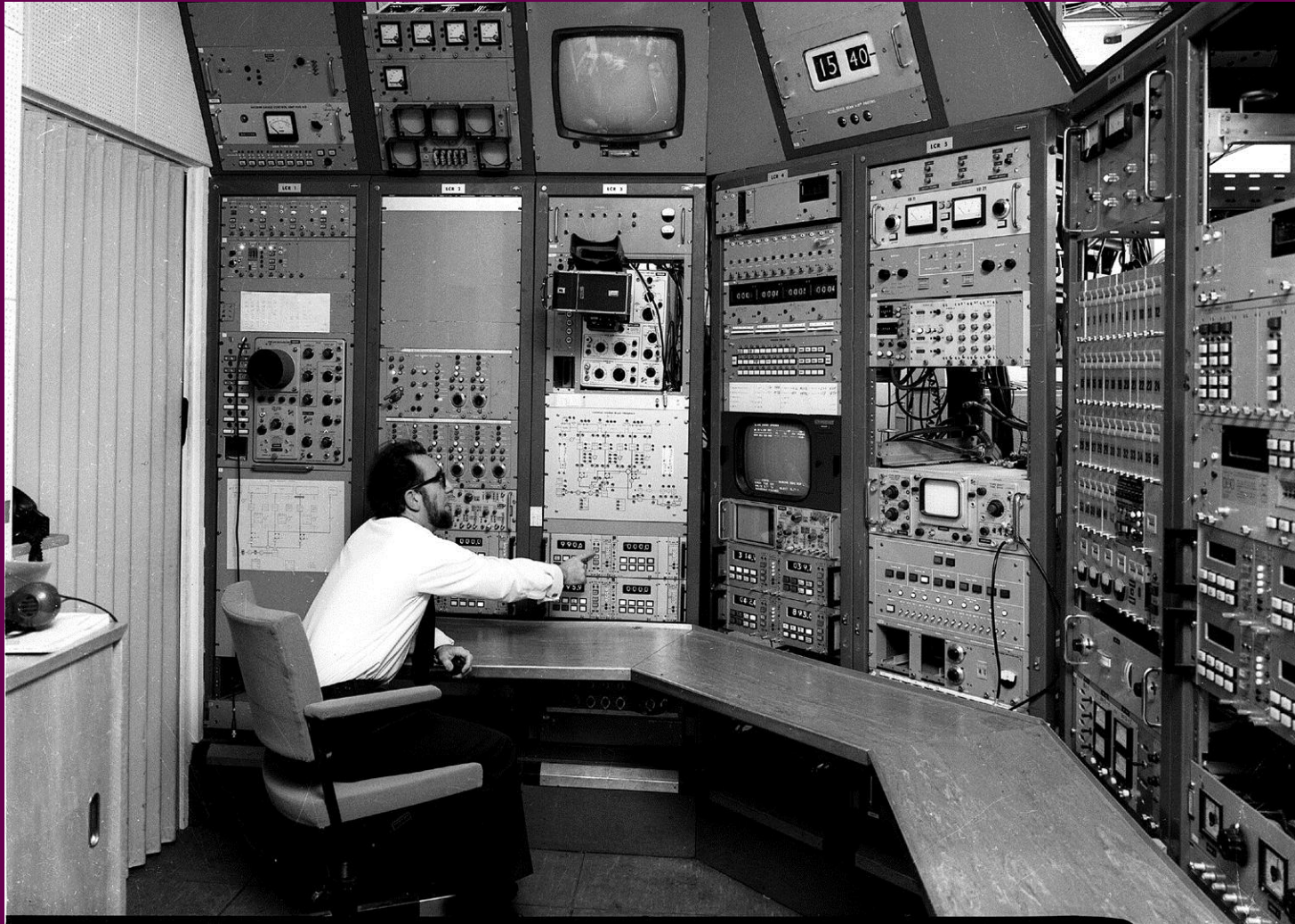


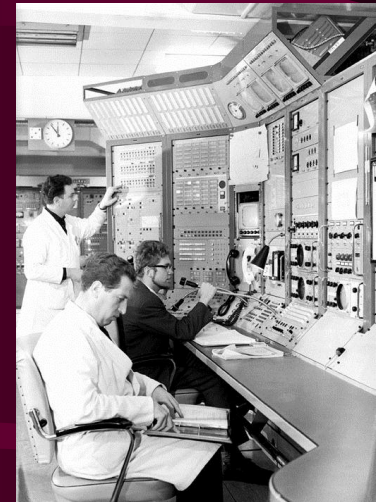
Accelerator Controls



Hermann Schmickler - CERN

Outline

- Controls technology
 - the good old days
 - the intermediate period (the 1980's...)
 - controls technology today
- What it needs before we can inject beams:
A rapid walk through technical services

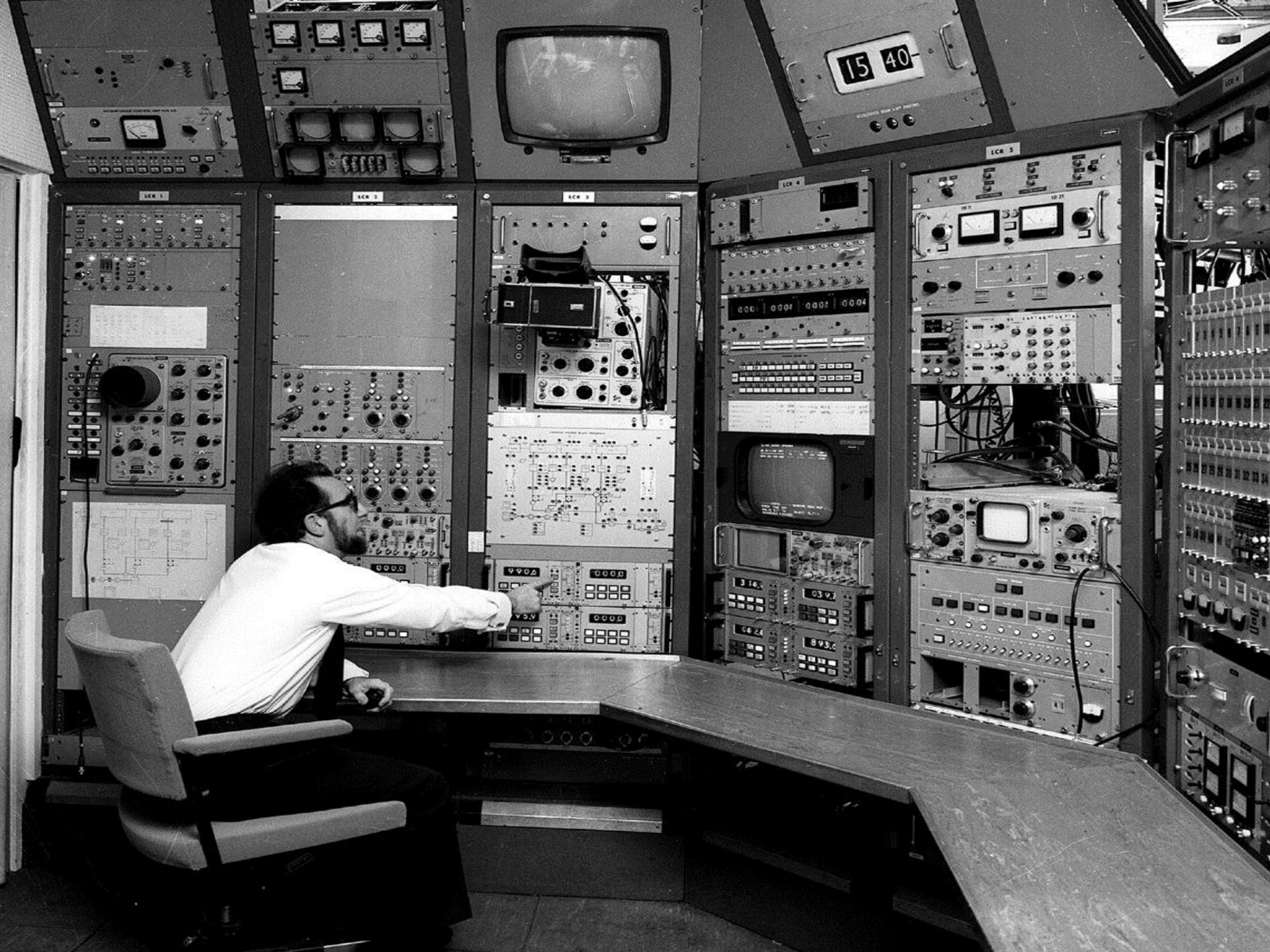


- Controlling beam parameters...
the central masterpiece of accelerator control
- Additional circuits to improve/protect the
accelerator... magnet protection, beam abort,
power abort, real time feedbacks, insertion
alignment feedback

Controls technology

- ...did barely exist in the « good old days ». Machines were small in size and all equipment control was routed via cables into a central control room.
- Switches, potentiometers and indicators (lamps, meters) were physically installed in the control room.
- Beam Diagnostics was done with instruments locally in the control room.







The intermediate period...

- Onset of computer control...
- No widely accepted industry standards existed for front-end computers and for console computers; low educational level of technical staff on computer technology
- Complete lack of standards for real time operating systems and systems intercommunication.
- Networking only in its beginning
- Performance limits of computers were significant. Still many systems (beam instrumentation and RF) with direct high frequency cables to control room.
- In terms of controls: a total mess

