# Crystal interlocks and OP tool for channeling re-optimization

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LHC Collimation Working Group #276 – Joint MPP

# Outline

***Interlock strategy***

# Introduction

- Document issued and uploaded on EDMS
- EDMS NO: 2803940
- Main aim: describe the interlocks to be deployed for crystal collimators prior to their operational use with heavy-ion beams

| EDMS NO. | REV. | VALIDITY |
|---|---|---|
| 2803940 | 0.1 | DRAFT |

| REFERENCE |
|---|
| LHC |


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## Strategy for Crystal Collimation Interlock for Ion-Beam Operation


### Abstract

This document describes the interlocks deployed for the crystal collimation system that is planned to be used operationally at the LHC as of 2022 for the operation of heavy-ion beams. In particular, we describe the interlocks put in place for the crystal primary collimators (called TCPCs).




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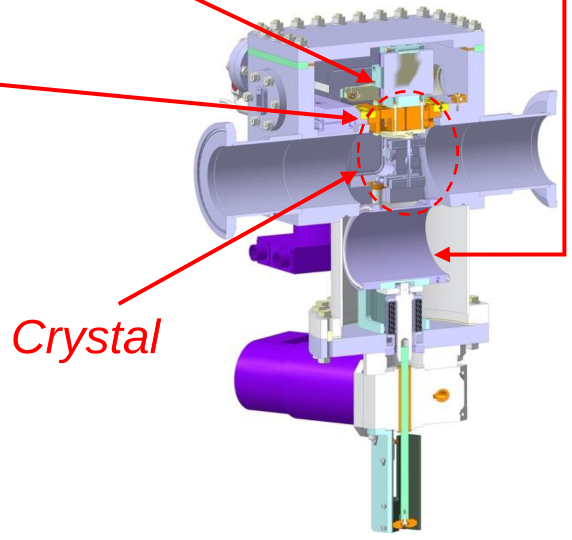
# Recap of TCPC hardware

The TCPC has three main components:

- A replacement pipe that ensures electrical continuity to the adjacent pipes when crystals are not used
- A linear stage based on stepper motors also used for standard LHC collimators
- A rotational stage based on a piezo actuator in closed loop

provide the required angular-adjustment performance

| Device | Installation | Version |
|---|---|---|
| **TCPCH.A4L7.B1** | YETS 2022-2023 | 3 |
| **TCPCV.A6L7.B1** | YETS 2021-2022 | 3 |
| **TCPCH.A5R7.B2** | YETS 2022-2023 | 3 |
| **TCPCV.A6R7.B2** | YETS 2021-2022 | 3 |




*If angular reference lost:*

1. recovery procedure
2. optimal channeling orientation must be established again
3. new ramp functions must be generated
4. test ramp with safe beams must be performed to validate the new settings

*Dedicated task in the sequencer to check closed loop while preparing the machine for injection*

# Operational Modes

| | *Physics production* | *Safe beams* |
|---|---|---|
| **Crystal insertion** | All fills during either proton or heavy ion physics | Dedicated fills during MDs or beam commissioning |
| **Crystal handling** | Automated via sequencer | Manual by collimation expert |
| **BE-CEM support** | Piquet must be called in the case of any issue | Support will be present in the CCC |

# Interlocking Strategy

| | *Proton physics* | *Ion physics* | **Machine Development** |
|---|---|---|---|
| **Operating mode** | Physics production | Physics production | Safe beams |
| **Replacement pipe** | Closed to “in-beam” | Open to “out-beam” | Open to “out-beam” |
| **Crystal position** | Fully retracted | Primary aperture restriction | Manual handling |
| **SIS interlock** | Active | Masked | Masked |
| **BIS interlock** | Active | Active | Masked |
| **Functional position limits** | Active | Active | Masked |
| **Redundant energy limits** | Active | Active | Masked |

# Interlocking Strategy – additional considerations

- **No interlock** on the crystal **angle** is applied because the RMS noise of the piezo actuator (~1μrad) is too close with critical channeling angle at 7 TeV (~2μrad)

- **Multi-turn** dynamics allows to **keep the channeling** regime with a misalignment of up to 1.5-2 critical angle

- Cleaning **performance** of the crystal assisted system will be validated by means of **loss maps** for both **optimal crystal orientation** and misalignments large enough to cause **losing the channeling regime**

- The **BLM thresholds** will need **important adjustments** particularly in IR7, based on numerical simulations and fine-tuned using results obtained during validation loss maps.

