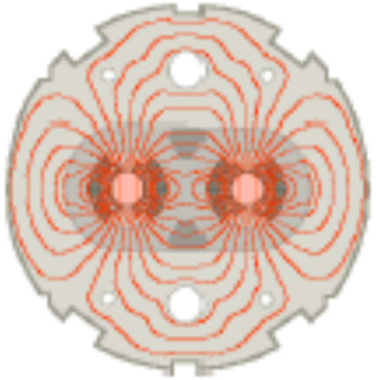
External Review on LHC Machine Protection
CERN, Geneva, CH
September 6th-8th, 2010

LHC Movable Devices Interlocking strategy

Stefano Redaelli
BE-OP-LHC



Outline

- Introduction
- LHC movable devices
- Interlock strategy
- Conclusions

Acknowledgments

BIC, SIS:	J. Wenninger
Beam instrumentation:	F. Roncarolo, B. Dehning
Vacuum:	V. Baglin, A. Macpherson
Safety blocks:	O. Brunner (RF), L. Ponce
Experiment:	M. Ferro-Luzzi, A. Di Mauro
Collimators:	Collimation team
Triplet alignment:	M. Acar, H. Mainaud-Durand

Introduction

About **500 movable devices** are installed in the LHC and could touch the beams!

This includes: collimators, beam instrumentation, vacuum valves, safety systems, experiment components...

Clearly, each requires a proper **interlock strategy** to minimize the risk of damage with high intensities injected or circulating in the machine!

Table 2: Inventory of Objects in the LHC and Transfer Lines

Name	Description	N°.	Position	Type	Comment
TED	Stopper	4	TI8/TI2	IN/OUT	Needs extraction interlock while moving
TBSE	Safety Stopper	1	TI8	IN/OUT	Needs extraction interlock while moving
BTV	Screens	18	TI8/TI2	IN/OUT	Limitation on extraction intensity with Al screen. Needs extraction interlock while moving
VV	TL Vacuum Valves	14	TI8/TI2	IN/OUT	
TCDI	TL Collimators	14	TI8/TI2	Mobile	
VV	Ring Vacuum Valves	249		IN/OUT	Veto activation with circulating beam
VVX	Fast Valves	2	IR8	IN/OUT	Very fast acting
VVX	Passive Valves	2	IR2	IN/OUT	Mechanical action only. Remote Status available
BTV	Injection & Matching Screens	13	IR2/IR8/ IR3/IR4	IN/OUT	Veto movement with circulating beam Limit on the number of turns vs. injected intensity
BWS	Wire Scanners	4	IR4	IN/OUT	Limits on intensity vs. energy
	RF Electron Stoppers	4	IR4	IN/OUT	Linked to LHC Access Safety System
	Safety Stoppers	2	IR6	IN/OUT	Linked to LHC Access Safety System
BEUV	Alignment Mirrors	2	IR4	IN/OUT	
VV	Dump line Vacuum Valves	4	IR6	IN/OUT	Dump Circulating beam on activation
BTV	Dump Line Screens	6	IR6	IN/OUT	Veto movement with intensity above a threshold Veto acceleration with screens in above threshold
TCP	Primary Collimators	8	IR3/IR7	Mobile	
TCSG	Secondary Collimators	30	IR3/IR7	Mobile	
TCT	Tertiary Collimators	16	IR1/IR5/IR2	Mobile	
TCLP	Absorbers	8	IR1/IR5	Mobile	Absorbers for Physics regions
TCLA	Absorbers	16	IR3/IR7	Mobile	Cleaning region absorbers
TCSP	Scrapers	6	IR3/IR7	Mobile	For special use.
TCDQ	Protection Elements	2	IR6	Mobile	Protect cold aperture from bad dump.
TCS	Protection Elements	2	IR6	Mobile	As above
TDI	Injection Protection	2	IR2/IR8	Mobile	
TCLI	Injection Protection	4	IR2/IR8	Mobile	
XRP	Totem Roman Pots	24	IR5	Mobile	Set at 10s in during stable data taking
XRP	Atlas Roman Pots	8	IR1	Mobile	
VELO	LHCb Vertex Locator	1	IR8	Mobile	At around 5mm from beam axis during data taking
ZDC	Alice Detectors	2	IR2	Mobile	Outside the beam vacuum.
BBLR	Beam-Beam Compensator	8	IR1/IR5	Mobile	Not baseline
	Total	476			

LHC Project Workshop - 'Chamonix XIV'

OBJECTS CAPABLE OF TOUCHING THE BEAMS

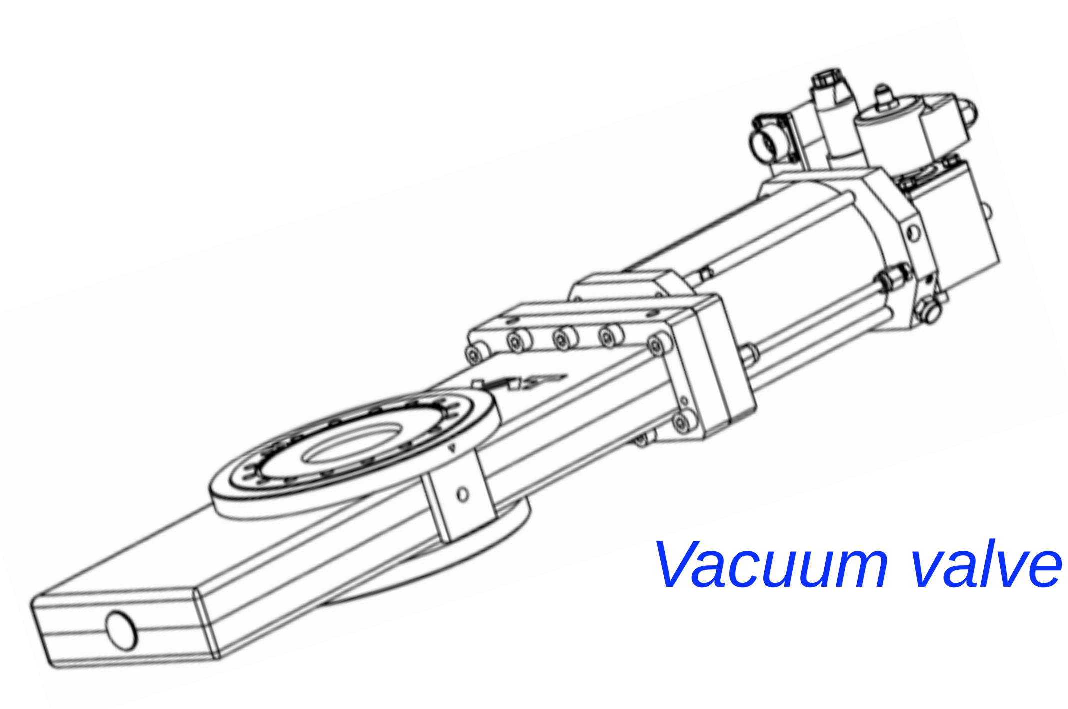
P. Collier, CERN, Geneva, Switzerland

Scope of this presentation

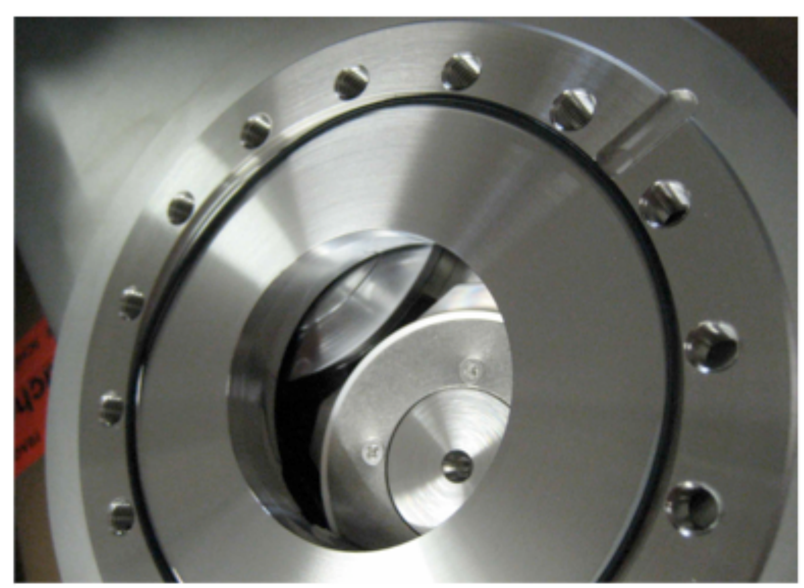
- ☑ Review / update figures on movable devices (list/categories).
- ☑ Present implemented interlock strategy for each type of device.
- ☑ Identify potential issues.
- ☑ Review present experience.
- ☑ Here, focus on the LHC ring (no transfer and dump lines)

IN/OUT movable devices

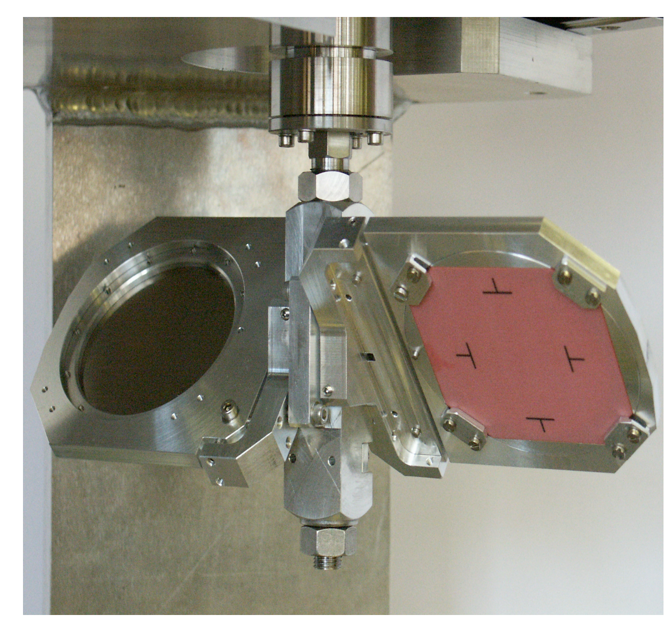
- **Vacuum equipment**:
  - Valves to isolate sub-sectors 250
  - Electron stopped (RF zone) 4
  - Safety beam stoppers (IR3) 2
- **Beam instrumentation**:
  - Beam screens (BTVs) 11
  - Mirrors of synchr. light monitor 2
  - Wire scanners 4
- **Movable masks**:
  - TCDD in IP2 (D1 dipole mask) 1



Vacuum valve



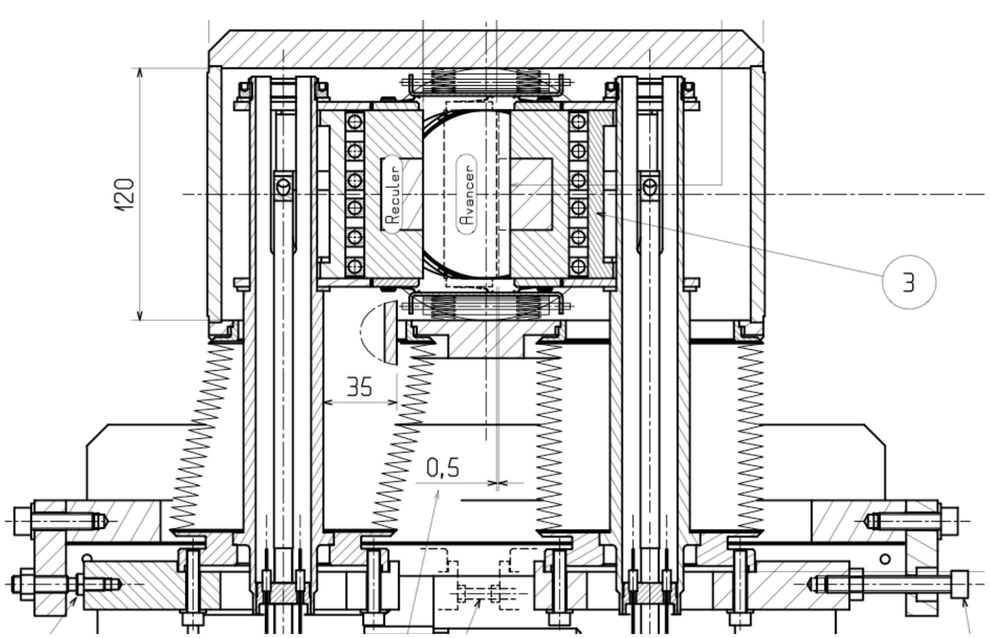
BTV screen



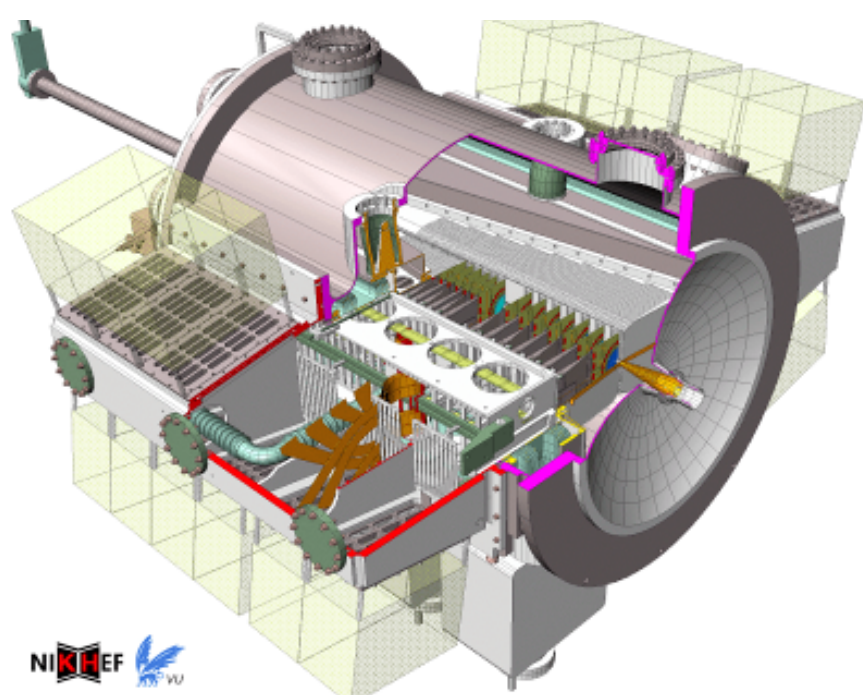
Operational movable devices

Collimators:	- two-sided collimators (4 motors)	98
	- one-sided: TCDQs (2 motors)	2
	- 5th motor axis	44
Experiments:	- TOTEM Roman pots	12
	- LHCb VELO (2 halves)	1
	- ALICE ZDC [outside vacuum]	2
Triplet alignment:	- Motorized jacks (32 per IP)	128

