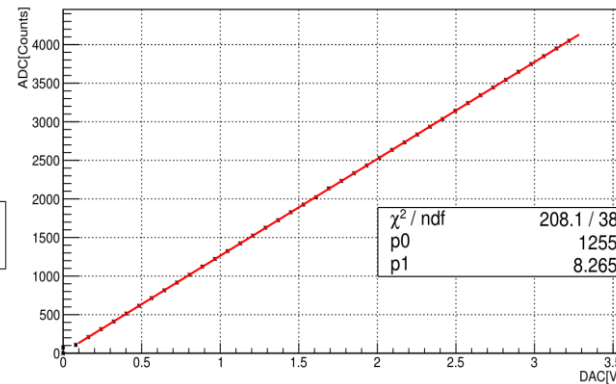
Mean values
for the 14 hours
without radiation

ADC8:14.5 hours without radiation



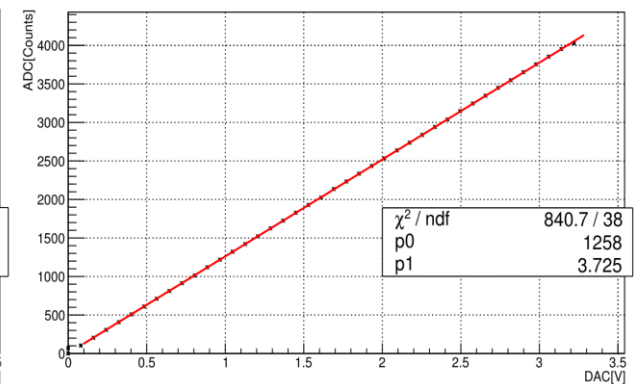
Mean values
for the last 20 hours at 2.7 Gy/h
Integral dose close to 540 Gy

ADC8: Integral dose=53.5krad

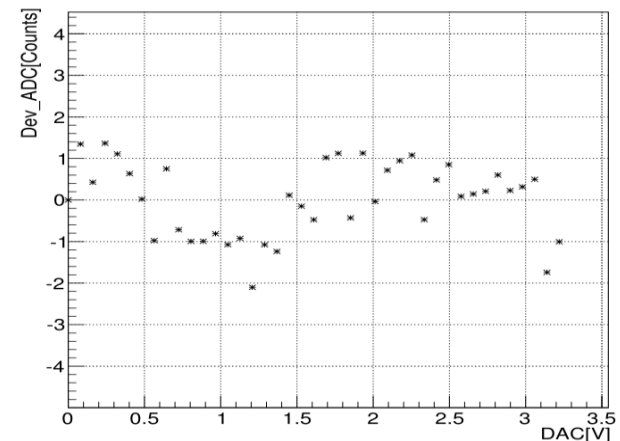


Mean values
for the last 20 hours
recovering

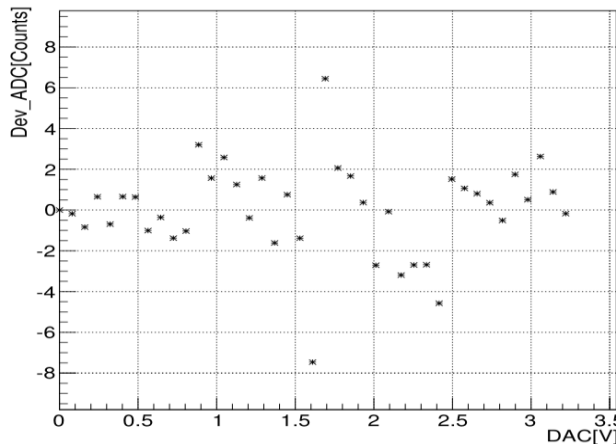
ADC8: After 7 days of recovering



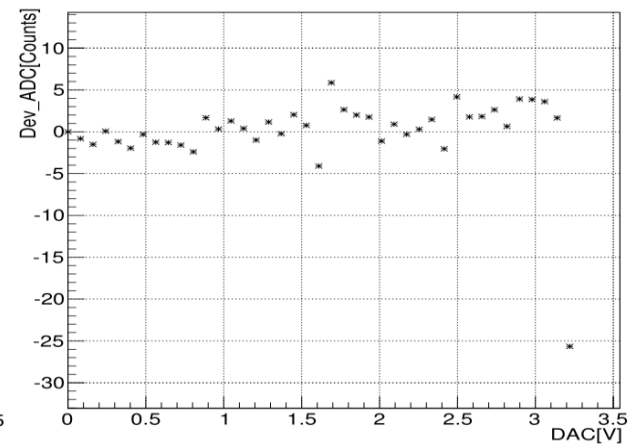
ADC8 deviations: 14.5 hours without radiation



ADC8 deviations: Integral dose=53.5krad



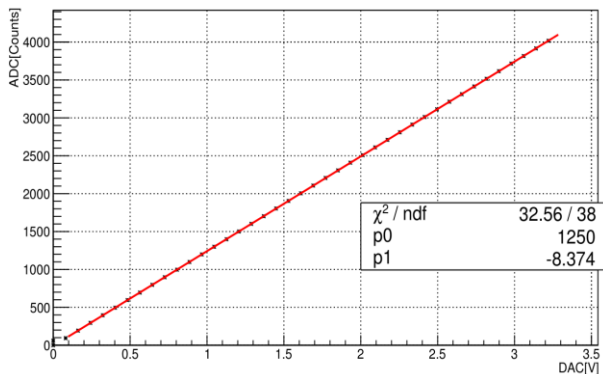
ADC8 deviations: After 7 days of recovering



Gamma test: ADC9=ADC121S021CIMF (Texas Instruments)

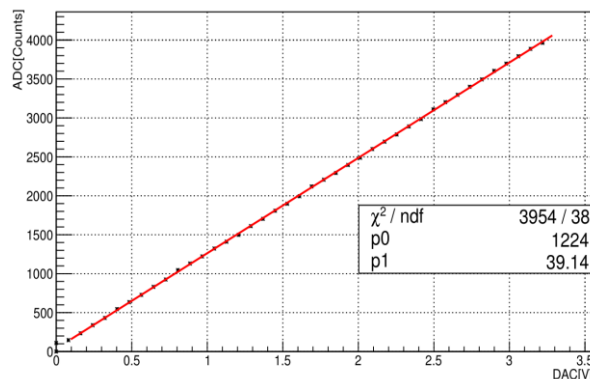
Mean values
for the 14 hours
without radiation

ADC9:14.5 hours without radiation



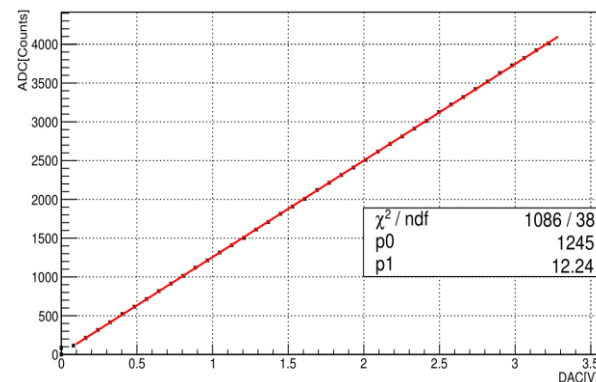
Mean values
for the last 20 hours at 2.7 Gy/h
Integral dose close to 540 Gy

