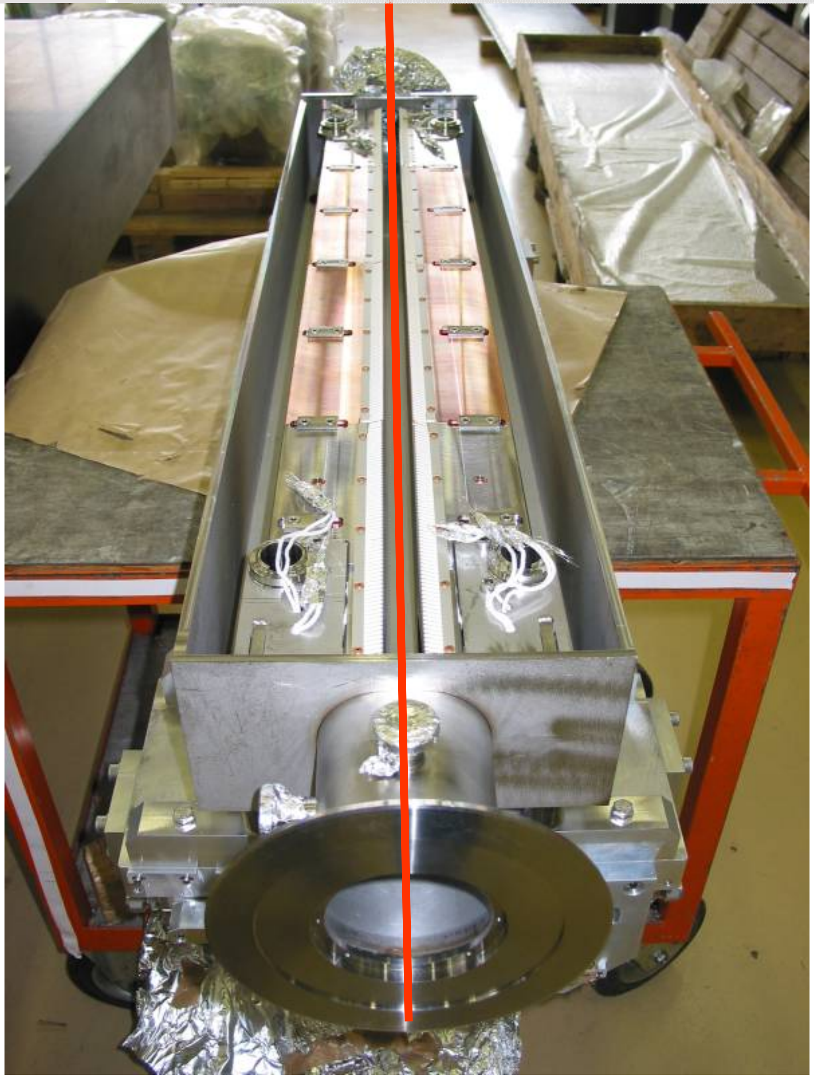
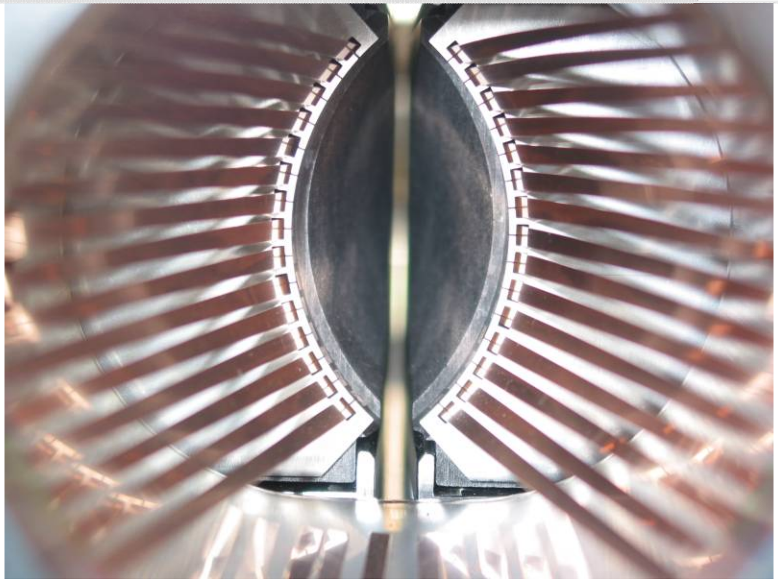
Controls for the LHC Collimation System

September 22nd, 2005

- Collimator Controls Specification Team (COCOST) started in April 2005 after presentation to the LTC on 23.3.2005, where responsibilities and approach was approved.
- COCOST:
  O. Aberle (ATB), R. Assmann (ABP, chairman), B. Goddard (BT), M. Jonker (CO, scientific secretary), V. Kain (CO), M. Lamont (OP), R. Losito (ATB), A. Masi (ATB), R. Schmidt (CO), C. Sicard (CO), M. Sobczak (CO), L. Nestre (OP), J. Wenninger (OP) + D. Macina, B. Dehning (BDI), E.B. Holzer (BDI), …
- Collimation system is complex and demanding:
  - LHC collimator has **5 degrees of freedom** and provides **10 measurements of absolute and relative positions and gaps**. Ten hardware switches must be handled. Additional DOF's and sensor/switch for spare surface movement of whole tank.
  - **In the LHC we have to control about 500 degrees of freedom (200 for LEP) with ten times better accuracy than in LEP**.
  - The number of collimators will be upgraded during LHC operation up to a maximum possible of 162 collimators. In this case there would be about 800 degrees of freedom.
- LHC collimators implement an advanced hardware and system design in order to gain 3 orders of magnitude in performance beyond other hadron colliders: They must be complemented by a powerful and state-of-the-art control system!

