





Operational Status of the LHC Crystal Goniometers and Foreseen Upgrade

Mario Di Castro,
BE-CEM

With inputs from BE-ABP and SY-STI

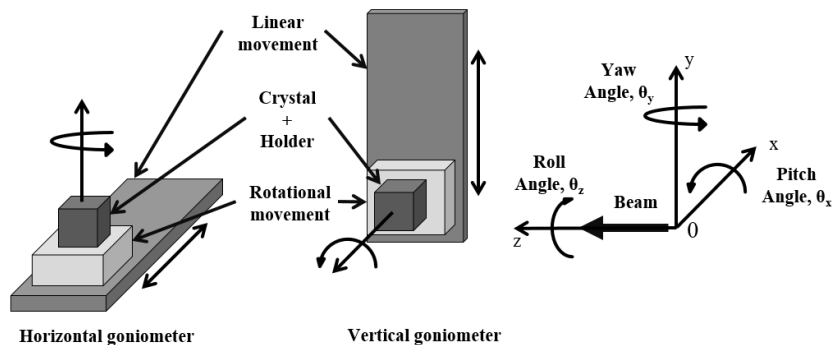


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Goniometers for Crystal Collimation Specifications— A technological challenge

- High-precision angular positioning system



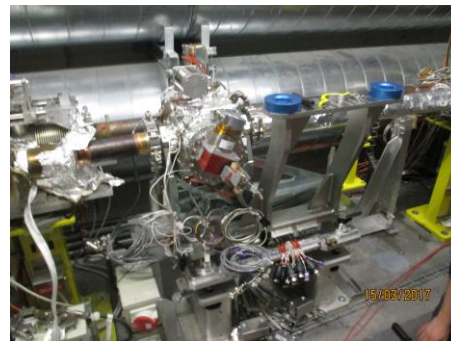
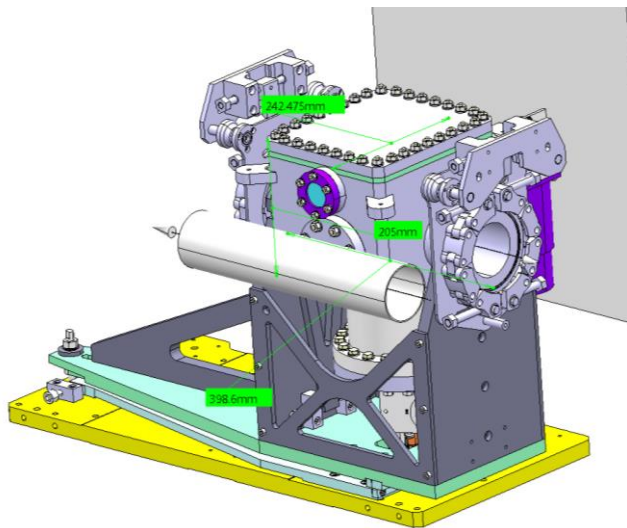
Property	Specification
Linear stroke	> 50mm
Linear resolution	5 μ m
Linear accuracy	+/- 20 μ m
Total angular range	+/- 10 mrad
Yaw angular resolution	0.1 urad
Yaw angular accuracy over the entire linear range	+/- 1 urad
Yaw angular overshoot	10%
Yaw angular settling time	20 ms
Yaw angle max speed in scan mode	50 urad/s
Pitch angular accuracy over last 10 mm travel	Few urad
Roll angular accuracy over last 10 mm travel	Few tens of urad

Orientation independent angle nomenclature	Angle w.r.t. beam	
	Horizontal goniometer	Vertical goniometer
Rotation	Yaw	Pitch
Tilt	Pitch	Yaw
Roll	Roll	Roll

From slides by A. Masi,
[HL-LHC Crystal collimation Day, 19.10.2018](#)