The CERN Control Center



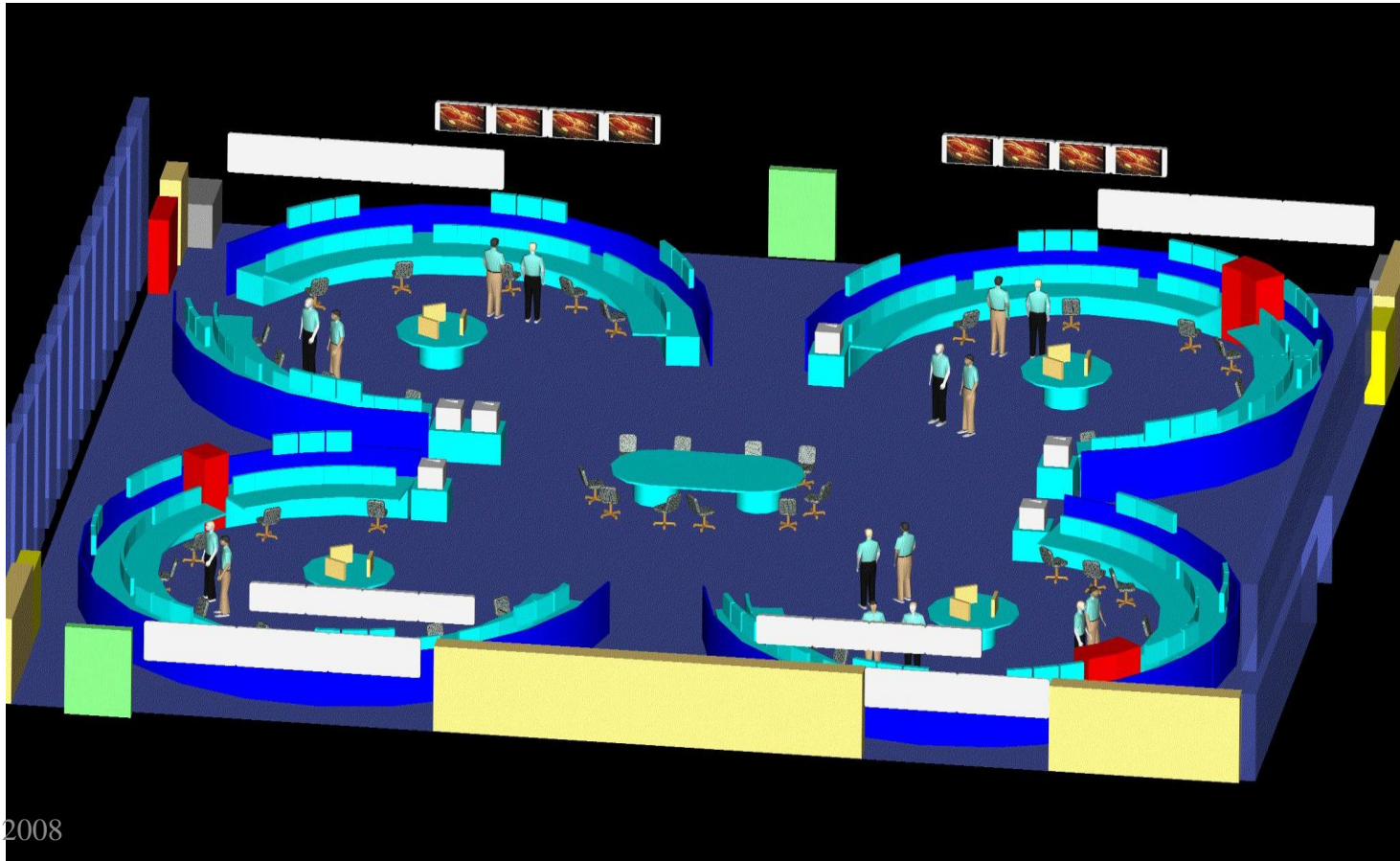
Workstation distribution

4 islands (TI, PS complex, SPS+EA, LHC) open towards each other

Access to each island without interfering with the other ones

Shared central area

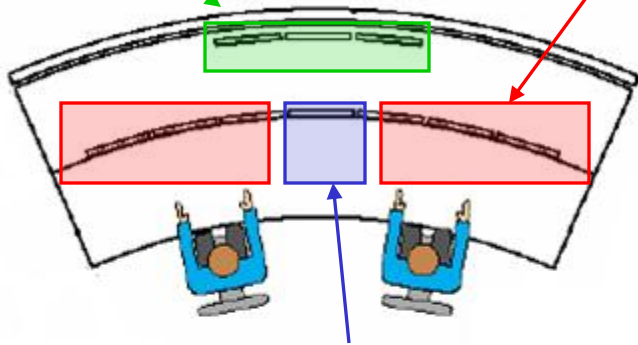
Minimisation of acoustic interference while allowing visual contact



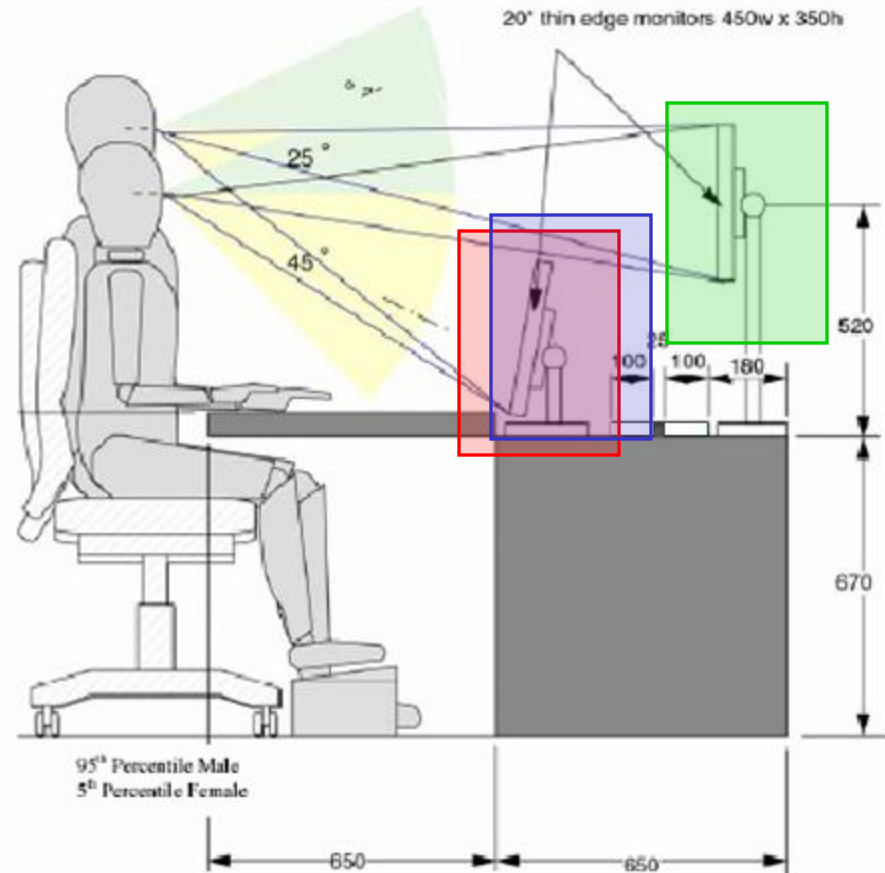
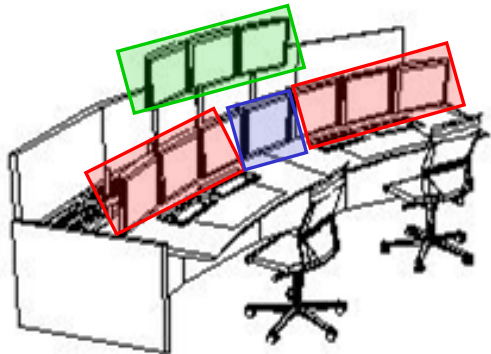
Workstation

3 fixed displays split between 2 workspaces

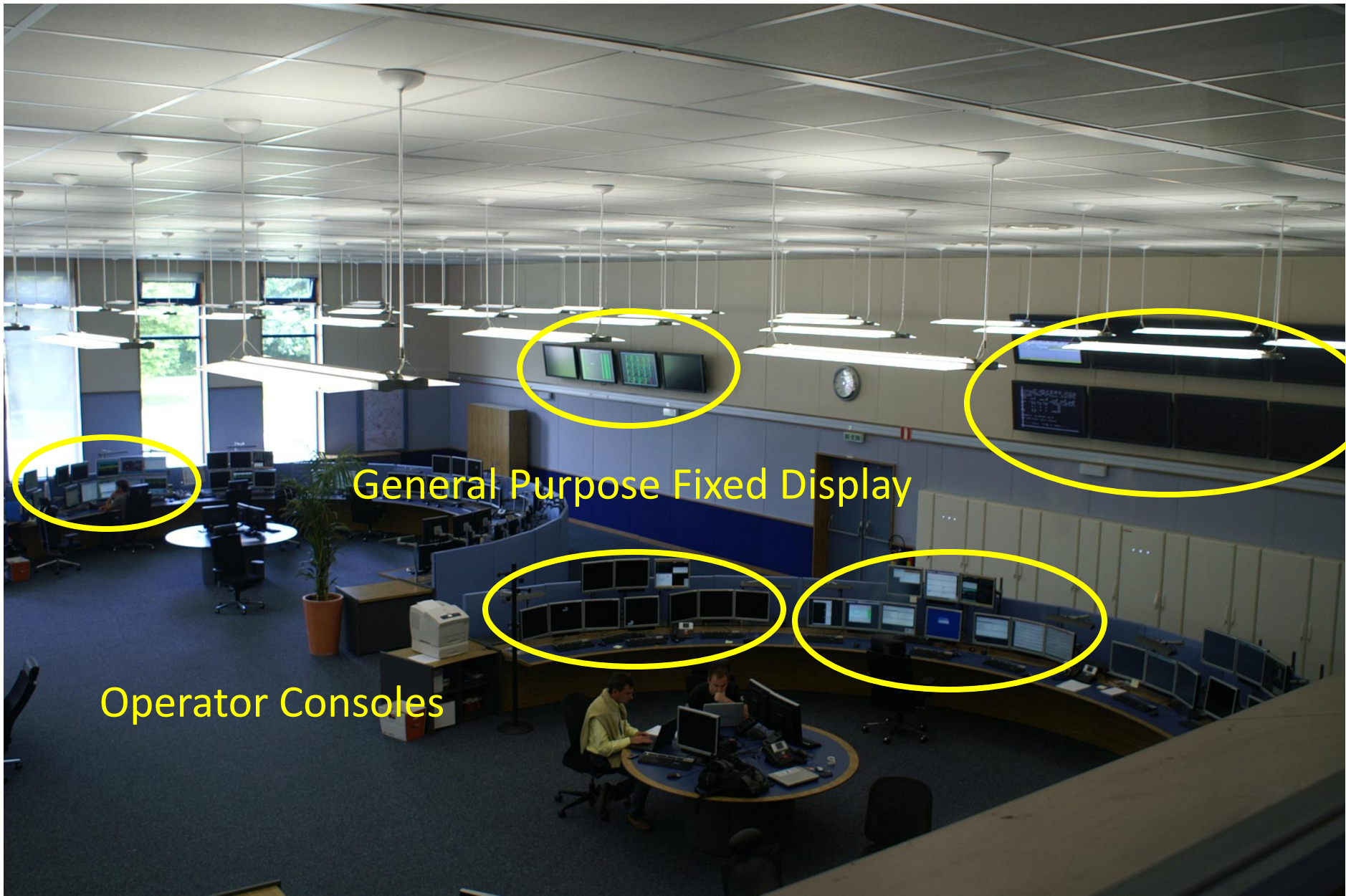
3 flat screens per workspace
1 keyboard
1 mouse



