A new crystal bender for the ID31 Laue-Laue monochromator

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ESRF | The European Synchrotron

SUMMARY

- Introduction: The ID31 Beamline
- Specification of the bender
- Principle and design
- Analysis: Analytical
  FEA - mechanical model
  FEA - non linear thermo-mechanical model
- Prototype
- Commissioning (optical and X-ray)
- Conclusion

Preliminary questions

1 What will be the behavior of the crystal when I will put the white beam?

2 Which parasitic stresses will be inside the crystal, when I will bend it?

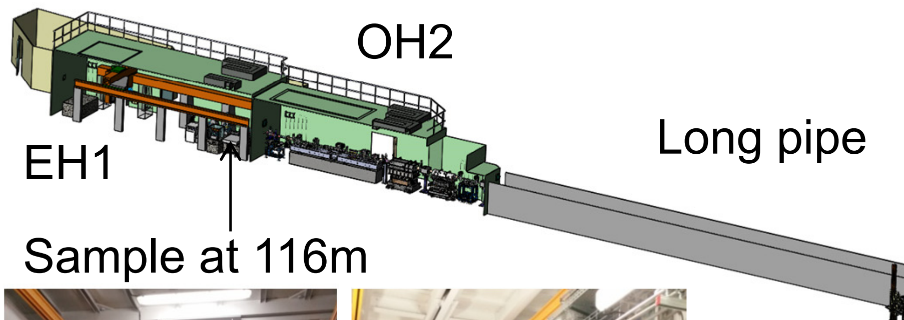
3 What is the parallelism between my surface and my crystalline planes?

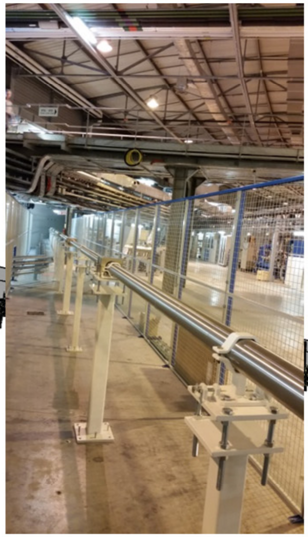
4 What will happen when I will clamp my crystal?

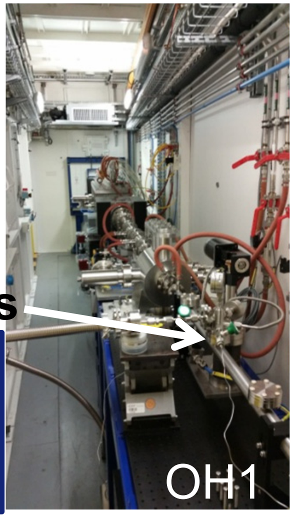
INTRODUCTION: THE ID31 BEAMLINE

Experimental techniques: tomography / reflectivity / SAXS / WAXS

Samples: fuel cells, solar cells, rechargeable batteries, catalytic materials...

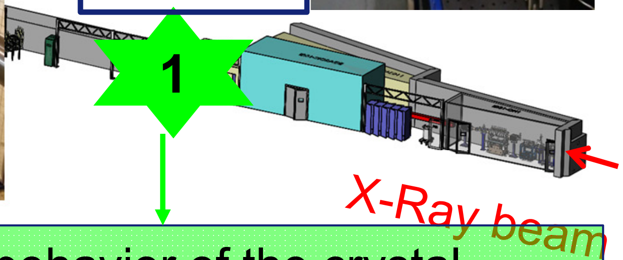




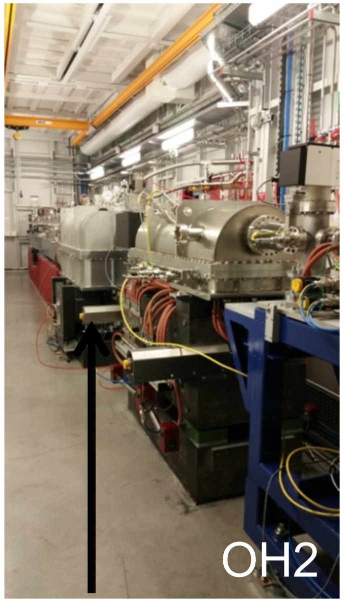


Absorbers

T_{si}=125K
$\varepsilon = 0$



1- What will be the behavior of the crystal when I will put the white beam?



Laue-Laue monochromator
At 105m from the source

The ID31 beamline:
X-Ray energies ranging from 20 to 150keV.
The energy range 50-150 keV is covered by a Laue-Laue monochromator located at 105 meters from the source.

The monochromator in short and bender specification

- The bandwidth is proportional to the inverse of the bending radius of the crystal.
The bending radius is given by the virtual source to crystal distance in the Rowland circle geometry
→ Convex and concave bending needed from ∞ to 20m.

- Non-dispersive diffraction geometry
→Crystal cut is oriented (refer to 100-010-001 planes) so that cross terms coefficients for the stress matrix are zero.
→ two Si(111) crystals with asymmetric cut of 36°

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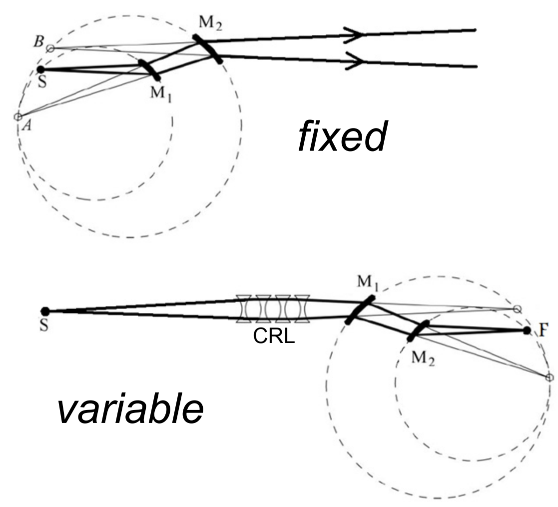
- High heat load
→ N2 cryo-cooled
→ High vacuum: 10^{-8}mBar

- The resolution in energy has to be 1ev
→ resolution of the piezo-jacks: 20nm
→ very high stiffness



"Rowland circle geometry"

2 Which parasitic stresses will be inside the crystal, when I will bend it?

BENDING PRINCIPLE

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"cylindrical bending with stiff mounting allowing LN_2-cooling"

$$AB_{crystal} = 2R\sin\alpha \approx L - \frac{L^3}{4!\,R^2} + O\left(L^5\right)$$

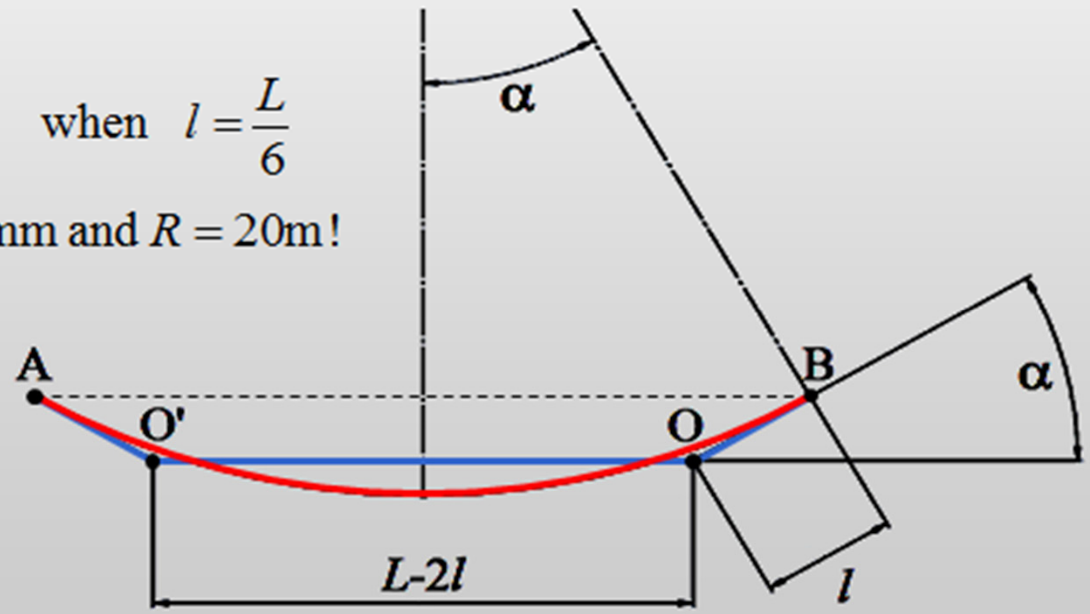
$$AB_{bender} = L - 2l + 2l\cos\alpha \approx L - l\,\frac{L^2}{4R^2} + l\,O\left(L^4\right)$$

$$\left|AB_{crystal} - AB_{bender}\right| \approx \frac{L^5}{6!\,4R^4}, \quad \text{when} \quad l = \frac{L}{6}$$

which is $\underline{\sim 50\text{fm}}$ for $L = 120\text{mm}$ and $R = 20\text{m}$!

