Crystals technology at INFN

Vincenzo Guidi and Andrea Mazzolari

CERN 19/10/2018

CRYSTALS TECHNOLOGY AT INFN

INFN
Istituto Nazionale di Fisica Nucleare

CERN

Collimation
Beam steering
Innovative radiation sources
Pair production studies
Innovative detectors

SLAC

Beam steering
Innovative radiation sources
Pair production studies

MAMI – Mainzer Mikrotron

Beam steering
Innovative radiation sources
Pair production studies

erc – European Research Council

CRYSBEAM
SELDOM

INFN COMPETENCIES

INFN has competencies related to

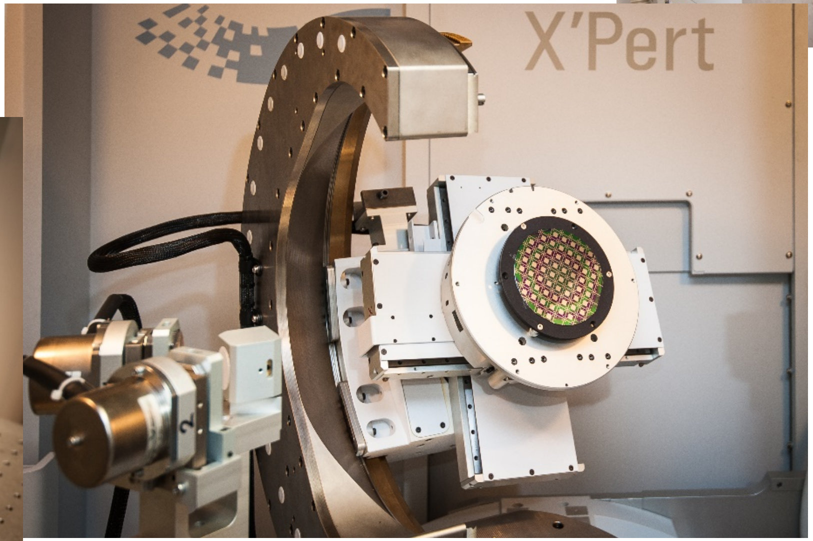
- Development of innovative ideas and researches (connected to channeling and related effects)
- Crystals manufacturing and characterization
- Holders manufacturing and characterization
- Goniometry
- Trackers and detectors
- Data analysis
- Channeling simulations (channeling implemented in Geant4 by INFN)
- Design of setups for channeling experiments

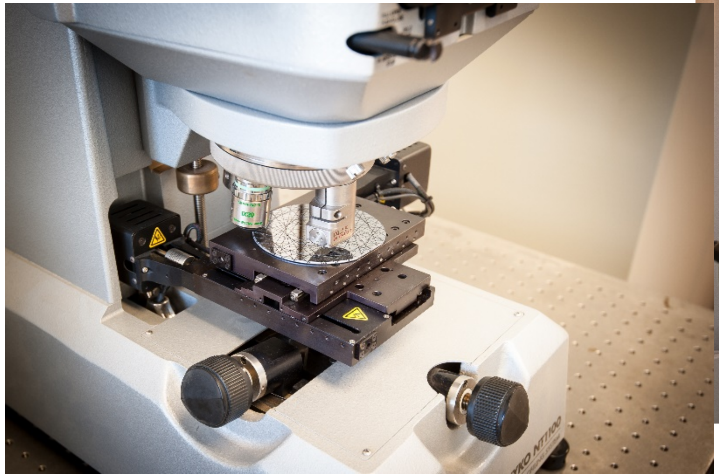
→ INFN is a scientific agency encompassing a full set of competencies related to studies of coherent effects between charged particle beams and crystals.

INFN INFRASTRUCTURE

Laboratory fully equipped for silicon micro and nanomachining
ISO4 certified clean room (130 m^2)

High-resolution x-ray diffraction
Dicing and polishing equipment
White light and Fizeau inteferferometers

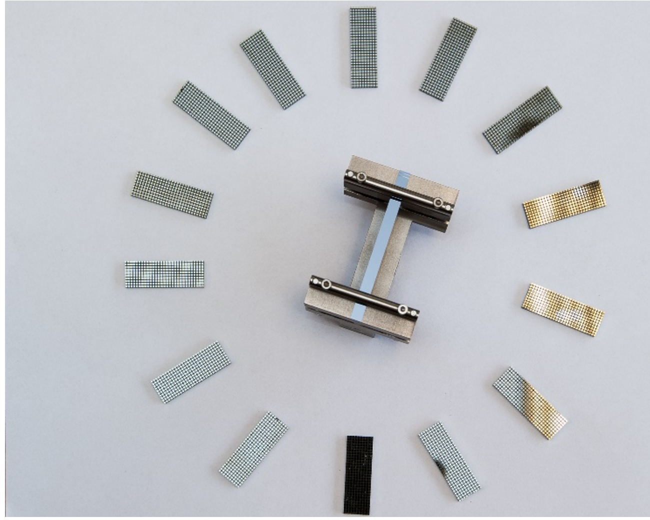


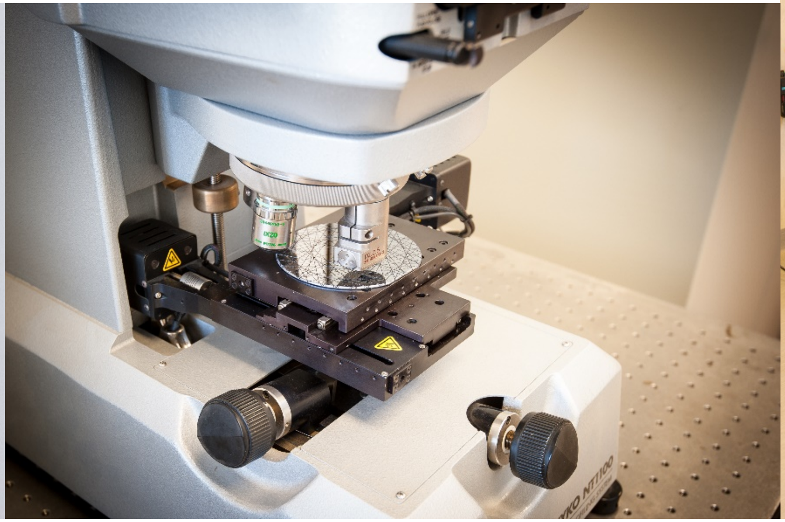


INFN INFRASTRUCTURE

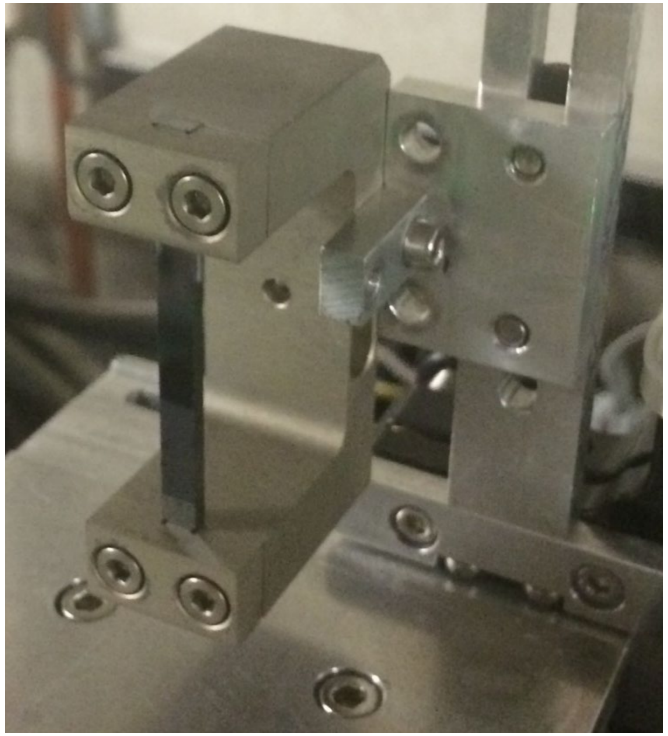
Laboratory fully equipped for silicon micro and nanomachining

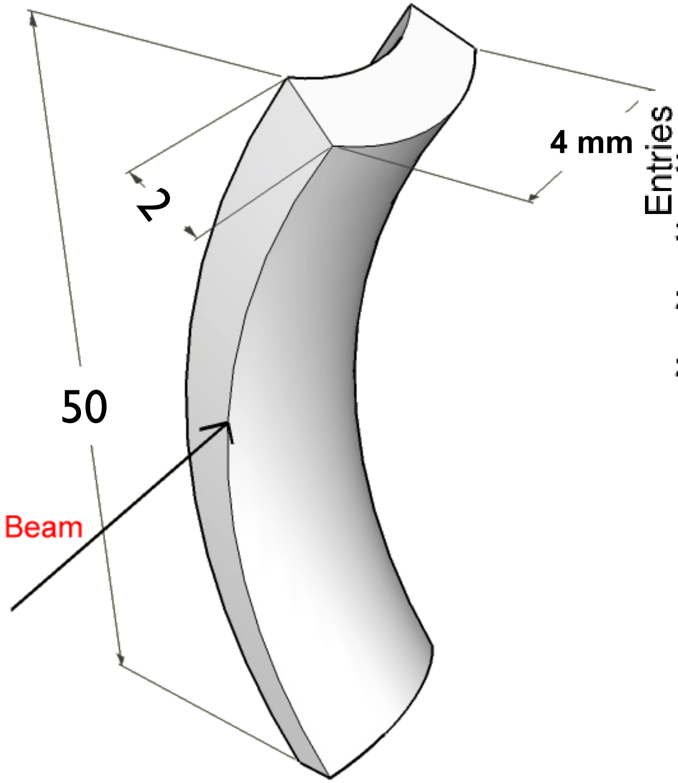
Fotolitography
Equipment for silicon chemical etching
Nanoimpringing