1 additional admin PC



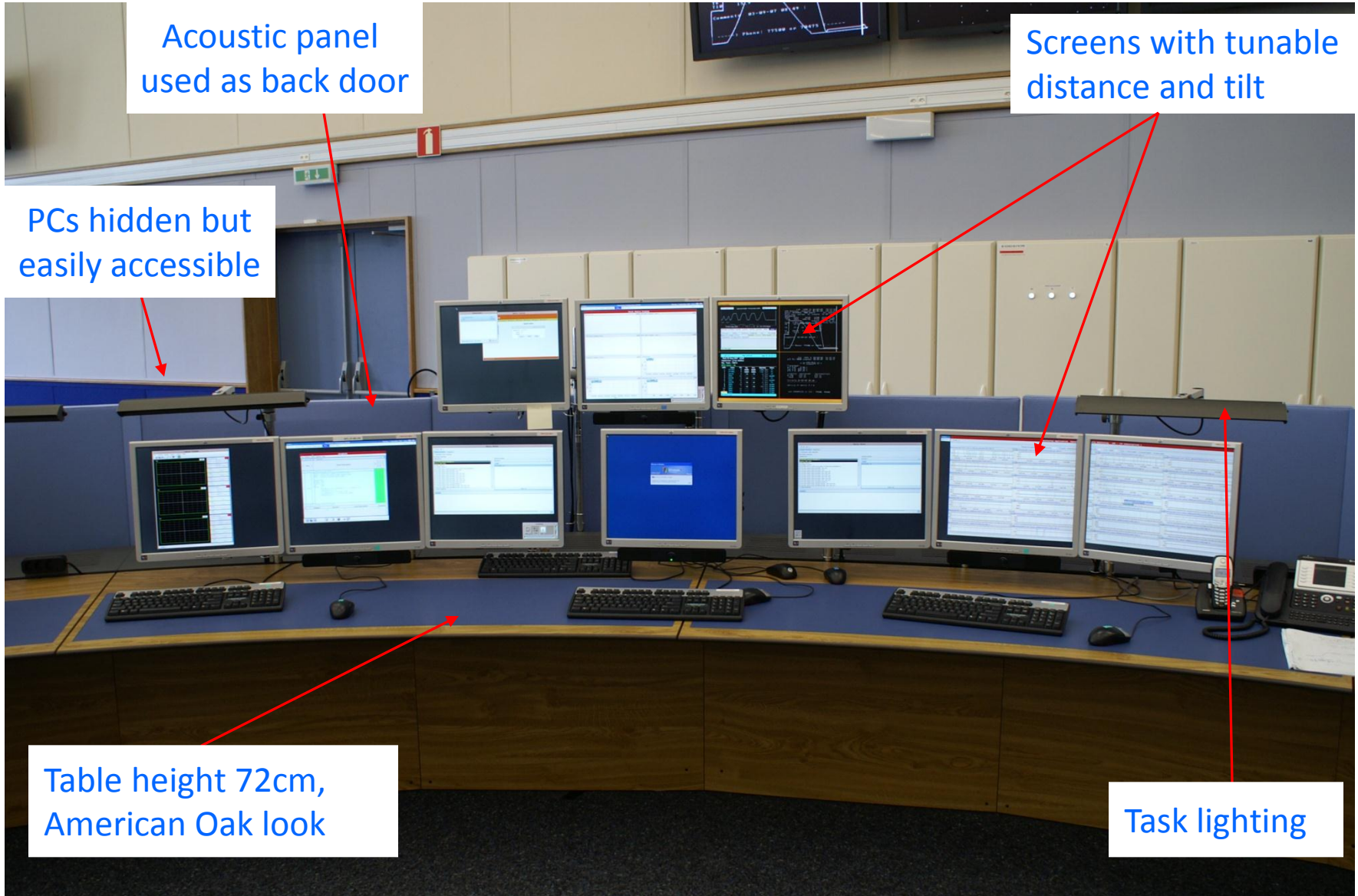
Inside CCC



General Purpose Fixed Display

Operator Consoles

A typical Operator Console





Some keywords for LHC controls technology

- **Base the HW architecture on available commercial standards and COTS:**
 - VME64x standard pour complex embedded I/O system with high performance demands commercial VME PPC processor boards(CES), including O/S integration and support (LynxOS)
 - commercial cPIC Intel based processor boards (Concurrent Technology for the time being) and digital scopes
 - commercial serial controller boards, ADCs, ...
 - commercial industrial PC platform for non-embedded systems (WorldFIP, PLC control)
 - HP Proliant servers for application servers and file servers
 - WorldFIP for applications requiring RT fieldbus features and radiation hardness
 - GPS for time stamping and overall accelerator synchronization
- **Apply whenever possible vertical industrial control system solutions:**
 - Siemens and Schnieder PLCs for industry-like process control (Cryo, vacuum, electrivty, RF power control, BT power control)
 - Supervisory Control and Data Acquisition Systems (SCADA) for commands, graphical user interfcaes, alarms and logging
- **Restrict home-made HW development to specific applications for which industrial solutions are not available:**
 - VME boards for BIC, BST, Timing
- distributed system architecture, modular,
- data centric, data driven,
- n-tier software architecture,
- Java 2 Enterprise Edition (J2EE) applications, Java technology,
- XML technology,
- client/server model,
- Enterprise Java beans technology,
- generic components,
- code generation,
- Aspect oriented programming (AOP)

Architecture - 3-tier approach

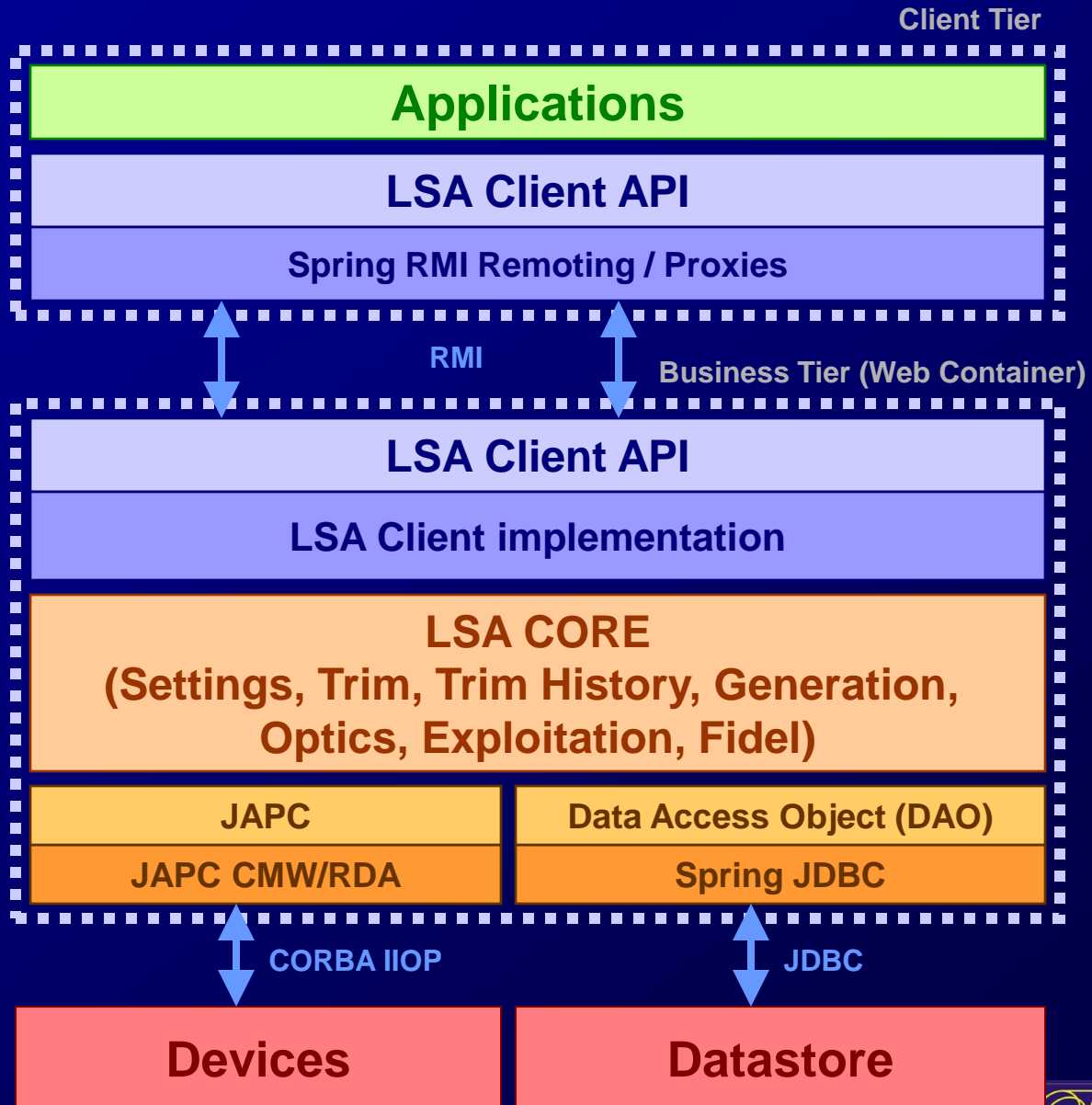
- We wanted to deploy the system in **3 physical layers** due to:
 - **Central access** to the **database** and to the **hardware**
 - **Central security**
 - **Caching**
 - **Reduced network traffic**
 - **Reduced load** on client consoles
 - **Scalability**
 - **Ease of web** development
- **With a minimal cost of 3-tier architectures**
 - **Complexity of programming**
 - **Testing & debugging**
 - **Deployment**
- **Plus we needed support for standard services**
 - **Transactions, remote access,...**



tier, tire or tyre ??

Architecture

- Modular
- Layered
- Distributed





...and an uncountable number of

The image displays a complex interface for accelerator control, featuring multiple overlapping windows and data visualizations:

- SPS OPTICS DISPLAY:** A central window showing beam position and profile data.
- SDDS logging monitor:** A window for monitoring data logging status.
- Equipment State:** A window showing the status of various equipment components like C1044.
- Parameter selection:** A window for selecting and managing parameters for different systems.
- Beam Position Plots:** Several windows showing horizontal and vertical beam positions over time.
- Beam Profile Plots:** A large window showing a 2D beam profile with a central red spot and surrounding blue and green regions.
- Active Selection:** A window for selecting active equipment or parameters.
- Data Plots:** Multiple windows showing various data plots, including histograms and line graphs.



Technical Services

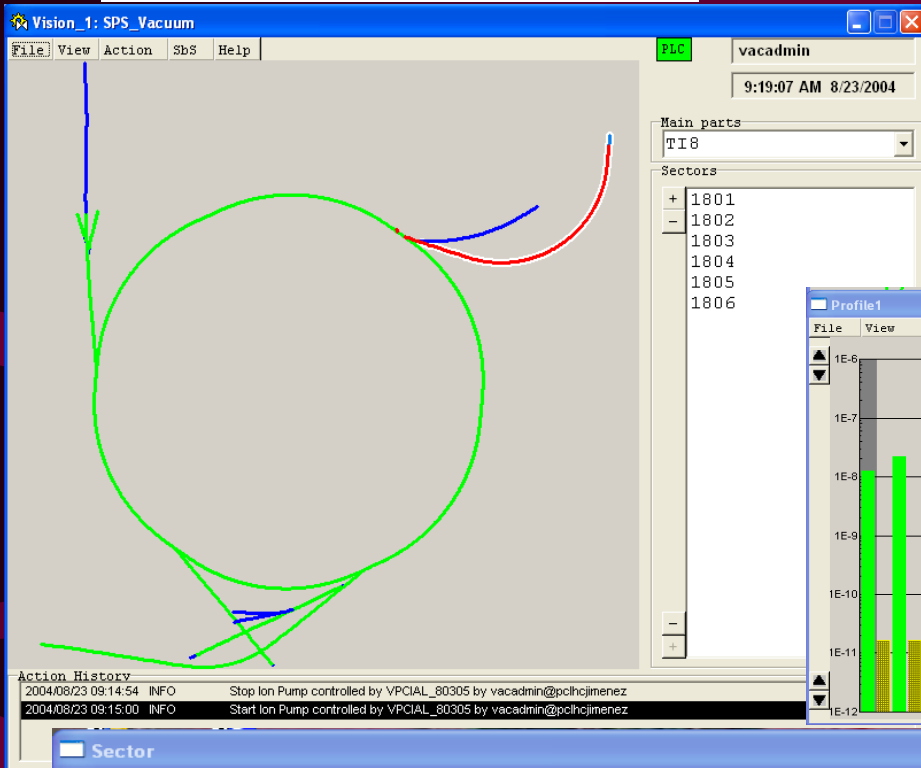
All we need even before thinking of injecting beam:

- Electrical supplies
- Uninterruptible Power Supplies (UPS),
Arret Urgence Generale (AUG)
- Cooling & Ventilation
- Cryogenics systems
- Vacuum systems
- Access System (Personal Safety)
- Interlock Systems (Material Safety)
i.e. powering interlocks, quench protection system
- General services
(temperature monitoring, radiation monitoring)

