LHC Machine Protection Workshop
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Hotel Les Trésoms, Annecy, France

LHC Collimators and Movable Devices

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M. Zerlauth and MP team, TOTEM+ALFA teams, and many others.

Outline

- ☑ Introduction
- ☑ Non-OP devices
- ☑ LHC collimators & Co.
- ☑ Settings and procedures
- ☑ Conclusions

Introduction

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

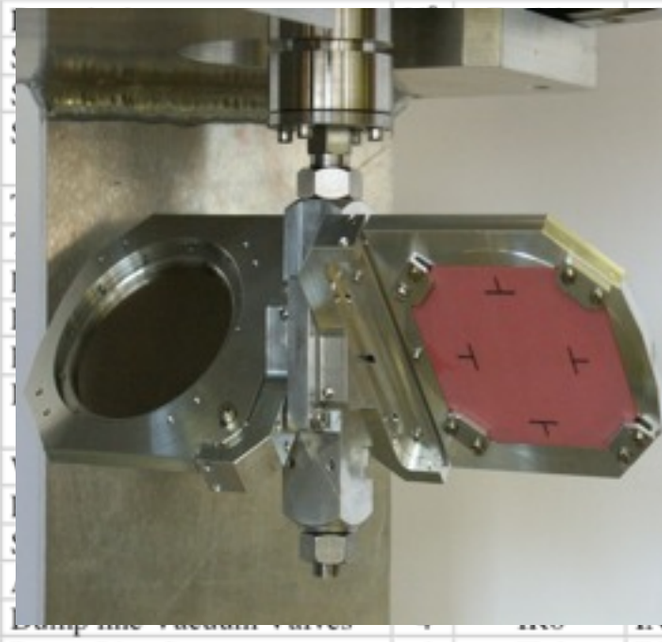
This includes: collimators, beam instrumentation, vacuum valves, safety systems, experiment detectors...

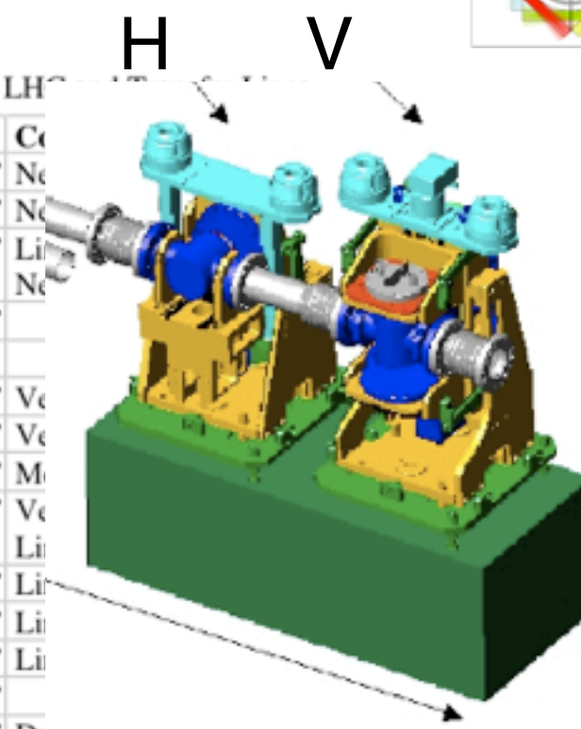
Classify in two categories: operational (settings) and non-OP (in/out) devices.

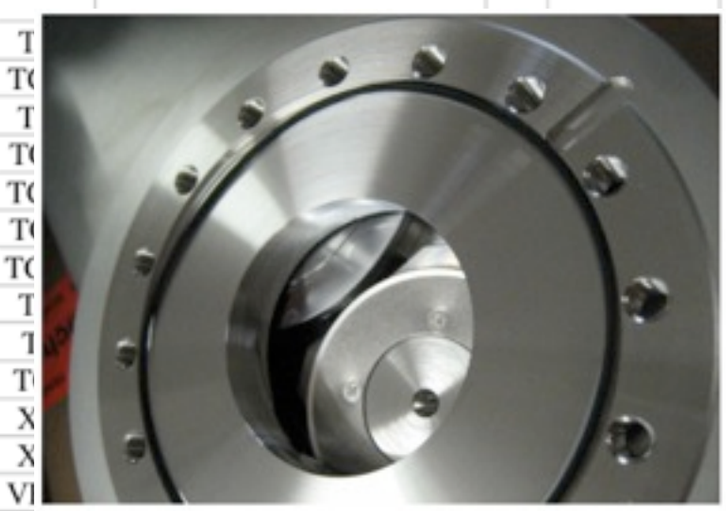
Clearly, each requires a proper **interlock strategy** for the operation with unsafe intensity!

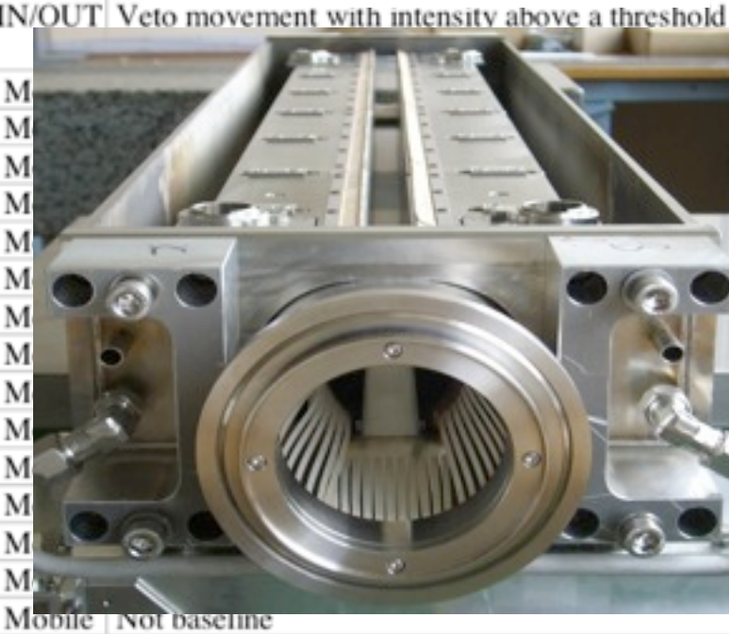
Table 2: Inventory of Objects in the LH

Name				Type	Co
TED				/OUT	Ne
TBSE				/OUT	Ne
BTV				/OUT	Li Ne
VV				/OUT	
TCDI				obile	
VV				/OUT	Ve
VVX				/OUT	Ve
VVX				/OUT	Mo
BTV				/OUT	Ve Li
BWS				/OUT	Li
				/OUT	Li
				/OUT	Li
BEUV				/OUT	
VV	Dump line vacuum valves			IN/OUT	Du
BTV	Dump Line Screens	6	IR6	IN/OUT	Veto movement with intensity above a threshold
ZDC	Alice Detectors	2	IR2	Mo	
BBLR	Beam-Beam Compensator	8	IR1/IR5	Mobile	Not baseline
	Total	476			









LHC Project Workshop - 'Chamonix XIV'