ADC9: Integral dose=53.5krad

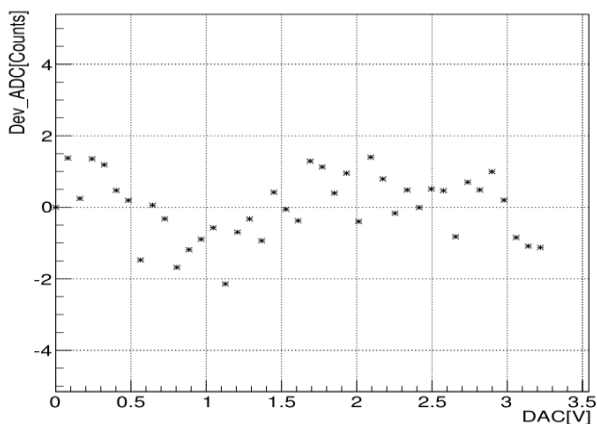


Mean values
for the last 20 hours
recovering

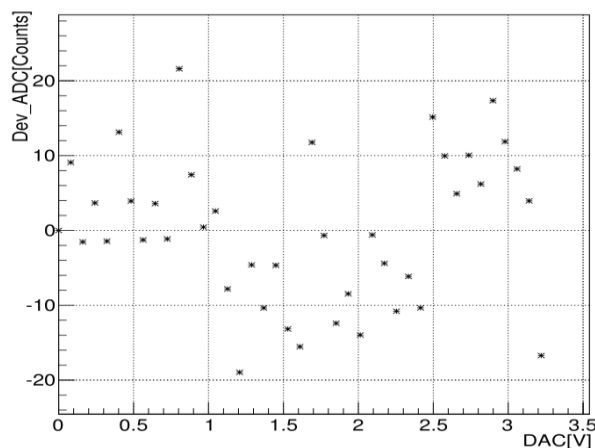
ADC9: After 7 days of recovering



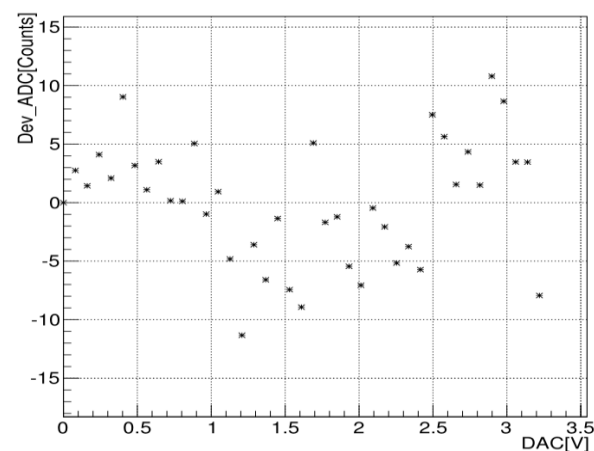
ADC9 deviations: 14.5 hours without radiation



ADC9 deviations: Integral dose=53.5krad



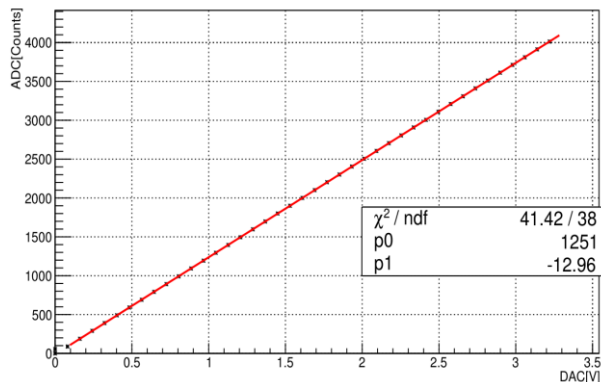
ADC9 deviations: After 7 days of recovering



Gamma test: ADC10=MAX11665AUT (Maxim Intergrated)

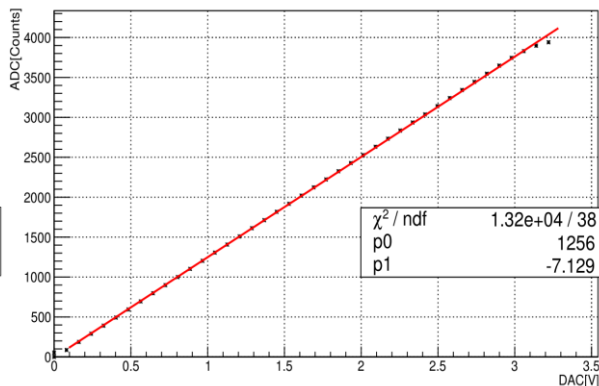
Mean values
for the 14 hours
without radiation

ADC10:14.5 hours without radiation



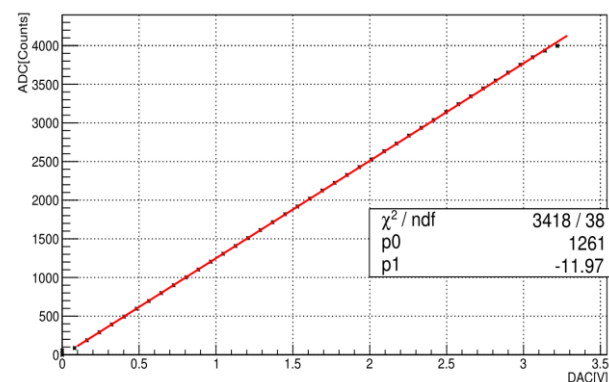
Mean values
for the last 20 hours at 2.7 Gy/h
Integral dose close to 540 Gy

ADC10: Integral dose=53.5krad

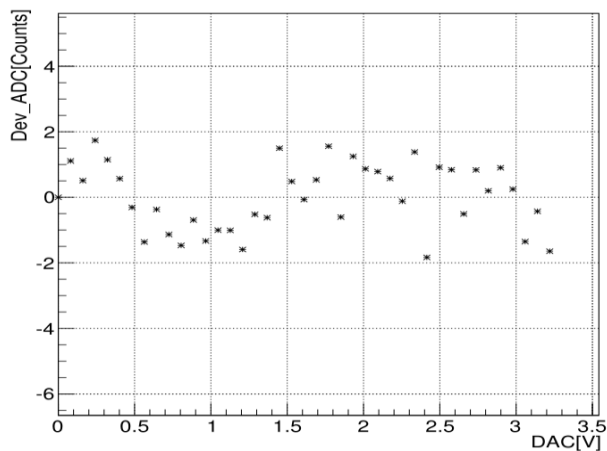


Mean values
for the last 20 hours
recovering

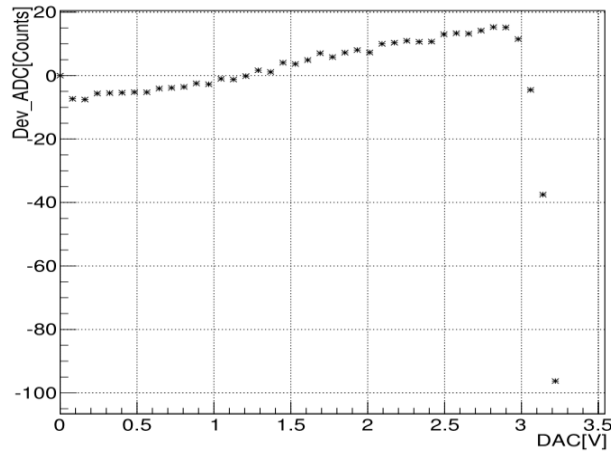
ADC10: After 7 days of recovering



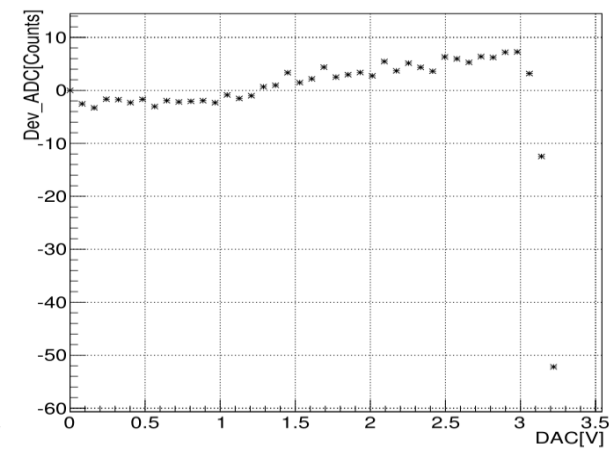
ADC10 deviations: 14.5 hours without radiation



ADC10 deviations: Integral dose=53.5krad



ADC10 deviations: After 7 days of recovering



Neutrons test. Stability: ADC on input analog signal 3,22V (4000 Counts)

Time period 0-87 hours– without irradiation

Time period 87-169 hours– integral dose 10^{12} neutrons per cm^2 :

Non-significant changes on all ADC except ADC6.