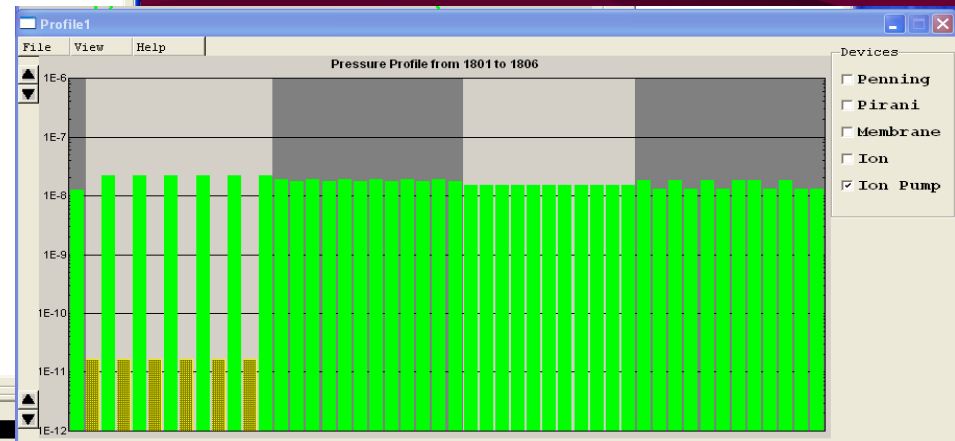


The “look and feel” of all these systems example: vacuum system for LHC transfer line

Synoptic of the SPS Complex

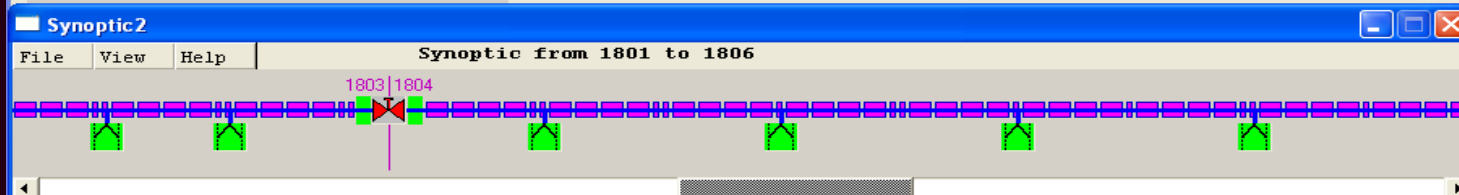
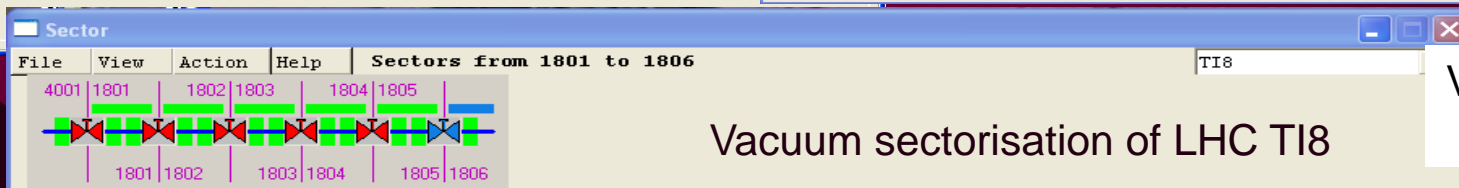


Pressure profile in LHC TI8



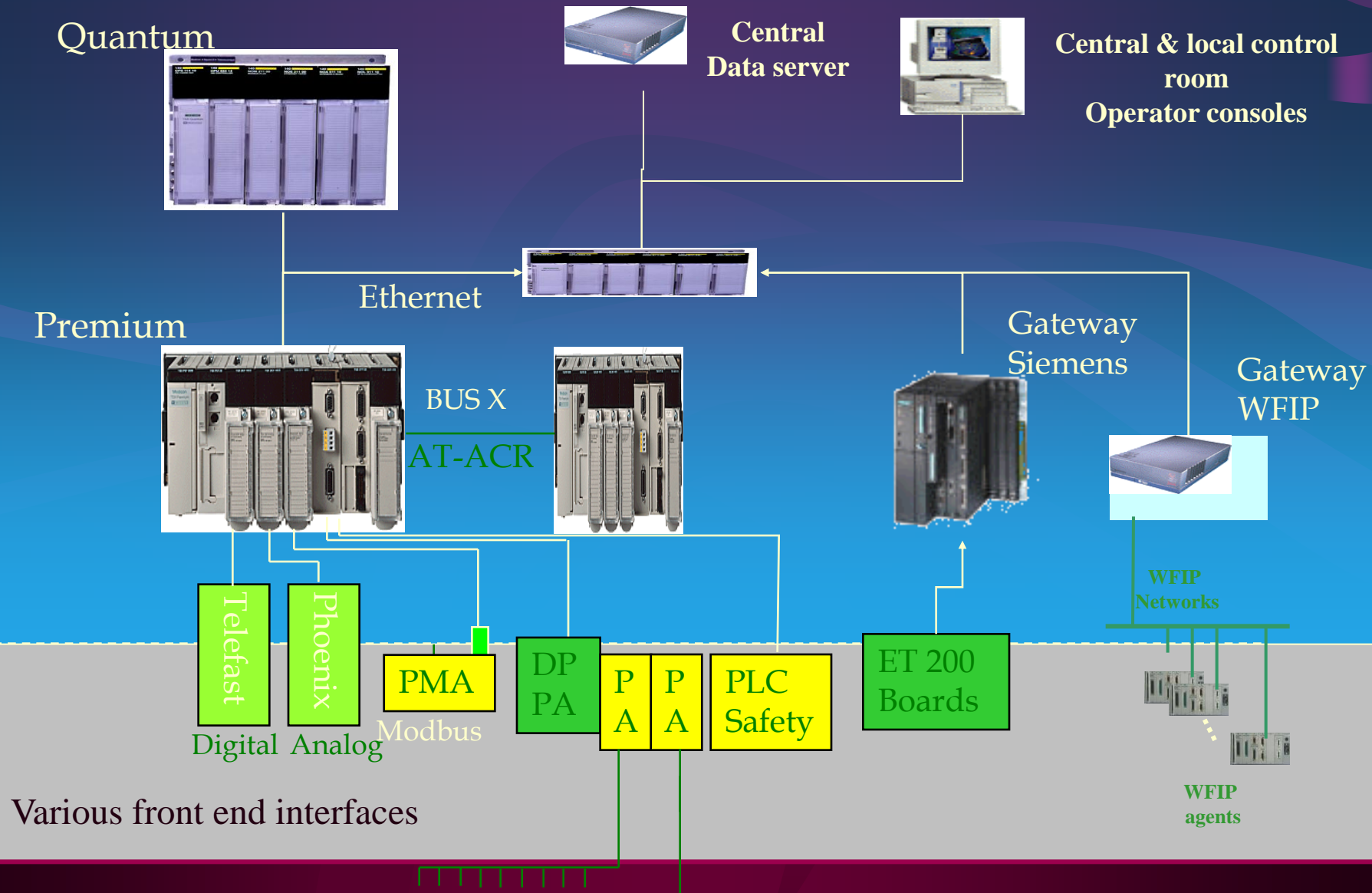
Vacuum sectorisation of LHC TI8

Vacuum layout of LHC TI8





A typical implementation

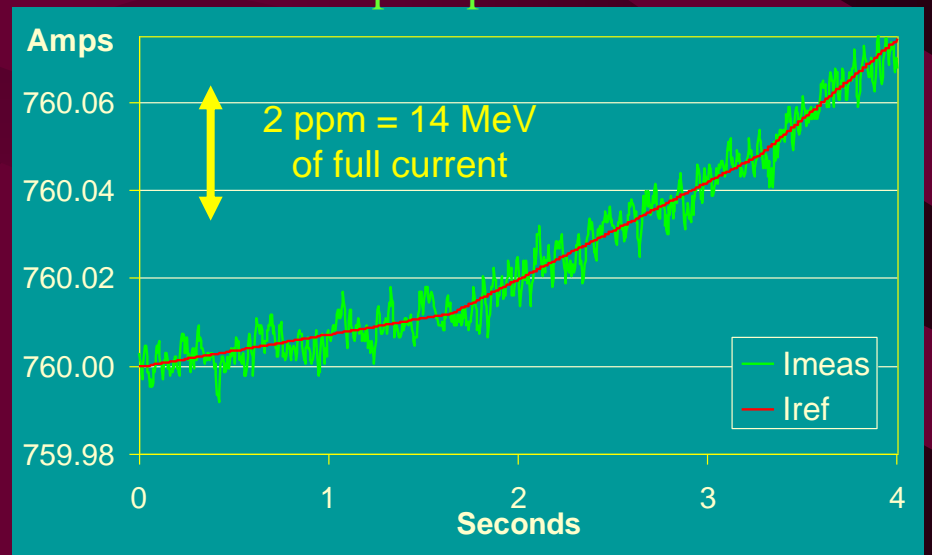




Finally: Beam Control

- Transfer lines
- Injection and Extraction (beam dumping system)
- Beam optics controls
i.e. all power converters
- Beam instrumentation
- RF
- Beam interlocks
- Collimation
- Real Time feedbacks
- Machine Protection
- Timing Systems
- Radiation monitors

Static and dynamic control,
We will discuss in detail the setting at injection and the ramping of the main dipole power converter





Tools for the control of beam parameters

Requested Functionality:

- Modern Graphical User Interfaces
- Settings Generation available on 3 levels: ex: Tune
 - a) Current in QF, QD: basic direct hardware level
 - b) strength of QF, QD: independent of energy
 - c) value of QH, QV: physics parameter; decomposition into QF, QD strength via optics model
- Function Generation for machine transitions (energy ramping, squeeze); viewing of functions; concept of breakpoints (stepping stones)
- Trimming of settings and functions
- Incorporation of trims into functions!
Very important: different models (constant value, constant strength...)
- Feed Forward of any acquired knowledge into functions:
Cycle history, Beam Measurements on previous cycle
- Trim and incorporation history, Rollbacks...



Generic Equipment Control

Equip State
[-] [x]

Current sequence - S653v1

C1044

Categories

SPSRING

T18

TT40

Cycle

C1044 (0->14400)

Sequence - S653v1

S653v1 (Active)

S540v2 (Resident)

S543v1 (Resident)

S546v1 (Resident)

S950v1 (Resident)

S954v3 (Resident)

S543v2

S543v3

S543v4

Refresh

Filtering on T18

Device Type	HWNName	Status
BCT	MClAH8260	OFF
BLM	MClAH8320	OFF
BPM	MClAH8340	OFF
BTV	MClAH8400	OFF
MUGEF	MClAH8420	OFF
MUGEF	MClAH8480	OFF
VIDEO_SWITCH	MClAH8500	OFF
	MClAH8560	OFF
	MClAH8580	OFF
	MClAH8640	OFF
	MClAH8660	OFF
	MClAH8720	OFF
	MClAH8740	OFF
	MClAV8010	OFF
	MClAV8070	OFF
	MClAV8130	OFF
	MClAV8150	OFF
	MClAV8210	OFF
	MClAV8230	OFF
	MClAV8290	OFF
	MClAV8310	OFF

Select All

Command	Parameter	Value
[M] READ-TABLE		
[M] PCCURRENTS		
[R] DETAILED-STATUS		
[R] EVLIST		
[R] MAG-CONNECTION		
[R] READ-CHECK-FUNCT		
[R] READ-POLARITY		
[R] TEMPERATURE		
[S] STATUS		
[L] LOAD-FUNCT		
[L] LOAD-ZERO-FUNCT		
[L] LOAD-TEST-FUNCT		
[W] CONNECT-MAG-1		
[W] CONNECT-MAG-2		
[W] HARD-INIT		
[W] INIT-ACQ		
[W] INIT-SOFTWARE		

Execute

Console Running tasks

```

09:04:37 - Executing command STATUS on cycle S653v1.C1044.CO on MBI8160M-M, MBI8160M-M, MBIAV8110M, MBIBV8774M, MClAH8020, MClAH8080,
MClAH8100, MClAH8160, MClAH8180, MClAH8240, MClAH8260, MClAH8320, MClAH8340, MClAH8400, MClAH8420, MClAH8480, MClAH8500, MClAH8560,
MClAH8580, MClAH8640, MClAH8660, MClAH8720, MClAH8740, MClAV8010, MClAV8070, MClAV8130, MClAV8150, MClAV8210, MClAV8230, MClAV8290,
MClAV8310, MClAV8370, MClAV8390, MClAV8450, MClAV8470, MClAV8530, MClAV8550, MClAV8610, MClAV8630, MClAV8690, MClAV8710, MClAV8770,
MClBH8040, MQID8010, MQID8030, MQID8710M, MQID8730, MQID8750, MQID8770, MQIF8020, MQIF8700M, MQIF8720, MQIF8740M, MQIF8760, MSIB8813M

```

Executing command STATUS on cycle S653v1.C1044.CO on MBI8160M-M, MBI8160M-M, MBIAV8110M, MBIBV8774M, MClAH8020, MClAH8080, MClAH8100, MClAH8160, ...



