



# ESRF

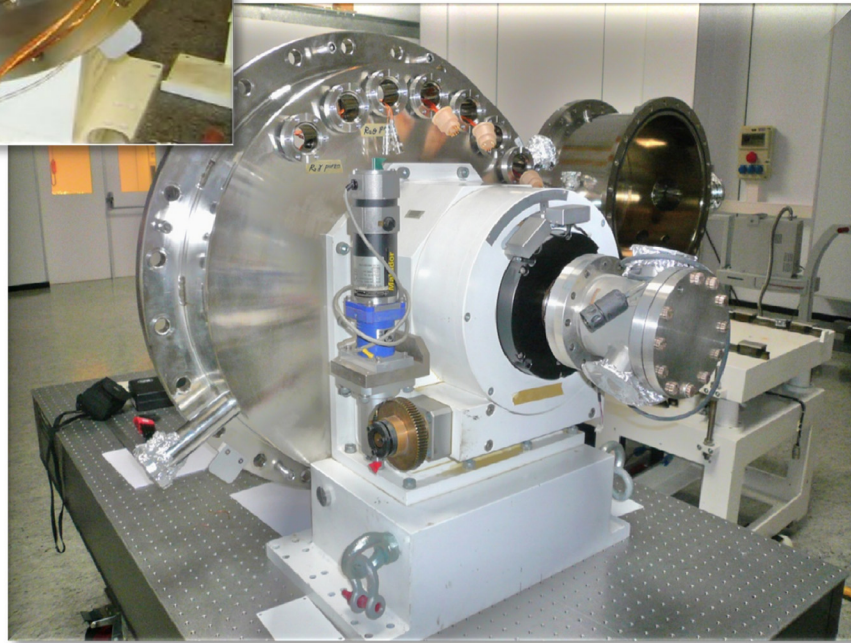
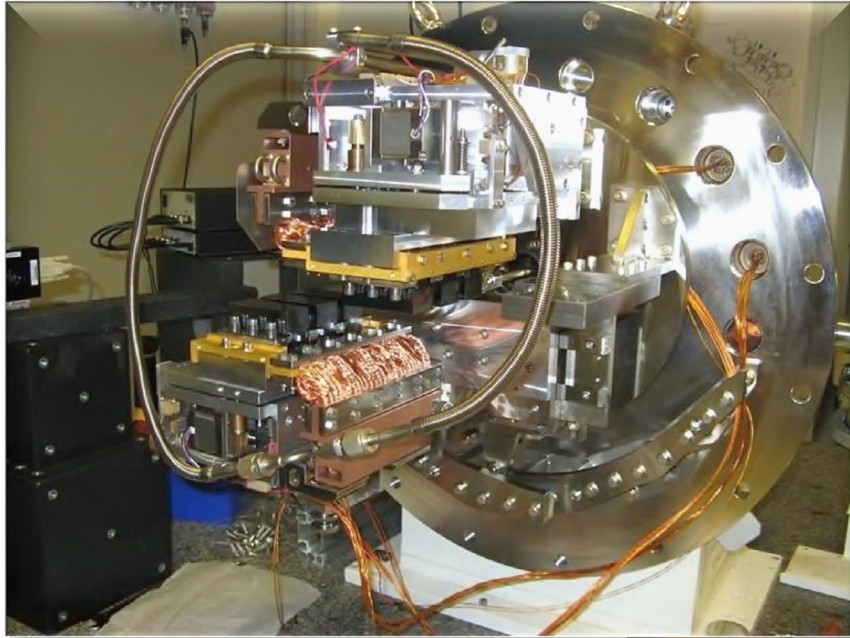
## Double Crystal Monochromator Prototype Project

Robert Baker

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- Design philosophy
- Bragg axis
  - Bragg drive
  - Bragg bearing & geometry
  - Feeder line management
  - Bragg metrology
- Crystal cage
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  - Crystal parallelism metrology
  - Fastjack
  - Crystal clamping
- Conclusion & status

# INTRODUCTION & HISTORY

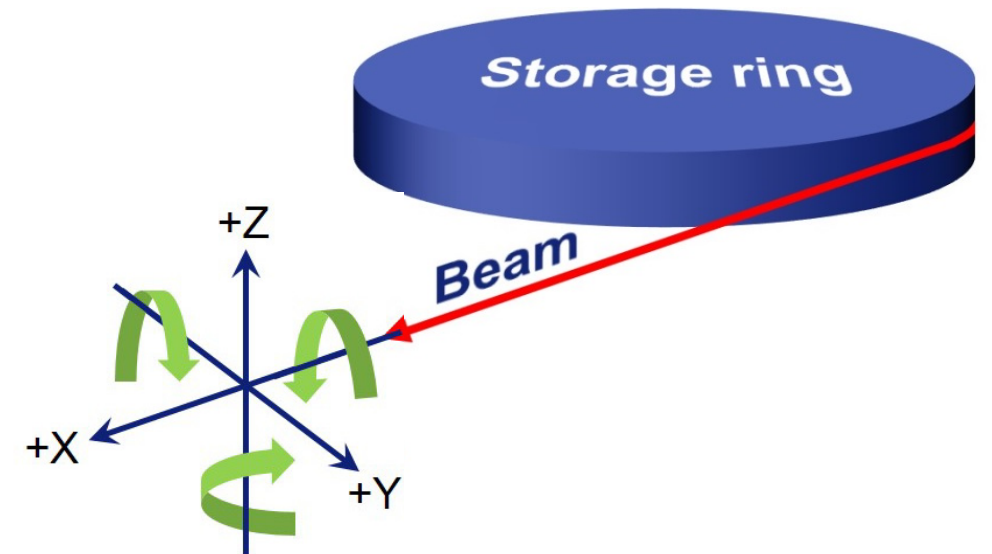


- ESRF has several DCMs which have been in service for more than 20 years
- Reliable service but showing signs of wear
- Not compatible with EBS specifications
- Decision to build a prototype
- Generic design for 6 client beamlines