(ADC6 was totally damaged: 2000 counts on 3.22V input)

Time period 169-255 hours – integral dose 10^{13} neutrons per cm^2 :

ADC1,2,6,7 (Analog Devices) are totally damaged.

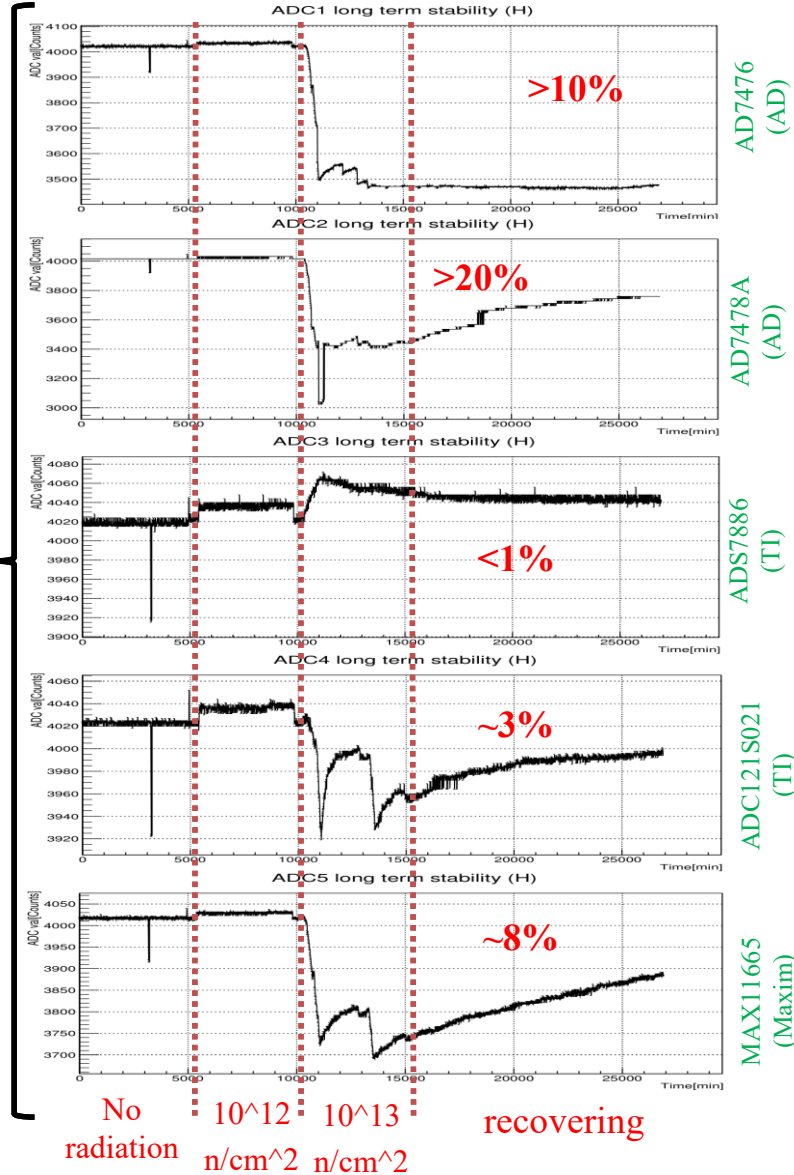
(ADC6 somehow started to recover)

Time period 255-450 hours – without radiation, recovering:

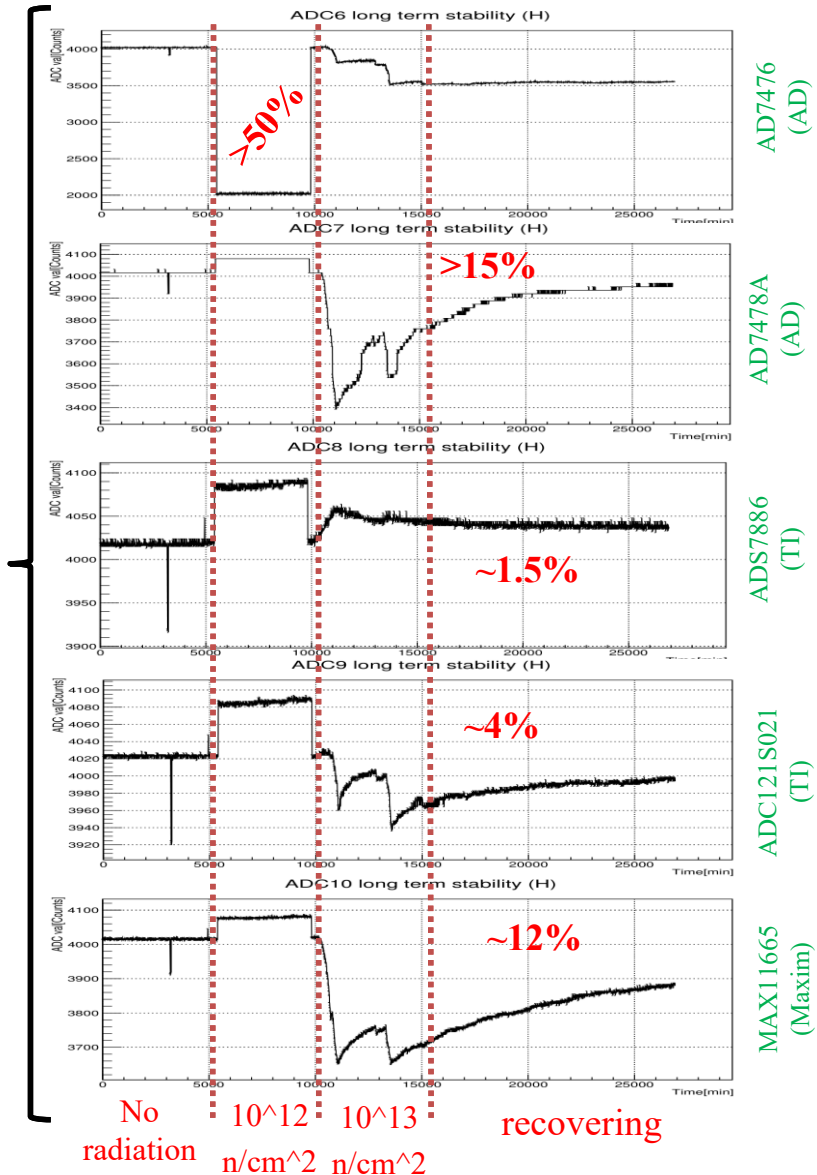
ADC1,2,6,7 (Analog Devices) were not recovered.

Neutrons test. Stability: ADC on input analog signal 3.22V (4000 Counts)

ADC PCB №1



ADC PCB №2

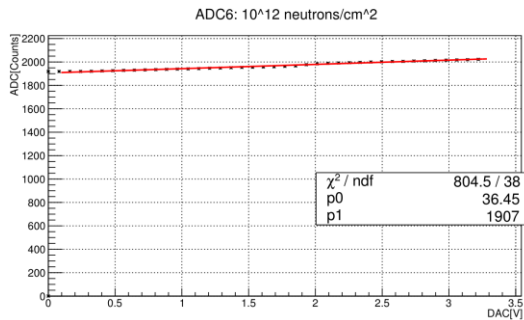


Neutrons test. Stability: ADC on input analog signal 3,22V (4000 Counts)

The similar effects on both PCBs for all input analog steps => next slides show results only for one PCB.

