RadFET Dose Monitor for SOLEIL

IBIC 2018

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Shanghai

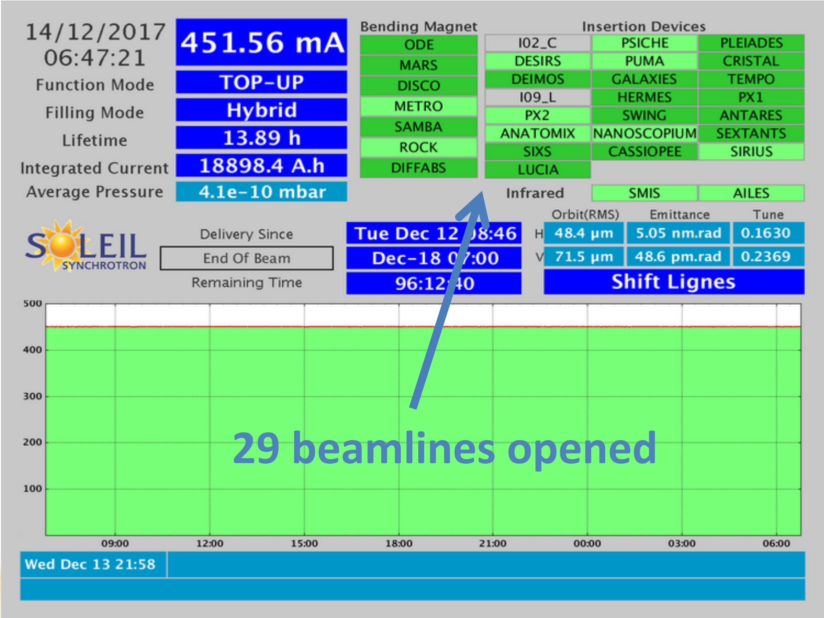
Nicolas HUBERT on behalf of the SOLEIL diagnostics group

OUTLINE

- RadFET Description
- Readout Electronics
- First Measurements With Beam

SOLEIL Synchrotron

- 3rd generation light source:
  - France, 20 km south Paris
  - In operation since 2006
  - 29 beamlines



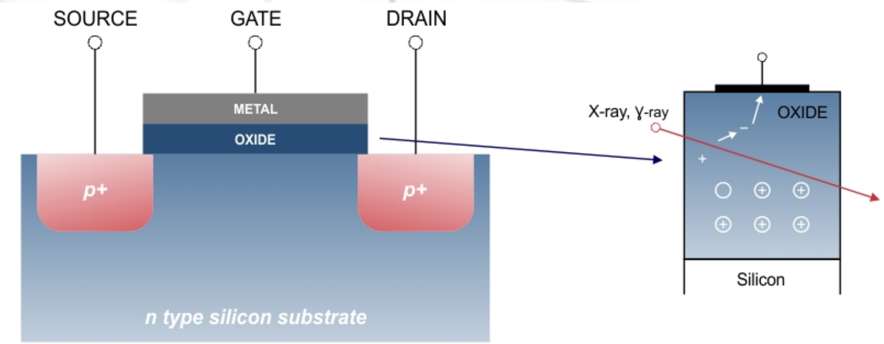
Mode of operation Bunch fill. patterns	User Operation in 2018
Multibunch (M2)	500 mA
Hybrid/camshaft mode (M)	445 mA + 5 mA
	+ Slicing on high intensity bunch
8 bunches (8)	100 mA
1 bunch (S)	16 mA
Low-α: Hybrid mode (L)	4.7 ps RMS for 65 µA

Introduction/Objectives

- Context:
  - >10 years of operation (20 000 A.h in 2018)
  - Pieces of equipment damaged by radiation
- What are our need?
  - Better **estimation** of the radiation flux to anticipate equipment replacement
  - Have a monitor to verify quickly shielding improvements
- Requirements
  - Compact sensor: to be placed in tiny areas
  - Sensitive to all type of radiations (X-rays, gammas, electrons…)
  - Low cost
  - Large measurement range
  - Sensitivity? Resolution?

RadFET Description

- RadFET Sensors
  - Metal Oxide Semiconductor **F**ield **E**ffect **T**ransistor (MOSFET) optimized for **rad**iation sensitivity.
    - Ionizing radiations remove electrons from gate oxide layer, resulting in remaining positive charges (permanent modification).
    - Threshold voltage for the transistor to be in conducting state increases with the positives charges.
    - Amount of received dose is deduced of threshold voltage measurement forcing a fixed DC current in the device.

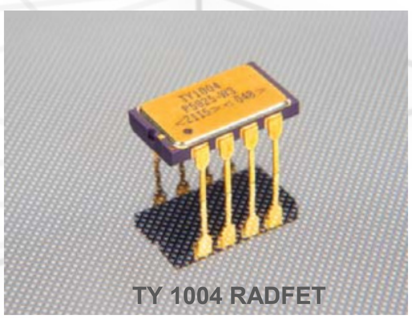


RADFET Schematics (source: Tyndall)

- Sensitivity depends on:
  - Gate oxide layer thickness
  - Gate bias during irradiation
    - Bias improves electron-hole generation process
    - Measurement range reduction.
  - Irradiation particle energy

RadFET Description

- RadFET Sensors
  - TY1004 from Tyndall Works (Tyndall National Institute, Ireland)
    - Two identical RadFETs on the same chip
    - Gate oxide layer thickness: 400 nm
    - Active area: 300x50 µm
    - Measurement range: from 1 rd to 100 krd (1cGy to 1 kGy)



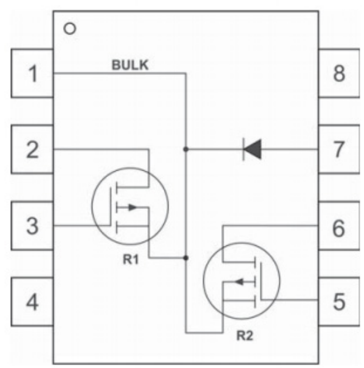


Figure 1: TY1004 pin-out drawing.

Table 1: TY1004 pin-out description.