LHC collimator



LHCb VELO

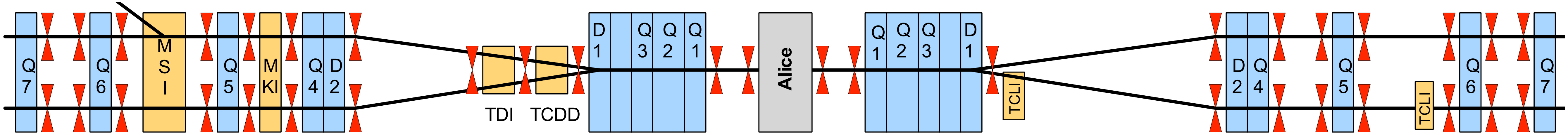


Motorized triplet foot

Outline

- Introduction
- LHC movable devices
- **Interlock strategy**
  - **- IN/OUT devices**
  - **- Movable devices**
- Conclusions

Vacuum valves



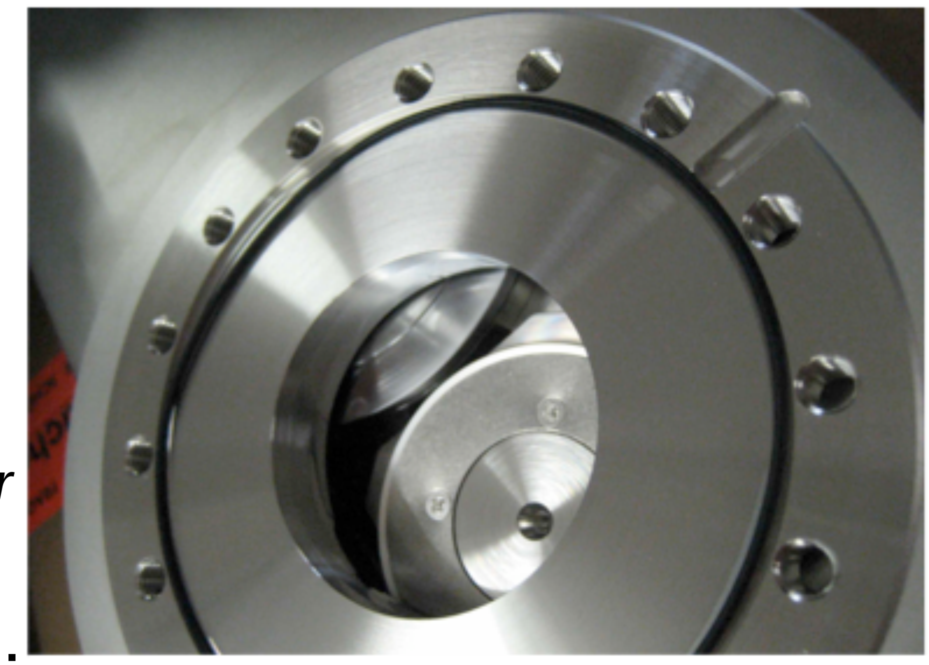
About **250 valves** in the machine: 110 per beam in separated sectors + 29 in common IRs + 1 manual (IP2).

All interlocked: valve not on OUT switch = no beam permit.

A measurement of vacuum > threshold in a sector triggers:

- **Beam dump;**
- **Sector valves closure.**

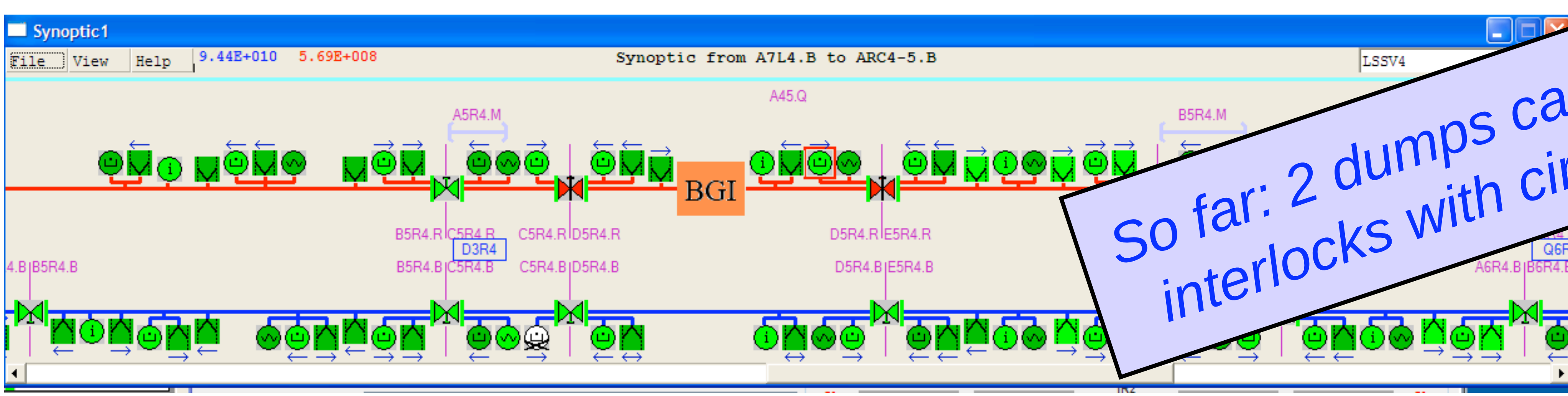
*Only "slow" valves in the machine (close in **2-3 s**) no need to wait for beam dump to close the valves (initially foreseen).*



Software inhibit prevents closing valves with beam loop closed.

One manual valve in IP2: interlocked + monitored.

All interlocks have been **tested individually**.



So far: 2 dumps caused by vacuum interlocks with circulating beams.

Special vacuum equipment

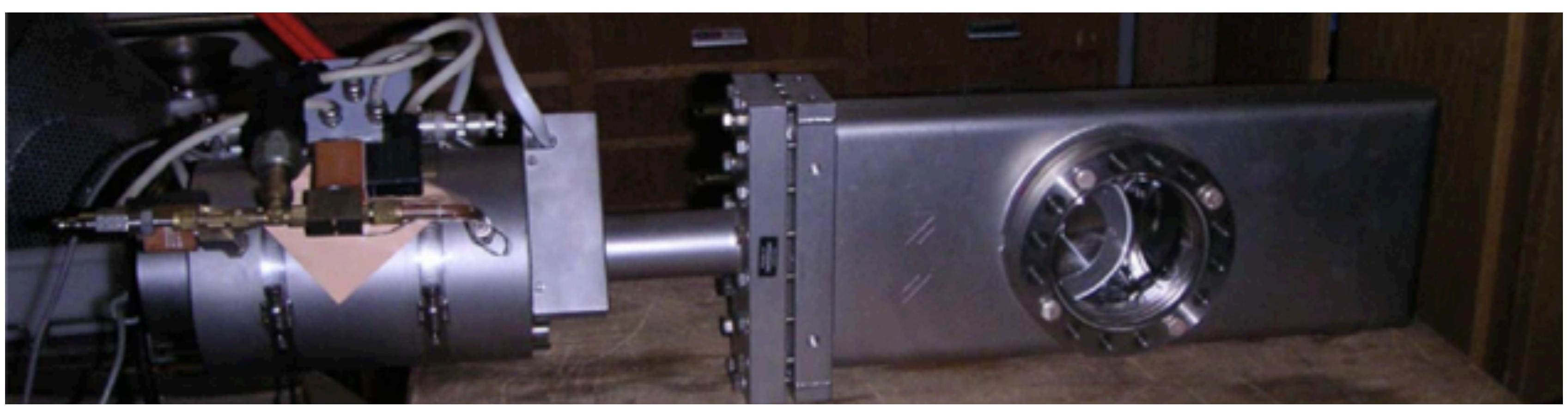
Special vacuum equipment used for **personnel safety**:

- Two **safety blocks** in point 3
  (prevent circulating beam in access mode or if the access chain is broken);
- Four **RF electron stoppers** in point 4
  (stop electron produced during RF conditioning).

Similar to standard valves: no beam permit if valves not open.
But they are not interlocked based on vacuum measurements.

Managed by the access control system. Dedicated HW channels into the BIC.

All interlock chains tested as a part of the DSO access system commissioning.



Images of the BIC channels

Beam screens in the ring

Total of **11 BTV screens** in the ring, in IP2/8 (injection) and IP3/4/7.

<u>Issues</u>: (1) limit of single-pass intensity; (2) screens can be damaged if IN with circulating beam.

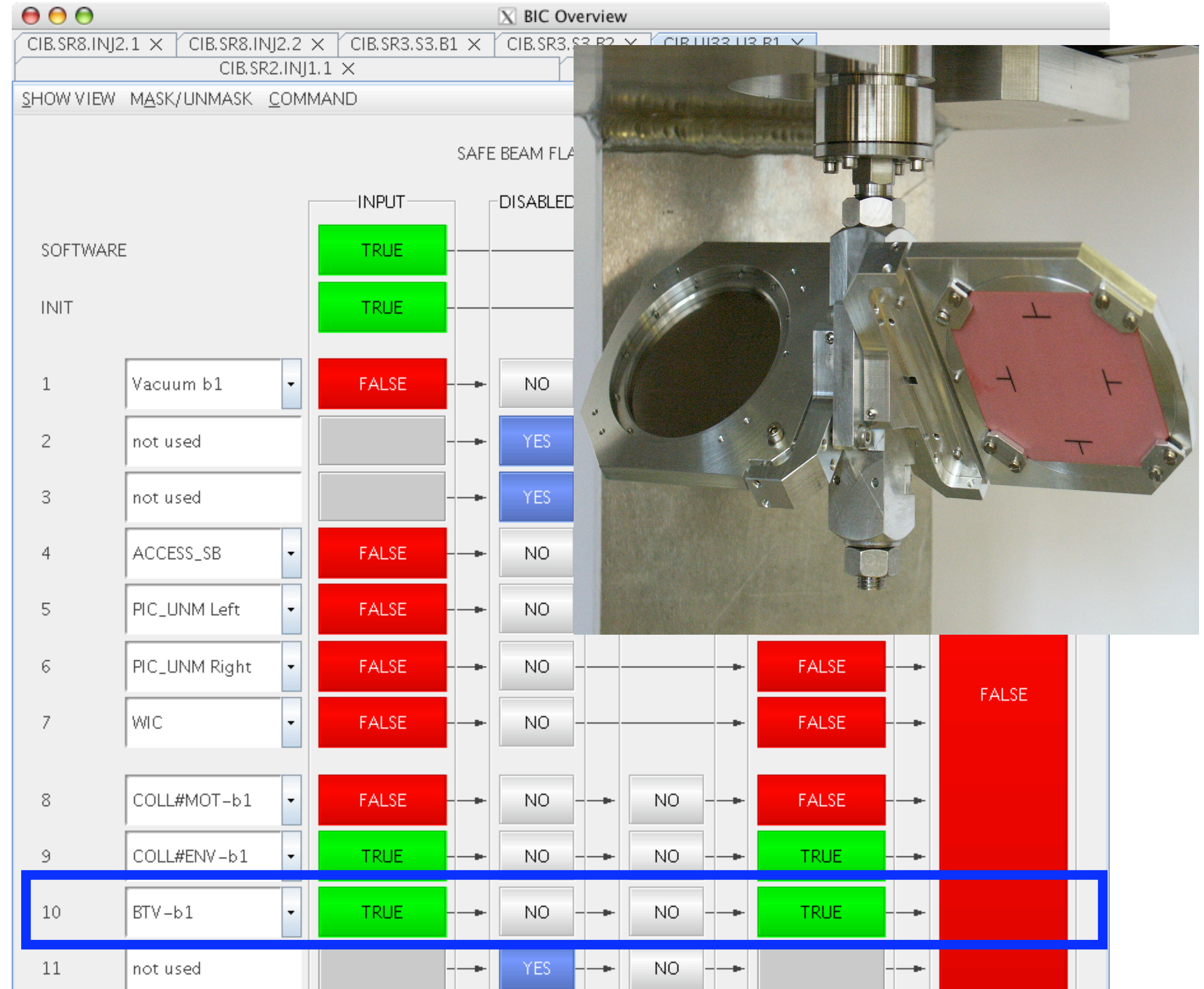
Limit = ~1.5x10^{14} [p x turns] for Ti

Limit = ~1.5x10^{13} [p x turns] for Al_3O_2

- **Maskable BIC interlock** if screens moving or IN. *But this would allow circulating safe beams!*

- **Software interlock**: injection with screens IN only allowed in INJ&DUMP mode with safe number of turns.