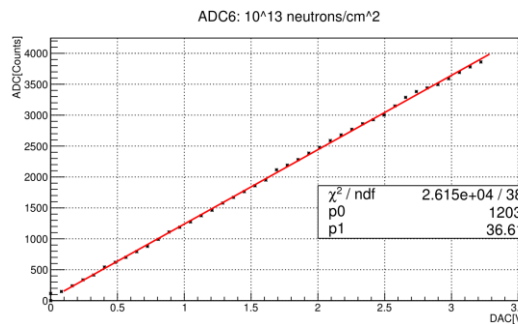
Neutrons test: ADC6=AD7476ARTZ (Analog Devices)

Mean values
for the last 16 hours
 10^{12} neutrons



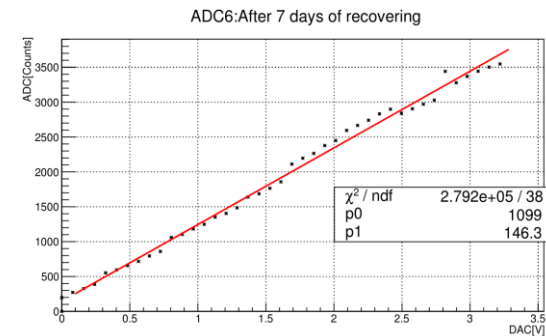
↑
*~2000 counts at every
step of input signal*

Mean values
for the last 21 hours
 10^{13} neutrons



↑
Some recovering effect

Mean values
for the last 24 hours
recovering

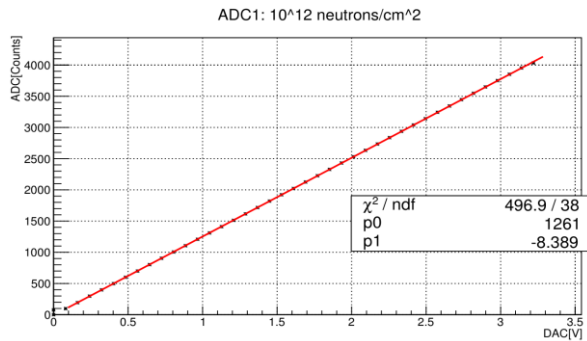


It makes no sense to consider the behavior of ADC6.

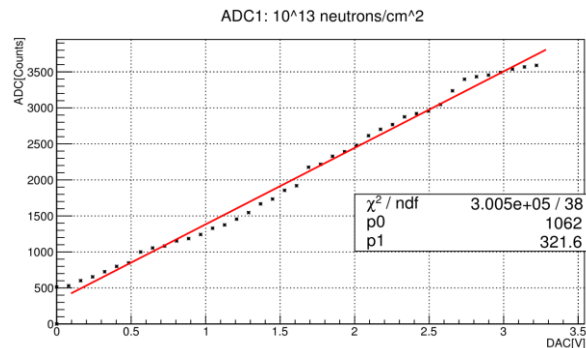
Neutrons test: ADC1=AD7476ARTZ (Analog Devices)

Behavior of the same chip (ADC1) on the another board ADC PCB №1:

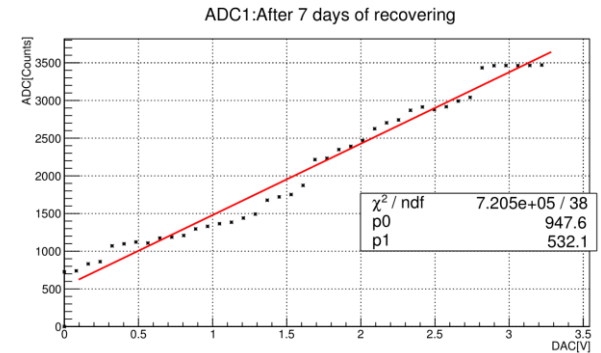
Mean values
for the last 16 hours
 10^{12} neutrons



Mean values
for the last 21 hours
 10^{13} neutrons

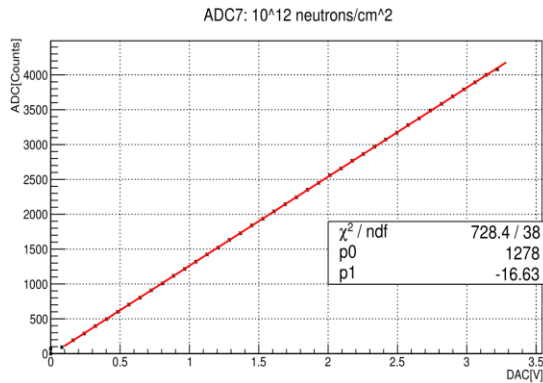


Mean values
for the last 24 hours
recovering

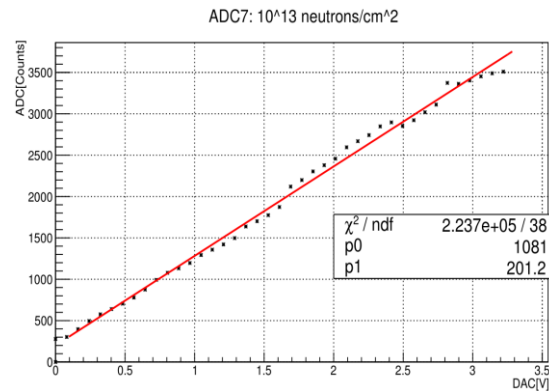


Neutrons test: ADC7=AD7478AARMZ (Analog Devices)

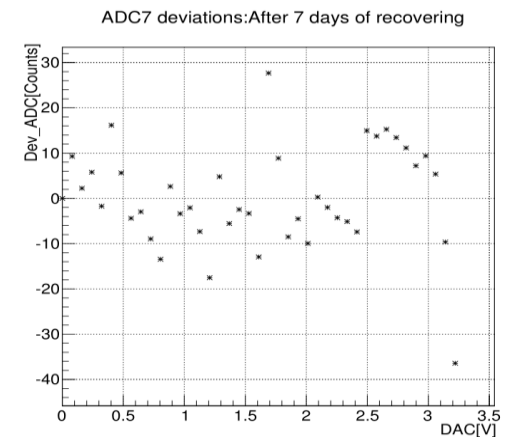
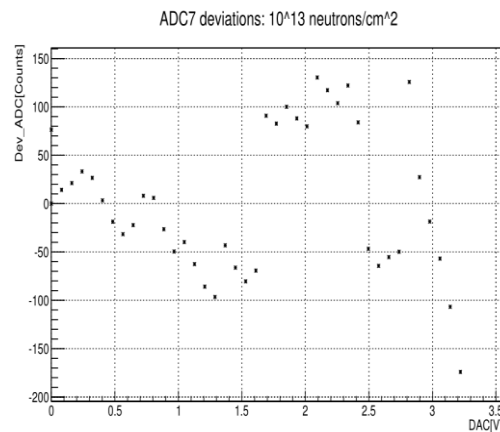
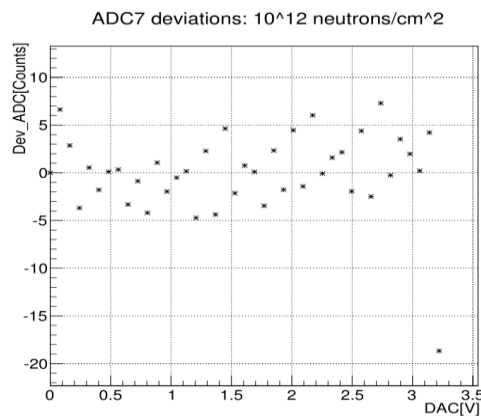
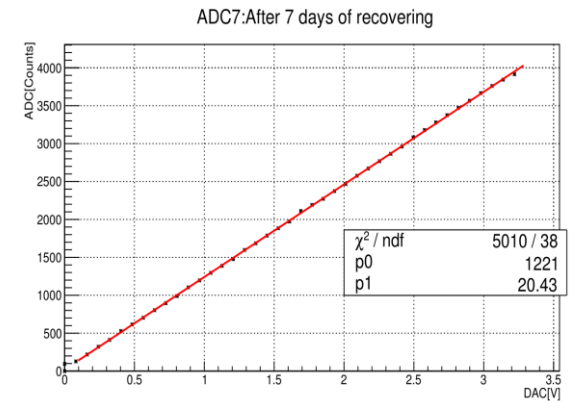
Mean values
for the last 16 hours
 10^{12} neutrons



