INSTITUTO TECNOLÓGICO DE ARAGÓN

Supercapacitors based power supply distribution system for ILC

Alvaro Pradas, Javier Piedrafita, Mateo Iglesias,
Ivan Echeverria, Fernando Arteche

Complex Electrical System Group at ITA

X Meeting of the Future Linear Colliders Spanish Network
10th-12th February 2014
ETS Ingenieros
Universidad de Sevilla

ita

OUTLINE

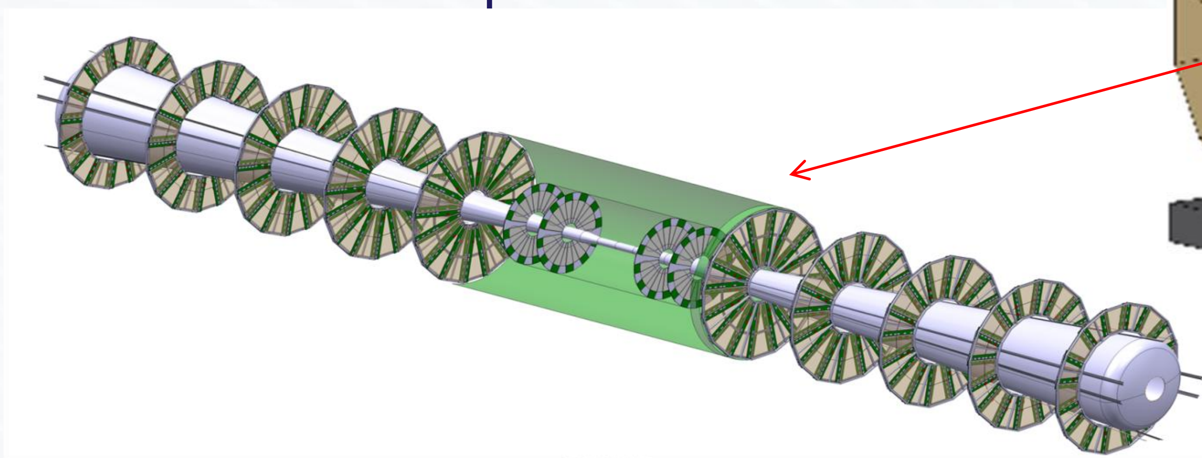
- 1. Introduction
- 2. Power requirements
- 3. Supercapacitors based power distribution.
  - Operation conditions
- 4.Supercapacitors
  - Characterization
  - Radiation test
- 5.FTD +6 Group: Real prototype
- 6.Conclusions

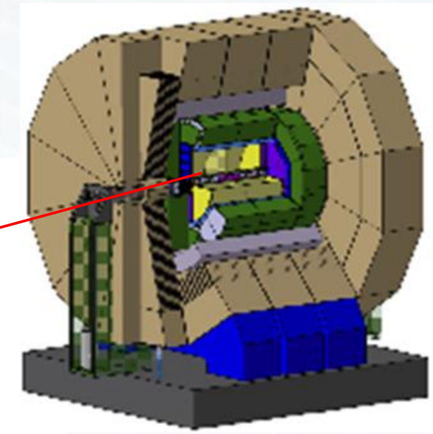
1. Introduction

- Future ILC experiments need low mass detectors in order to increase the accuracy of the physics measurements.
  - Minimize or No cooling pipes
  - Low copper/aluminum components
- For that purpose, the synchronization of the FEE power consumption with the accelerator beam duty cycle is planned.
- However, special attention should be paid in the design of the power systems – It is quite complex
- There are several topologies that are under study
  - DC-DC-based power distribution
  - Super-capacitor based power distribution
- Each of them has some advantages and disadvantages
- This talk is focused on **SC based power supply for FTD-ILD**
  - **It may be extended to any other system**

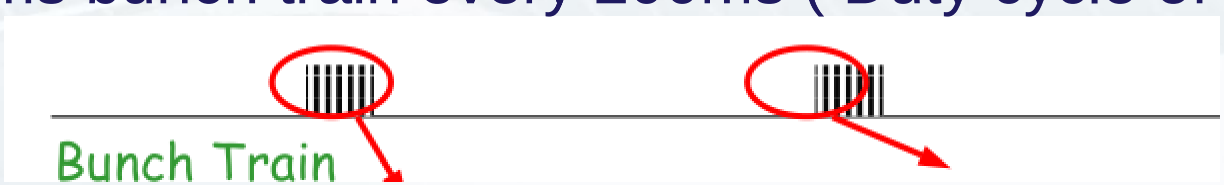
2. Power requirements

- The mstrip-FTD system is a silicon strip tracker located in the innermost part of the tracker region of the ILD.
  - It consists of 10 disks.
    - Each disk has 16 petals

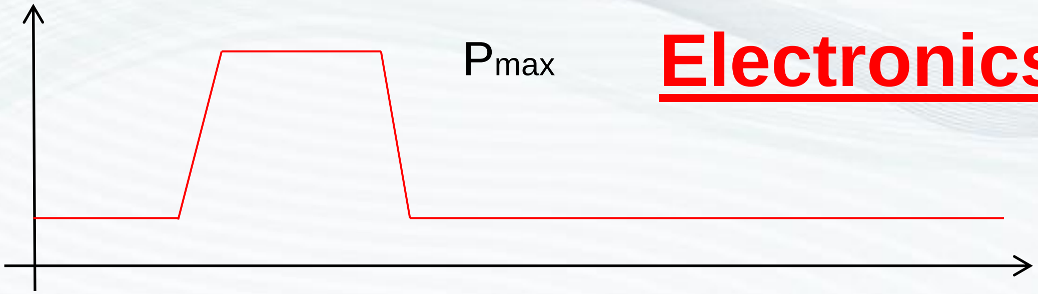




- The FTD electronics will operate synchronously (or coordinated) with ILC accelerator....
  - 1 ms bunch train every 200ms (Duty cycle of 0.5%)



2. Power requirements



Electronics duty cycle /power ?

$P_{standby} = 20\% \ P_{max}$

- Several conservative considerations have been assumed in the electronics operation:
  - **Electronics duty cycle operation** (2.5% - 5ms / 200ms).
    - 1 ms power up / down
    - 3 ms operation state to stabilize power and operate.
    - It minimizes transients
  - **Power consumption during the standby** (20% Pmax). !!!
    - It is a critical parameter (100W / 20W): 22 W/cycle
      - 2.5W/cycle - FEE ON (11%)
      - 19.5W/cycle – STAND BY (89 %)
    - *If standby power 10W : Ptotal = 12.25 W/cycle*
    - *If FEE operation time 2.5ms: : Ptotal=21W/cycle*

2. Power requirements

- The total Strip-FTD current / power demanded is:
  - Bunch crossing state 458 A (**≈ 860 W**)
  - Stand-by state 91.6A (**≈ 171W**)

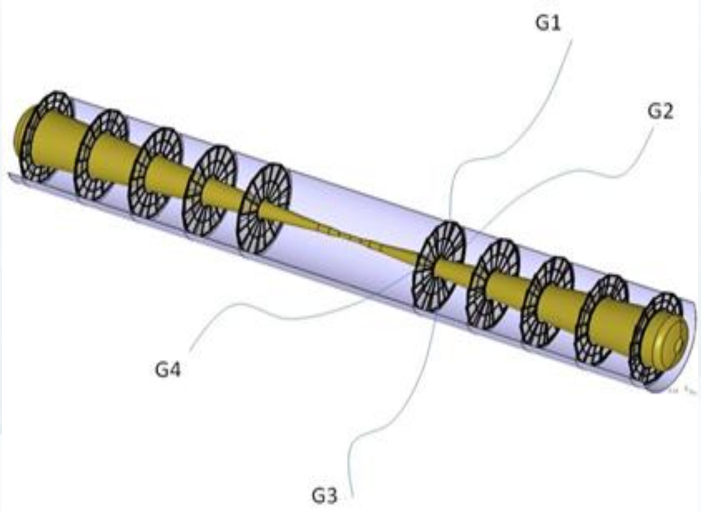
	MIDDLE PITCH									
FTD	*FTD3*		*FTD4*		*FTD5*		*FTD6*		*FTD7*	
	INN	*OUT*	*INN*	*OUT*	*INN*	*OUT*	*INN*	*OUT*	*INN*	*OUT*
Nº Readout	***33920***	***61504***	***41600***	***64224***	***45472***	***65504***	***51232***	***67424***	***63424***	
Chips per petal (256 ch)	*24*		*26*		*28*		*29*		*16*	
Optical links per petal	*1/2*		*1/2*		*1/2*		*1/2*		*1/2*	
I1.5 (A) per Petal	*1.75 / 0.35*		*1.9 / 0.38*		*2.05 / 0.41*		*2.12 / 0.42*		*1.16 / 0.23*	
I2.5 (A) per Petal	*1.05 / 0.21*		*1.13 / 0.23*		*1.22 / 0.24*		*1.27 / 0.25*		*0.7 / 0.14*	
I per petal	*2.79 / 0.56*		*3.03 / 0.61*		*3.26 / 0.65*		*3.39 / 0.68*		*1.86 / 0.37*	
I per disk	*44.6 / 8.9*		*48.5 / 9.71*		*52.08 / 10.42*		*54.19 /10 .84*		*29.76 /5.95*	
TOTAL Mstrip- FTD Current (both sides)			*458 A / 91.6 A*							

(CMS upgrade TK elec.)