Piezo goniometer design concept

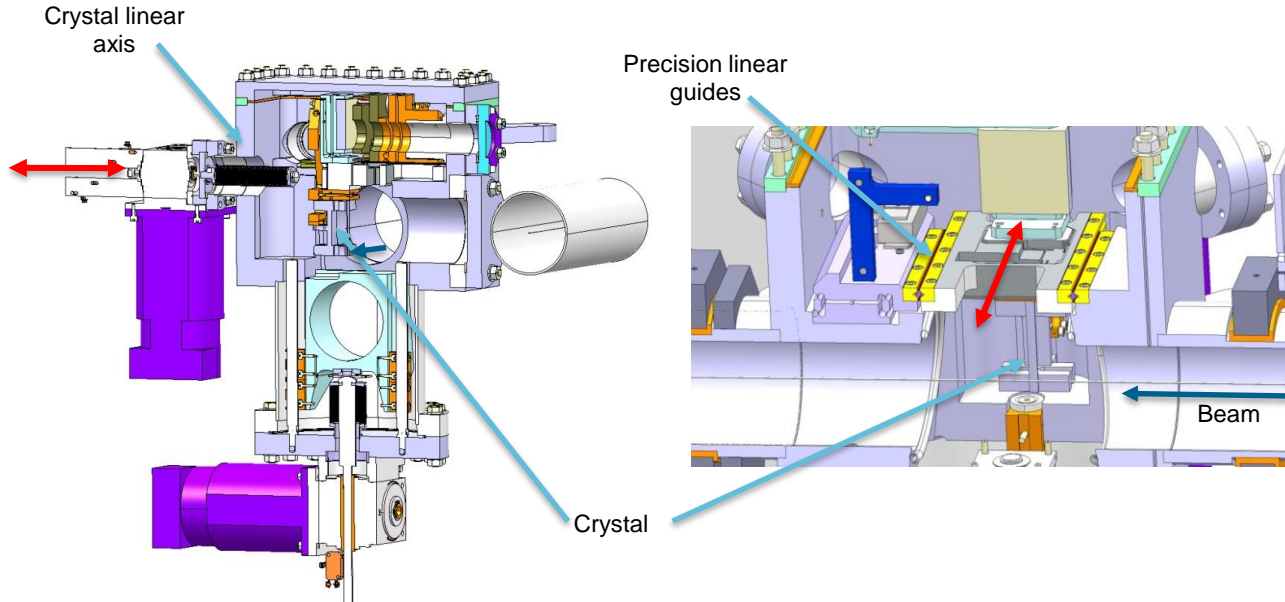
- Linear movement: Stepper motor actuated lead screw drive axis
- Rotational movement: Piezo actuated rotational stage
- Present design is not usable with high-intensity proton beam
 - ✓ Impedance concerns can be solved with a new chamber design



TPCV.A6R7 B2 Vertical

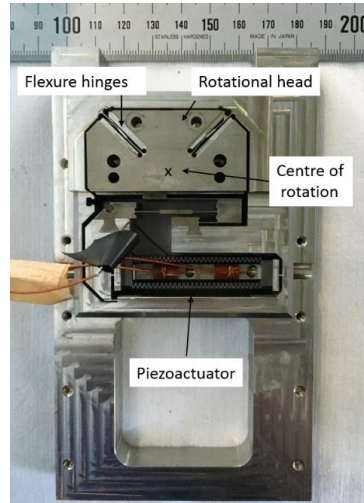
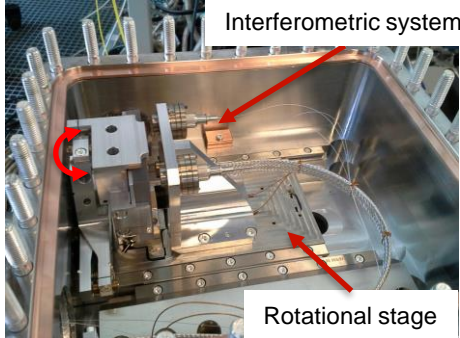
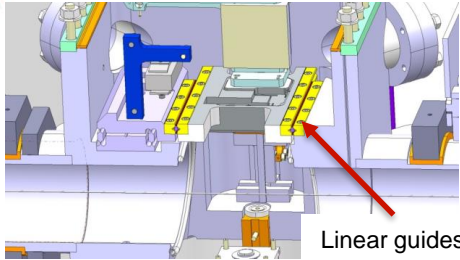
Linear movement

- Stepper motor actuated linear axis to insert/move-out the crystal from beam path
 - ✓ Beam pipe segment inserted when goniometer not in operation to make device 'transparent' to the high-intensity circulating proton beam
- Precise linear roller ceramic bearings with cage in stainless Steel AISI 316L to minimize the crystal parasitic angles during the linear movement



