Accelerator Division

Full Characterization at Low Temperature of Piezoelectric Actuators Used for SRF Cavities Active Tuning

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- **In the frame of the CARE project activities supported by EU, IPN Orsay participate to the development of fast cold tuning system for Superconducting RF cavities operating at a temperature T=2 K. The study is aimed at characterization of piezoelectric actuators at low temperature. A new experimental facility was developed for testing various prototypes piezoelectric actuators and successfully operated for T in the range 1.8 K-300 K. Different parameters were investigated: piezoelectric actuator displacement vs. applied voltage V and T, capacitance vs. T, dielectric properties vs. T, thermal properties, and finally heating due to dielectric losses vs. modulating voltage and frequency as function of T. The experimental data show that the full range displacement of the actuator decreases with T reaching a value between 1.8 µm and 4 µm depending on both material and fabrication process of the piezo-element. Note that both these parameters (material and process) have a strong influence on displacement vs. T dependence. Moreover, the variations of losses tangent with temperature show a maximum at a T in the range 30 K-120 K. Finally a dedicated facility located at CERI (Orléans, France) for radiation hardness tests of piezo-element with fast neutrons at liquid helium temperature (T=4.2 K) was developed and successfully operated: beam tests were performed with PICMA and NOLIAC type actuators and the corresponding results are reported.**

Topics

- **Full characterization at low temperature**

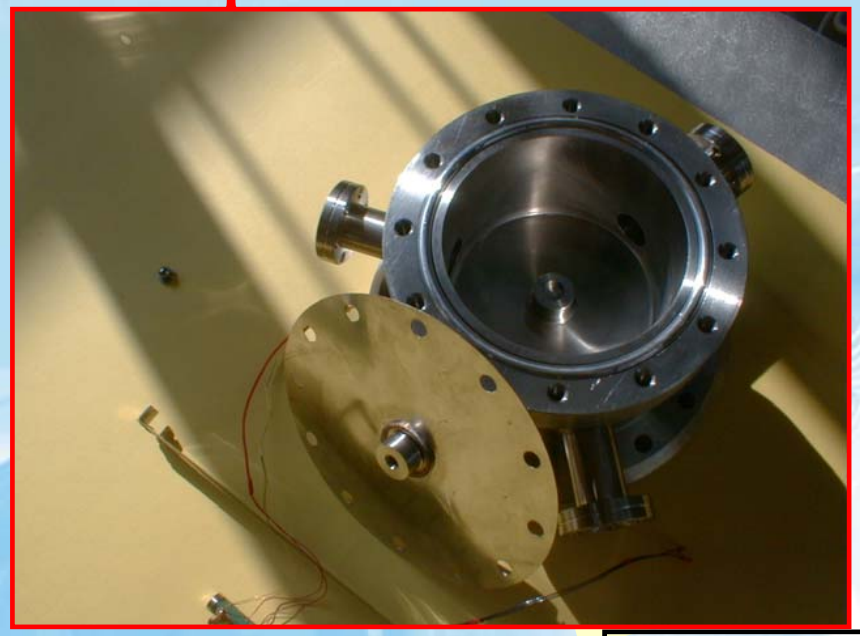
-Experimental setup

-Previous results with Piezosystem JENA actuators

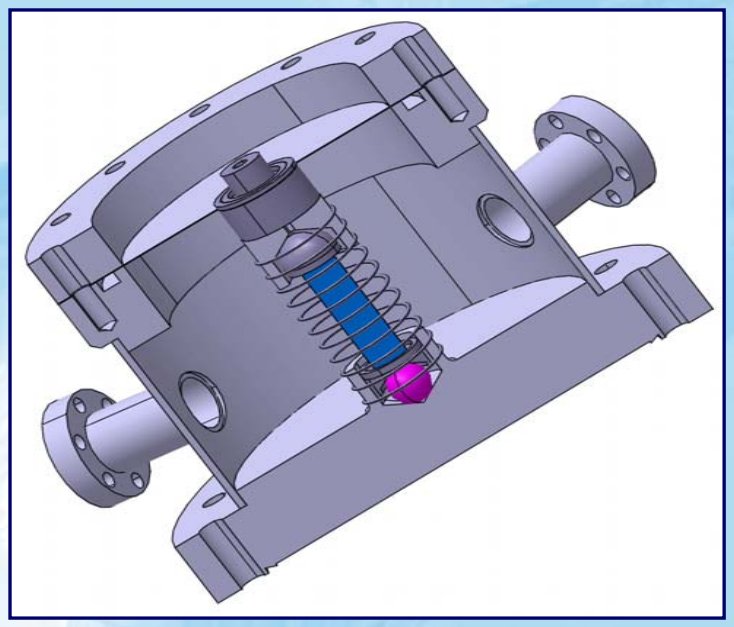
-Results with Physik Instrument PICMA actuators and NOLIAC actuators

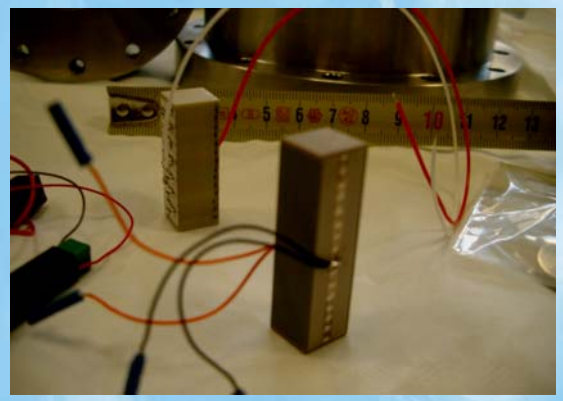
- **Low temperature radiation hardness test results**
- **Experimental program at IPN Orsay**
- **Conclusion and outlook**