- <u>Redundancy</u>: BLM thresholds could be set to prevent damage with circulating beam (not yet set).



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the **Large Hadron Collider** project

LHC Project Document No.
LHC-BTV-ES-0001 rev 1.0

CERN Div./Group r Supplier/Contractor Document No.
AB/BT

EDMS Document No.
821083

Date: 2007-08-10

Functional Specification

Interlocking of LHC BTV Screens

E. Bravin, B. Goddard, J. Wenninger

Wire scanners

One per plane per beam = **4 wires**.

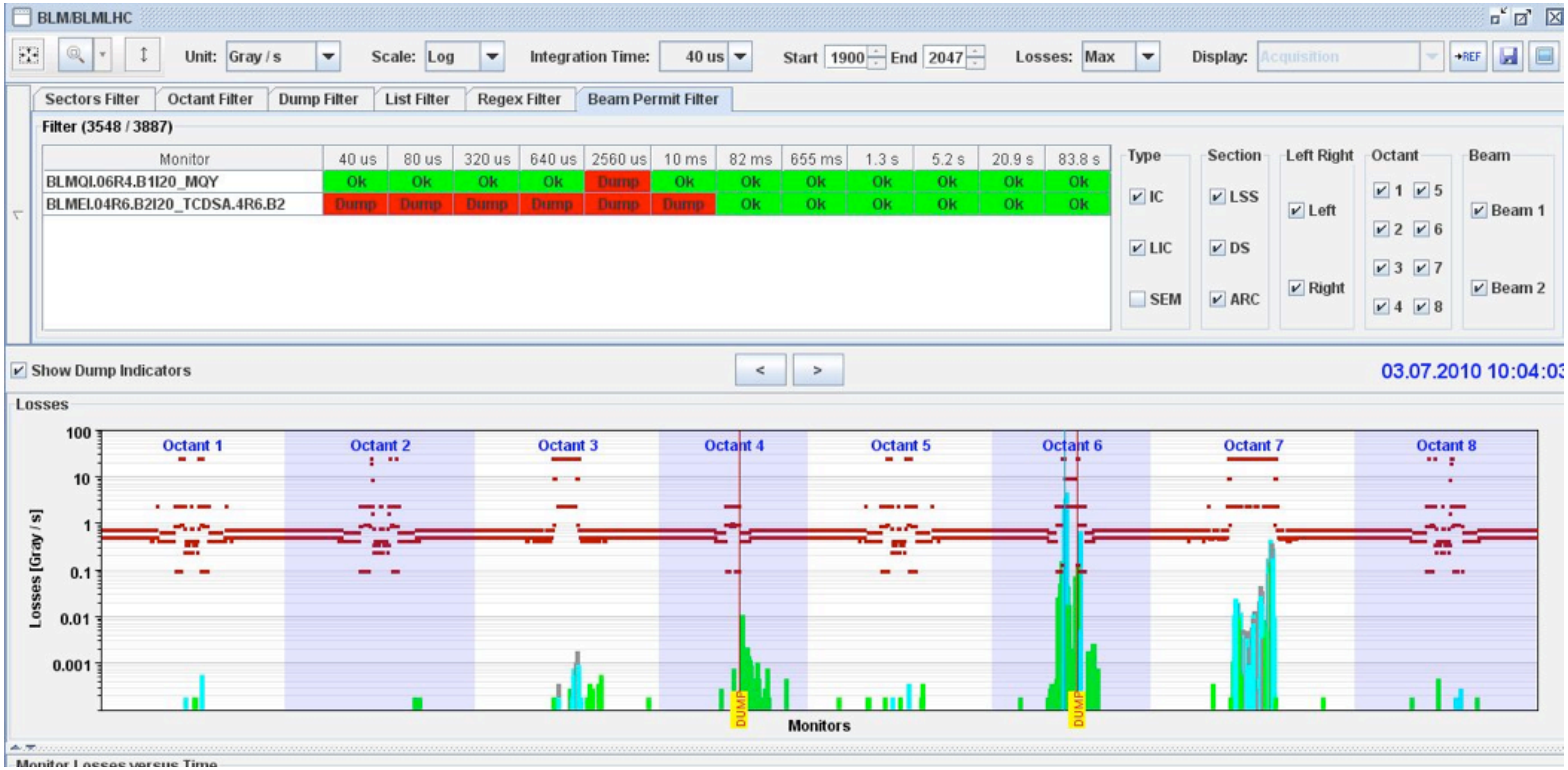
No restriction on their operation, neither on beam intensity nor on energy.
They have no inputs in BIC nor SIS.

BUT: wires can **break** and/or magnets downstream can **quench**! *See BLM talk.*

Protection relies on the BLMs!

Fine tuning of the BLM thresholds is ongoing. So far, ok up 2×10^{12} p at 3.5 TeV.

Software protection on the application side (inhibit on beam current > limit) available but not yet deployed.



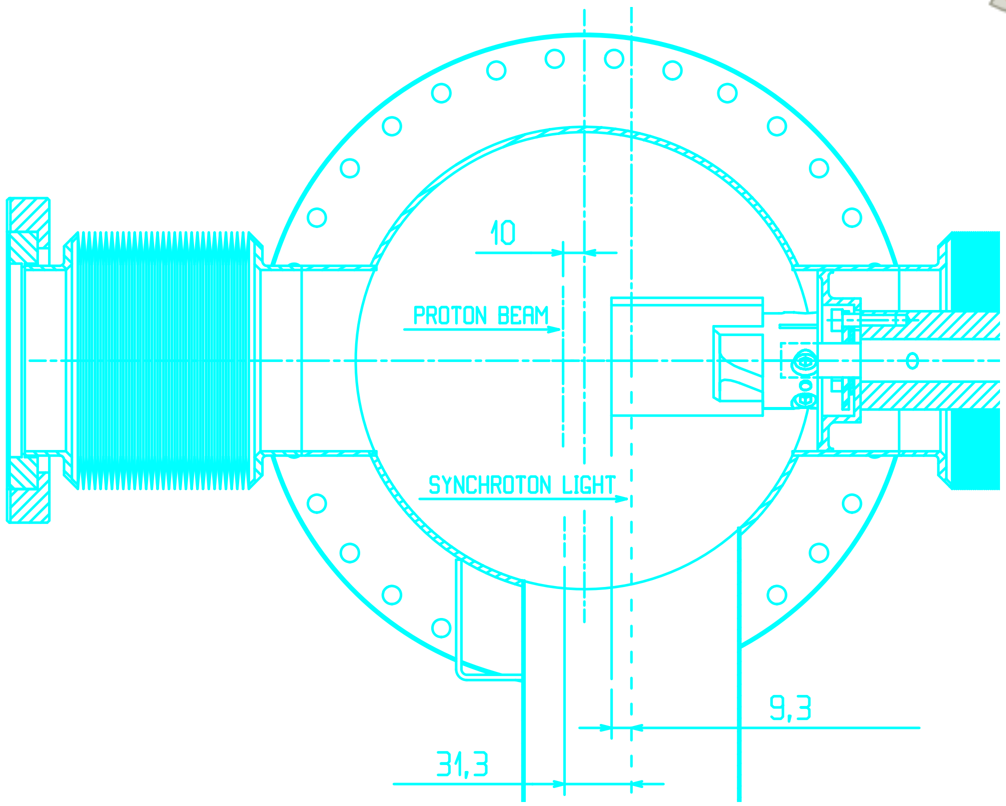
Beam dump triggered by Q6R4 while firing a wire at the end of the ramp (M. Zerlauth).

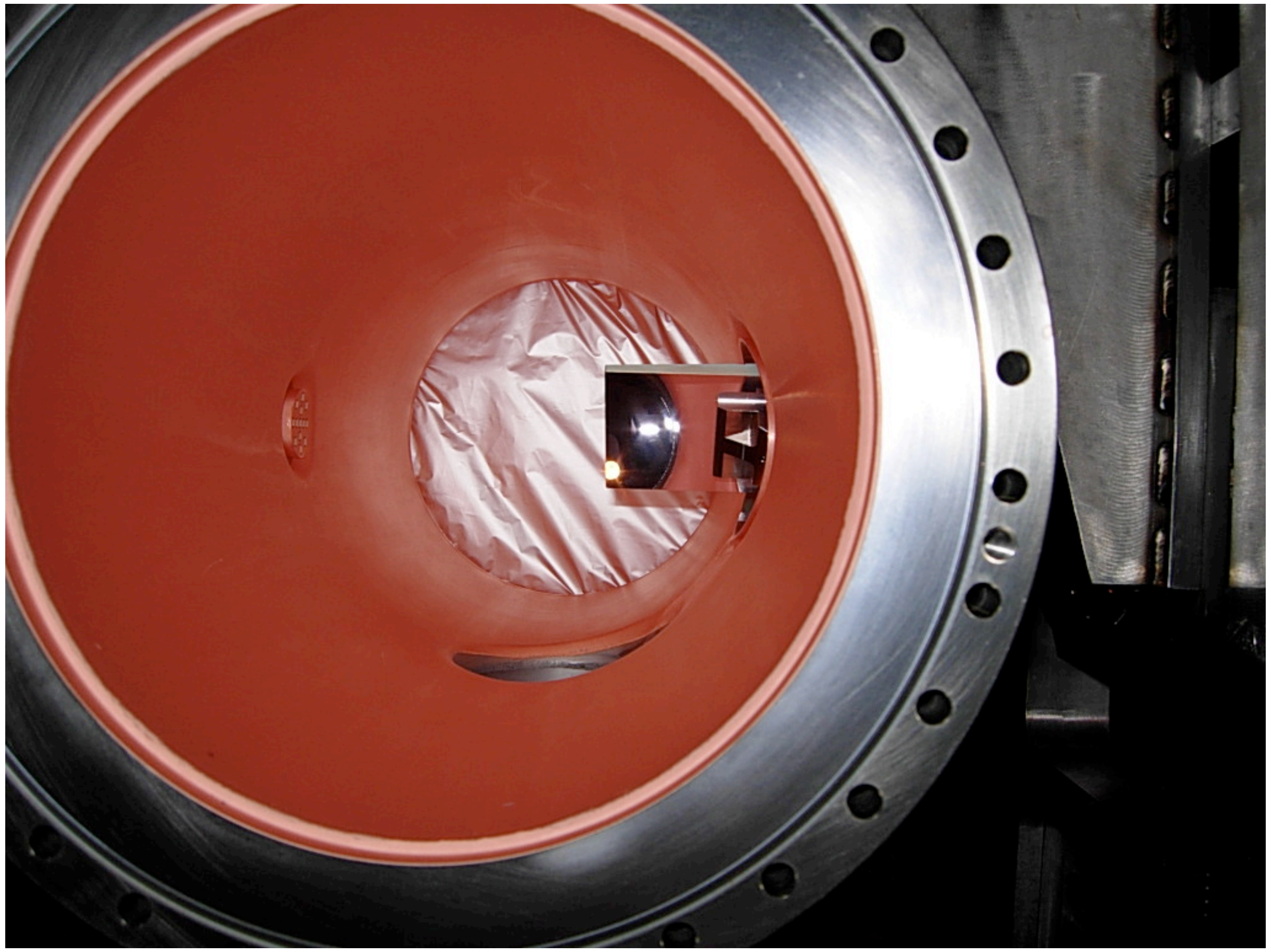
Mirrors of synchrotron light monitor

One mirror per beam in IP4.

IN position of mirror shadowed by the aperture: no interference with the beam.

Mirror positions not controlled by operation.
No interlocks needed.