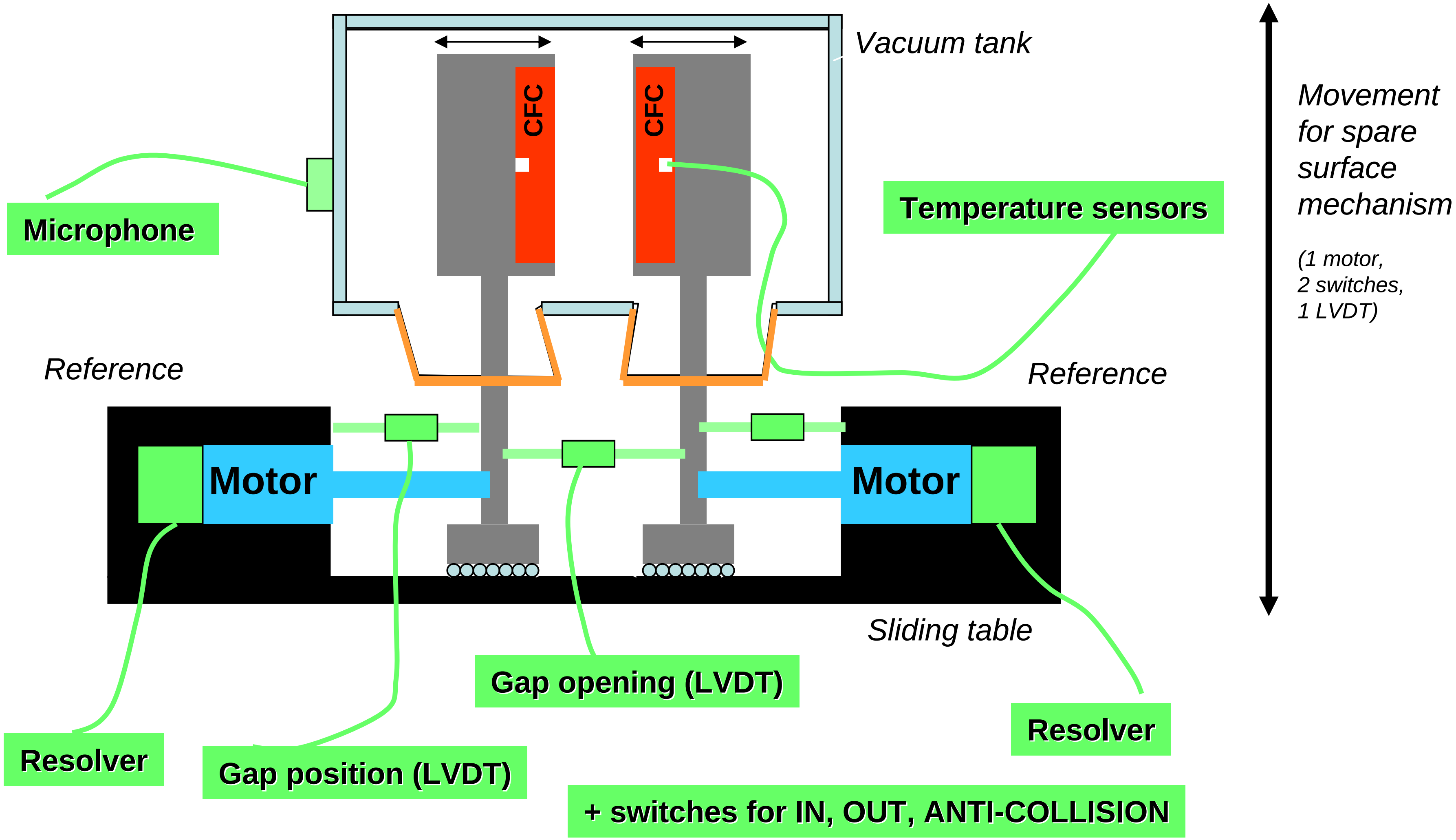
The LHC phase 1 collimator





Using Sensors to Monitor LHC Jaw Positions

Side view at one end



Basic Collimator Actions

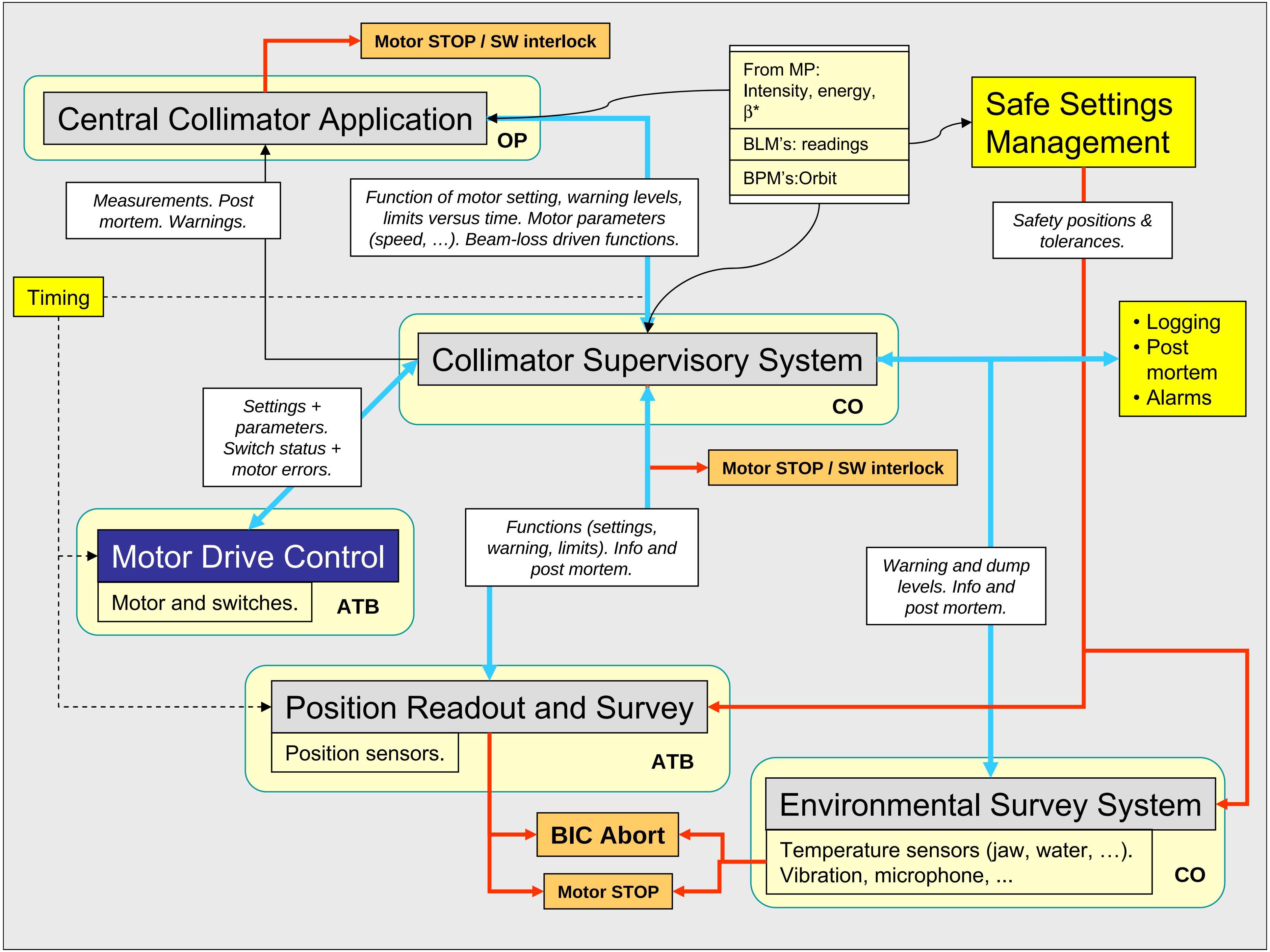
Basic collimator actions are relatively simple:

1. Move 2 motors to control **position and angle of each jaw.**
2. Move 4 motors to **control gap width and angle.**
3. During each movement **monitor 10 switches** to avoid damage to mechanical system (stop on in, out and anti-collision switches).
4. **Monitor 10 position sensors** on the collimator to assure in a redundant and fail-safe way the absolute value of the gap and the jaw positions. **Interlock** the beam if necessary.
5. **Monitor the jaw temperatures** and **interlock** the beam if necessary.
6. Move 1 motor to **control spare surface** by movement of whole tank **(+ 2 switches and 1 sensor**).

Note: Higher complexity due to safety-criticality of collimation system (no one-sided cleaning like in Tevatron and RHIC, two jaws to define gaps, always ensure the right gaps)!

Where is it Complicated?

- LHC collimators must act as a coherent system:
  - **All collimators for beam cleaning and protection included into one common control (also Roman Pots).**
  - **Tolerances on settings are at the 0.1 σ level (~ 20 μm at 7 TeV).**
  - **System hierarchy must always be respected (primary, secondary, tertiary collimators, protection, …)**
  - **accuracy, reproducibility and synchronicity of jaw movements down to the 20 μm level must be assured.**