Si crystal

Bender



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UPBL2 – TDR – 27th May 2013

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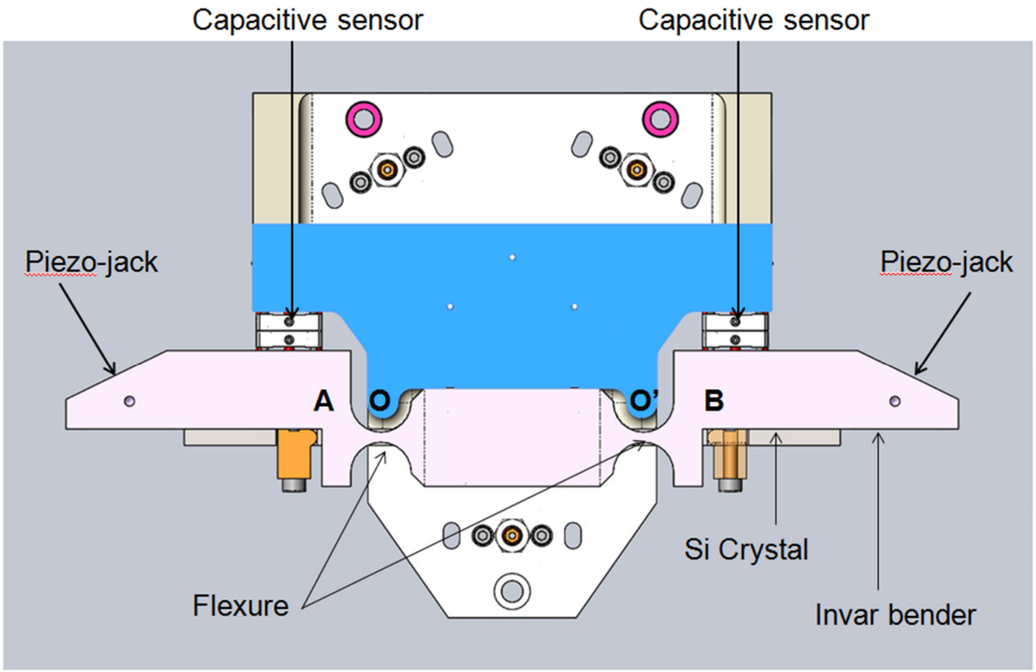
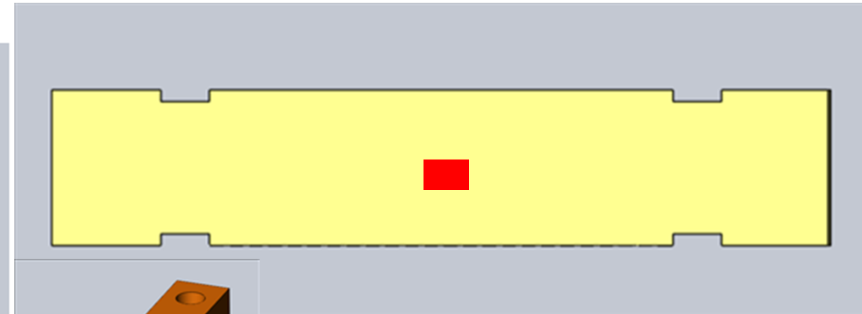
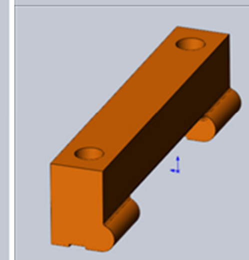
BENDER DESIGN

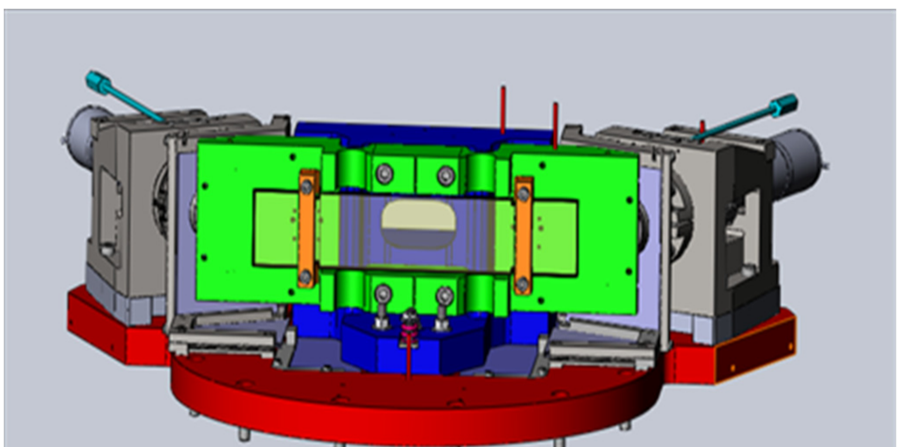


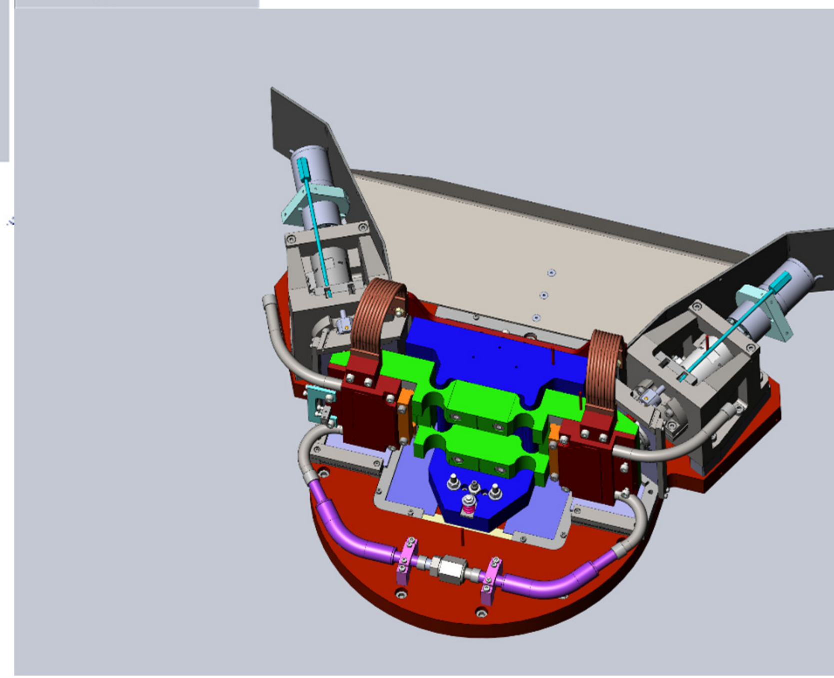




Beam size max: $4x6mm^2$

OO'= L-2l=80mm; AB=L=120mm ➔ l=(120-80)/2=20mm = L/6

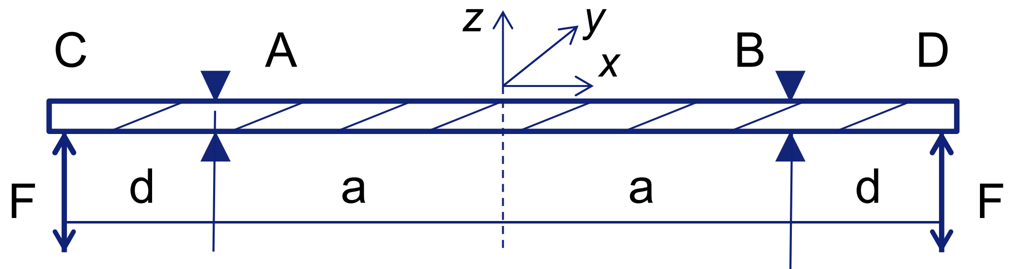




ANALYTICAL APPROACH

Hypothesis

- Mechanical beam theory approximation formula (1)
- The weight is negligible because the crystal is vertical.
- The forces F [N] applied by the two jacks are equal.
- The anticlastic effect is not considered here
- (x,y) origin is taken at the middle of the crystal
- *u(x=0)= 0*



Axis of symmetry

$$\frac{d^2u}{dx^2} = \frac{M(x)}{EI} \qquad (1)$$

With : E Young modulus of Si [N/m²]
I the inertia of the beam = constant=$bh^3/12$ [m⁴]
b: width of the crystal, h: thickness
M(x): local bending moment [N.m]

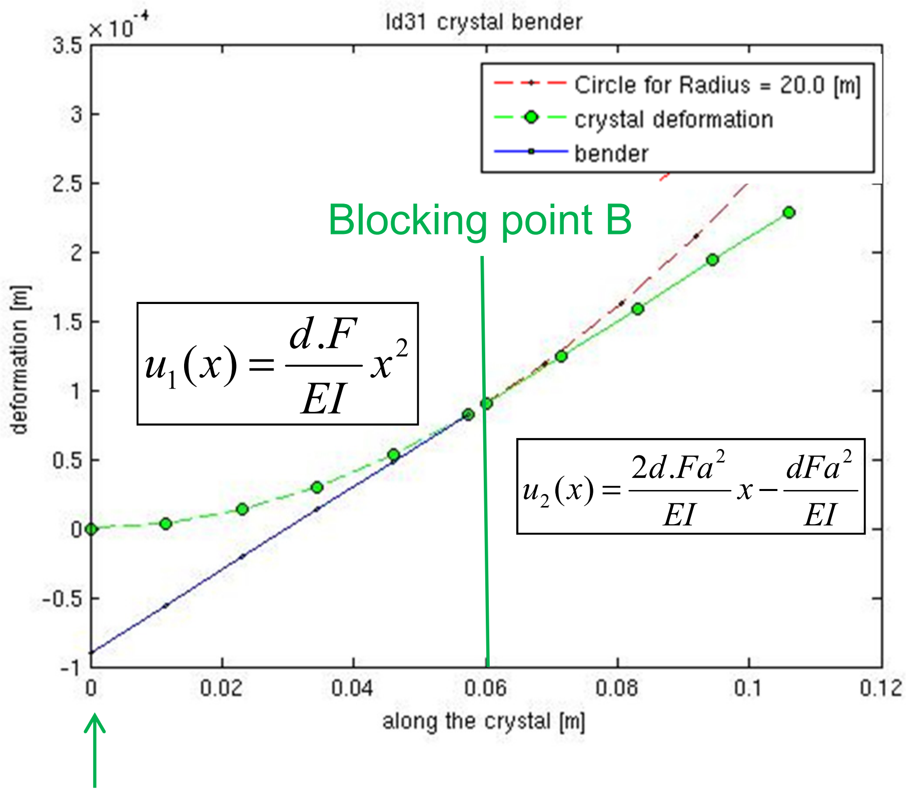
Deflection $u_1(x)$ of the crystal between the fixing points A and B and $u_2(x)$ beyond A,B

$$u_1(x) = \frac{d.F}{EI}x^2 \qquad u_2(x) = \frac{2d.Fa^2}{EI}x - \frac{dFa^2}{EI} \qquad (2)$$

ANALITYCAL APPROACH

Example of deflection calculation on half of the crystal using Matlab.

For a given expected radius, the program gives the displacement to be requested to the jacks. Reference of all the values are position “flat” of the crystal.