Rotational movement

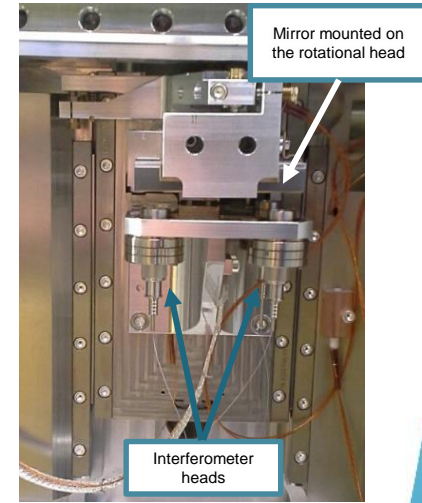
- Piezo actuated high-precision rotational stage mounted on linear axis
 - ✓ Controlled in closed-loop
- Interferometric system to monitor the crystal rotation w.r.t. beam axis



Rotational stage (V1) used in Beam 1 goniometers.



High stiffness rotational stage (V2) used in Beam 2 goniometers.



Interferometric system common in all goniometers.

Goniometers for Crystal Collimation

- **4 Goniometers installed for RUN2-MDs. They were not designed/conceived to be in operation for RUN3 without any upgrade during LS2**

Functional Type	Position	Crystal Type	Installation Year	Version
TCPCH	A4L7.B1	SD (INFN)	2013 (LS1)	1
TCPCV	A6L7.B1	QM (PINP)	2013 (LS1)	1
TCPCH	A5R7.B2	SD (PINP)	2018	2
TCPCV	A6R7.B2	QM (PINP)	2017	2

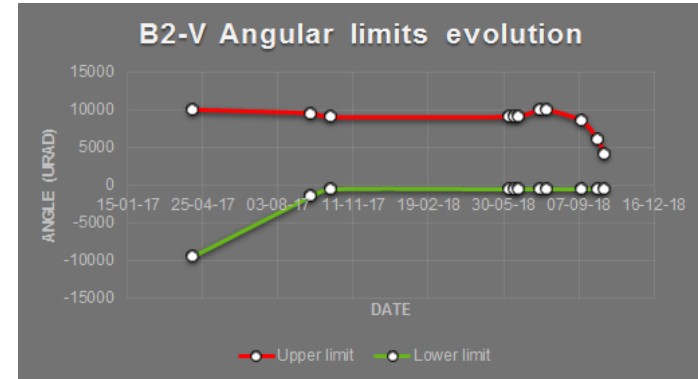
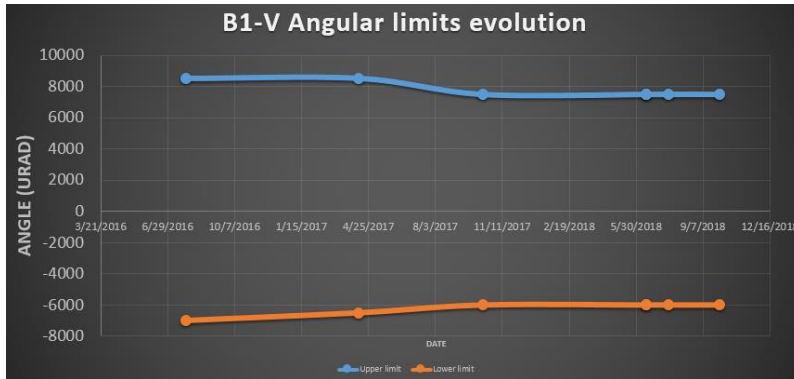
- ✓ Version 1 used for beam 1 (2015)
- ✓ Improved hardware V2 installed on B2 (2016-2017)

*From slides by M. Calviani,
[HL-LHC Crystal collimation Day, 19.10.2018](#)*

- **Different type of crystals**
 - ✓ 2 Strip and 2 Quasi-mosaic (less performance with ions)
- **New Goniometer generation (Version 3) under production to increase reliability, availability, maintainability and safety (RAMS)**

Operational Issue during RUN2– Interferometric system angular range reduction

- The interferometer signals were degrading slowly during RUN2, most probable due to radiation effect on the fibers. Crystal angular motion ranges were decreasing w.r.t. installation



Example of crystal angular range reductions on goniometers during RUN2, range stable during LS2