Experimental setup



Test chamber

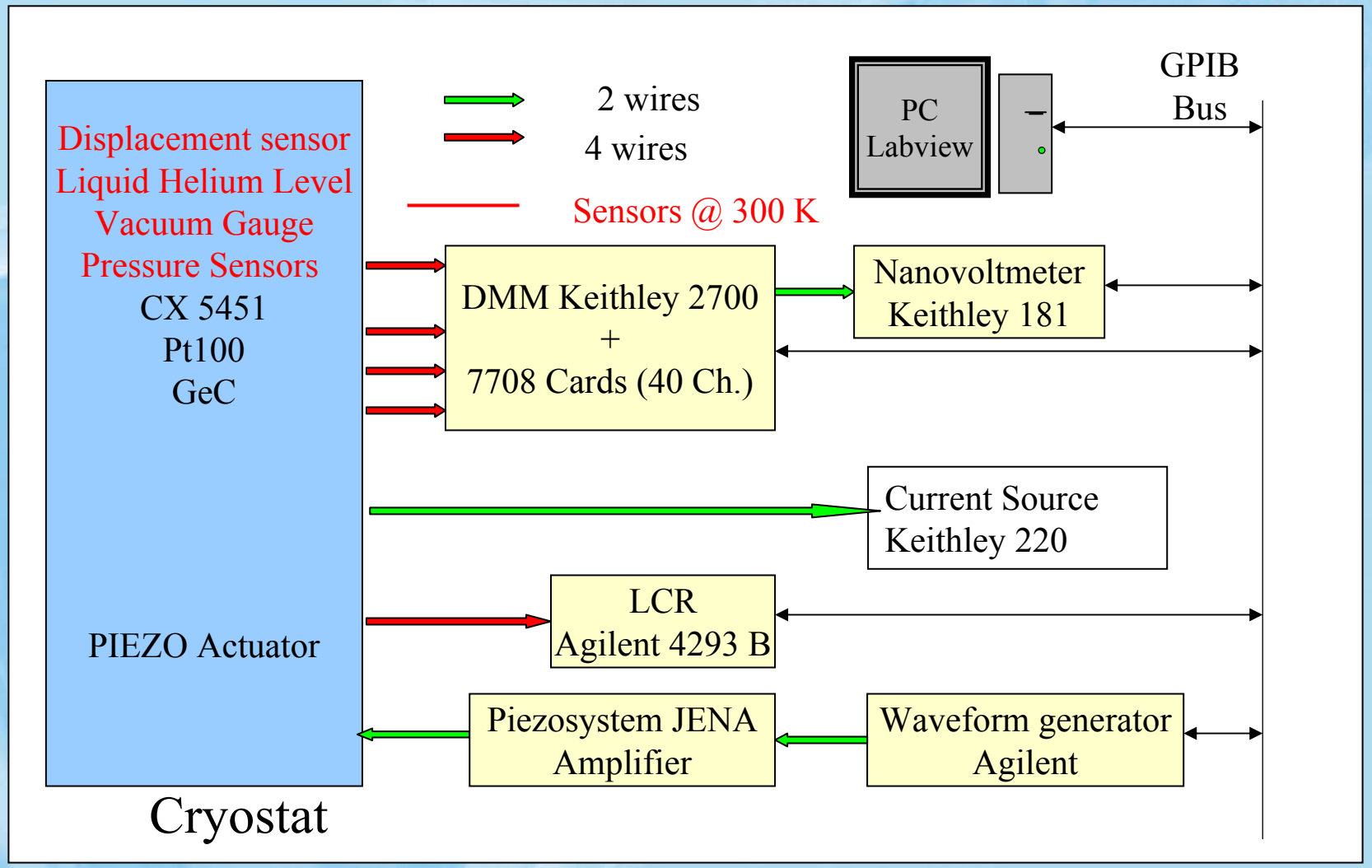




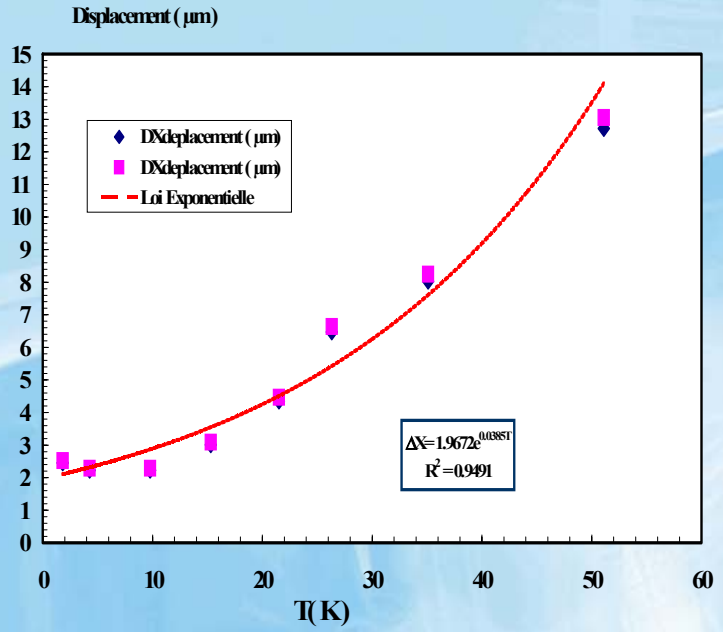
Actuators

- **FEATURES**
- Temperature range : 1.8 K – 300 K
- Calibration: Displacement versus Piezo Voltage
- Electrical properties : Cp, Rp, Z, ϕ, tg(δ)
- Heating due to dielectric losses
- Thermal resistance, Specific heat

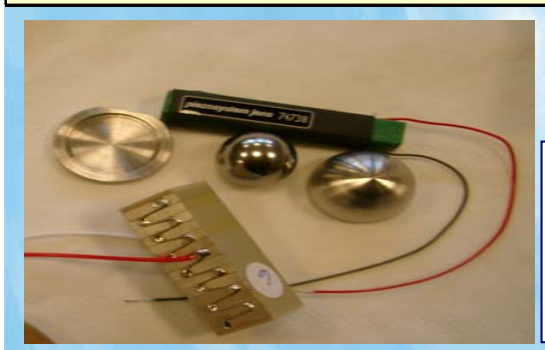
Data Acquisition system



Previous results for JENA actuators



FULL RANGE (V_{max}=150 V) DISPLACEMENT AT LOW TEMPERATURE FOR ACTUATOR #9221

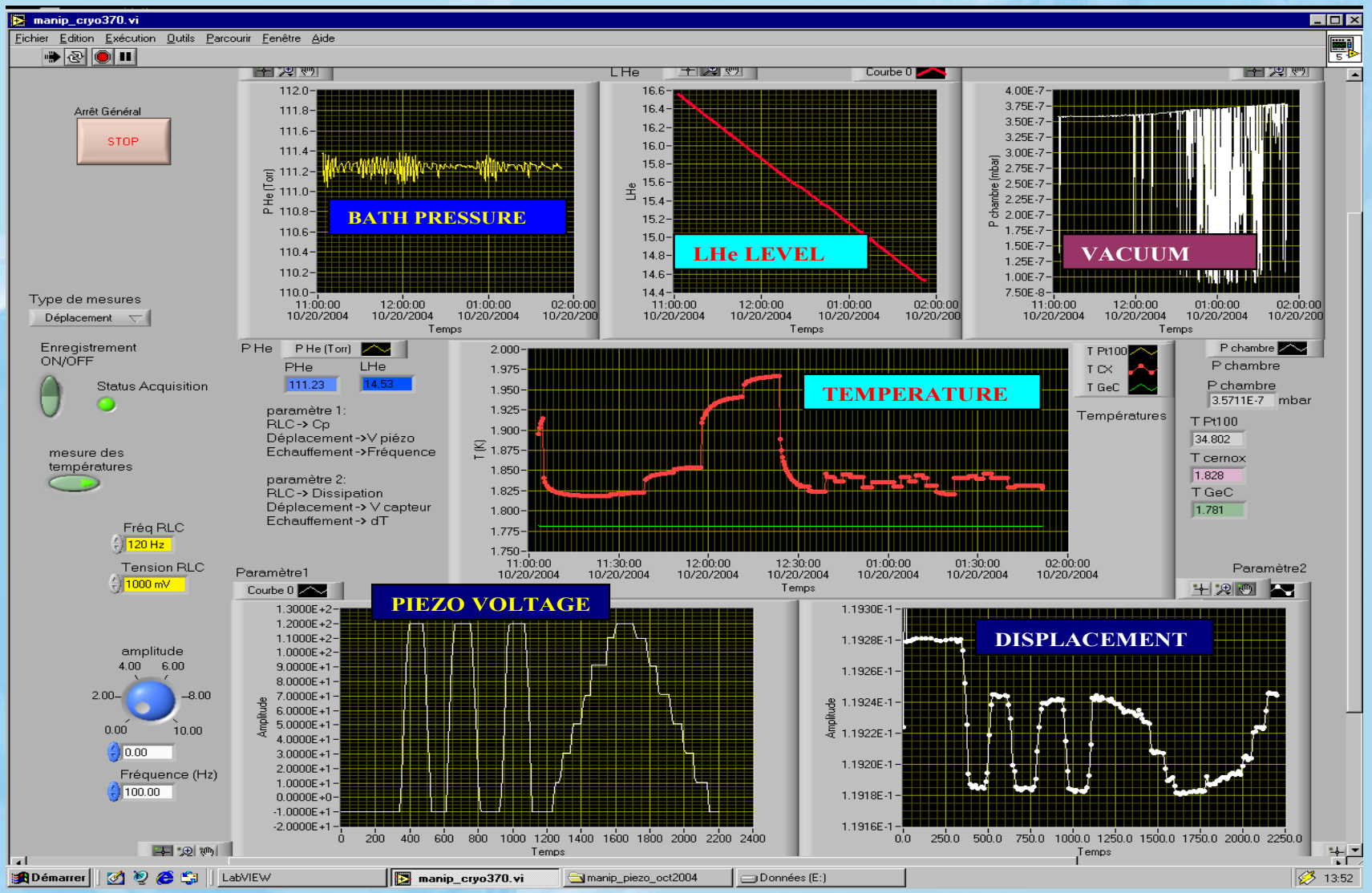


Several piezoelectric actuators from piezosystem JENA were investigated. These actuators were rejected because five main drawbacks and limitations:

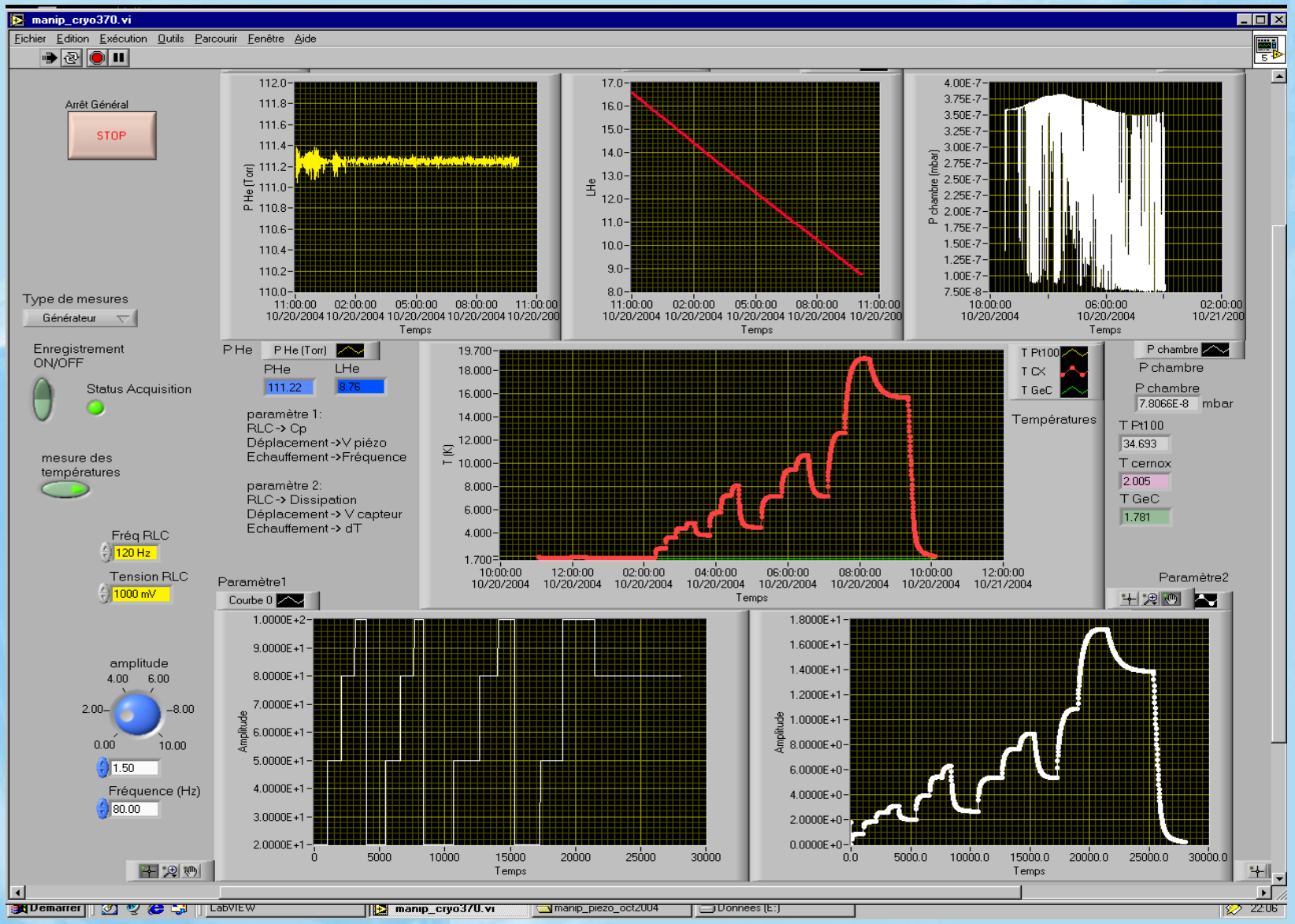
- Maximum **stroke less than 3 µm at 2K**
- Insufficient **blocking force ~1kN@300K**
- **Low mechanical stifness : 25N/µm**
- Fabrication **reproducibility from batch to batch**
- Very **short lifetime when operated at 2 K** (electrical breakdown and/or mechanical damages)

Other prototype actuators from two different companies (PI and NOLIAC) were tested.

LHe TEST#1: PIEZO PICMA #01 RUN OF 20/10/2004 (Tbath=1.83K)



LHe TEST#1: PIEZO PICMA #01 RUN OF 20/10/2004 (Tbath=2.005K)



PICMA actuators

Dimensions: 10 X 10 X 36 mm

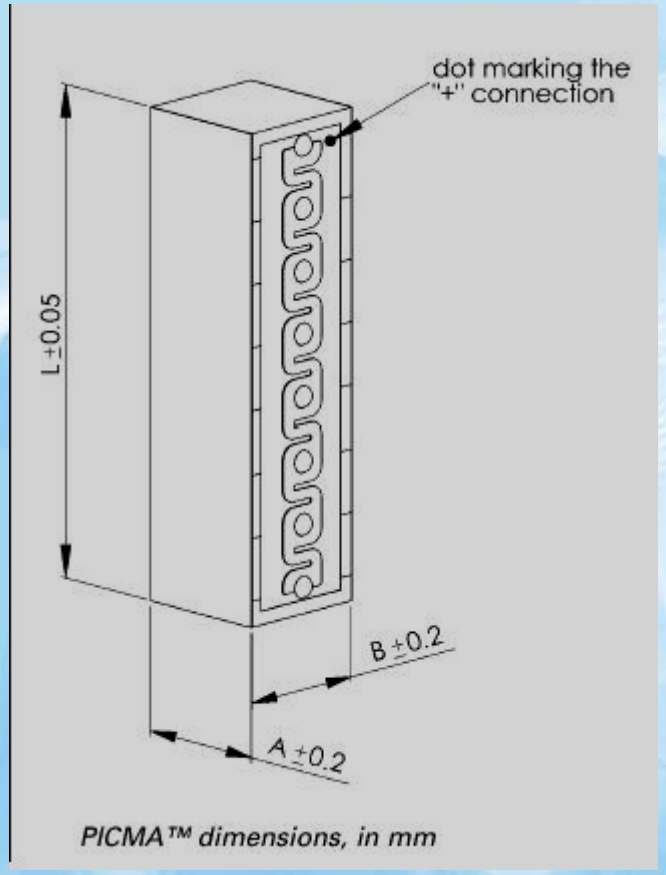
Max. displacement : 38 µm @ 120V (10%)