Pin Number	Description
1	Source/Bulk (Common)
2	Drain of R1
3	Gate of R1
4	Not Connected
5	Gate of R2
6	Drain of R2
7	Diode
8	Not Connected

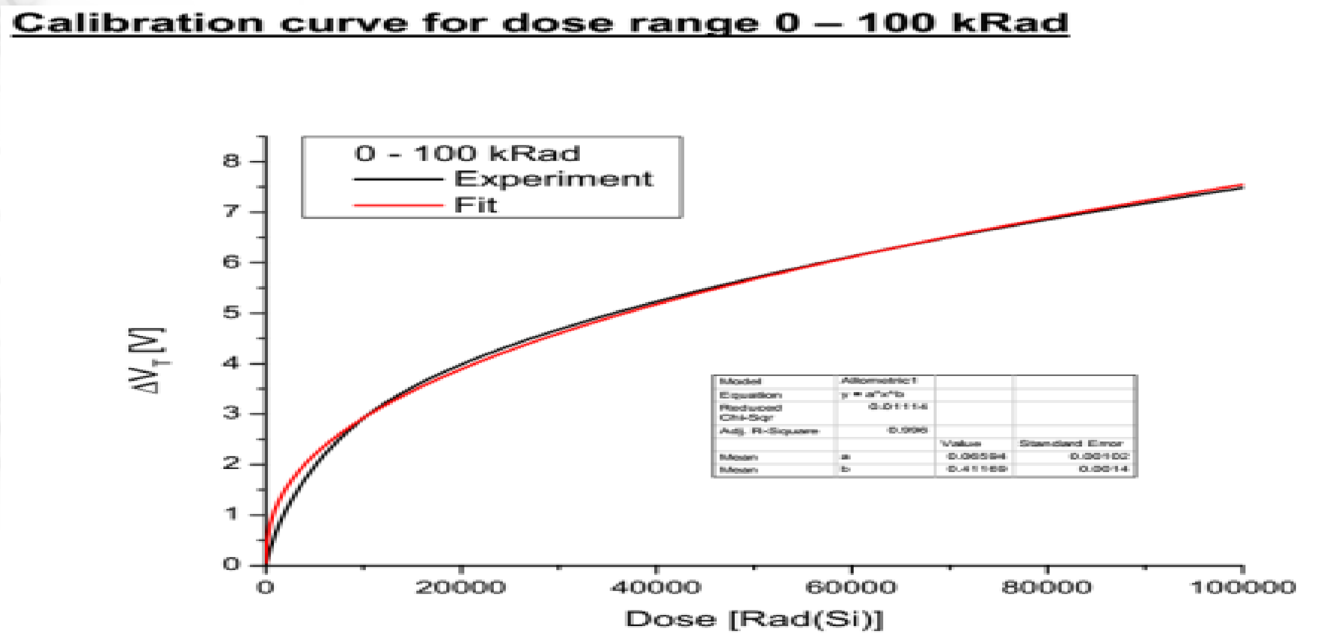
Tyndall Works

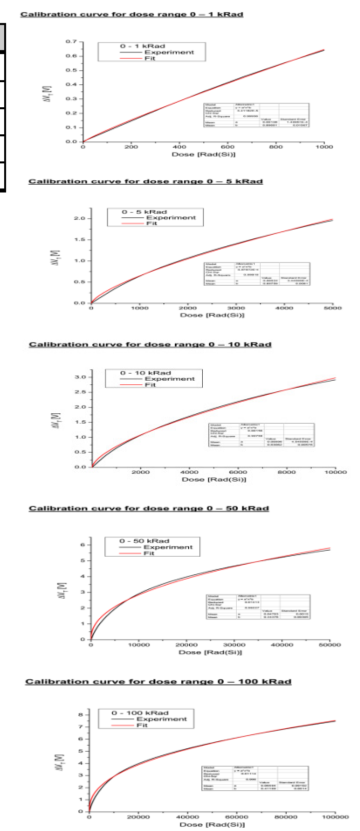
RadFET Description

- Calibration
  - Non linear response
  - Calibration curves provided by manufacturer based on irradiation with a Co60 source (assuming all RadFET from the same batch have the same sensitivity)

$$\Delta V = A \times Dose^{B}$$

Dose range	A	Sigma (A)	B	Sigma (B)	R-SQUARE
0 – 100 kRad	0.0659	1.020E-03	0.4117	1.400E-03	0.996
0 – 50 kRad	0.0478	1.500E-03	0.4438	3.050E-03	0.992
0 – 10 kRad	0.0090	4.546E-04	0.6306	5.780E-03	0.998
0 – 5 kRad	0.0052	3.446E-04	0.6976	8.100E-03	0.998
0 – 1 kRad	0.0014	1.440E-04	0.8900	1.567E-02	0.999