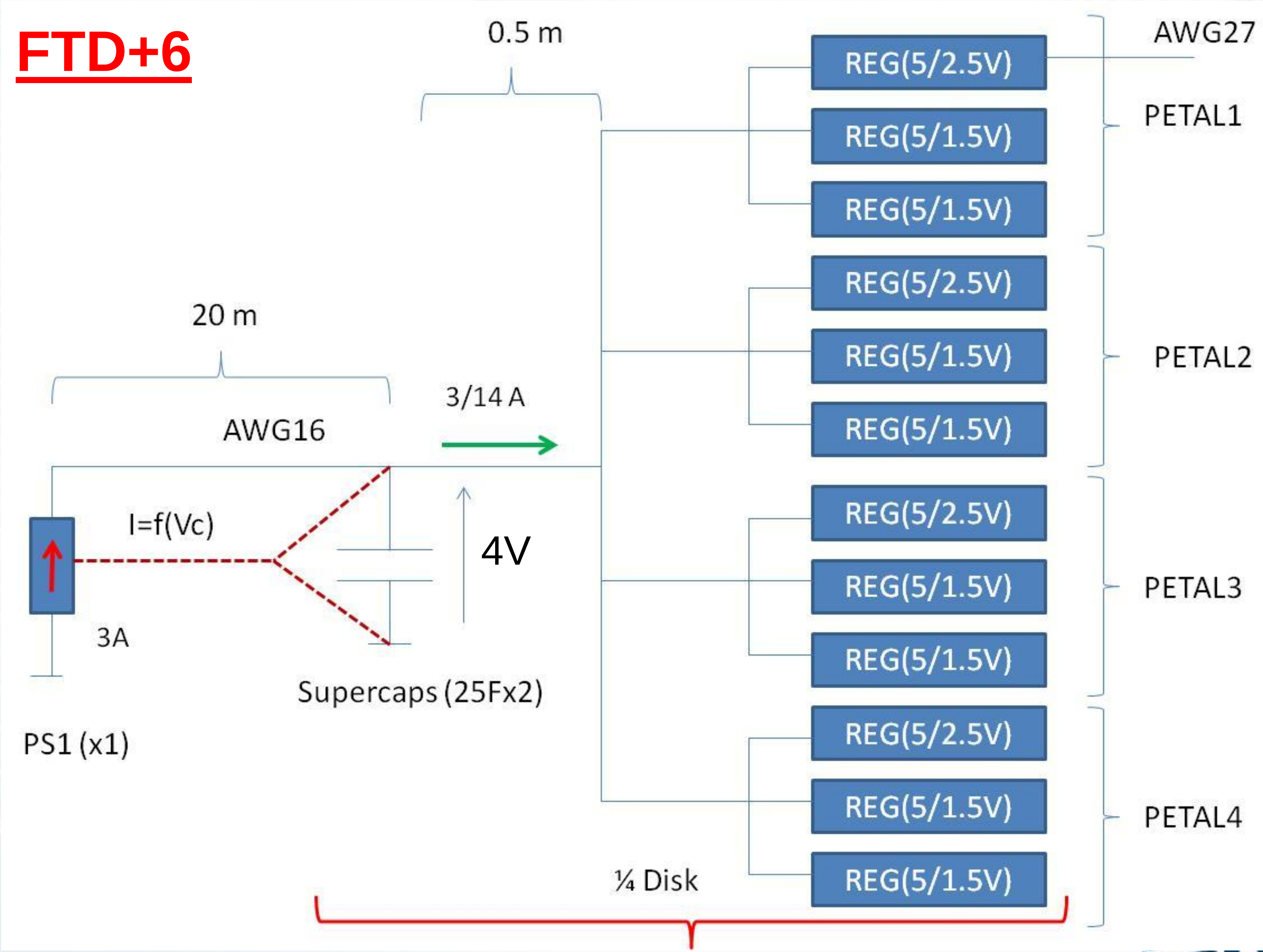
X Meeting of the Future LC Spanish Network
Sevilla, February 2014

3. Supercapacitor based PS

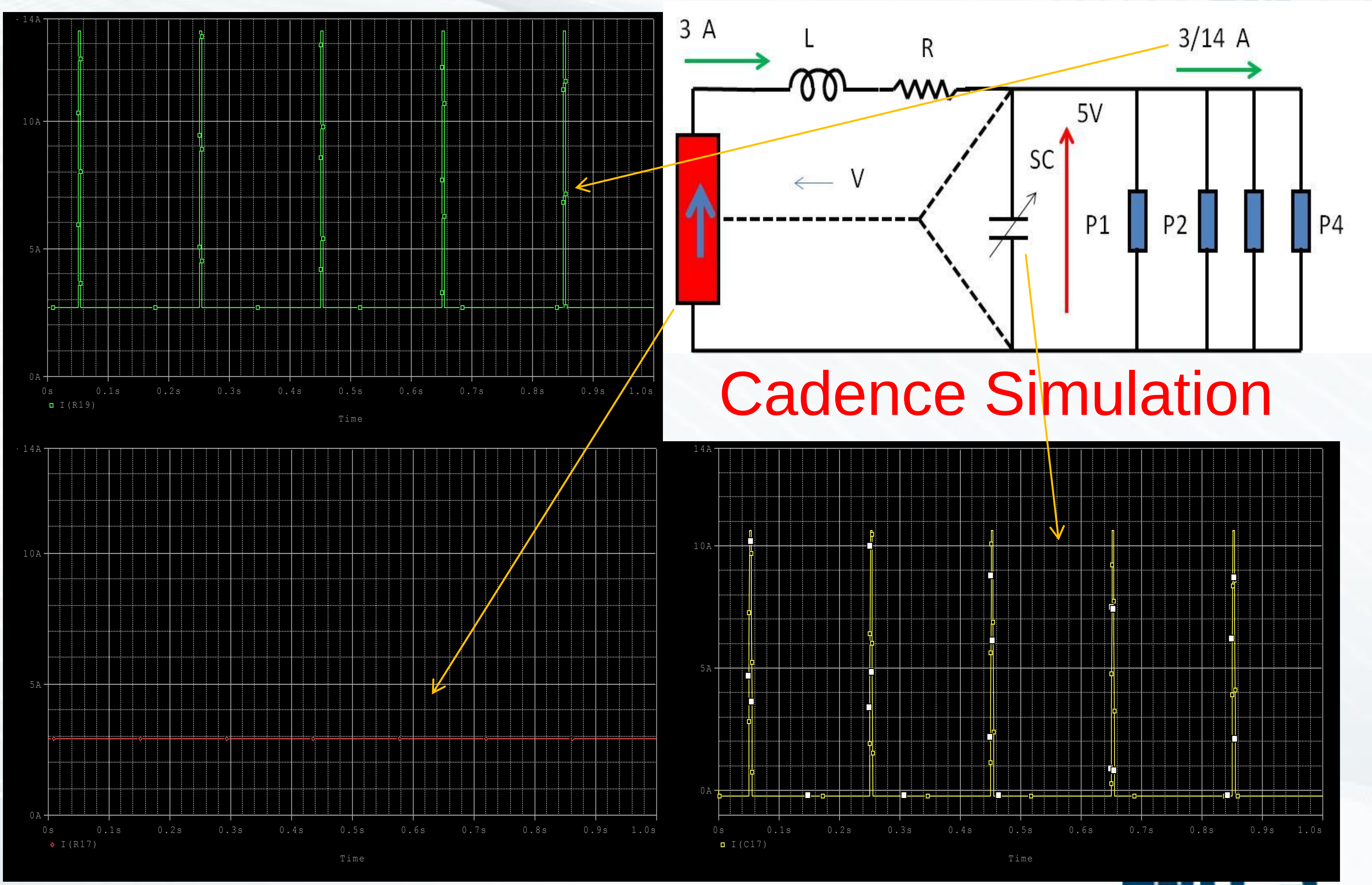
- Several important issues have to be considered during the design of the power system:
  - Transient phenomena
  - Power dissipation effects
  - Reliability
- They have an impact on the design of the power supply distribution system – Granularity (1/4 Petal)
- The main elements of this topology are:
  - Supercapacitors:
    - Pulse power – Transients locally
  - LV regulators:
    - Stabilize FEE voltage
  - Current source :
    - Controls super-capacitor voltage
- All these elements are crucial



3. Supercapacitor based PS



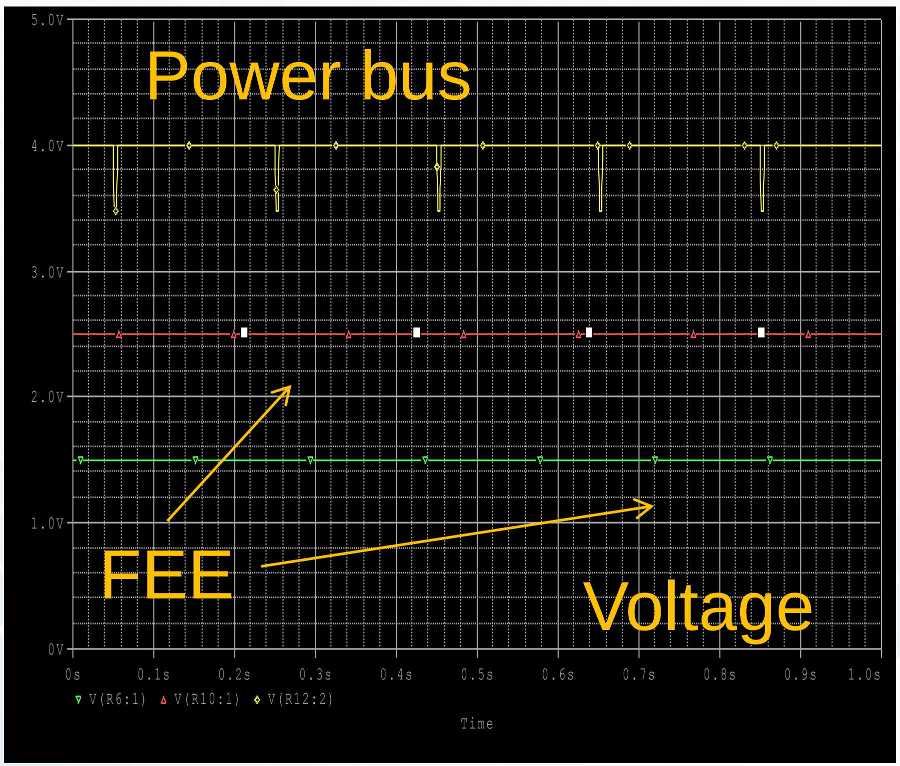
3.1 Supercapacitor based PS: Operation conditions