Generic Measurement

Equip State

Current sequence - S653v1

C1044

Categories

SPSRING

TI8

TT40

Cycle

C1044 (0->14400)

Sequence - S653v1

S653v1 (Active)

S540v2 (Resident)

S543v1 (Resident)

S546v1 (Resident)

S950v1 (Resident)

S954v3 (Resident)

S543v2

S543v3

S543v4

Refresh

Filtering on SPSRING

Device Type	HWName	Status	Command	Parameter	Value
BLRING	LSDA		[M] READ-TABLE	End time (ms)	13000
MUGEF	LSDB		[M] PCCURRENTS	Start time (ms)	0
	LSFA		[R] DETAILED-STATUS	Step (ms)	50
	LSFR				

Measurement Display

LSFB @ Cycle 21410101

Update 16:27:21 113

Name	Type and Value	Axis
outputCurrent	(double[:261] -> 3.0762659156251835, 2....	Y
referenceCurrent	(double[:261] -> 6.564531730664454, 6.5...	Y
theoreticalCurrent	(double[:261] -> 6.550798400683984, 6.5...	Y
time	(int[:261] -> 0, 50, 100, 150, 200, 250, 300,...	X

Active keys : [X] -> x axis, [Y] -> y axis, [Z] -> z axis (image), [D] -> display line, [H] -> display histogram, [SPACE] -> clear

Y

X

theoreticalCurrent

referenceCurrent

outputCurrent

Point #

X

Y

Z

Console

Running tasks

16:23:54 - Executing command Losses in mGray on

16:24:19 - Executing command Screen Position on

16:24:38 - Executing command PCCURRENTS on cycle

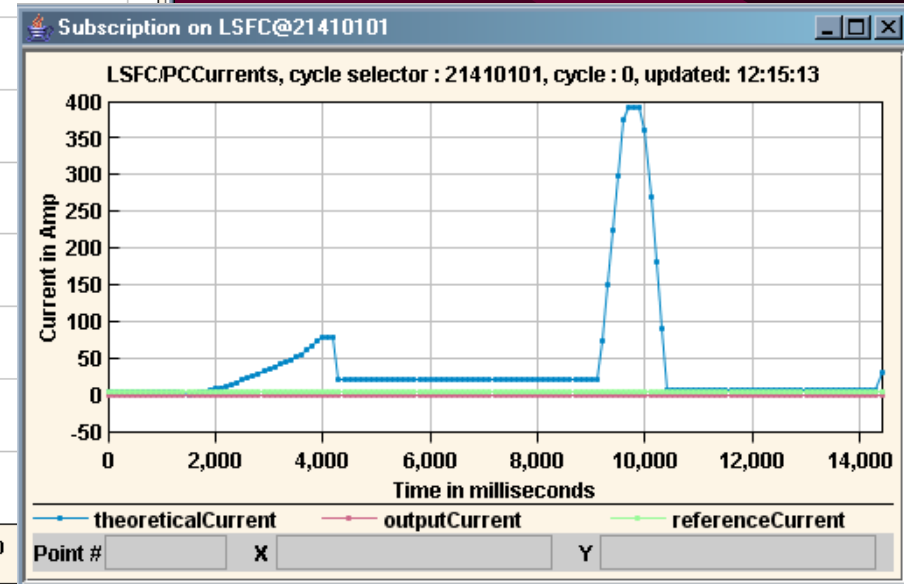
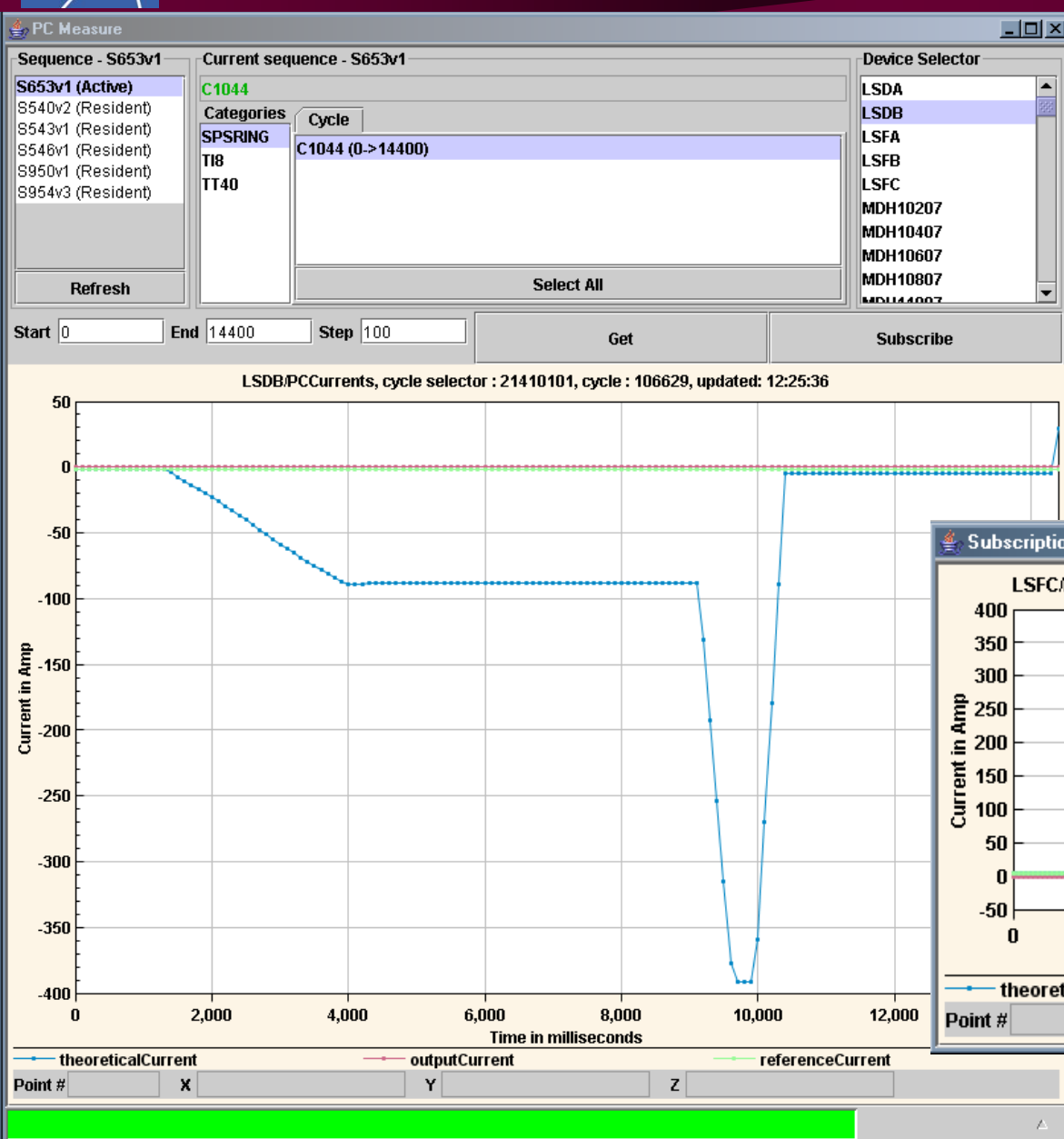
16:24:55 - Executing command PCCURRENTS on cycle

16:24:59 - Executing command PCCURRENTS on cycle

Executing command PCCURRENTS on cycle S653v1.C1044.C0 on

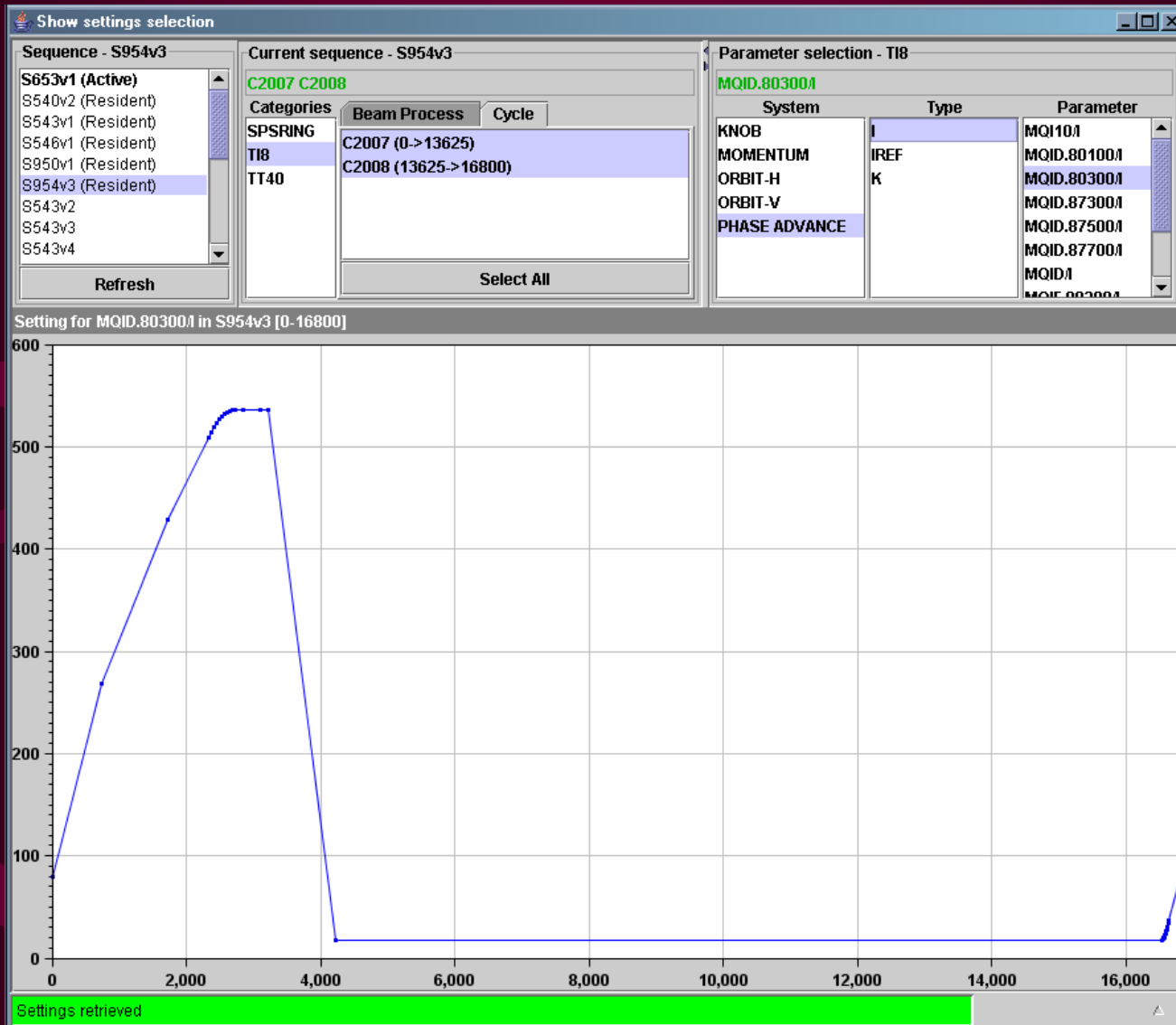


Measurement of power converters





Visualization of the settings





Trim

SPS Manual Trim V2.0-2004

Sequence - S653v1

- S653v1 (Active)
- S540v2 (Resident)
- S543v1 (Resident)
- S546v1 (Resident)
- S950v1 (Resident)
- S954v3 (Resident)
- S543v2
- S543v3
- S543v4