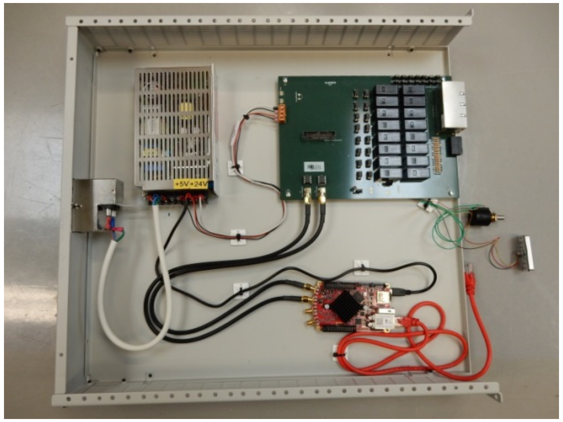




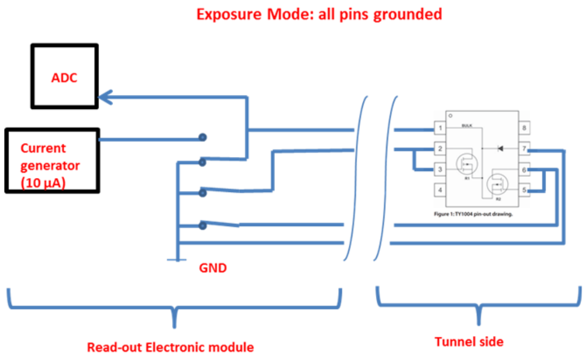
Tyndall Works

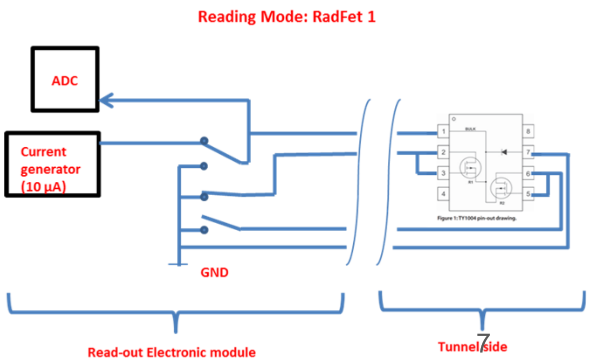
Readout Electronics

- Dedicated electronics designed
  - First prototype tested in May/June 2018, and second one (improved) has been just installed on the machine.
    - Periodic automated reading (2/day)
    - Multiplexed to read several sensors with the same electronics (7 RadFETs x2)



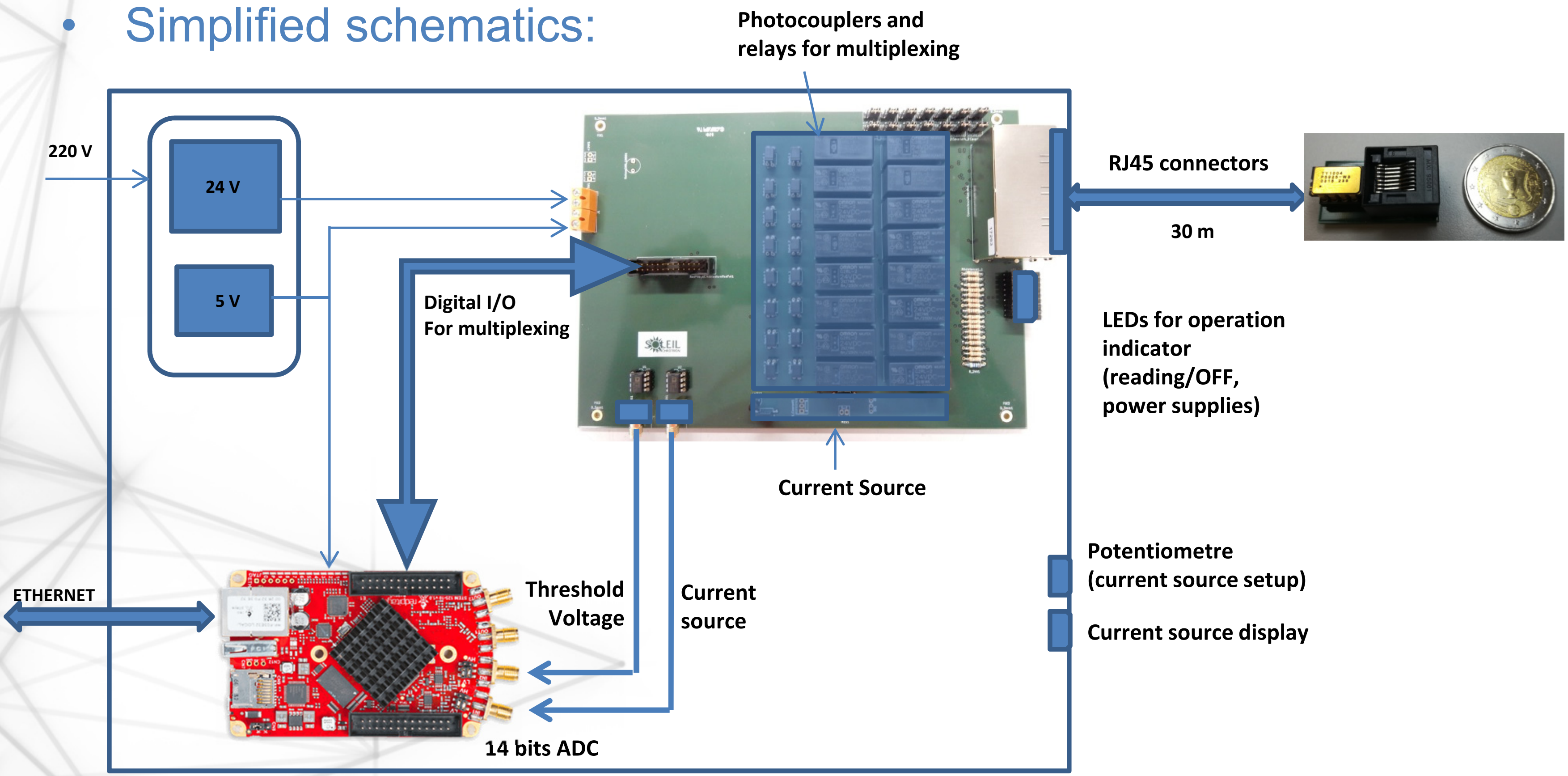
- Operating modes
  - Exposure Mode
    - All pins grounded
  - Reading Mode
    - 10 µA forced between ground and source
    - Threshold voltage @ 10 µA for minimum temperature dependence
    - Preferably performed without irradiation

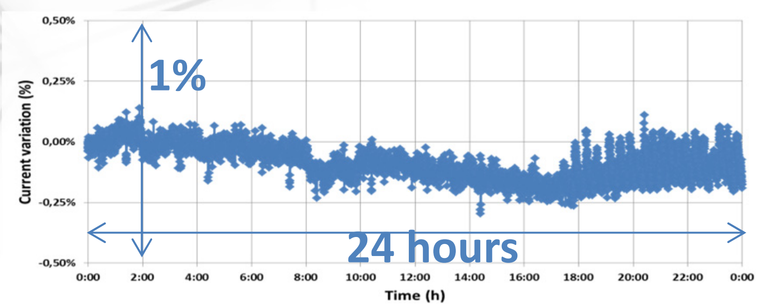




Readout Electronics

- Simplified schematics:

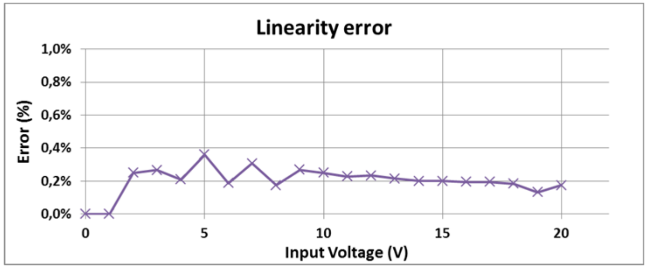




– Current source stability: < 0.5% drift /24 h
– Continuously monitored when RadFETs are not read

Readout Electronics

- Acquisition & multiplexing control
  - Red Pitaya board
    - 14 bits ADC
      - Extended range configuration (+-23V)
      - Resolution of 2.8 mV (~2 rd)
      - Input impedance adaptation with unity gain buffer
    - 16 digital I/Os
    - Integrated into control system with embedded generic Tango device server (ARM processor) for Red Pitaya.



