



# Irradiation test of Commercial (BASLER) digital cameras @ CHARM



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*Thanks to S.Danzeca & Co. for support and discussions*

- Introduction / Motivation
- Cameras
- CHARM Setup / Installation
- Results
- Conclusion

# Introduction / Motivation



BI group has a large number of instruments mainly based on **analogue** cameras (standard CCD, “rad hard” like tube based or from ThermoFisher cameras, etc...)

“We are camera users, not camera nor radiation expert...”

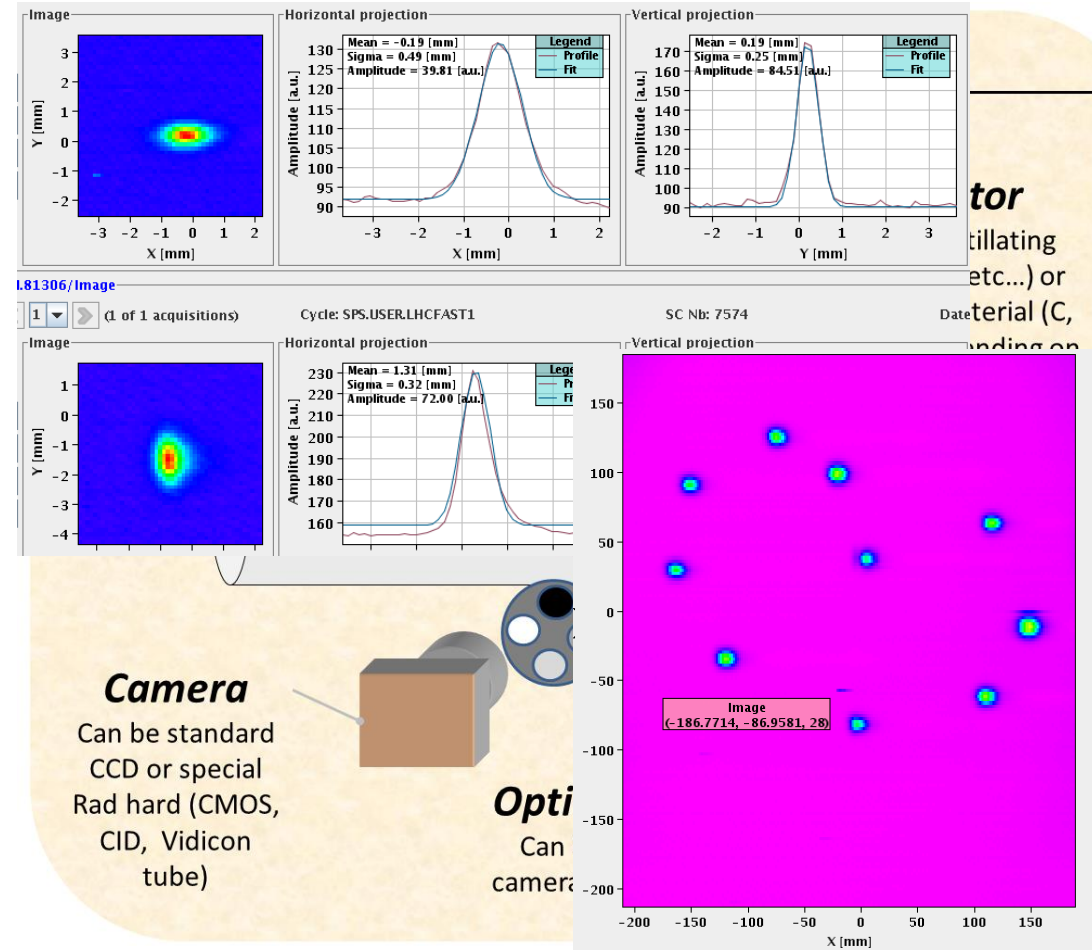
Analogue cameras are getting to an end in the market.

→ **Investigation is then needed to find a replacement product.**

In principle digital cameras are obvious candidates to replace analogue ones but...

It is known that they don't work in radioactive environment but so far no values are available.

The goal here is to characterize the performance under radiation of commercial products (define some radiation limits).



# Cameras (1)



BASLER was chosen as it is one of the biggest digital camera producer:

- Easy procurement (from many different vendors)
- Many different chips available...

CMOS cameras to be tested under radiation						
	acA1300-60gm	acA1920-50gm	acA1920-40gm	acA640-300gm	acA800-200gm	acA2000-50gm
Sensor type	CMOS	CMOS	CMOS	CMOS	CMOS	CMOS
Sensor	E2V EV76C560	SONY IMX174	SONY IMX249	ONsemi PYTHON 300	ONsemi PYTHON 500	ONsemi PYTHON 500
Exposure Method	Global / rolling shutter	Global shutter	Global shutter	Global shutter	Global shutter	Global shutter
Resolution H	1280	1920	1920	640	800	2048
Resolution V	1024	1200	1200	480	600	1088
Pixel size H [um]	5.3	5.86	5.86	4.8	4.8	5.5
Pixel size V [um]	5.3	5.86	5.86	4.8	4.8	5.5
H [mm]	6.784	11.2512	11.2512	3.072	3.84	11.264
V [mm]	5.4272	7.032	7.032	2.304	2.88	5.984
Optical size	1/1.8"	1/1.2"	1/1.2"	1/4"	1/3.6"	2/3"
Frame Rate	60 fps	50 fps	42 fps	376 fps	240 fps	50 fps
Interface	GigE	GigE	GigE	GigE	GigE	GigE
Synchronisation	Y	Y	Y	Y	Y	Y
Dark Noise	24.7e-					13.9 e-
Saturation capacity	9.5Ke-					9.3Ke-
Power supply	+12V					