OBJECTS CAPABLE OF TOUCHING THE BEAMS

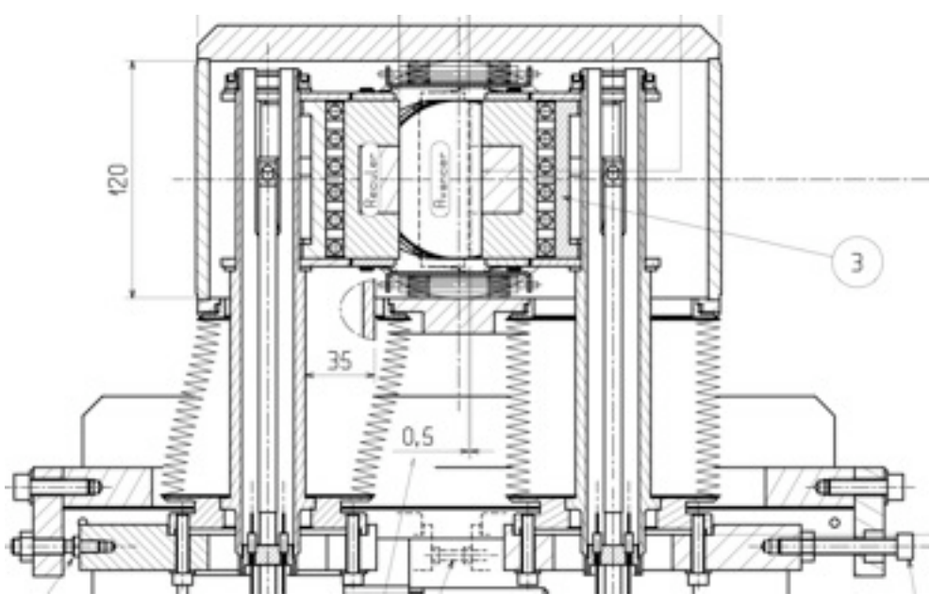
P. Collier, CERN, Geneva, Switzerland

See also my talk at the 2010 MP external review.

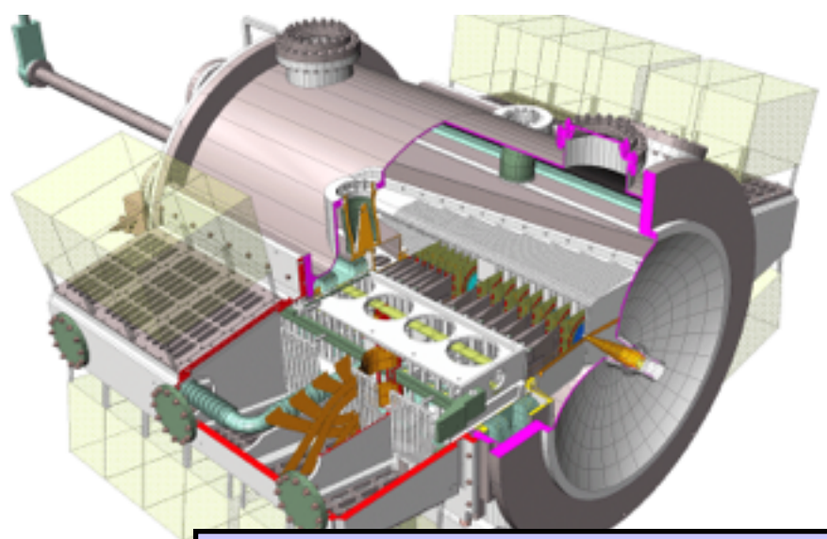
Operational movable devices

☑ **Collimators**:	- two-sided collimators (4 motors)	98
	- one-sided: TCDQs (2 motors)	2
	- 5th motor axis	44
☑ **Experiments**:	- TOTEM/ALFA Roman pots	32
	- LHCb VELO (2 halves)	1
☑ ***Triplet alignment***:	*- Motorized jacks (32 per IP)*	*128*

LHC collimator



LHCb VELO

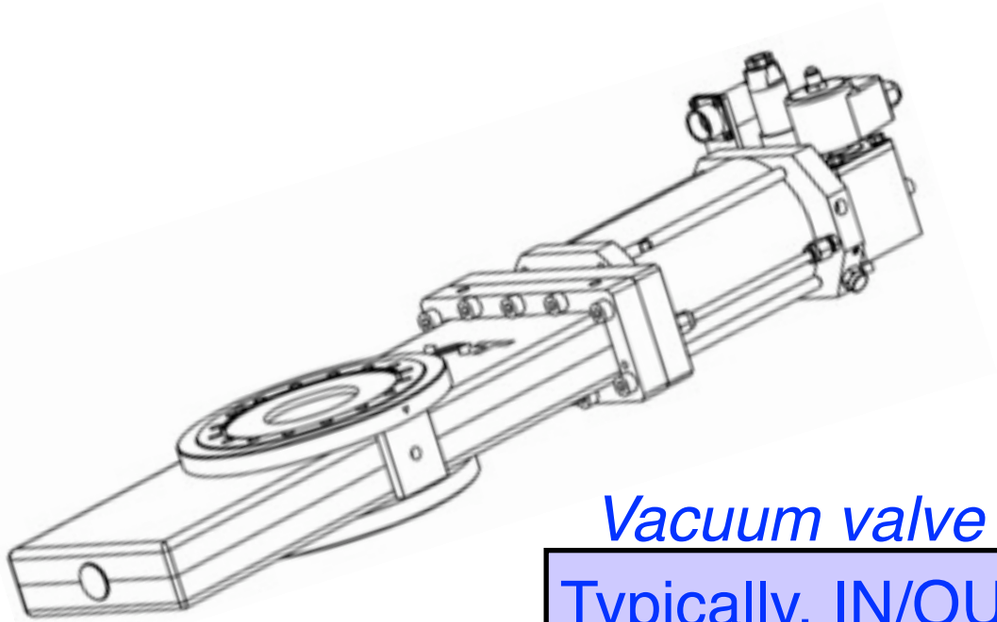


Motorized triplet foot

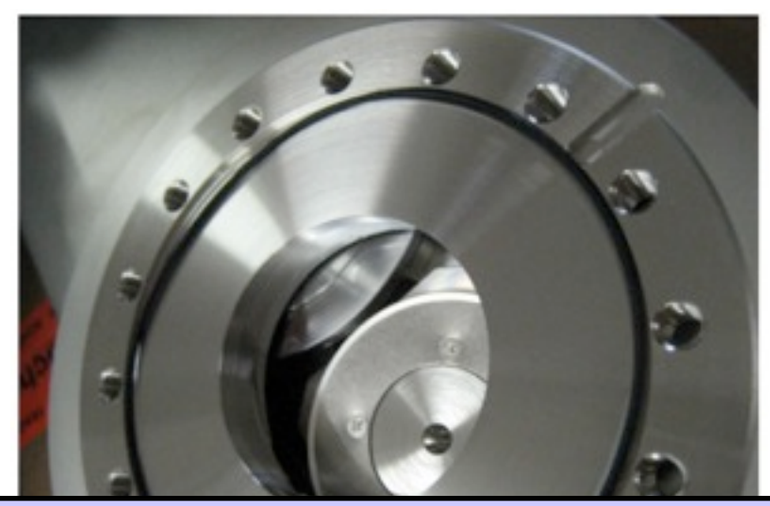
Under OP responsibility (except VELO), complex settings management of positions and interlock values that depend on time/machine mode.