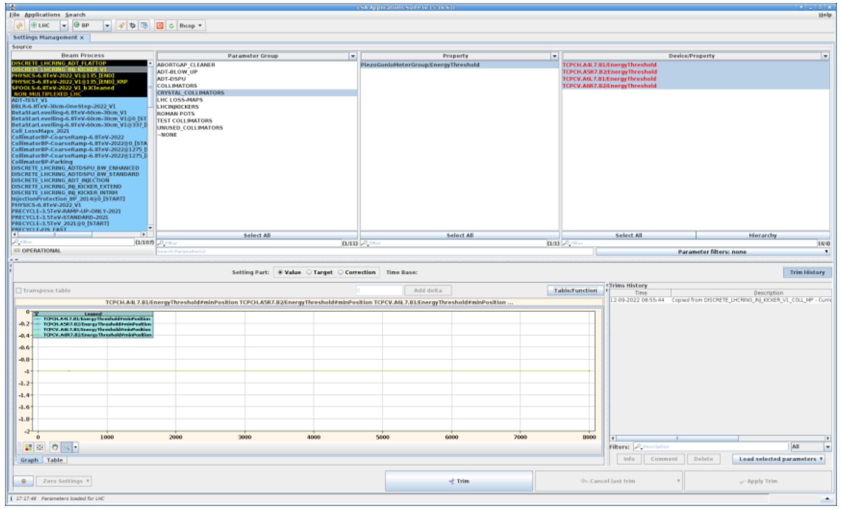
# Outline

***Operational handling***

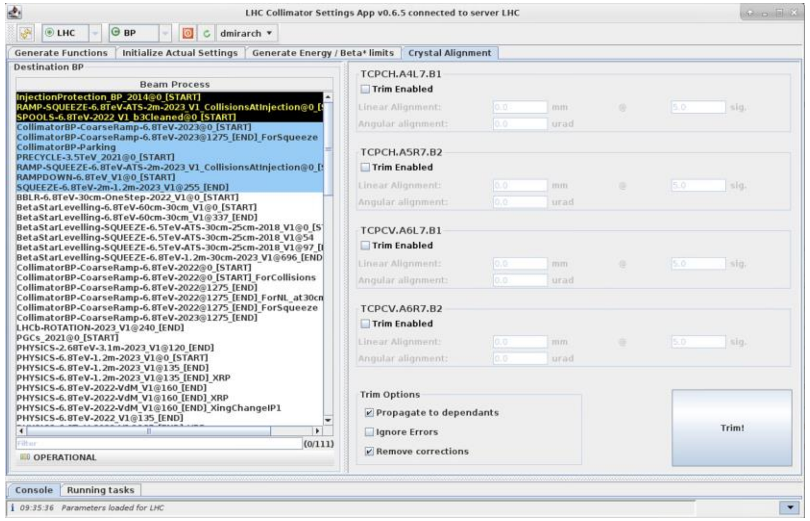
# Settings

- **Improved FESA** interface has been deployed and tested in order to make LHC crystal goniometers compatible with operations over long runs and the complete machine cycle, taking as reference the class of standard collimators

**Settings** for both rotational and linear stages are stored in **LSA**, together with limits on the latter



Possible to **rely on well-established high-level settings generation** and handling with a minimal set of changes required




Both **Interlock Threshold Functions and Energy Threshold** are defined as critical settings and can be edited only by owners of **MCS-Collimation** role

# Sequences – an example

**Crystals treated as any other collimator and already part of nominal sequence**
(complete overview can be found in backup)

- PREPARE LHC FOR INJECTION (ALL BUT PCS) - 2022 - v2
  - CHECK MACHINE READY FOR PREPARATION - 2022
  - INCREMENT FILL NUMBER
  - RAMP-UP (NO WAIT) THE UNDULATORS
  - MKI SANITY CHECK
  - CHECK BLM MCS AND START BLM SANITY CHECK
  - PREPARE MACHINE PROTECTION FOR INJECTION
  - PREPARE INSTRUMENTATION FOR INJECTION
  - PREPARE FEEDBACKS FOR INJECTION
  - SEND COLLIMATORS FROM PHYSICS TO INJECTION
  - SET OUT THRESHOLDS CRYSTALS
  - SET OUT THRESHOLDS FOR ROMAN POTS
  - SEND RF AND ADT TO INJECTION SETTINGS
  - RESET LUMINOSITY SERVER
  - RESET COUPLING SERVER SETTINGS
  - PREPARE KICKERS FOR INJECTION
  - CHECK INJECTION TABLE LOADED
  - SEND INJECTION OPTICS TIMING EVENT
  - SET BEAM MODE=SETUP
  - INJECTION HANDSHAKE
  - END SUBSEQUENCE BREAK

- SET OUT THRESHOLDS CRYSTALS
  - MAKE LHC.USER.INJECTION RESIDENT
  - LOAD OUT-OF-BEAM THRESHOLDS FOR CRYSTALS
  - CHECK OUT-OF-BEAM THRESHOLDS FOR CRYSTALS