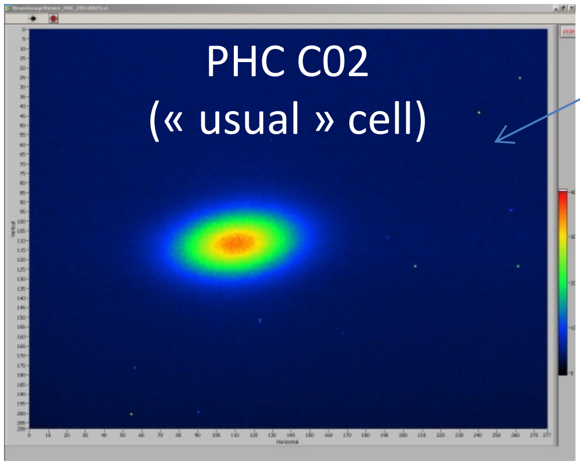
Red Pitaya linearity error measurement

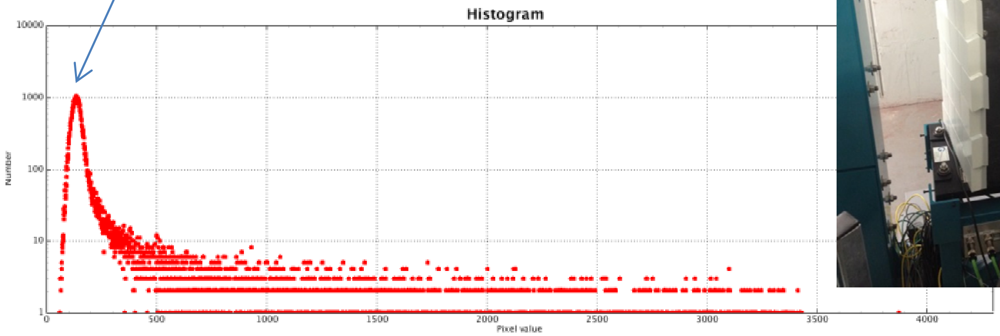
  - Labview high level application:
    - Multiplexing logic
    - Fixed delay reading to be insensitive to drift phenomenon just after applying the current to the transistor (reversible electrons tunneling from the substrate)

First measurements with beam

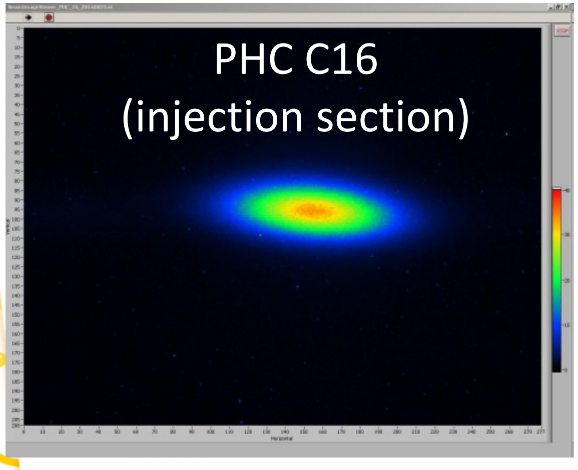
- Pinhole camera CCD Survey:
  - Unexplained faster ageing of the CCD for the pinhole camera in cell N°2

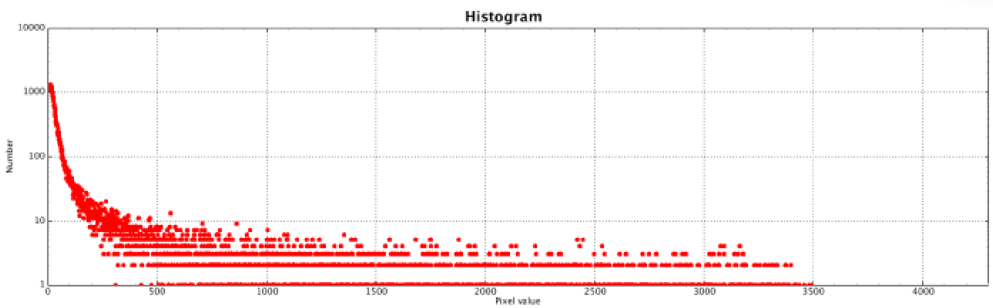
Increase of background amplitude





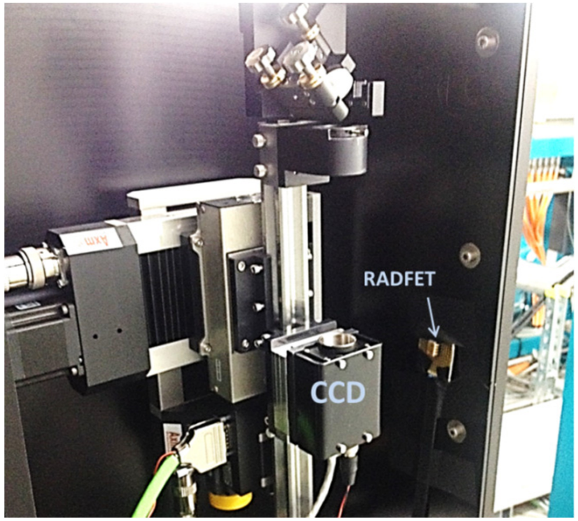
CCD Background histograms (without beam)