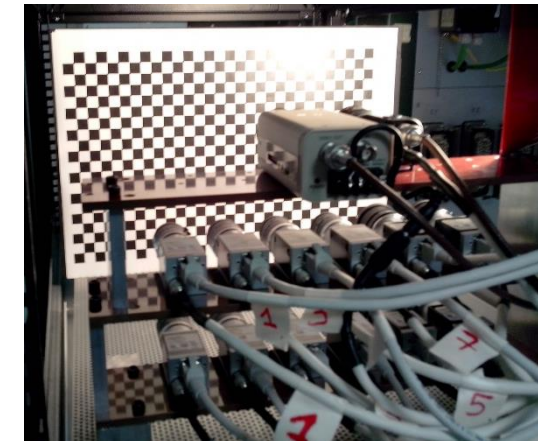
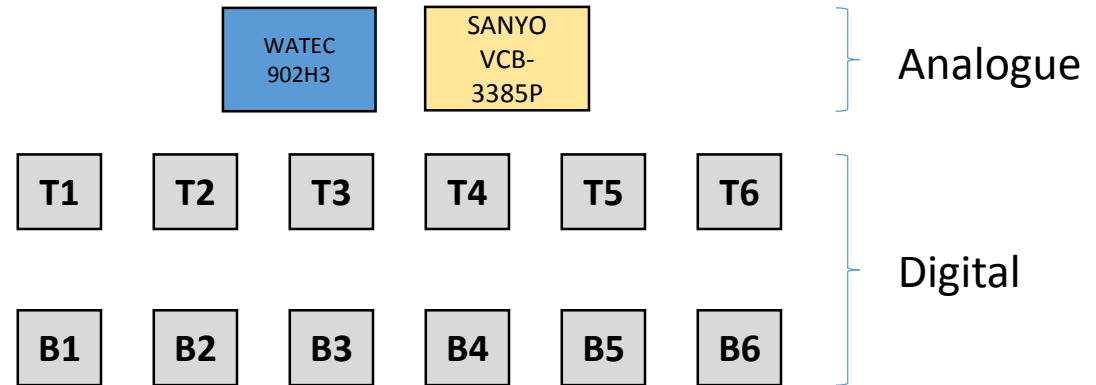


- 2 of each type have been tested

# Setup (1)



Tests setup CHARM irradi test Q4 2016	
Camera Model	Ref. for Acquisition
acA640-300gm	Top 6
acA640-300gm	Bottom 6
acA800-200gm	Top 5
acA800-200gm	Bottom 5
acA1300-60gm	Top 4
acA1300-60gm	Bottom 4
acA1920-40gm	Top 3
acA1920-40gm	Bottom 3
acA1920-50gm	Top 2
acA1920-50gm	Bottom 2
acA2000-50gm	Top 1
acA2000-50gm	Bottom 1
SANYO-vcb3385p	0x100000
WATEC 902H3	0x200000



→ Image acquisition done every 5 minutes

# Setup (2)

## Analogue camera specs



SPECIFICATIONS		
Model	WAT-902H2 ULTIMATE (EIA)	WAT-902H2 ULTIMATE (CCIR)
Pick-up element	1/2" interline transfer CCD image sensor	
Number of total pixels	811(H) × 508(V)	795(H) × 596(V)
Number of effective pixels	768(H) × 494(V)	752(H) × 582(V)
Unit cell size	8.4um(H) × 9.8um(V)	8.6um(H) × 8.3um(V)
Shutter speeds	EI1: 1/60 sec. - 1/100000 sec. EI2: 1/100 sec. - 1/100000 sec. FL: 1/100 sec. OFF: 1/60 sec.	EI1: 1/50 sec. - 1/100000 sec. EI2: 1/120 sec. - 1/100000 sec. FL: 1/120 sec. FL: 1/50 sec.
	1/250, 1/500, 1/1000, 1/2000, 1/5000, 1/10000, 1/100000 sec.	
Minimum illumination	0.0001 lx. F1.4	
Model	WAT-902H3 ULTIMATE (EIA)	WAT-902H3 ULTIMATE (CCIR)
Pick-up element	1/3" interline transfer CCD image sensor	
Number of total pixels	811(H) × 508(V)	795(H) × 596(V)
Number of effective pixels	768(H) × 494(V)	752(H) × 582(V)
Unit cell size	6.35um(H) × 7.40um(V)	6.50um(H) × 6.25um(V)
Shutter speeds	EI1: 1/60 sec. - 1/100000 sec. EI2: 1/100 sec. - 1/100000 sec. FL: 1/100 sec. OFF: 1/60 sec.	EI: 1/50 sec. - 1/100,000 sec. EI2: 1/120 sec. - 1/100000 sec. FL: 1/120 sec. FL: 1/50 sec.
	1/250, 1/500, 1/1000, 1/2000, 1/5000, 1/10000, 1/100000 sec.	
Minimum illumination	0.0002 lx. F1.4	
Common specifications		
Synchronizing system	Internal sync.	
Video output	1Vp-p, 75ohms, unbalanced	
Resolution (H)	570TVL (Center)	
SN ratio	More than 50dB (AGC OFF)	
AGC	①HI: 5-60dB ②LO: 5-32dB ③MGC(5-60dB)	
Back light compensation	①OFF(Default) ②Center ③Lower ④Center + lower	
Gamma correction	①HI ( $\gamma \approx 0.35$ ) ②LO ( $\gamma \approx 0.45$ ) ③OFF ( $\gamma \approx 1$ )	
Power supply	DC12V ± 10%	
Power consumption	1.32W (110mA)	
Operating temperature	-10°C - +40°C	
Storage temperature	-30°C - +70°C	
Dimensions(W×H×L)	35.5 × 40 × 63 (mm)	
Weight	approx. 98g	