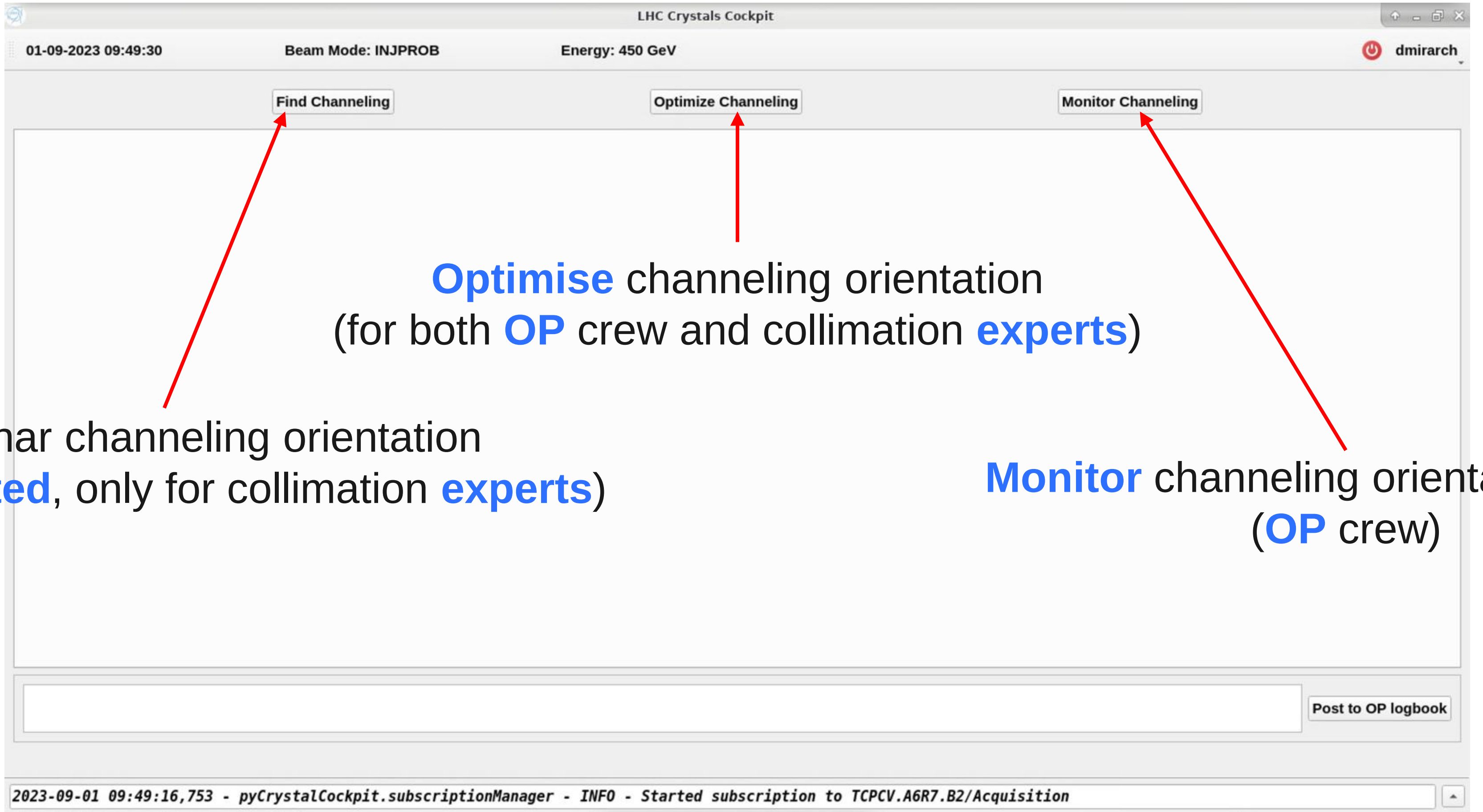
**Enforce** crystals are **fully retracted** even if the replacement **pipe is closed**
(thresholds stored in standard injection BP)
***To be run with p, skipped with Pb***

The motion of both rotational and linear stages can be started by either a **software** or **hardware trigger** (HX.COLLST-CT with payload 111)

# Outline

***pyCrystalCockpit***

# Functionalities

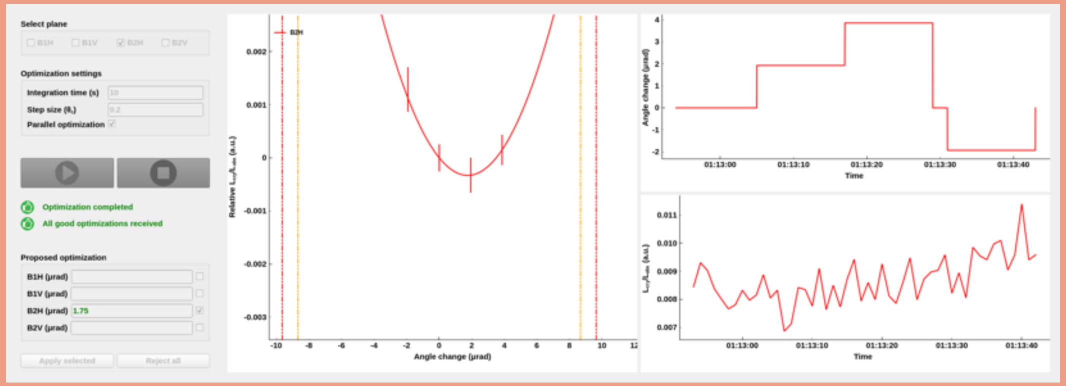



**Optimise** channeling orientation
(for both **OP** crew and collimation **experts**)

**Find** planar channeling orientation
(**RBAC protected**, only for collimation **experts**)

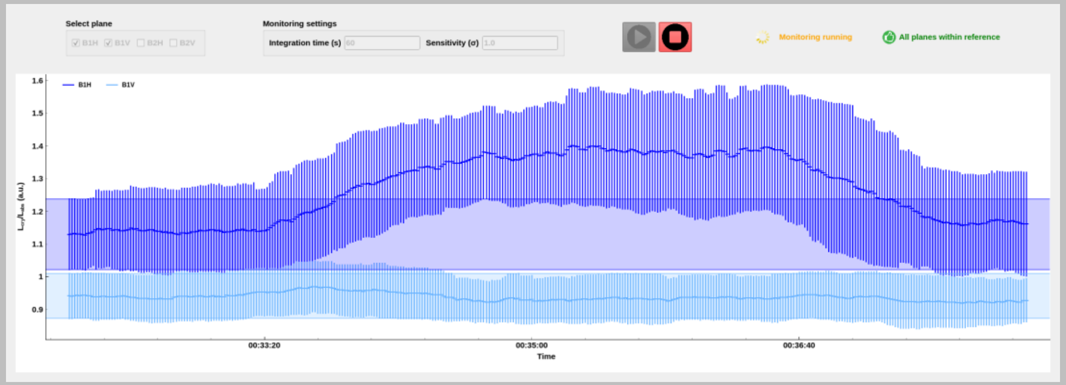
**Monitor** channeling orientation is kept
(**OP** crew)