## SUMMARY OF CRITICAL SPECIFICATIONS

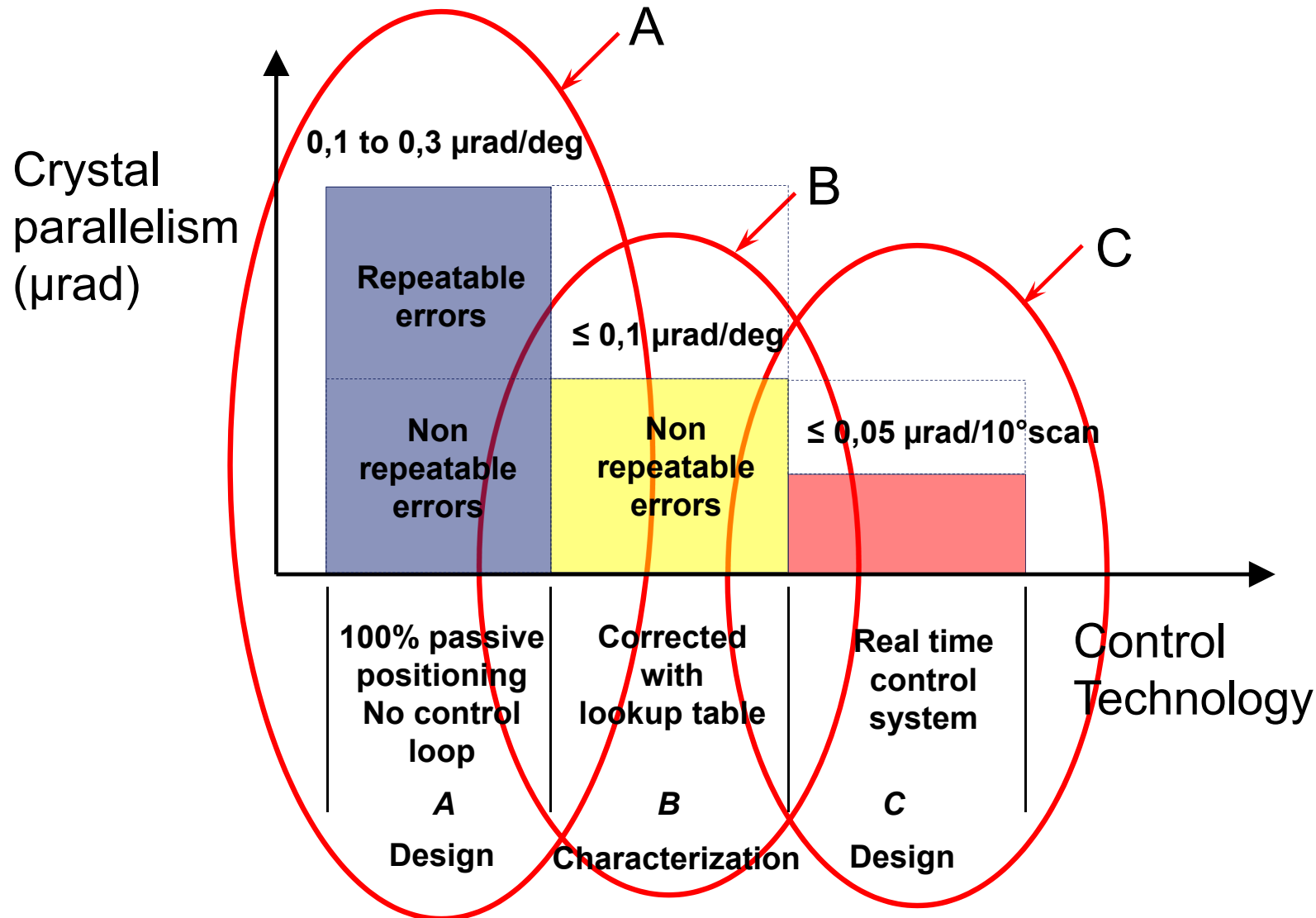
| BL                               | 4 BLs          | 2 BLs   |
|----------------------------------|----------------|---------|
| <i>Bragg angle range</i>         | 4 - 80°        | 2 - 35° |
| <i>Rotation speed</i>            | 0.001 - 3°/sec |         |
| <i>Bragg repeatability</i>       | 0.2μrad        |         |
| <i>Bragg precision</i>           | 2μrad          | 5μrad   |
| <i>RX stability fixed energy</i> | 100nrad        | 300nrad |
| <i>RY stability fixed energy</i> | 15nrad         |         |
| <i>RX stability 1° scan</i>      | 100nrad        | 300nrad |
| <i>RY stability 1° scan</i>      | 15nrad         |         |
| <i>RX stability 5° scan</i>      | 300nrad        | 600nrad |
| <i>RY stability 5° scan</i>      | 30nrad         |         |

| Parameter                              | Value  |
|----------------------------------------|--------|
| Energy range [keV]                     | 2 - 90 |
| Max power density (W/mm <sup>2</sup> ) | 300    |



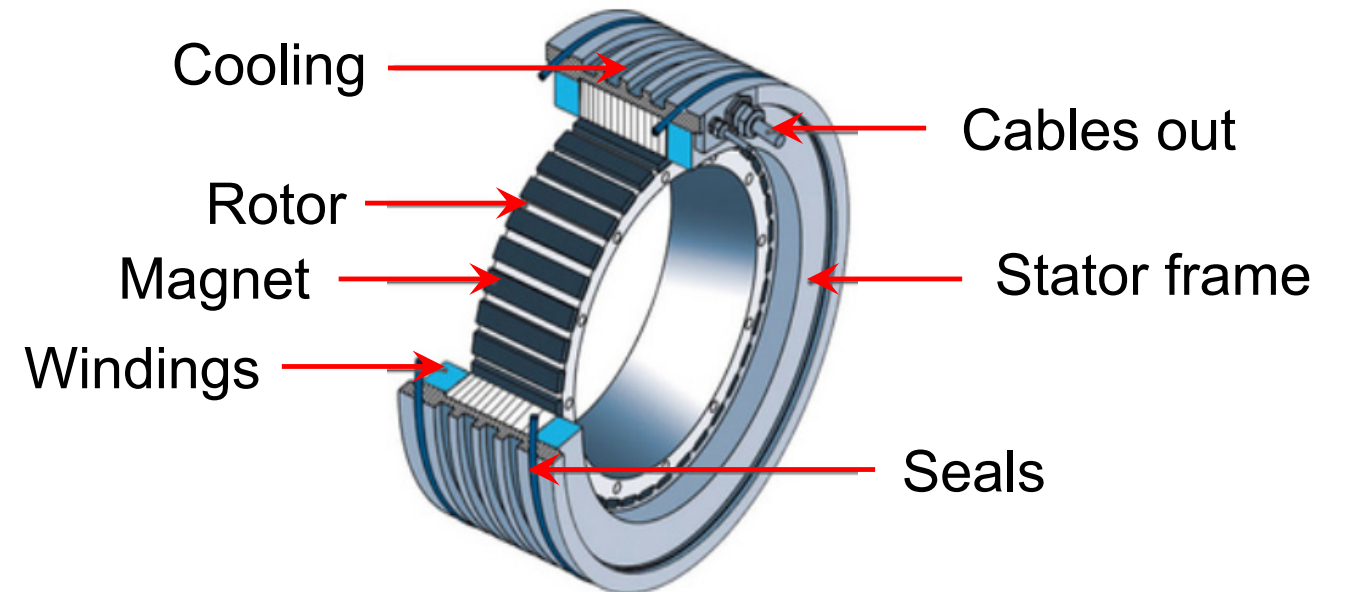
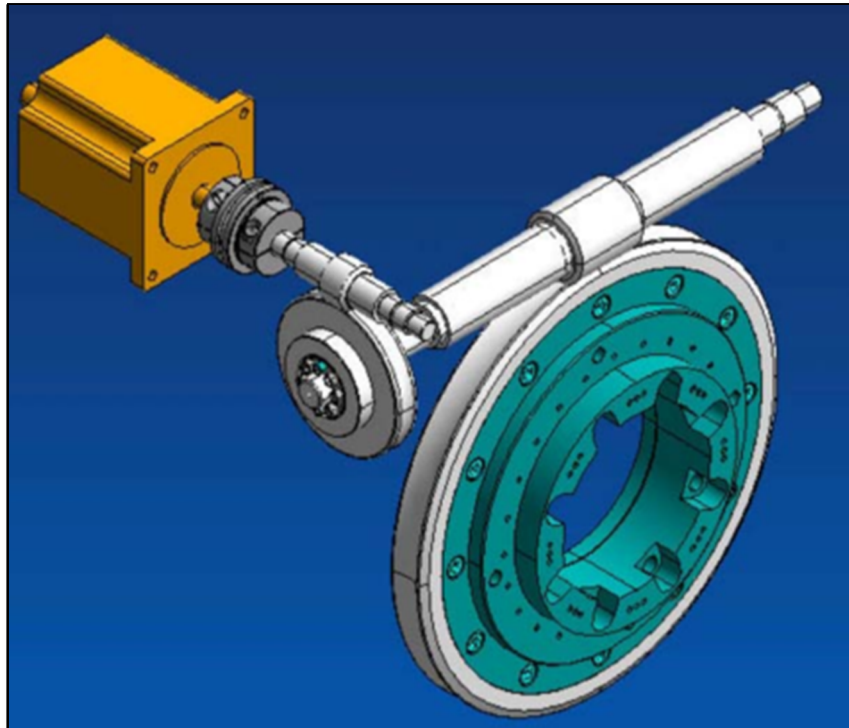