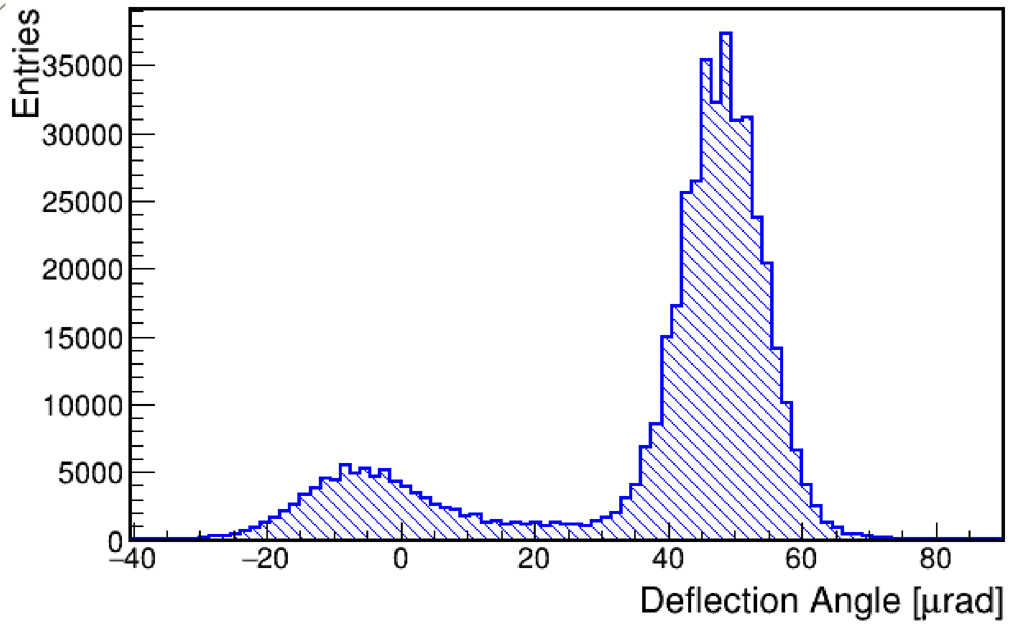




STRIP CRYSTALS FOR THE LHC

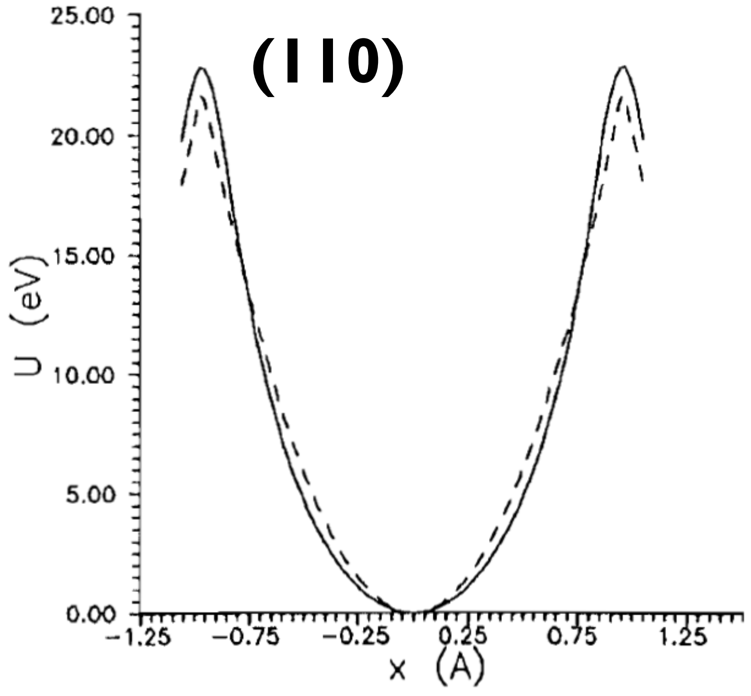


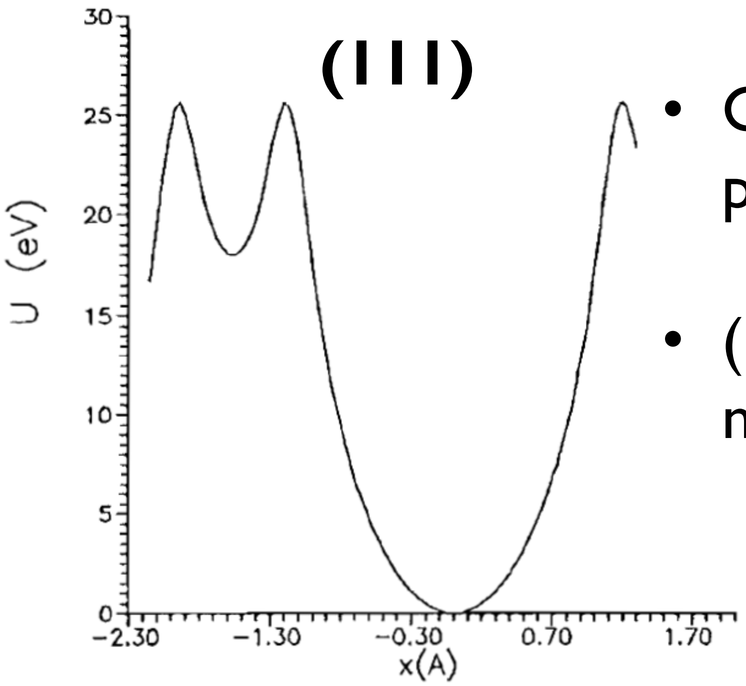




A primary bending is mechanically imposed along the 50 mm size.
As a result, «anticlastic bending» manifests along the 4 mm size.

CHOICE OF CRYSTALLINE PLANES





- Comparable depth of potential well
- (110) Planes offers lower nuclear interaction rate

See also W. Scandale et al., Eur. Phys. J. C (2018) 78:505

BRIEF RECAP ABOUT CRYSTALS MANUFACTURING

2006 Manufacturing based on mechanical dicing followed by chemical etching

2007 Manufacturing based on purely chemical methods

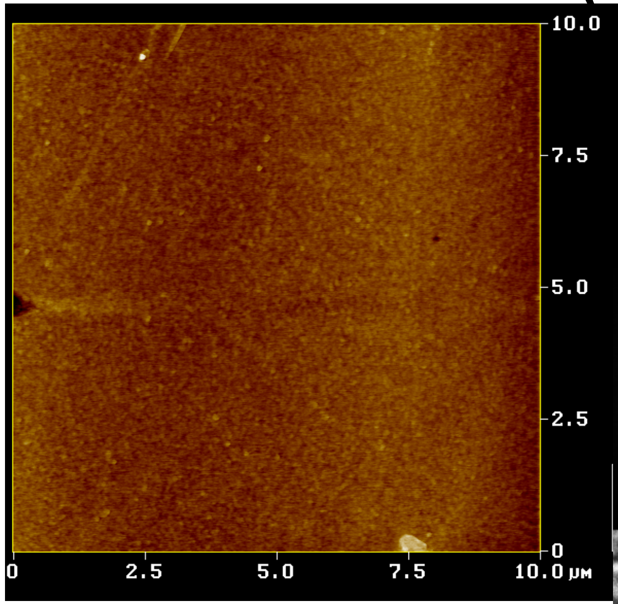
2014 Manufacturing of low-miscut crystals (<10 urad)

2018 Manufacturing based on mechanical dicing followed by chemical etching and polishing of surface entry face
Manufacturing of ultra low-miscut crystals (<1 urad)

CRYSTAL MANUFACTURING – AFM AND HRTEM –

High-quality surfaces achieved via anisotropic chemical etching

Lateral surface (AFM)