- State-of-art at Tevatron and RHIC includes:
  - Movement of jaws based on beam loss measurements (move jaw x until BLM y reads the value z, then stop and move to next jaw).
  - Fast and automatic set-up routines for the overall system are (and must be) performed each fill.
  - Possibility to adjust setup order of collimators, include other information (orbit, jaw position readings, intensity, …).
- LHC: Introduce strict positioning monitoring and tolerances, while providing also functionality of BLM-based procedure.
- LHC collimator controls system architecture broken down such that basic and advanced features are in separate controls packages (also put into different, optimized locations).



Motor STOP / SW interlock
Central Collimator Application
OP
From MP:
Intensity, energy,
β*
BLM's: readings
BPM's:Orbit
Safe Settings Management
Measurements. Post mortem. Warnings.
Function of motor setting, warning levels, limits versus time. Motor parameters (speed, …). Beam-loss driven functions.
Safety positions & tolerances.
Timing
Collimator Supervisory System
CO
• Logging
• Post mortem
• Alarms
Settings + parameters. Switch status + motor errors.
Motor STOP / SW interlock
Motor Drive Control
Motor and switches.
ATB
Functions (settings, warning, limits). Info and post mortem.
Warning and dump levels. Info and post mortem.
Position Readout and Survey
Position sensors.
ATB
Environmental Survey System
Temperature sensors (jaw, water, …).
Vibration, microphone, ...
CO
BIC Abort
Motor STOP