# Status and main features of OP related functionalities




### *Optimization of channeling orientation*

- ✓ Based on ratio of losses at crystal and relative absorber
- ✓ Angular motion limited to ±1 critical angle ($\theta_c$)
- ✓ Achieved required resolution of 0.1 $\theta_c$
- ✓ To be performed whenever needed




### *Optimal orientation monitoring*

- ✓ Based on ratio of losses at crystal and relative absorber
- ✓ Conceptual validation obtained with barely visible losses
- ✓ Both visual alarm and announcer sent out if channeling lost

Main pending validation:

- ➢ Minimum detectable angle change
- ➢ Cross talk from losses in other beam

# Outline

***Conclusions***

# Conclusions

- **Interlock strategy** ready and documented in **EDMS** **2803940**

- **Settings generation** and **storage**, plus operational handling **fully automated** and crystals treated **as any other collimator**

- **Dedicated application** deployed to **monitor and optimize channeling** developed to prevent any foreseeable issue linked to operational stability of crystals collimation (which has not yet being proved in the history of particle accelerators over long runs)

# *BACKUP*

# Machine preparation

- PREPARE LHC FOR INJECTION (ALL BUT PCS) - 2022 - v2
  - CHECK MACHINE READY FOR PREPARATION - 2022
  - INCREMENT FILL NUMBER
  - RAMP-UP (NO WAIT) THE UNDULATORS
  - MKI SANITY CHECK
  - CHECK BLM MCS AND START BLM SANITY CHECK
  - PREPARE MACHINE PROTECTION FOR INJECTION
  - PREPARE INSTRUMENTATION FOR INJECTION
  - PREPARE FEEDBACKS FOR INJECTION
  - SEND COLLIMATORS FROM PHYSICS TO INJECTION
  - SET OUT THRESHOLDS CRYSTALS
  - SET OUT THRESHOLDS FOR ROMAN POTS
  - SEND RF AND ADT TO INJECTION SETTINGS
  - RESET LUMINOSITY SERVER
  - RESET COUPLING SERVER SETTINGS
  - PREPARE KICKERS FOR INJECTION
  - CHECK INJECTION TABLE LOADED
  - SEND INJECTION OPTICS TIMING EVENT
  - SET BEAM MODE=SETUP
  - INJECTION HANDSHAKE
  - END SUBSEQUENCE BREAK

- SEND COLLIMATORS FROM PHYSICS TO INJECTION
  - LOAD COLLIMATORS ENERGY THRESHOLDS B1 & B2
  - CHECK COLLIMATORS ENERGY THRESHOLDS
  - LOAD COLLIMATORS BETASTAR LIMITS
  - CHECK COLLIMATORS BETASTAR LIMITS
  - SEND ALL COLLIMATORS B1 & B2 TO PARKING
  - ELOGBOOK: END B1 AND B2 COLL TO PARKING
  - SEND ALL COLLIMATORS B1 & B2 TO INJECTION SETTINGS
  - RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS
  - CHECK NO COLLIMATOR POSITION OUT OF CONSTANT LIMITS
  - CHECK NO POSITION INTERLOCK FOR ALL COLLIMATORS
  - CHECK NO COLLIMATOR RESOLVER OUT OF RANGE
  - ~~CHECK CRYSTAL GONIOMETER LOOP~~

- LOAD COLLIMATORS ENERGY THRESHOLDS B1 & B2
  - MAKE LHC USER INJ_KICKER RESIDENT
  - B1: LOAD RING COLL ENERGY THRESHOLDS
  - B2: LOAD RING COLL ENERGY THRESHOLDS
  - B1: LOAD INJ PROT ENERGY THRESHOLDS
  - B2: LOAD INJ PROT ENERGY THRESHOLDS
  - B1: LOAD TCDQ COLL ENERGY THRESHOLDS
  - B2: LOAD TCDQ COLL ENERGY THRESHOLDS
  - B1: LOAD TI2 COLL ENERGY THRESHOLD
  - B2: LOAD TI8 COLL ENERGY THRESHOLDS
  - B1&B2: LOAD CRYSTALS ENERGY THRESHOLDS
  - ~~ELOGBOOK: END LOAD COLL ENERGY THRESHOLDS~~

- CHECK COLLIMATORS ENERGY THRESHOLDS
  - B1: CHECK RING COLL ENERGY THRESHOLDS
  - B2: CHECK RING COLL ENERGY THRESHOLDS
  - B1: CHECK INJ PROT ENERGY THRESHOLDS
  - B2: CHECK INJ PROT ENERGY THRESHOLDS
  - B1: CHECK TCDQ ENERGY THRESHOLDS
  - B2: CHECK TCDQ ENERGY THRESHOLDS
  - B1: CHECK TI2 ENERGY THRESHOLDS
  - B2: CHECK TI8 ENERGY THRESHOLDS
  - B1&B2: CHECK CRYSTALS ENERGY THRESHOLDS