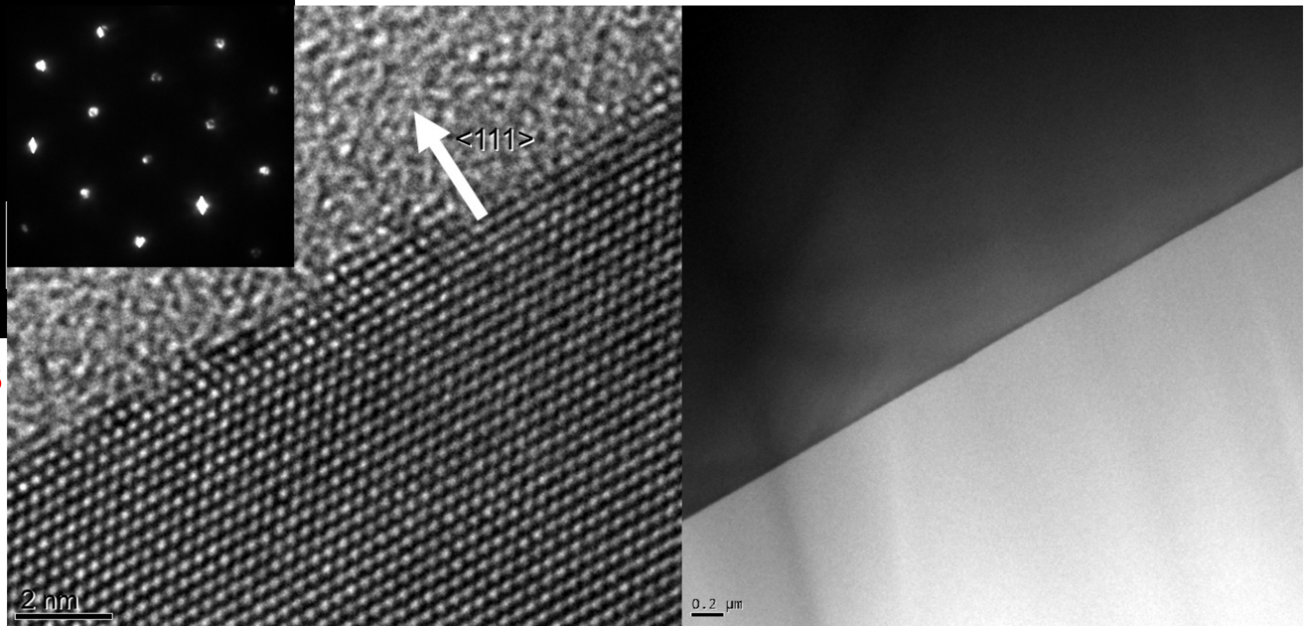


Sub-nm roughness achieved (0.2 nm)

V. Guidi et al.,
J. Phys. D: Appl. Phys. 41 (2008) 245501

Entry surface (High Resolution transmission electron microscopy).

Zero nm amorphous layer



BRIEF RECAP ABOUT HOLDERS MANUFACTURING

2006 First holders version (in collaboration with IHEP), made of Al7075

2007 FEM-assisted optimization of holder geometry

2008 First prototypes of pre-shaped holders (aluminum)

2013 Request for holders with the following specs:

- weight<90 g
- UHV compatible (bakeable)
- electron cloud compatible

→ Titanium.

About 90 commercial alloys, most common is «titanium grade 5» (90% Ti 6% Al 4% V)

2014 First generation of titanium grade 5 holders → not compatible with bake-out

2018 Pre-shaped titanium grade 5 holders now fits LHC requirements

CRYSTALS FOR THE LHC

Thickness along the beam: 4.0±0.1 mm

Height < 55 mm.

Weight < 150 g

Channeling plane: (110)

Channeling axis: <111> or <110>

Miscut for axial channeling: 0±18 mrad

Miscut for planar channeling: < 10 μrad.

Torsion: < 1 μrad/mm

Bending angle: 47.5-52.5 μrad

Dislocation density < 1 cm^2

Bake out

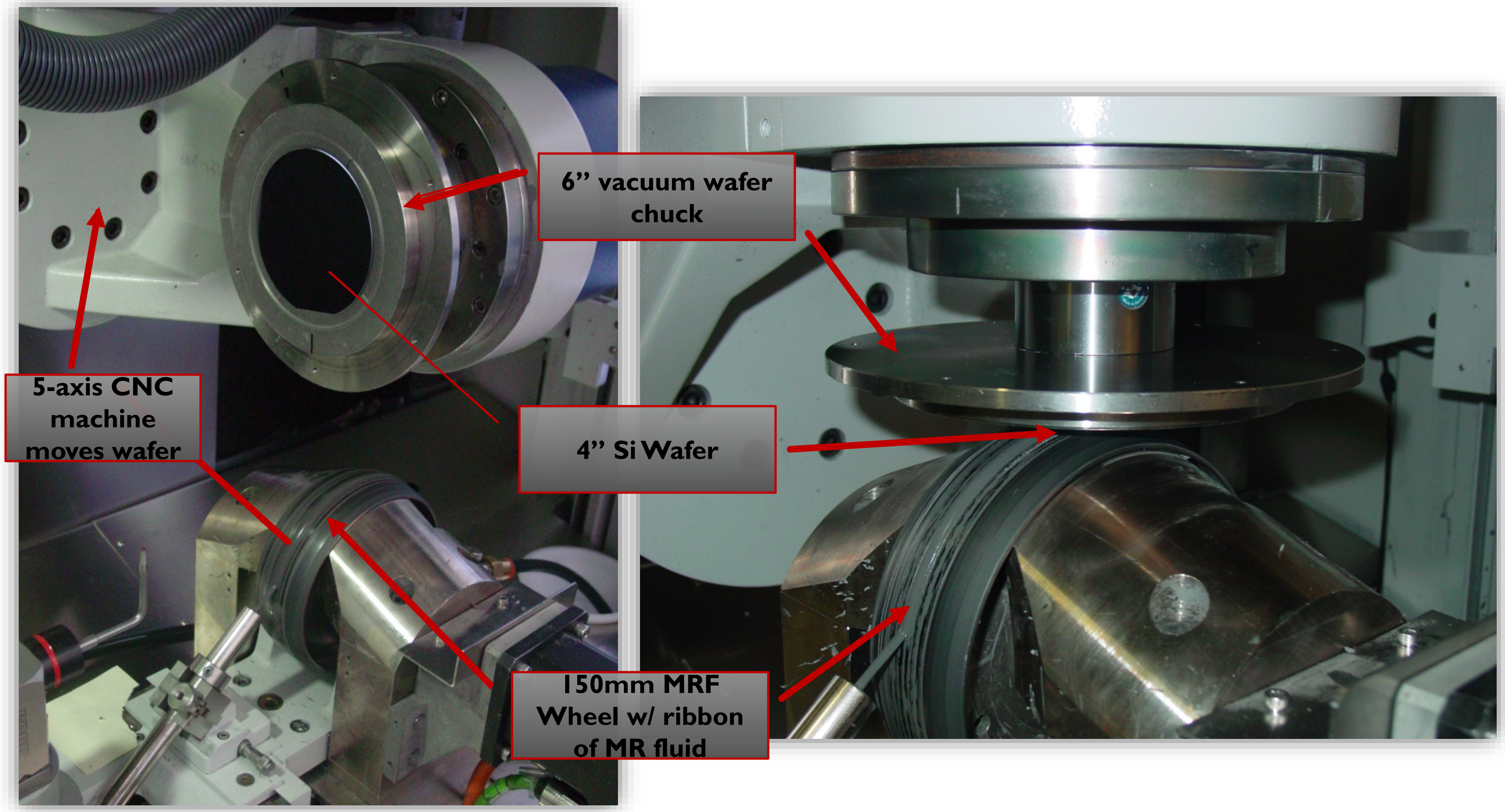
- Bake out temperature= 250°C
- heating ramp= 50°C/h
  - Bake out time =48h00
  - Number of thermal cycles: 3 at least
- Maximum allowed total outgassing after each bake out: $1*10^{-7}$ mbar·l·s^{-1}

The compliance of the mechanical properties of the crystal assemblies to the specifications of Table 1, in particular the bending angle, must be assessed after at least 3 thermal cycles.

CHALLENGING ASPECTS

- ✓ Planar miscut: < 10 µrad→ MRF finishing
- ✓ Torsion: < 1 µrad/mm → ultra precise machining and assembly.
- ✓ Bending angle: 47.5-52.5 µrad → ultra precise machining and assembly.
- ✓ Dislocation density < 1 cm^2 → standard for microelectronics is 1 order of magnitude higher→ purchase of large quantity of silicon wafers and selection of the best ones.