Mean values
for the last 21 hours
 10^{13} neutrons

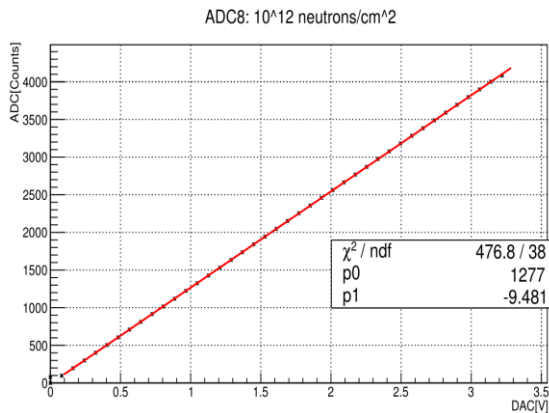


Mean values
for the last 24 hours
recovering

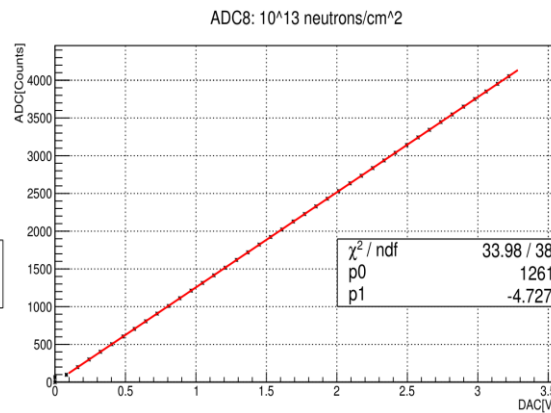


Neutrons test: ADC8=ADS7886SBDBVT (Texas Instruments)

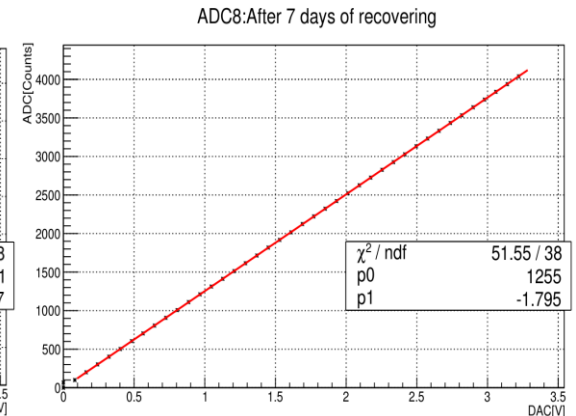
Mean values
for the last 16 hours
 10^{12} neutrons



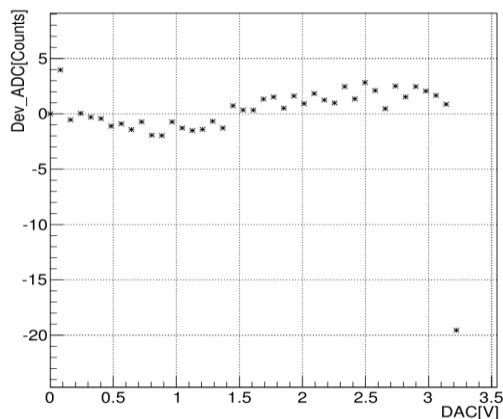
Mean values
for the last 21 hours
 10^{13} neutrons



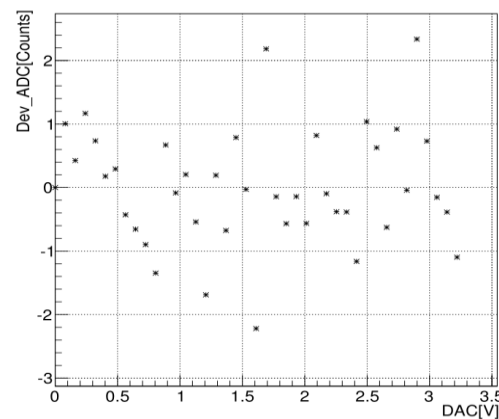
Mean values
for the last 24 hours
recovering



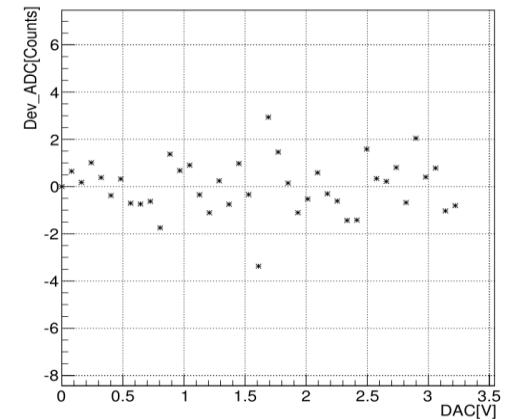
ADC8 deviations: 10^{12} neutrons/cm²



ADC8 deviations: 10^{13} neutrons/cm²

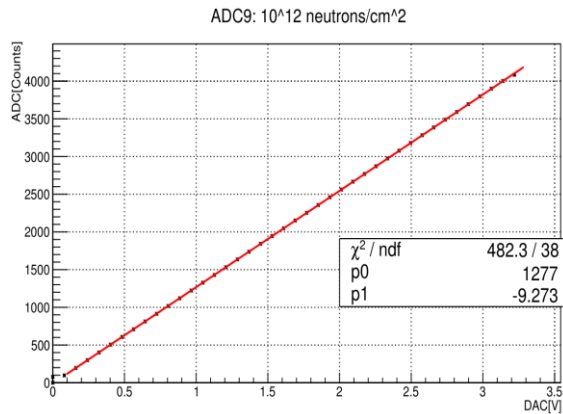


ADC8 deviations: After 7 days of recovering

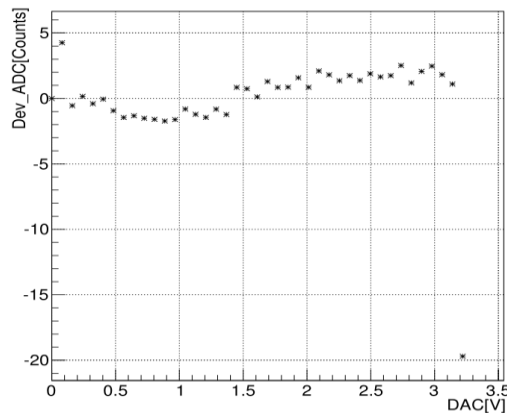


Neutrons test: ADC9=ADC121S021CIMF (Texas Instruments)

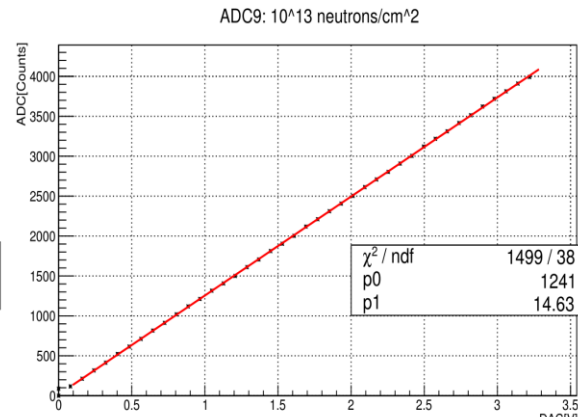
Mean values
for the last 16 hours
 10^{12} neutrons