Refresh

Current sequence - S653v1

TT40 TT40 0-->0

Categories

- SPSRING
- TI8
- TT40

Beam Process

- [C1044] TT40 (10000->10500)
- [C1044] TT40 0-->0 (10500->24400)

Select All

Parameter selection - TT40

MBHA/I

System	Type	Parameter
EXTRACTION	I	MBHA/I
KNOB	IREF	MBHC/I
MOMENTUM	K	
PHASE ADVANCE	MOMENTUM	
TRAJECTORY		

Trim

Views

S653v1.TT40.BP3->MBHA/I: 24/11/04 12:25:32

current / A

time / ms

VALUE

Trim

Trim Point

Abort

Trim History

Send to Hardware

Undo last trim

Editing MBHA/I

Console

```
12:26:14 - Trimming setting for MBHA/I from 10000 ms to 24400 ms
12:26:32 - Trimming setting for MBHA/I from 10000 ms to 24400 ms
```

Trimming setting for MBHA/I from 10000 ms to 24400 ms

erator Controls



Trim history

SPS Manual Trim V2.0-2004

Sequence - S546v1

- S653v1 (Active)
- S540v2 (Resident)
- S543v1 (Resident)
- S546v1 (Resident)
- S950v1 (Resident)
- S954v3 (Resident)
- S543v2
- S543v3
- S543v4

Refresh

Current sequence - S546v1

TI8

Categories

- SPSRING
- TI8
- TT40

Beam Process

- [c1052] TI8 (1900)
- [c1052] TI8 0-->0

Trim Archive

Archived Trims

- 23-10-2004 @ 14:57:41 : MICADO 2 correctors - f = 1.00
- 23-10-2004 @ 15:08:39 : MICADO 2 correctors - f = 0.30
- 23-10-2004 @ 15:11:27 : Pt-Threader @ BPMIV.85704 - f = 0.50
- 23-10-2004 @ 15:12:55 : Pt-Threader @ BPMIV.85704 - f = -0.50
- 24-10-2004 @ 22:38:19 : Single kick @ MCIIV.85504 - f = 1.00
- 24-10-2004 @ 22:38:51 : Single kick @ MCIIV.85504 - f = 1.00
- 24-10-2004 @ 22:39:21 : Single kick @ MCIIV.85504 - f = 1.00

Load Add trim comment Quit

Type Parameter

Type	Parameter
	MCIIV.83104/K
	MCIIV.83704/K
	MCIIV.83904/K
	MCIIV.84504/K
	MCIIV.84704/K
	MCIIV.85304/K
	MCIIV.85504/K
	MCIIV.85404/K

VALUE

Trim

Trim Point

Abort

Trim History

Send to Hardware

Undo last trim

Ready

Ready

Legend: current reference (white), old reference (blue)

time / ms



Supporting Tools for Operation

- Beam Measurement – Inspection – Correction – Trim
ex: Orbit Correction...The whole suite of beam diagnostics
- Sequencing
- Online Machine Models
- Archiving of measurements
- Automatic logging and data retrieval (correlation studies)
- Post Mortem Analysis Tools
- Fixed Displays (the 16 big screens in the CCC...)
- ELogBook
- Statistics



Orbit Steering

YASP V1.111/Nov 04 SPSRING / S546v1 [Size 25.4 Mb (7.4 free)]

File Tools Optics Help

Action progress
Acq finished

Active Selection
SPSRING / S546v1 / SPS.USER.LHC546 : 0-20550 ms

Acquisition

Acquire Mon

Single Repeat

Single FT Orbit

19000 ms

Read CODs IN Coast

Steering

References

Reference Data Sets

Use as reference :

Last Acquisition **Active**

Last Correction **From Catalog**

Right-click on button for orbit details !

Show Reference

Parameter : MOPOS.Shared.Acti
Event : 211b0301
Autosave is ON
Active orbit set as reference
Building DV views
MOPOS config read from resource
Read MOPOS config for 229 eleme
Saved data to
... //hpdepot/opdata/orbit/dat
Data header :

YASP Dataviewer SPSRING S546v1

Monitors H + V

Views

Monitor H - SPSRING S546v1 SPS.USER.LHC546 : 15/11/04 15:30:31

7500.0
2500.0
-2500.0
-7500.0

H Pos(um)

15/11/04 15-30-47 - SC # 278 CO @ 19000 ms
Mean = -125 / RMS = 2740 / Dp = -0.05

0.0 25.0 50.0 75.0 100.0 125.0

Monitor H

Monitor V - SPSRING S546v1 SPS.USER.LHC546 : 15/11/04 15:30:31

7500.0
2500.0
-2500.0
-7500.0

V Pos (um)

15/11/04 15-30-47 - SC # 278 CO @ 19000 ms
Mean = 87 / RMS = 2257 / Dp = -0.05

0.0 25.0 50.0 75.0 100.0 125.0

Monitor V



Optics Display

Optics display _ □ ×

SPS OPTICS DISPLAY

Beam parameters (for beam size)

<i>E_h</i>	<i>E_v</i>	<i>sigmaE</i>
3.0	3.0	1.0E-03

Views Horizontal : 24/11/04 12:55:29

Horizontal Vertical : 24/11/04 12:55:29

Horizontal Plot: Beam Size/um vs Order (0.0 to 90.0). Y-axis: -10.0 to 40.0. Shows a sawtooth pattern with amplitude increasing from ~10 um at order 0 to ~25 um at order 90.

Vertical Plot: Beam Size/um vs Order (0.0 to 90.0). Y-axis: -5.0 to 45.0. Shows a sawtooth pattern with amplitude increasing from ~10 um at order 0 to ~25 um at order 90.

Left Panel:

CATEGORY	KEYWORD
LEIR	Everything
MAINRING	HKICKER
SPSRING	INSTRUMENT
TI8	MONITOR
TT10	QUADRUPOLE
TT40	RBEND
	SROTATION
Y Display parameter	
OPTICS	Beam size
TI8-JULY-04	Beta
TI8-MARCH-04	Sqrt(beta)
TI8-OCT-04-v1	Alpha
TI8-SEPT-04-v1	Phase advance
	Dispersion
X Display parameter	
	Order
	Position
	Phase advance

DISPLAY

Beam size displayed for optic TI8-OCT-04-v1



Logging & Monitoring

SDDS logging monitor

File

Configuration File: ds\accsoft-sdds-writer\src\accsoft-sdds-writer\SDDSConfig.xml **T18**

Destination directory: C:\Temp\SDDS **MD**

Parameter	Last update	Cycle ID
BTVI_LSS4.41895/getProfiles	11:30:27	34771
⚠ BTVI_T18.81204/getImage	11:29:56	0
BTVI_T18.81204/getProfiles	11:30:27	34771
⚠ BTVI_T18.81306/getImage	11:30:01	0
BTVI_T18.81306/getProfiles	11:30:27	34771
BTVI_T18.84304/getImage	11:30:26	34771
BTVI_T18.84304/getProfiles	11:30:26	34771
BTVI_T18.84404/getImage	11:30:26	34771
BTVI_T18.84404/getProfiles	11:30:26	34771
BTVI_T18.84604/getImage	11:30:26	34771
BTVI_T18.84604/getProfiles	11:30:26	34771
BTVI_T18.87437/getImage	11:30:26	34771
BTVI_T18.87437/getProfiles	11:30:26	34771
BTVI_T18.87604/getImage	11:30:26	34771
BTVI_T18.87604/getProfiles	11:30:26	34771
BTVI_T18.87750/getImage	11:30:26	34771
BTVI_T18.87750/getProfiles	11:30:26	34771
BTVI_TT40.400105/getImage	11:30:27	34771
BTVI_TT40.400105/getProfiles	11:30:27	34771
BTVI_TT40.400222/getImage	11:30:27	34771
BTVI_TT40.400222/getProfiles	11:30:27	34771
BTVI_TT40.400343/getImage	11:30:27	34771
BTVI_TT40.400343/getProfiles	11:30:27	34771
✖ MSE4183M/PCCurrents		
STEP_1_gpsbb4/PSN	11:30:38	34772

Console | Running tasks

```
11:30:40 - Start monitoring parameter [MSE4183M/PCCurrents]
11:30:40 - Exception occurred: [MSE4183M/PCCurrents]asynchronous operation on MSE4183M/PCCurrents@21890301 failed
cern.jpac.ParameterException: Error -132 : StartTime exceeds cycleLength
Caused by:
cern.jpac.ParameterException: Error -132 : StartTime exceeds cycleLength
11:30:40 - Stop monitoring parameter [MSE4183M/PCCurrents]
11:30:40 - Monitoring parameter [MSE4183M/PCCurrents] will be restarted in about 33 seconds
```