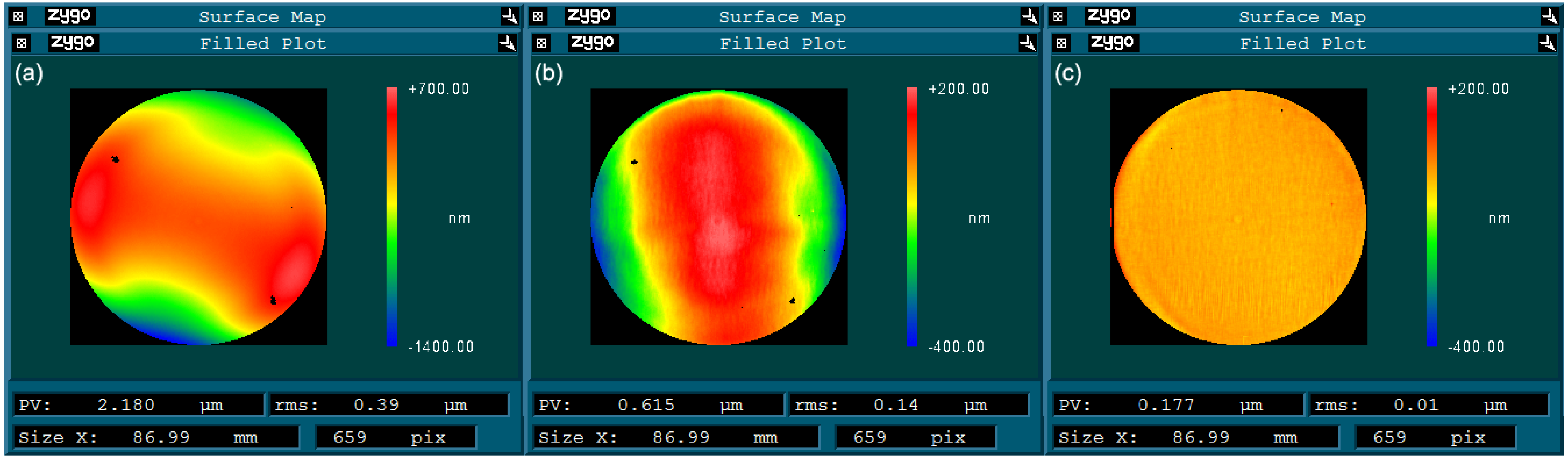
MRF FINISHING



Technique developed for astronomy applications (glasses and ceramics, i.e. amorphous materials)

After a 2 years R&D the tecnique was adapted to operate on crystalline materials.

MRF FINISHING



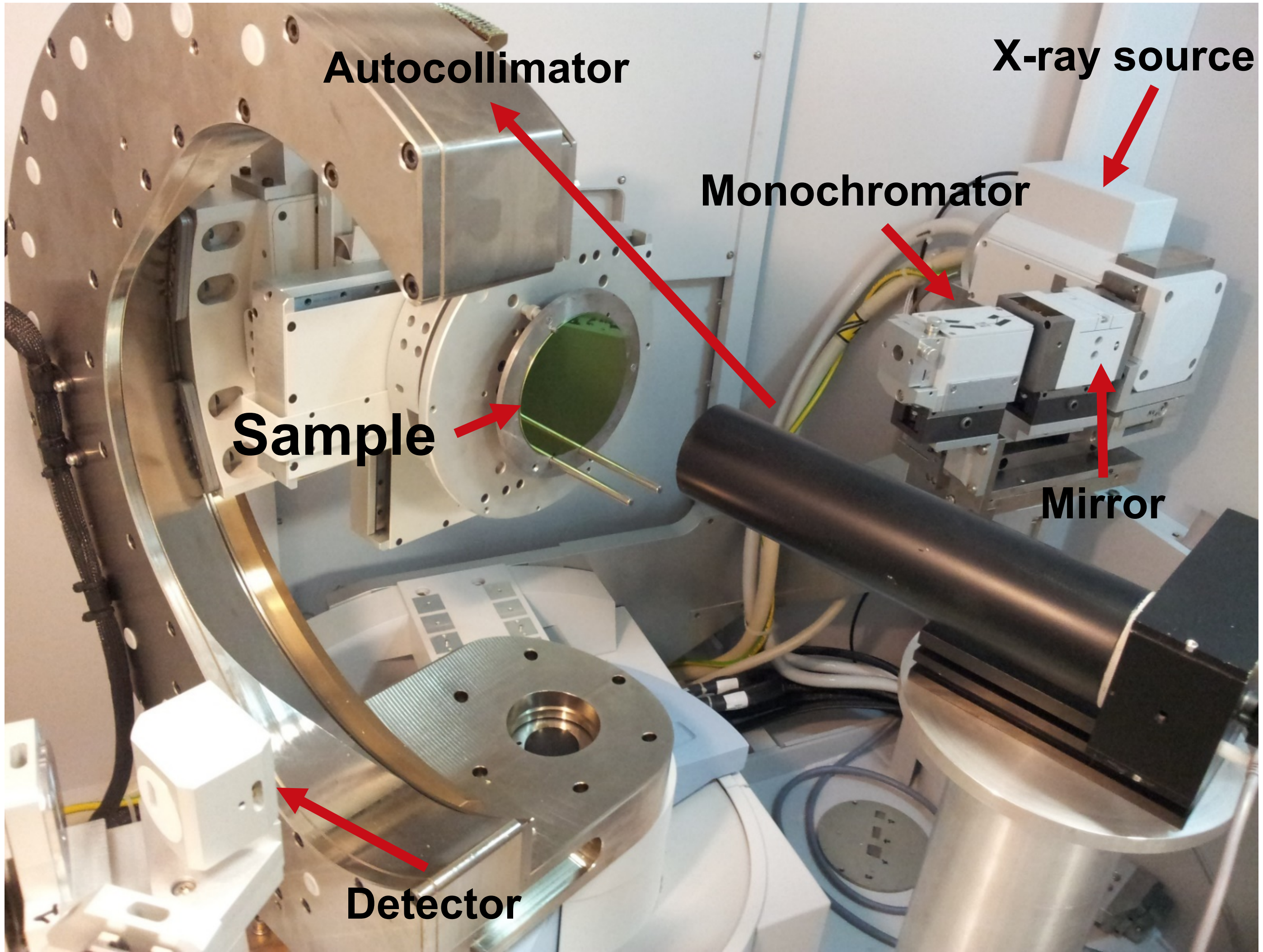
Starting surface
PV 2.18 um
RMS 0.39 um

Surface after first treatment
PV 0.615 um
RMS 0.14 um

Final surface
PV 0.177 um
RMS 0.01 um

- MRF is a deterministic polishing process
- Does not induce any lattice damage
- Miscut < 1 urad

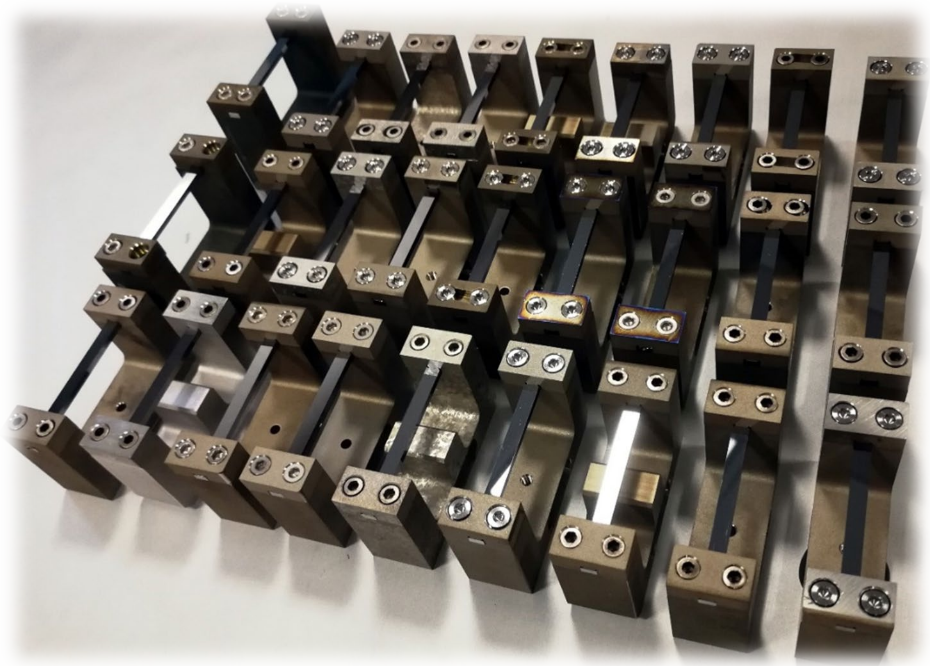
MISCUT REDUCTION



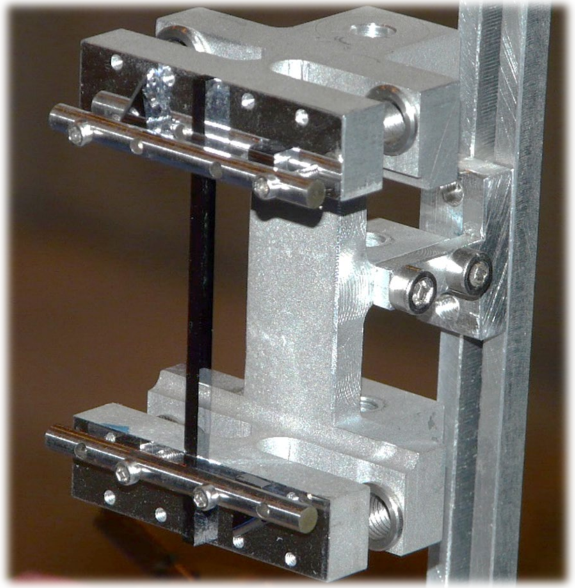
- High resolution x-ray diffractometer (PANALYTICAL)
- Miscut: angle between optical surface and atomic planes
- Requested miscut < 10 μad.