## Specifications

Model No.	VCB-3380P	VCB-3385P
Scanning system	CCIR standard 625 lines, 25 frames/sec	
Image sensor	Interline transfer method CCD	
Image size	1/3" (approx. 4.8mm x 3.6mm)	
Picture elements	Total 795(H) x 596(V)	
	Effective 752(H) x 582(V)	
Unit (pixel) cell size	6.5(H) x 6.25(V) μm	
Synchronizing system	Internal sync / Line lock (manual switching)	Internal sync / Line lock (manual switching) External sync (automatical switching)
External sync.	VS: 1.0 Vp-p/75 ohms	
Interlace	PLL 2:1 interlace	
Horizontal resolution	570 TV lines	
Video output level	1.0 Vp-p (75 ohms, composite)	
Video S/N ratio	More than 50dB	
Minimum illumination (approx.)	0.07 lx (with F1.2 lens, 50 IRE)	
Electronic shutter	1/50-1/100,000 sec.	
Backlight compensation	Set to "ON" or "OFF"	
Lens mount	CS mount	
Flange back	12.5mm ± 0.5mm adjustment	
Camera mount	1/4"—20 UNC (top / bottom selectable)	
Controls	V phase adjustment	LINE PHASE — VR (Side)
	Lens iris level	LEVEL: L, H —VR (Side)
	Auto iris lens	AI LENS: DC/VIDEO —Slide SW (Side)
	Electronic iris/ Backlight compensation	EI: ON/OFF —Slide SW (Side) BLC: ON/OFF
	Electronic shutter	3-setting, DIP switches (Side)
		[OFF = 1/50, 1/120, 1/500, 1/1000, 1/2000, 1/5000, 1/10000, 1/100000]
Sockets	Video signal	VIDEO OUT: BNC
	External sync.	— VS IN: BNC
	Auto iris lens	LENS: 4-pin (Side)
Power supply	Power cord	3-pin terminal
Light control	Electronic iris (indoor use) or optional auto iris lens	
Auto iris output	DC: Drive coil (+, -), Brake (Damp) coil (+, -) VIDEO: +12V DC (Max. 50mA), Video signal (hi-Z), GND	
Environmental conditions	Storage	Temperature: -20°C to +70°C, Humidity: within 70% RH
	Operating	Temperature: -10°C to +50°C, Humidity: within 90% RH
Power requirement	220-240V AC, 50Hz	24V AC, 50Hz / 12-15V DC
Power consumption (approx.)	3.5W	3.0W
Dimensions (w/o lens, approx.)	57 (W) x 45 (H) x 121.8 (D) mm [2.2 (W) x 1.8 (H) x 4.8 (D) in.]	
Weight (w/o lens, approx.)	490g (1.1 lb.)	245g (0.5 lb.)



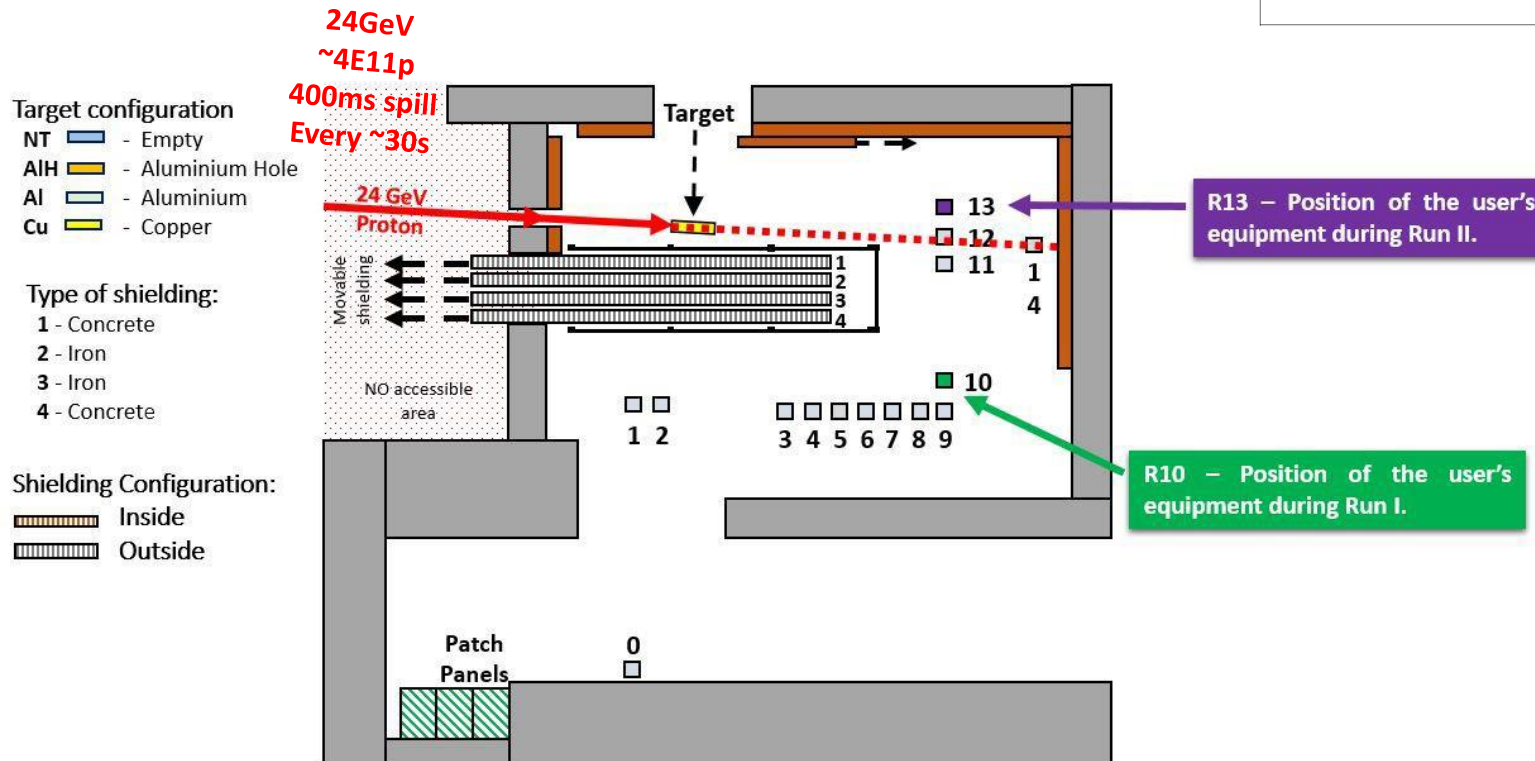
# Setup (2)