*Load and check energy threshold, stored in DISCRETE_LHCRING_INJ_KICKER_V1 as for all coll.*

***To be run always***

# Machine preparation

**SEND COLLIMATORS FROM PHYSICS TO INJECTION**
- **LOAD COLLIMATORS ENERGY THRESHOLDS B1 & B2**
- **CHECK COLLIMATORS ENERGY THRESHOLDS**
- **LOAD COLLIMATORS BETASTAR LIMITS**
- **CHECK COLLIMATORS BETASTAR LIMITS**
- **SEND ALL COLLIMATORS B1 & B2 TO PARKING**
- ELOGBOOK: END B1 AND B2 COLL TO PARKING
- **SEND ALL COLLIMATORS B1 & B2 TO INJECTION SETTINGS**
- **RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS**
- **CHECK NO COLLIMATOR POSITION OUT OF CONSTANT LIMITS**
- **CHECK NO POSITION INTERLOCK FOR ALL COLLIMATORS**
- **CHECK NO COLLIMATOR RESOLVER OUT OF RANGE**
- ~~**CHECK CRYSTAL GONIOMETER LOOP**~~

**SEND ALL COLLIMATORS B1 & B2 TO PARKING**
- **B1: COLLIMATORS TO PARKING**
- **B1: CHECK ALL COLL HAVE ENERGY INTERLOCK**
- **B1 : CHECK ALL COLL HAVE BIC INTERLOCK**
- **B2: COLLIMATORS TO PARKING**
- **B2 : CHECK ALL COLL HAVE ENERGY INTERLOCK**
- **B2 : CHECK ALL COLL HAVE BIC INTERLOCK**
- **B1&B2: TCDQ TO PARKING**
- **B1&B2: CHECK TCDQ HAVE ENERGY INTERLOCK**
- **B1&B2: CHECK TCDQ HAVE BIC INTERLOCK**
- ~~**B1&B2: CRYSTALS TO PARKING**~~
- ~~**B1&B2: CHECK CRYSTALS HAVE ENERGY INTERLOCK**~~
- ~~**B1&B2: CHECK CRYSTALS HAVE BIC INTERLOCK**~~
- ELOGBOOK: END B1 AND B2 COLL TO PARKING

**B1&B2: CRYSTALS TO PARKING**
- MAKE LHC.USER.PARKING RESIDENT
- LOAD CRYSTALS THRESHOLDS = PARKING
- **LOAD DISCRETE SETTINGS CRYSTAL = PARKING**
- CHECK LINEAR STAGE MDC = ARMED
- CHECK ROTATIONAL STAGE MDC = ARMED
- SEND START COLL (111) EVT
- WAIT FOR ALL CRYSTAL LINEAR MOV FINISHED
- WAIT FOR ALL CRYSTAL ROTATIONAL MOV FINISHED

**LOAD DISCRETE SETTINGS CRYSTAL = PARKING**
- LOAD TCPCH.A4L7.B1 SETTINGS
- SLEEP 1s
- LOAD TCPCV.A6L7.B1 SETTINGS
- SLEEP 1s
- LOAD TCPCH.A5R7.B2 SETTINGS
- SLEEP 1s
- LOAD TCPCV.A6R7.B2 SETTINGS
- SLEEP 1s

*Some parameters rejected if discrete setting sent all together: built parametrized sequence to load discrete settings individually for each device*

*Send TCPC to parking position (stored in std parking BP)*
***Skipped with p, to be run with Pb***

# Machine preparation

- SEND COLLIMATORS FROM PHYSICS TO INJECTION
  - LOAD COLLIMATORS ENERGY THRESHOLDS B1 & B2
  - CHECK COLLIMATORS ENERGY THRESHOLDS
  - LOAD COLLIMATORS BETASTAR LIMITS
  - CHECK COLLIMATORS BETASTAR LIMITS
  - SEND ALL COLLIMATORS B1 & B2 TO PARKING
  - ELOGBOOK: END B1 AND B2 COLL TO PARKING
  - SEND ALL COLLIMATORS B1 & B2 TO INJECTION SETTINGS
  - RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS
  - CHECK NO COLLIMATOR POSITION OUT OF CONSTANT LIMITS
  - CHECK NO POSITION INTERLOCK FOR ALL COLLIMATORS
  - CHECK NO COLLIMATOR RESOLVER OUT OF RANGE
  - ~~CHECK CRYSTAL GONIOMETER LOOP~~

- SEND ALL COLLIMATORS B1 & B2 TO PARKING
  - B1: COLLIMATORS TO PARKING
  - B1: CHECK ALL COLL HAVE ENERGY INTERLOCK
  - B1 : CHECK ALL COLL HAVE BIC INTERLOCK
  - B2: COLLIMATORS TO PARKING
  - B2 : CHECK ALL COLL HAVE ENERGY INTERLOCK
  - B2 : CHECK ALL COLL HAVE BIC INTERLOCK
  - B1&B2: TCDQ TO PARKING
  - B1&B2: CHECK TCDQ HAVE ENERGY INTERLOCK
  - B1&B2: CHECK TCDQ HAVE BIC INTERLOCK
  - ~~B1&B2: CRYSTALS TO PARKING~~
  - ~~B1&B2: CHECK CRYSTALS HAVE ENERGY INTERLOCK~~
  - ~~B1&B2: CHECK CRYSTALS HAVE BIC INTERLOCK~~
  - ELOGBOOK: END B1 AND B2 COLL TO PARKING