Responsibility of the Controls Group

- Controls group has an agreed responsibility for parts of the collimation controls system (development and ongoing service will be required).
- Agreed specific responsibilities:
  - Participation in the specification of the collimator controls system.
  - Support in the required controls infrastructure (timing signals, BIC, …).
  - Implementation of the **Collimator Supervisory Systems** around the ring (1-2 per IR with collimators and in the transfer line).
  - Implementation of the Environmental Survey System (ESS).
- The success of the CSS is crucial to a working collimation control system…

➔ prove with a simple study…

Modeling of BLM Based Collimator Set-Up (During Standard Operation)

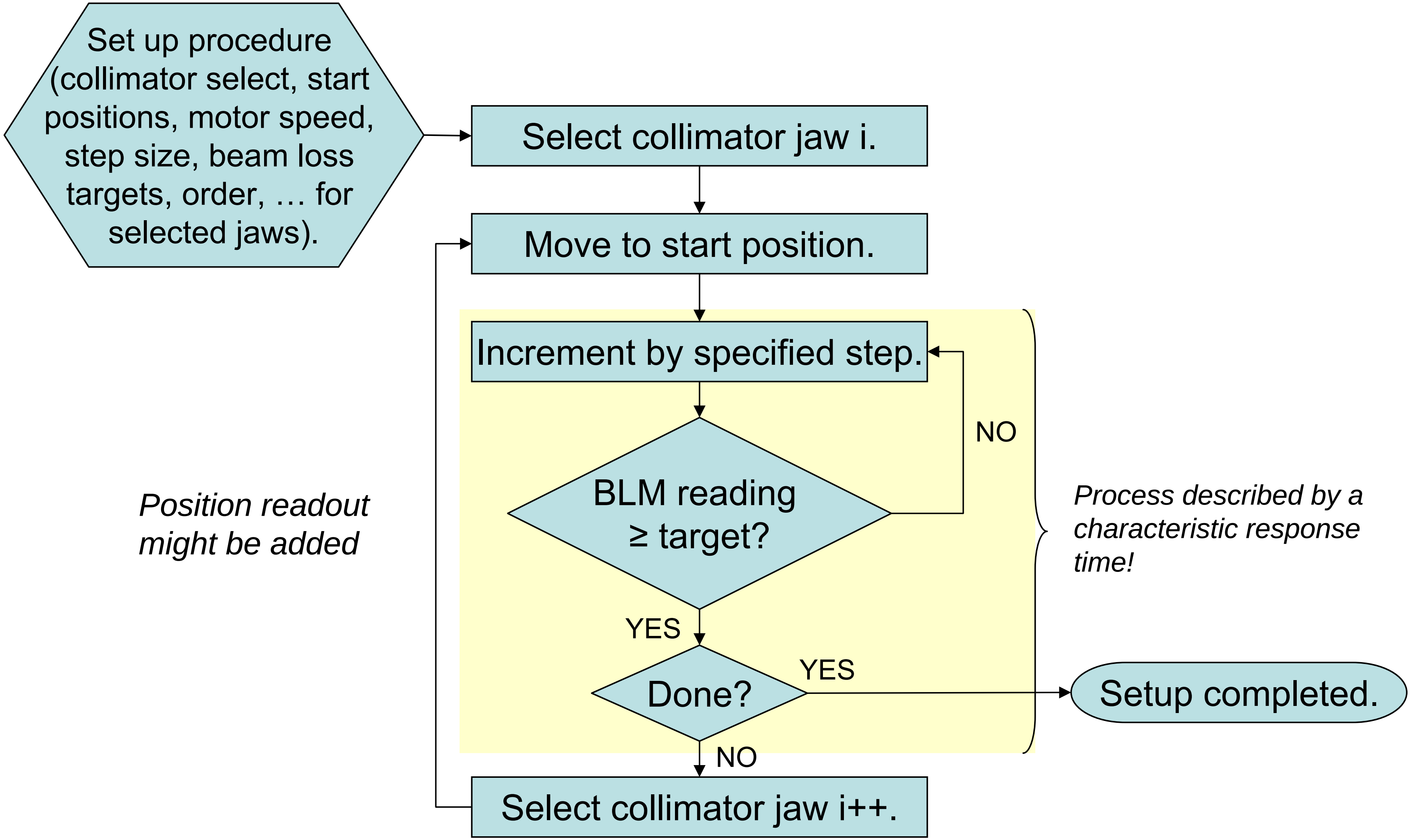
- Two rings can be tuned in parallel ➔ Otherwise multiply numbers by factor 2.
- Tuned collimators are left in place (no retraction) ➔ Otherwise add time for retraction.
- Fully automatic tuning procedure ➔ no time required for human intervention or study of a few problem cases.
- Beam-loss based set-up of all collimators in the ring.
- Reproducibility of the machine at 1.5 σ level.
- In many aspects: Best case for a full beam-based set-up during routine operation.

  ➔ Remember: TEVATRON/RHIC have to do this for each fill during routine operation (**twice**).
- Machine conditions:
  - Set-up would be done with **partially filled ring at injection** (~1-10% of nominal total intensity, depending on the risk we accept).
  - Can envisage this **injection set-up for each fill**.
  - Set-up at **7 TeV** would be done with **few nominal bunches** and can be done only **exceptionally** (rely on extrapolation from 450 GeV to 7 TeV – reproducibility of the ramp).

Why this BLM-Based Setup?