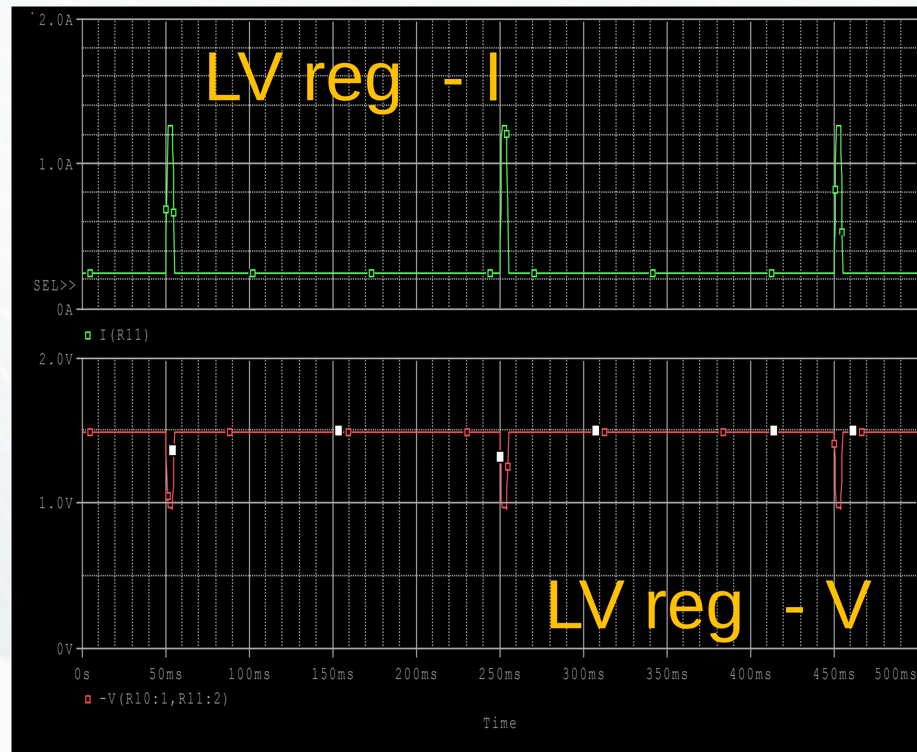


X Meeting of the Future LC Spanish Network
Sevilla, February 2014

3.1 Supercapacitor based PS: Operation conditions

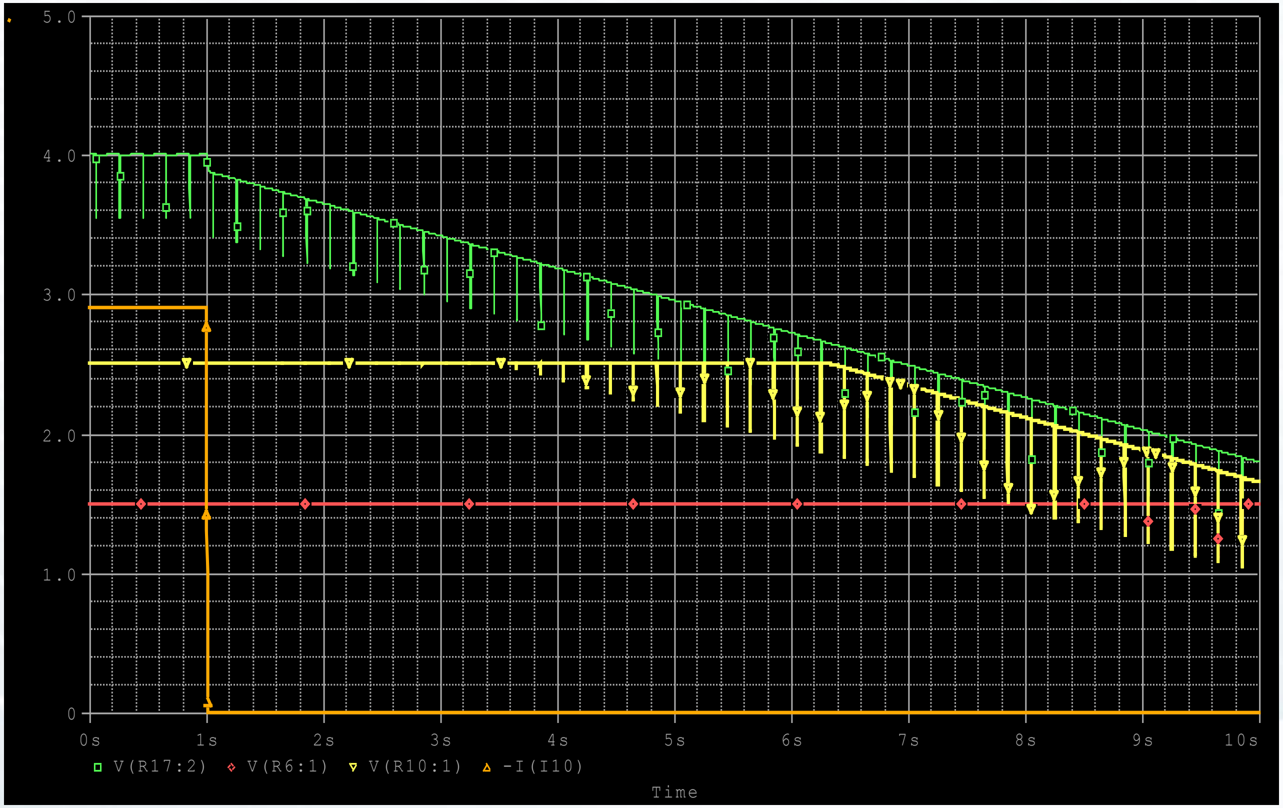
- Each pulse generates a voltage dip
  - It is mainly influenced by the ESR of the super-capacitors
    - Line impedance, too.
- Transient can be easily absorbed by the LV regulator
  - It should be a RAD tolerant component
- The voltage dips helps to decrease the power dissipated by LV reg.





3.1 Supercapacitor based PS: Operation conditions

- The high capacitance has two advantages:
  - It will protects the system in case mains failure – Similar to UPS
    - It helps shutdown the system in a controlled way.
  - The dynamic response of primary power unit may be very slow
    - Remote regulation of the supercap voltage will be easy



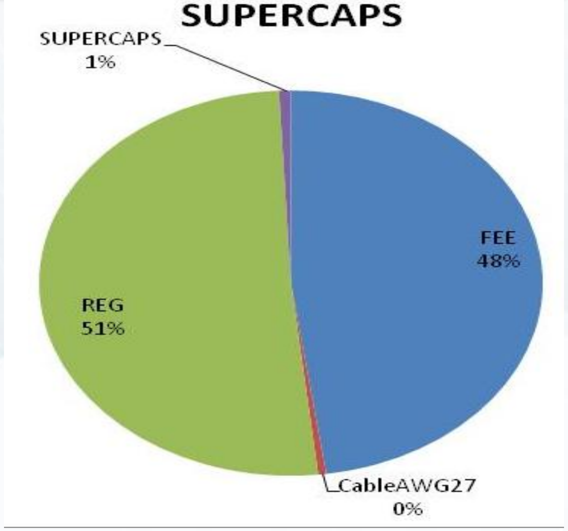
- The duration of the shut-down capability will depend on :
  - Capacitance
  - Voltage

3.1 Supercapacitor based PS: Operation conditions

- Power dissipated per ILC cycle (W/cycle):

Group	FTD 3+	FTD4+	FTD5+	FTD6+	FTD7+
FEE	4.6	5	5.4	5.6	3
CABLE AWG 27	0.04	0.04	0.05	0.06	0.02
LV REG	4.9	5.41	5.74	5.96	3.24
SUPERCAPS	0.06	0.072	0.083	0.089	0.027
TOTAL (1/4)	9.63	10.6	11.3	11.7	6.4
TOTAL DISK	38.5	42.1	45	46.5	25.5
External cable (20m) – AWG 16	2.92	3.515	4	4.4	1.26

	POWER (W)
HALF SIDE	197 W
TOTAL FTD	**395 W**



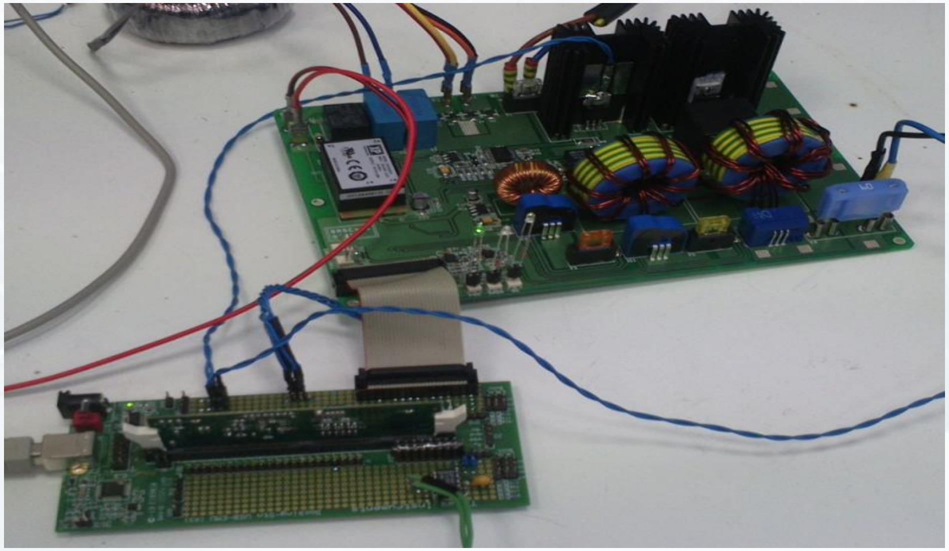
FTD6

4 Super-capacitors

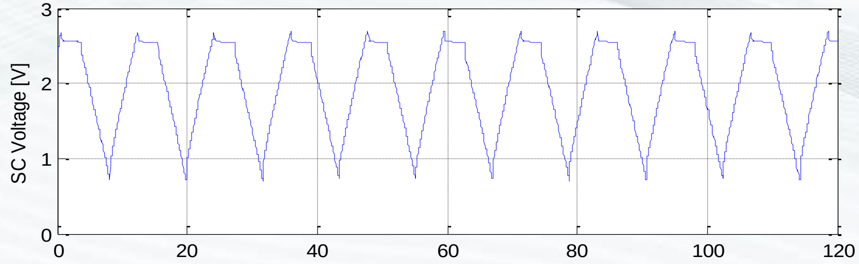
- The most important element in SC-LV regulation option is the super-capacitor.
  - It is new for HEP but not for industrial applications
- There are three elements that have to be analyzed in detail for HEP applications
  - Material Budget:
    - Most of SC material is carbon – It has to be analyzed in detail (DC-DC too)
  - Cycling issues
  - Radiation issues
- Cycling issues (Reliability).
  - Super-capacitor should be able to operate more that 10 million of cycles per year (DC-DC too)
- Radiation issues
  - Type of radiation: gammas & electrons
  - Total dose: 1 or 2 Mrad.

4.1 Super-capacitors: Characterization

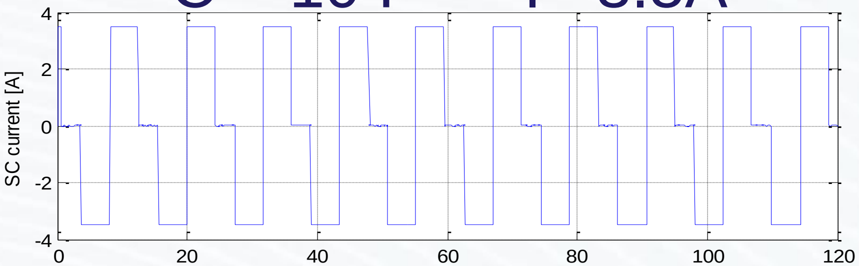
- A power converter has been developed to test the super-capacitors for HEP applications.
- It is an automatic system that measures:
  - ESR, capacitance and capacitor temperature (synchronize)
  - It storage of the operational cycles (V, I, t,T)
  - High dynamic range - 0.1 F up to 6500 F
- The system performs charge and discharge cycles at a constant current (0.5 A to 50 A) – fsw=150 / 200 kHz