Non-OP in / out devices

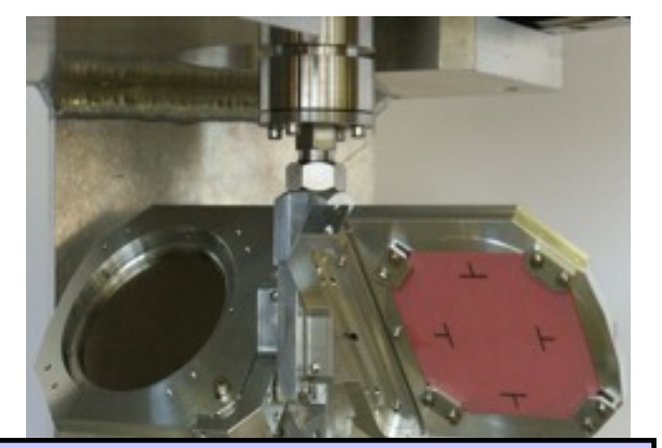
☑ **Vacuum equipment**:	- Valves to isolate sub-sectors	250
	- Electron stopped (RF zone)	4
	- Safety beam stoppers (IR3)	2
☑ **Beam instrumentation**:	- Beam screens (BTVs)	11
	- Mirrors of synchr. light monitor	2
	- Wire scanners	4
☑ **Movable masks**:	- TCDD in IP2 (D1 dipole mask)	1



Vacuum valve



BTV screen



Typically, IN/OUT devices with no operational settings along the cycle. Designed to allow hardware interlocks ensuring minimum interference with operation (out switches, slow moving speed, etc...)

Update on non-OP devices for LS1+

No major changes are foreseen for the LS1.

- ☑ **Proposal to add fast vacuum valves in IP4**
  - *Fast valves removed from baseline before LHC run1: critical for LHC safety.*
  - *Now proposed to limit collateral damage in case of failures like in 2008.*
  - *Ongoing LMC action for for the MP team - closure in ~20ms considered potentially more dangerous than collateral damage (which should have low priority after LS1 consolidation!).*
  - *Possible concern on required resources to design appropriate interlock in time.*
- ☑ **New VELO aperture in LS2 (still far in the future...)**
  - *Plan to change the aperture from 5mm to 3.5mm recently approved (LMC).*
  - *Depending on the case, the aperture could be as small as 30 sigmas, see https://cds.cern.ch/record/1499441?ln=en*
  - *Present strategy: positions handled by LHCb (fill to fill measurements of vertex positions). Might have to re-consider this for scenarios in which we get closer to the beam than other movable devices.*
- ☑ **Minor other changes that do not imply major changes**
  - *Change motorization of the BSRT to keep it fixed*
  - *New longitudinal positions of safety blocks in IR3*

See my talk at the 2010 MP review for interlock strategy.

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Collimation layout

Two warm cleaning insertions, 3 collimation planes

- **IR3: Momentum cleaning**
  - 1 primary (H)
  - 4 secondary (H)
  - 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

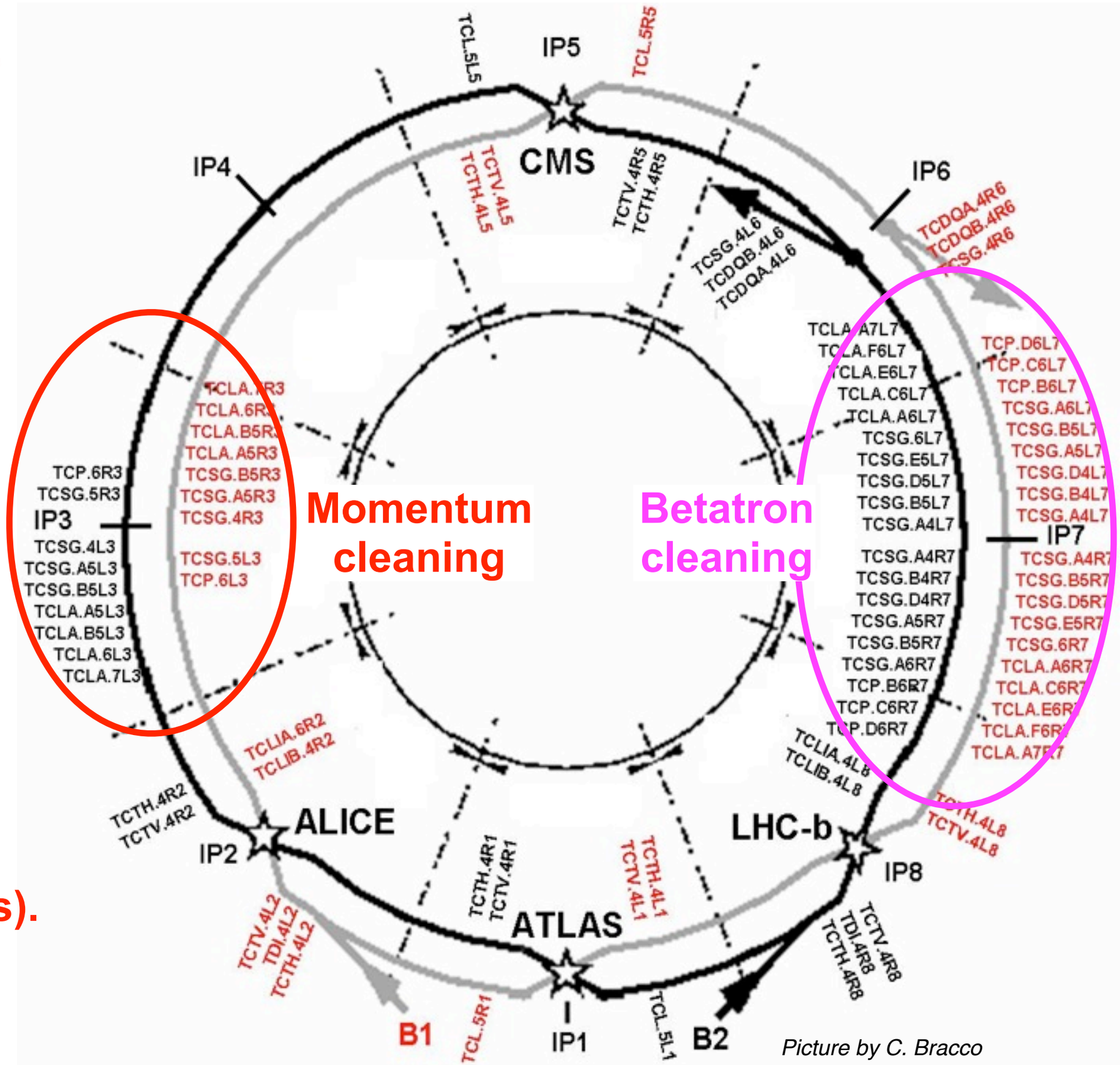
- 8 tertiary (2 per IP)

Passive absorbers for warm magnets

Physics debris absorbers

Transfer lines (13 collimators)
Injection and dump protection (10)

Total of 108 collimators (100 movable x 4 motors). 32 Roman pots in IR1/5.