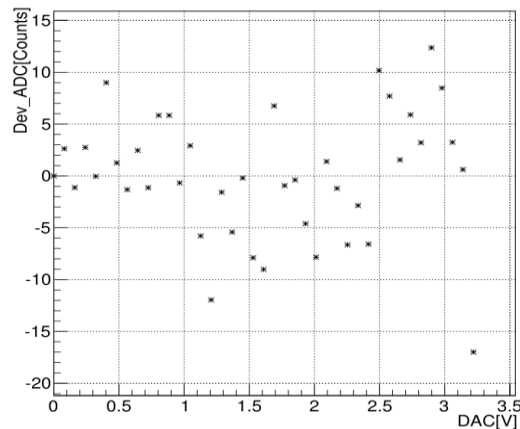
ADC9 deviations: 10^{12} neutrons/cm²



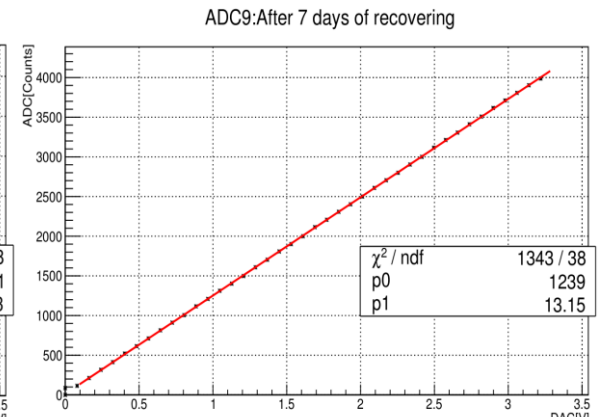
Mean values
for the last 21 hours
 10^{13} neutrons



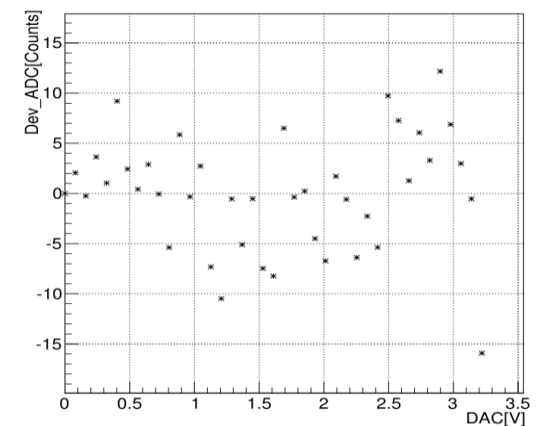
ADC9 deviations: 10^{13} neutrons/cm²



Mean values
for the last 24 hours
recovering



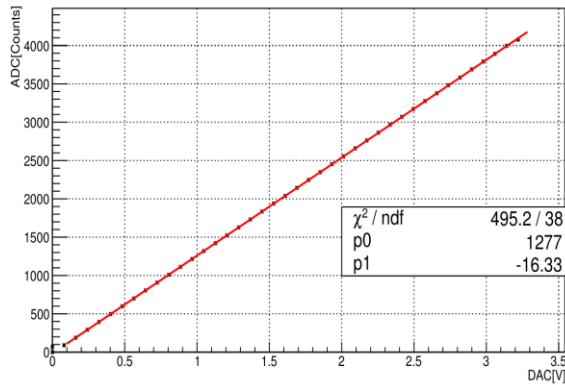
ADC9 deviations: After 7 days of recovering



Neutrons test: ADC10=MAX11665AUT (Maxim Intergrated)

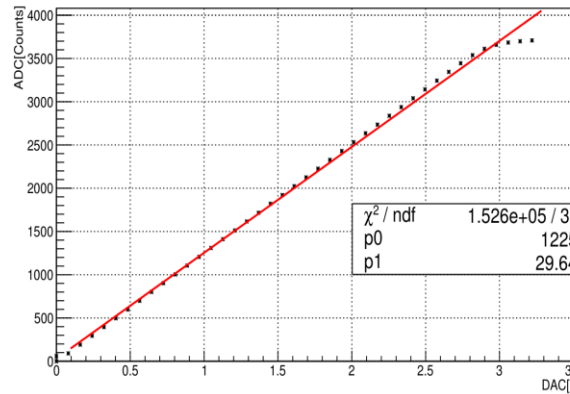
Mean values
for the last 16 hours
 10^{12} neutrons

ADC10: 10^{12} neutrons/cm²



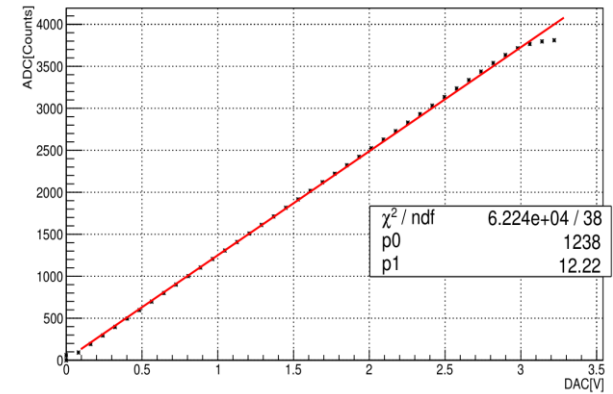
Mean values
for the last 21 hours
 10^{13} neutrons

ADC10: 10^{13} neutrons/cm²

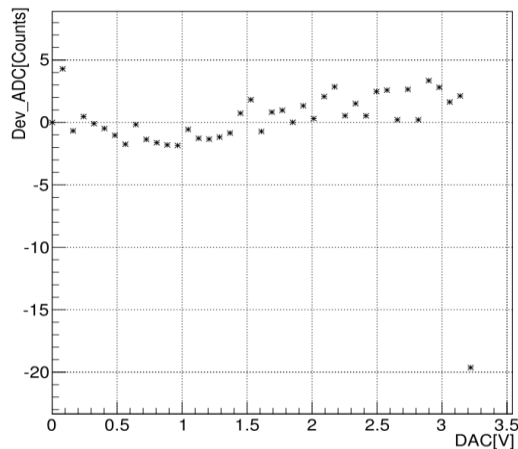


Mean values
for the last 24 hours
recovering

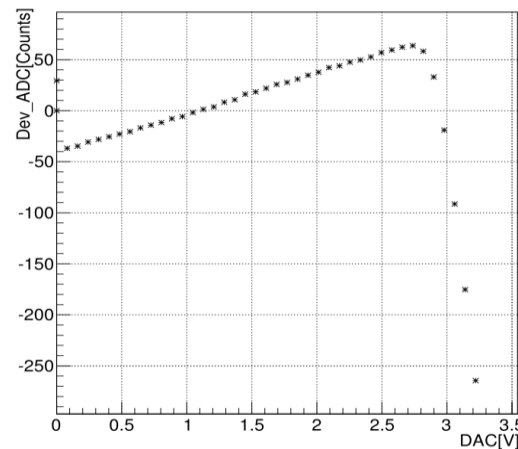
ADC10: After 7 days of recovering



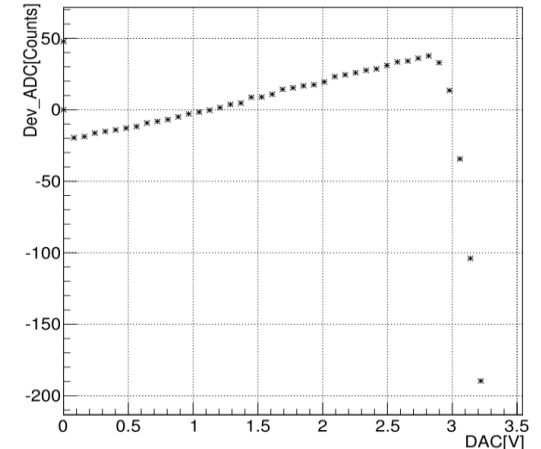
ADC10 deviations: 10^{12} neutrons/cm²



ADC10 deviations: 10^{13} neutrons/cm²



ADC10 deviations: After 7 days of recovering



Neutrons test: Temperature sensors

On the neutron irradiation we also tested 1-wire temperature sensors produced by Dallas:

- 1) 8-bit DS1820
- 2) 12-bit DS18B20
- 3) 12-bit DS18B20

- 4) 12-bit DS18B20 close to microcontroller unit, out of radiation zone

Neutrons test: Temperature sensors

Time period 0-87 hours– without irradiation

Time period 87-169 hours– 10^{12} neutrons per cm^2 :

Last 30 hours the false values from all 4 sensors: only one could be damaged under the radiation and could corrupt all data on wire.