- B1&B2: CHECK CRYSTALS HAVE ENERGY INTERLOCK
  - B1&B2: CHECK CRYSTALS HAVE ENERGY INTERLOCK

- B1&B2: CHECK CRYSTALS HAVE BIC INTERLOCK
  - B1&B2: CHECK CRYSTALS HAVE BIC A INTERLOCK
  - B1&B2: CHECK CRYSTALS HAVE BIC B INTERLOCK

*Check that energy interlock and BIC correctly fired with TCPC at parking settings*

***Skipped with p, to be run with Pb***

# Machine preparation

- SEND COLLIMATORS FROM PHYSICS TO INJECTION
  - LOAD COLLIMATORS ENERGY THRESHOLDS B1 & B2
  - CHECK COLLIMATORS ENERGY THRESHOLDS
  - LOAD COLLIMATORS BETASTAR LIMITS
  - CHECK COLLIMATORS BETASTAR LIMITS
  - SEND ALL COLLIMATORS B1 & B2 TO PARKING
  - ELOGBOOK: END B1 AND B2 COLL TO PARKING
  - SEND ALL COLLIMATORS B1 & B2 TO INJECTION SETTINGS
  - RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS
  - CHECK NO COLLIMATOR POSITION OUT OF CONSTANT LIMITS
  - CHECK NO POSITION INTERLOCK FOR ALL COLLIMATORS
  - CHECK NO COLLIMATOR RESOLVER OUT OF RANGE
  - ~~CHECK CRYSTAL GONIOMETER LOOP~~

- SEND ALL COLLIMATORS B1 & B2 TO INJECTION SETTINGS
  - B1: INJECTION SETTING COLLIMATORS TL
  - B2: INJECTION SETTINGS COLLIMATORS TL
  - B1: INJECTION SETTINGS COLLIMATORS INJ PROTECT
  - B2: INJECTION SETTINGS COLLIMATORS INJ PROTECT
  - B1: INJECTION SETTING COLLIMATORS RING CLEANING
  - B2: INJECTION SETTING COLLIMATORS RING CLEANING
  - B1&B2: TCDQ TO INJECTION SETTINGS
  - ~~B1&B2: CRYSTALS TO INJECTION SETTINGS~~
  - ~~SEND COARSE SETTINGS 2022 RING CLEANING & TCDQ~~
  - ELOGBOOK: B1&B2 COLL INJECTION SET

- B1&B2: CRYSTALS TO INJECTION SETTINGS
  - MAKE LHC.USER.PARKING RESIDENT
  - LOAD CRYSTALS THRESHOLDS = PARKING
  - MAKE LHC.USER.INJECTION RESIDENT
  - LOAD DISCRETE SETTINGS CRYSTAL = INJECTION
  - CHECK LINEAR STAGE MDC = ARMED
  - CHECK ROTATIONAL STAGE MDC = ARMED
  - SEND START COLL (111) EVT
  - WAIT FOR ALL CRYSTAL LINEAR MOV FINISHED
  - WAIT FOR ALL CRYSTAL ROTATIONAL MOV FINISHED
  - LOAD CRYSTALS THRESHOLDS = INJECTION

*Send TCPCs to injection settings (stored in std injection BP),*
*Similar loading of discrete settings as for parking,*
***Skipped with p, to be run with Pb***

# Machine preparation

- SEND COLLIMATORS FROM PHYSICS TO INJECTION
  - LOAD COLLIMATORS ENERGY THRESHOLDS B1 & B2
  - CHECK COLLIMATORS ENERGY THRESHOLDS
  - LOAD COLLIMATORS BETASTAR LIMITS
  - CHECK COLLIMATORS BETASTAR LIMITS
  - SEND ALL COLLIMATORS B1 & B2 TO PARKING
  - ELOGBOOK: END B1 AND B2 COLL TO PARKING
  - SEND ALL COLLIMATORS B1 & B2 TO INJECTION SETTINGS
  - RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS
  - CHECK NO COLLIMATOR POSITION OUT OF CONSTANT LIMITS
  - CHECK NO POSITION INTERLOCK FOR ALL COLLIMATORS
  - CHECK NO COLLIMATOR RESOLVER OUT OF RANGE
  - ~~CHECK CRYSTAL GONIOMETER LOOP~~

- RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS
  - B1: RESET INJ COLL ERRORS, WARNINGS AND INTERLOCKS
  - B2: RESET INJ COLL ERRORS, WARNINGS AND INTERLOCKS
  - B1: RESET CLEANING COLL ERRORS, WARNINGS AND INTERLOCKS
  - B2: RESET CLEANING COLL ERRORS, WARNINGS AND INTERLOCKS
  - B1&B2: RESET CRYSTAL ERRORS, WARNINGS AND INTERLOCKS
  - B1: RESET TL COLL ERRORS, WARNINGS AND INTERLOCKS
  - B2: RESET TL COLL ERRORS, WARNINGS AND INTERLOCKS
  - B1: RESET TCDQ INTERLOCKS
  - B2: RESET TCDQ INTERLOCKS
  - SLEEP 5sec