# CRYSTAL CAGE DESIGN PHILOSOPHY



- 1<sup>st</sup> crystal length: 80mm
- Max 2<sup>nd</sup> crystal length: 200mm
- Fixed impact point on 1<sup>st</sup> crystal
- Bragg axis rotation on 1<sup>st</sup> crystal plane
- Vertical fixed exit deflection -10mm vertically
- Entrance beam vertical size = 1mm
- 2 crystal pairs max

# BRAGG AXIS – DRIVE MOTOR



## BRAGG AXIS – DRIVE MOTOR

| Parameter                     | Direct drive                     | Stepper & reduction gears       |
|-------------------------------|----------------------------------|---------------------------------|
| Max scan speed                | High                             | Medium (ratio dependent)        |
| Wear & maintenance            | None (non contact)               | High (mechanical transmission)  |
| Radial parasitic forces       | Low                              | Preload dependent               |
| Aptitude to multiple scans    | Good                             | Backlash & wear                 |
| Theoretical resolution        | Limited by encoder & dynamics    | Smallest step / reduction ratio |
| Frictional torque sensitivity | High                             | Lower                           |
| Friction losses               | None                             | Preload dependent               |
| Backlash                      | N/A                              | Can be compensated              |
| Heat generation               | High – requires water cooling    | ??                              |
| Integration                   | Simple (frameless, hollow shaft) | Complex (gearing or end drive)  |

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| Theoretical resolution     | High                             | Reduction ratio                |
| Frictional torque          | Low                              | Preload dependent              |
| Friction losses            | Low                              | Preload dependent              |
| Backlash                   | N/A                              | Can be compensated             |
| Heat generation            | High – requires water cooling    | ??                             |
| Integration                | Simple (frameless, hollow shaft) | Complex (gearing or end drive) |

Users are cautious:  
Conclusion: build prototype with direct drive torque motor,  
but include a safety system!