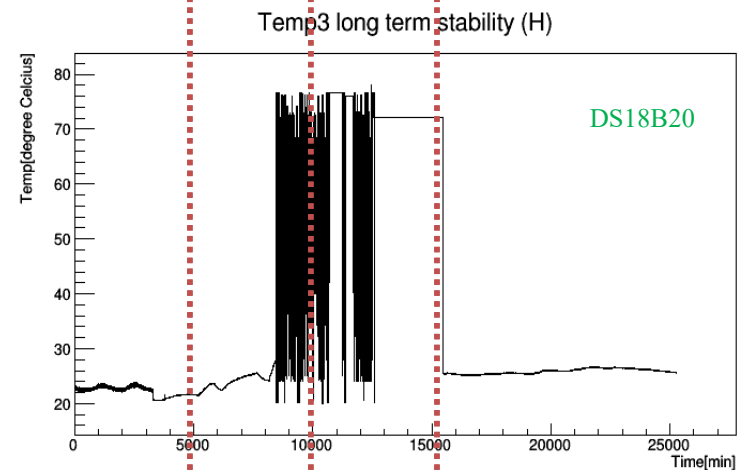
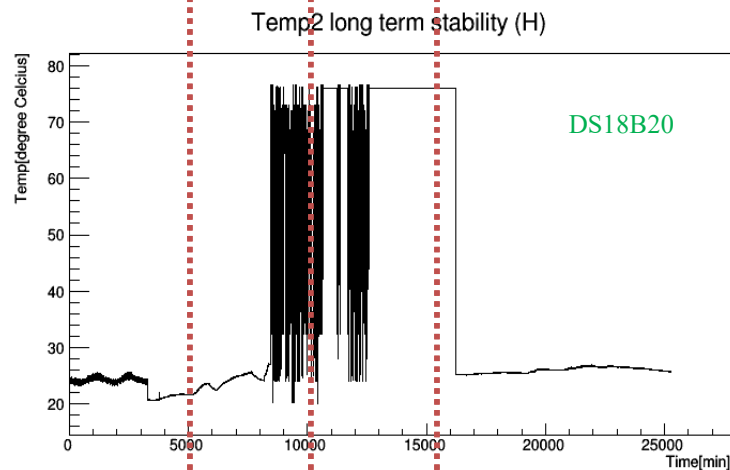
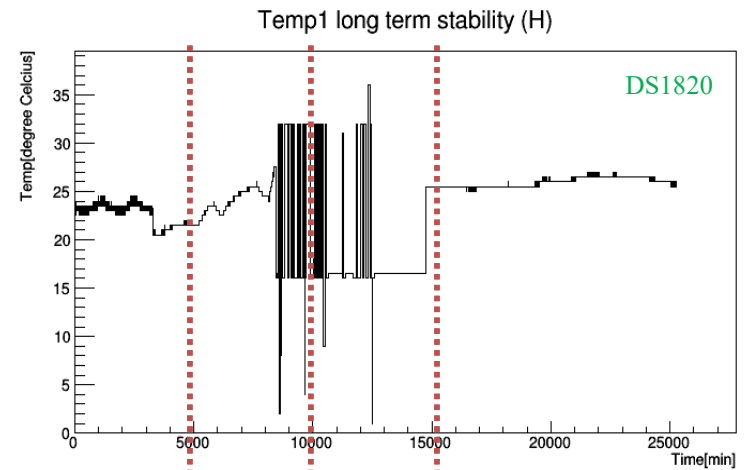
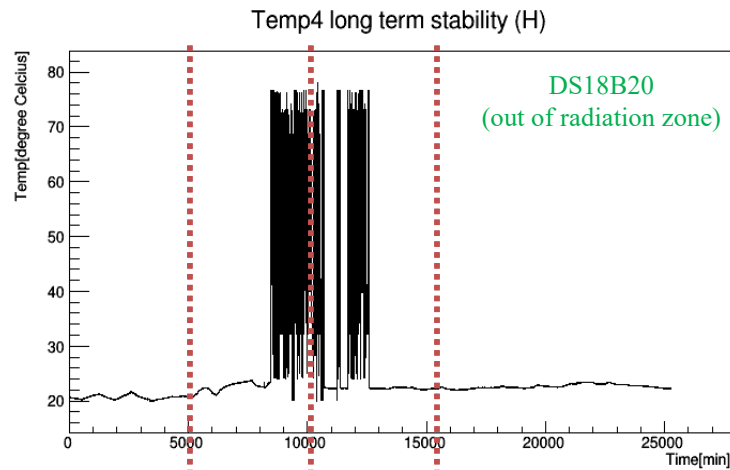
Time period 169-255 hours – 10^{13} neutrons per cm^2 :

After 40 hours the sensors were so much damaged that 1-wire bus was “released” and DS18B20 (4) out of the radiation zone started to work correct.

Time period 255-450 hours – without radiation, recovering:

All sensors were recovered after a few hours after irradiation was off.

Neutrons test: Temperature sensors



No radiation 10^{12} 10^{13} recovering
 n/cm^2 n/cm^2

No radiation 10^{12} 10^{13} recovering
 n/cm^2 n/cm^2

Standard Deviations.

StdDev were calculated for the different time stamps of the whole radiation periods at the input signal = 161mV (200 counts) to estimate how the ADC noise is changing under the radiation.

For gamma test:

First time stamp – after 14 hours without radiation

Time stamps 1...10 – every 20 hours at radiation 2.7 Gy/h

Time stamps 11...18 – every 20 hours of recovering period

For neutron test:

First time stamp – after 30 hours without radiation

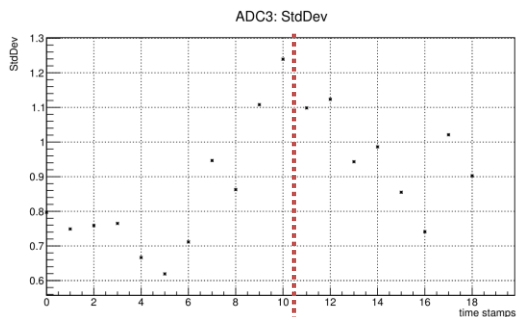
Time stamps 1...5 – every 16 hours (integral dose on 5th is 10^{12} neutrons per cm^2)

Time stamps 6...9 – every 21 hours (integral dose on 9th is 10^{13} neutrons per cm^2)

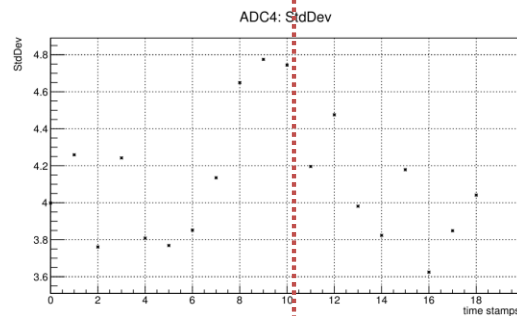
Time stamps 10...15 – every 24 hours of recovering period

Gamma test. Standard Deviations.