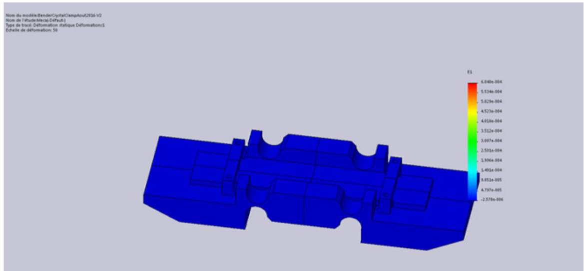


Middle of the crystal

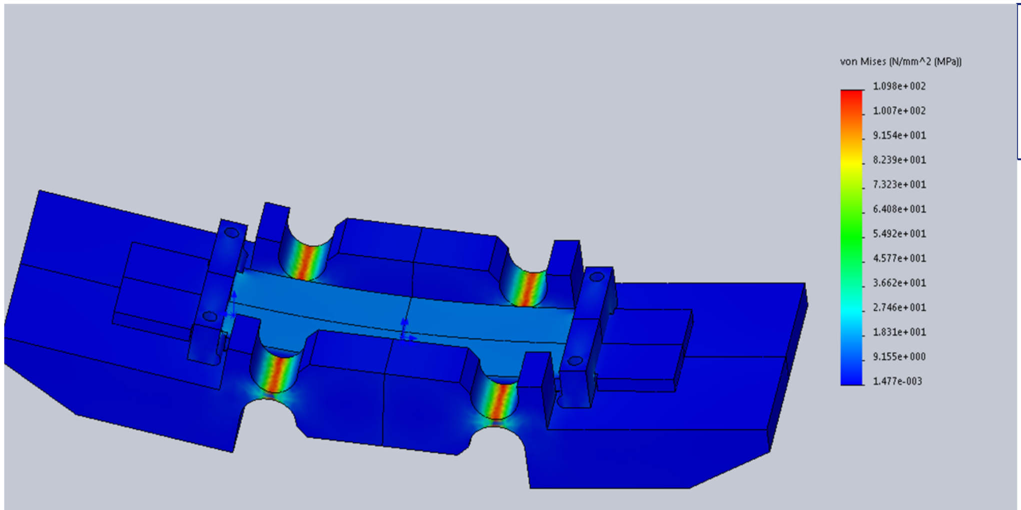
```
>> Bender_en_x2

Enter the required radius value in [m]: R=20

Displacement (0 for flat crystal) to be requested to
the jack [m]= 283.71e-06
```

FEA - MECHANICAL MODELISATION – MOTION OF THE SYSTEM

Maximum stress in the flexure: 110MPa
(Invar limit: 450MPa)
Pushing force for one jack: 140N (jackMax:240N)



Video: motion of the system



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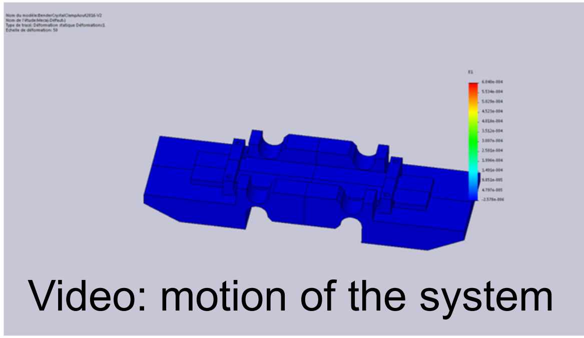

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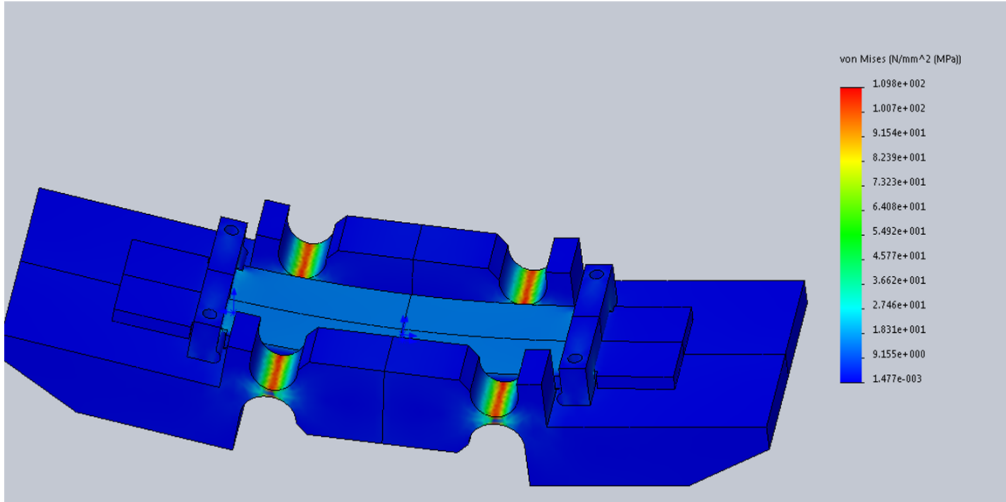

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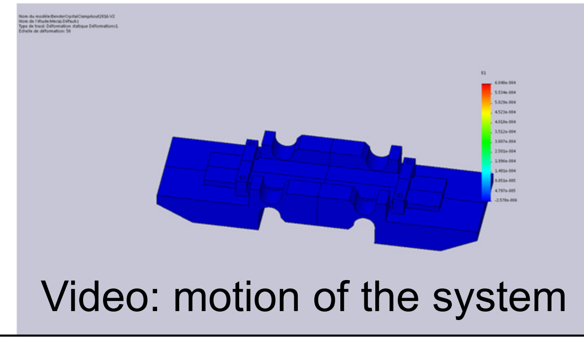

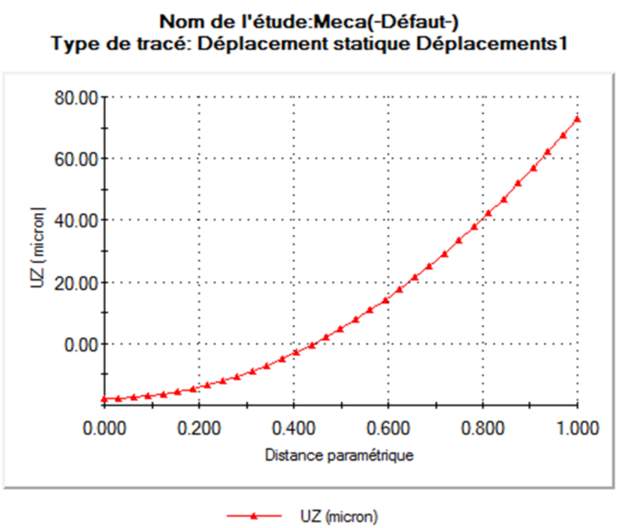

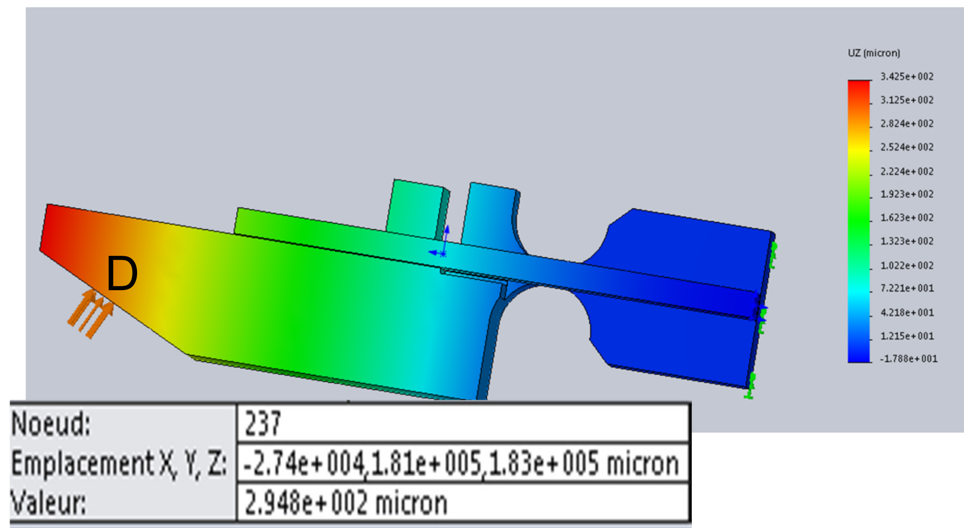

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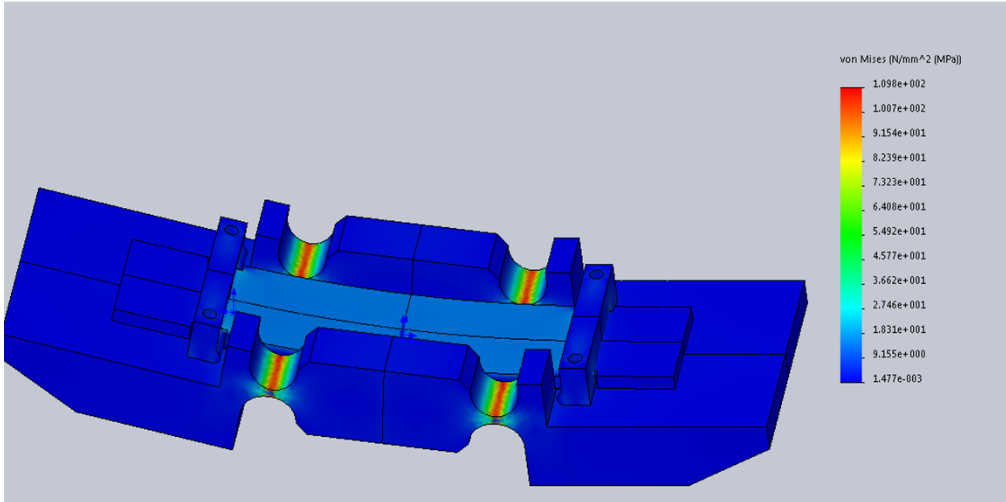