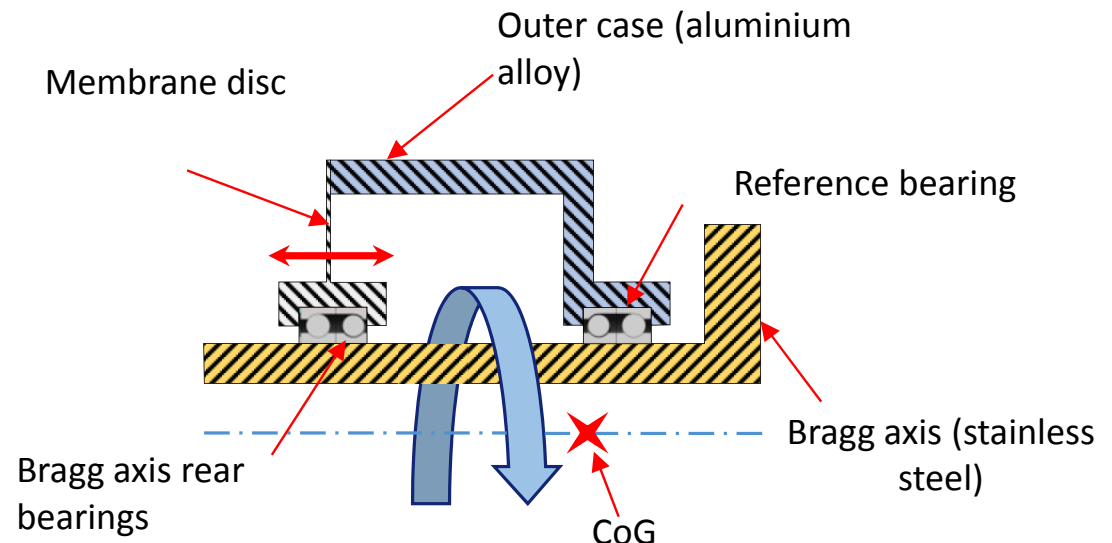
# BRAGG AXIS - BEARING AND GEOMETRY

## AIR BEARING VERSUS 2 PAIRS OF ANGULAR CONTACT BEARINGS

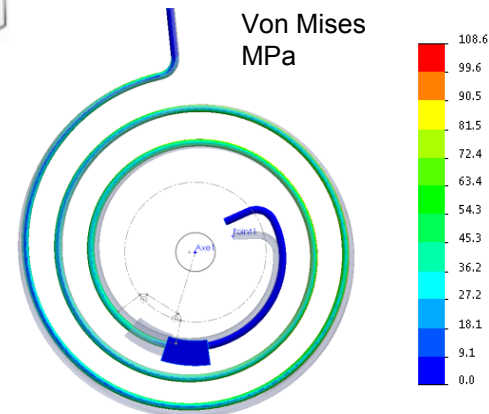
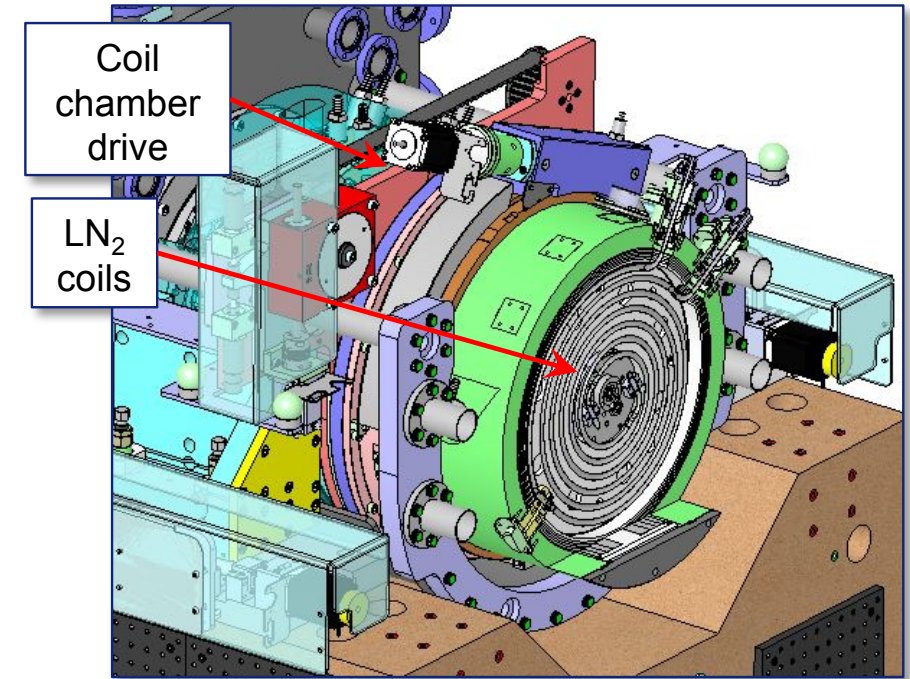
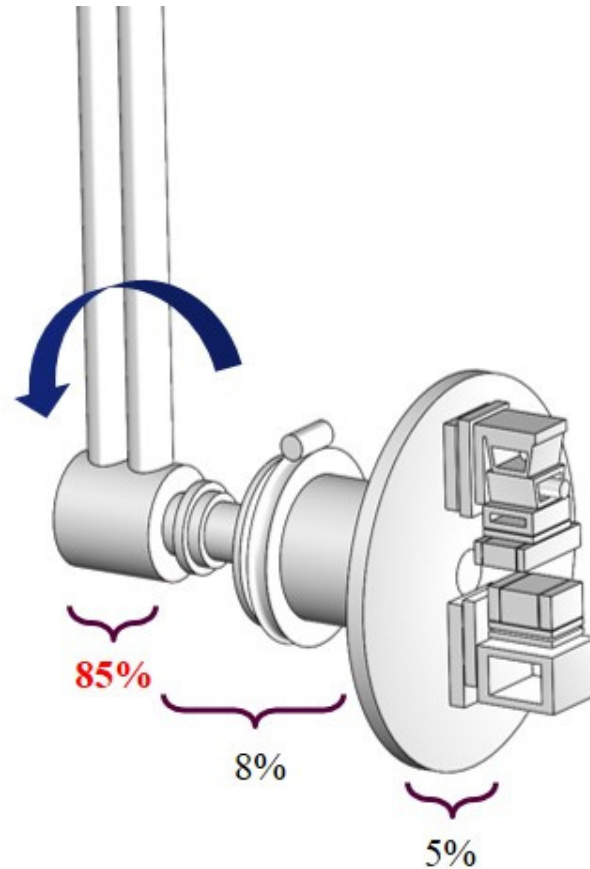
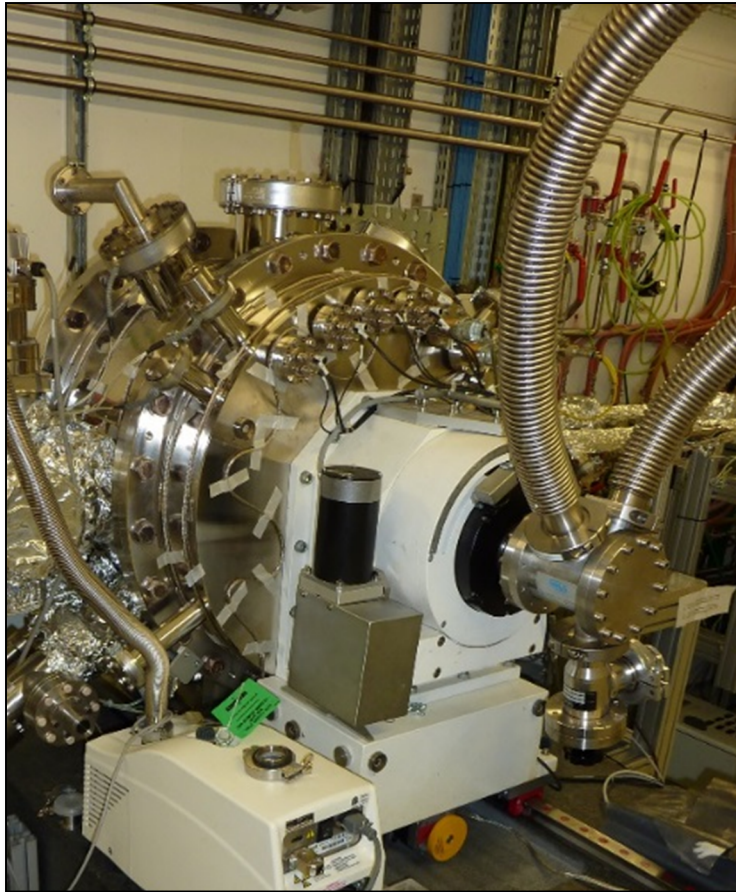
| Parameter                                  | Air                  | Angular contact                |
|--------------------------------------------|----------------------|--------------------------------|
| <i>Typical values (geometry dependent)</i> |                      |                                |
| Frictional torque                          | -                    | 2Nm (depends on axial preload) |
| Runout                                     | 25 nm                | 2 $\mu\text{m}$                |
| Wobble                                     | 0.1 $\mu\text{rad}$  | 5 - 10 $\mu\text{rad}$         |
| Radial stiffness                           | 350 N/ $\mu\text{m}$ | 2000 N/ $\mu\text{m}$          |



- Recommended high precision spindle geometry
- 15° contact angle = higher radial stiffness
- Pre defined axial preload: 640N
- Thermal compensation membrane
- Double “X” configuration limits hyperstaticity

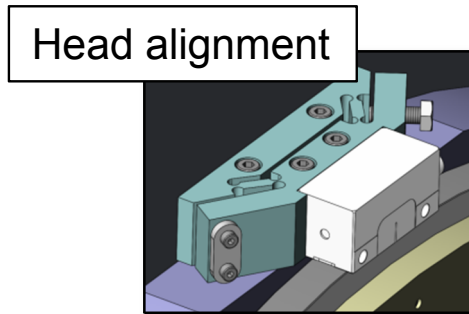
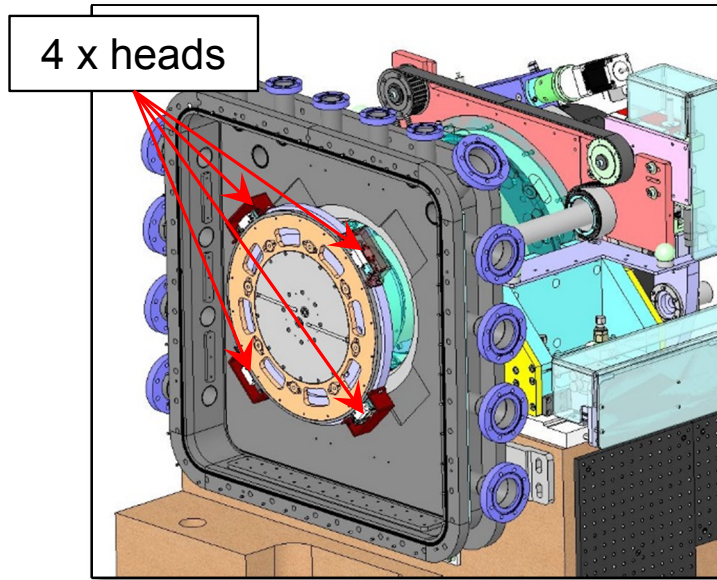