- CHECK NO COLLIMATOR POSITION OUT OF CONSTANT LIMITS
  - SLEEP 5s
  - B1 : CHECK COLL INJ PROTECT POSITION NOT OUT OF CONSTANT LIMIT
  - B2 : CHECK COLL INJ PROTECT POSITION NOT OUT OF CONSTANT LIMIT
  - B1 : CHECK COLL TL NOT OUT OF CONSTANT LIMITS
  - B2 : CHECK COLL TL NOT OUT OF CONSTANT LIMITS
  - B1 : CHECK COLL RING POSITION NOT OUT OF POSITION LIMITS
  - B2 : CHECK COLL RING POSITION NOT OUT OF POSITION LIMITS
  - B1 : CHECK TCDQ POSITION NOT OUT OF POSITION LIMITS
  - B2 : CHECK TCDQ POSITION NOT OUT OF POSITION LIMITS
  - B1&B2: CHECK CRYSTALS POSITION NOT OUT OF POSITION LIMITS

- CHECK NO POSITION INTERLOCK FOR ALL COLLIMATORS
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR COLL INJ PROTECT B1
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR COLL INJ PROTECT B2
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR COLL TL B1
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR COLL TL B2
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR COLL RING B1
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR COLL RING B2
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR TCDQ B1
  - CHECK NO POSITION INTERLOCK LEFT JAW FOR TCDQ B2
  - CHECK NO POSITION INTERLOCK RIGHT JAW FOR COLL INJ PROTECT B1
  - CHECK NO POSITION INTERLOCK RIGHT JAW FOR COLL INJ PROTECT B2
  - CHECK NO POSITION INTERLOCK RIGHT JAW FOR COLL TL B1
  - CHECK NO POSITION INTERLOCK RIGHT JAW FOR COLL TL B2
  - CHECK NO POSITION INTERLOCK RIGHT JAW FOR COLL RING B1
  - CHECK NO POSITION INTERLOCK RIGHT JAW FOR COLL RING B2
  - CHECK NO POSITION INTERLOCK FOR CRYSTALS B1&B2

- CHECK NO COLLIMATOR RESOLVER OUT OF RANGE
  - B1 : CHECK COLL INJ PROTECT RESOLVER NOT OUT OF RANGE
  - B2 : CHECK COLL INJ PROTECT RESOLVER NOT OUT OF RANGE
  - B1 : CHECK COLL TL RESOLVER NOT OUT OF RANGE
  - B2 : CHECK COLL TL RESOLVER NOT OUT OF RANGE
  - B1 : CHECK COLL RING RESOLVER NOT OUT OF RANGE
  - B2 : CHECK COLL RING RESOLVER NOT OUT OF RANGE
  - B1&B2: CHECK CRYSTAL LINEAR STAGE NOT OUT OF RANGE

*Reset and check as for all coll.*

***To be run always***

# Machine preparation

- SEND COLLIMATORS FROM PHYSICS TO INJECTION
  - LOAD COLLIMATORS ENERGY THRESHOLDS B1 & B2
  - CHECK COLLIMATORS ENERGY THRESHOLDS
  - LOAD COLLIMATORS BETASTAR LIMITS
  - CHECK COLLIMATORS BETASTAR LIMITS
  - SEND ALL COLLIMATORS B1 & B2 TO PARKING
  - ELOGBOOK: END B1 AND B2 COLL TO PARKING
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  - RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS
  - CHECK NO COLLIMATOR POSITION OUT OF CONSTANT LIMITS
  - CHECK NO POSITION INTERLOCK FOR ALL COLLIMATORS
  - CHECK NO COLLIMATOR RESOLVER OUT OF RANGE
  - ~~CHECK CRYSTAL GONIOMETER LOOP~~

- CHECK CRYSTAL GONIOMETER LOOP
  - CHECK ROTATIONAL STAGE IN CLOSED LOOP

*Additional sanity check for TCPCs only: the rotational stage must be in closed loop*

***Skipped with p, to be run with Pb***

# Machine preparation

- PREPARE LHC FOR INJECTION (ALL BUT PCS) - 2022 - v2
  - CHECK MACHINE READY FOR PREPARATION - 2022
  - INCREMENT FILL NUMBER
  - RAMP-UP (NO WAIT) THE UNDULATORS
  - MKI SANITY CHECK
  - CHECK BLM MCS AND START BLM SANITY CHECK
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  - SET OUT THRESHOLDS CRYSTALS
  - SET OUT THRESHOLDS FOR ROMAN POTS
  - SEND RF AND ADT TO INJECTION SETTINGS
  - RESET LUMINOSITY SERVER
  - RESET COUPLING SERVER SETTINGS
  - PREPARE KICKERS FOR INJECTION
  - CHECK INJECTION TABLE LOADED
  - SEND INJECTION OPTICS TIMING EVENT
  - SET BEAM MODE=SETUP
  - INJECTION HANDSHAKE
  - END SUBSEQUENCE BREAK

- SET OUT THRESHOLDS CRYSTALS
  - MAKE LHC.USER.INJECTION RESIDENT
  - LOAD OUT-OF-BEAM THRESHOLDS FOR CRYSTALS
  - CHECK OUT-OF-BEAM THRESHOLDS FOR CRYSTALS

*Enforce crystals are fully retracted even if the replacement pipe is closed (stored in std injection BP)*