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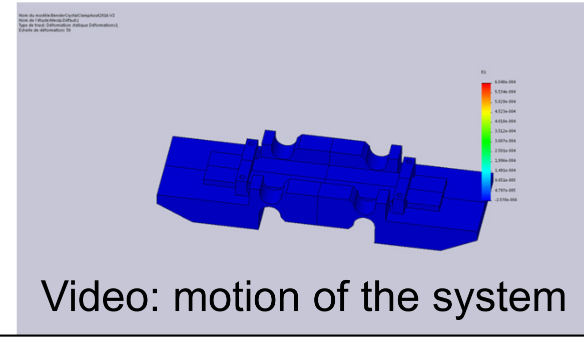
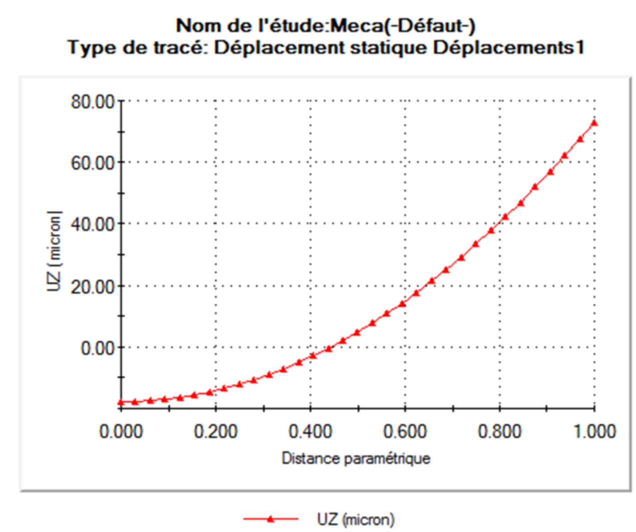
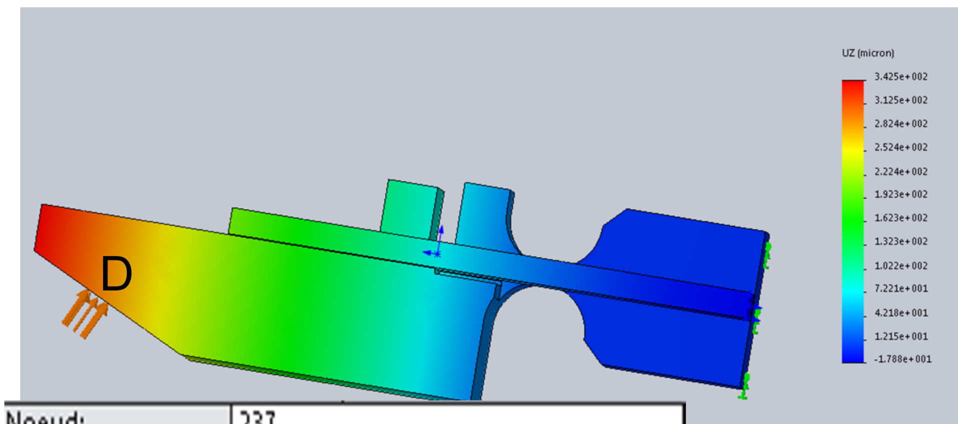




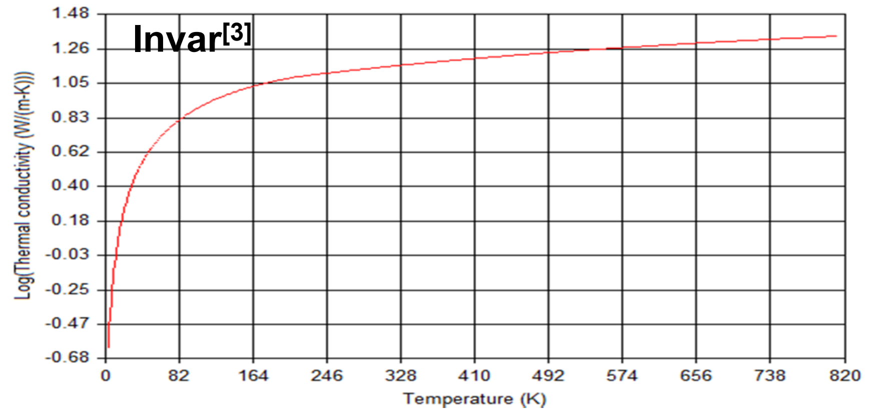


Noeud:	237
Emplacement X, Y, Z:	-2.74e+004,1.81e+005,1.83e+005 micron
Valeur:	2.948e+002 micron

Radius of curvature: 19.5m
Analytical displacement to be requested to the jack [m]= 291e-06
Solidworks simulation displacement in D[m]: 294.8e-6

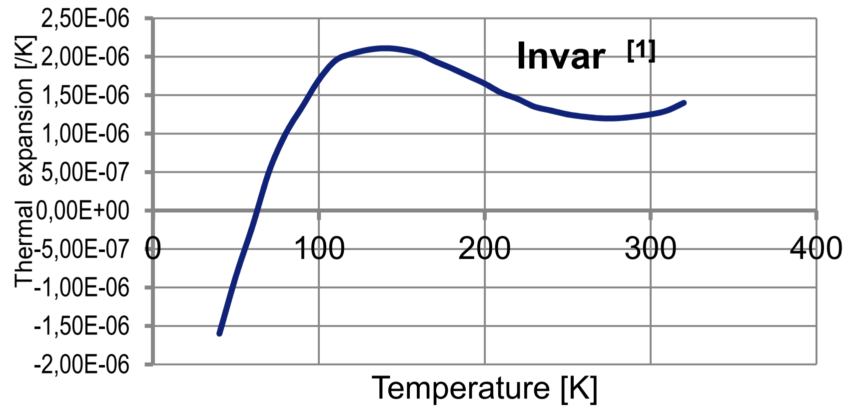
CRYO BEHAVIOR: PHYSICAL PROPERTIES FOR INVAR (FE-36NI) AND SILICON

Thermal conductivity (log scale)

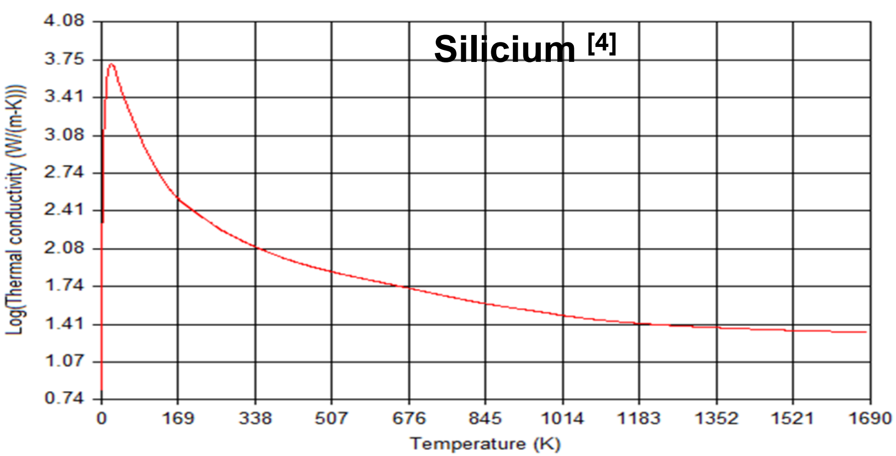


[3]Watson, T.W. and Robinson, H.E., ASME J. Heat Transfer, v83(4), 403-8 (1961) and NIST, Physical and Chemical Properties Division, Cryogenics Technologies Group at http://cryogenics.nist.gov

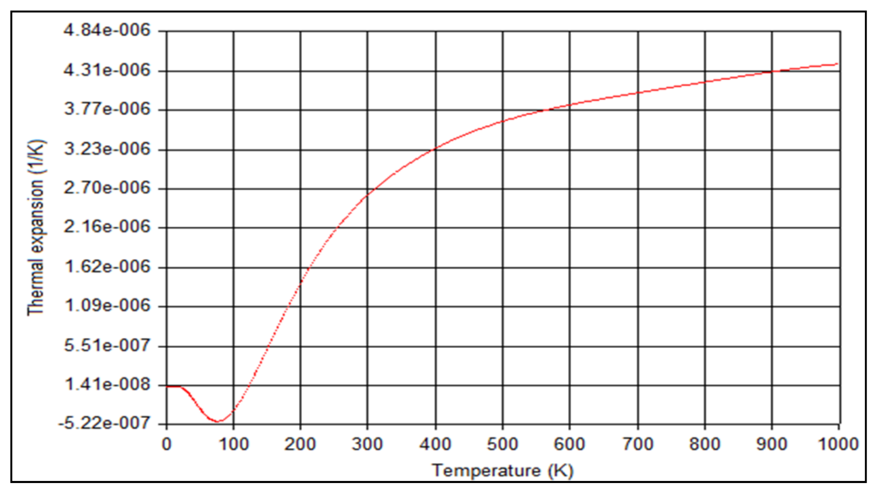
Thermal expansion coefficient



[1] "The JPL cryogenic dilatometer: measuring the thermal expansion coefficient of aerospace materials" P.G. Halverson and al,Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109



[4] C.Y. Ho, R.W. Powell and P.E. Liley, J. Phys. Chem. Ref. Data, v1, p279 (1972)



(2) C.A. Swenson, J. Phys. Chem. Ref. Data, vo. 12(2), p179 (1983)