# BRAGG AXIS - CRYOGENIC FEEDER LINE MANAGEMENT

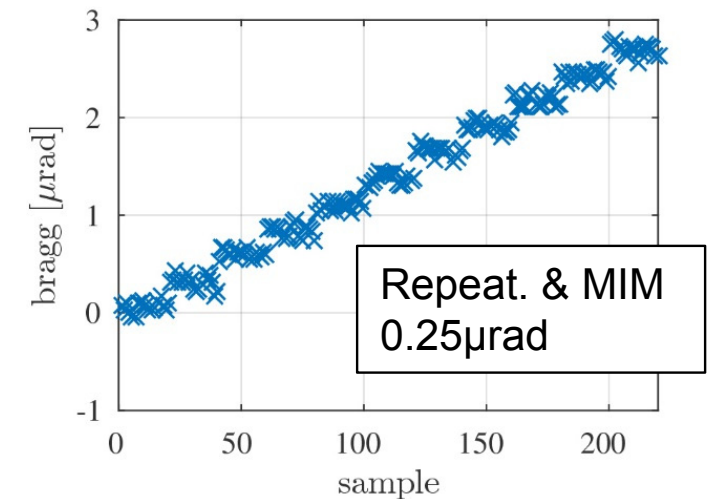




# BRAGG AXIS - METROLOGY

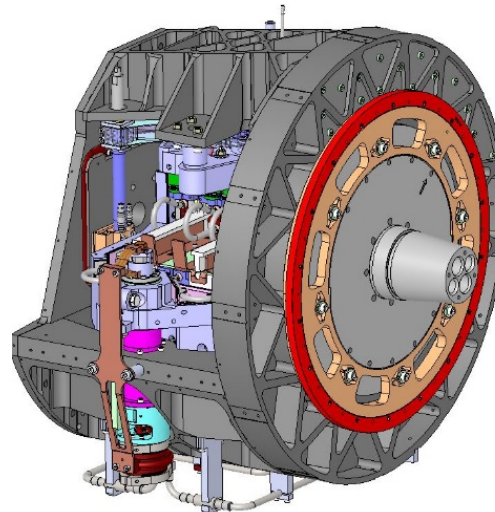
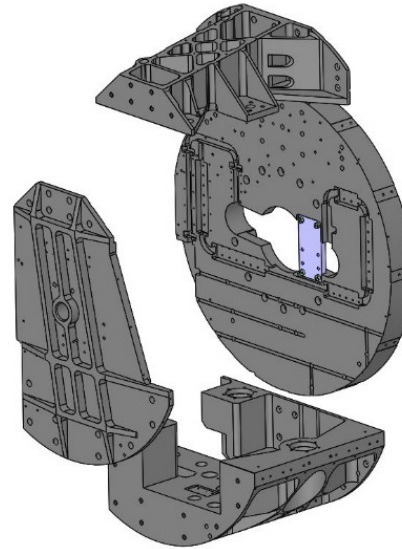


- On the prototype mono, two rotary encoders are installed In vacuum / Ex vacuum. Objective: compare measurement accuracy
- Renishaw UHV absolute encoder and Biss protocol giving 1.45nrad resolution (32 bit encoding)
- As close as possible to crystals
- 4 heads compensate for guiding errors
- Identical ex vacuum option on prototype
- ESRF PEPU board acquisition & averaging



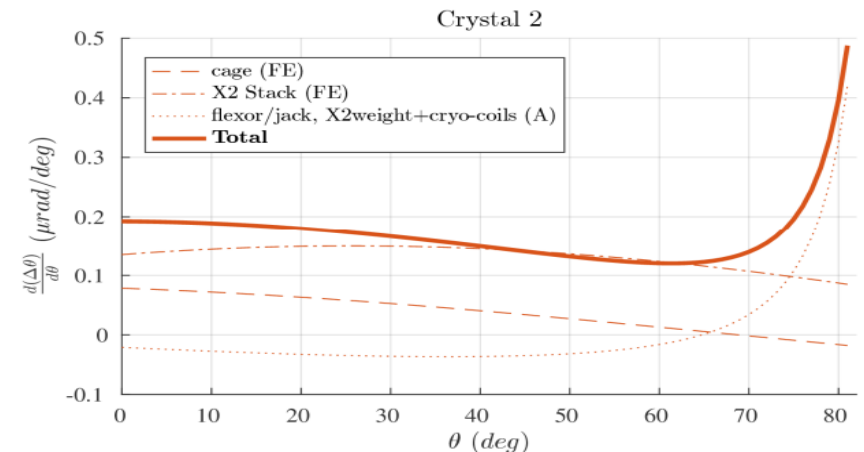
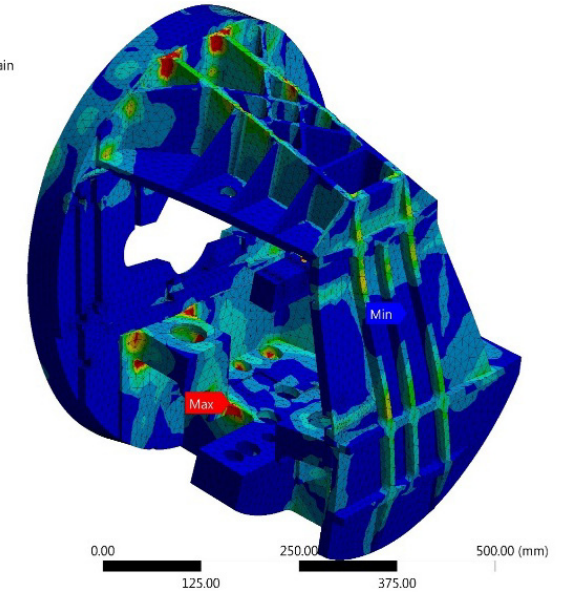
# CRYSTAL CAGE – PLATEAU & CONE

- 4 part plateau high stiffness plateau
- Optimised for minimum parallelism error between crystals over full operation range
- Complete 2<sup>nd</sup> crystal assembly mass included in FEA
- High stiffness conical interface to Bragg axis
- Thermal FEA to define optimal cooling



C: 0deg Bragg  
Equivalent Elastic Strain  
Type: Equivalent Elastic Strain  
Unit: mm/mm  
Time: 1  
20/09/2017 13:44

7.0217e-5 Max  
1.3587e-5  
1.1889e-5  
1.019e-5  
8.492e-6  
6.7936e-6  
5.0952e-6  
3.3968e-6  
1.6984e-6  
2.3058e-18 Min