- LHC baseline:
  - Calibrate collimator positions (protection and cleaning) infrequently (many weeks) in a special and lengthy MD setup.
  - Beam characteristics are very reproducible over many weeks!
  - Set collimators to reference positions (in mm) to reestablish protection and cleaning.
- Experience at running facilities (Tevatron, RHIC):
  - Approach does not work. Something changes fill-to-fill.
  - Positions in mm's do not reestablish cleaning efficiency from previous fill.
  - **Instead reestablish efficiency by reproducing measured beam loss pattern!**
  - Fast collimator setup for each fill with automatic setup procedure, based on beam loss measurements.
- Experience shows that beam loss pattern is more closely related to collimation efficiency than collimator positions which are affected by orbit, beta beat, coupling, …
- Procedure allows to re-establish beam loss pattern instead of collimator positions (should be compatible to some level).
- High-Z jaws in the LHC are of concern!?

BLM Based Setup Algorithm

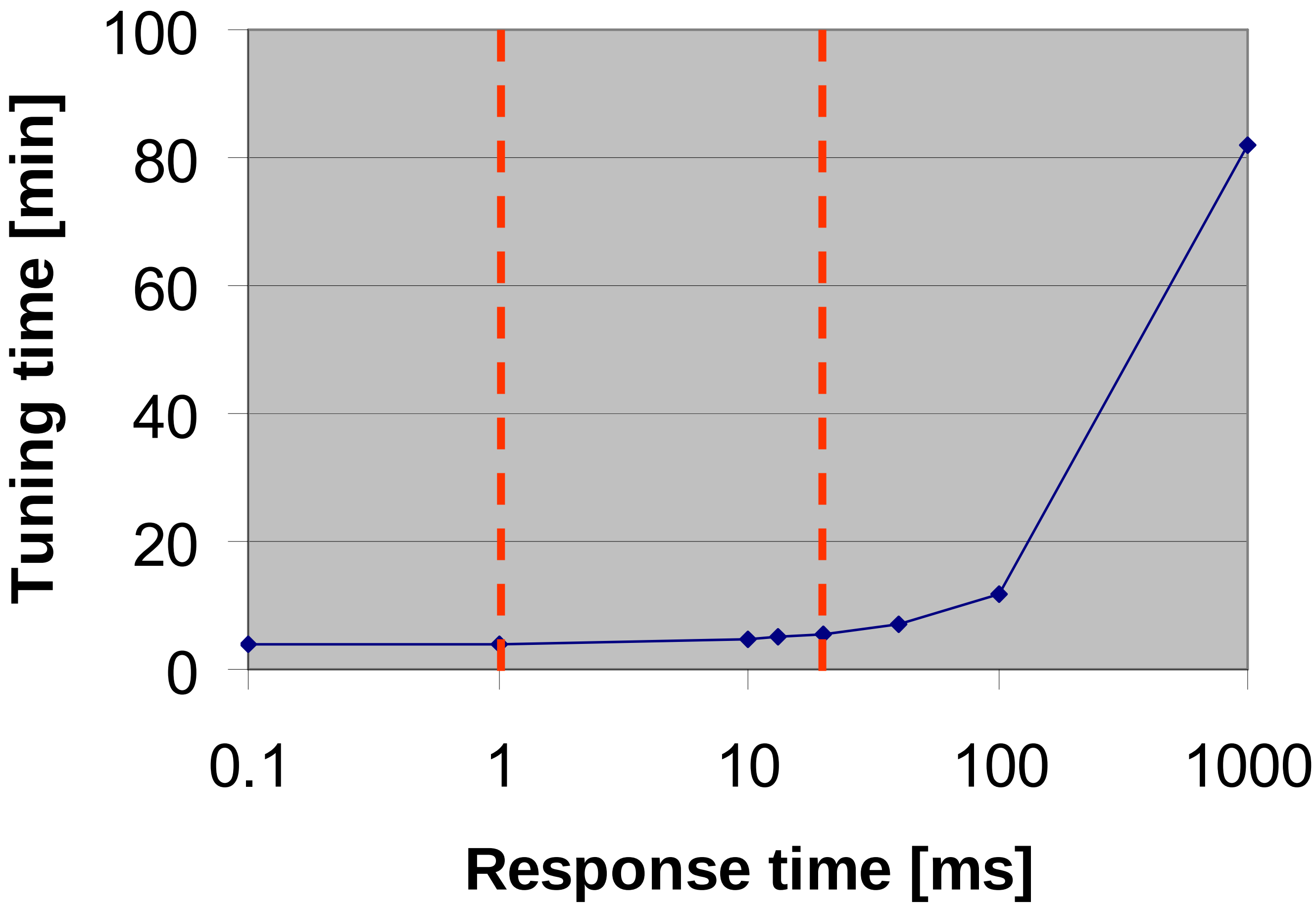


Analysis

	Unit	Injection	7 TeV	
Collimators/ring		39	41	
DOF/collimator		2	2	*without angle*
		4	4	*with angle*
Reproducibility of machine	[sigma]	**1.5**	**1.5**	*20 % beta beat + 1 sigma orbit*
Setting accuracy (step size)	[sigma]	**0.05**	**0.05**	
Assumed beam sigma	[micron]	1000	250	
Actual step size	[micron]	50	12.5	
Motor speed	[mm/s]	**1**	**1**	
Time per step	[ms]	50	12.5	
Frequency f DAQ	[Hz]	**100**	**100**	
Read response (=1/f)	[ms]	10	10	
Read delay	[ms]	**1**	**1**	
Waiting time	[ms]	**0**	**0**	*Due to beam dynamics or lags*
Total time per step	[ms]	61	23.5	*(to be determined)*
Without angle				
Number of DOF (jaws)		78	82	
Number of steps / DOF		30	30	
Total number of steps		2340	2460	
Total time	[s]	142.7	57.8	
	[min]	**2.4**	**1.0**	
With angle adjustment				
Number of DOF (jaws)		156	164	
Number of steps / DOF		30	30	
Total number of steps		4680	4920	
Total time	[s]	285.5	115.6	
	[min]	**4.8**	**1.9**	