Phase I collimation system

Two warm cleaning insertions

IR3: Momentum cleaning
- **1 primary (H)**
- **4 secondary (H,S)**
- **4 shower abs. (H,V)**

IR7: Betatron cleaning
- **3 primary (H,V,S)**
- **11 secondary (H,V,S)**
- **5 shower abs. (H,V)**

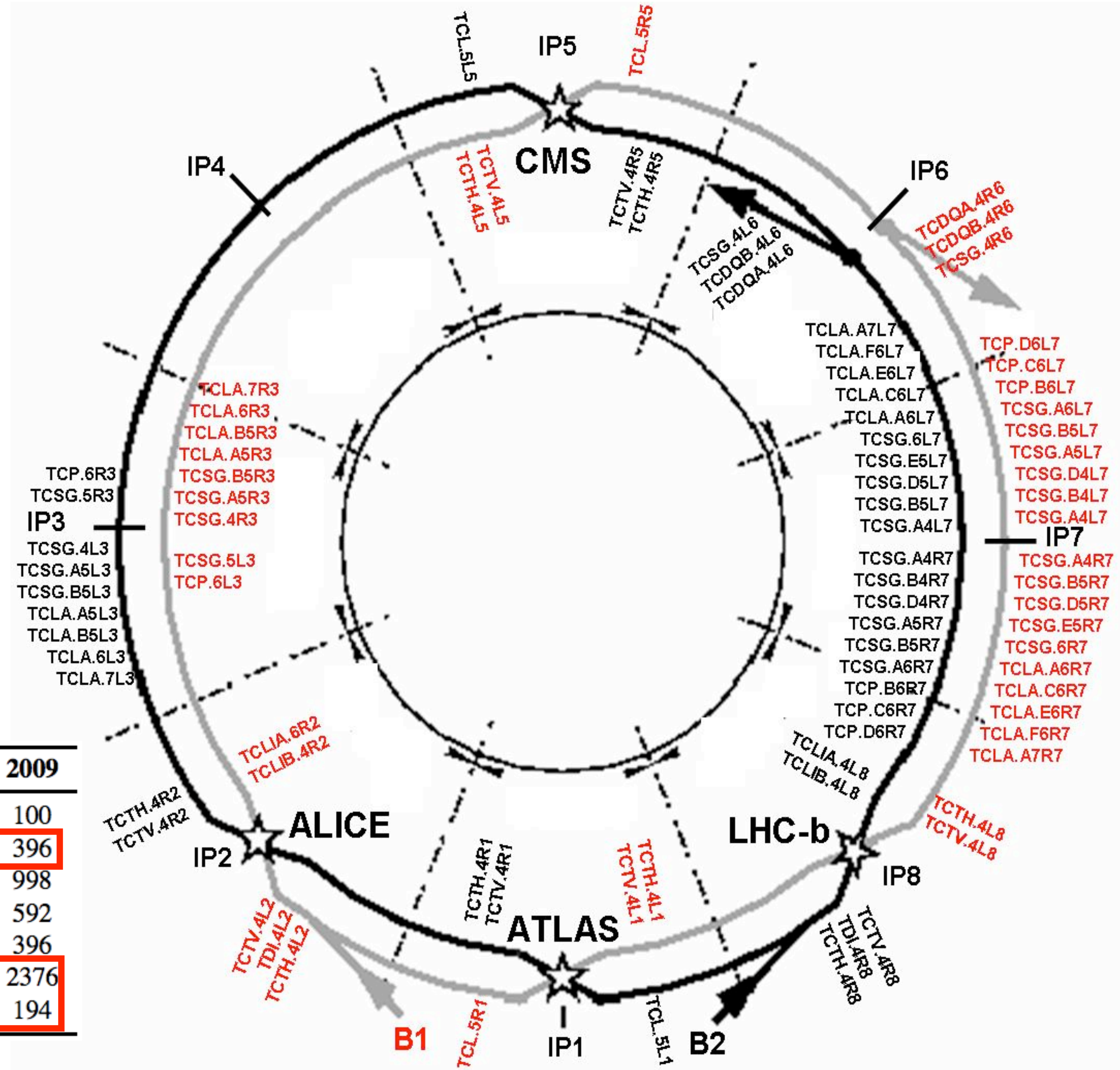
Local cleaning at triplets

8 tertiary (2 per IP)

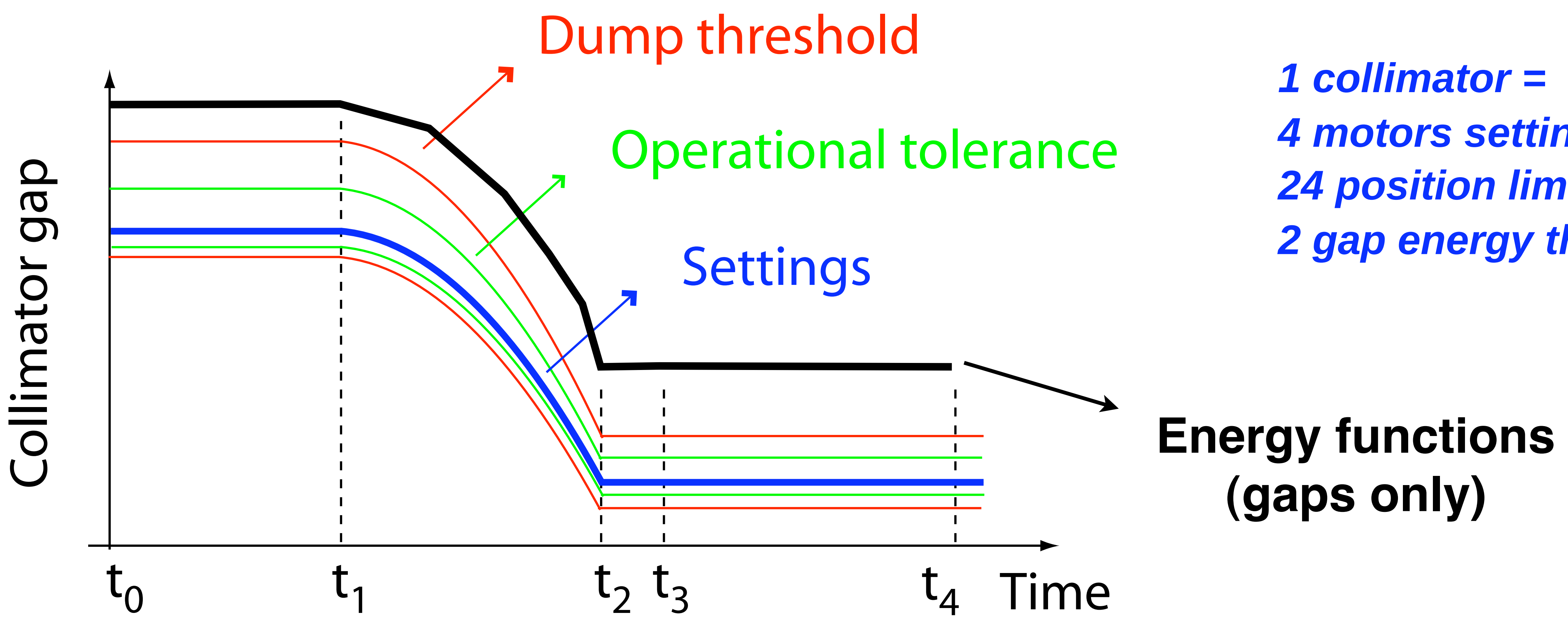
- Absorbers for warm magnets
- Transfer lines (13 collimators)
- Injection and dump protection (10)
- Physics debris absorbers (4)

Total of 108 collimators!

Parameters	2008	2009
Number of movable collimators	80	100
Degrees of freedom	316	396
Position sensors	788	998
Interlocked position sensors	472	592
Motor settings versus time	316	396
Threshold settings versus time	1896	2376
Threshold settings versus energy	154	194



Collimator position/gap interlocks

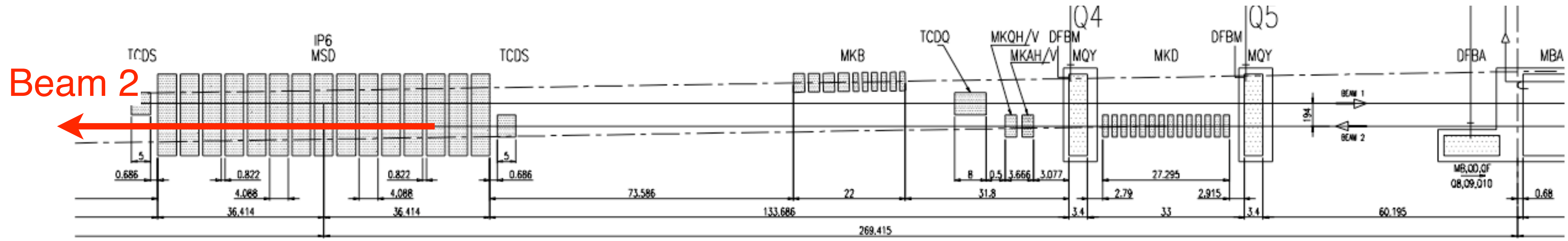


1 collimator =
4 motors settings +
24 position limits +
2 gap energy thresholds

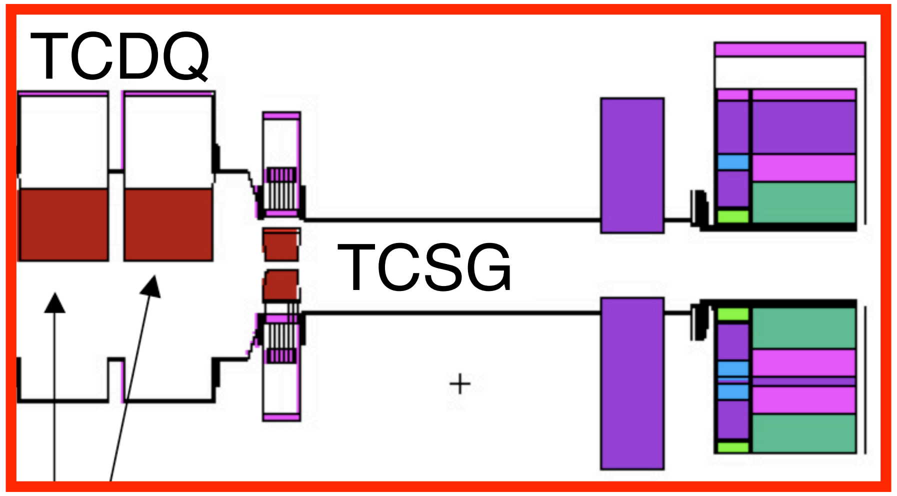
- Time-dependent limits for jaw positions and collimator gaps.
- Stop jaw motion if limits are exceeded.
- Energy-dependent limits on gap: redundancy during energy ramp.
- Similar implementation for limits versus beta* foreseen for the shutdown.

For a defined set of limits (generated and managed by with software), the interlock goes into a **hardware BIC input**.

Collimators - TCDQ/TCSG retraction



The TCDQ collimator that protects the machine against asynchronous dumps is **one-sided**.
HW interlocks on the "gap" are therefore not possible!



We do have limits versus energy that ensure that it starts moving during the ramp.

Additional **software interlocks** check that:

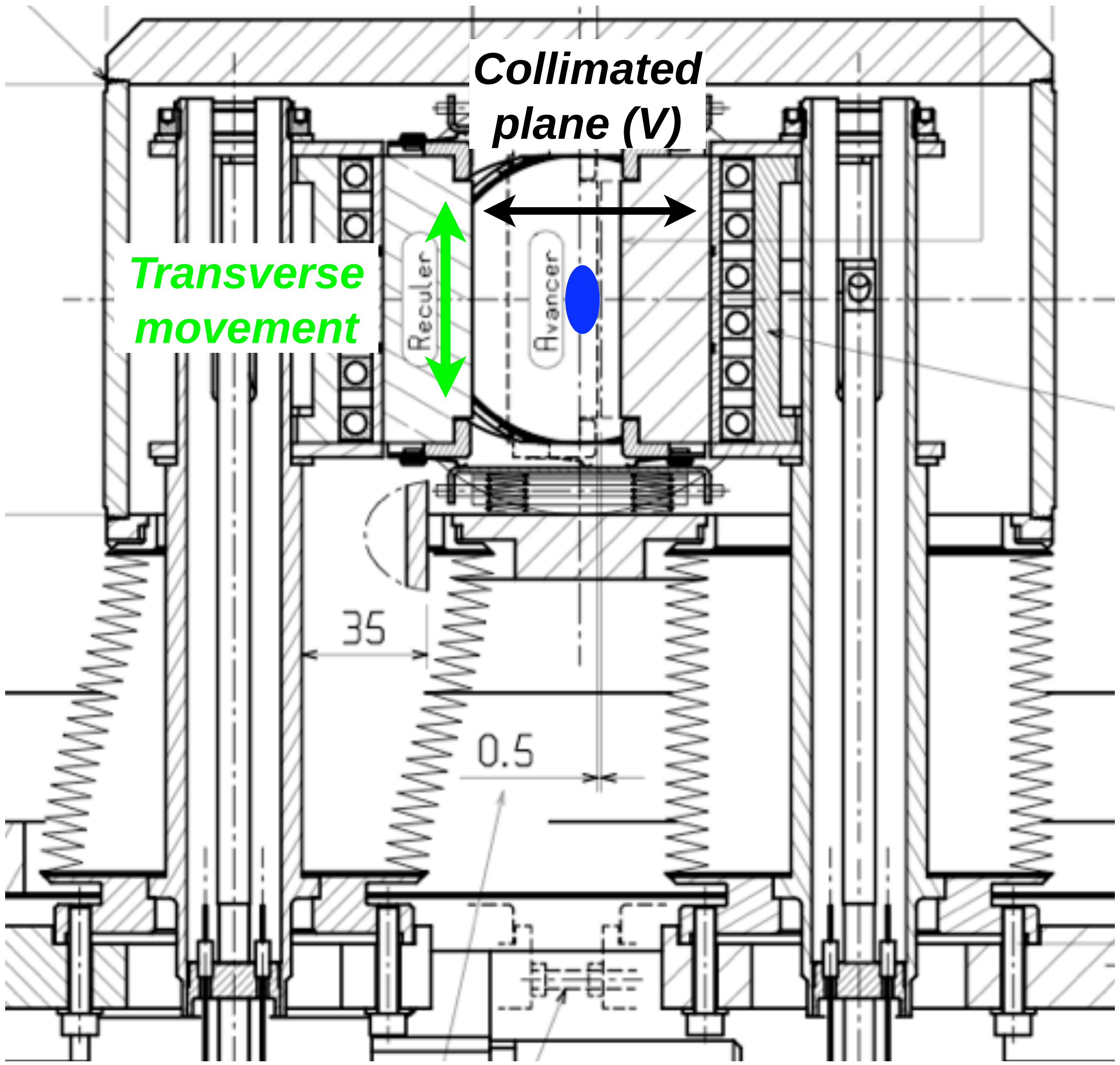
- The TCDQ remains centred with respect to the TCSG nearby;
- The TCDQ "half-gap" scales down correctly with the energy.