RECENTLY DEVELOPED CRYSTALS

- Developed «pre-shaped» holders made of titanium grade 2 and grade 5.
- High-resolution x-ray diffraction characterizations: analysis of correlation
- Investigated thermal stability of holders+crystal assembly.
- Crystals for the LHC

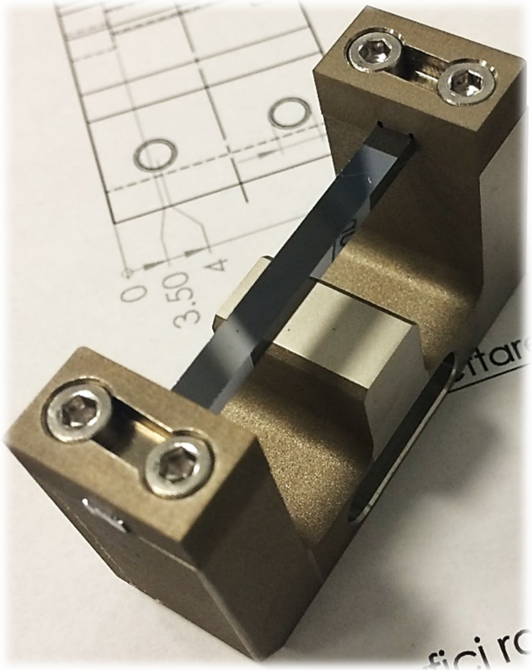


PRE-SHAPED HOLDERS



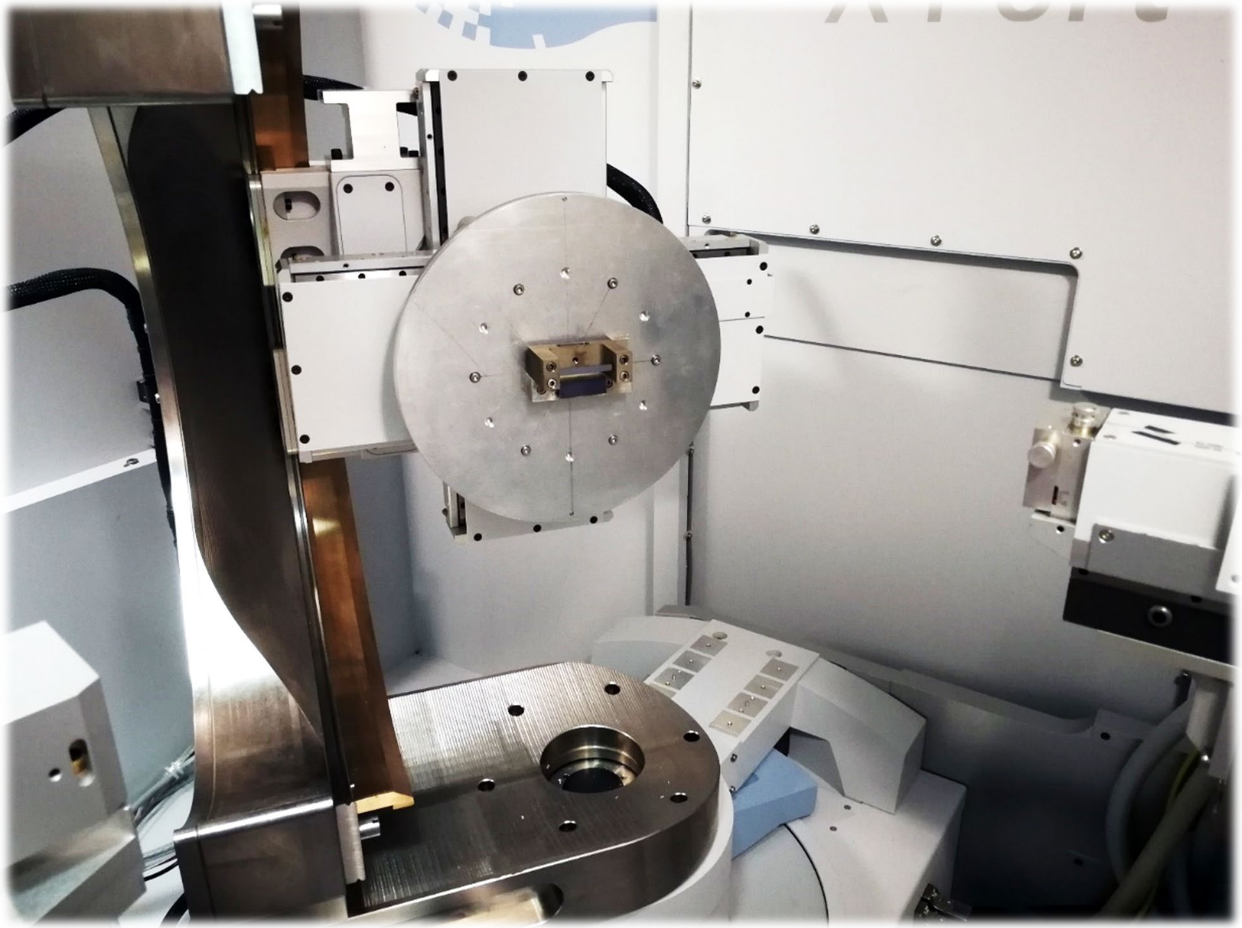
A pre-shaped holder manufactured in 2011 for UA9. Holder was made from aluminium and torsion correction mechanism still used. Base for development of current holders.

- Ultra-high precision machining provides holders with crystal-supporting surfaces inclined at a proper angle to impart to the crystal the desired deformation.
  - At first step, the holders are manufactured with approaches typical of conventional precision mechanics.
  - selected holders are treated with super-finishing techniques to adjust surface inclinations.
- Approach already developed for crystals installed in the SPS and for studies of multiple-volume reflections (~2010÷2015)
- Design is now revisited:
  - holders made of titanium grade 2 and grade 5 (previous version was made of aluminium).
  - removed torsion-adjustment mechanism.



A pre-shaped holder for LHC. Holder is made of titanium. Flexure for torsion adjustment have been removed.

Crystal	Deflection angle (μrad)		Consistency
	High resolution x-ray diffraction	Channeling	
STF47	33±2	35±2	YES
STF48	144±2	142±2	YES
STF49	247±3	246±2	YES
STF50	142±5	143±2	YES
STF51	33±2	33±2	YES
STF70	56±2	55±2	YES
STF71	60±5	62±2	YES
STF99	119±3	120±2	YES
STF100	67±6	63±2	YES
STF101	170±6	165±2	YES
STF102	45±3	42±2	YES
STF103	52±5	54±2	YES
STF104	95±5	91±3	YES
STF105	49±3	50±2	YES
STF106	42±2	42±2	YES
STF107	56±2	56±2	YES
STF110	52±3	54±2	YES
STF110	56±10	62±2	YES
STF112	64±3	63±2	YES
STF113	46±3	45±1	YES
STF114	52±3	52±1	YES
STF117	53±3	50±1	YES
STF118	52±3	53±1	YES
STF119	54±3	52±1	YES
STF120	54±3	52±1	YES
STF121	48±3	48±1	YES
STF122	50±3	46±1	YES
SFT123	52±3	52±1	YES
PL08	715±30	706 ± 2	YES
PL09	1040±50	1067 ± 2	YES

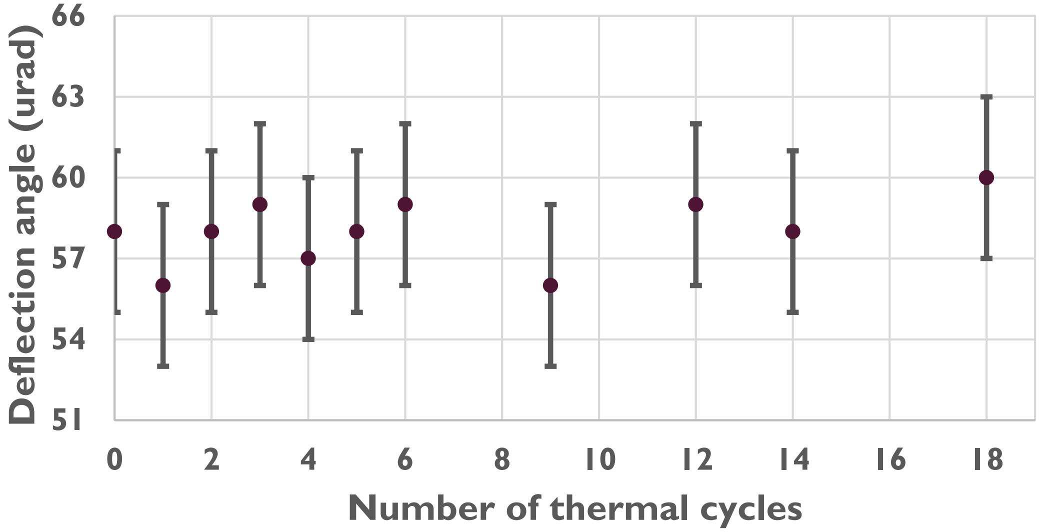


Determinantion of crystal bending angle with high-resolution x-ray diffraction and channeling of high-energy particles are in good agreement.