- The request was to reach 500 Gy (= max value observed with analogue camera)
- Irradiation session has been divided in two consecutive campaigns to have two different dose rates
  - From 12-10-2016 to 18-10-2016 (~150 Gy)
  - From 19-10-2016 to 25-10-2016 (~350 Gy)

**Configuration: Cu0000**

IRRADIATION SESSION	MONITORING TOOL INFORMATION	
	RUN I	Test code
Position		R10U4
RUN II	Test code	CHARM037
	Position	R13U4



## CHARM report in EDMS

[https://edms.cern.ch/ui/file/1736243/1/Charm\\_UD\\_D\\_-\\_CHARM035-037\\_-User\\_BE-BI\\_-\\_Burger\\_S.pdf](https://edms.cern.ch/ui/file/1736243/1/Charm_UD_D_-_CHARM035-037_-User_BE-BI_-_Burger_S.pdf)



Use **Monitoring tool** to extract dose/HEH/1MeV eq. fluence

# Installation



Cameras installed in the rack ready for automatic transport into the facility...



Rad Meas.



Camera failures rapidly after the beam arrived

A night a image acquisition was lost

Power cycle was put in place from the second day

Logging the cameras status to evaluate the failure rate put in place the 4<sup>th</sup> day:

- Check if cameras are alive
- Apply power cycle
- Re-check if camera is alive
- Image acquisition

# Results (3)



Average impact on the camera for a single extraction ( $\sim 4E11p$  beam/24Gev/400ms)

Run 1 ( $\rightarrow 150Gy$ )	
Dose [Gy]	4.8E-3
POT	4.1E11
1 MeV Neutron eq. Fluence / cm <sup>2</sup>	5.4E7
HEH eq. Fluence / cm <sup>2</sup>	1.68E7

Run 2 ( $\rightarrow 350 Gy$ )	
Dose [Gy]	11.2E-3
POT	4.12E11
1 MeV Neutron eq. Fluence / cm <sup>2</sup>	9.38E7
HEH eq. Fluence / cm <sup>2</sup>	2.99E7

# Results (4) TID Lifetime



	SANYO		WATEC			
First image	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17		
Last image	2016-10-16_06:22	2016-10-26_09:46	2016-10-26_09:46	2016-10-26_09:46		
HEHeqFluence [cm-2]	3.07E+11	1.48E+12	1.48E+12	1.48E+12		
Dose [Gy]	87.5	506.5	506.5	506.5		
	T1	T2	T3	T4	T5	T6
First image	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17
Last image	2016-10-18_04:52	2016-10-19_19:44	2016-10-12_18:13	2016-10-18_04:42	2016-10-17_21:18	2016-10-17_16:30
HEHeqFluence [cm-2]	5.17E+11	5.56E+11	-	5.16E+11	4.82E+11	4.58E+11
Dose [Gy]	147.2	158.4	-	146.9	137.3	130.5
	B1	B2	B3	B4	B5	B6
First image	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17	2016-10-12_15:17
Last image	2016-10-17_12:47	2016-10-17_03:12	2016-10-19_21:07	2016-10-17_12:47	2016-10-17_17:01	2016-10-17_21:03
HEHeqFluence [cm-2]	4.41E+11	4.07E+11	5.65E+11	4.40E+11	4.60E+11	4.80E+11
Dose [Gy]	125.6	116.0	161.0	125.4	131.1	136.8

Ranking	Position	Name
1	B3	acA1920-40gm
2	T2	acA1920-50gm
3	T1	acA2000-50gm
4	T4	acA1300-60gm
5	T5	acA800-200gm
6	B6	acA640-300gm
7	B5	acA800-200gm
8	T6	acA640-300gm
9	B1	acA2000-50gm
10	B4	acA1300-60gm
11	B2	acA1920-50gm
12	T3	acA1920-40gm