# CRYSTAL CAGE - CRYSTAL PARALLELISM - METROLOGY CONCEPT

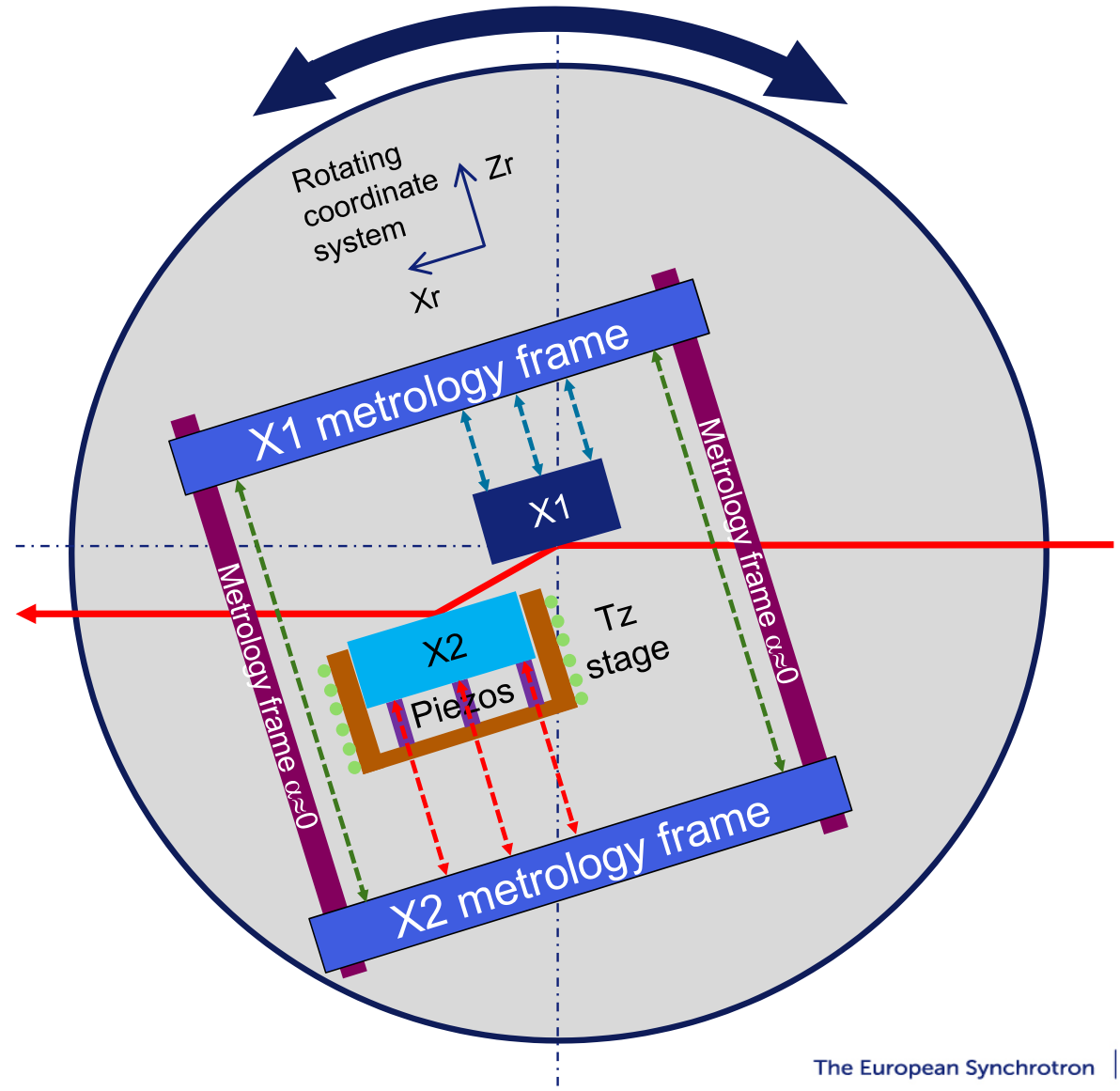
ONLINE Itarget Io Ref METROLOGY for a Parallelism Stability up to 15 nrad for  $\theta$

## Critical 2<sup>nd</sup> crystal specifications for 10% change of virtual source size

| Movement     | Parallelism       |
|--------------|-------------------|
| $\Delta r_x$ | 100 nrad          |
| $\Delta r_y$ | 14 nrad           |
| $\Delta t_z$ | 0.2 $\mu\text{m}$ |

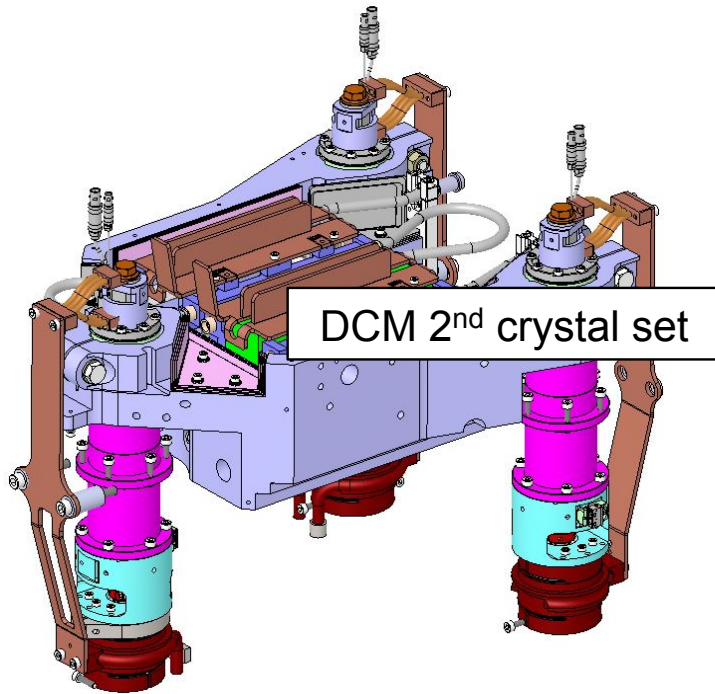
## Theoretical performance

| Movement     | Resolution | Repeatability |
|--------------|------------|---------------|
| $\Delta r_x$ | <8 nrad    | <110 nrad     |
| $\Delta r_y$ | <3 nrad    | <42 nrad      |
| $\Delta t_z$ | 0.3 nm     | 5 nm          |

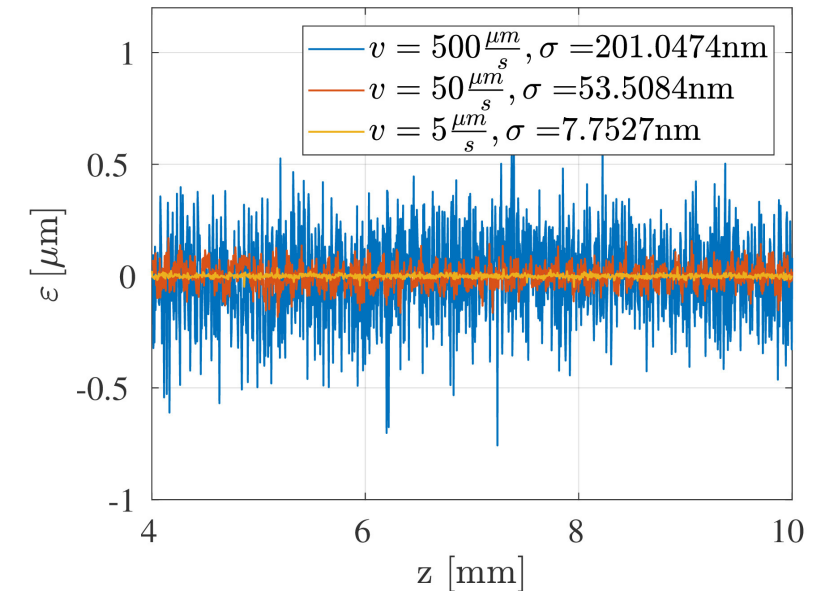
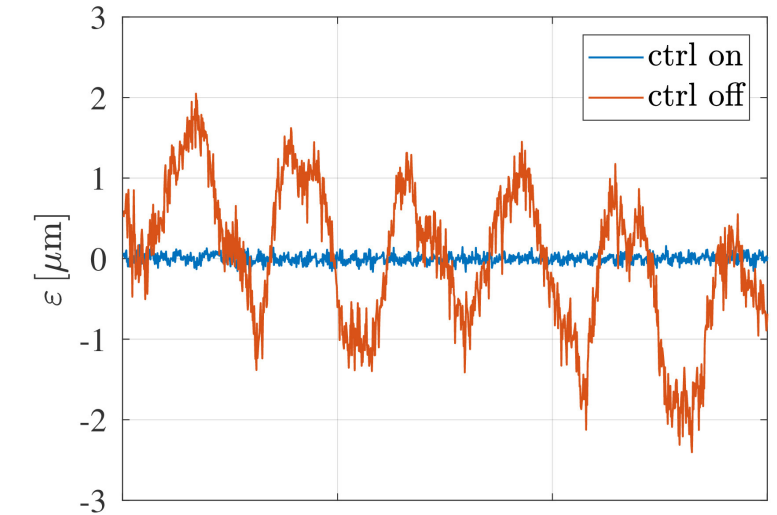
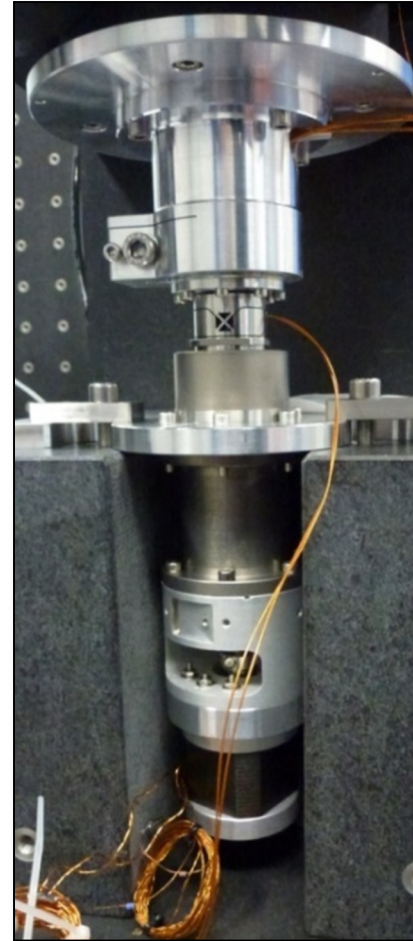