Electrical capacitance : 12.4 µF

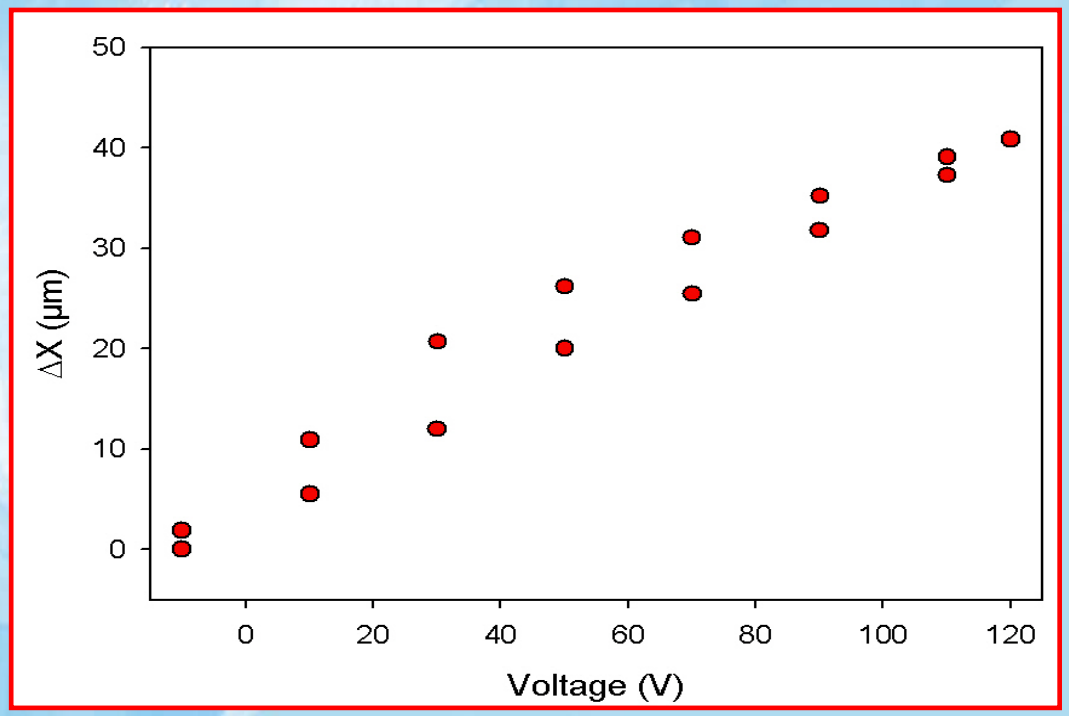
Blocking force : **3600 N @ 120V**

Stiffness : **105 N/µm**

Resonant frequency : 40 kHz

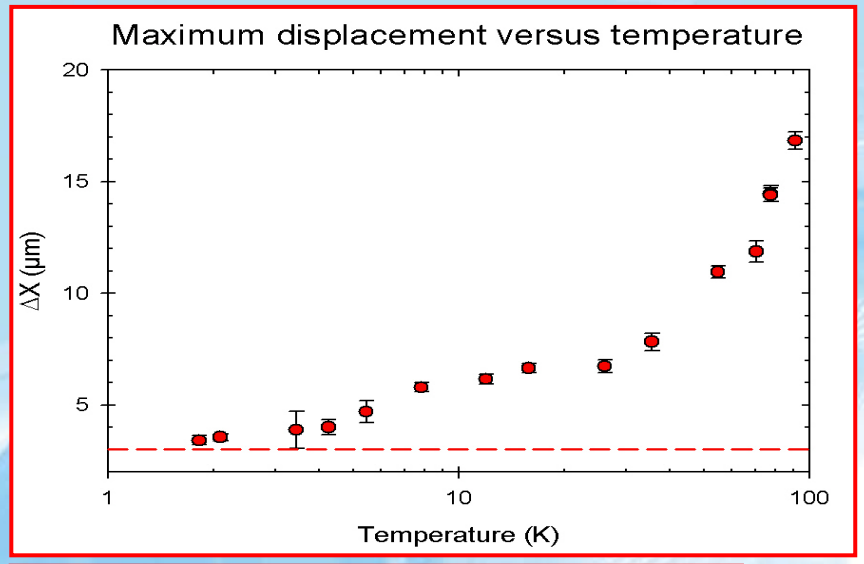


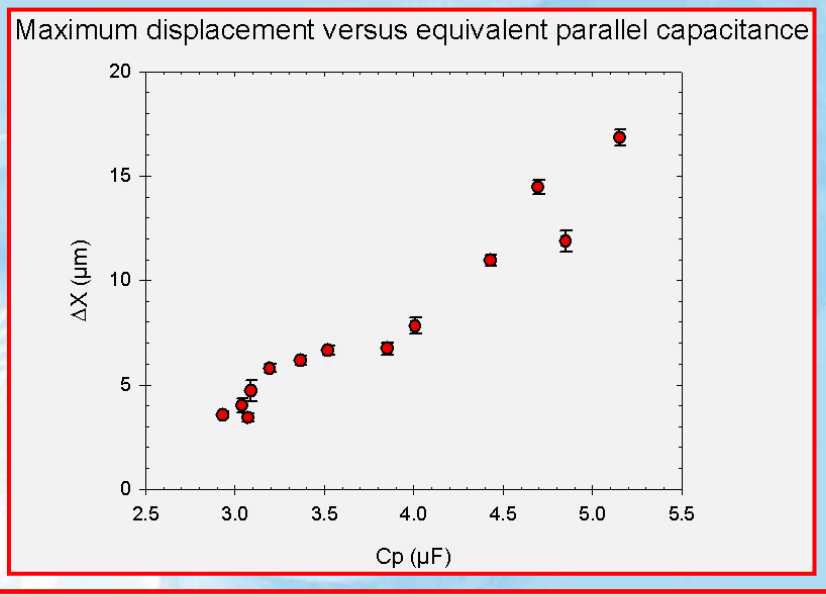
PICMA™ dimensions, in mm

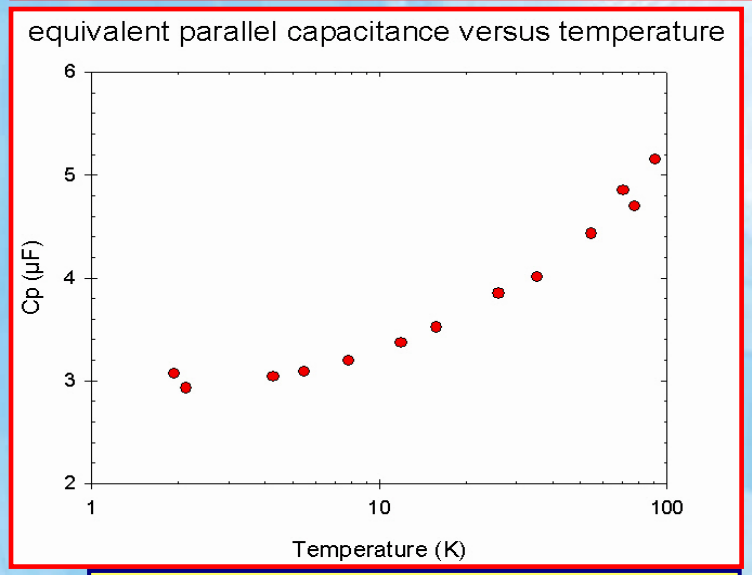


Calibration results of a PICMA actuator @300 K

First test results for PICMA#01 actuator



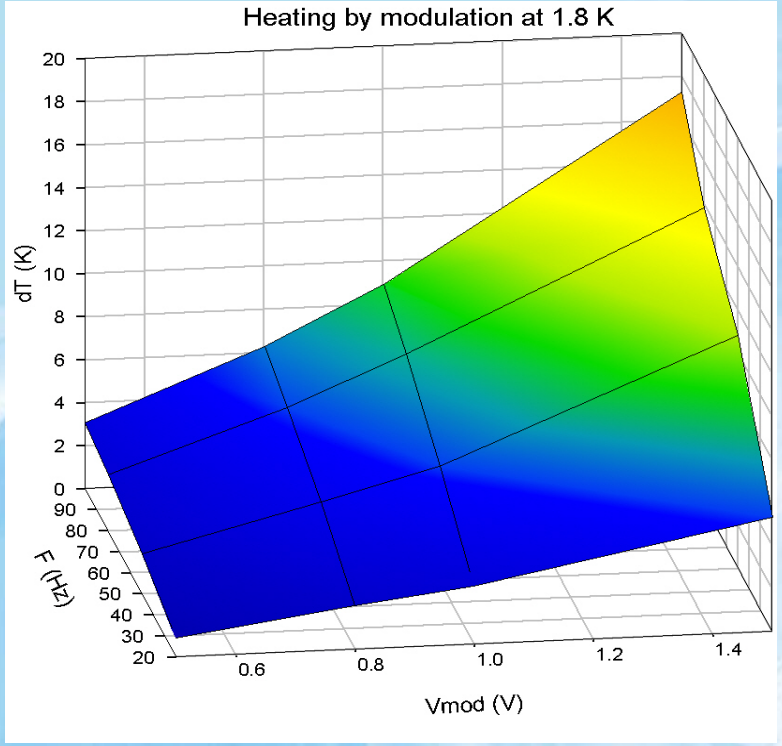




Promising results!

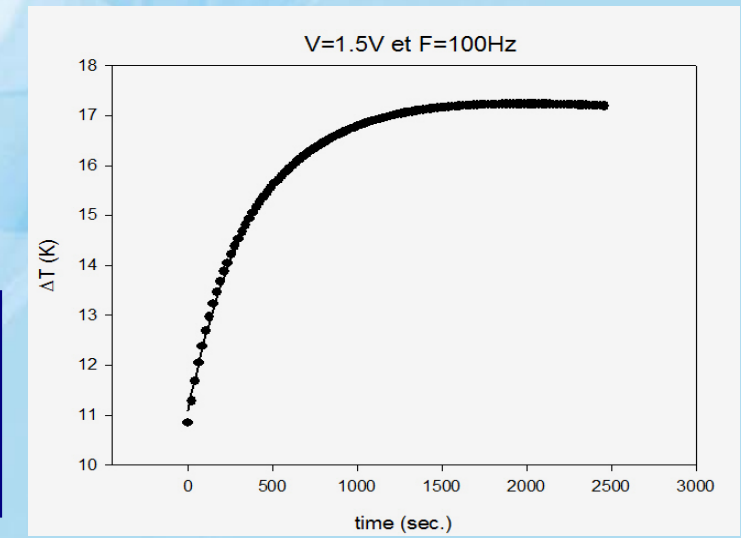
1) Maximum displacement at 1.8 K > 3µm
Actuators suited for TESLA cavity Lorentz detuning compensation (~1kHz)
2) No electrical breakdown and no damage observed during the tests
Life time
3) Strong correlation between capacitance and maximum displacement
A simple mean for calibration of a large number of actuators

Heating due to Dielectric losses at 1.8K



Thermal time constant of the actuator τ and specific heat C0 are easily deduced from heating (DT) versus time while the piezo is subjected to a modulation voltage.