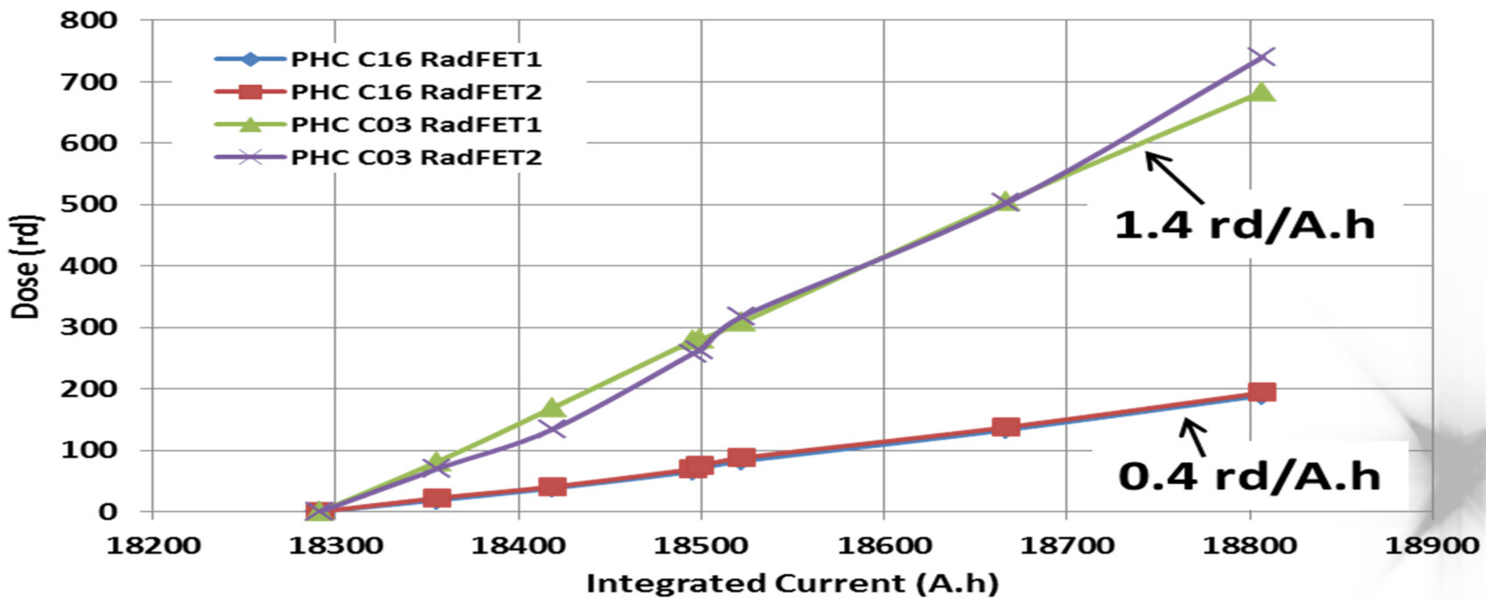




First measurements with beam

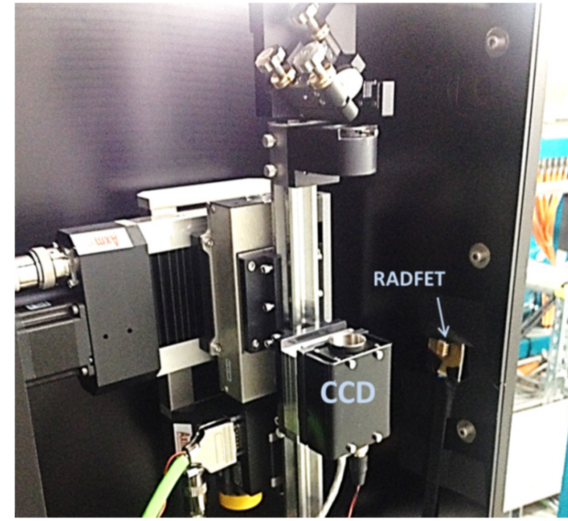
- Pinhole camera CCD Survey
  - RadFET installed in the two optical boxes in September 2017
  - Recorded dose is **linear with stored current and not correlated with beam losses**
  - Confirmation of a dose rate 3.5 times higher in cell N°2 optical box