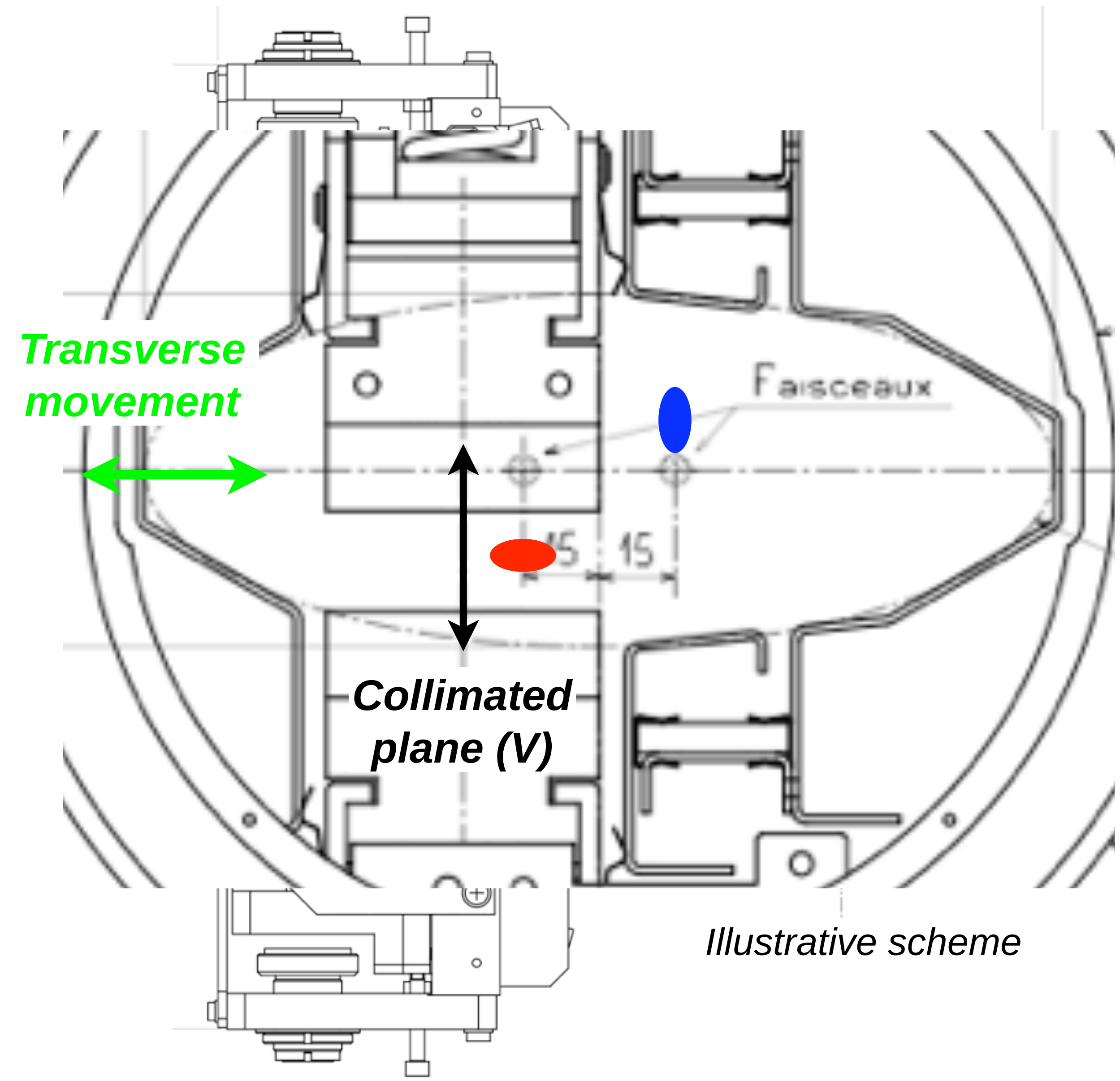
SIS interlock based on the **1 Hz** acquisition of **collimator positions** and **orbit** and **beam energy**. *More details on JW's talk.*

[AND] TCDQ_BEAM_B1
- TCDQ_RETRACTION_B1
- TCS_BEAM_OFFSET_B1
- TCS_GAP_B1

SIS interlock tree

Collimator 5th (transverse) motorization





Illustrative scheme

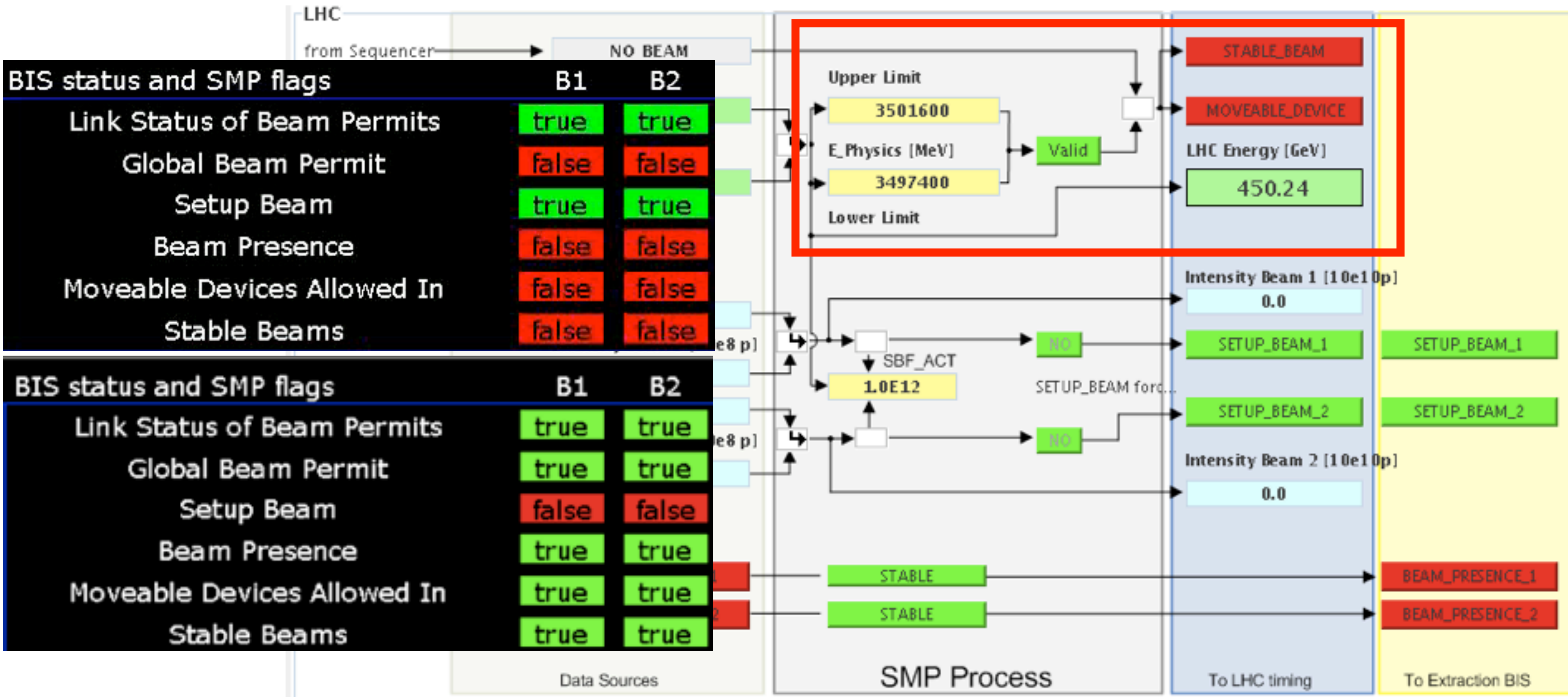
Transverse motorization to provide "fresh" surface in case of jaw damage.

Range of **± 10 mm** around

No issue for standard collimators: circulating beam and settings along collimated plane are unaffected!

Possible concerns for the **2-in-1 collimators** (4 TCTVs, 2 TCLIs). 5th motor not yet commissioned with beam. Can add limits as for the other motors is needed.

Logic for experiment movable devices



Movable detectors only allowed if the “Movable Device Allowed In” (MDA) flag is true.

MDA .TRUE. = (**PHYSICS ENERGY**) [HW] **.AND.** (**STABLE BEAMS**) [declared by OP]

MDA is one of the Safe Machine Parameters. *See B. Puccio’s talk.*

If **MDA = .FALSE.**:

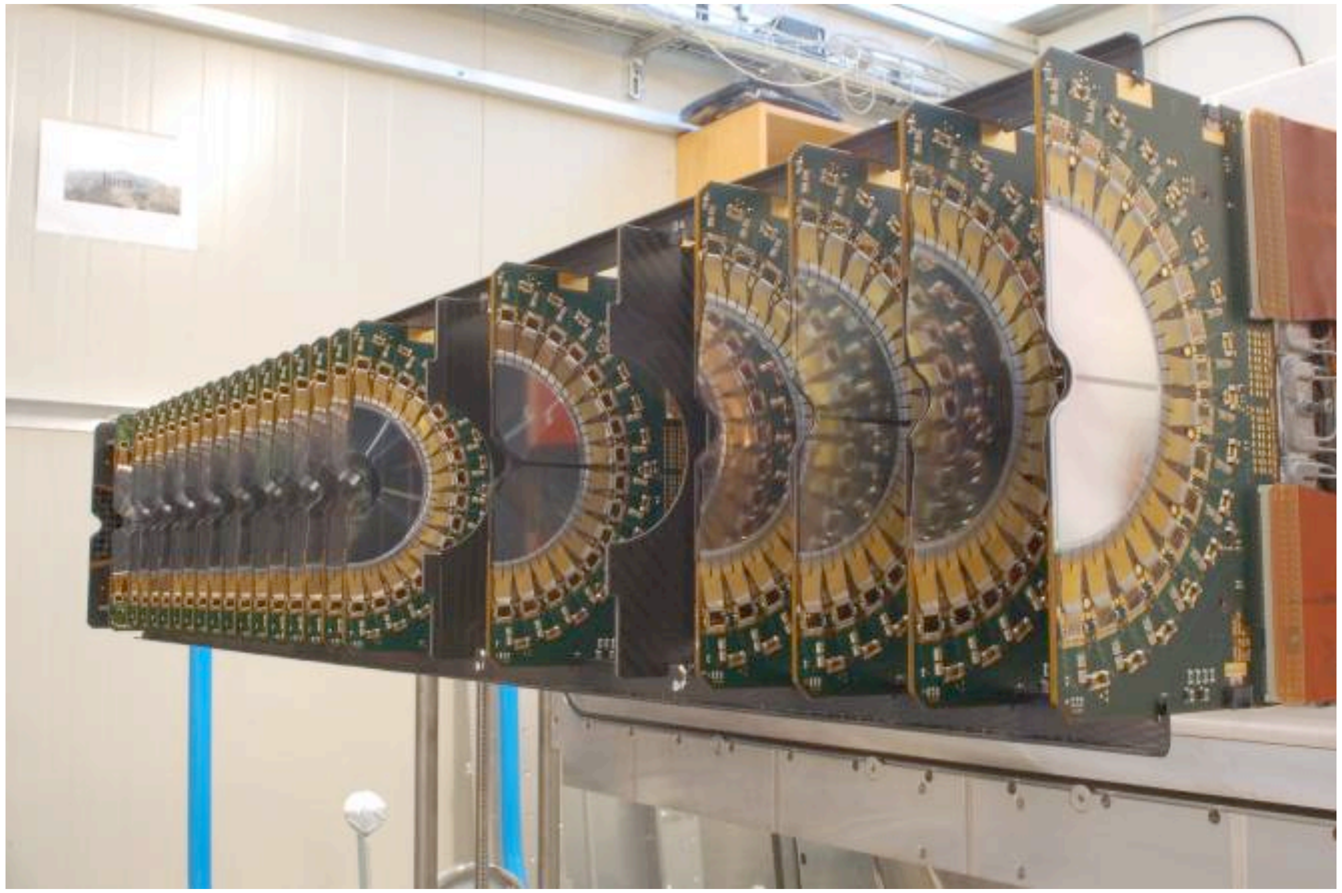
(1) a **movement inhibit** (SW or HW) prevent movements;
(2) **beam dump** is triggered if movable devices are not out (“home” position).

ers: Overview GUI

LHCb VELO

VELO detector of LHCb consists of two halves that can move from their safe position at 29 mm from the beam centerline to 5 mm on the “other side”.
Whenever one of the halves is at **less than 28 mm** from the beam centerline and the **MDA-flag is NOT set**, the User Permits will be set to **FALSE** by the motion PLC.
This toggling of the User Permit signals has been tested extensively in October 2009.
(see http://lblogbook.cern.ch/VELO/1092)

Motion control is done via a PVSS-project which communicates with a dedicated PLC.