# CRYSTAL CAGE – FASTJACK HYBRID ACTUATOR

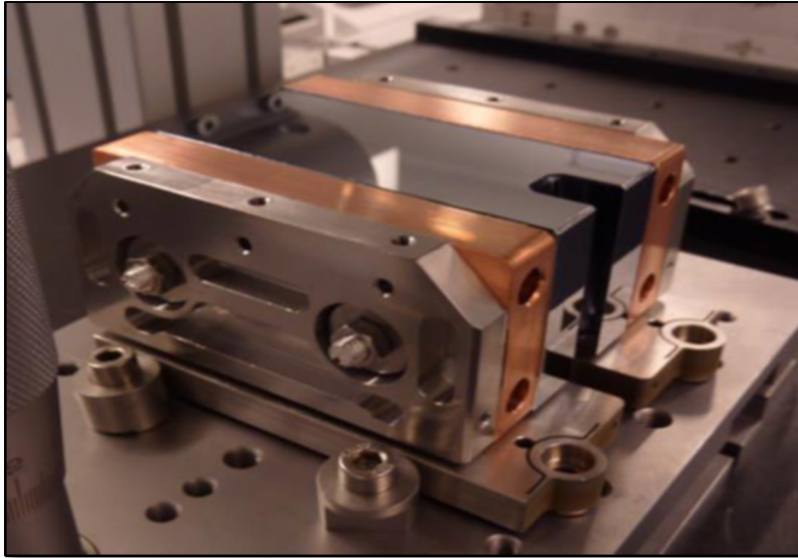


- Travel range 30mm
- Preloaded satellite roller screw
- 15 $\mu$ m piezo
- Custom ball bush guide
- Dynamic bandwidth >100Hz
- Custom flexure connection to 2<sup>nd</sup> crystal cage
- Water cooled motor