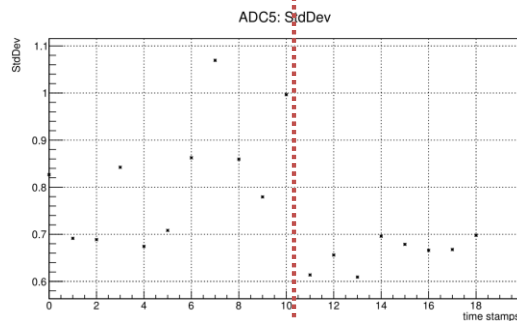
ADC PCB №1



ADS7886
(TI)



ADC121S021
(TI)

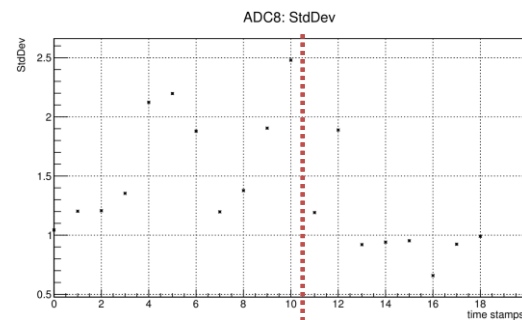


MAX11665
(Maxim)

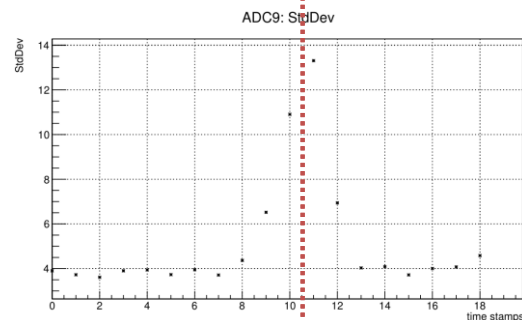
2.7 Gy/h recovering

540 Gy

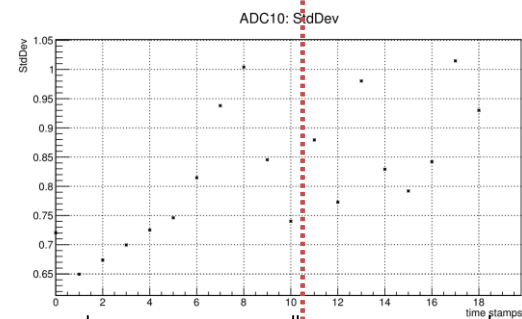
ADC PCB №2



ADS7886
(TI)



ADC121S021
(TI)



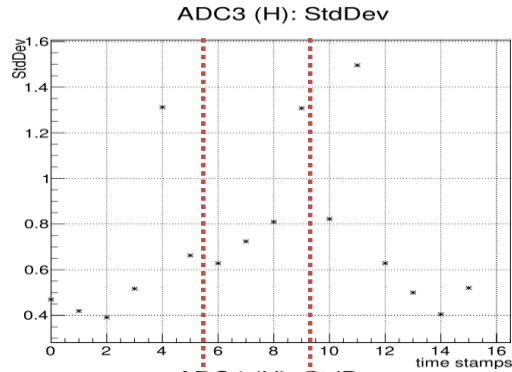
MAX11665
(Maxim)

2.7 Gy/h recovering

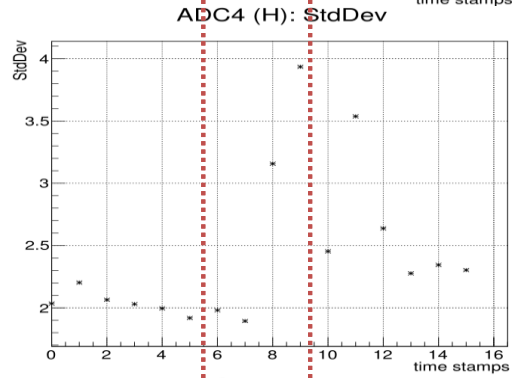
540 Gy

Neutrons test. Standard Deviations.

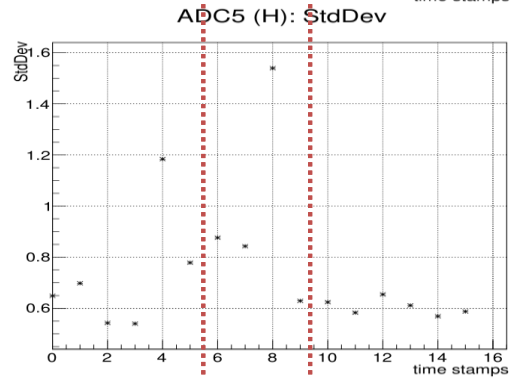
ADC PCB №1



ADS7886
(TI)



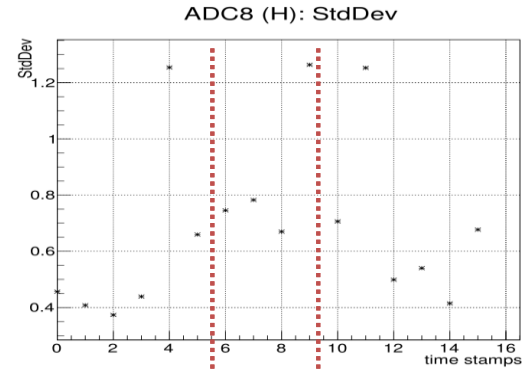
ADC121S021
(TI)



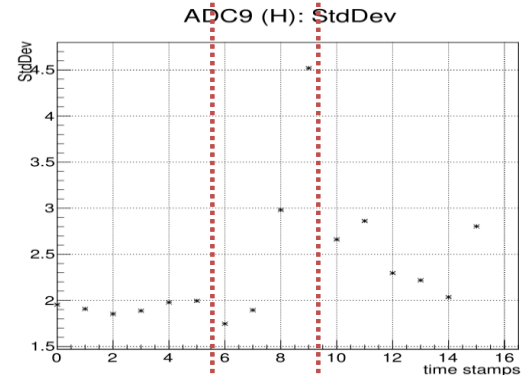
MAX11665
(Maxim)

10¹² 10¹³ recovering

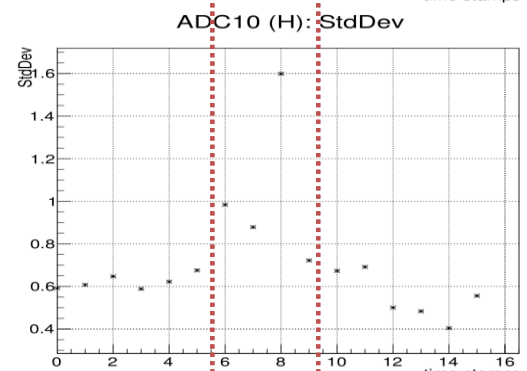
ADC PCB №2



ADS7886
(TI)



ADC121S021
(TI)



MAX11665
(Maxim)

10¹² 10¹³ recovering

Results

ADC AD7476ARTZ and AD7478AARMZ produced by Analog Devices were totally damaged in both tests.

MAX11665AUT (Maxim Intergrated) shows good results, but its output was corrupted at high values of input signal (gamma and neutron test – the same result).

ADS7886SBDBVT and ADC121S021CIMF (Texas Instruments) show the best results, but StdDev for ADC121S021CIMF was slightly increased and was not fully recovered.

ADS7886SBDBVT was not changed in both tests and can be used on Cockcroft-Walton generators at forward calorimeter.