Picture by C. Bracco

Summary of collimator-like objects

	N	Team	Step. motors	Discrete settings	Function settings	Timing card	Time limits	Energy limits	Beta* limits	"Redundant" limit	Temp. intrlck
LHC coll†	98	STI	X	X	X	X	X	X	X		X
TCDQ	2	ABT		X	X	X	X	X	X††		
TDI	2	STI	X	X		X	X				
XRP	32	PH / ICE	X	X			X			X‡	

Development for the LHC collimators (ABP, OP, STI with initial participation by CO) was the main "driving force". Other controls derived from this design.

Remarks:

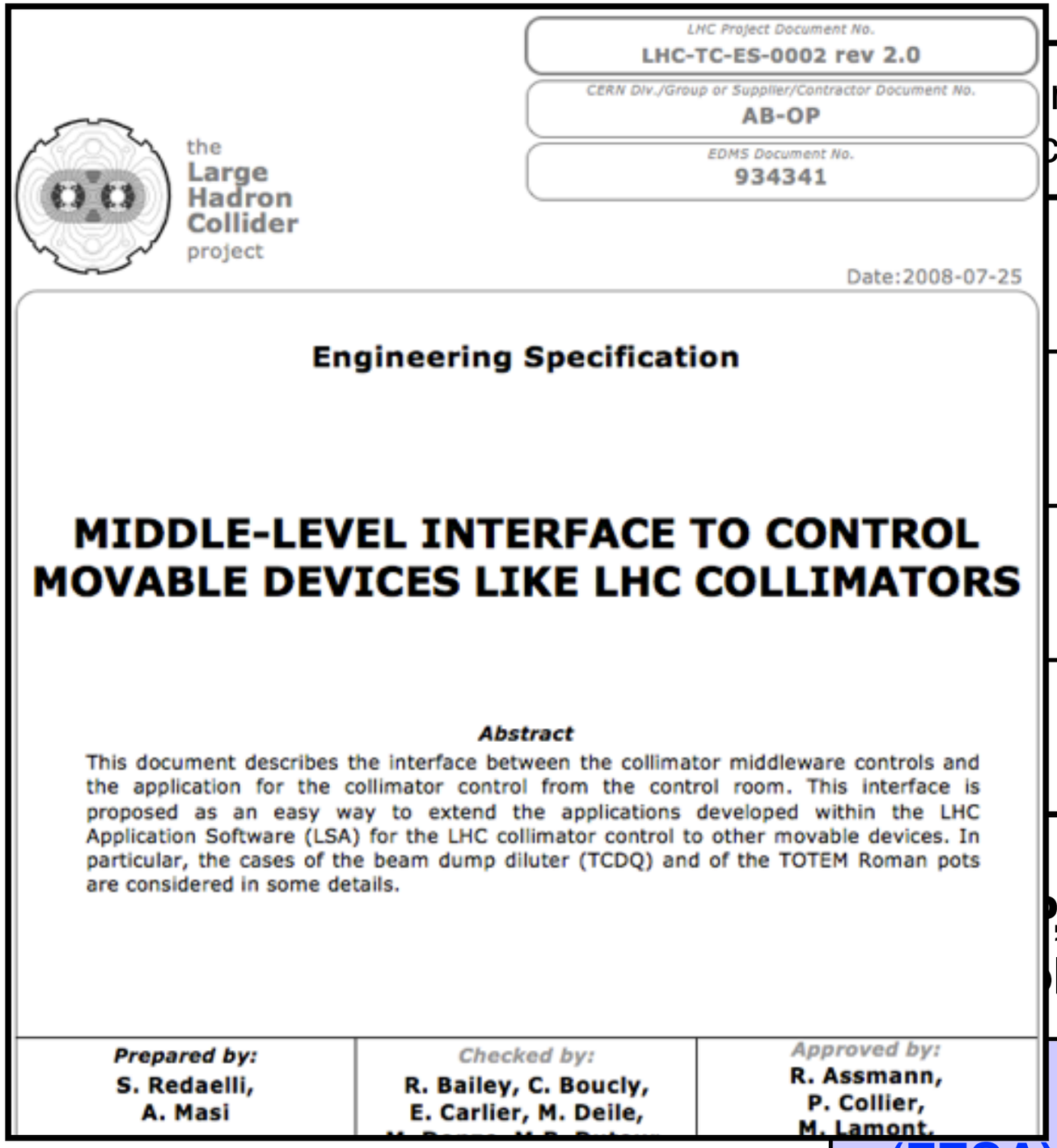
† : Includes TL colls and TCDD: SAME software as ring collimators!

†† : Not yet deployed with beam.

‡ : No hardware redundancy: SW redundancy to avoid..

TCDQ: servo loop system. Decided not to upgrade it to stepping motors.

Summary of collimator-like objects



LHC Project Document No.
LHC-TC-ES-0002 rev 2.0

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

EDMS Document No.
934341

the Large Hadron Collider project

Date:2008-07-25

Engineering Specification

MIDDLE-LEVEL INTERFACE TO CONTROL MOVABLE DEVICES LIKE LHC COLLIMATORS

Abstract

This document describes the interface between the collimator middleware controls and the application for the collimator control from the control room. This interface is proposed as an easy way to extend the applications developed within the LHC Application Software (LSA) for the LHC collimator control to other movable devices. In particular, the cases of the beam dump diluter (TCDQ) and of the TOTEM Roman pots are considered in some details.

Prepared by:	*Checked by:*	*Approved by:*
S. Redaelli, A. Masi	R. Bailey, C. Boucly, E. Carlier, M. Deile,	R. Assmann, P. Collier, M. Lamont,

ming card	Time limits	Energy limits	Beta* limits	"Redundant" limit	Temp. intrlck
X	X	X	X		X
X	X	X	X††		
X	X				
	X			X‡	