CRYO BEHAVIOR: PHYSICAL PROPERTIES FOR INVAR (FE-36NI) AND SILICON

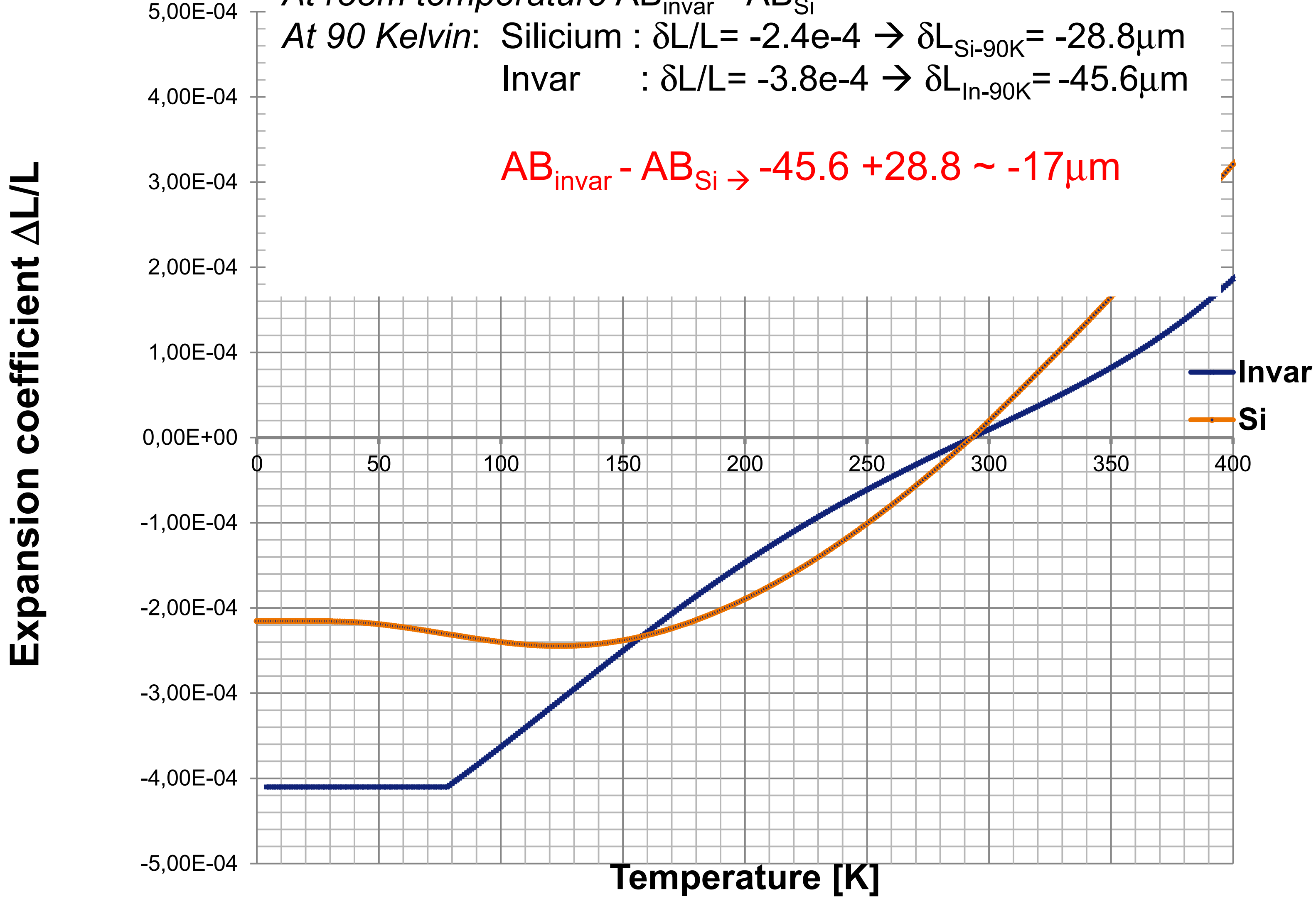
Length AB (~120mm) of the Invar and the Si:

At room temperature $AB_{invar} = AB_{Si}$

At 90 Kelvin: Silicium : $\delta L/L = -2.4e\text{-}4 \rightarrow \delta L_{Si\text{-}90K} = -28.8\mu m$

Invar : $\delta L/L = -3.8e\text{-}4 \rightarrow \delta L_{In\text{-}90K} = -45.6\mu m$

$AB_{invar} - AB_{Si} \rightarrow -45.6 + 28.8 \sim -17\mu m$



Non linear thermo-mechanical FEA modelisation and first X-Ray commissioning

The maximum stress between clamp and crystal is ~100MPa
→ **solution**: we put indium at the interface to absorb the mechanical stresses.

Video of deformation when cooling down

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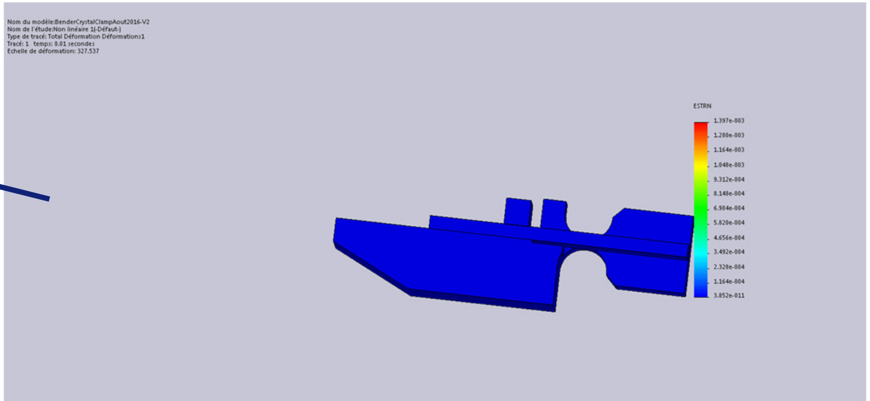

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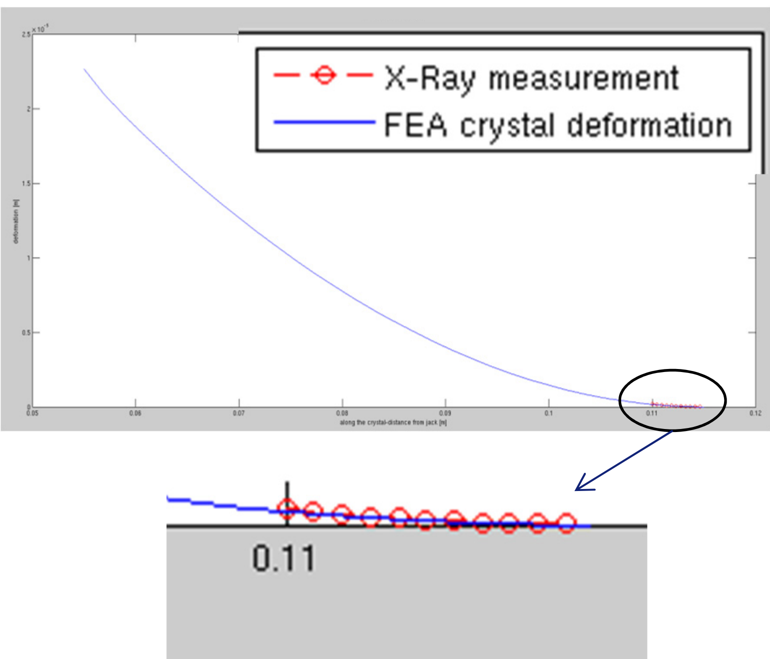

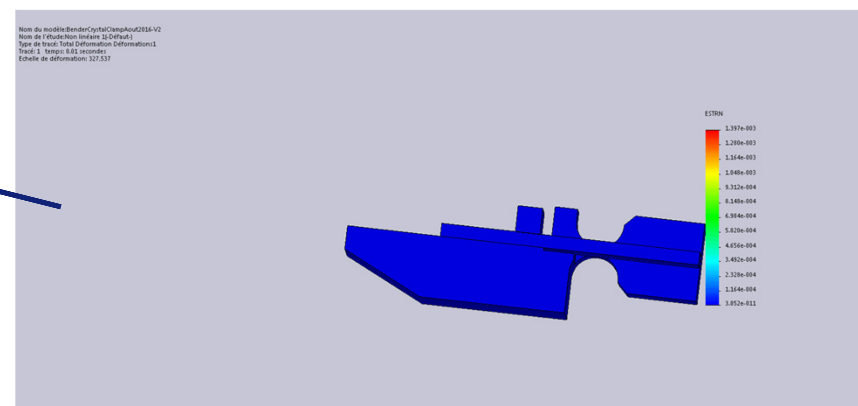

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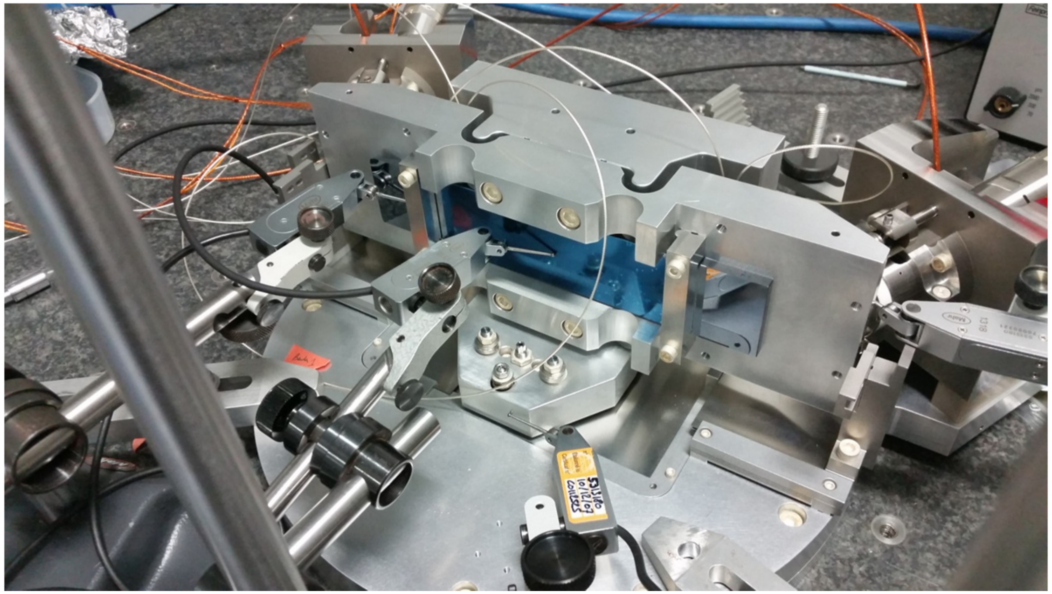
PROTOTYPE AND TEST BENCHES