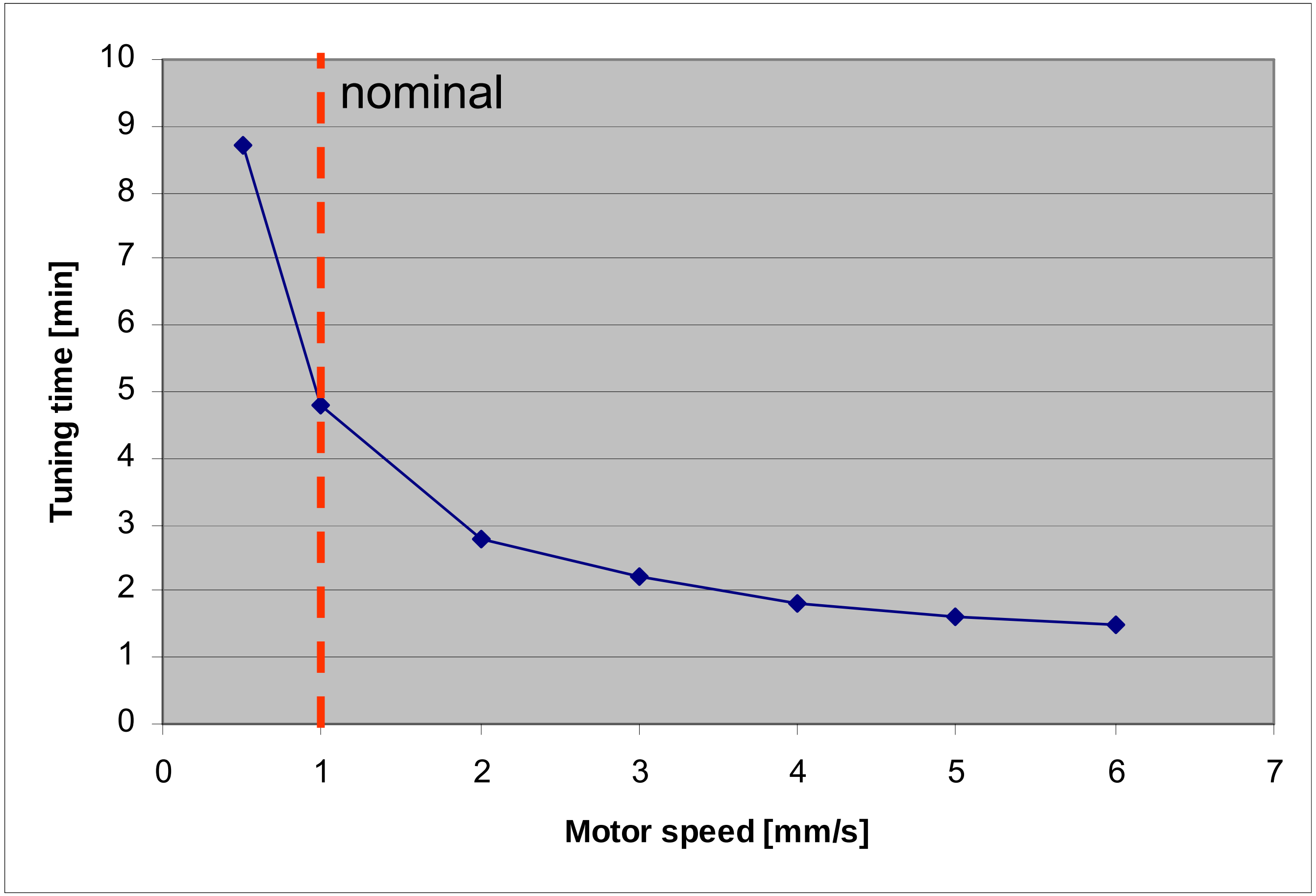
Dependence on Response Time of Tuning Loop (Injection)

Frequency [Hz]	Time [min]
1	**82.0**
10	**11.8**
25	**7.1**
50	**5.5**
75	**5.0**
100	**4.8**
1000	**4.1**
10000	**4.0**



Dependence on motor speed (Injection)