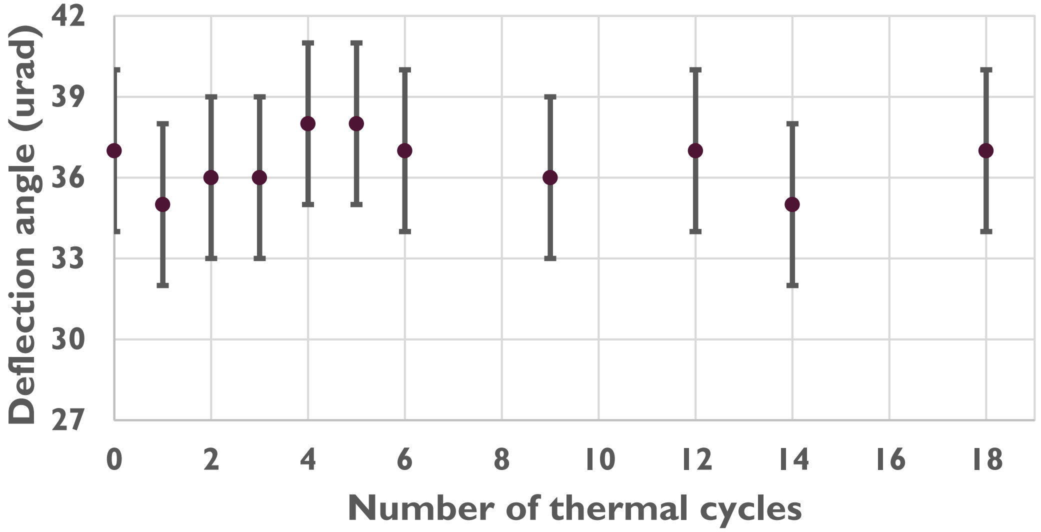
HOLDERS THERMAL STABILITY

Crystal bending angle is measured through high-resolution x-ray diffraction before and after thermal cycles for 41 holder+crystals assemblies.

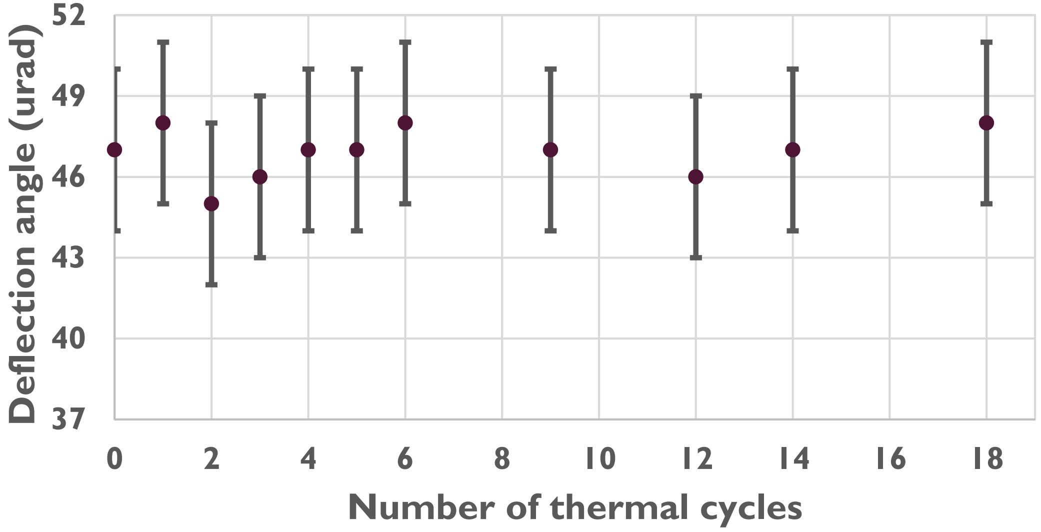
Crystal #1



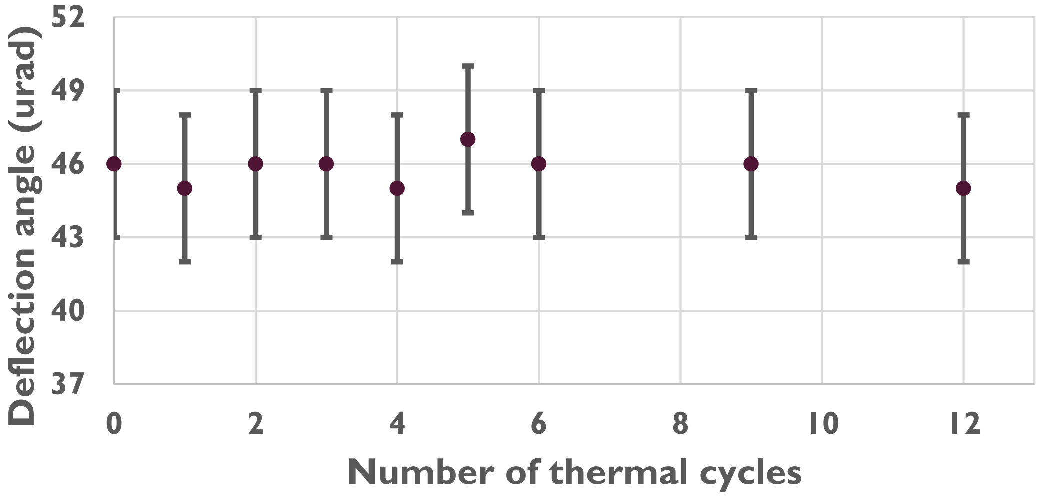
Crystal #2



Crystal #3

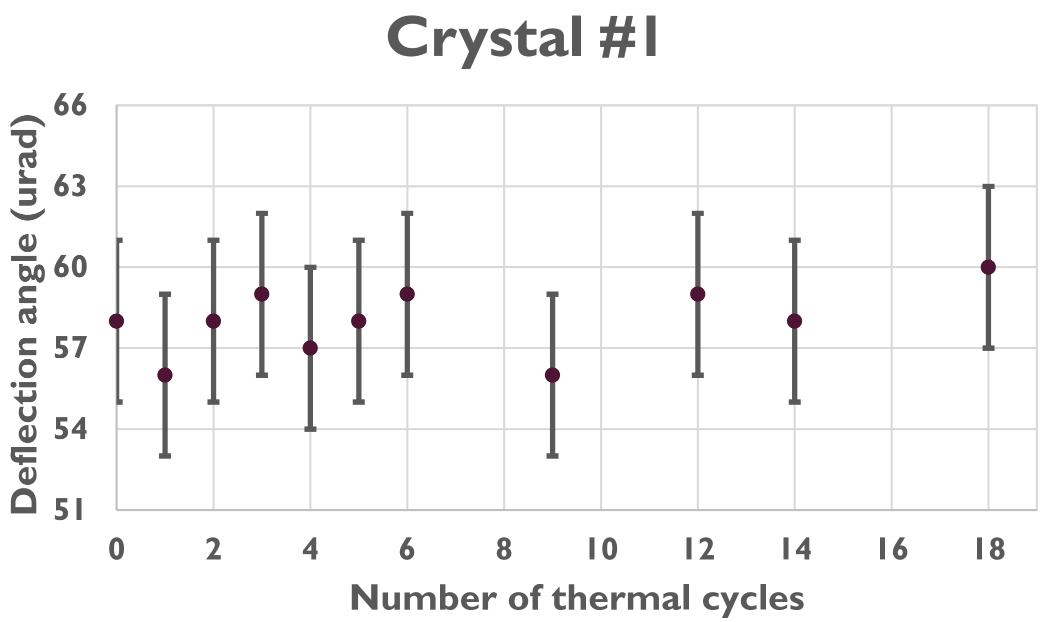


Crystal #4



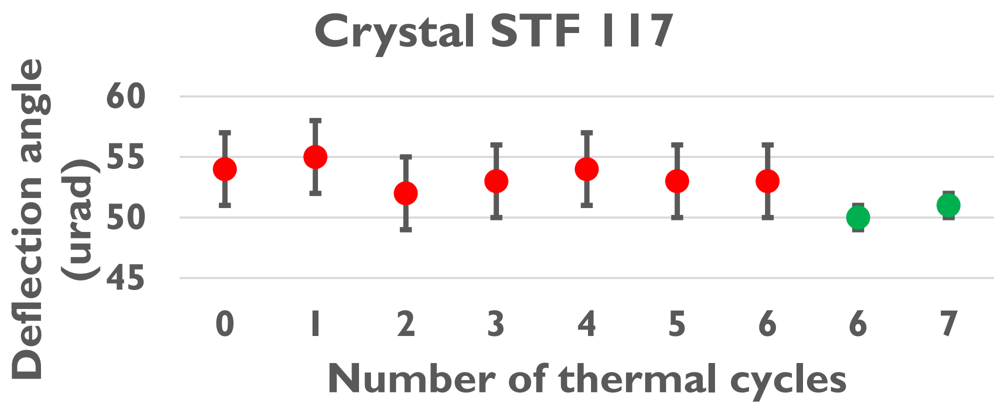
HOLDER STABILITY VS BAKE-OUT: CONCLUSIONS