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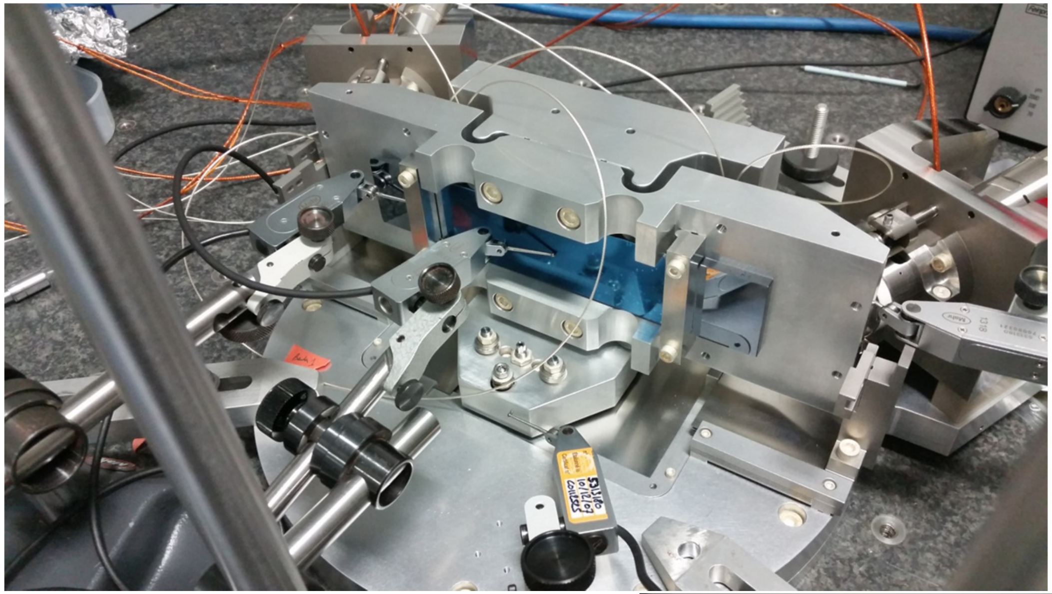
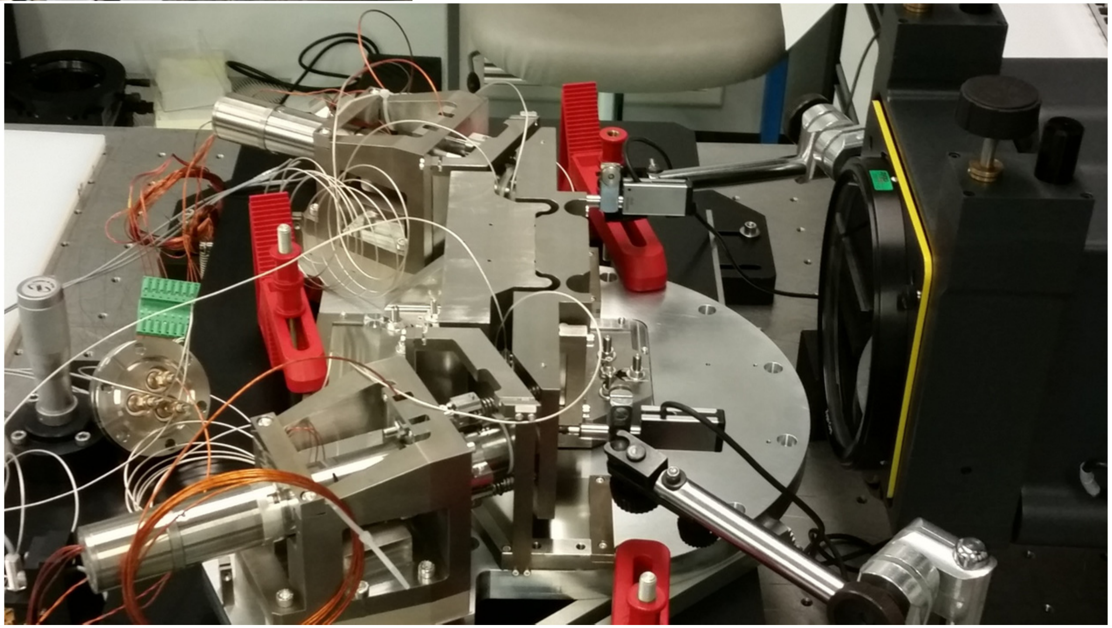
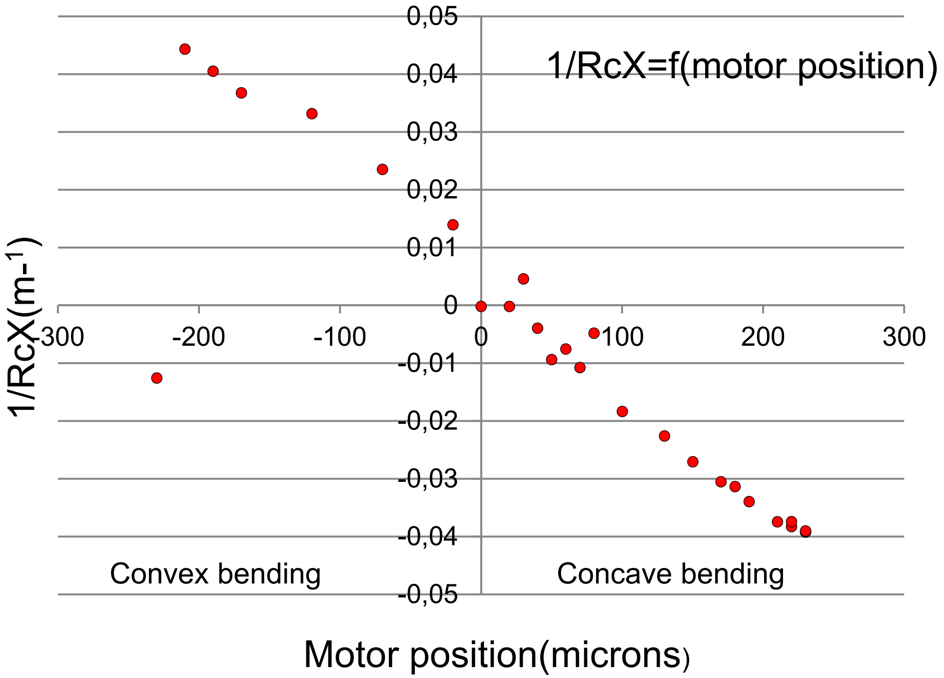




Radius= 20m → measurement: 236µm (Matlab:284m)

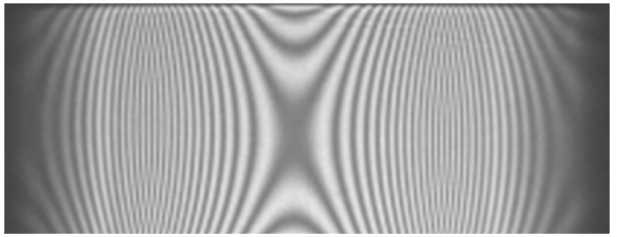
Radius= -20m → measurement:269µm (Matlab:284m)

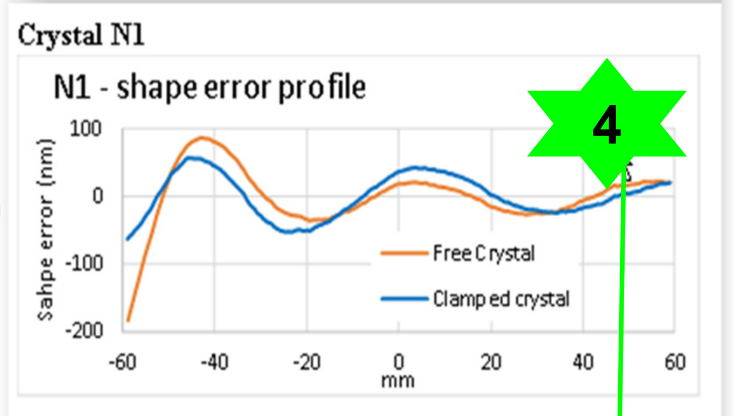


We set the zero of the jacks at the radius of the free crystal.

3

Fringes from topography at Rc = 20.5m concave Measured with a Fizeau interferometer.





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Courtesy B. Lantelmne

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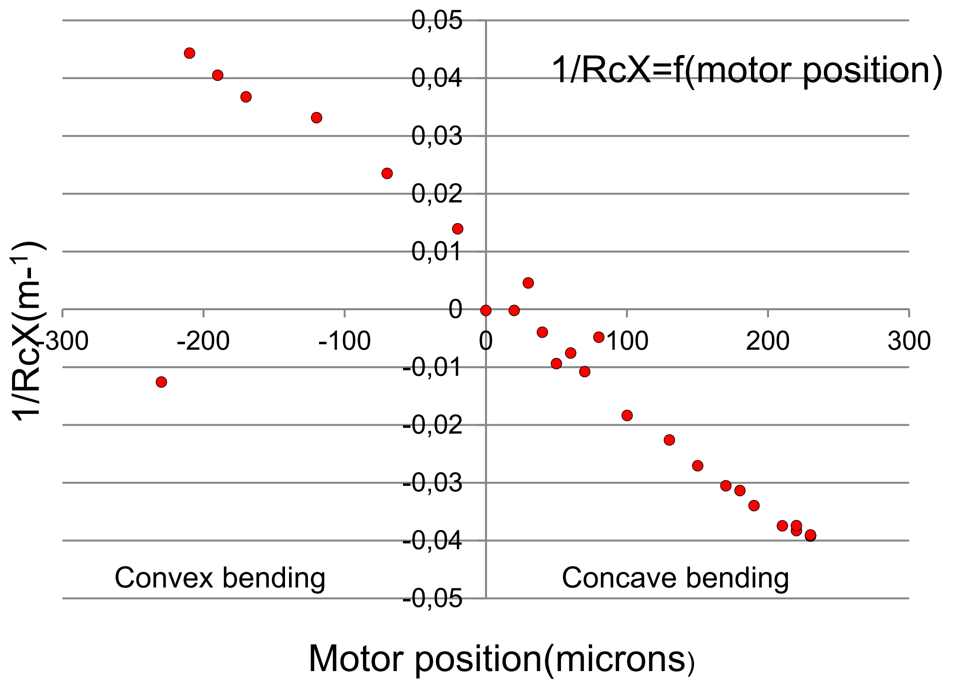