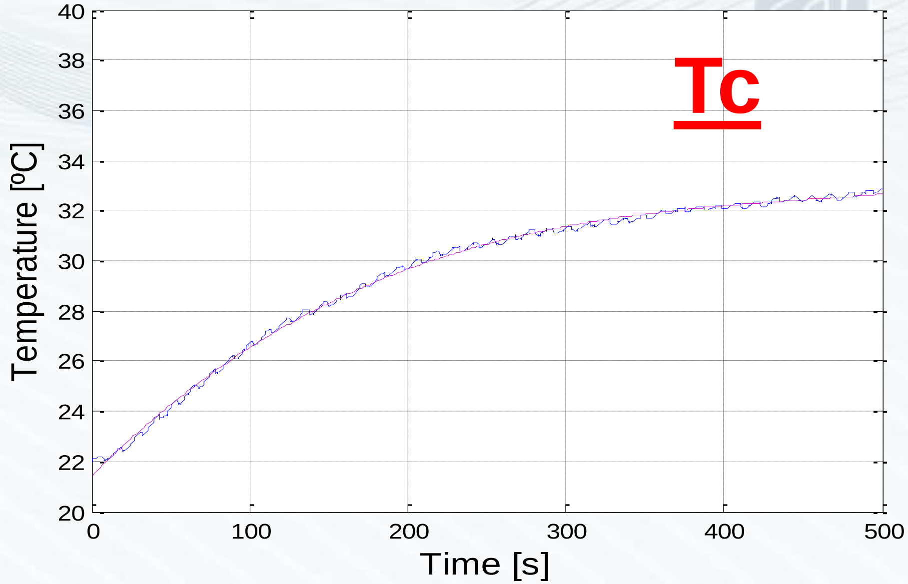


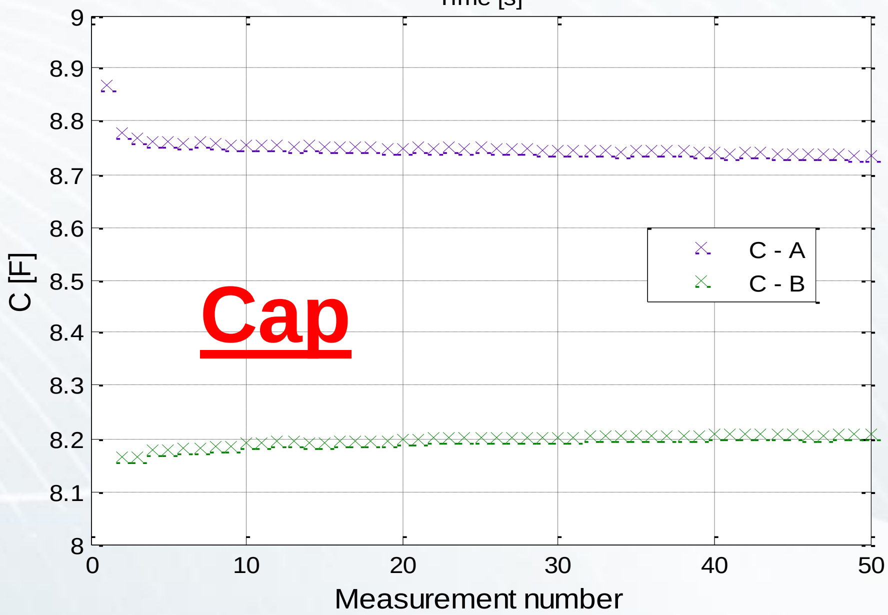
4.2 Super-capacitors: Characterization

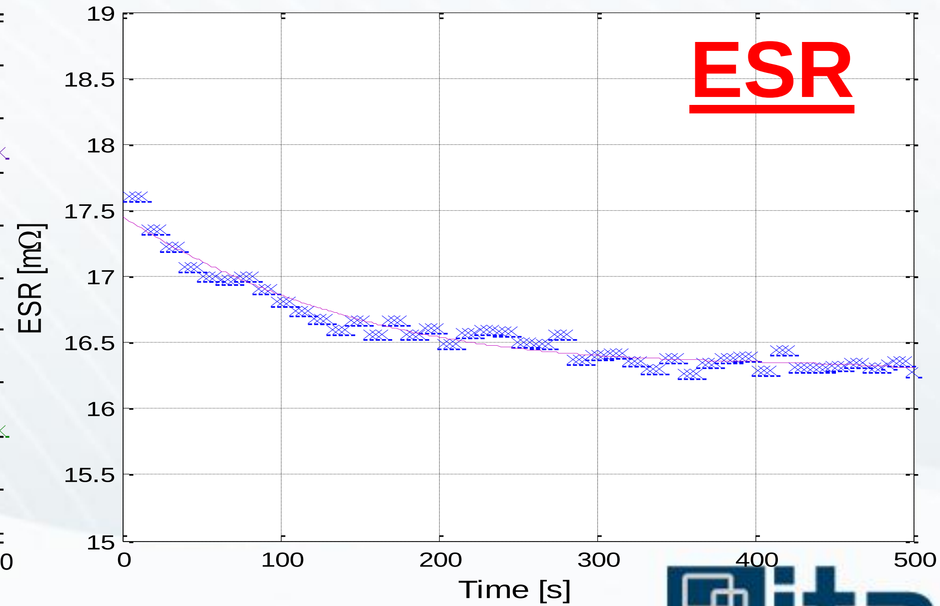


C = 10 F – I= 3.5A







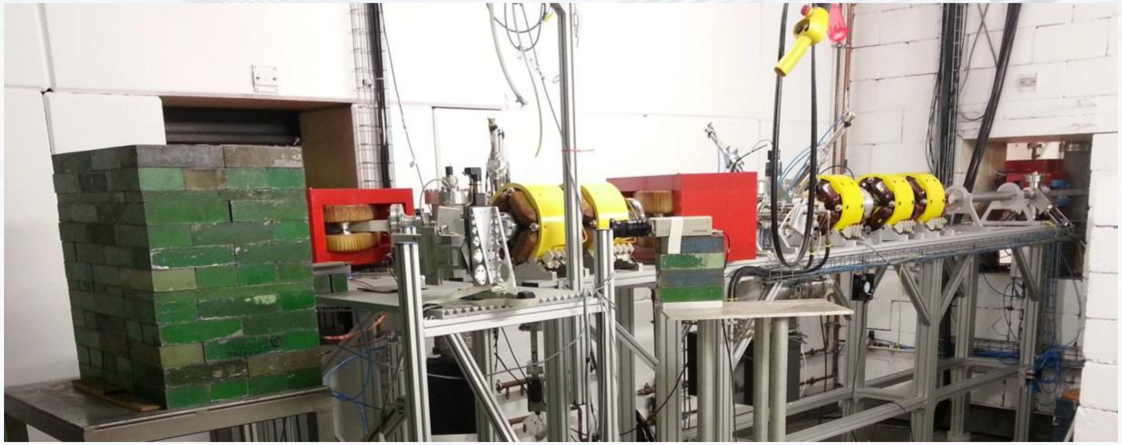


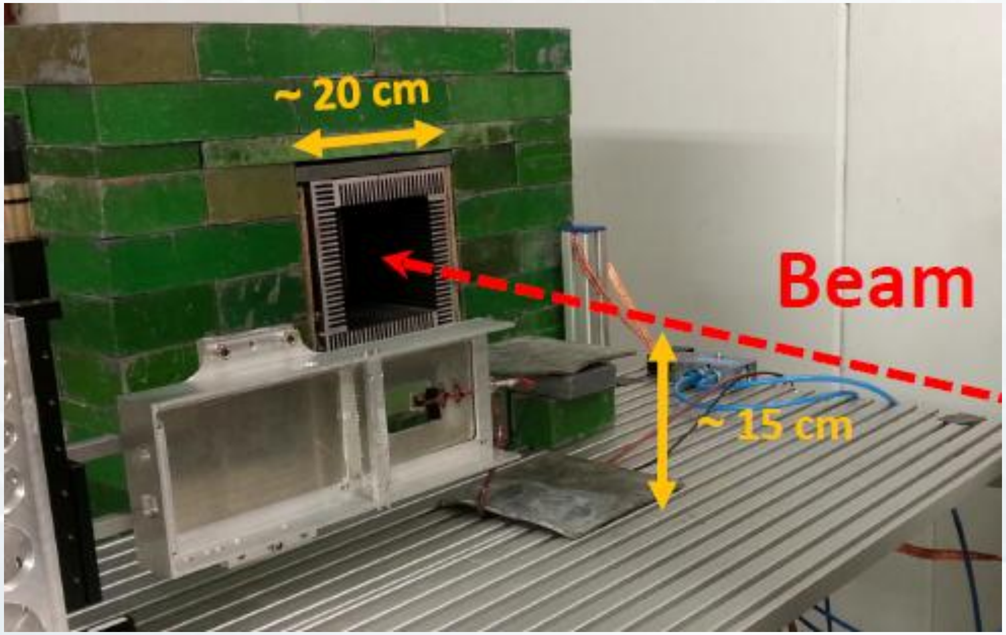
4.2 Radiation test for Super-capacitors

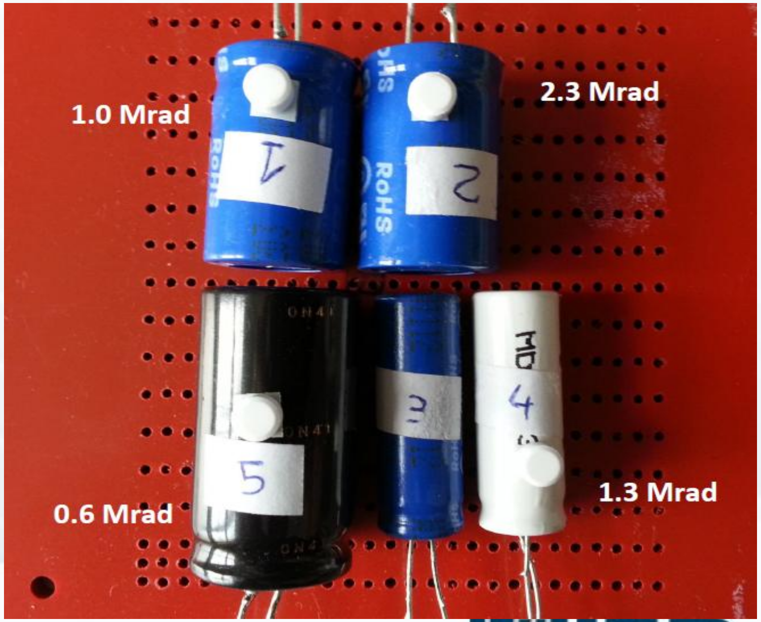
- A radiation test has been carried out in order to start the super-capacitor validation for FTD-ILD
- 5 super-capacitors have been tested – ESR(T) & C(T)
  - Different rates
    - 3 x 10 F & 2 x 25 F
  - Different companies (Maxwell, Nesscap & Panassonic)
- They have been tested before and after radiation at 4 different current rates
- Radiation parameters:
  - Electrons at 20 MEV
  - Beam spot – 3x3 cm2
  - 4 hours of irradiation.
  - Total dose :
    - 0.6 Mrad -2.3 Mrad (3%)

4.2 Radiation test for Super-capacitors

Radiation test has been performed at Electron Stretcher Accelerator **(ELSA, Bonn)**