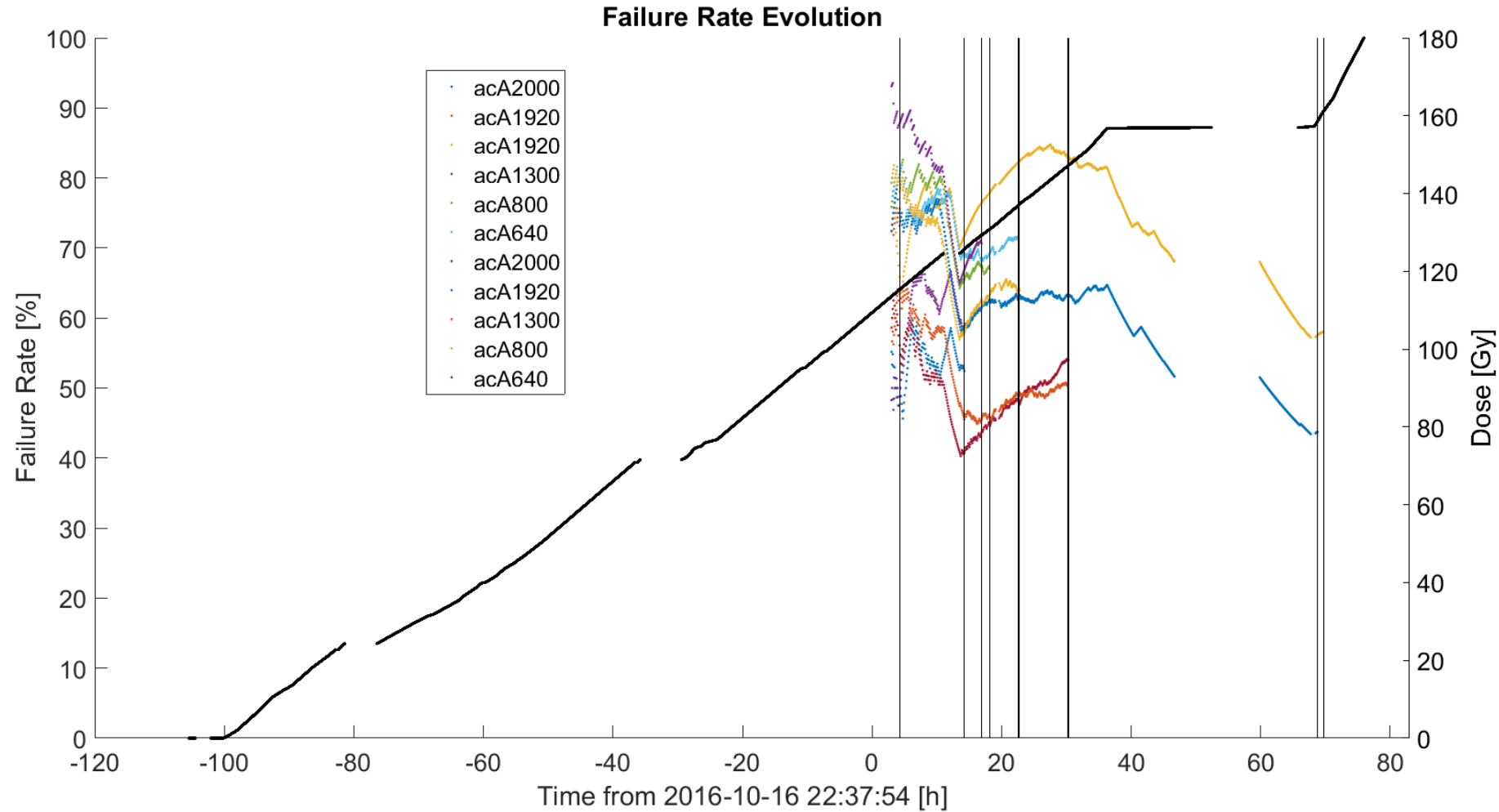
Dose Type	Mean	Median	Min	Max
HEH/cm <sup>2</sup>	4.84E11	4.80E11	4.07E11	5.65E11
Gy	137.3	131.1	116	161

Basler cameras only,  
Excluding acA1920-  
40gm device (T3)

Dead 1<sup>st</sup> day !  
Radiation issue ?!