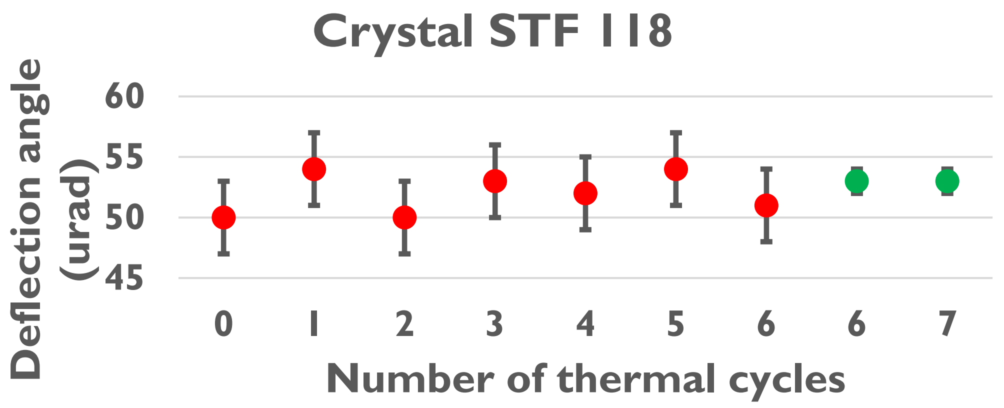
- Manufactured 41 holders (31 titanium grade 2+10 titanium grade 5).
- 41 holders subjected to bake-out thermal cycles. Performed a total of 243 thermal cycles.
- For all the cases crystal bending angle is stable.

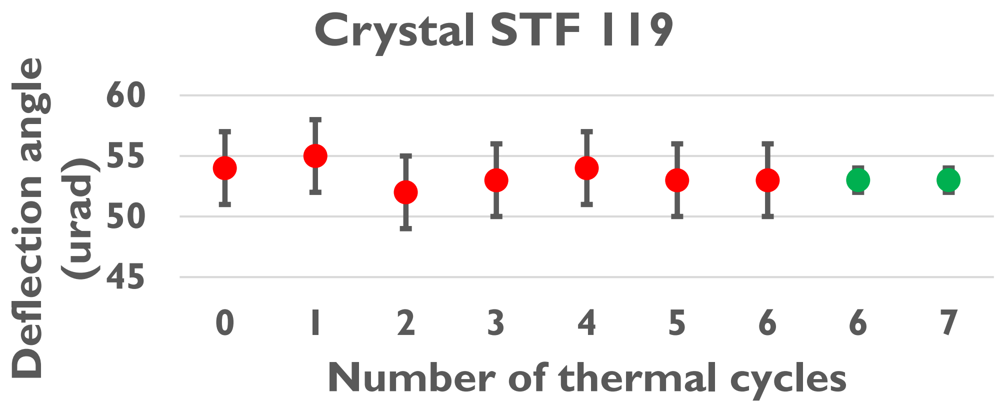


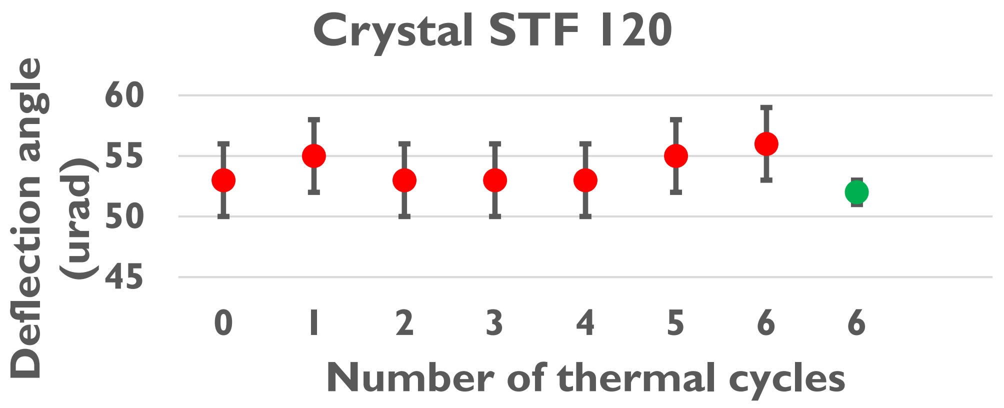
Newly developed holders (both titanium grade 5 and titanium grade 2) are thermally stable with respect to bake-out cycles.