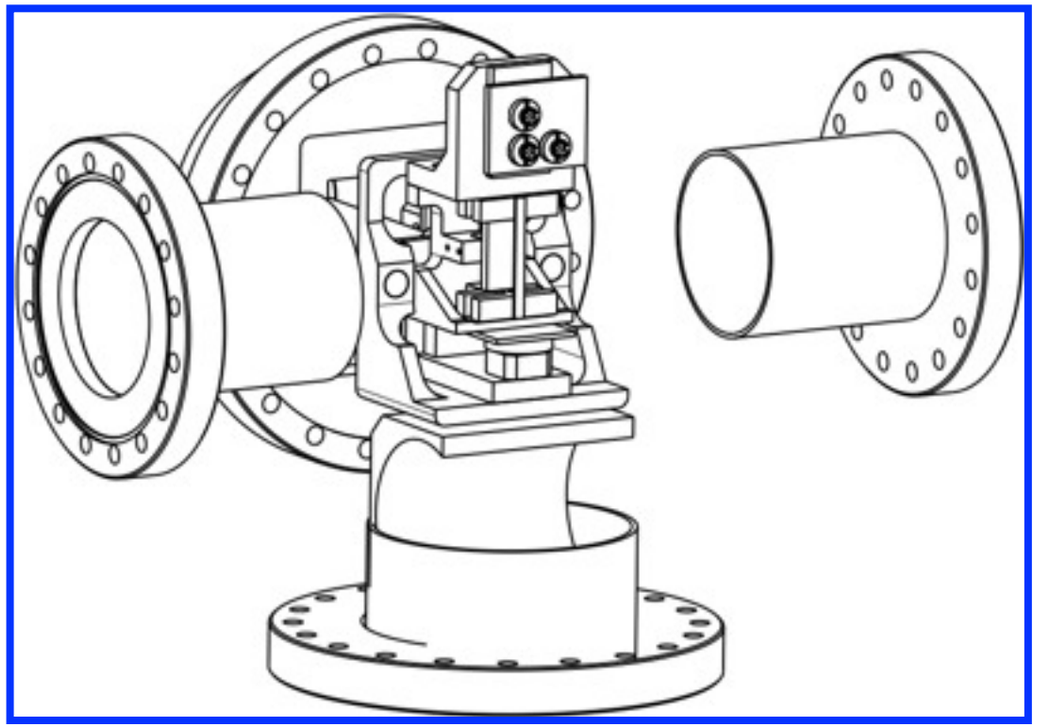
, OP, STI with initial participation by CO)
ls derived from this design.

†† : Not yet deployed with beam.
‡ : No hardware redundancy: SW redu
TCDQ: servo loop system. Decided not

in 2007 to define **a common middleware (FESA)** layer for a "transparent" control from the CCC (expert applications, fixed displays, settings, operational sequences). **Good strategy for future!**

News for post-LS1 operation (HW)

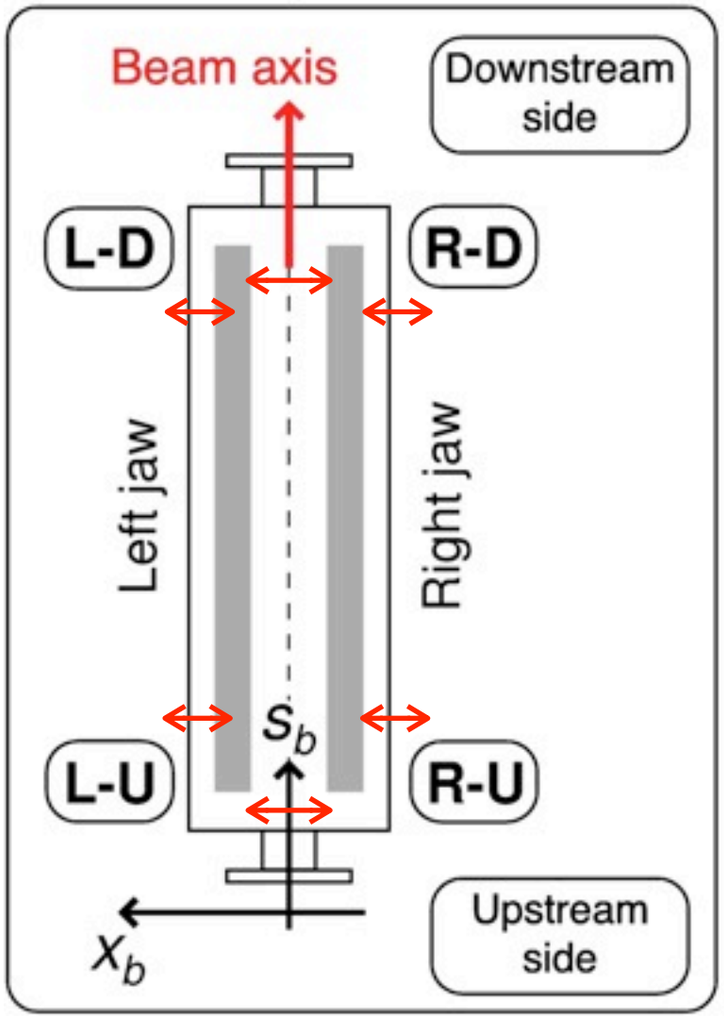
- **New collimators with integrated BPM's**
  18 new TCT's+TCSG-IP6 - see talks by GV+RB
- **Additional standard collimators**
  2-4 new TCL collimators per beam.
- **New XRP layout in IR1/5**
  Pots close to D4 might be moved in cell 5.
  No Hamburg beam pipes in LS1.
- **New TCDQ hardware** (see Bren's talk)
  From 6m to 9m - no change of motorization
- **New TDI hardware** (see Wolfgang's talk)
  Basically, same controls strategy
- **Crystal experiment in IR7**
  One or two goniometers for the installation of bent crystals in IR7 for MD purposes.
  Final layout being finalized - STI will ensure controls standards and interlocking as for LHC collimators.
  Additional detectors à la Roman pot being proposed - unlikely.