More info:

[120th HL-LHC Technical Coordination Committee](#)

Overview of current situation

Name	Position	Status	Current Rotational range [μ rad]	Total range reduction during RUN2 w.r.t. range at installation [%]
TCPCH.A4L7.B1	B1 Horizontal	Operational	[-6000, +5000]	20 %
TCPCV.A6L7.B1	B1 Vertical	Operational	[-6000, +7500]	30 %
TCPCH.A5R7.B2	B2 Horizontal	Operational	[-5500, +8500]	30 %
TCPCV.A6R7.B2	B2 Vertical	Operational	[-500, +3000]	85 %^o

Performance issue,
Quasi-mosaic crystal
(M. D'Andrea, [COLUSM#137](#))

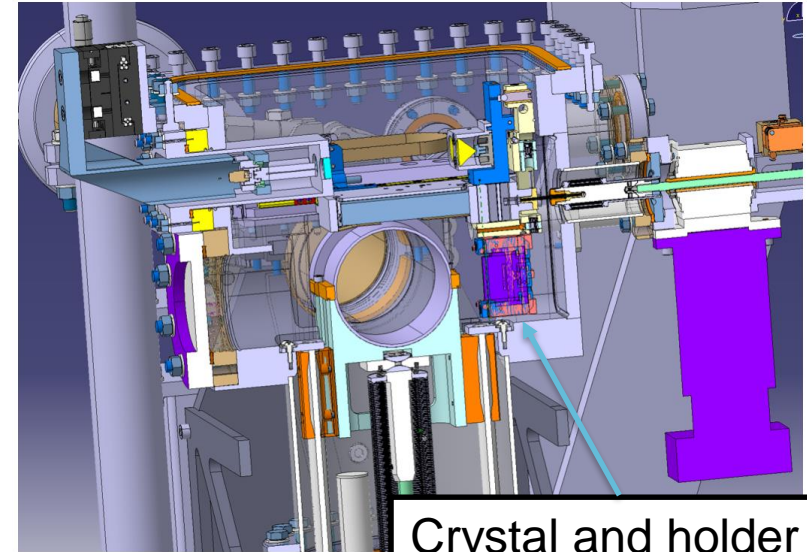
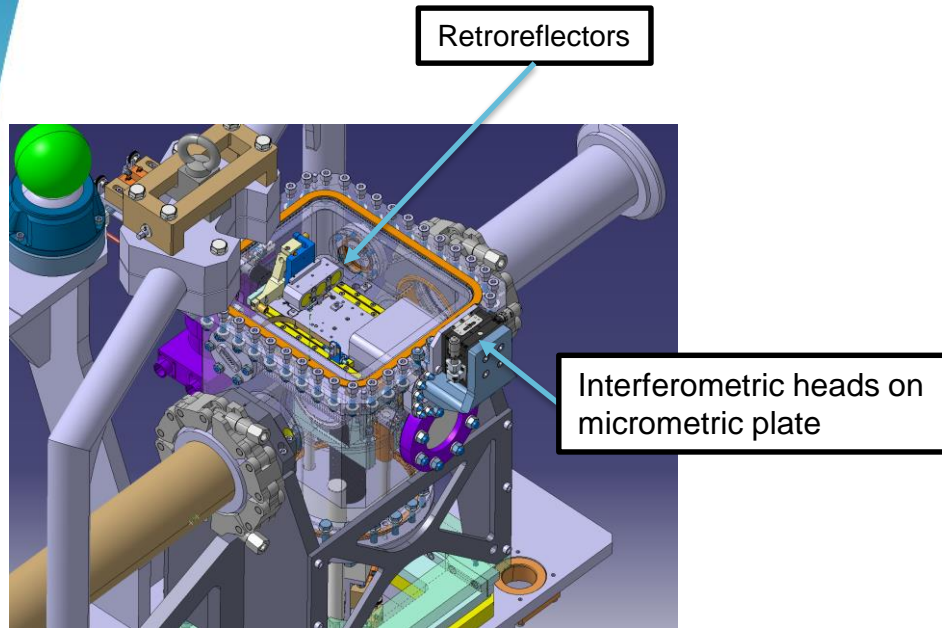