# Results (5) SEE



**Probability of having the camera not 'alive' every 5 minutes**

Mean value of failure after 10 shots is 70%

This corresponds to

→ 5.4E8 1MeV fluence /cm<sup>2</sup>

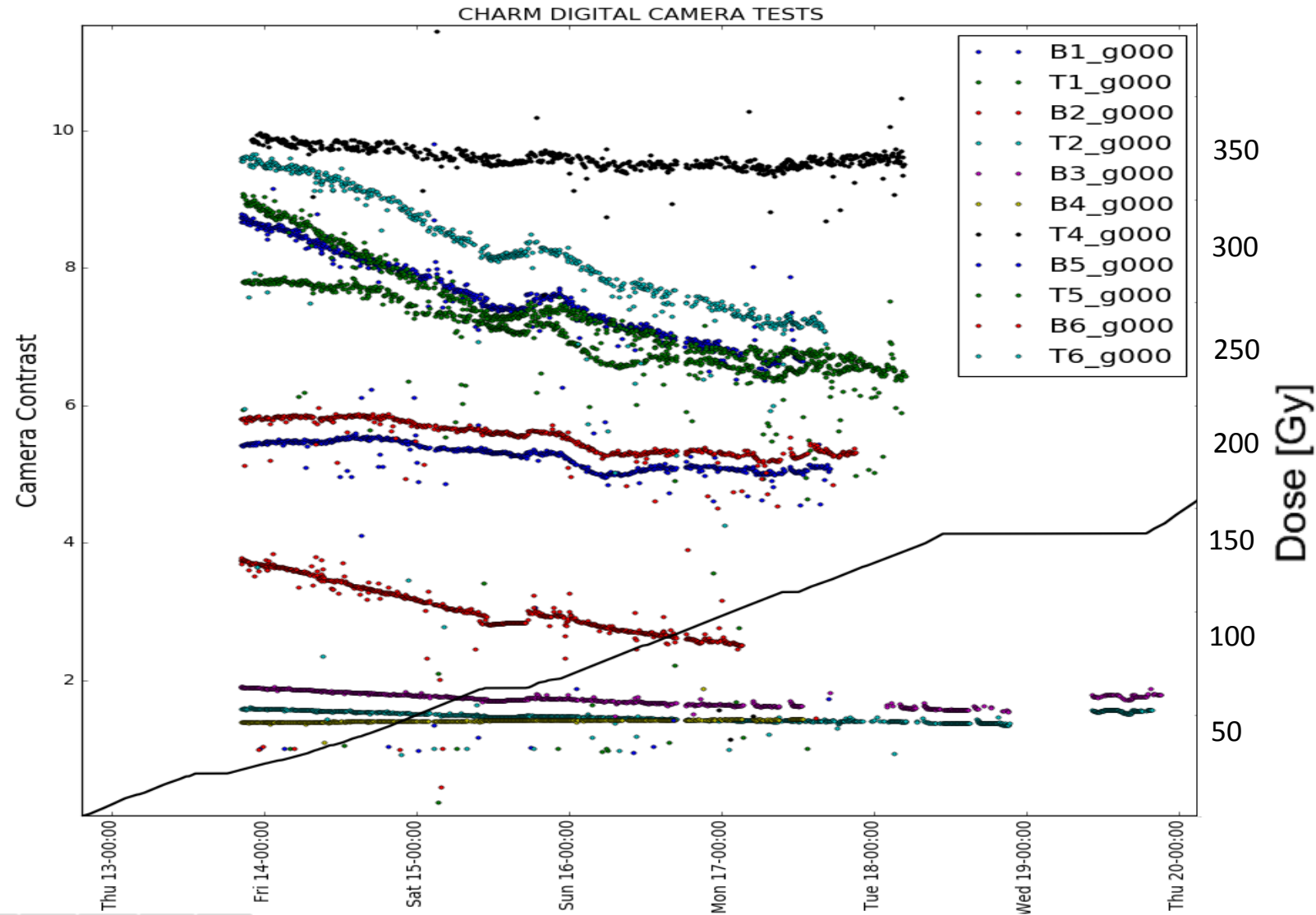
→ 1.68E8 HEH eq fluence/cm<sup>2</sup>

$$P_{surv} = (1 - P_{SEU})^N$$

$$P_{SEU} = 1 - P_{surv}^{(1/N)}$$

→ SEU probability per shot is 11%

# Results (6) Contrast evolution



Evolution of the contrast during the irradiation test

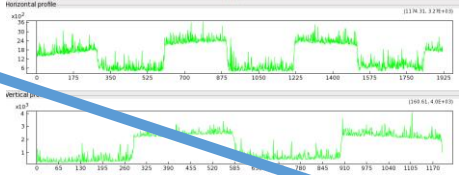
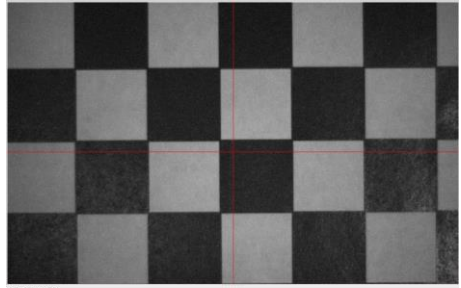
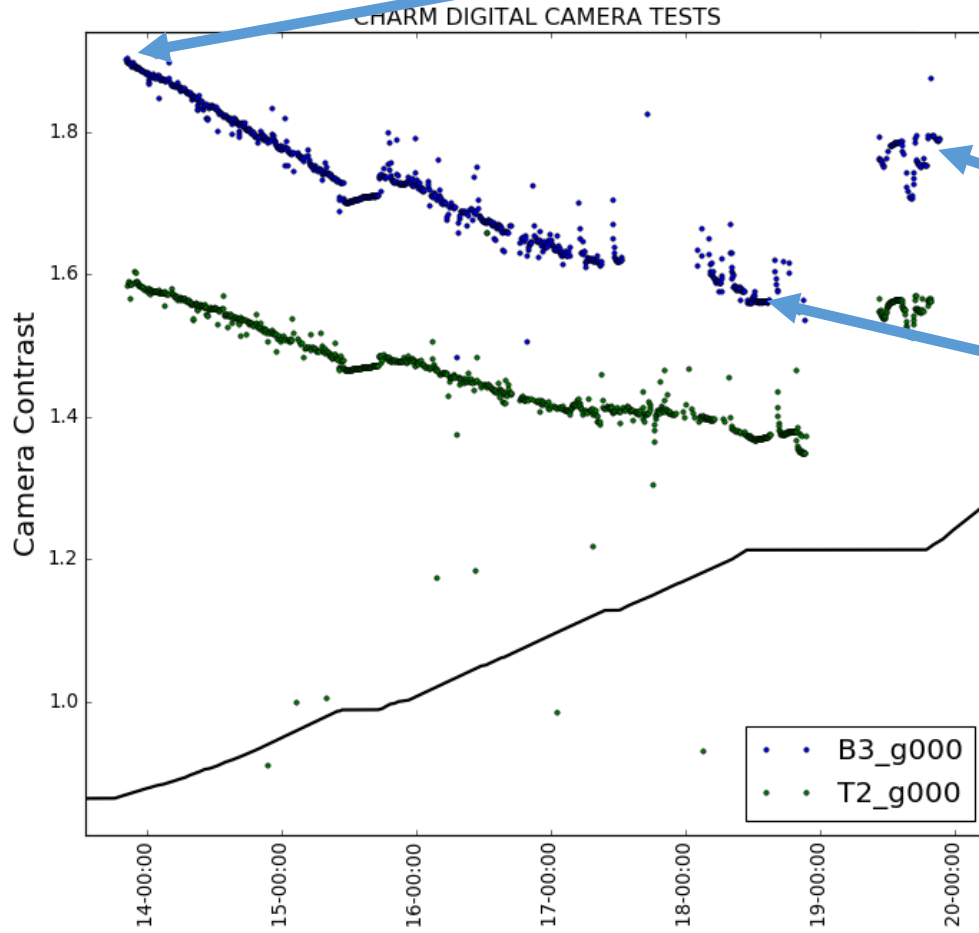
Camera	Position	Contrast down by [%]
acA640-300gm	Top 6	25.0
acA640-300gm	Bottom 6	10.3
acA800-200gm	Top 5	17.9
acA800-200gm	Bottom 5	7.4
acA1300-60gm	Top 4	3.1
acA1300-60gm	Bottom 4	-0.7
acA1920-40gm	Top 3	
acA1920-40gm	Bottom 3	18.4
acA1920-50gm	Top 2	13.3
acA1920-50gm	Bottom 2	33.5
acA2000-50gm	Top 1	27.8
acA2000-50gm	Bottom 1	25.3