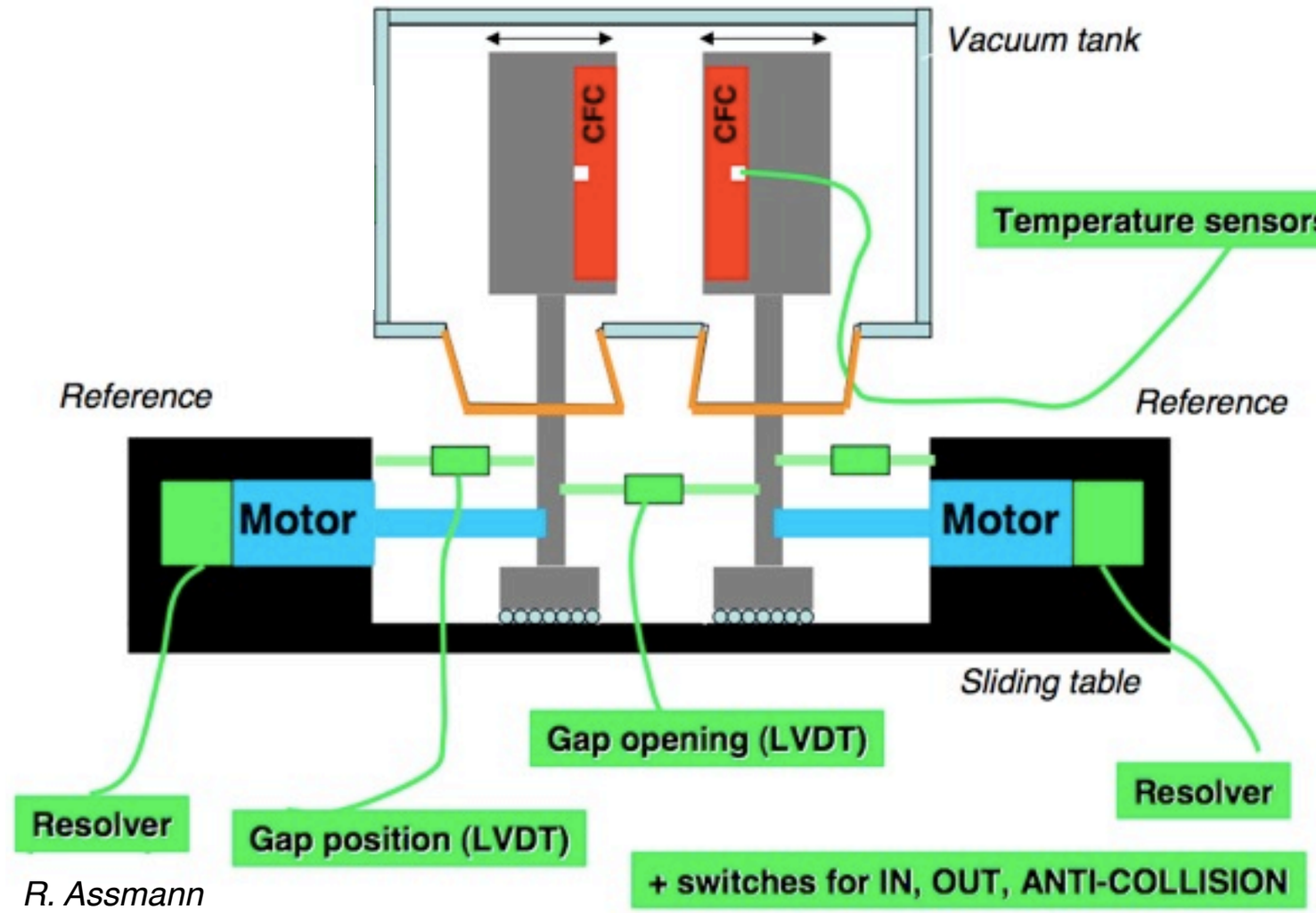


Court. A Masi.

Focus on the "standard" collimator controls in the next slides.

Collimator controls





R. Assmann

Settings: **4 stepping motors** for jaw corners - 1 motor for tank position.

Survey: 7 direct measurements: **4 corners** + **2 gaps** + tank

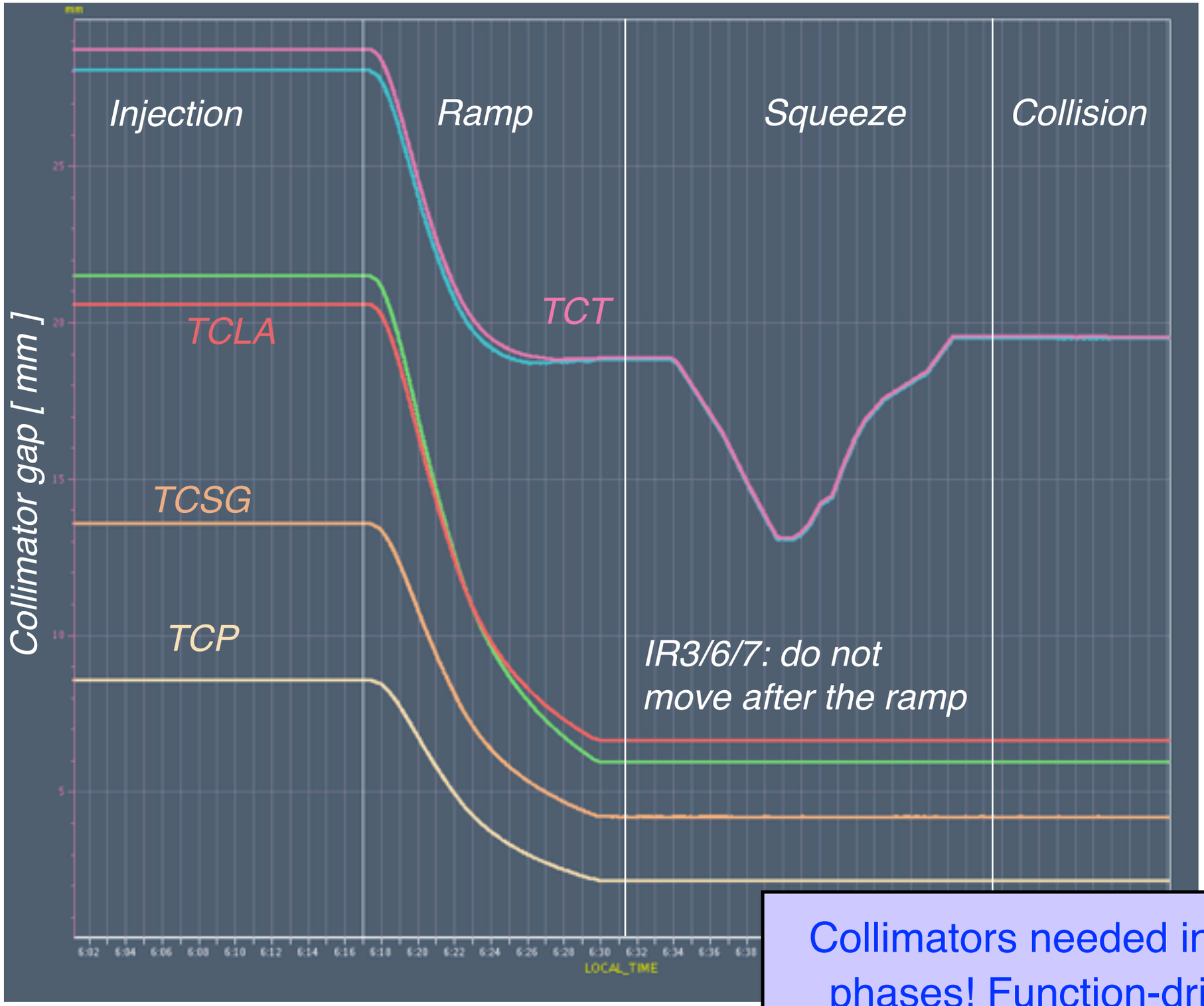
4 resolvers that count motor steps

10 switch statuses (full-in, full-out, anti-collision)

Redundancy: motors+resolvers+LVDT's (*Linear Variable Differential Transformer*) =