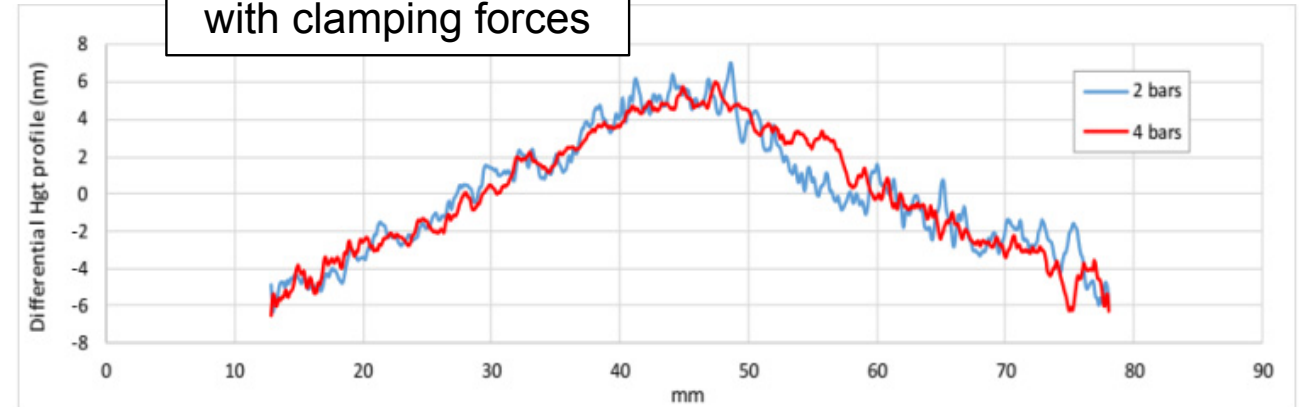




# CRYSTAL CAGE - CRYSTAL CLAMPING

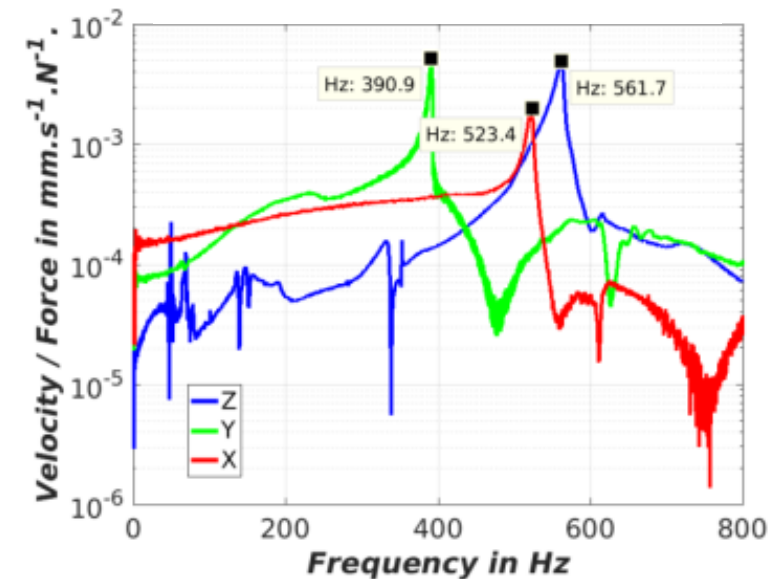


Crystal deformation with clamping forces

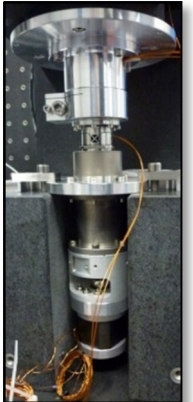
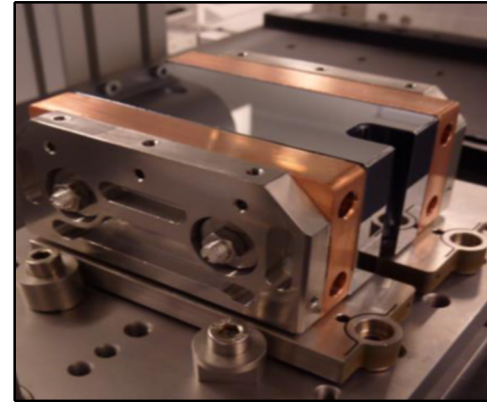
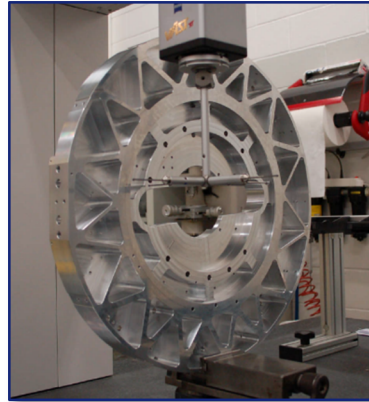
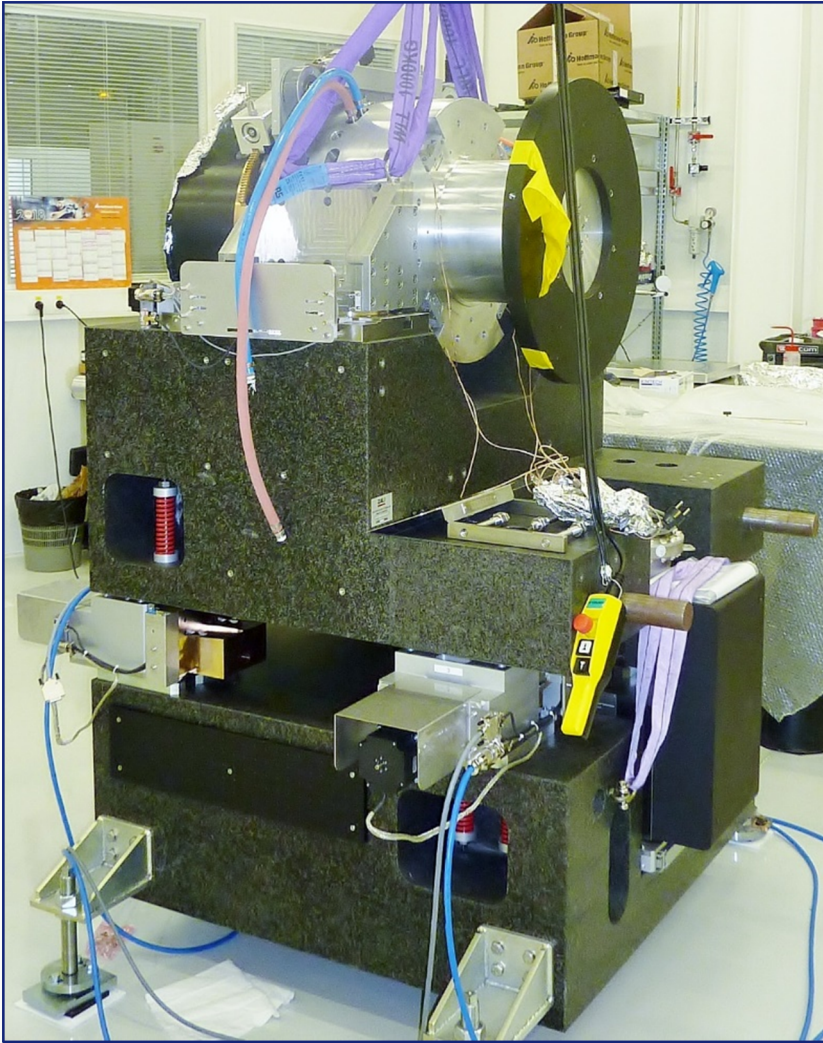


- Crystal clamping from below with transversal pins
- Dynamic measurements: 1st mode (transversal) 390 Hz
- 2 and 4 bars cooling block clamping pressure tests
- 12.6 nm P-V deformation on meridional axis

Dynamic response



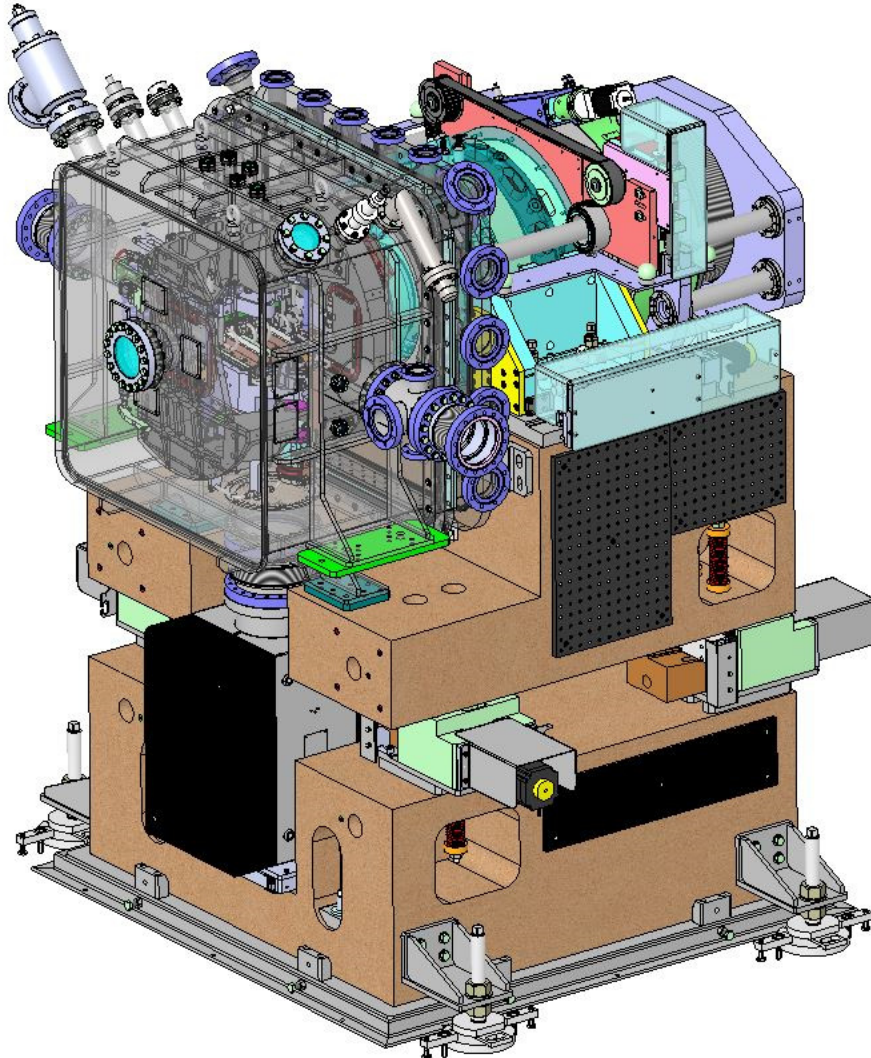
# CONCLUSION



- Improved cantilever design
- Several innovative solutions
- Real time control required to reach ultimate specifications but...
- Designed to function with no active feedback loops
- All parts will be delivered by July 2018
- Beamline commissioning before ESRF long shutdown (December 2018)







## Collaborators

- Kader AMRAOUI
- David BUGNAZET
- Marine COTTE
- Rodolph GRIVELET
- Ricardo HINO
- H.P. van der KLEIJ
- Marc LESOURD
- Kieth MARTEL
- Murielle SALOMÉ
- Leo ROUSSET
- Pascal VOISIN
- Amparo VIVO
- ...



**END OF PRESENTATION**  
**THANK YOU FOR YOUR ATTENTION**