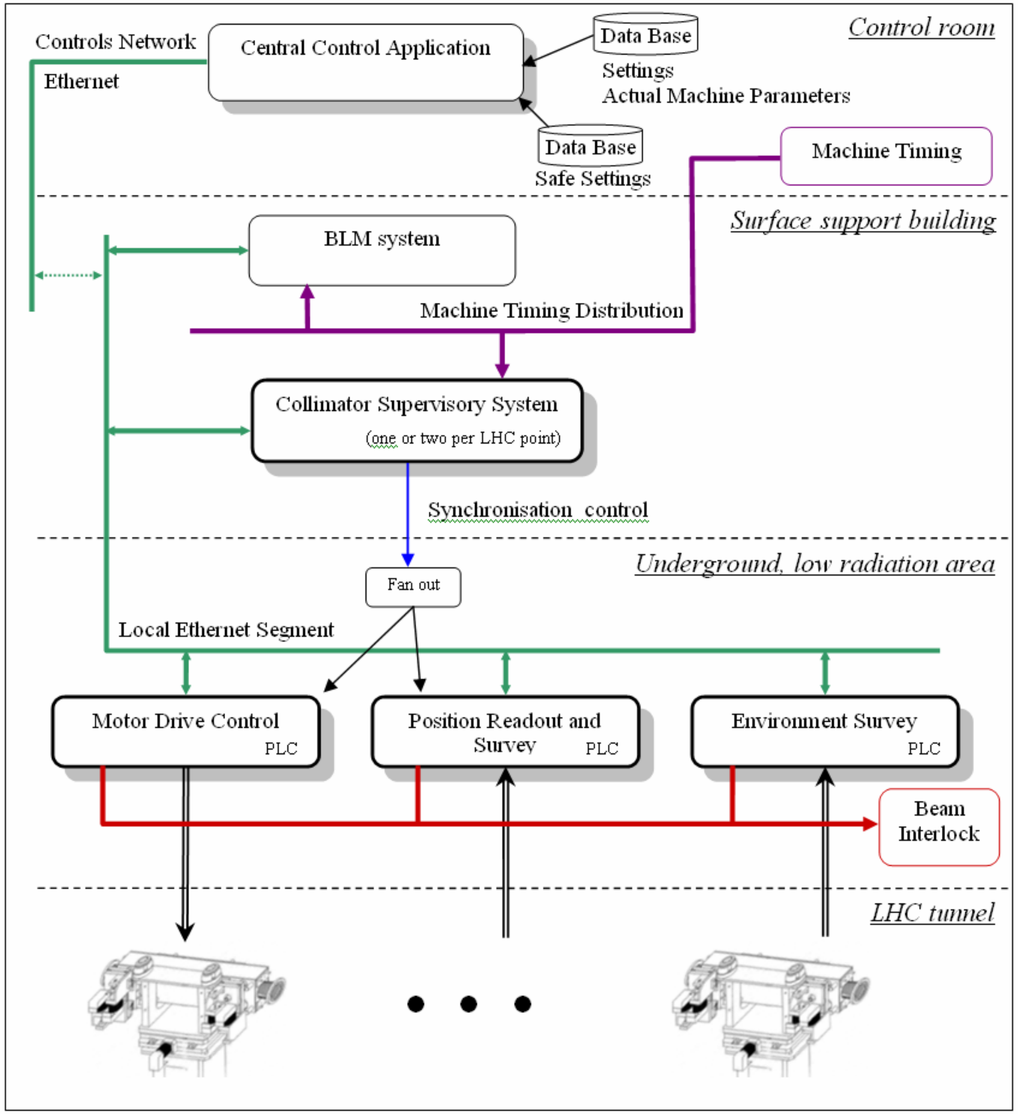
Motor [mm/s]	Time [min]
0.5	**8.7**
1	**4.8**
2	**2.8**
3	**2.2**
4	**1.8**
5	**1.6**
6	**1.5**



Conclusion on Automatic Set-Up Procedure

- Manual set-up (~ 2s per step) would require at least 3 hours. EXCLUDED for routine operation!
- Will be painful even quite early in the run (at 10% of nominal intensity collimation must already be fully working with unprecedented performance).
- Tevatron applies a 300 Hz DAQ frequency: overkill for us!
- For the LHC a DAQ frequency of 100 Hz gives us an acceptable situation (~ 5min set-up time, similar to Tevatron).
- **Specification:**
  - CSS should implement beam-loss based automatic setup with **100 Hz** internal frequencies.
  - An overall reaction time of **30 Hz** must be guaranteed!
  - A **fast link to the BLM system** is required (located CSS close to BLM crates, away from the collimator controls).
  - Lags in the system must be kept **compatible with 30 ms reaction time**!

Controls View on Architecture



Important issue:

Communication and reaction speeds through the different levels.

Inter-system delays, e.g. CSS to BLM and backwards?

Can PLC's support the overall response time of ~30 ms?

Hardware must be chosen based on achievable overall response time (PLC, VME, VME-like, …).

➔ **Systematic analysis** of lag, data rates and response times has been started! "At the limit" but feasible…