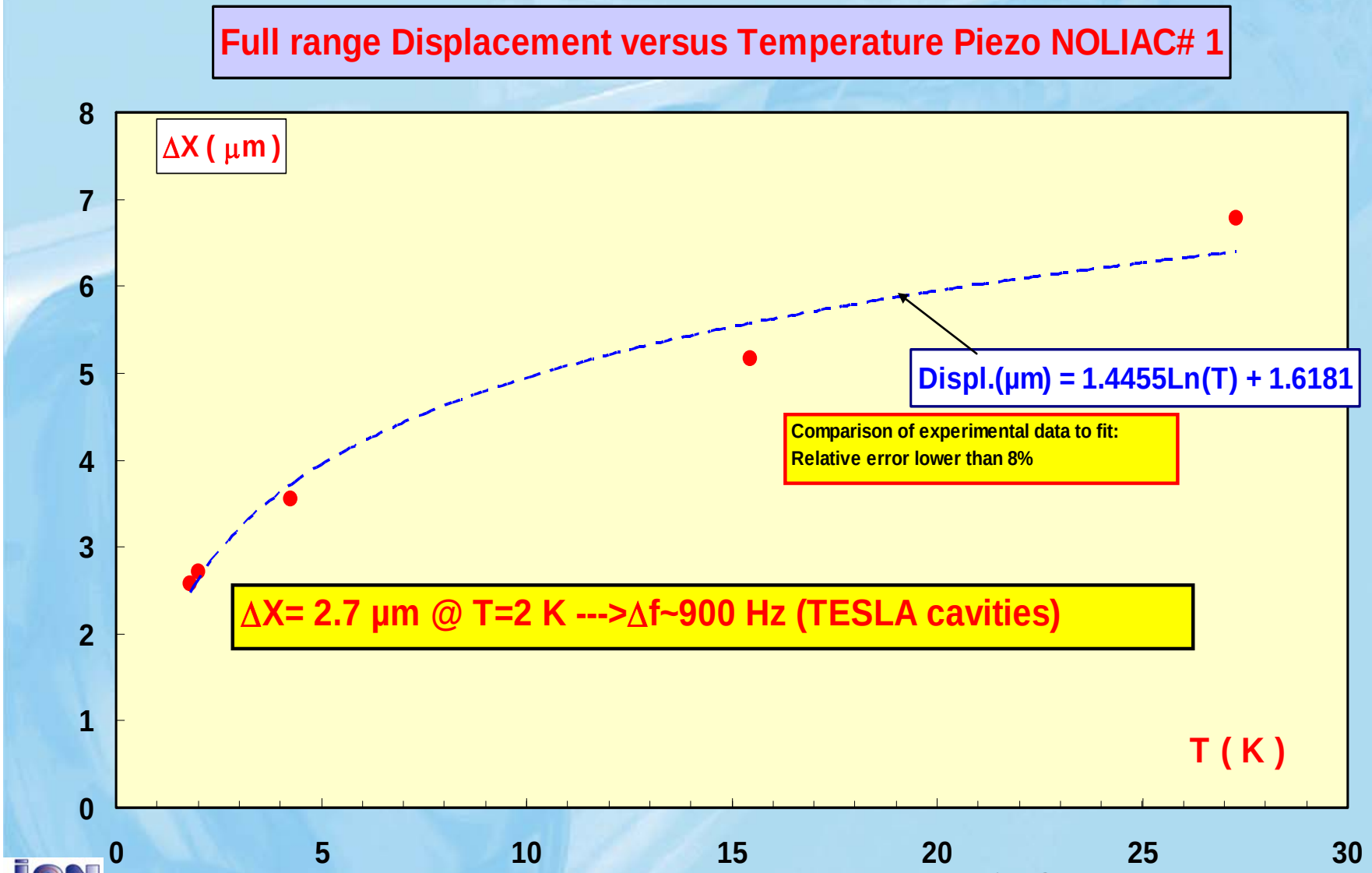
τ = 375.5 s.
mC0 = τ / Rth = 4.32 10-4 J/K
for a piezo mass m~20g,
C0~0.02 J/Kg.K

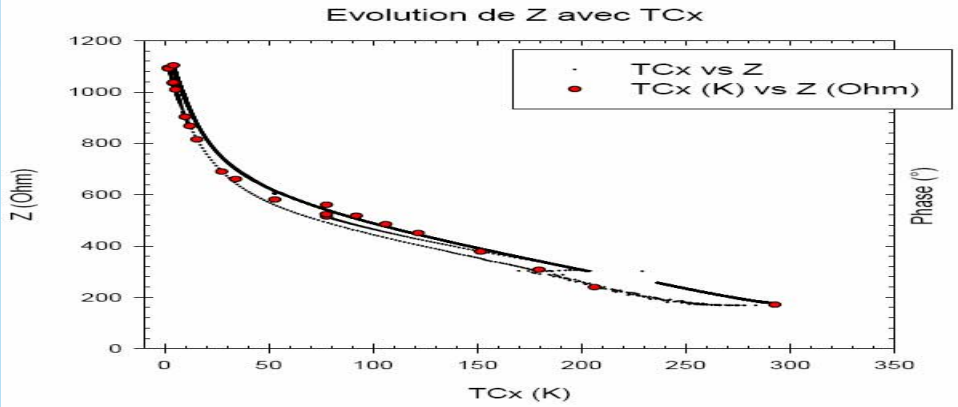


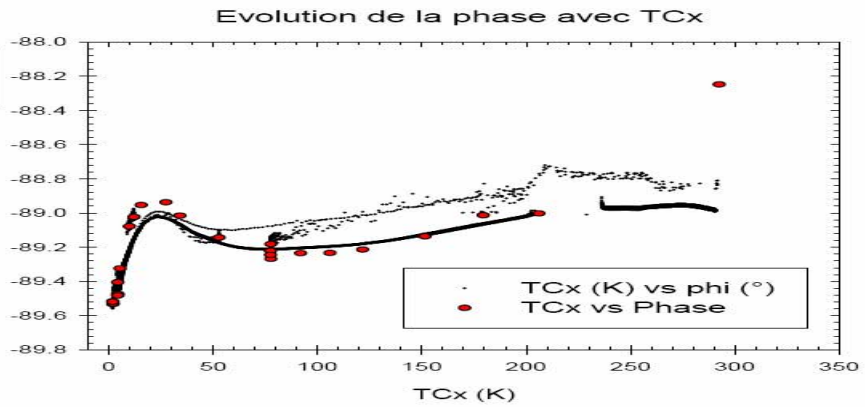
Dielectric losses : $P_d = \pi f C_p V^2 \sin(\delta)$
Thermal resistance : $R_{th} = \Delta T / P_d$

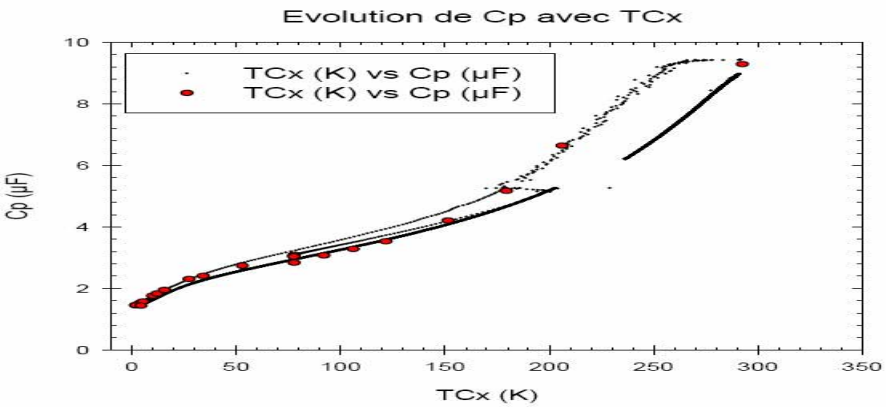
@f_{mod}=100Hz :
ΔV_{mod}=3V⇔ ΔX=167 nm ⇔ Δf_{cav}=68Hz
P_d=20µW ⇔ ΔT=17K => R_{th}~9.10^5 mK/mW

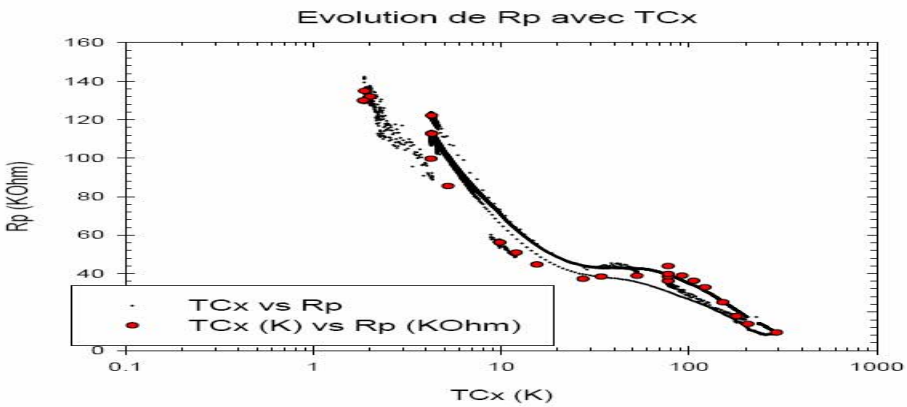
First test results for NOLIAC#01 actuator