***To be run with p, skipped with Pb***

# Injection probe

- INJECTION PROBE BEAM - 2022
  - ~~LOAD ADT POS SETTINGS FOR PILOT INTENSITY~~
  - LOAD ADT POS SETTINGS FOR NOMINAL INTENSITY - DO NOT DAMP PILOT (TUNE MEAS)
  - CHECK FEEDBACKS READY FOR INJECTION
  - CHECK COLLIMATOR INJECTION SETTINGS
  - ~~CHECK CRYSTAL GONIOMETER LOOP~~
  - CHECK RF AND ADT READY FOR INJECTION
  - CHECK MKISS FINISHED - SWITCH ON MKI B1&B2
  - CHECK B1 & B2 MKI ARE READY FOR INJECTION
  - SWITCH BBLR TO IDLE AT STANDBY CURRENT
  - RESET QPS OF ALL SECTORS
  - DRIVE INJECTION SETTINGS IN PC AND START FIDEL
  - RESET COLLIMATOR WARNING, ERRORS AND INTERLOCKS
  - RESET BSRTM INTERLOCKS
  - PREPARE BCCM (DIDT) (B1 & B2 / SYS-A & SYS-B)
  - RESET RF BIC
  - CHECK ALL MAGNETS CURRENTS ARE AT INJECTION
  - TRIM CHROMA B1H TO 10
  - TRIM CHROMA B2H TO 10
  - WAIT FOR CHROMA TRIM FINISHED
  - TRIM CHROMA B1V TO 10
  - TRIM CHROMA B2V TO 10
  - TRIM LANDAU DAMPING TO ZERO
  - UNLATCH ALL ALLOWED SIS CHANNELS
  - ARM LHC BIC B1 AND B2
  - ARM LBDS B1 AND B2 2015
  - PREPARE WS FOR BEAM
  - CHECK OP INJ INHIBIT SWITCHES ALLOW INJECTION
  - SET BEAM MODE=INJPROBEAM
  - ~~LOG START LHC FILLING~~
  - END SUBSEQUENCE BREAK

- CHECK CRYSTAL GONIOMETER LOOP
  - CHECK ROTATIONAL STAGE IN CLOSED LOOP

*Again sanity check for rotational stage*
*(some time can elapse between preparation and first injection)*
***Skipped with p, to be run with Pb***

# Prepare ramp

**PREPARE RAMP - 2022**

- PLEASE CHECK THE ABORT GAP AND CLEAN IF NECESSARY
- ~~TRIM LANDAU DAMPING B1 TO -3.5~~
- ~~TRIM LANDAU DAMPING B2 TO -3.5~~
- **START FULL DETUNING MODE**
- **RF CHECKS: WATCHDOG&FREQ B1/B2 LINKED**
- **DISABLING INJECTION AND INJ COLL OUT 2015**
- **DISABLE INJECTION CLEANING**
- **END OF INJECTION HANDSHAKE**
- **CHECK LHC READY FOR PREPARE RAMP**
- SET BEAM MODE=PREPARE RAMP
- **SWITCH OFF ABORT GAP CLEANING**
- LOAD OPTICS CHANGE EVENT TABLE FOR RAMP (20)
- LOAD PC INTERLOCK START TABLE FOR RAMP (20)
- **INCORPORATE INJECTION TRIMS INTO THE RAMP AND PAUSE FIDEL**
- MAKE LHC USER FIDEL RESIDENT (USED FOR SPOOL SETTINGS)
- MAKE LHC.USER.RAMP RESIDENT
- **PREPARE FEEDBACKS FOR RAMP - 2022**
- **LOAD RAMP SETTINGS IN PC&RF FGC**
- **LOAD RAMP SETTINGS IN UNDULATORS**
- **ARM LONGITUDINAL BLOW-UP**
- ~~**SET RF HV VOLTAGE TO 50kV**~~
- **SET RF HV VOLTAGE TO 58kV**
- **LOAD CLEANING & DUMP PROTEC COLL RAMP SETTINGS**
- ~~**LOAD CLEANING & DUMP PROTEC COLL RAMP COARSE SETTINGS**~~
- **CHECK COMMON SBF FORCING MISTAKES**
- ANNOUNCE END OF PREPARE RAMP SEQUENCE
- END SUBSEQUENCE BREAK

**LOAD CLEANING & DUMP PROTEC COLL RAMP SETTINGS**

- MAKE LHC.USER.INJECTION RESIDENT
- B1: CHECK COLL SETTINGS
- B2: CHECK COLL SETTINGS
- **B1: LOAD COLL RAMP FUNCTIONS (PARAMETRIZED)**
- **B2: LOAD COLL RAMP FUNCTIONS (PARAMETRIZED)**
- **LOAD TCDQ RAMP FUNCTIONS (PARAMETRIZED)**
- ~~**LOAD CRYSTALS RAMP FUNCTIONS**~~

**LOAD CRYSTALS RAMP FUNCTIONS**

- MAKE LHC USER PARAMETER RESIDENT
- LOAD CRYSTALS THRESHOLDS = RAMP
- LOAD CRYSTALS SETTINGS = RAMP
- WAIT FOR LINEAR STAGE MDC = ARMED
- WAIT FOR ROTATIONAL STAGE MDC = ARMED
- WAIT FOR LINEAR STAGE PRS = ARMED
- CHECK LINEAR STAGE MDC = ARMED
- CHECK ROTATIONAL STAGE MDC = ARMED
- CHECK LINEAR STAGE THRESHOLD = ARMED

*Load ramp functions (stored in std ramp BP)*

***Skipped with p, to be run with Pb***

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