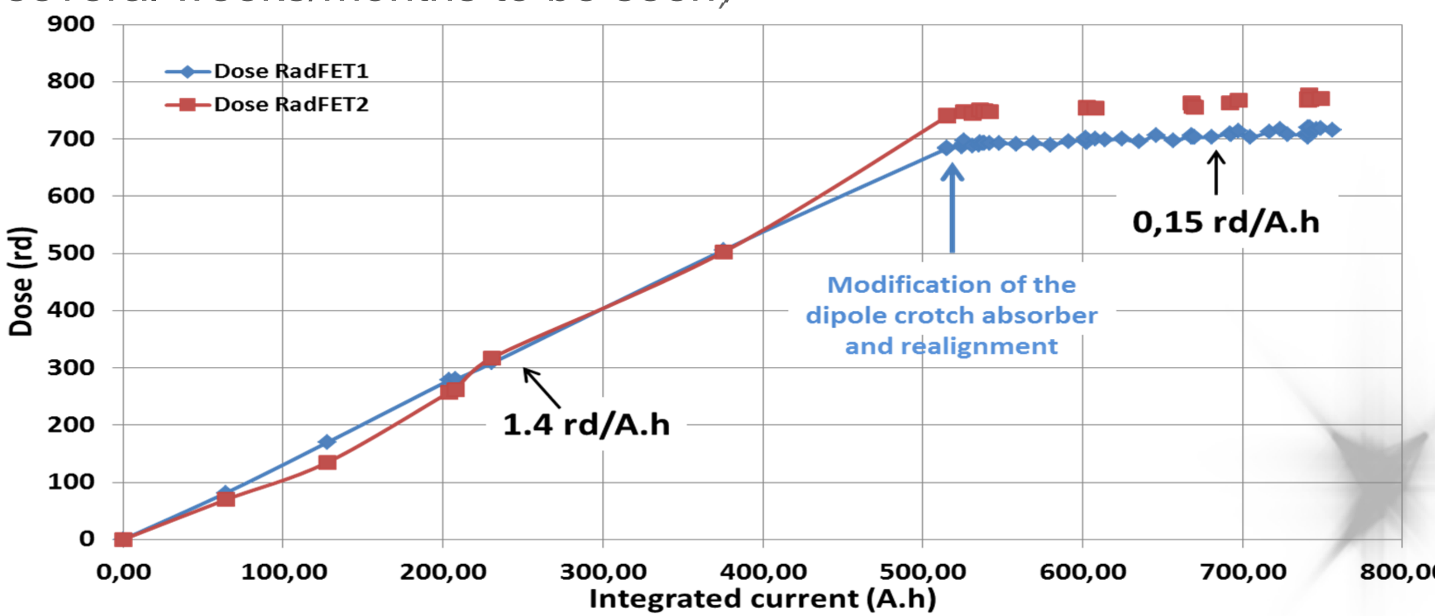




First measurements with beam

- Pinhole camera CCD Survey
  - For independent reasons, in may 2018, modification of the upstream dipole crotch absorber and realignment of the Al window and optical box in cell N°2
  - Immediate drop of the dose rate measured by the RadFET (by a factor ~10!)
  - CCD ageing has slowed down (but requires several weeks/months to be seen)

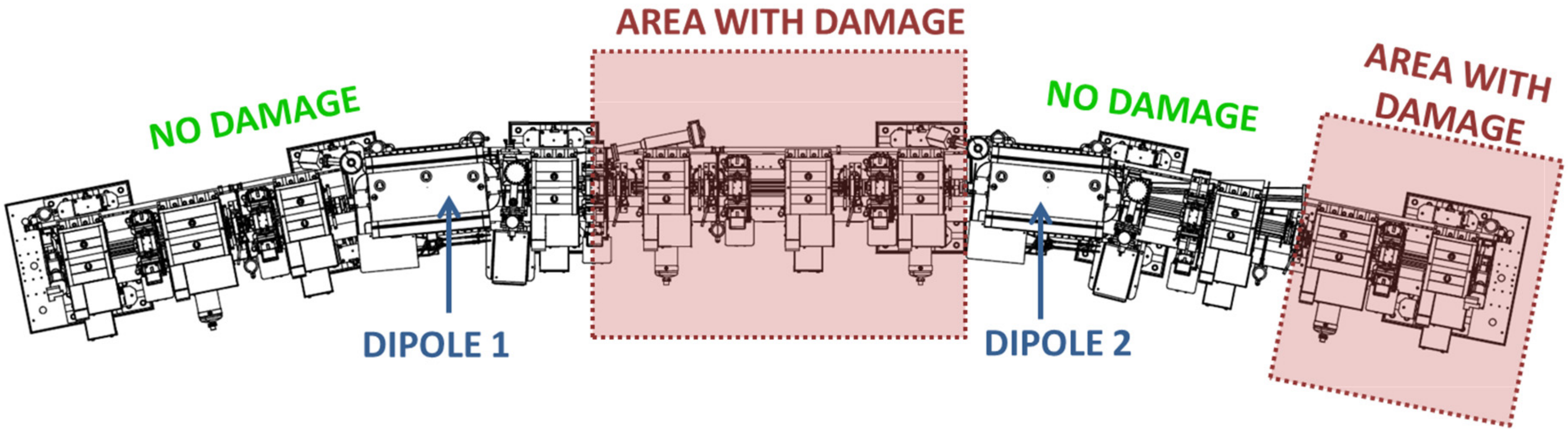




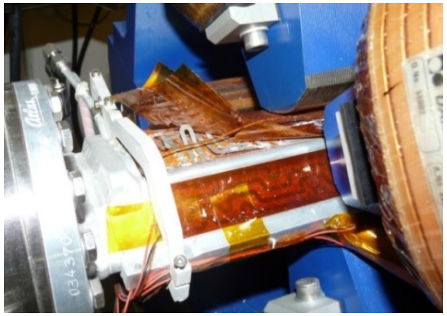
First measurements with beam

- Insulator Survey
  - Radiation damages located downstream every dipole around aluminum vacuum chambers

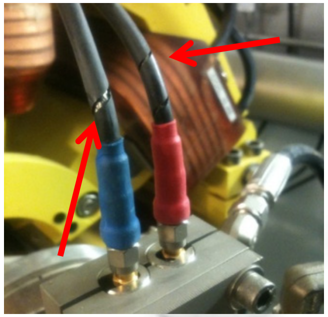
N. Hubert *et al.*, "**Radiation Damages and Characterization in the SOLEIL Storage Ring**", in *Proc. IBIC'13*, Oxford, UK, Sep. 2013, pp. 644-647.