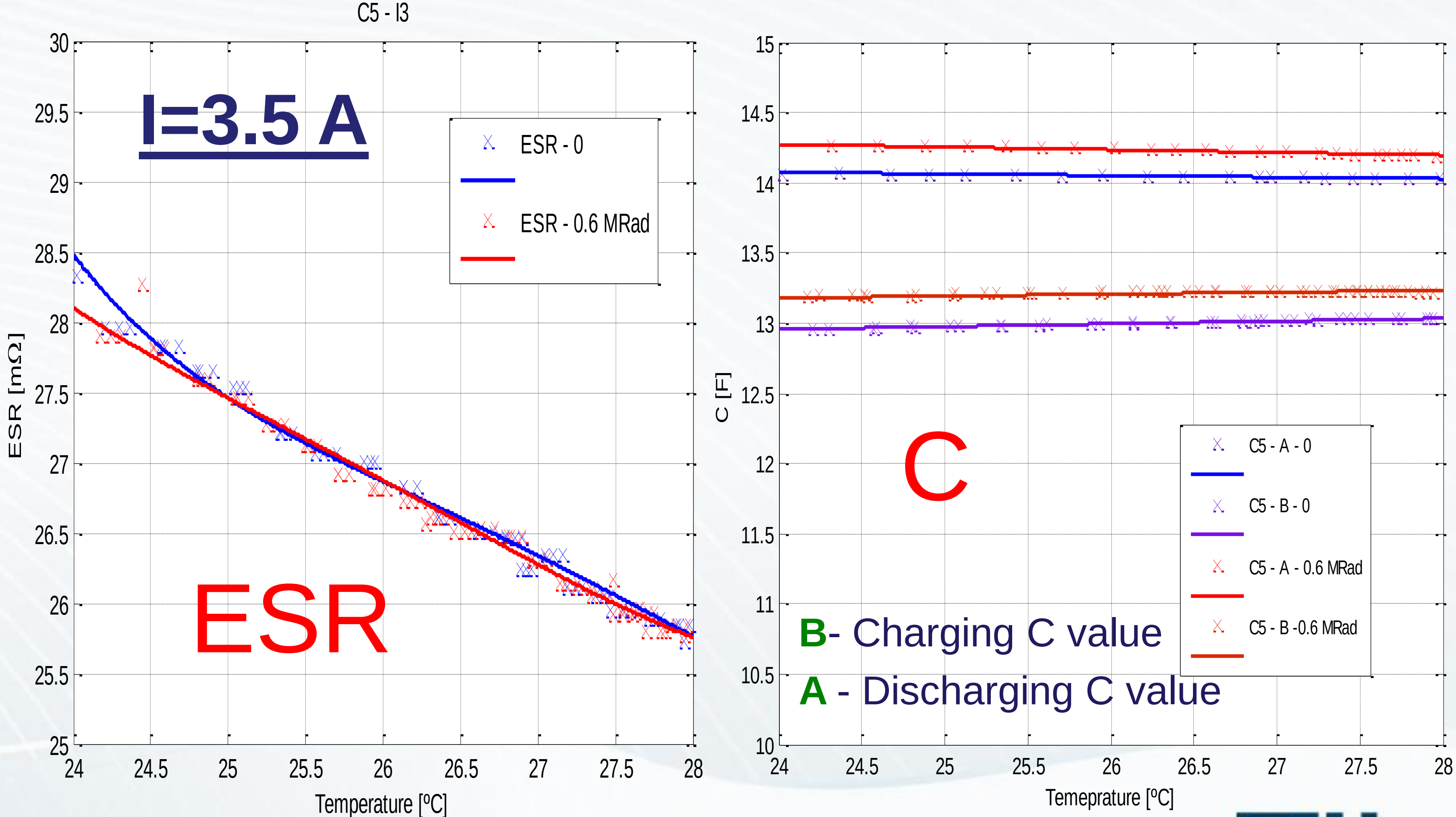


4.2 Radiation test for Super-capacitors

Blue – Before radiation / Red – After radiation

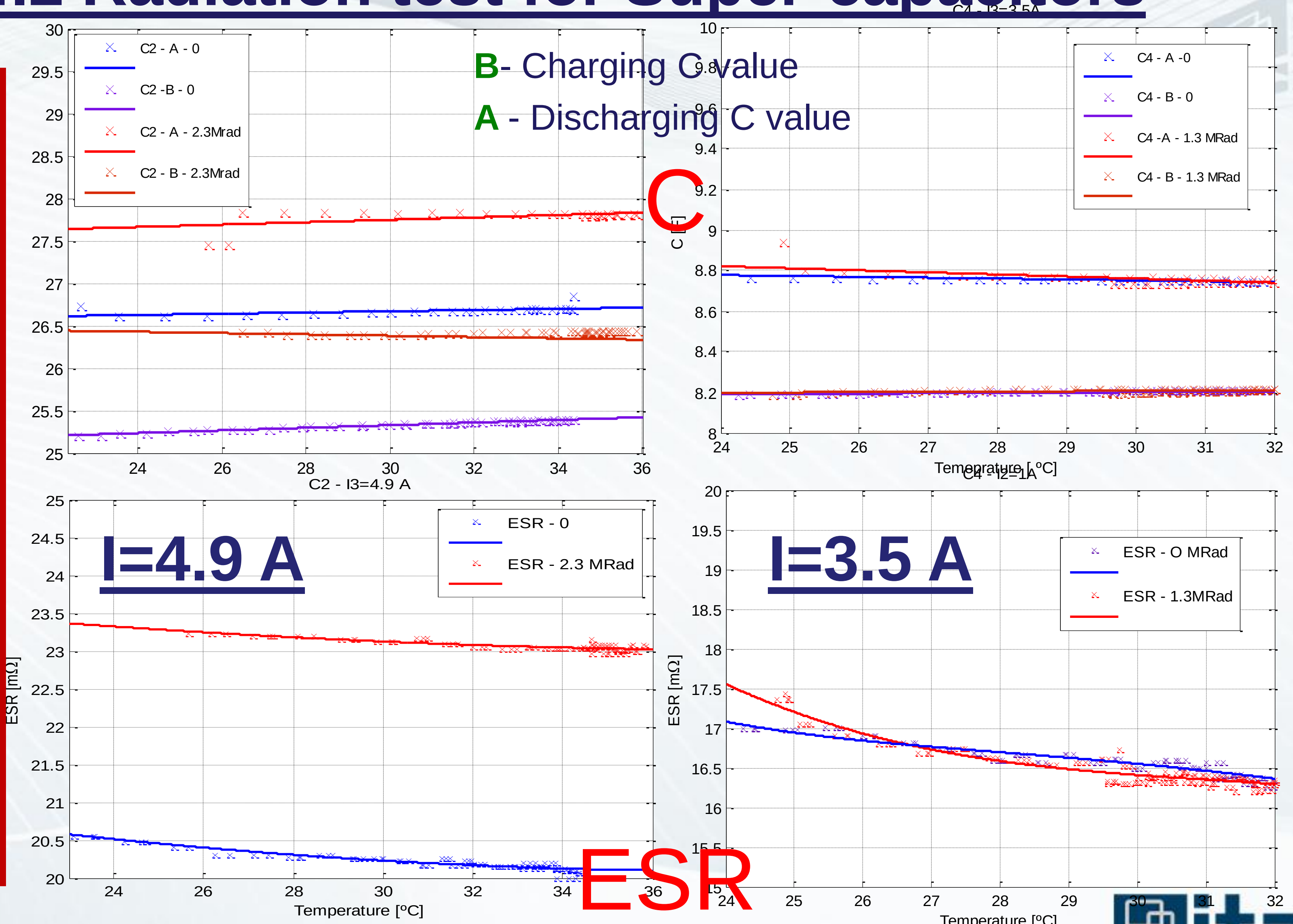
X Measured values / - Fitted values

C = 10 F – Panasonic - 0.6 Mrad



4.2 Radiation test for Super-capacitors

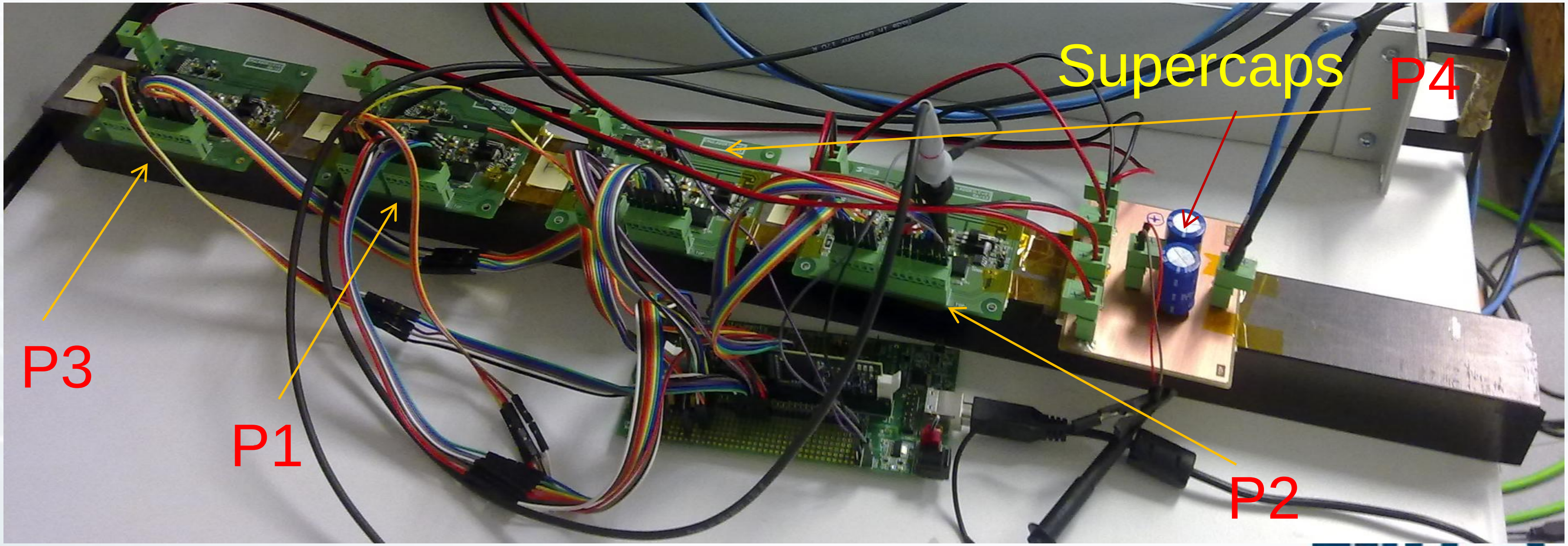
C = 25 F – Maxwell- 2.3 MRad



C = 10 F – Nesscap- 1.3 MRad

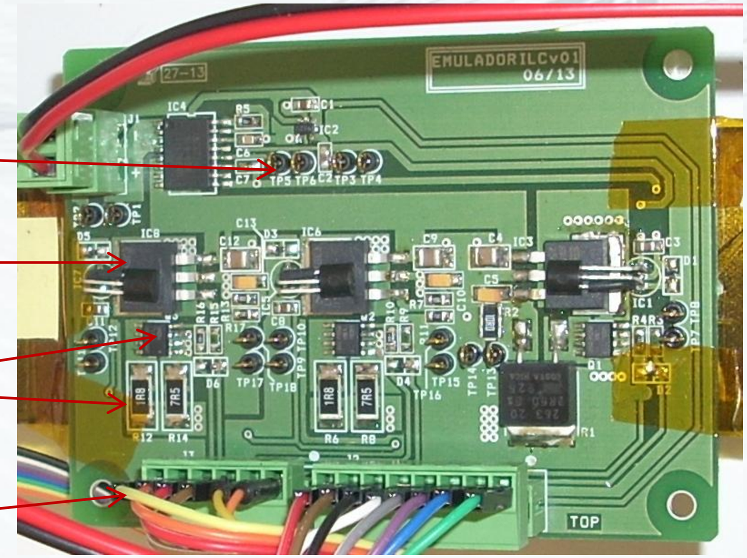
5.FTD +6 Group: Real prototype

- A real prototype of 1 Group of FTD sub-detector (FTD +6) has been developed
  - 4 load boards - It simulates the FEE (hybrid) per petal
  - 2 Super-capacitors
  - 1CF structure – It has been developed by FERMILAB–CMS Tracker II
  - Ip=13.5A – Isb =2.7A (Per petal – Ip=3.4A / Isb=0.7A)
  - Vsc = 4.2 V / Vinp=4V