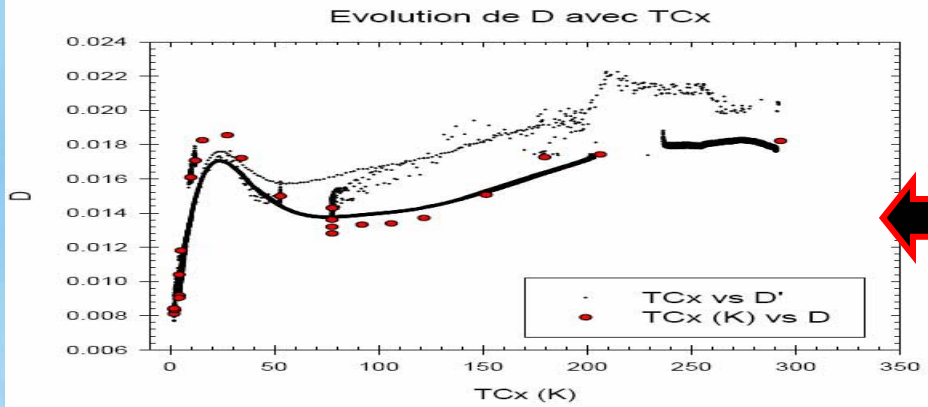












NOLIAC Actuators results

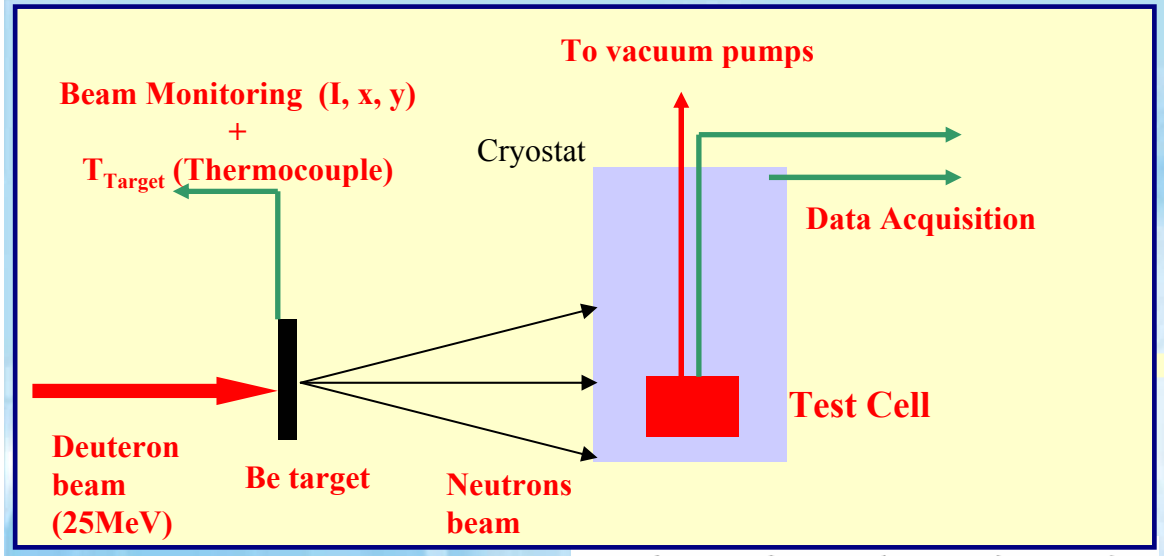
RADIATION HARDNESS EVALUATION PROGRAM AT LOW TEMPERATURE

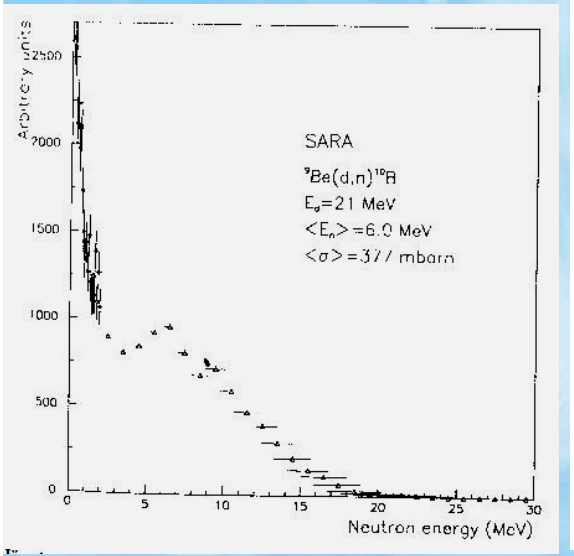
Main Goal : study the effect of fast neutrons radiations on the characteristics (performance, lifetime…) of different piezoelectric actuators at low temperature

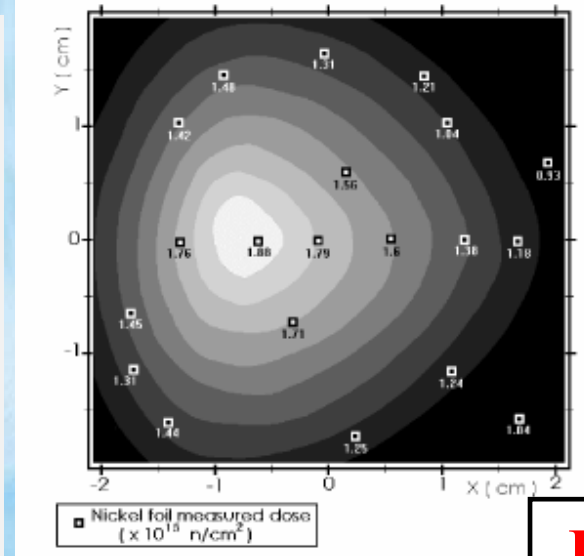
➔ Neutrons irradiation facility at the CERI cyclotron (Orléans)

- **Deuterons beam (25 MeV, up to 35 µA)**
  - ➔collide with a thin (thick. =3 mm) **Beryllium target,**
  - ➔Production of **a high neutrons flux with low γ dose (20%)**
  - ➔**Neutrons energy spectrum in the range** **1-15 MeV**
  - ➔The **total dose of 10^{15}n/cm^2** (10 years LHC operation) is achieved **in 20 hours of exposure.**
- Cryostat main dimensions **(I.D : 270 mm, Height : 600 mm)**
  - ➔ Could be operated either with Liquid helium or Liquid Argon
  - ➔ Minimum distance between neutron source and irradiated component :**80 mm**