Architecture and Timing

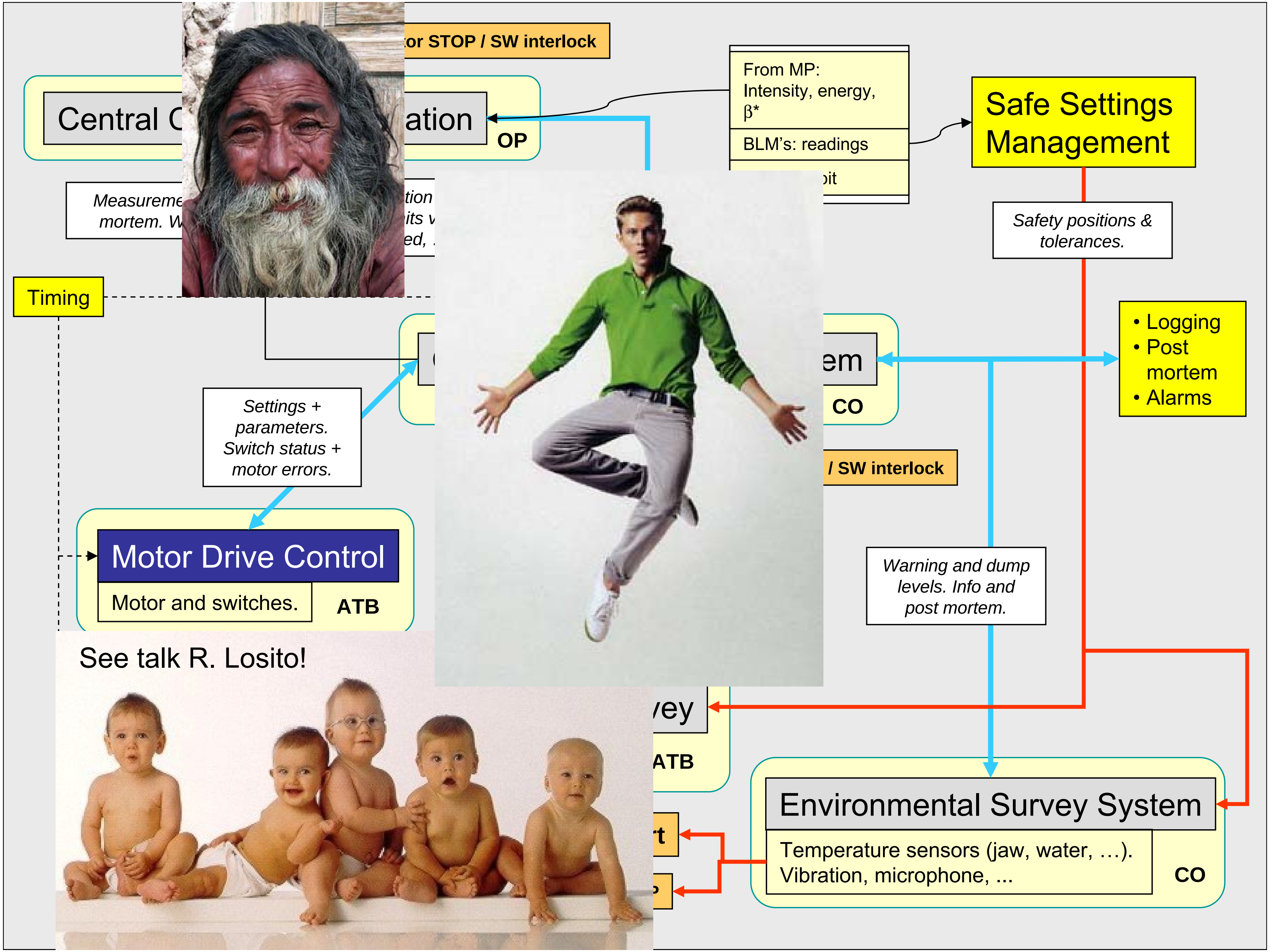
M. Sobczak
R. Losito

Status of Implementation

- Optimized system architecture has been agreed in COCOST.
- The Collimator Supervisory System is a crucial piece of the architecture and takes much of the complexity in the system (in some sense it is the translator between the operator action and the collimator hardware) .
- Some discussions with BLM team have been performed but are still ongoing.
- Fiber cables have been ordered for the link from CSS to the tunnel.
- Low level cables have been pulled.
- Rack space has been analyzed, requested and allocated for most sub-systems.

Responsibilities of AB/CO in the Collimation Project

- Participate in the specification of the collimator controls system.
- Provide the required controls infrastructure (timing signals, BIC interface, post-mortem, logging, alarms, …).
- Implement the Collimator Supervisory Systems around the ring (1-2 per IR with collimators):
  - Provide interfaces to other machine information, in particular the BLM system.
  - Generate and transmit timing events per IR with required synchronicity (20 μm maximum jaw lag, or 20 ms).
  - Implement a BLM-based movement of jaws.
  - Control an automatic beam-based (BLM) setup with a minimum guaranteed response at 30 Hz, nominally 100 Hz.
  - Link top level application software and low level controls (take functions from top level and pass on in the right format to the low level (maximum time span of function, …).
- Implement the Environmental Survey System (ESS):
  - Monitor and log temperatures.
  - Generate an interlock for excessive temperatures.
- Implementation means design, prototyping, programming, installation, test, support of operation.



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Vibration, microphone, ...
CO

Project Milestones on Collimation Control

1) Sep 2005:	Draft of functional specification of overall collimator control system (COCOST meeting).
2) March 2006 …	Hardware commissioning: collimators, TDI, … Required: Low level controls (MDC, PRS, ESS).
3) Jul-Nov 2006:	Beam tests: a) SPS beam test for LHC collimator with LHC motors/electronics and control system. Twice 24h for "collimator controls test". b) TI8 tests with transfer line collimators. c) Sector test with TDI. Required: First version of medium level: CSS. First version of top level: CCA and SSM.
➔	*If not ready, failure will trigger crisis effort to be ready for 2007!*
4) July 2007:	Commissioning of all hardware with final collimator controls system.
5) Aug-Nov 2007:	LHC beam commissioning of collimation.

Conclusion

- Collimation and protection is crucial for the LHC (**extend 3 orders of magnitude beyond present state of the art**).
- A **powerful collimation system** has been designed and is being produced for the LHC, much more performing than previous systems (3 to 4 stage cleaning, tight protection).
- If the system does not work properly then beam intensities will be extremely limited in the LHC (**easily less than 1% of design**).
- About **200 collimator jaws must be set up precisely with beam** (active system with 400 motors) to make the system work. Keep positions
- Precise, efficient and safe collimator control is a big worry ➔ **Chamonix 2004**! Now **extremely time critical**. Various important milestones in 2006!
- Serious effort has been started just 6 months ago (new staff available). Work is now getting momentum: **CO expertise covers a crucial part of the collimation controls system. The required controls expertise is not available elsewhere!**
- Work must continue full speed… **Failure will directly affect the success of LHC commissioning (risk of low intensities, excessive setup times, damage, …)!**