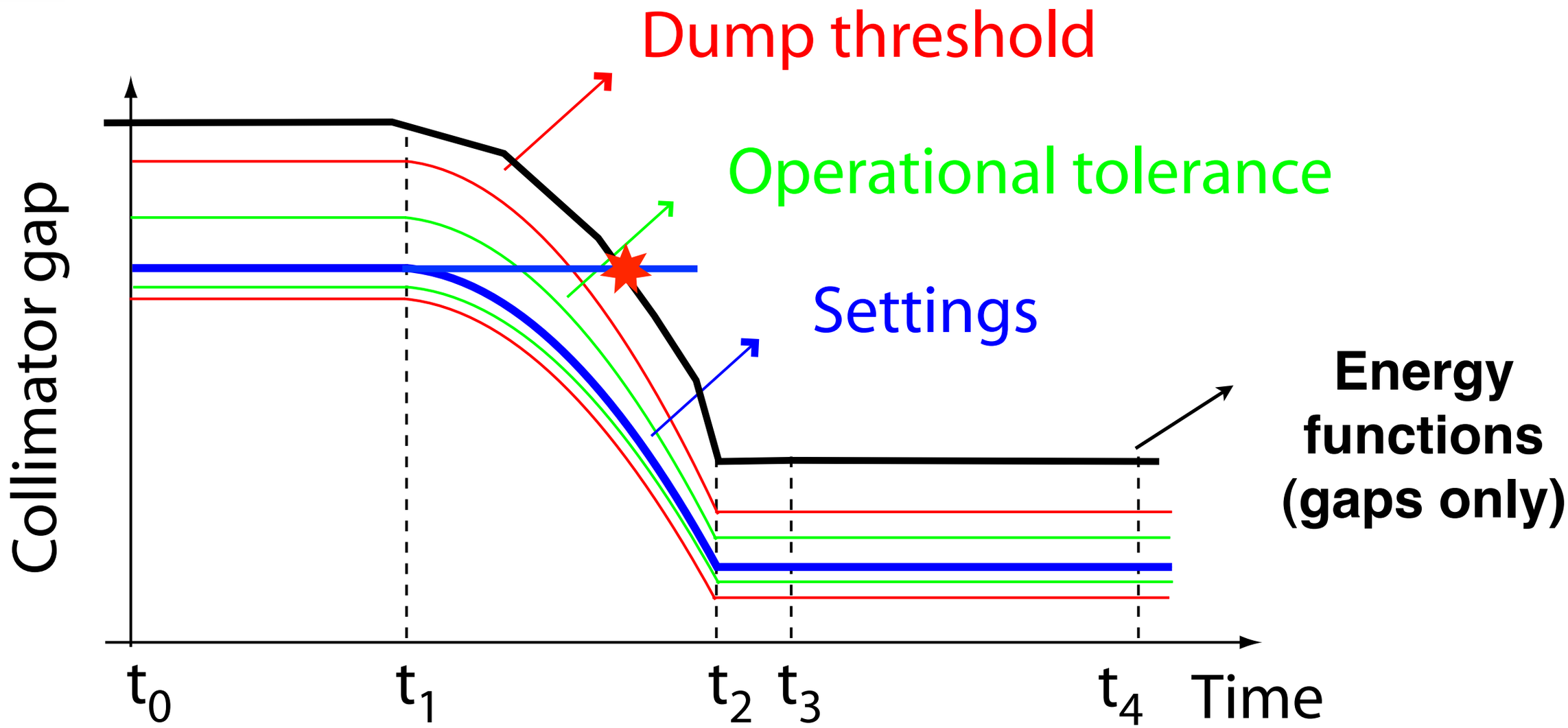
14 position measurements per collimator

Settings during the cycle



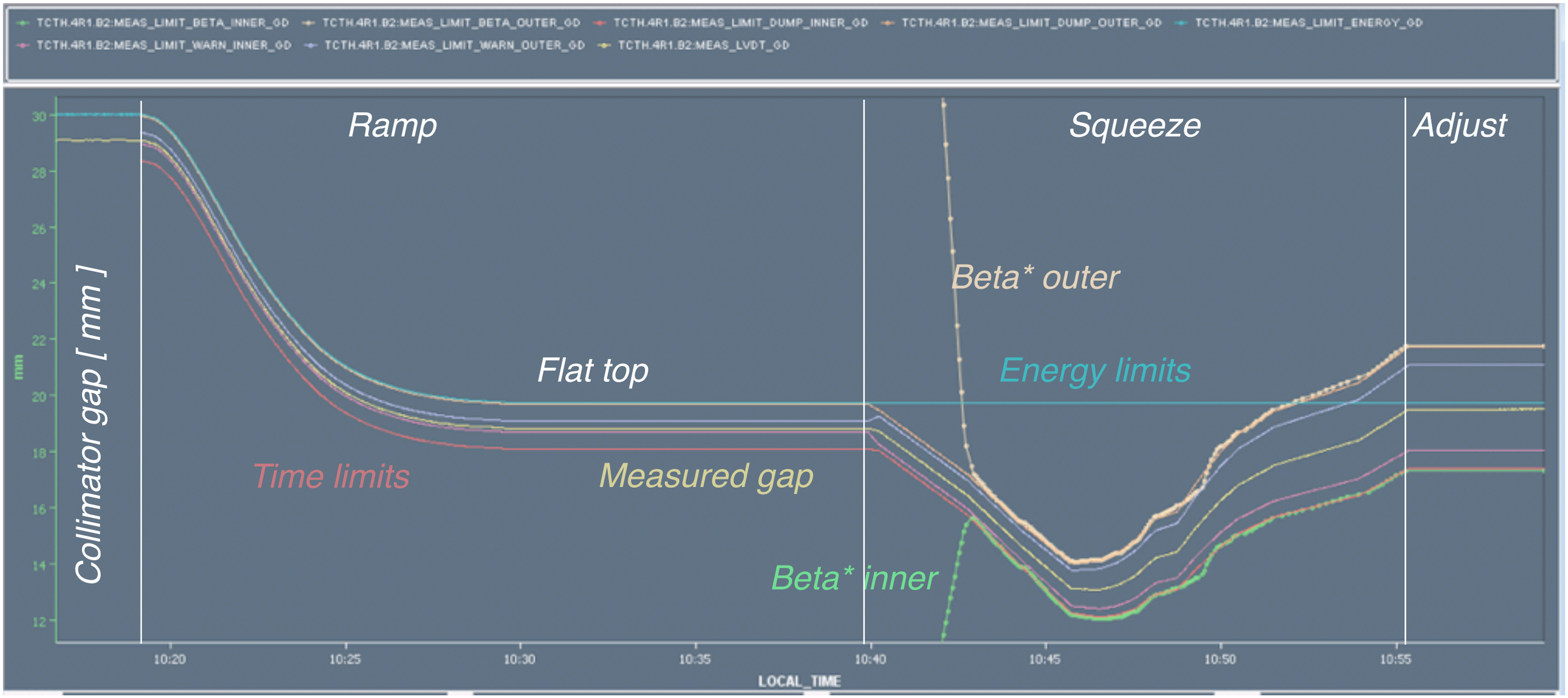
Collimators needed in ALL operational phases! Function-driven motion and precise synchronization mandatory.

Interlock implementation



- Two regimes: discrete ("actual") and time-functions *(internal clock at 100 Hz)*
- **Inner** and **outer thresholds** as a function of **time** for each motor **axis** and **gap** (24 per collimator). Triggered by timing event (e.g. start of ramp).
  "Double protection" → BIC loop broken AND jaw stopped
- Redundancy: **maximum allowed gap versus energy** (2 per collimator)
- Redundancy: **max. and min. allowed gap versus beta*** (4 per collimator)
- Temperature interlocks: 5 independent inputs per collimator

Example for TCT gaps



Energy limits active already at injection:

- Prevent injection of unsafe beams if collimators are open!
- Test at every fill the interlock chain, when collimators go to parking.
- They dump the beams if a collimator does not start ramp functions.