Functional issue

^o The optimal channeling orientation of RUN2 is close to the lower limit

- Interferometric axis have reduced their operational range during RUN2 operation
- Regular checks during LS2 are confirming operational conditions and stable angular ranges
- Further degradation to be expected during the whole RUN3
- No spare device
- Current operational conditions clearly not sustainable in 2022 for the TCPCV.A6R7.B2
 - ✓ High probability of channeling angle exclusion w.r.t. the angular operational range
- Vertical goniometers need to be upgraded first during YETS-2021

New Design -> Version 3 - Overview



From slides by I. Lamas, [130th CoLUSM](#)

New Design -> Version 3 – Main Improvements

- Replacement chamber for high-intensity proton operation
- Added redundancy in angle measurements
- Retroreflectors substitute mirrors in the interferometric system to increase angular acceptance ranges
- Interferometer heads moved to the outside of the vacuum chamber allowing:
 - ✓ Maintenance/replacement of fibres without opening the tank
 - ✓ Reduced radiation degradation risk
- 2 x new generation Goniometers to be installed for RUN3 during YETS 2021, which will replace two existing goniometers (vertical ones)
 - ✓ ECR under finalization (EDMS Nr. 1973224)

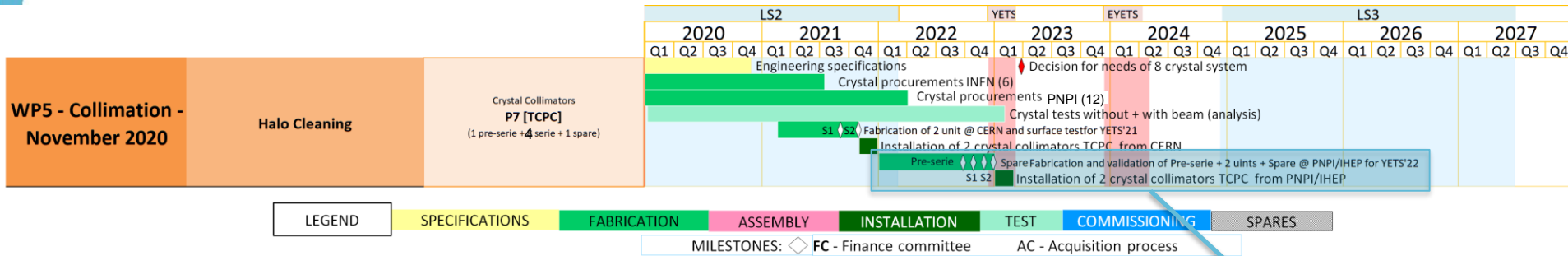
Operational Considerations for RUN3

- Crystals validation tests
 - ✓ Test using X-Ray beam are ongoing/planned
 - ✓ Tests with beam are needed to measure crystals efficiency for the final decision on which one to install

- Functions for crystals positioning control should be prepared for RUN3 operation
 - ✓ The interlocking strategy and the requirements for the operational sequence were discussed
 - ✓ Time-dependent interlock limit functions will be added for the crystal linear stage to allow changes in dynamic machine phases, for example in the energy ramp (discussed at the [LHC Collimation Working Group #252 - Joint MPP](#))
 - ✓ Insertion in the proton sequence of crystal checks

- Crystal Goniometers will be “treated” like any other operational Collimators
 - ✓ Device ownership and responsibility within SY/STI
 - ✓ Controls hardware, low-level control software and operational piquet responsibility within BE/CEM

Preliminary Timeline



Needed to be respected by PNPI/IHEP

Conclusions

- The probability of further rotational range reduction on installed goniometers, can increase during RUN3, with the risk of excluding channeling achievement.
 - ✓ Crystals angular ranges are currently within acceptable tolerances on 3 goniometers
- The installation of 2 new units for YETS-2021 replacing the vertical goniometers, + 2 new ones replacing the remaining horizontal units during YETS 2022, will strongly decrease the probability of failures during RUN3
 - ✓ The probability of failures on the horizontal goniometers is much lower w.r.t. the vertical one TCPCV.A6R7.B2
 - ✓ LS2 checks are confirming a stable conditions of the angular ranges
- Requested beam time to test the installed goniometers in the Oct. 2021 run
- The new generation goniometer can ensure an operational device for RUN3, characterized by a proper reliability, availability, maintainability and safety

Thank you!