Radiation Hardness tests : experimental setup

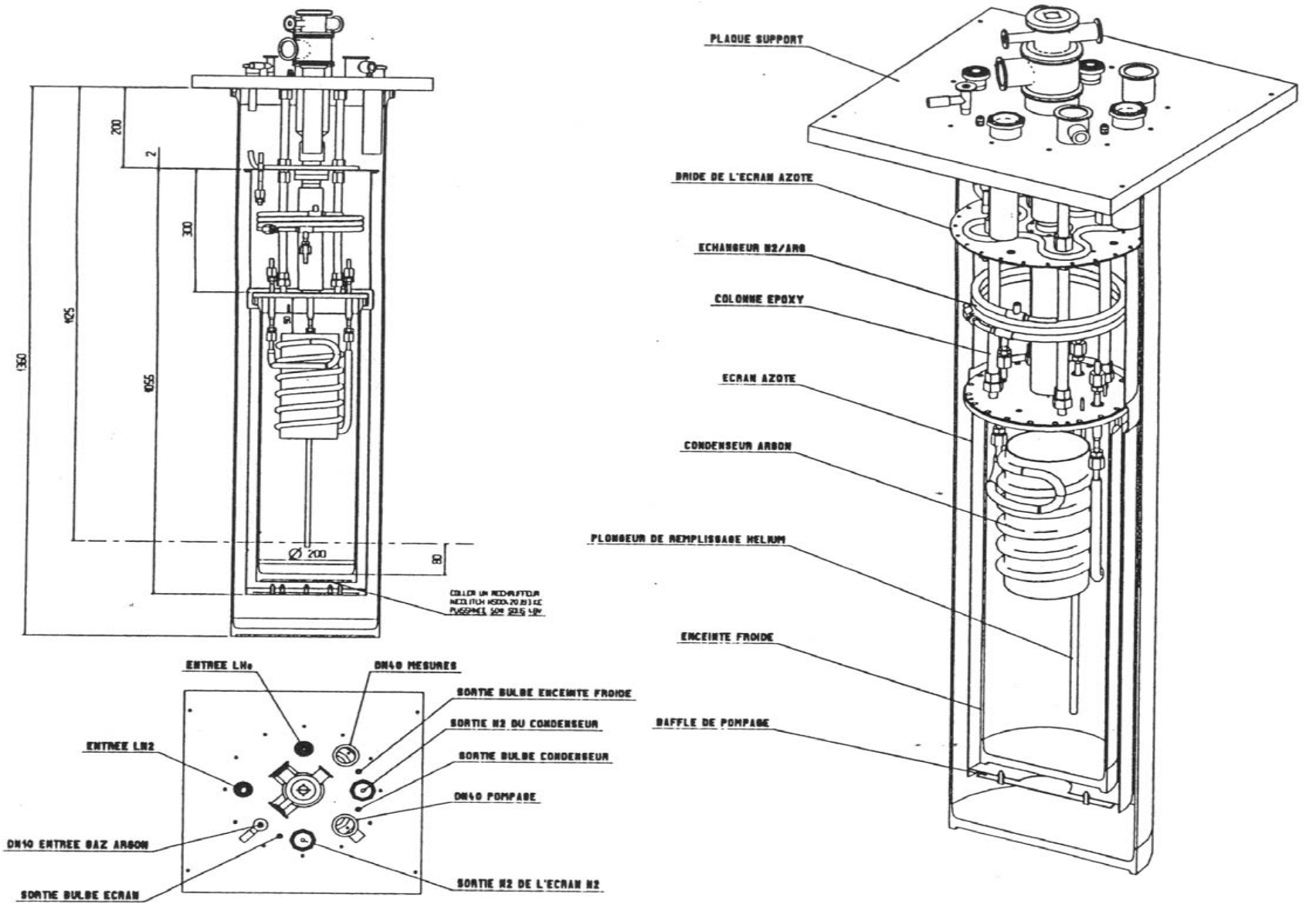




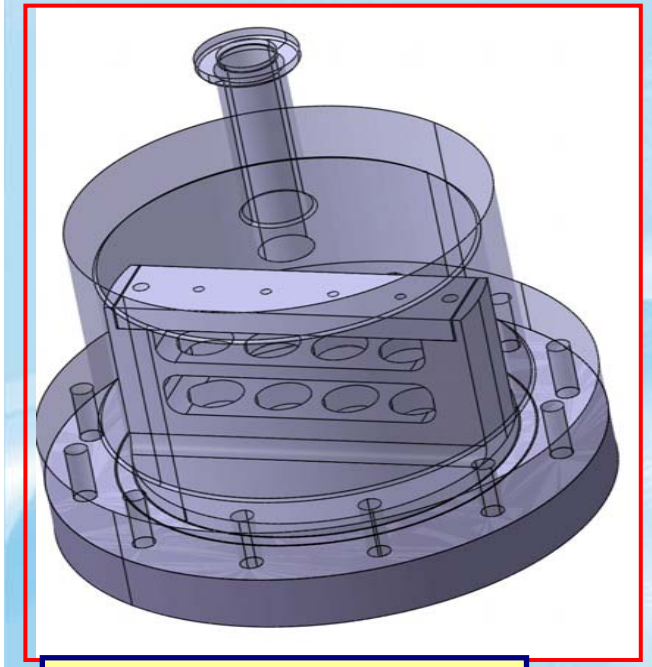


Be Target mounted on 14/02

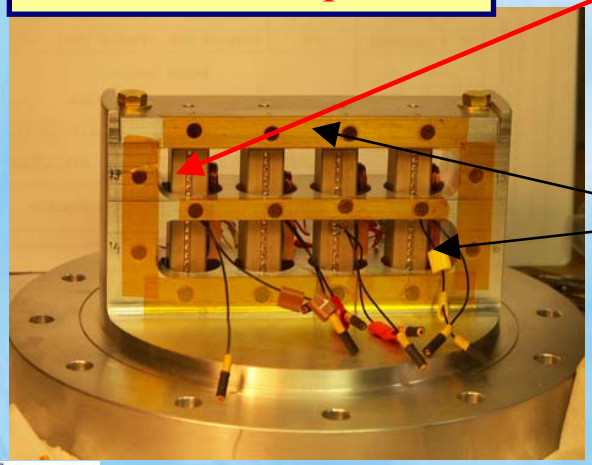
Fast neutrons irradiations cryostat



Fast Neutrons irradiations test-cell



Four PICMA piezos



Aluminium Chamber AU4G

-Main Dimensions :

Ø100 (Chamber)

Ø160 (Actuator supports)

Ø16 (Pumping line & Feedthrough)

-Tests of four actuators each run

-Fixture using Copper-Berryilium spring on actuator top

- Indium Foil sandwich : improve thermal contact
- Heater and thermal anchoring

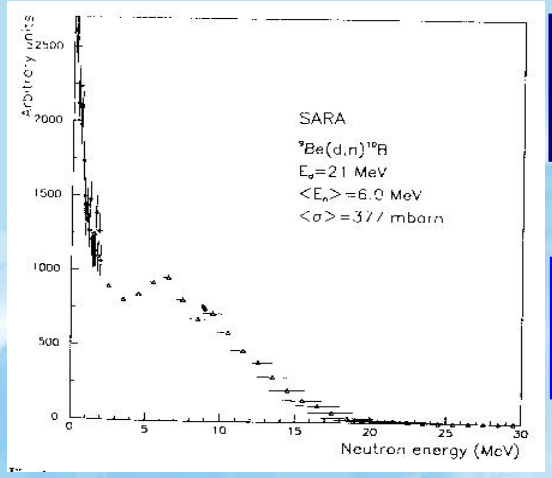
-Piezos Cooling time (300K→4.2 K : 16h) : improved

- Integrated dose measurements: via off line activation (γ spectroscopy) of high purity Ni foils (Disks:Φ4, 0.2 mmThick)