Sextupole wires



Baking film glue



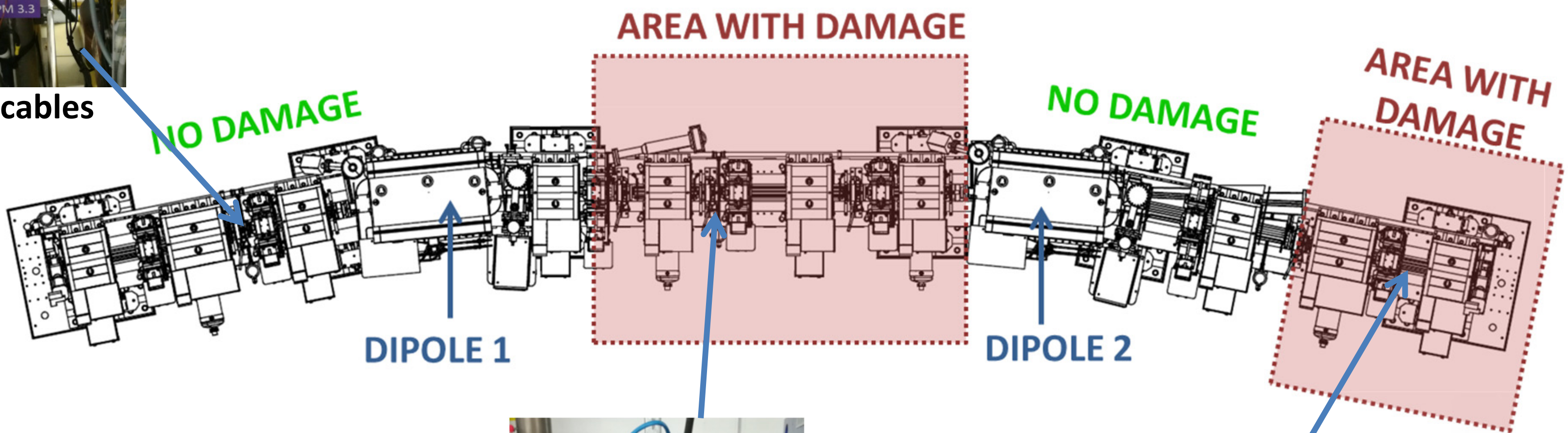
BPM cables

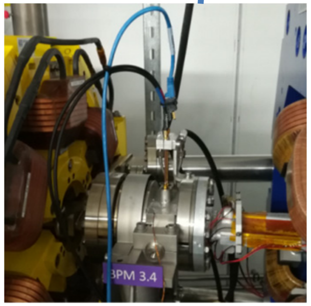
First measurements with beam

- Insulator Survey
  - 5 RadFET installed in July 2018

BPM cables

External wall





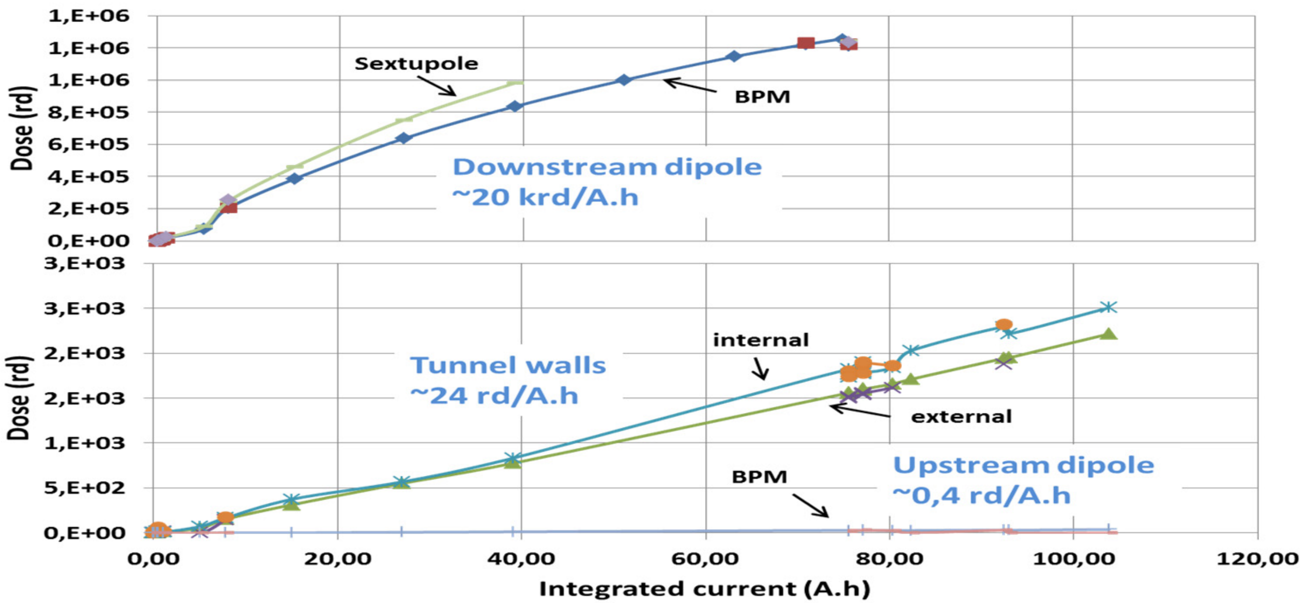
BPM cables

Sextupole

Internal wall

First measurements with beam

- Insulator Survey
  - RadFET measurement confirmed the huge difference in the amount of radiation measured upstream and downstream dipoles.



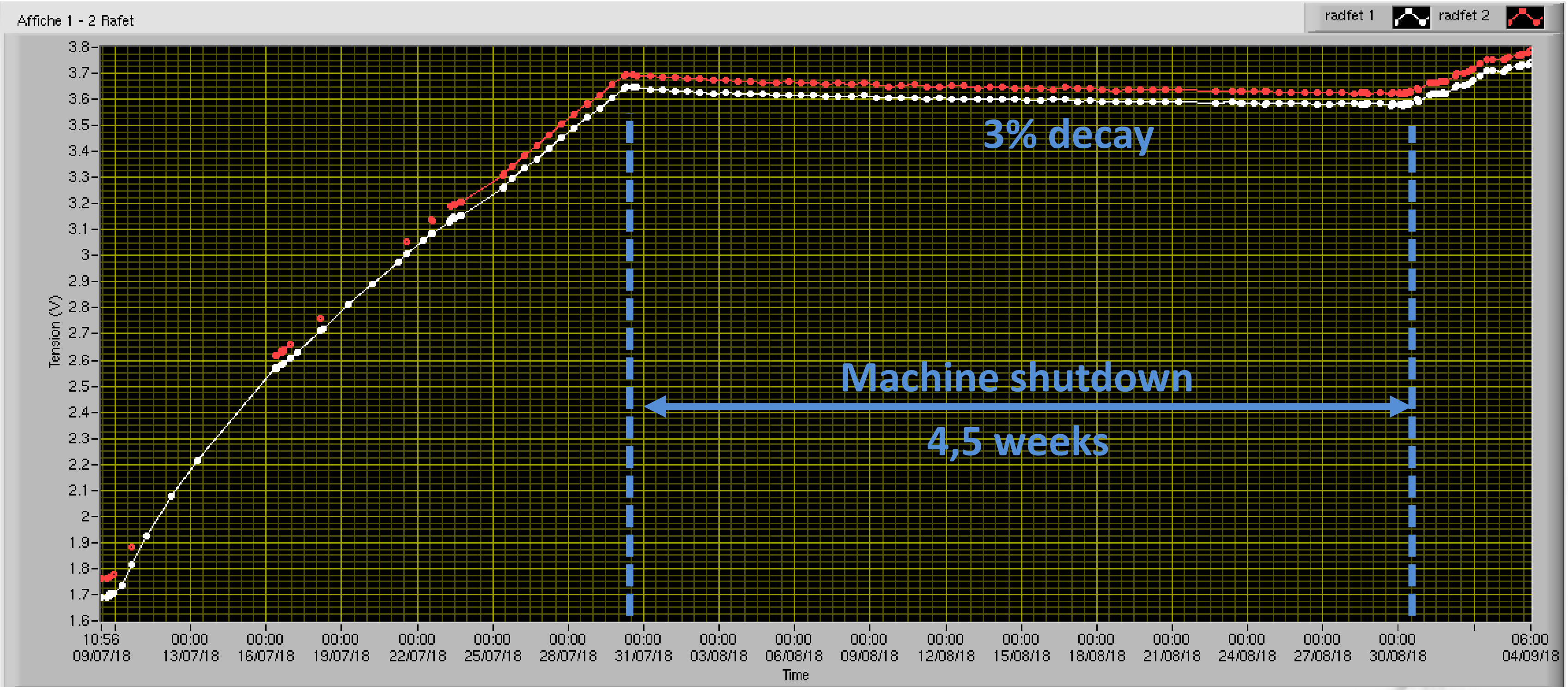
RadFET sensitivity may differ for X-rays <150 keV (photoelectric effect dominates)