Average contrast down by 16%

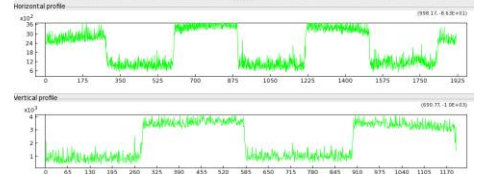
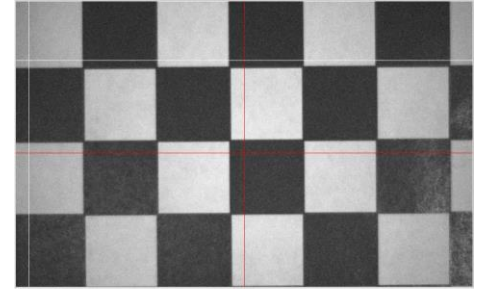
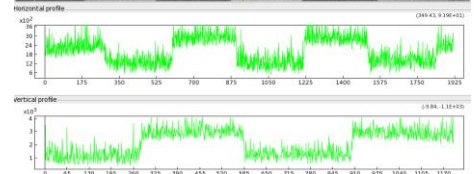
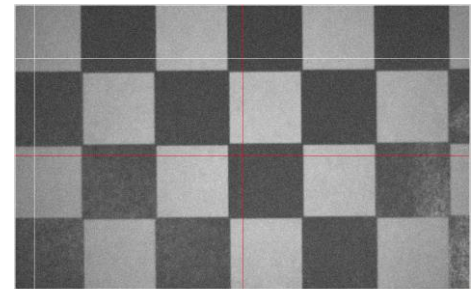
# Results (6)



Example 1 with B3: acA1920-40gm



350  
300  
250  
200  
150  
100  
50



Annealing effect (!?)

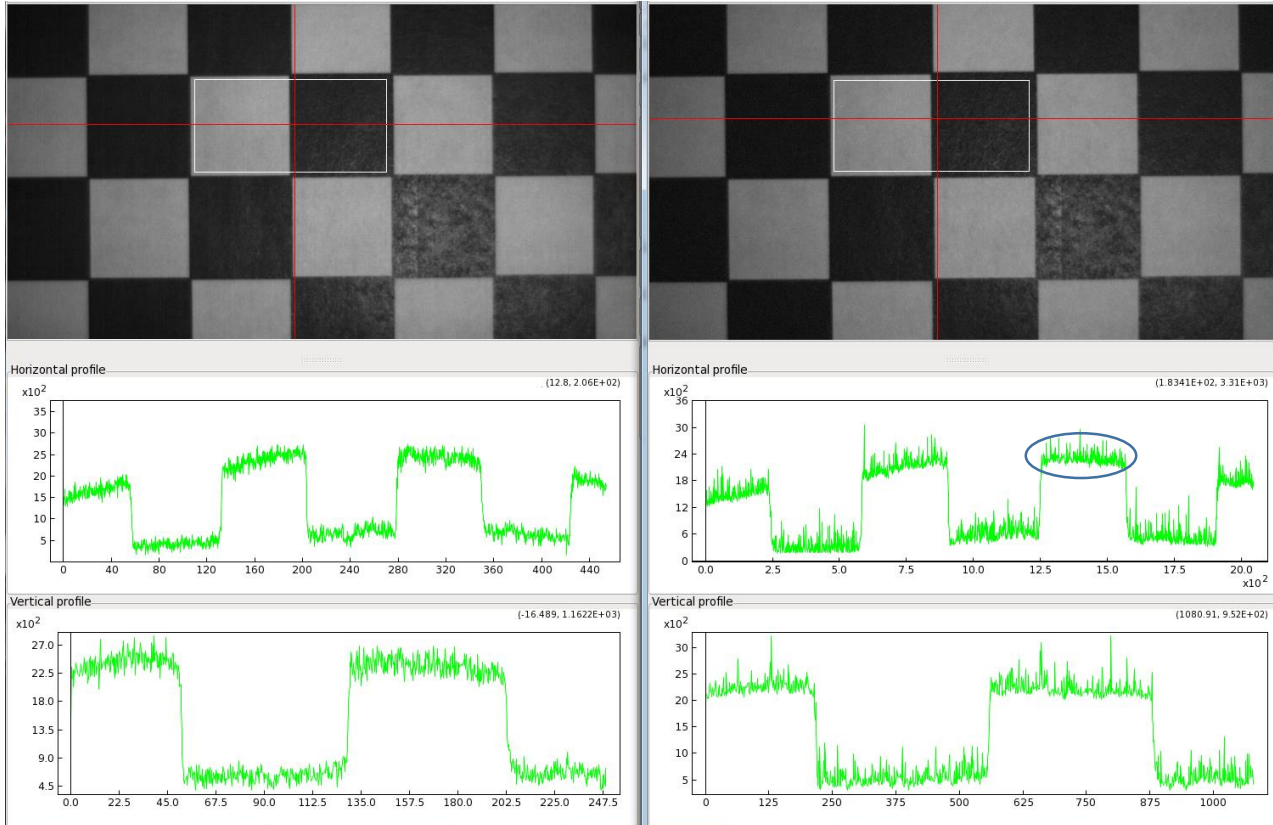
# Results (5)



Example 2 with B1: acA2000-50gm

0 Gy

Last image	2016-10-17_12:47:30
HEHeqFluence [cm-2]	4.41E+11
Dose [Gy]	1.26E+02



A bit more noisy...