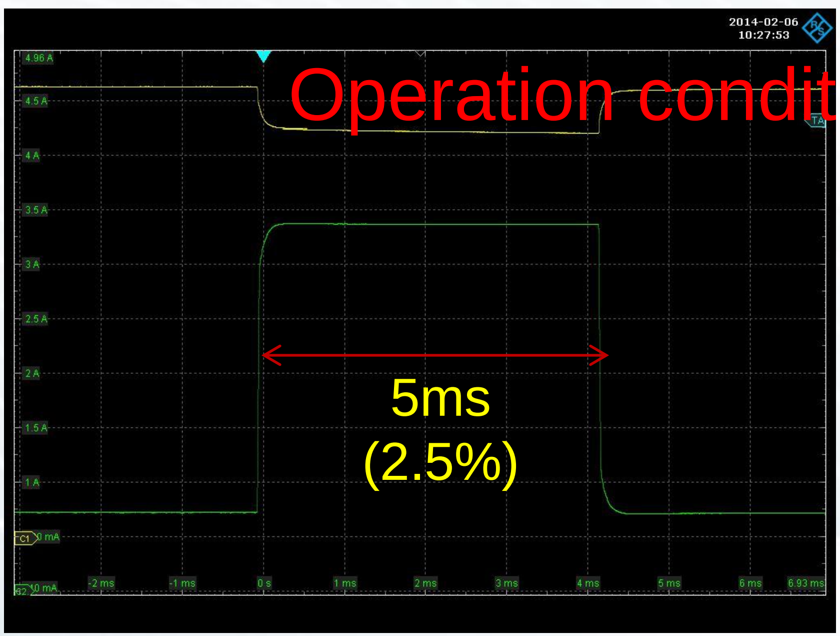


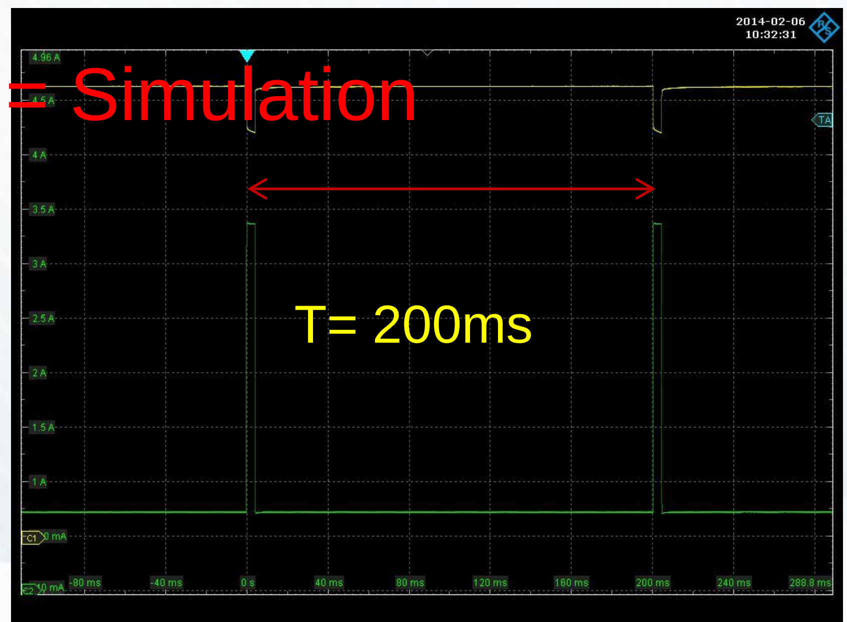
5.FTD +6 Group: Real prototype

- An ILC emulator has been designed
  - Testing points
- 3 LV regulators
  - 2x1.5V / 1x2.5V
- Pulse load: 3 x (2 resistors)
  - 3 x MOSFET
  - Driven by Texas Instruments CB