Beta* limits became active for the TCTs at the first squeeze step to 9m.

Physics: 3 redundant limits (vs time, energy and beta*active at the same time!!

Some numbers and dump statistics

Big and distributed system!

Parameters	Number
Movable collimators in the ring	85
Transfer line collimators	13
Stepping motors	392
Resolvers	392
Position/gap measurements	584
Interlocked position sensors	584
Motor settings functions versus time	480
Motor discrete settings	1820
Threshold settings functions versus time	2880
Threshold discrete settings	8568
Threshold settings versus energy	196
Threshold settings versus β^*	384
Active (TCT's only)	64

(Without TCDQ)

Dump/faults statistics 2012-13:

- **11 dumps from position survey above 450 GeV**
  - *5 HW failure (4 in stable beams)*
  - *6 mistakes by OP or collimator expert*
  - *No spurious dumps*
- **3 temperature dumps**
  - *2 real, 1 spurious (fake sensor reading).*
- **1 TCDQ dump in 2013**
  - *Issue to be addressed with energy limits*

No issues of not-dumping when it should!

Injection:

10 "OP mistakes"/tests (5 without beam)
4 TDI hardware problems
1 glitch on beta* limits.

Thanks to B. Todd

Estimate **downtime** from collimator intervention (remote or local), by A. Masi:
- **26.3 h** for LHC collimator faults in 2012-13; **10.6 h** for TDI problems.

Interestingly, longest downtimes triggered by faults that do not cause beam dumps!
Discuss this further at the reliability WG. Obviously, time for beam checks not included.

Interesting for this workshop: when dangerous situations were **<u>not</u>** dumped?

Problems not detected

- **Isolated problems with collimator settings**
  - *Wrong value entered in the controls system: TCT's + TCLA in IR3*
  - *Software improvements deployed in 2102 catch this.*
  - *New hardware after LS1 (BPM collimators) will improve further!*

Next talk by Gianluca

- **Issues with injection protection settings**
  - *Wrong TL's settings during ~3 weeks in 2011 (pointed to wrong beam process).*
  - *Beta function issue when moving to Q20 optics.*
  - *Wrong selection of beam process for 1 MD in 2012.*

Injection talk by Wolfgang

- **TCT's not starting collision functions**
  1. *Issue with local timing down in IR1 - Caught as foreseen by state machine.*
  2. *TCT sequence skipped by shift crew at transition between commissioning standard operation (2013 ion run).*
  - *Note that safety still relies on manual actions! Show we work on mechanisms to enforce execution of sequences?*
- **Tricky issue with Roman pot settings**
  - *Hybrid situation when cloning physics settings from an obsolete BP.*
  - *Detected by SR + JW before deploying physics settings.*

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Recap. of settings management

User list used by sequence

Database entities were actual settings are stored

Hypercycle

Users		Beam process
INJ	→	Injection-BP
RAMP	→	RampFunction-BP
FLATTOP	→	FlatTop-BP
SQUEEZE	→	SqueezeFunction-BP
ADJUST	→	EndOfSqueeze-BP
COLLISION	→	CollisionFunction-BP
PHYSICS	→	StableBeam-BP

A simplified view for illustration purposes.

Several instances of beam processes: Each can be assigned to any user within a beam process.

Beam process'	Beam process''
Injection-BP'	Injection-BP''
RampFunction-BP'	RampFunction-BP''
FlatTop-BP'	FlatTop-BP''
SqueezeFunction-BP'	SqueezeFunction-BP''
EndOfSqueeze-BP'	EndOfSqueeze-BP''
CollisionFunction-BP'	CollisionFunction-BP''
StableBeam-BP'	StableBeam-BP''

Time-dependent settings and limits are stored in beam processes (BPs).

4 people on the world can change the settings of a BP (MCS protected), but...

At any given time, 3-4 people in the CCC can changes the assignment BP↔ user!

"Protection by complexity" for ring collimators, more issues for **injection protection**.

Proposal to add RBAC protection for some BP's - not deployed in 2012.

Redundant limits versus energy and beta* are always resident in the hardware ("discrete BP") and are not changed during the OP cycle (1-3 changes per year!).

This scheme works for ramp and squeeze but it is not in place for collision functions.

Additional redundancy for collision

- We should consider the possibility to add **limit functions for the jaw positions** (not for the gaps that remain constant) **as a function of the beam separation in the IPs**

  This would "close the loop" and ensure by HW interlock that the TCTs move during collision functions (only function execution with no redundancy).

  Do we need also limits versus crossing angle?

- **Open points:**

  How do we calculate reliable the beam separation?

  LSA settings versus time sufficient or need to re-compute it from corrector strengths, like for beta?*

  Put new information in timing and eventually in SMP. Decode it in front ends.

  Need to change collimator controls to add one more limit: (inner+outer)x4 axes

  Generation of new parameters, update of MP sequences, logging, etc...

- **This feature can be detected by the new BPM-collimators!**

  Is it work making the change?

  Note that we might not have all the new TCTP's by the startup in LS1...

  Machine state checks could be improved further as an alternative measure.

General comments on procedures

(See also talks by Markus and Brennan)

- More on settings management and validation in next two talks
- Typical validation of new machine configuration (at start up):

  Pilot cycle, cycle with nominal bunch intensity (orbit setup), collimator alignment fill, validate new cycle settings in parallel with loss maps.

  → *Time to look at data and loss maps, test sequences, double check settings...*
- The situation **degraded** during the year (victims of our success?).

  Pressure to reduce setup time ("minimum theoretical commissioning time" becomes the baseline); re-discussion on-the-fly of validation procedures; handling of settings and validations systematically done during night!

  Had to insist a lot to repeat doubtful loss maps...

  Specifically bad for Roman pot runs because same people must be available 24h+ (revert settings for stable beams at top intensity after "MD"!)
- No dangerous situations caused by that, but no ideal conditions...
- In view if 7 TeV OP, should we enforce improvements by procedures?

  No validations during night? Convenient for OP, but then leave time for analysis.

  Mandatory low-intensity fills after special runs?

  Mini-intensity ramp up after each configuration change?

  Circulate new settings for comments before deployment? Etc...

Conclusions

- Reviewed the **LHC movable devices** and recalled their **interlocks**.
- Despite the **unprecedented complexity** of the collimator operation at the LHC, the system **worked well!**

  Ensured a safe operation with a very limited number of spurious dumps.
  Basically, all design choices for controls and interlocks were validated.
- A few **issues** encountered in the operation with the settings.

  Problems with wrong position settings for ring and injection protection.
- "Known" weakness of missing TCT redundancy for **collision functions** was observed in 2012.

  SW checks in place for the moment. Dependence on sequence execution.
  Considering the addition of new redundant limits vs. beam separation (tricky!)
- Collimator hardware improvement in LS1: **BPM-embedded design**!

  Expect significant improvements at different levels, see next talks.
  Otherwise, we are happy with the present controls: not major changes in LS1.
- The **LSA settings management** can be improved: some weak connections should be **improved**.
- Commented on **procedures** to ensure safer conditions at new startup