Two tests performed up to now

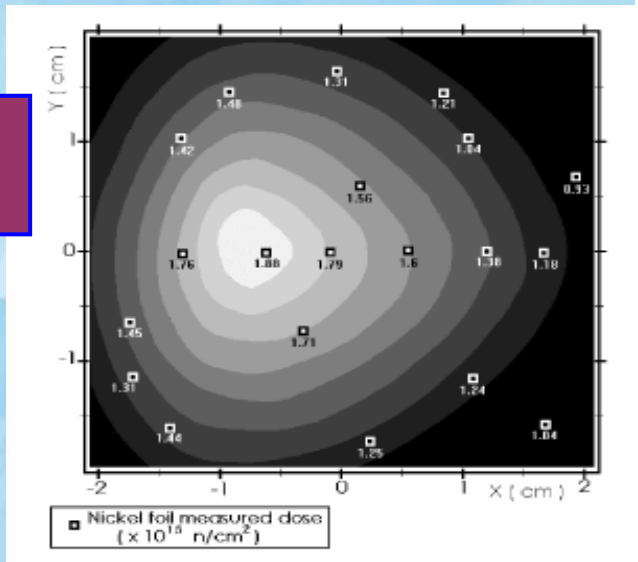
Neutrons Beam Characteristics

Available total Dose : up to 10^{15} n/cm²

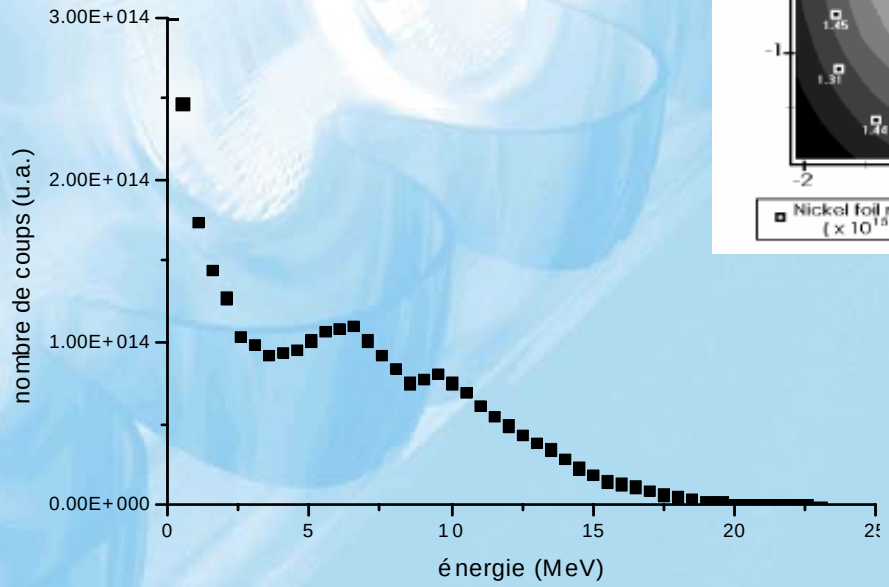


SARA : deuterons Beam, I=7µA
Total dose ~ 1-2.10^{15} n/cm² for 20h

CERI : faisceau deuton à 35 µA
Total Dose ~ 2-4.10^{15} n/cm² in 8h

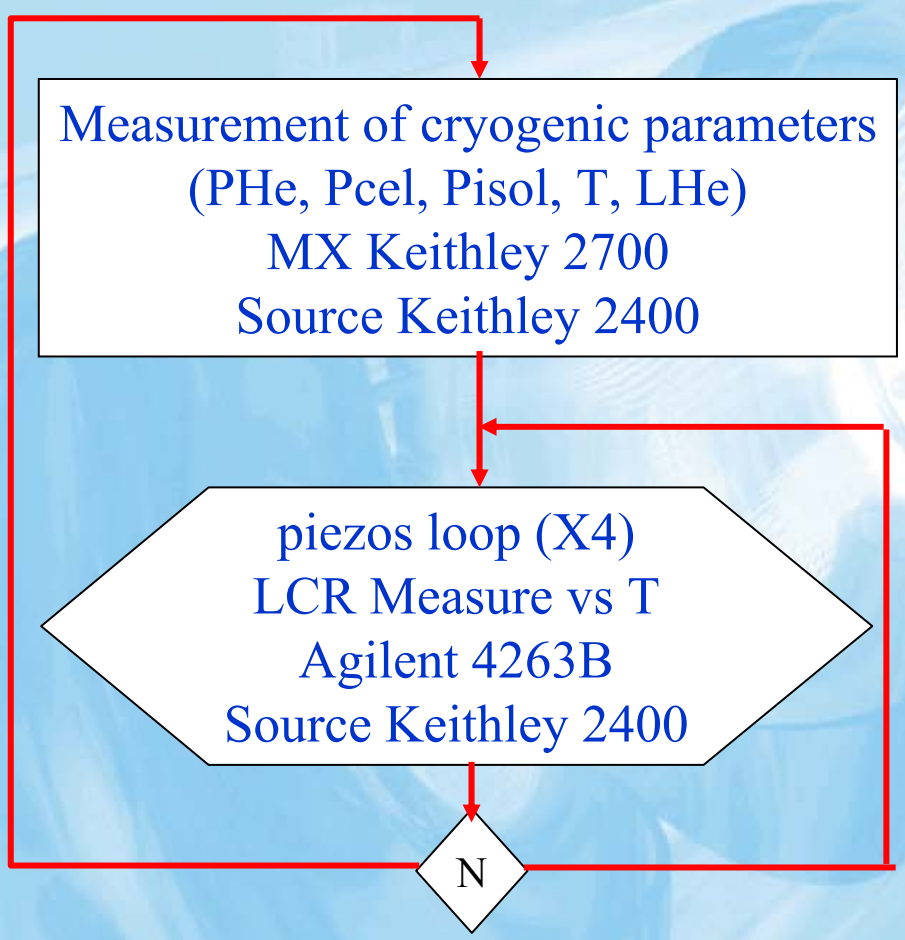


Expected Spectrum at CERI Facility



Data acquisition system

1 PC Labview (piezos and cryostat)
On line Measurements with Beam



1 PC Labwindow (Beam)

Beam Monitoring during irradiations:
4 'shovels' for X et Y
Beam intensity
Be Target Temperature

Planning of irradiations tests

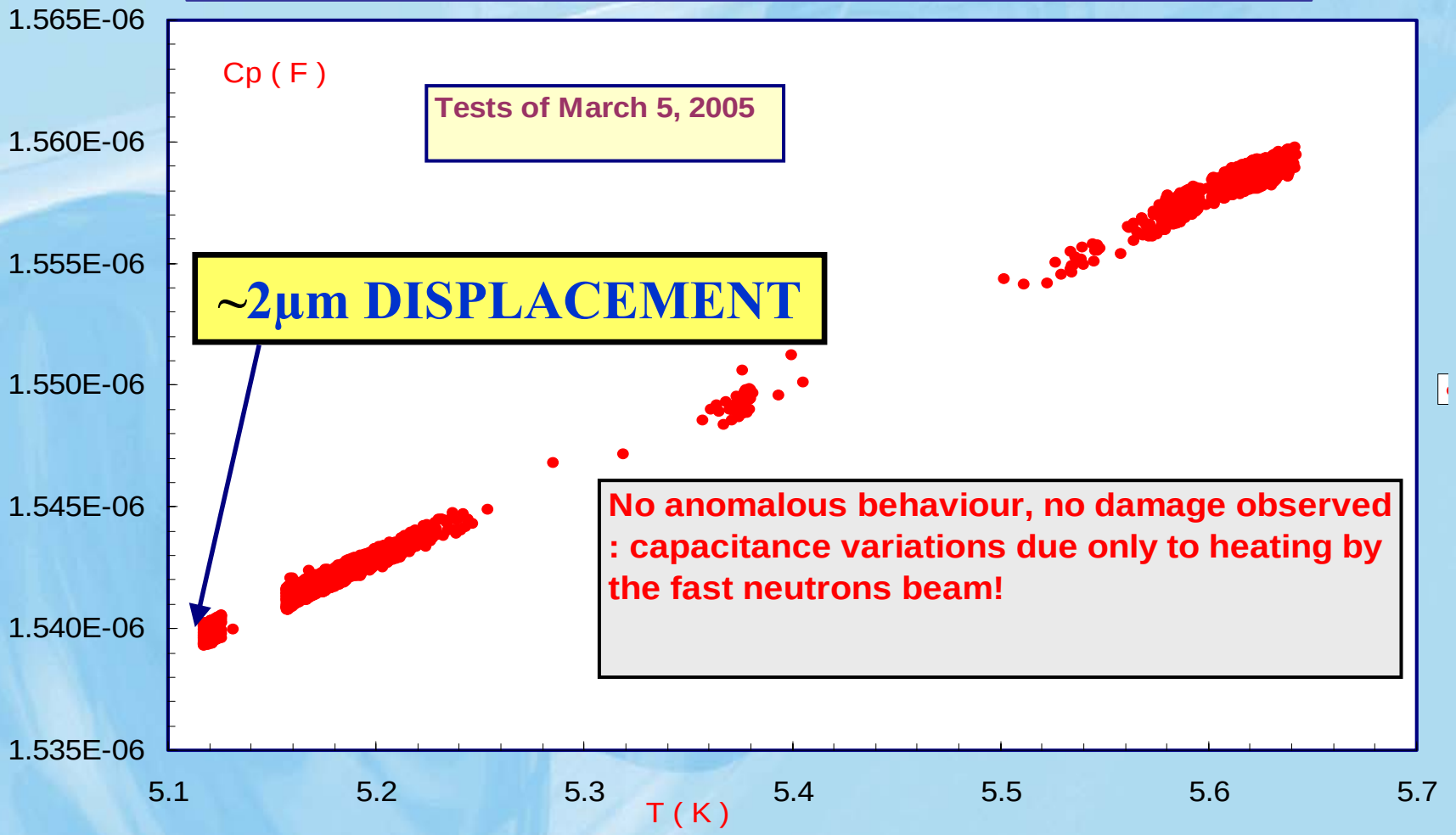
First irradiation on Week 7: four PICMA actuators
Cool down and Be target mounting: Monday and Tuesday
Beam ON (START) : Wednesday14h-22h, 10 µA.
Beam ON(FINISH) : Thirsday 14h-22h, 35 µA.

Wait two weeks before dismounting cryostat, test cell,….
Be TARGET activated!

Week 11, irradiation of Noliac
Similar schedule

Irradiation test results

Capacitance vs Temperature during Fast Neutrons Beam Tests - NOLIAC #2 Actuator



EXPERIMENTAL PROGRAM AT ORSAY

EXPERIMENT-TOPICS	MAIN GOAL
Characterization of different piezoelectric actuators at low temperature T in the range 1.8 K-300 K	Displacement vs Piezo Voltage @ different T Dielectric properties vs T (Capacitance, dielectric constant, loss tangent, dielectric losses) Thermal behaviour (Heating, heat capacity, thermal resistance, time constant)
Preparation of radiation hardness with fast neutrons at Liquid Helium (LHe, T=4.2 K) temperature experiment	Developpement and validation of experimental set-up and procedure without neutrons beam Set a reference test for piezoelectric actuator properties
Radiation hardness tests with fast neutrons at Liquid Helium LHe temperature	Characteristics of piezoelectric actuators as function of neutron fluence at LHe temperature
Measurement of the mechanical stiffness of piezoelectric actuators- Effect of preloading force on actuator properties- Validation test at room temperature	Determination of piezoeltric actuator stiffness Developpement of a method and procedure for adjusting and precise measurement of the preloading force using the actuator as sensor
Mechanical stiffness @ low temperature (LHe and LN2)	Displacement vs force at different temperature Capacitance vs force @ different temperatures Deformation vs force @ different temperatures
Resonance spectrum of piezoelectric actuator under various loading force at different temperature (RT, LN2, LHe)	Effect of the preloading force on the electro-mechanical properties of piezoelectric actuator @ different T

Resonance spectrum and mechanical stiffness experiments will be performed soon!

Conclusion and outlook

- 16 actuators prototypes (19 PICMA+6 NOLIAC) tested for acceptance @ 300 K
- Two piezos (1 PICMA+ 1 NOLIAC) fully characterized in the range 1.8 K – 300 K leading to promising results
- Piezo actuators as a sensor (Preloading) investigated at 300 K
- **Radiation hardness tests experiment with fast neutrons :**

  → two beam tests performed **(4 PICMA+ 4 NOLIAC) no damage observed (Heating due to beam only!)**

  →**Next test (last test ?) in two weeks**
- Gamma radiation should be investigated at Liquid helim temperature
- Calibration and Integration of actuators in CTS developed at Saclay will be studied in the next months

. **A facility for testing magnetostrictive tuner designed**