CRYSTALS FOR THE LHC

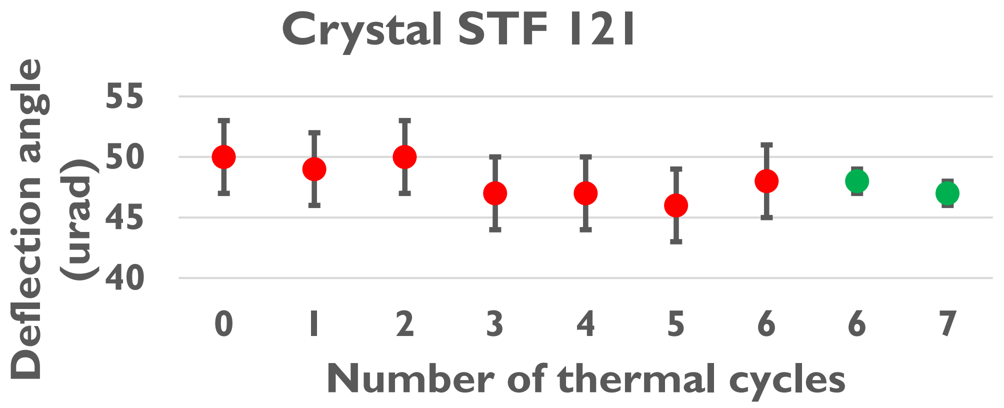


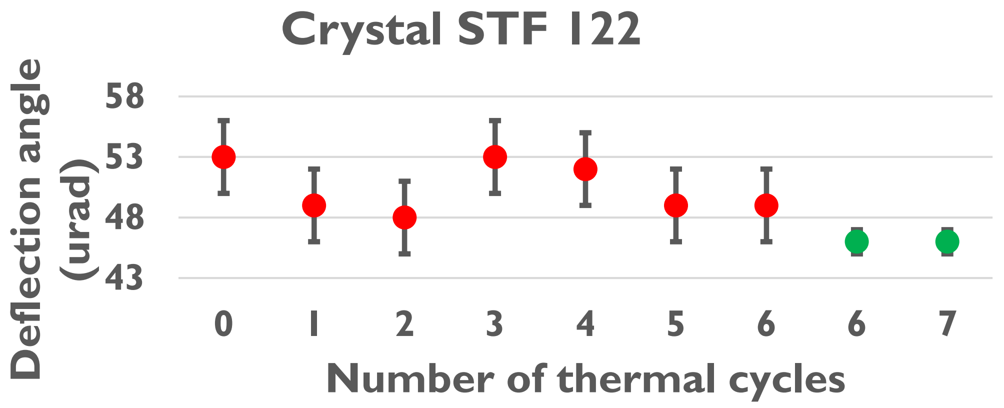


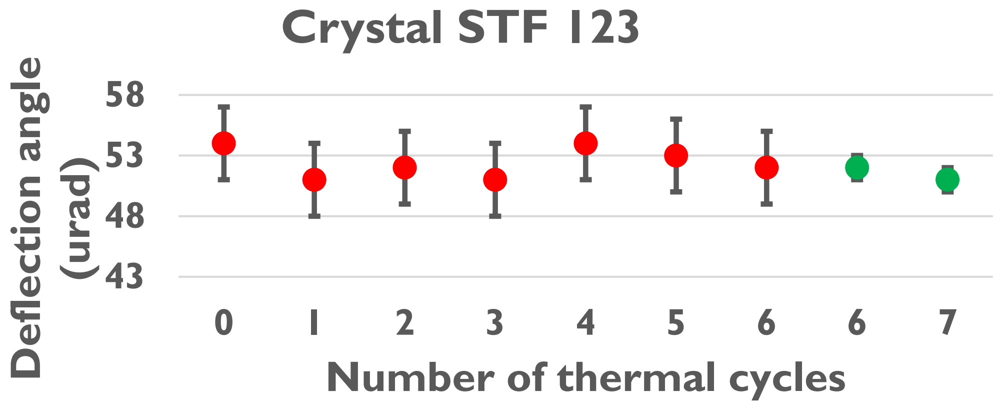


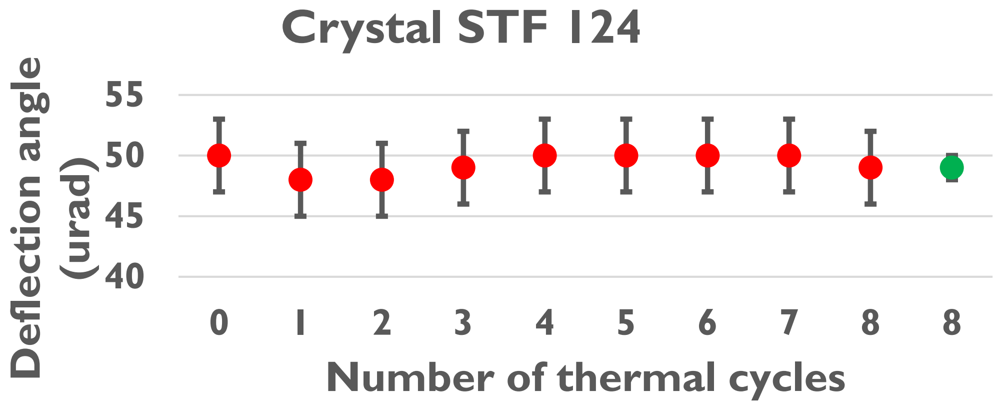


CRYSTALS FOR THE LHC

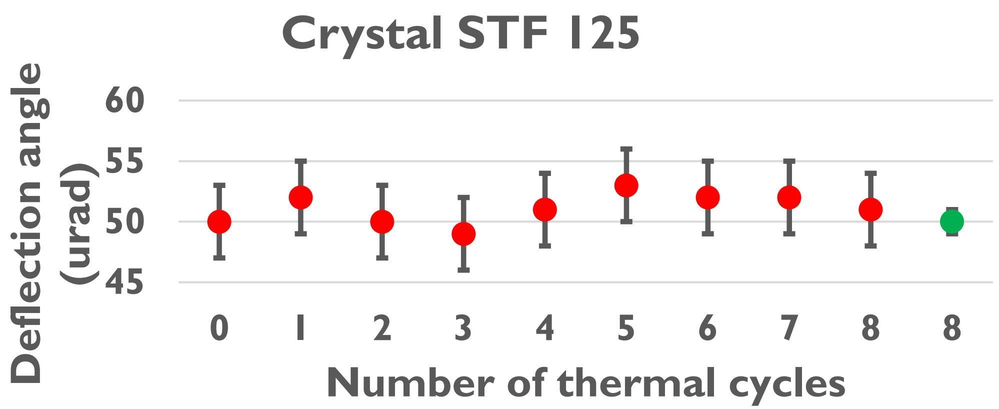


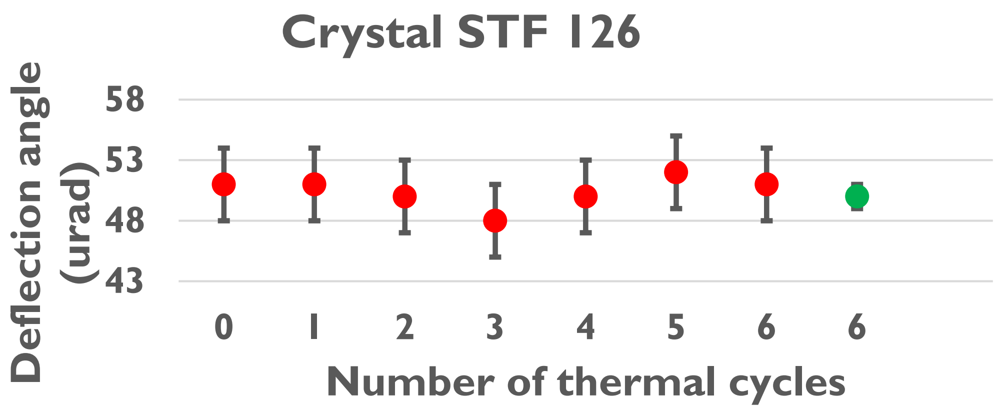




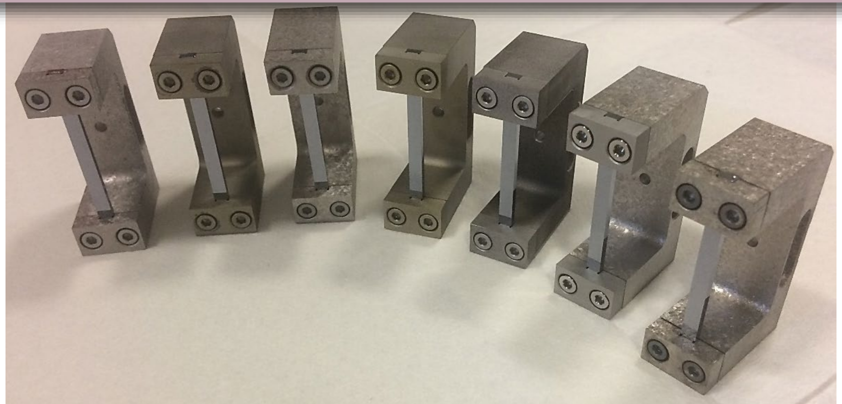


CRYSTALS FOR THE LHC



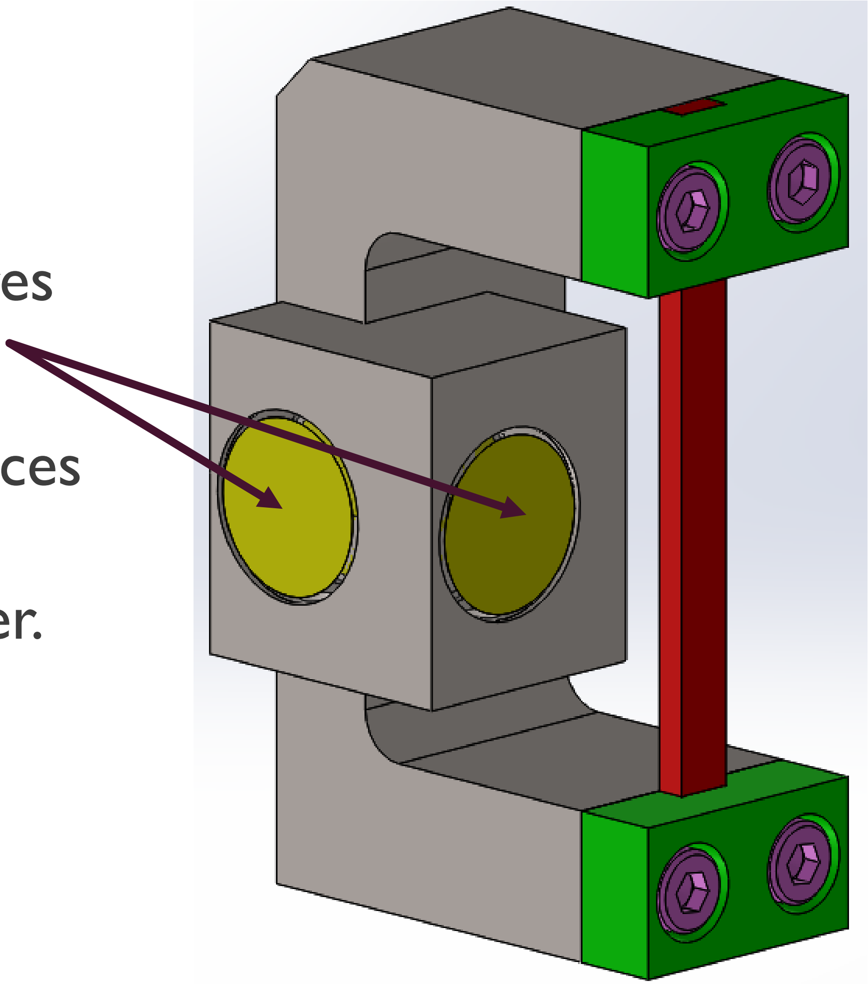


Crystal code	Bending angle	Miscut	Bakeable
STF117	51±1	6±1	YES
STF118	53±1	6±1	YES
STF119	53±1	6±1	YES
STF120	52±1	6±1	YES
STF121	47±1	6±1	YES
STF122	46±1	6±1	YES
STF123	51±1	6±1	YES
STF124	49±1	6±1	YES
STF125	50±1	6±1	YES
STF126	50±1	6±1	YES



INSTALLATION IN THE LHC

- Prealigment of the crystal to the beam requires presence of references mirrors.
- Alignment of the mirror surfaces to the surfaces of the crystal measured with a accuracy and precision of a few μrad with an interferometer.



MOST RECENT DEVELOPMENTS (ONLY IN 2018)

- Crystals with miscut less than 1 urad
- Assessed a correlation between x-ray and particle measurements
- Improved manufacturing approach delivers mirror-like entry face surfaces (for an easier aligment of the crystal to the beam)
- Thanks to the experience already gained in development of holders for the SPS, pre-shaped holders made of titanium (grade 2/grade 5) are now available
- Holders/crystals assembly are now bakeable to 250 °C
- Tight requirement on bending angle can be routinely satisfied
- Recent progresses on torsion reduction

CONCLUSIONS

- INFN owns the expertise, technical resourses, manpower to perform channeling experiments at any wordwide facility.
- Established a protocol for manufacturing of crystals free from crystalline defects.
- Possibility to deliver crystals with miscut lower than 1 urad.
- Holders made of titanium (grade 2 and grade 5) are thermally stable.
- Developed a protocol to manufacture crystals matching requirements for installation in the LHC.