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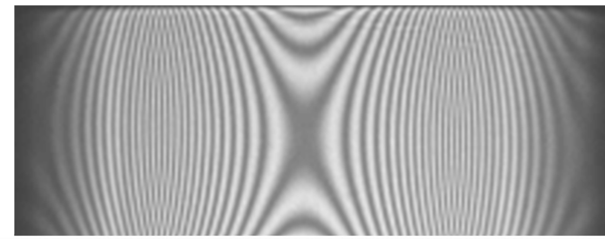

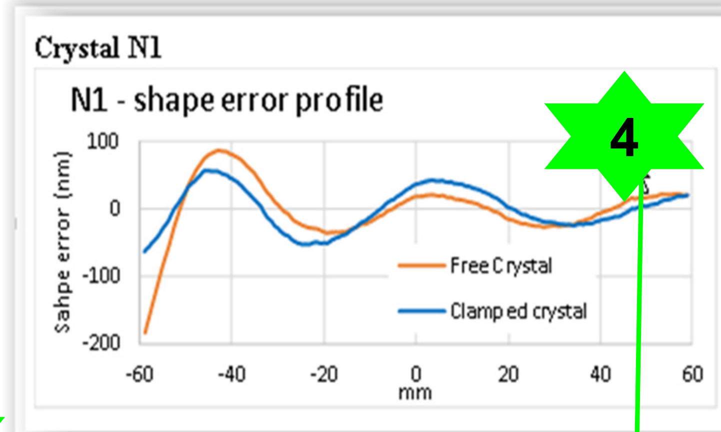

Courtesy B. Lantelmne

3

Results analysis: the theoretical and FEA values are closed to what is measured optically.

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CONCLUSION

DIFFICULTIES

Capacitive sensors

The noise of the capacitive sensors remains a little high. Their behavior at very low temperature is not fully tested yet.

Piezo-jacks control

The control of the piezo-jack is not straight-forward due to the fact that only one sensor (the capacitive one) reads the displacement of both the piezo and the stepper motor.

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CONCLUSION

- ❑ Despite of all the difficulties, the systems works well.
- ❑ The stability in time is very good.
- ❑ Analytical model/FEA model/ optical tests and first X-ray commissioning gives very similar results in the behavior of the system .

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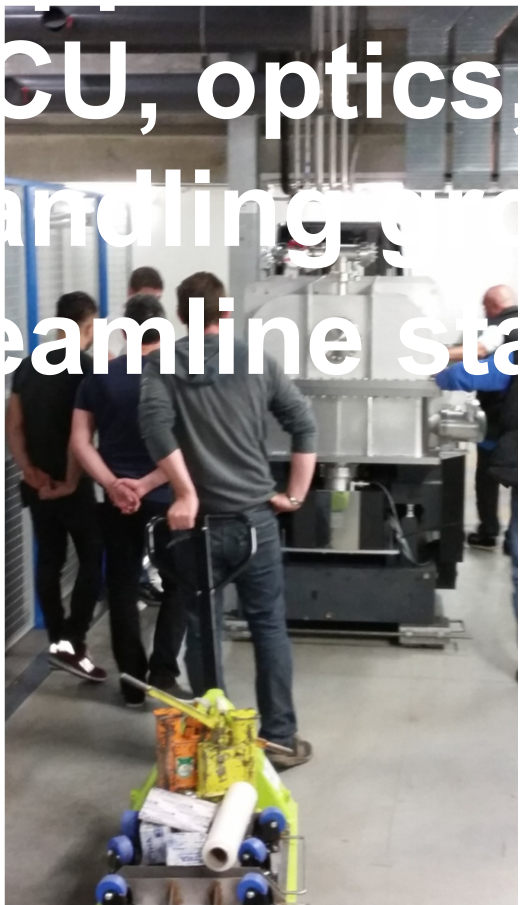

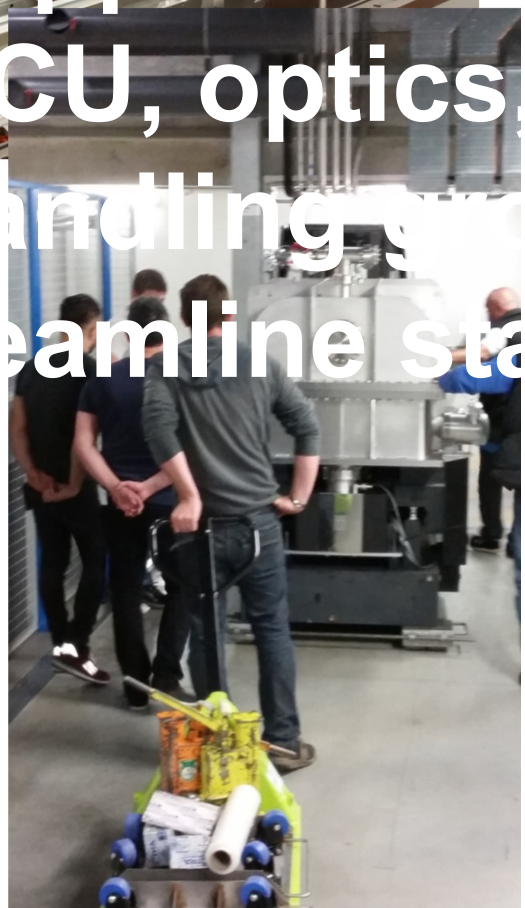

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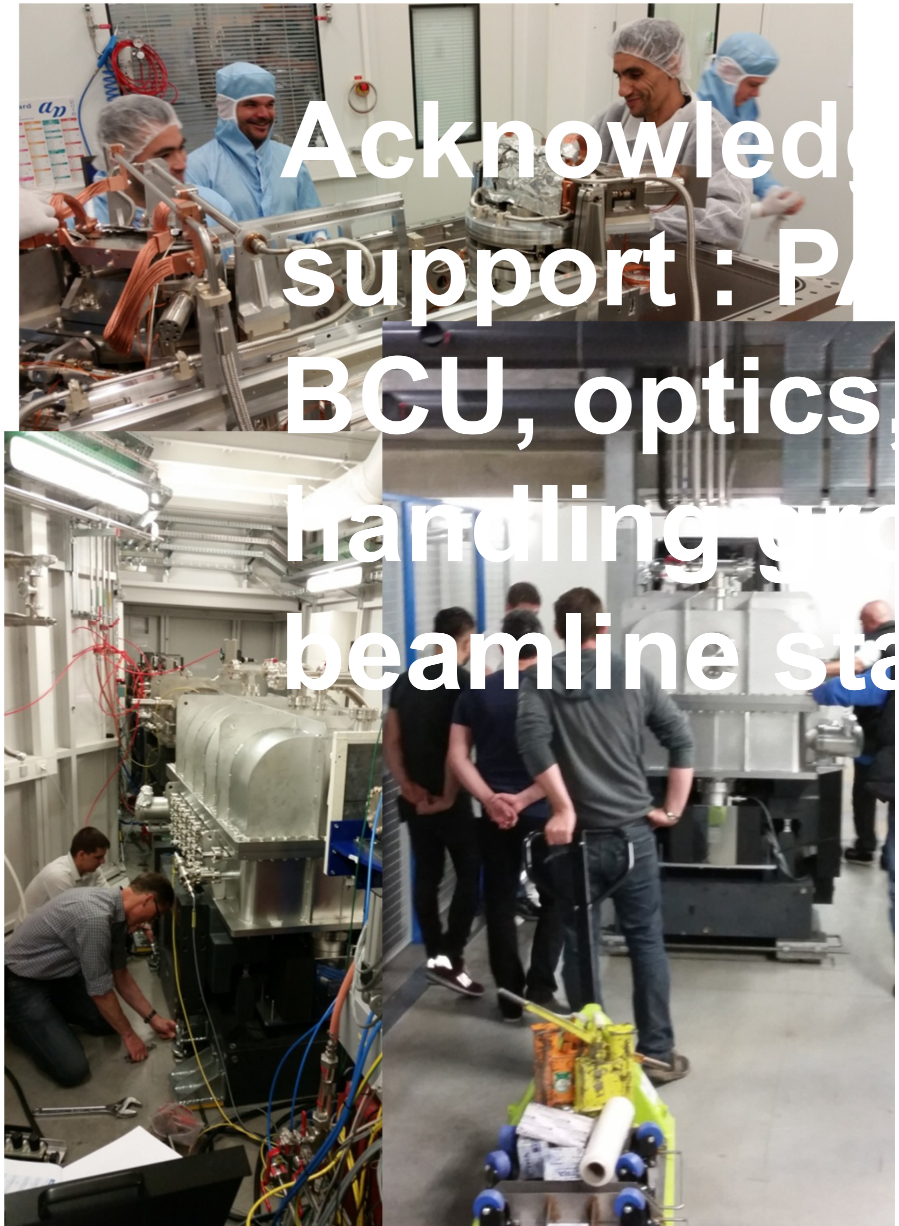