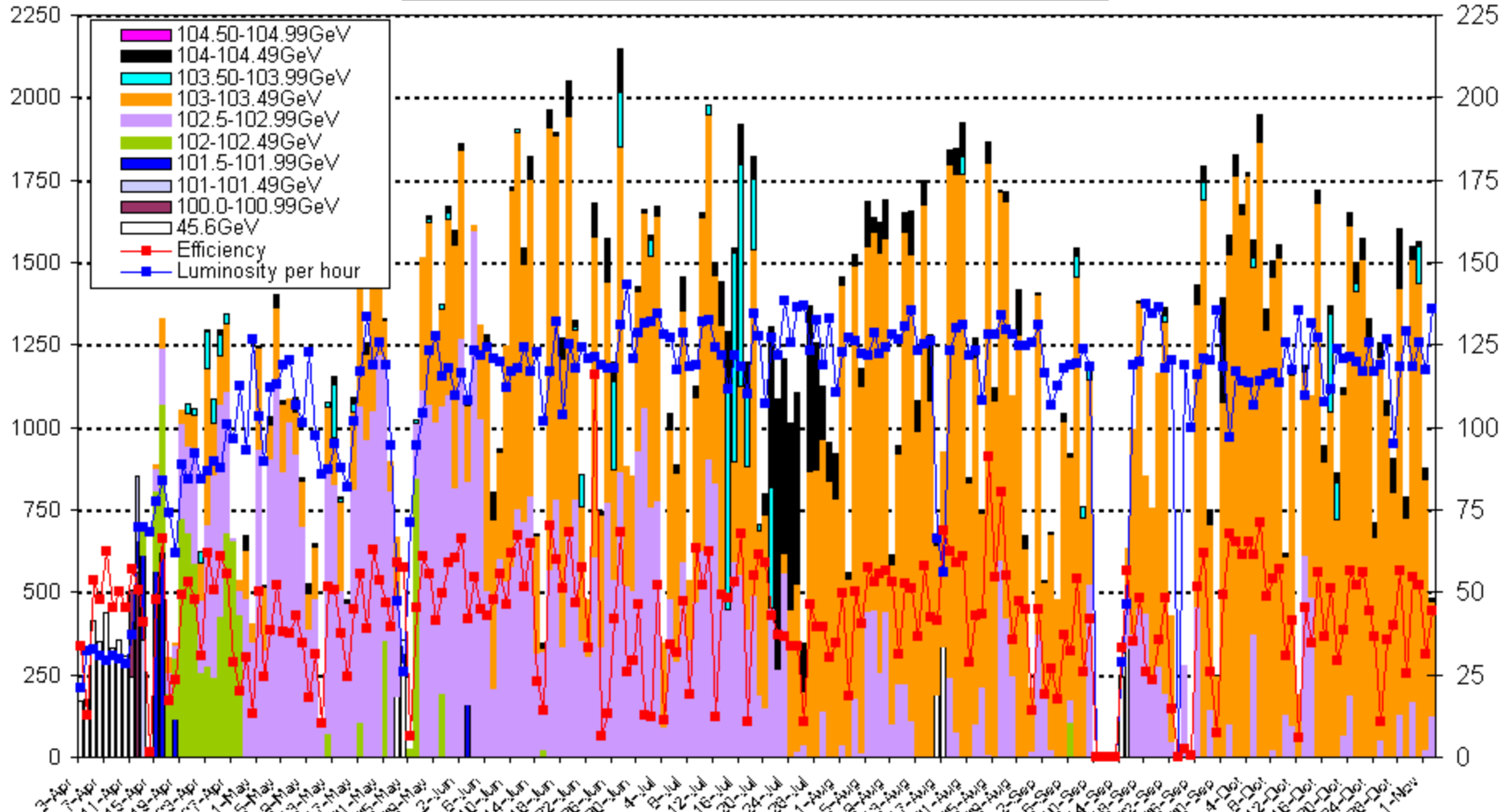
Error -132: StartTime exceeds cycleLength

controls

Integrated luminosity per day in 2000

nb-1

nb-1/hour & %



Data hauled from database automatically at end of fill



Retrieval of archived measurements

The screenshot shows a Windows Explorer window titled "\\hpdepot\opdata4\SSDDS_LOGGING\23_10_04\BTVI_LSS4.41831#getImage". The address bar shows the path: "\\hpdepot\opdata4\SSDDS_LOGGING\23_10_04\BTVI_LSS4.41831#getImage".

The left pane shows a folder tree under "SSDDS Data":

- lost+found
- SSDDS_LOGGING
 - 05_11_04
 - 06_11_04
 - 07_11_04
 - 08_11_04
 - 09_11_04
 - 22_10_04
 - 23_09_04
 - 23_10_04
 - BCTFI_T18DWN#BCTFI.Shared.Actions.acquisition
 - BCTFI_TT40#BCTFI.Shared.Actions.acquisition
 - BMLM_T18#BMLM.ClassGlobalCommactionList.blmacq
 - BPMI_T18#BPMI.Shared.Actions.dabCrateAverage
 - BPMI_T18DWN#BPMI.Shared.Actions.crateBunchPositions
 - BPMI_T18UP#BPMI.Shared.Actions.crateBunchPositions
 - BTVI_LSS4.41831#getImage**
 - BTVI_LSS4.41831#getProfiles
 - BTVI_LSS4.41895#getImage
 - BTVI_LSS4.41895#getProfiles
 - BTVI_T18.81204#getImage
 - BTVI_T18.81204#getProfiles
 - BTVI_T18.81306#getImage
 - BTVI_T18.81306#getProfiles
 - BTVI_T18.84304#getImage
 - BTVI_T18.84304#getProfiles
 - BTVI_T18.84404#getImage
 - BTVI_T18.84404#getProfiles
 - BTVI_T18.84604#getImage
 - BTVI_T18.84604#getProfiles
 - BTVI_T18.87437#getImage
 - BTVI_T18.87437#getProfiles
 - BTVI_T18.87604#getImage
 - BTVI_T18.87604#getProfiles
 - BTVI_T18.87750#getImage
 - BTVI_T18.87750#getProfiles
 - BTVI_TT40.400105#getImage
 - BTVI_TT40.400105#getProfiles
 - BTVI_TT40.400222#getImage
 - BTVI_TT40.400222#getProfiles
 - BTVI_TT40.400343#getImage
 - BTVI_TT40.400343#getProfiles
 - 24_10_04
 - 25_10_04
 - 26_10_04
 - Chao_Data

The right pane displays a list of files, each with a file icon, a name, and a date. The files are organized in three columns:

- Column 1: Files from 09_48_47 to 09_54_57.
- Column 2: Files from 10_11_16 to 10_32_52.
- Column 3: Files from 10_11_16 to 10_32_52.

Each file name follows the pattern: BTVI_LSS4.41831#getImage [time] [date].sdds. For example, "BTVI_LSS4.41831#getImage 09_48_47 10048.sdds".



Browser & Viewer

SDDS Browser

File Options

SDDS root directory: \\hpdepotprod4\SDDS_LOGGING\123_10_04 Choose directory...

Parameters

BTVI_T18.84404/getImage

Time	CycleID
19:14:40	11227
19:15:08	11228
19:15:37	11229
19:16:06	11230
19:16:35	11231
19:17:04	11232
19:17:32	11233
19:18:01	11234
19:18:30	11235
19:18:59	11236
19:19:28	11237
19:19:56	11238
19:20:25	11239
19:20:54	11240
19:21:23	11241
19:21:52	11242
19:22:20	11243
19:22:49	11244
19:23:18	11245
19:23:47	11246
19:24:16	11247
19:24:44	11248
19:25:13	11249
19:25:42	11250
19:26:11	11251
19:26:40	11252
19:27:08	11253
19:27:37	11254
19:28:06	11255
19:28:35	11256
19:29:04	11257
19:29:32	11258
19:30:01	11259
19:30:30	11260
19:30:59	11261
19:31:28	11262
19:31:56	11263
19:32:25	11264
19:32:54	11265
19:33:23	11266
19:33:52	11267
19:34:20	11268

SDDS Default View

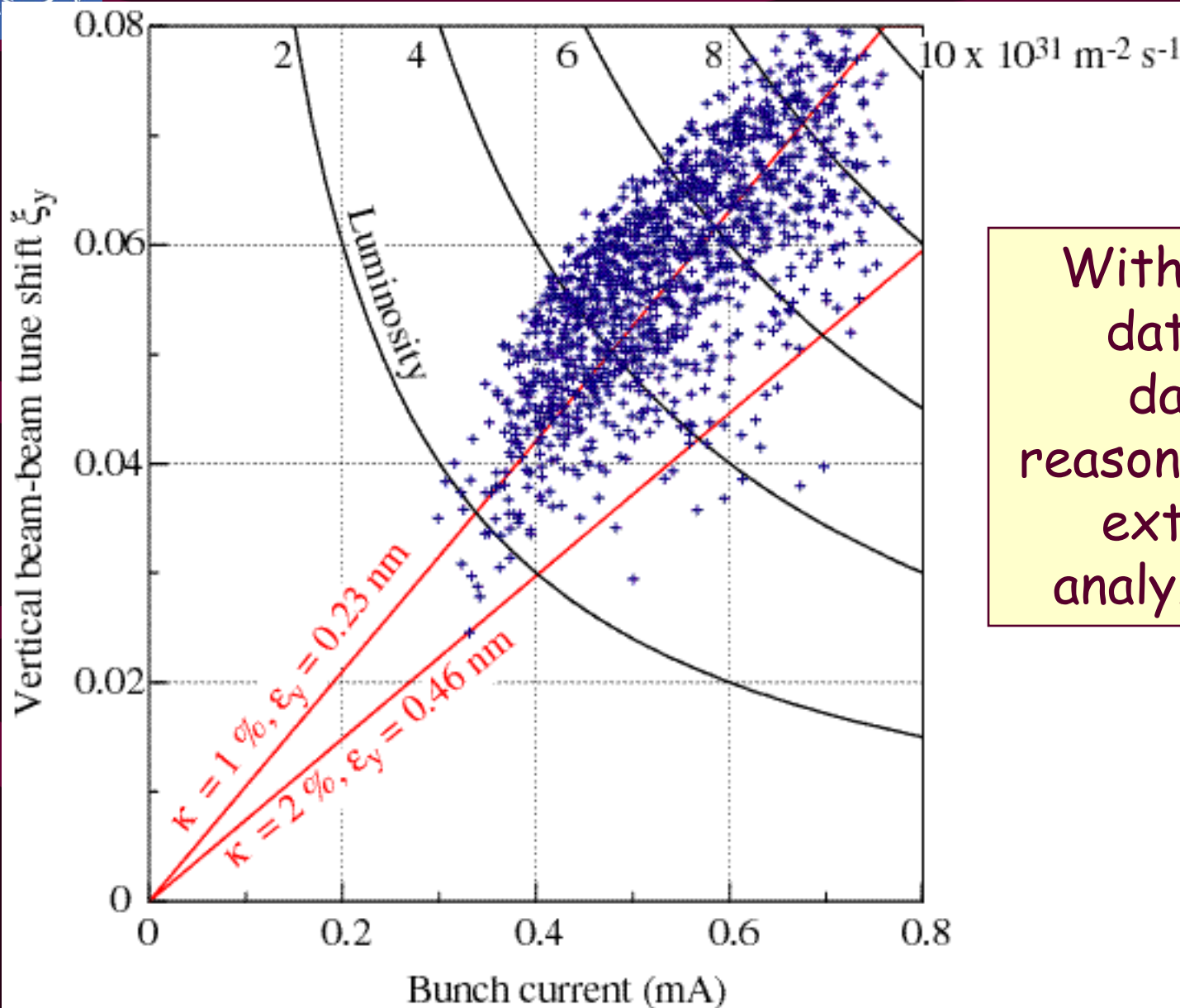
BTVI_T18.84404 @ Cycle sdds.19:19:56 Update 13:07:48 925

Name	Type and Value	Axis
sizeX	(long: 1) -> 354	X
sizeY	(long: 1) -> 284	Y
timeStampNSec	(long: 1) -> 687951803	
timeStampSec	(long: 1) -> 1098551995	
videoGain	(short: 1) -> 0	
zoom	(short: 1) -> 0	

Active keys : [X] -> x axis, [Y] -> y axis, [Z] -> z axis (image), [D] -> display line, [H] -> display histogram, [SPACE] -> clear

Point # x Y Z

DATA EXTRACTION → POST RUN ANALYSIS



With historical data on the database, reasonably easy to extract and analyze off-line