-> to be calibrated with an X-ray source.

Gafchromic film measurement (2013) showed a dose rate a factor two lower.

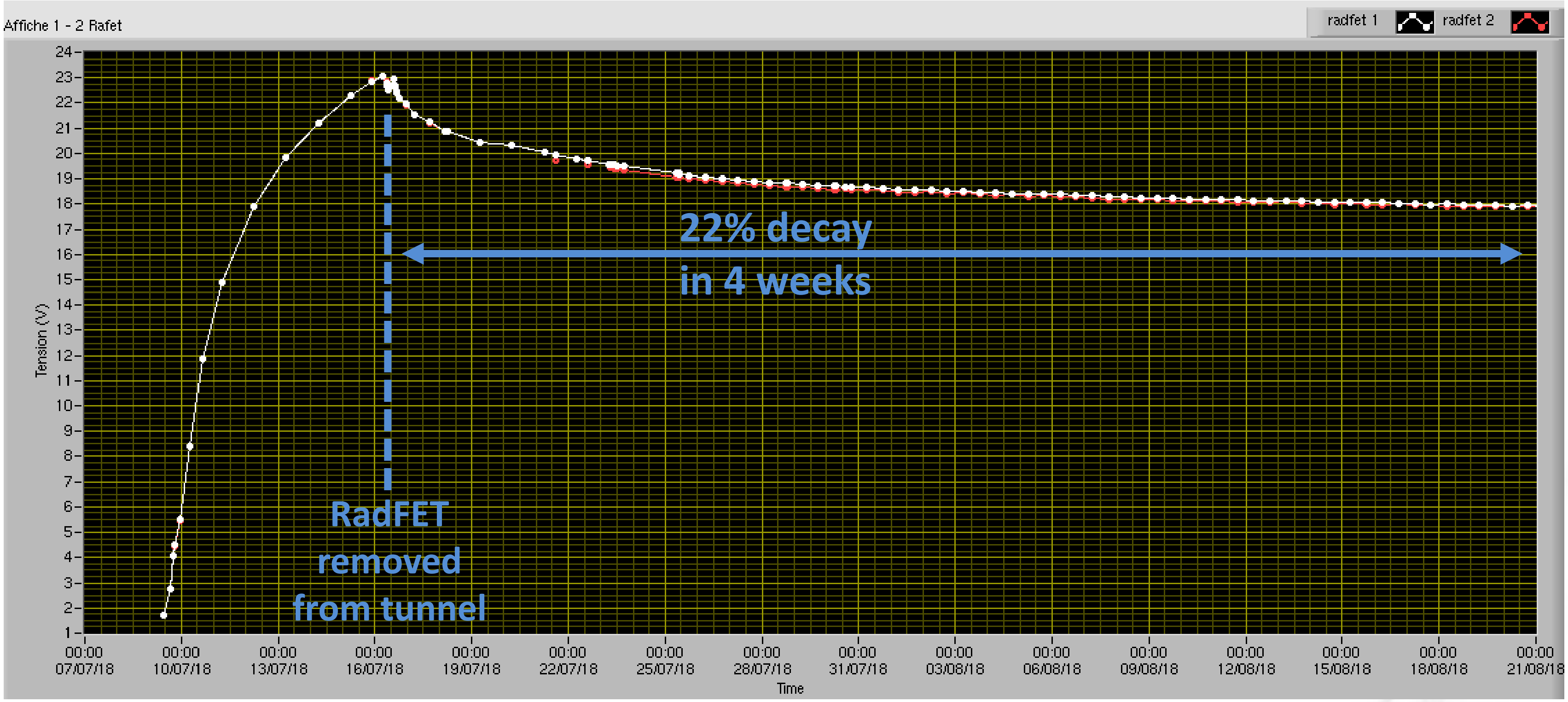
First measurements with beam

- Fading effect
  - Electron tunneling from the silicon substrate
  - Neutralized the holes trapped close to the oxide/silicon interface
  - Decay of the threshold voltage
  - Small effect for RadFET exposed at 10 krd (~4V threshold voltage)



First measurements with beam

- Fading effect
  - Electron tunneling from the silicon substrate
  - Neutralized the holes trapped close to the oxide/silicon interface
  - Decay of the threshold voltage.
  - Strong effect at 20 V (but outside nominal measurement range!)



Conclusion

- RadFET System for SOLEIL:
  - Monitor the integrated dose deposited around equipment damaged by radiations
  - Sensitive to all types of radiations (X-rays, gammas, electrons), but sensitivity may vary with particles energy:
    - Calibration done with a Co source,
    - Calibration to be done with X-rays
  - Dedicated readout electronics
    - Multiplexed reader: up to 7 RadFET chips (14 measurements)
    - Prototype validated and installed on the machine
  - First measurements are in good correlation with damages observed
  - Extended measurement range to be investigate (without increasing too much fading…)

Acknowledgements

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- Lars Froehlich (DESY)
- Monique Taurigna (LAL)

Thank you for your attention!