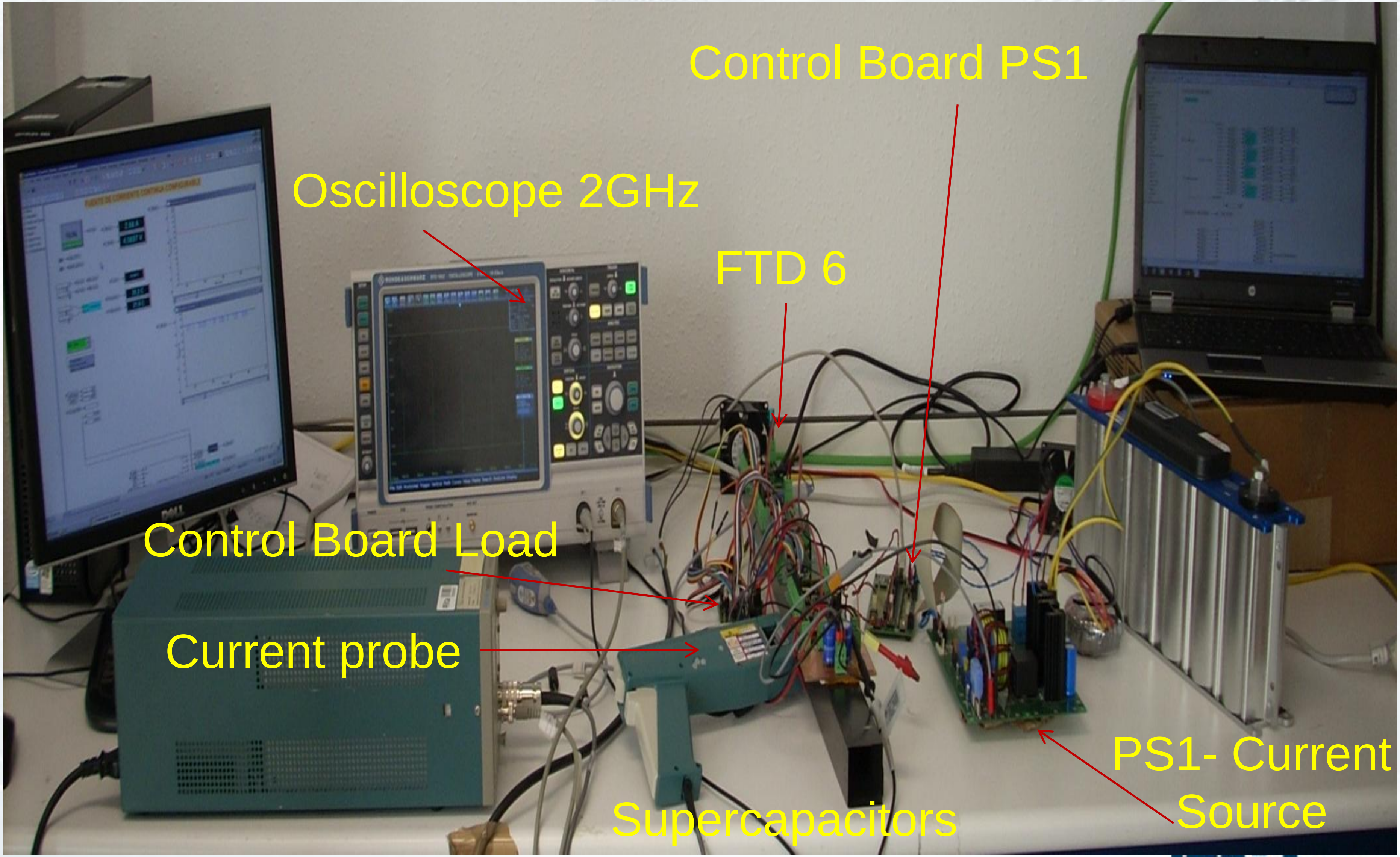


Operation condition = Simulation

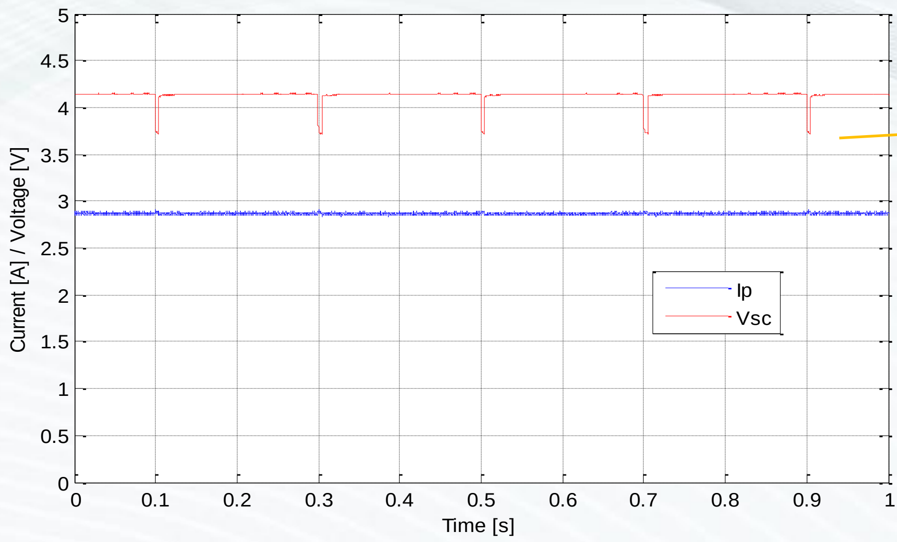


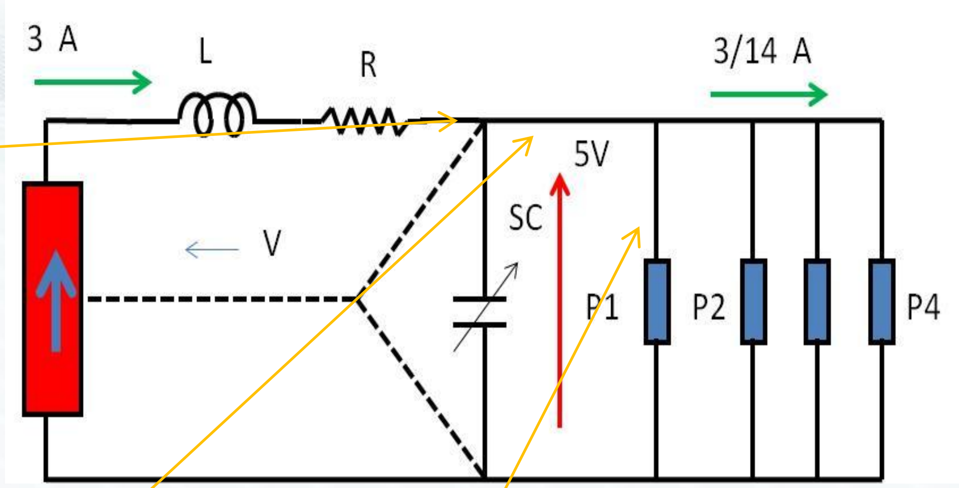


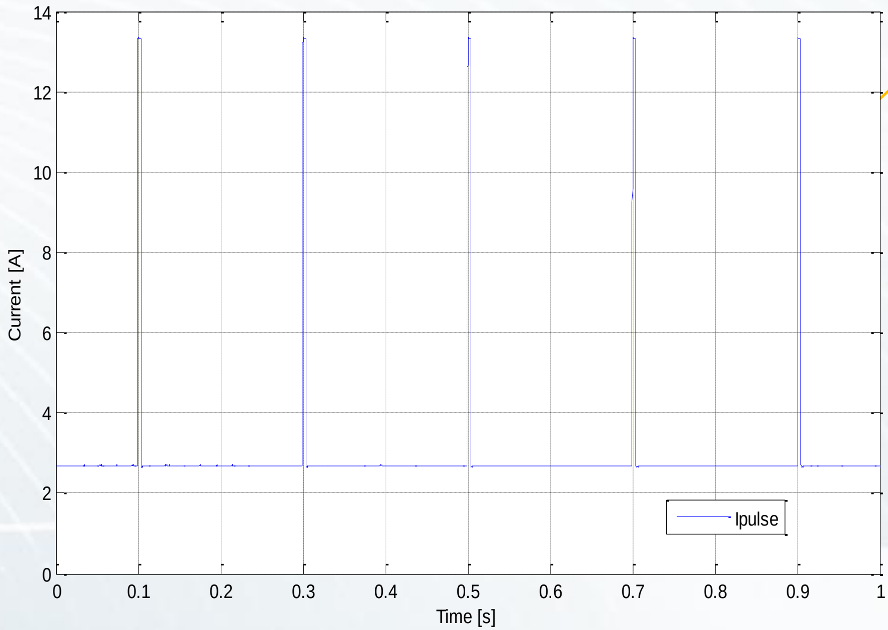
5.FTD +6 Group: Real prototype

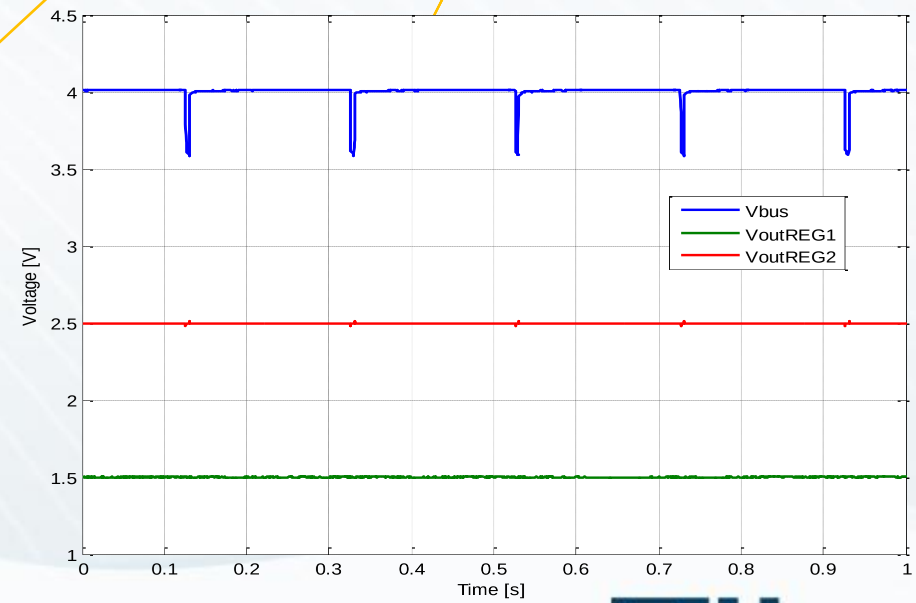


5.FTD +6 Group: Real prototype





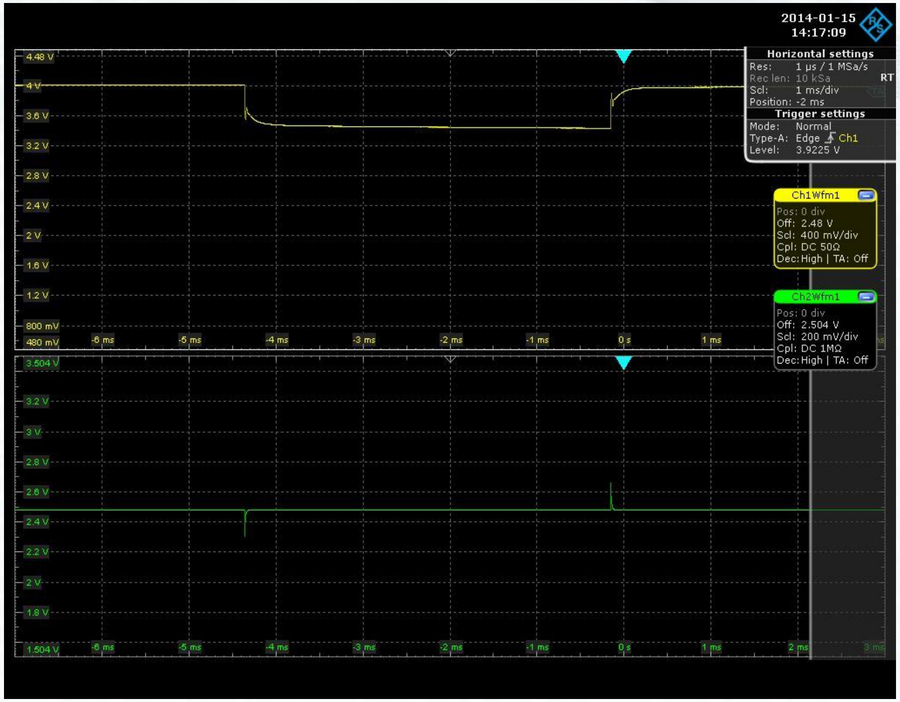


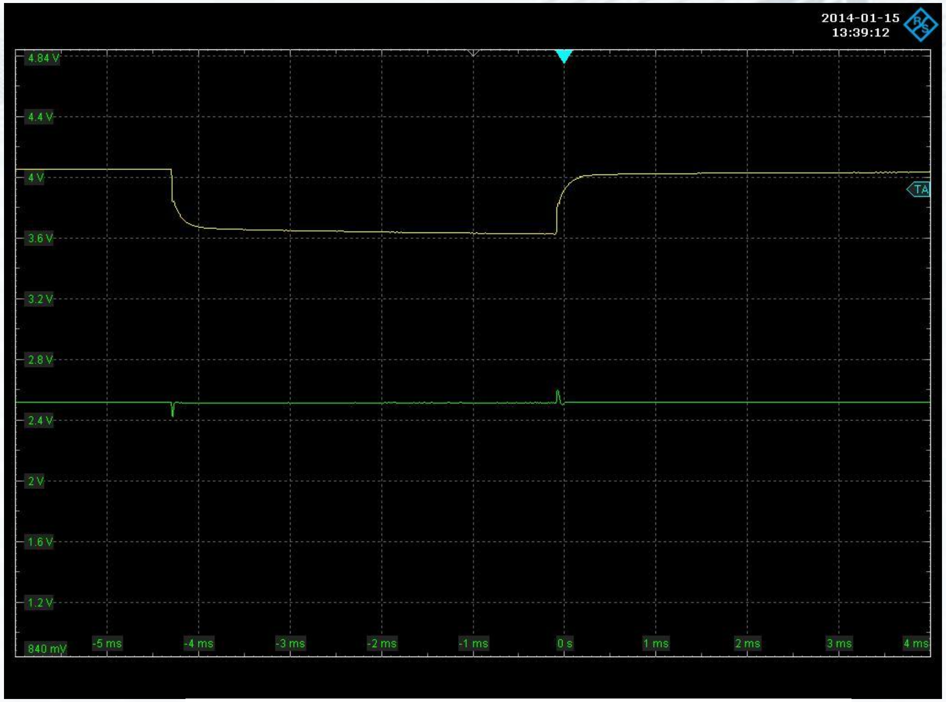


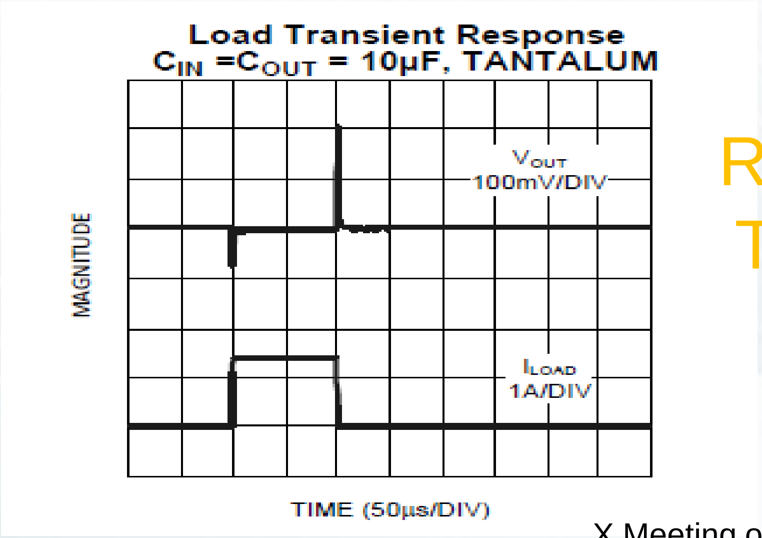
5.FTD +6 Group: Real prototype

TRANSIENTS

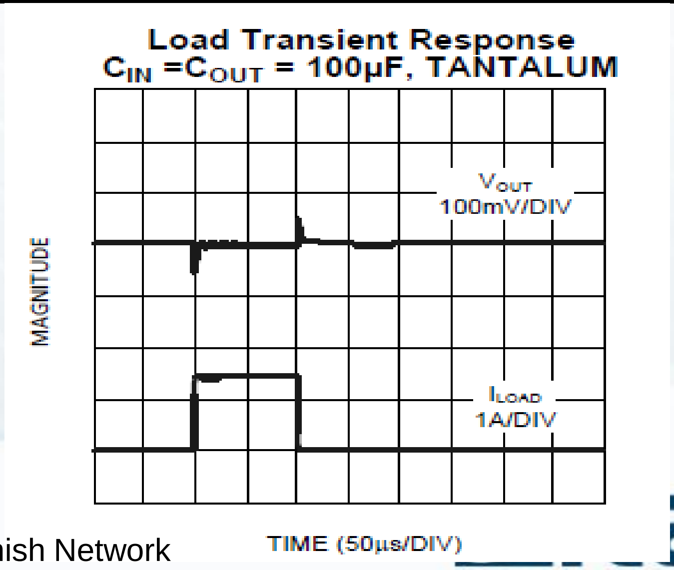
5.FTD +6 Group: Real prototype



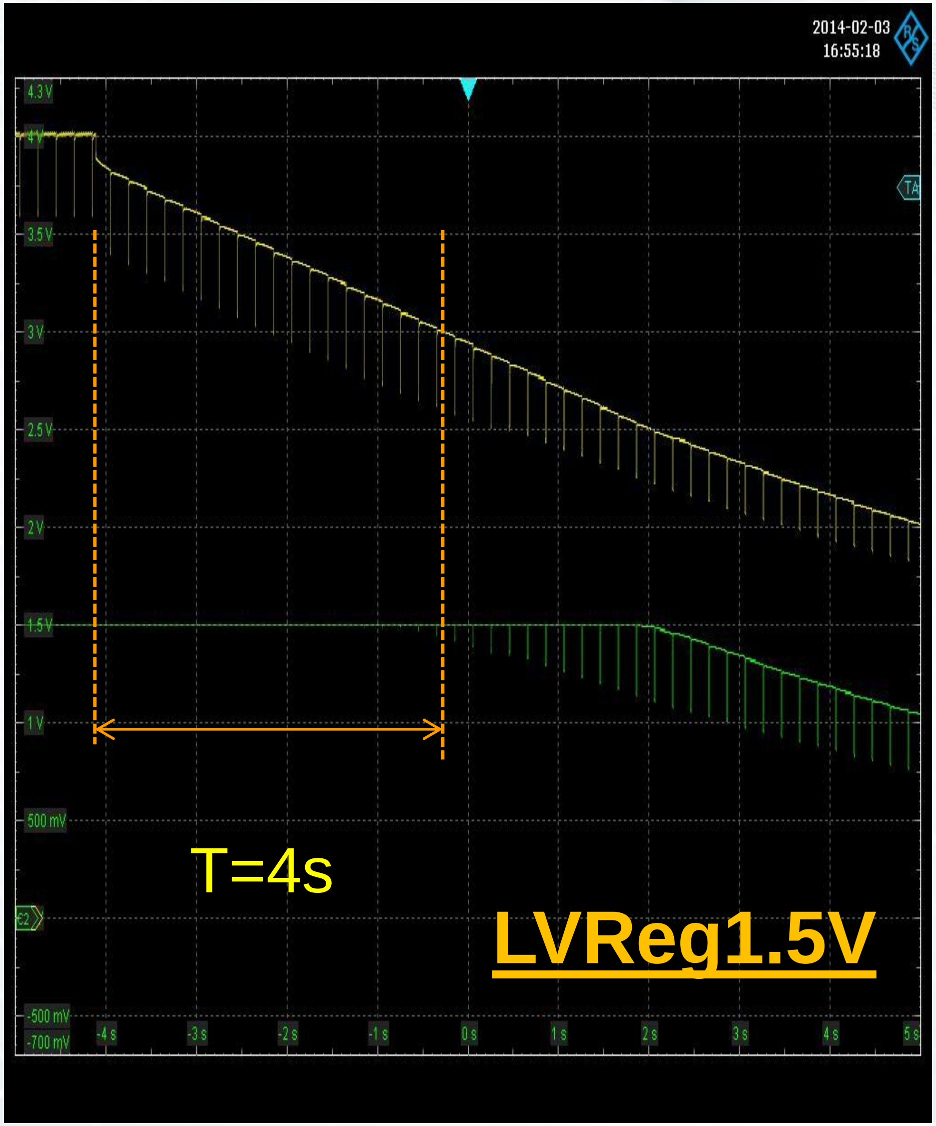




Regulator Transient



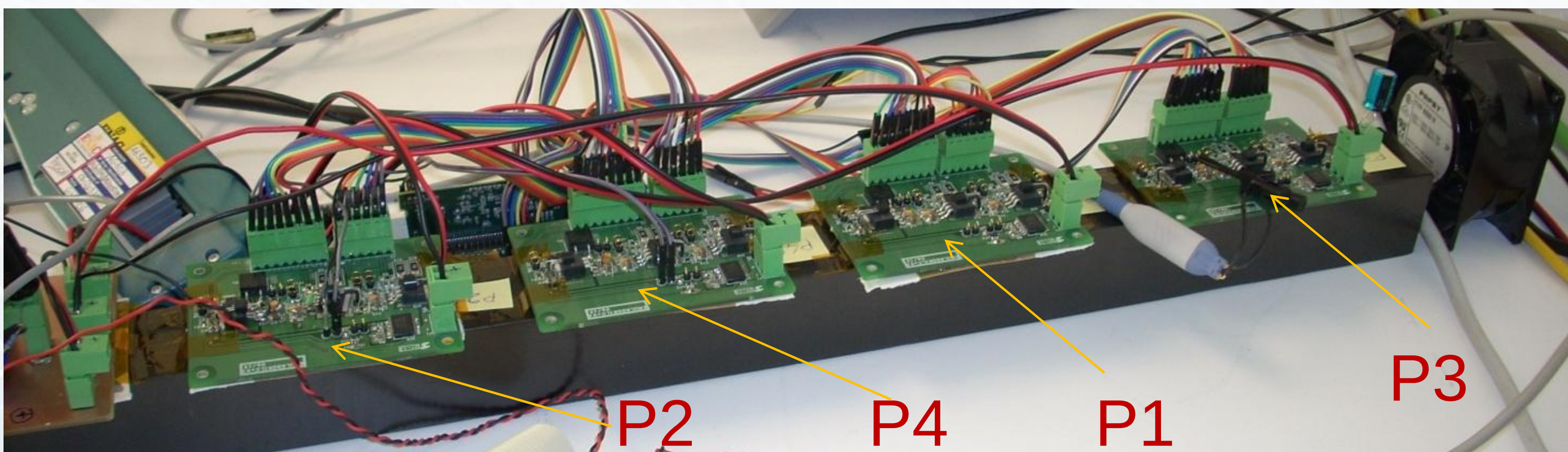
5.FTD +6 Group: Real prototype



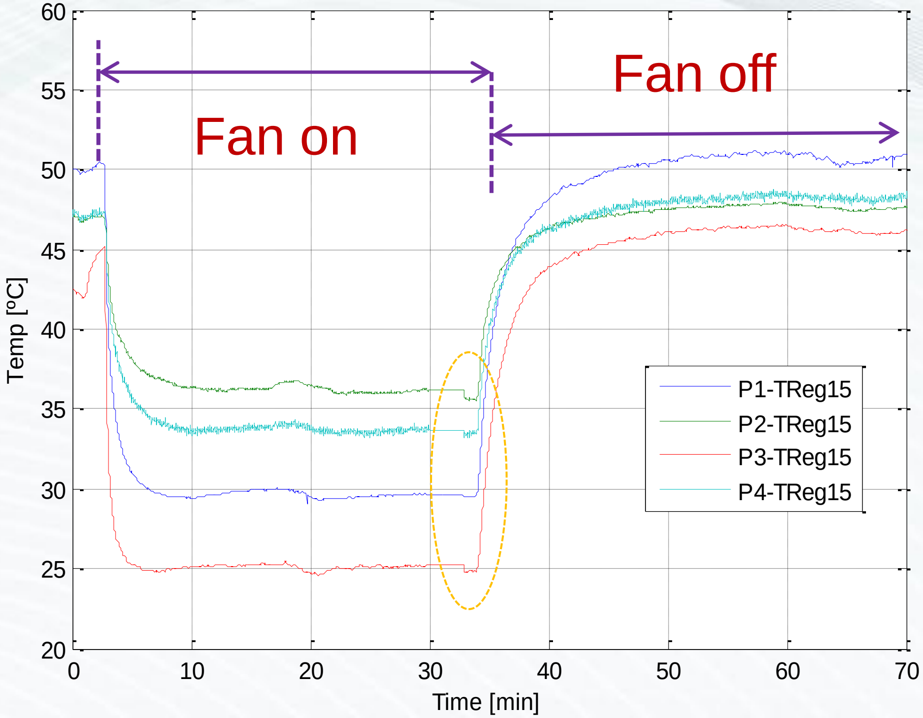
Major Fault – UPS capability

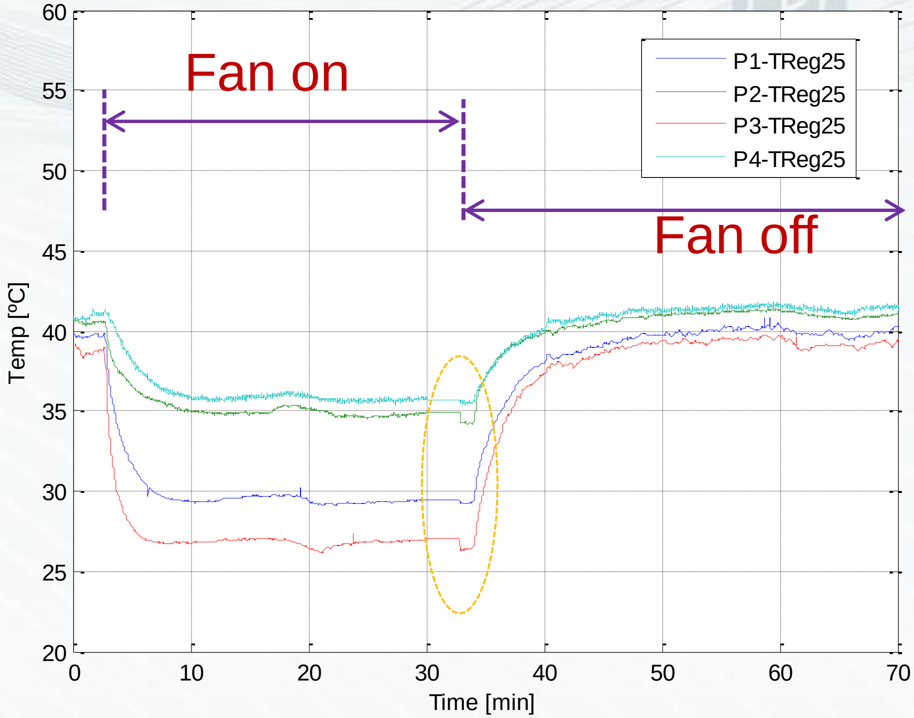
5.FTD +6 Group: Real prototype

- A very simple temperature test has been performed
- Temperature sensors were installed on each board:
  - One Termistor (PTC) per LV regulator
  - Temperature is processed by the control board
- A fan has been installed on one side of the CF structure
  - It has been switched on /off
- Systems were running more than 3 hours
- Baseline Temperature : 21ºC



5.FTD +6 Group: Real prototype





- LVReg (1.5V) dissipates more power than LV (2.5V)
- From the point of view of electronics, “this prototype” does not need to be cooled (resistances dissipate power too)
  - Not Cooled: Tmax(P1)≈51ºC (ΔT ≈ 30ºC) / Tmin(P3)≈ 46ºC (ΔT ≈ 25ºC)
  - Cooled: Tmax(P2)≈34ºC (ΔT ≈ 13ºC) / Tmin(P3)≈ 25ºC (ΔT ≈ 4ºC)
- Pulsing effect is very small from the point of view temperature

6. Conclusions

- A general overview of the supercapacitor based power supply distribution system for FTD has been presented
- Main characteristics and key elements have been shown
  - Operation condition (regulation , pulsing , supercapacitors..)
- Supercapacitors fit quite well power pulsing requirements
  - Radiation hardness shows no stoppers
    - It still requires a detail analysis
- A real prototype of 1 group has been developed and tested
  - Very good agreement with simulations
- Power dissipation aspects :
  - From electronics point of view, this system does not need to be cooled
  - The pulsing effect seems not to have a big impact
- The results are very promising but a long study of the system is required in order to define final specification