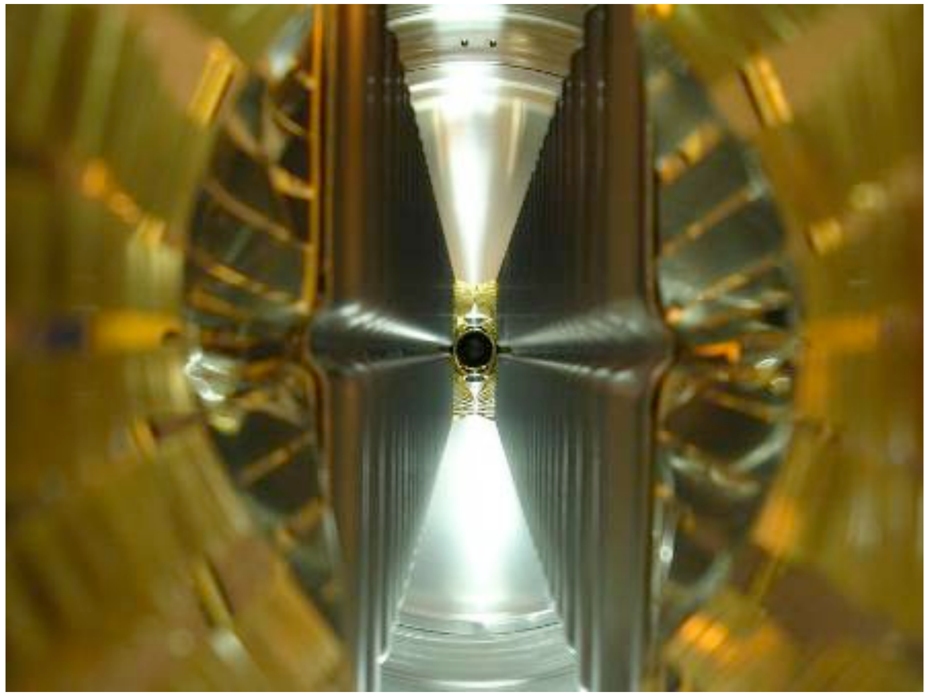
Courtesy of M. Ferro-Luzzi

Moved by LHCb when OP declares the appropriate conditions.

Closed successfully more than 100 times by the end of August!

Special care needed when going from STABLE BEAMS to ADJUST or BEAM DUMP modes.

Seen from the beams



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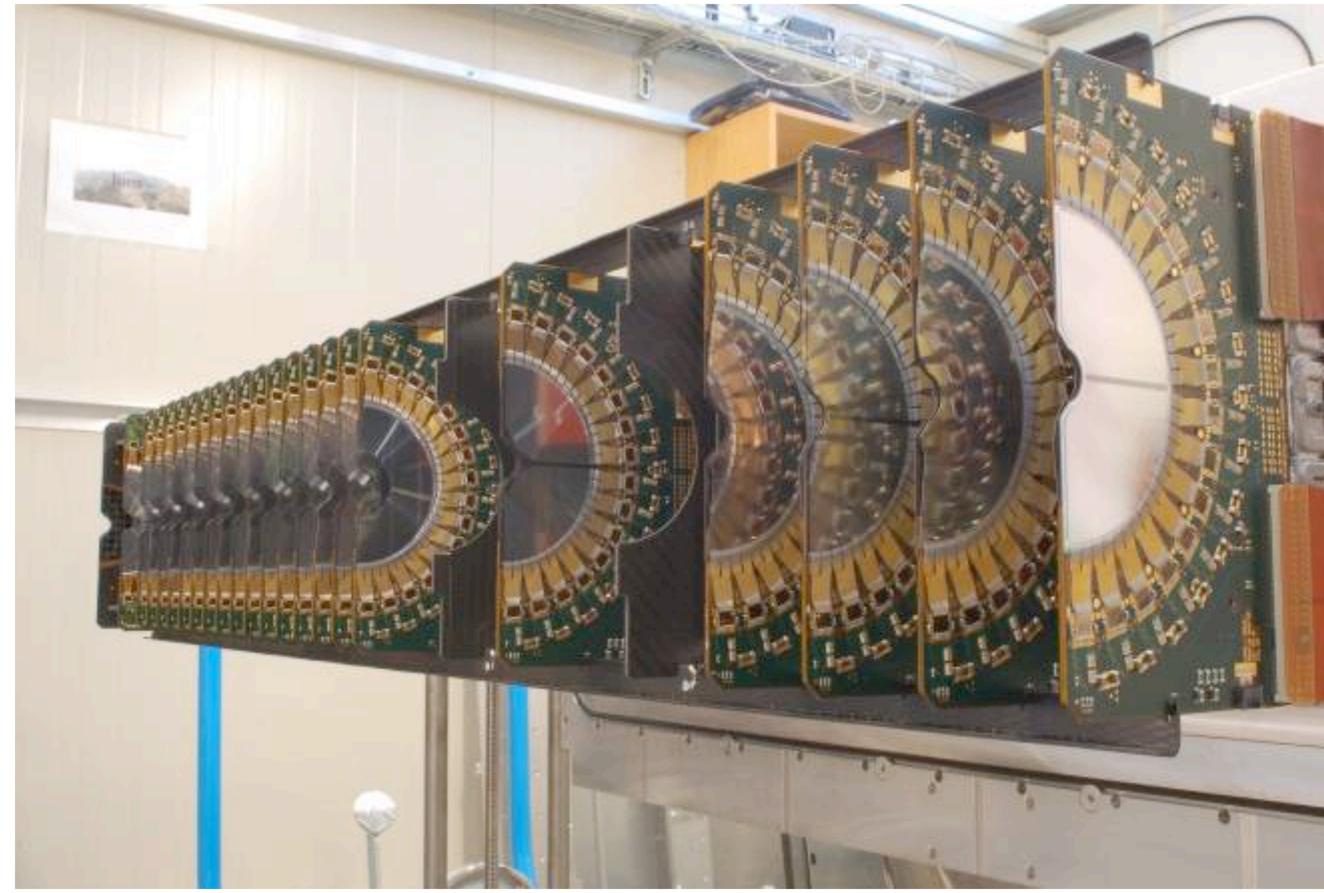

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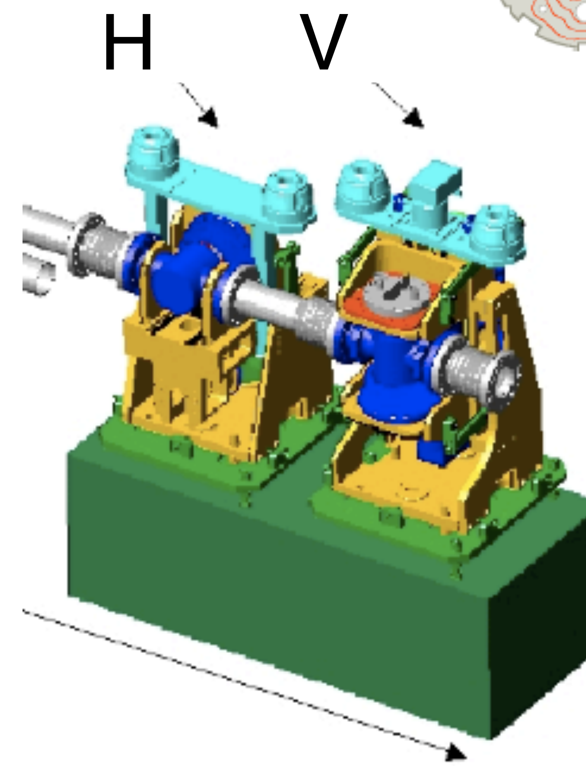
Special care needed when going fro BEAMS to ADJUST or BEAM DUMP r

One beam dump caused by removing the Mov. Dev. Allowed flag before VELO was fully out (wrong closure of adjust handshake by LHCb)

Roman pots of TOTEM



Controls derived from the collimator's (PXI). Same applications and interlock strategy as collimators: **IN+OUT limits for each pot**.

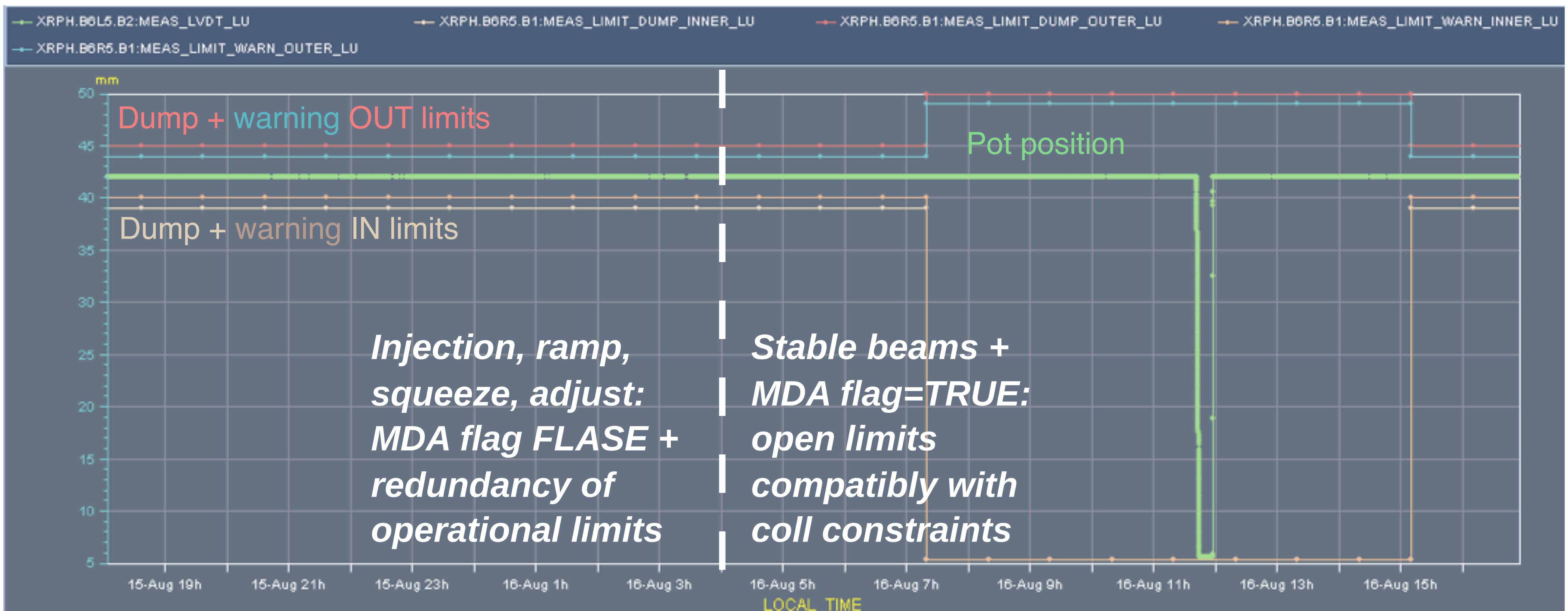
Operational limits apply on top of the Mov. Dev. Allowed IN flag!

Operational ranges defined by the **collimation team** to ensure that the **pots respect the hierarchy** (aperture > TCT).

Motion driven by OP: sequences set limits and positions.

No function- nor energy-based limits (only used in stable beams).

Motor speed limited: safe minimum step beyond threshold.