→ Camera dead but CMOS response seems still OK

# Results (6)



Example 3 with analogue camera WATEC

0 Gy

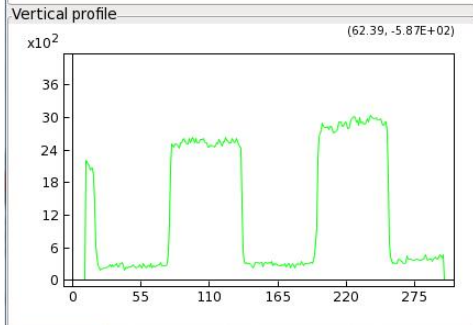
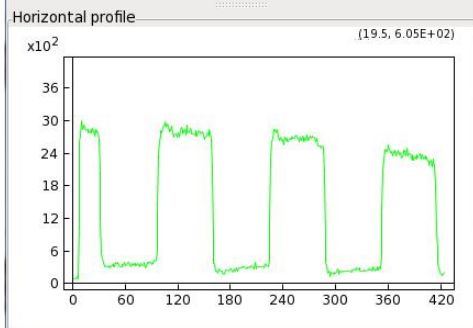
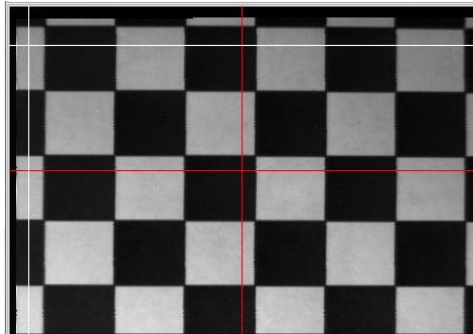


Image after 125.6 Gy

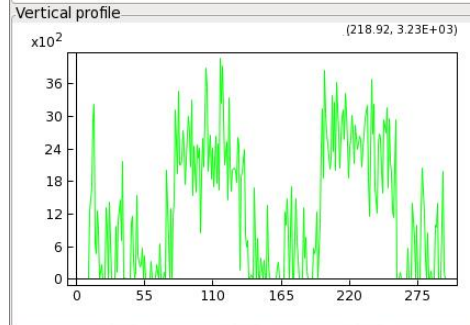
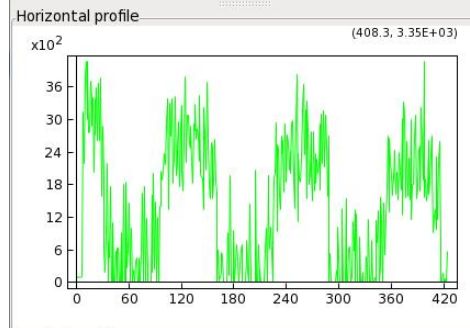
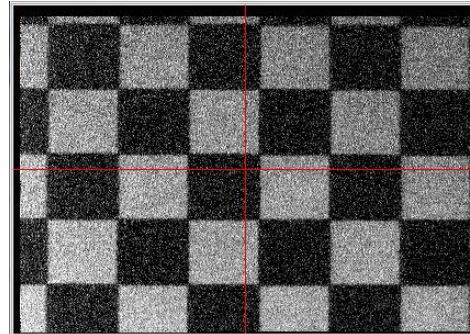
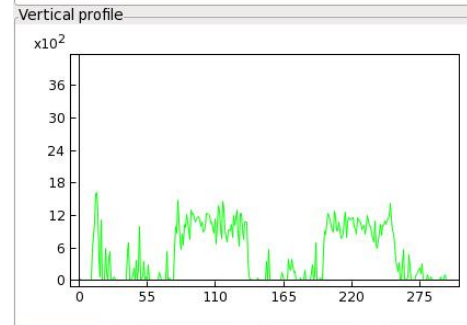
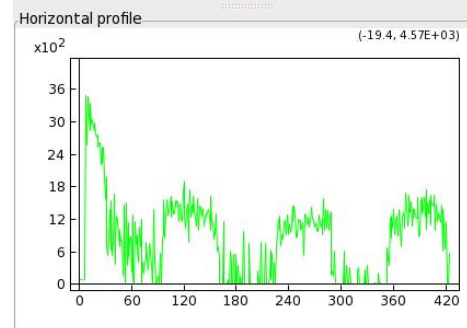
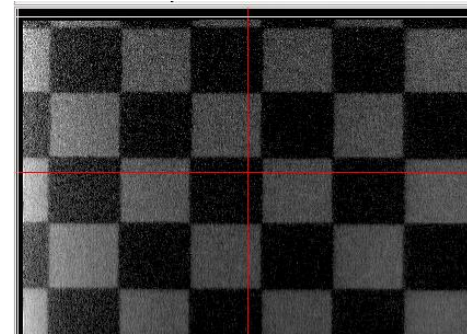


Image after 500 Gy



→ Degradation is clearly visible.

Camera is much noisier than CMOS one

Main advantage, camera still alive after 500Gy



As expected using commercial digital cameras is not easy to 'use' under radiation (limited TID and SEU sensitive).

With this test we can now refer to some values to estimate the viability of using digital cameras for our diagnostics (checking FLUKA simulations or RP measurements)

**TID limit**                    **116 - 161 Gy**

How would be TID with different dose rate?

**HEH/cm2 limit**        **4.07 – 5.65e11**                    *(with few hundreds of power cycles)*

**Image quality (contrast degradation) max by 33% (average 16%)**

The cause of the camera not working anymore is not identify. But the sensor is for all case still operational in term of image quality

→            might be the power supply, ADC, fpga or data transfer module in cause rather than the CMOS itself. To be determined...)

**THANKS!**