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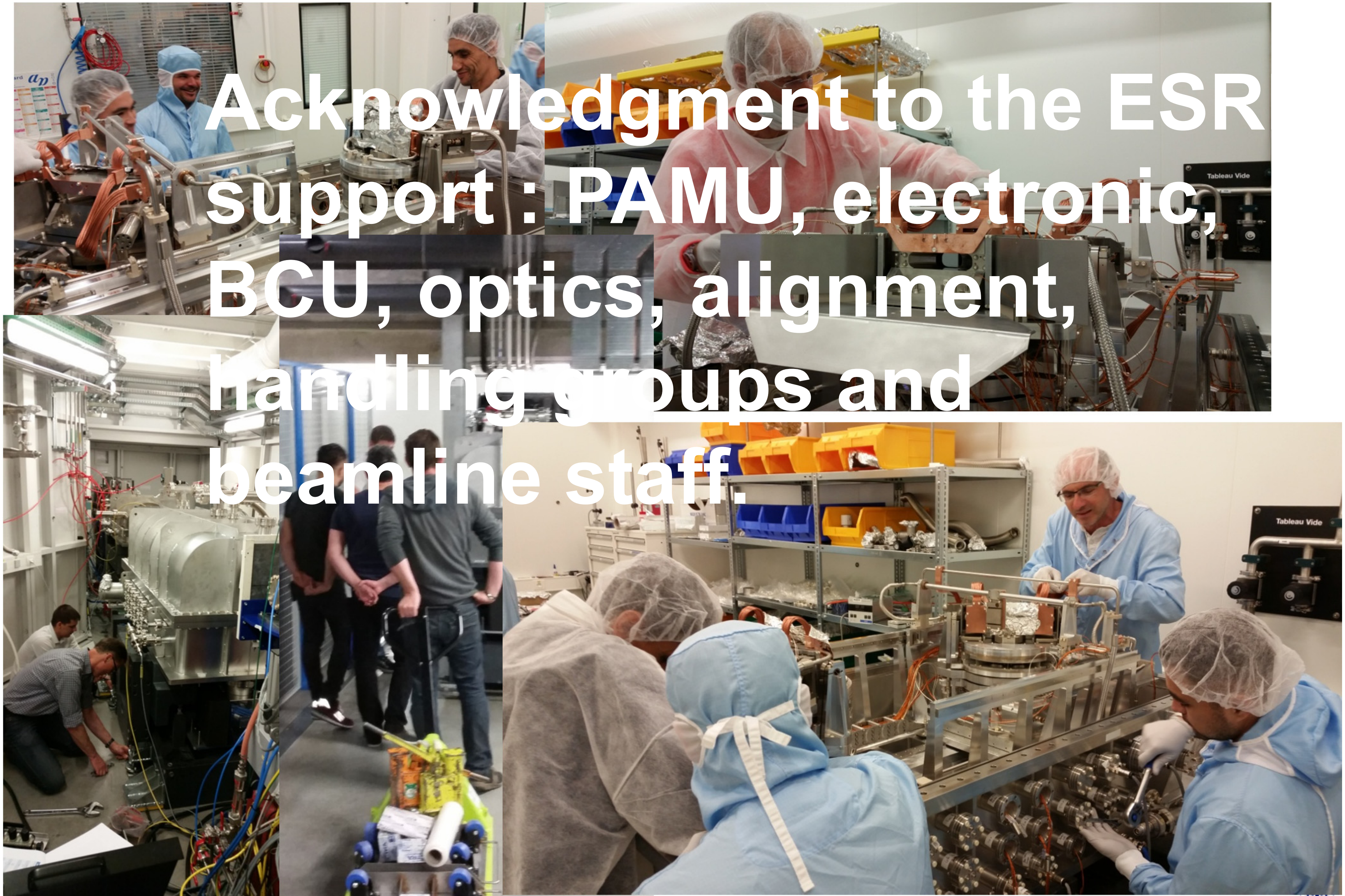

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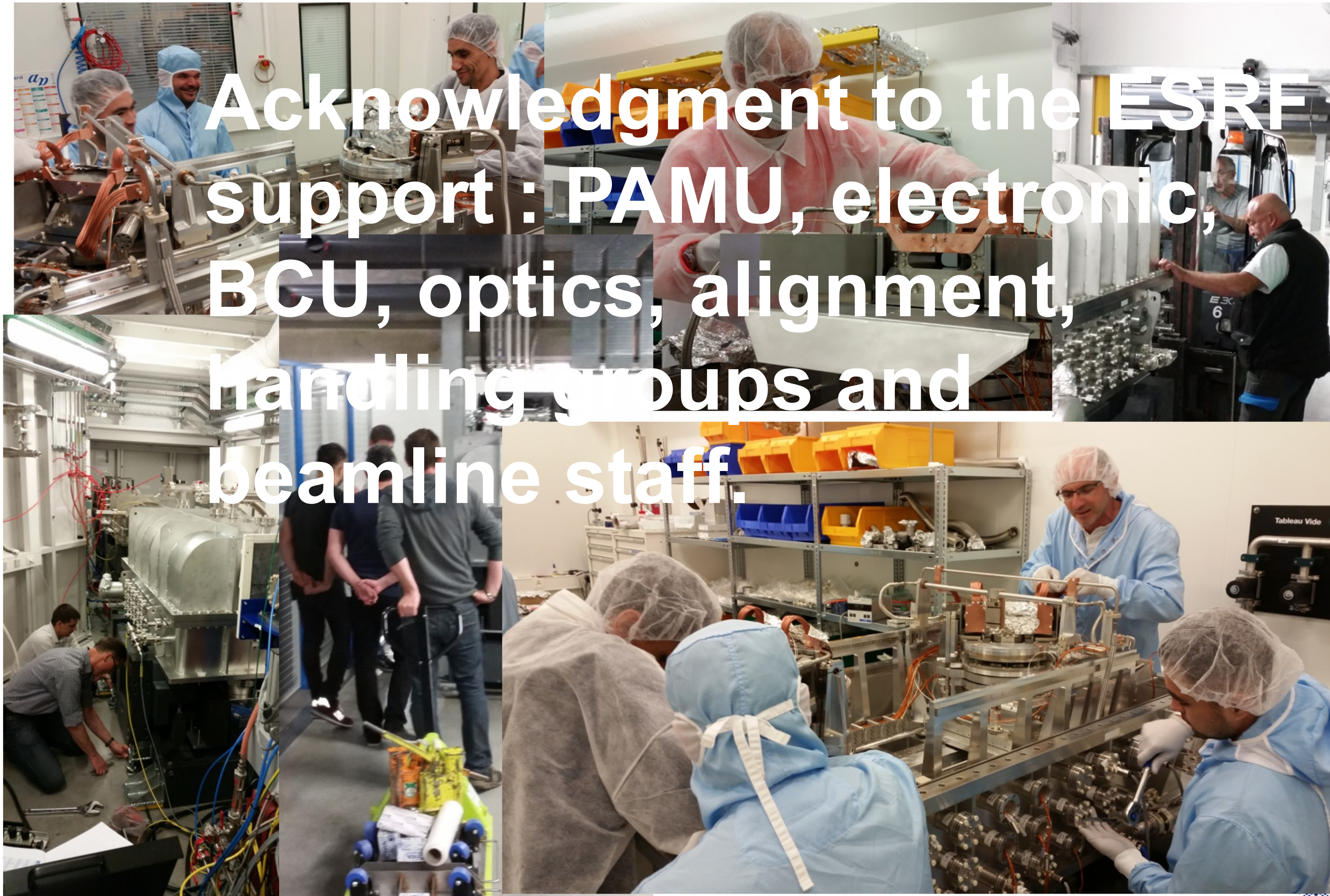

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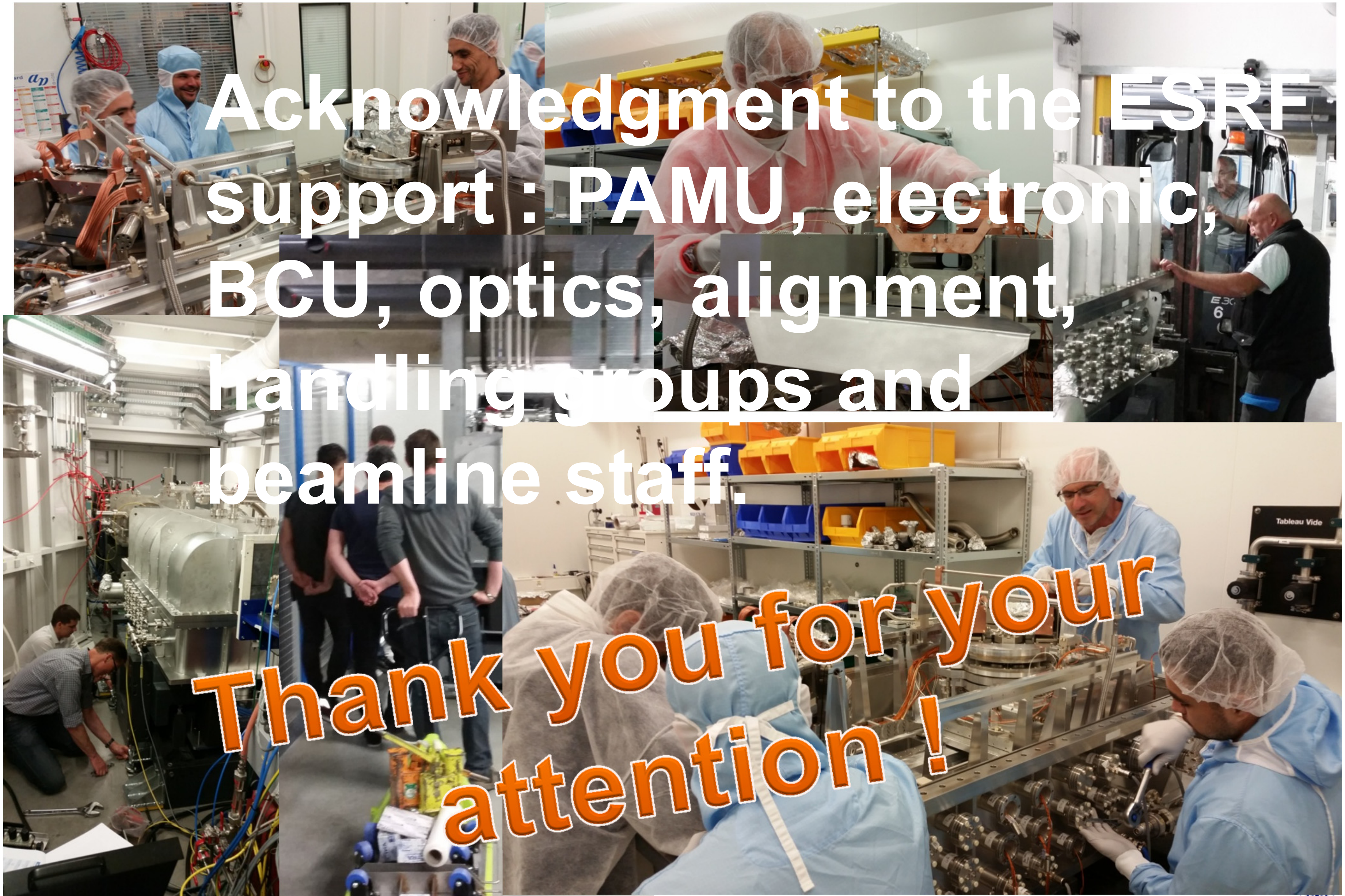

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