Illustrative graph

Roman pots of TOTEM

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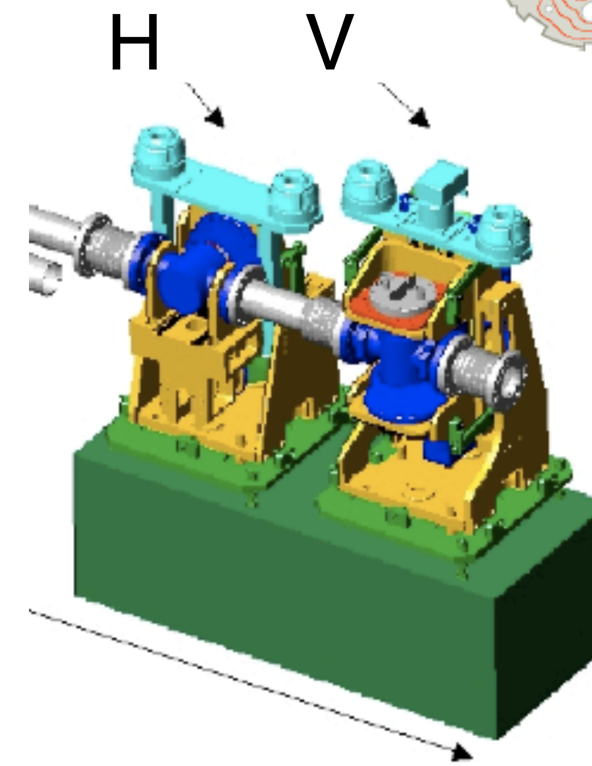
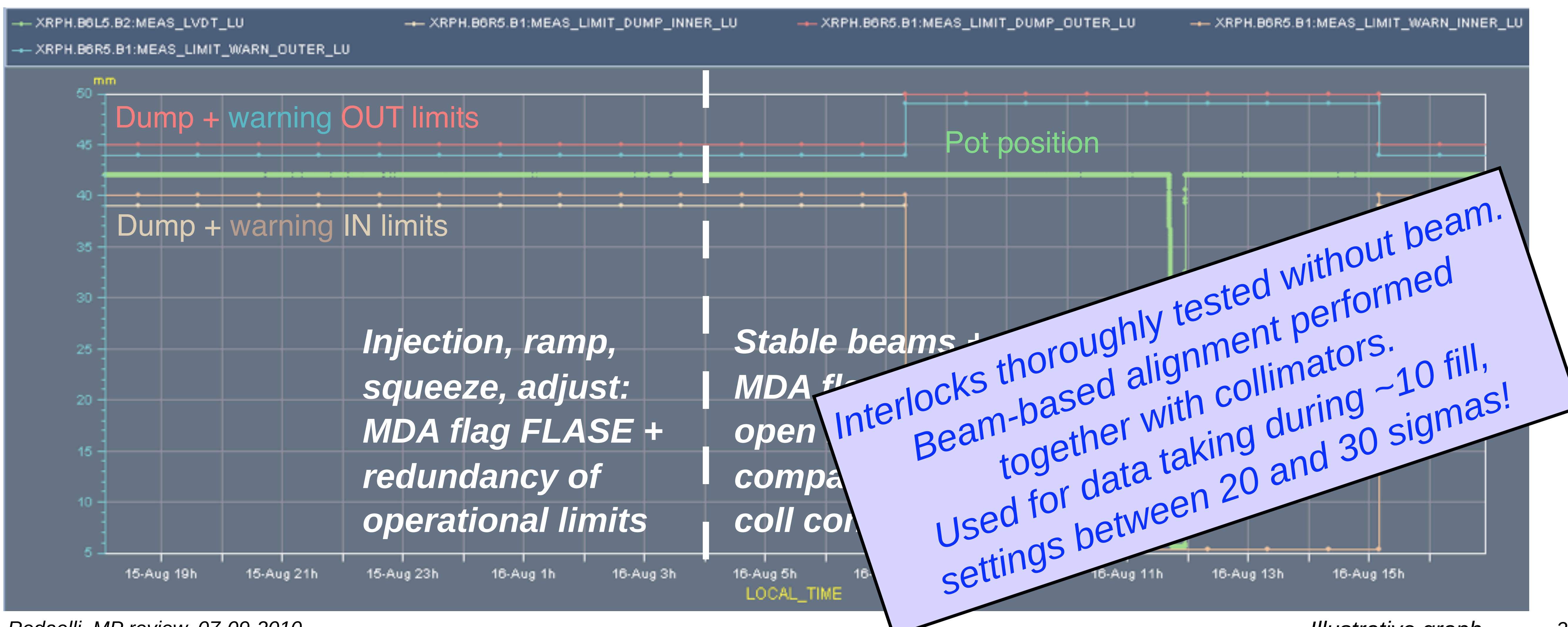
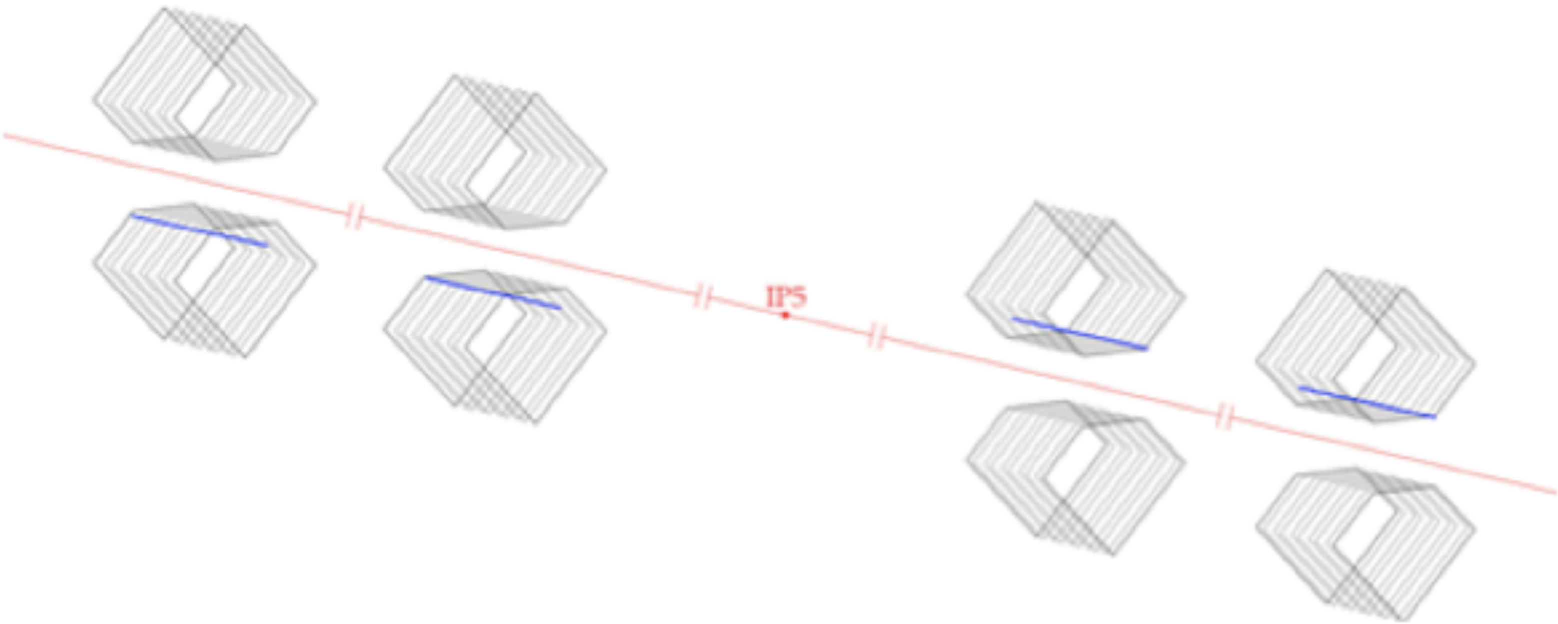




Illustrative graph

We even made it to the CERN news

29.07.10: The proton as seen by the TOTEM experiment



Two protons have collided head-on in the LHC and scattered like two billiard balls, leaving tracks (shown in blue) in some of TOTEM's detectors (grey) located 220m from the interaction point (IP5).

TOTEM, one of the smaller experiments at the LHC, has recently recorded the first signals of proton-proton elastic scattering at a collision energy of 7 TeV. It is the first time that such data has been made available to researchers at such high energy. Studying the elastic scattering between two protons is a powerful way of exploring the inner structure of the proton, one of the most common, yet still poorly understood, particles we observe in Nature.

MORE INFORMATION

- Bulletin: *The proton as seen by TOTEM*
- Overview of the TOTEM experiment

Tools for movable device controls

Effort to control with the same software application 5 different movable device type:

- Standard collimators (TCP, TCSG, ...)
- TCDQ
- TDI
- TCDD
- Roman pots

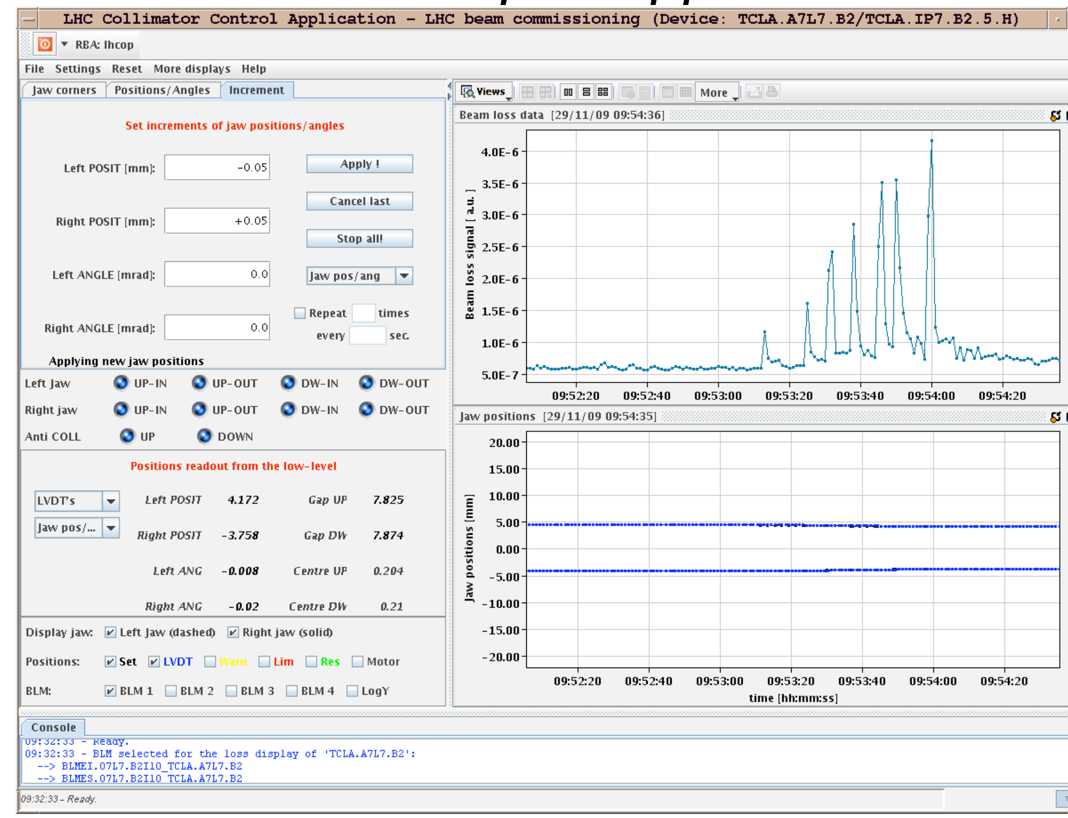
This means:

- same "expert" application for commissioning and setup;
- same setting management:
- common operational sequences:
- same handling of interlock functions.

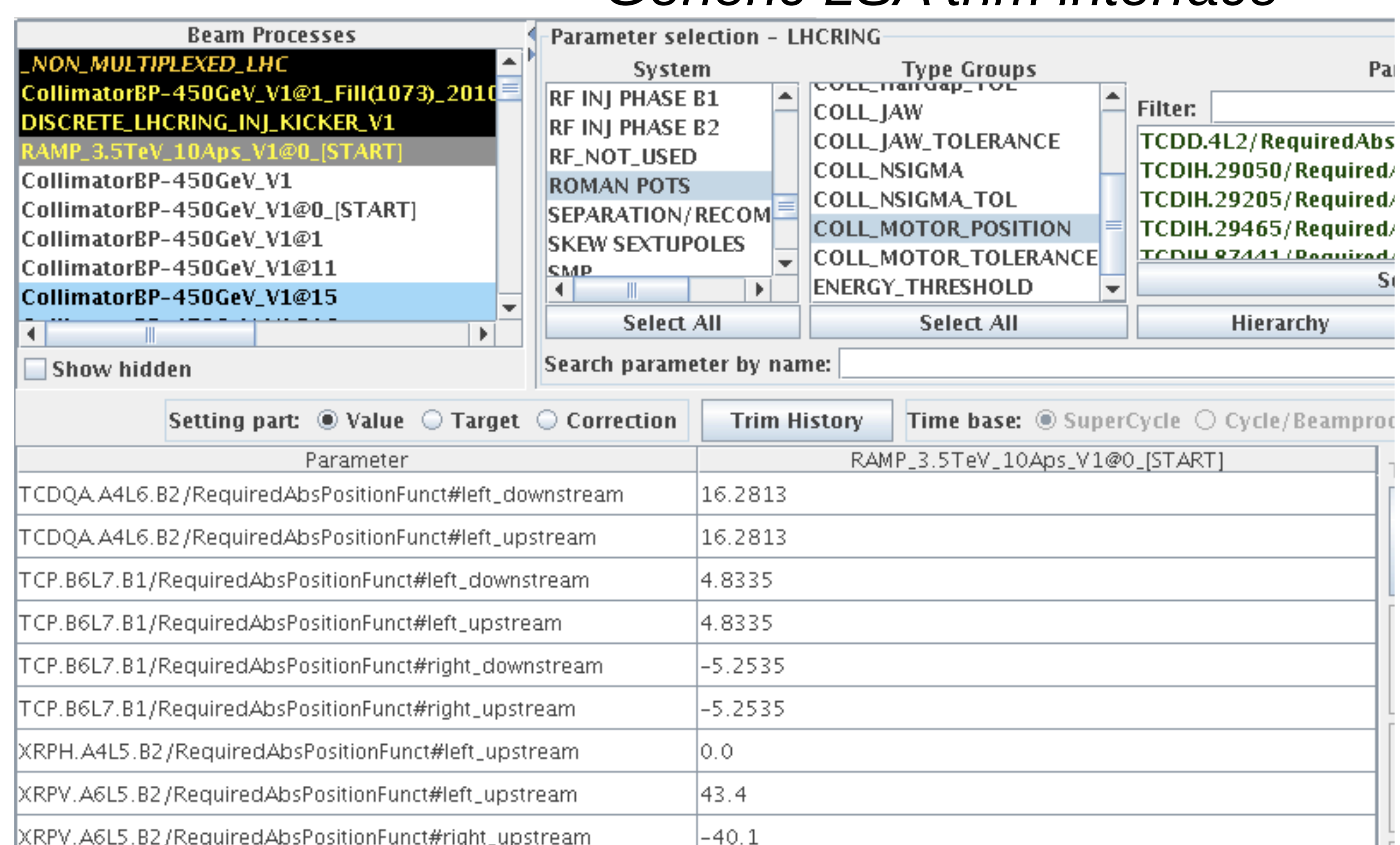
All under responsibility of OP.

Critical limits defined by the same people (LHC collimator role).

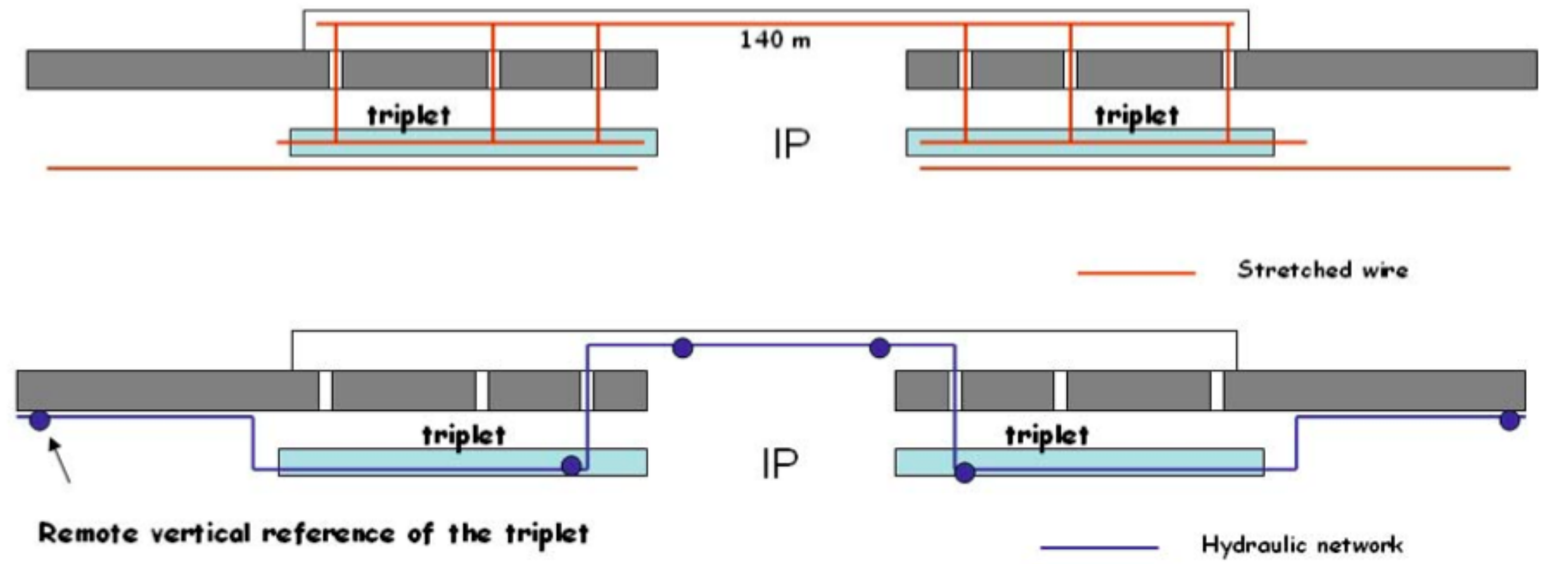
Expert application



Generic LSA trim interface



Remote control of triplet magnets



Courtesy of H. Mainaud, M. Acar.

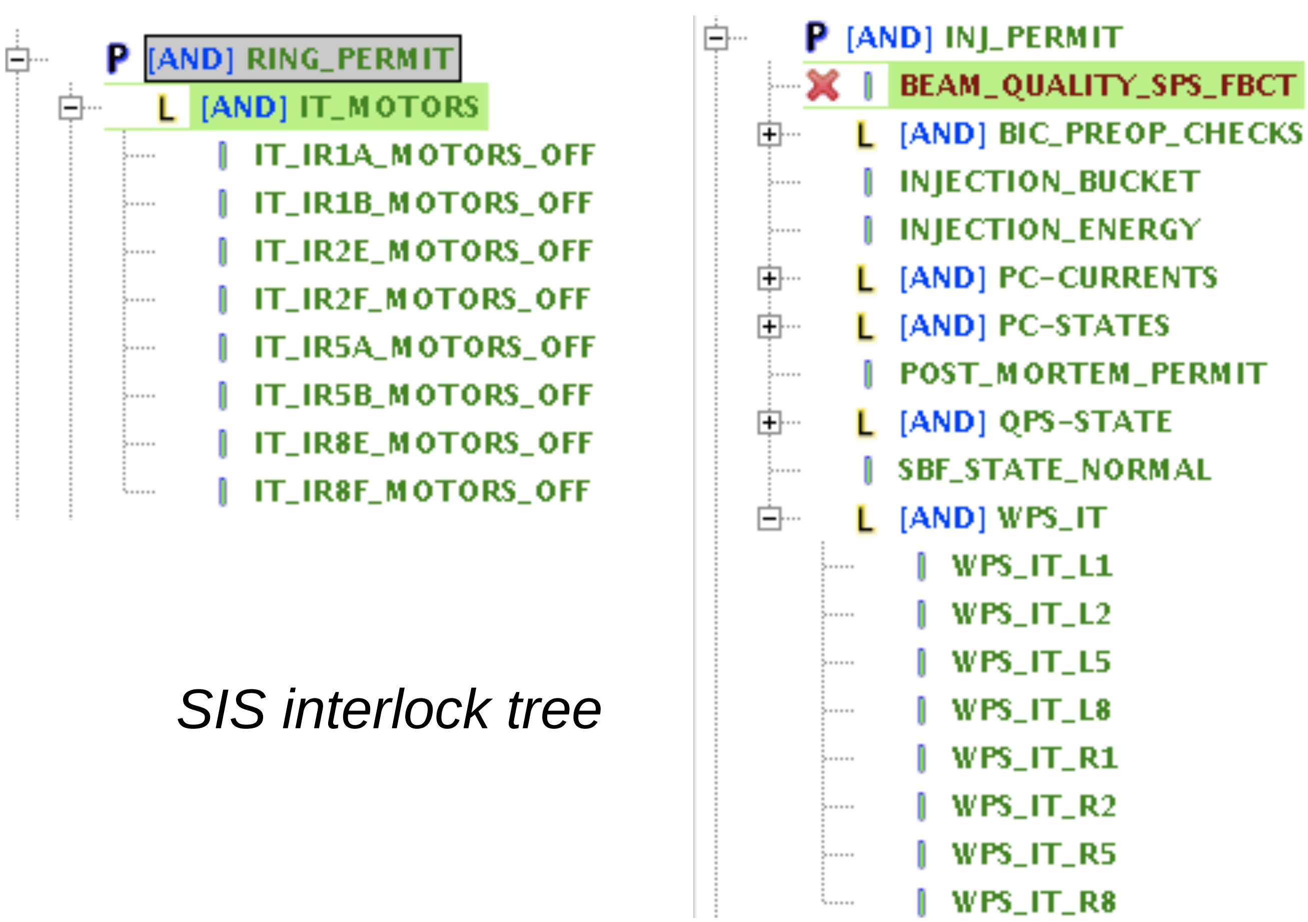
Interlock strategy for triplet magnets

The system has no inputs into the BIC. In 2008, we decided to put in place appropriate **software interlocks** to:

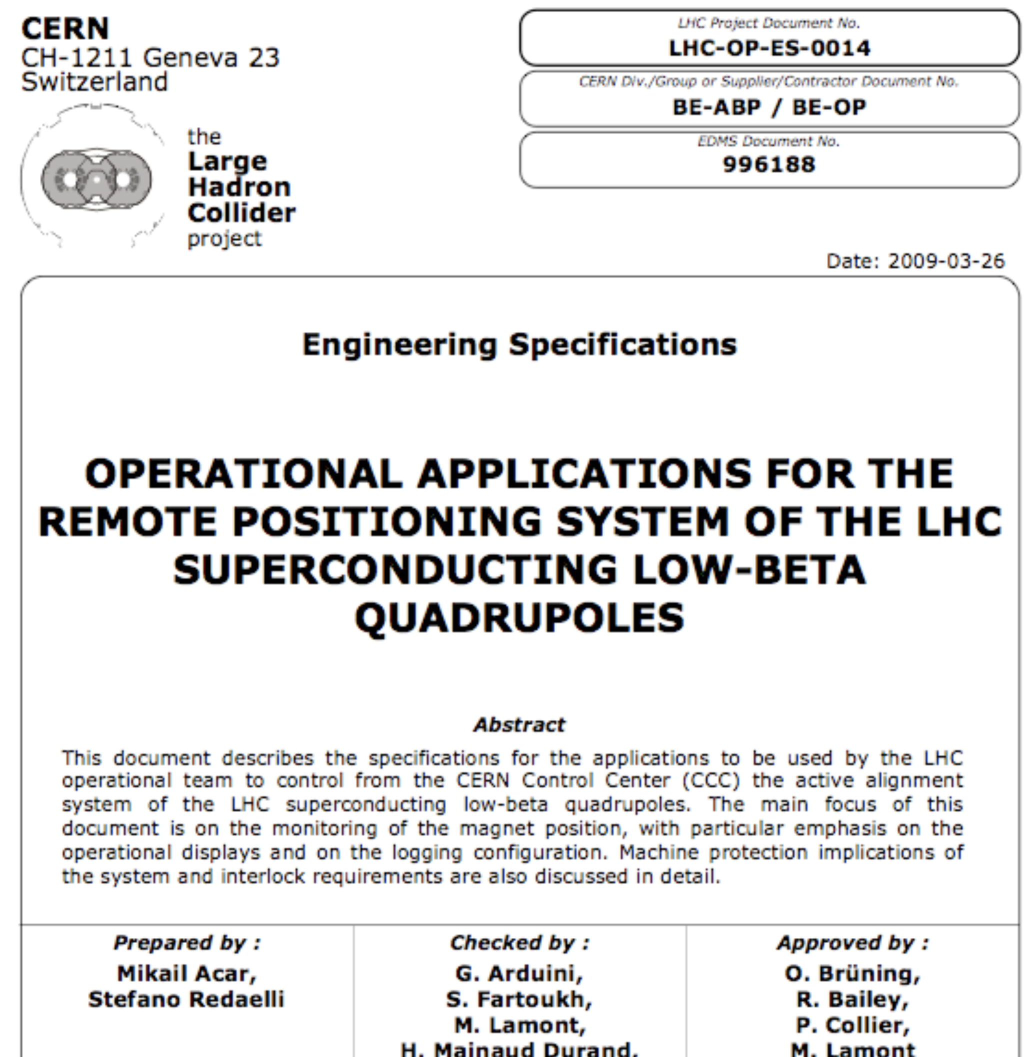
- Avoid movements of the triplet with beam in the machine;
- Prevent injection if magnets moved from values of previous fill.

Also defined appropriate RBAC role for controlling access to the equipment.

Specification of operational variables available.



SIS interlock tree



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the **Large Hadron Collider** project

LHC Project Document No.
LHC-OP-ES-0014

CERN Div./Group or Supplier/Contractor Document No.
BE-ABP / BE-OP

EDMS Document No.
996188

Date: 2009-03-26

Engineering Specifications

OPERATIONAL APPLICATIONS FOR THE REMOTE POSITIONING SYSTEM OF THE LHC SUPERCONDUCTING LOW-BETA QUADRUPOLES

Abstract

This document describes the specifications for the applications to be used by the LHC operational team to control from the CERN Control Center (CCC) the active alignment system of the LHC superconducting low-beta quadrupoles. The main focus of this document is on the monitoring of the magnet position, with particular emphasis on the operational displays and on the logging configuration. Machine protection implications of the system and interlock requirements are also discussed in detail.

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Movable device status vs. machine mode

The machine protection depends in several cases on the “knowledge” of the machine mode.

Hardware protection is provided in some cases:

- *Closing collimators during ramp OK (energy interlocks!).*
- *Experiments allowed only in physics conditions.*

Note: protection is ensured, not necessarily efficiency!

BUT, often we still have to rely on **manual actions** or **software checks**:

- *Injection protection in the ring relies ONLY on executing OP sequences;*
- *Injection protection OUT at the end of injection as well (only quench issue);*
- *Tertiary collimators to protect the triplet during the squeeze and stable beams (will be cured by the beta* factor);*
- *Screens IN only with low intensities and never with circulating beams (SIS protection only).*

Clearly, this situation can be improved. Implementation of **machine state** in ongoing (M. Solfaroli *et al.*).

We also work on sequencer **check lists** to help operation.

Reviewer’s feedback welcome...

Conclusions

- **Several hundred devices can touch the LHC beams!**
  Movable devices represent well known operational issues in all machines. This was followed up closely in the past years to be ready for a safe LHC operation.
- **The interlock strategy for each of them was presented.**
  All device types are addresses by software or hardware interlock.
- **We did not find yet specific issues in the present interlocking strategy.**
  Interlocks worked as designed so far (limited statistics in some cases).
  No reason to think that proposed approaches are not valid.
- **Some improvements should be done.**
  Dependence on machine mode is not fully safe or redundant.
  Some part of the safety rely on following procedures/sequences.