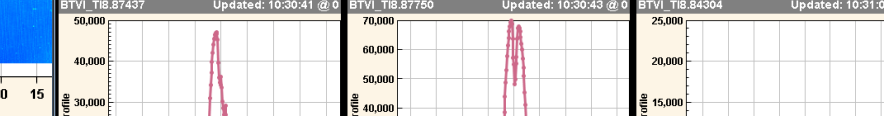
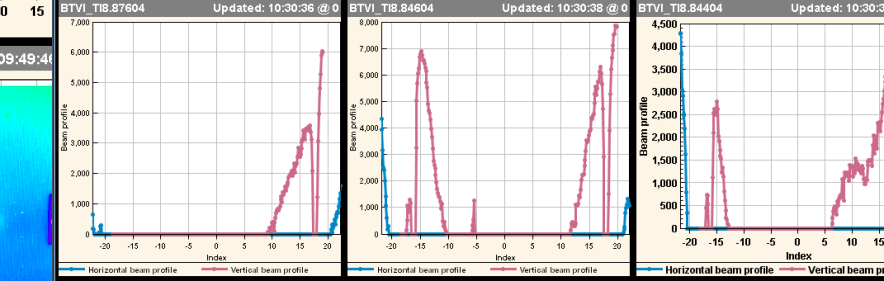
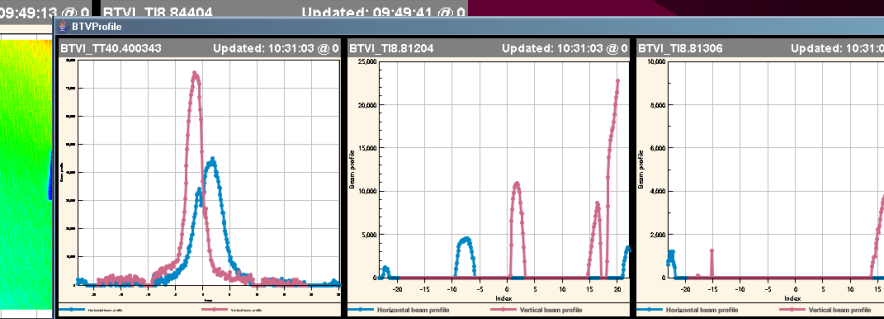
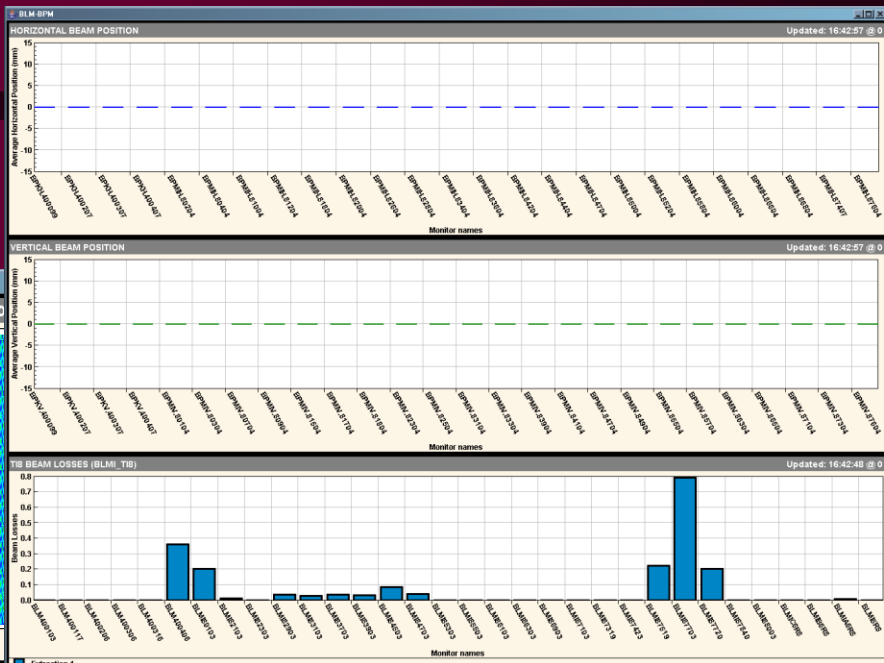
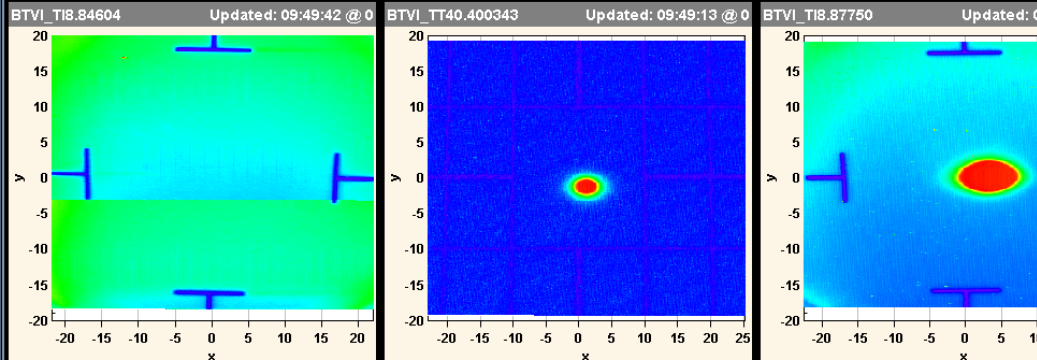
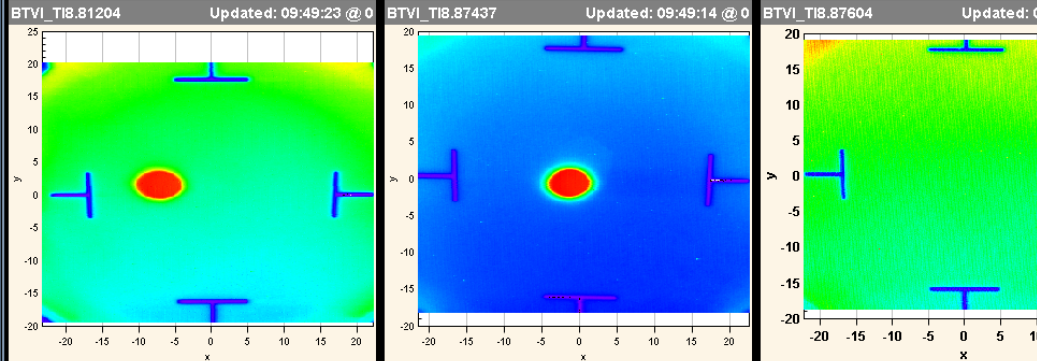
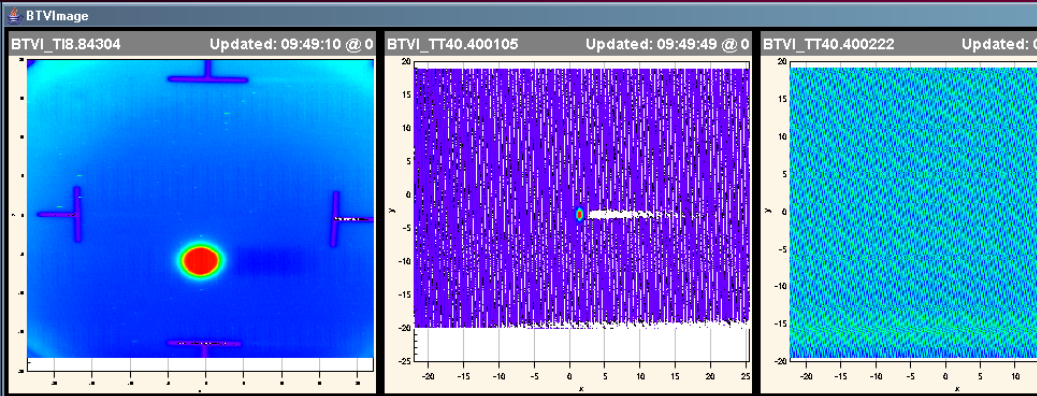
Dedicated Video (FAST) Signals (LEP)



Data sampled at slower rate
 → logging database



Fixed Displays Large screens in CCC)





Now we take a closer look:

Injection Setting generation for a main dipole string:

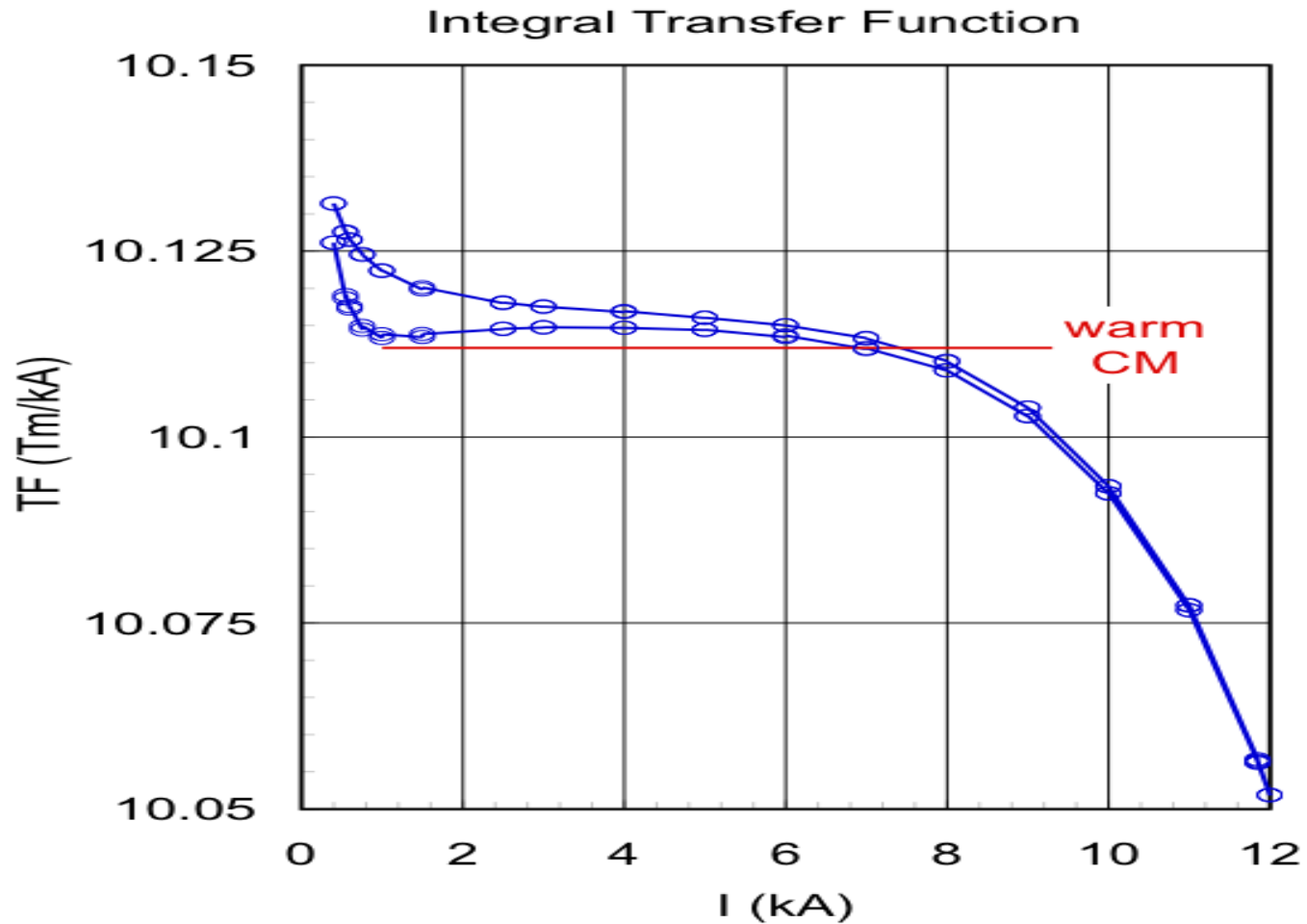
- 1) injection setting from requested beam momentum setting and calibration curve of Magnet
 - 2) Magnetic history of dipoles handled via specific hysteresis cycles before injection (called: degaussing...)
 - 3) Online Feedback to actual setting via reference magnet
 - 4) Requested beam momentum refined by measuring extraction energy of preinjector
 - 5) Other cycle history handled as trim and rollback utility (i.e. “cold machine after shutdown”, “warm machine after 1 day of permanent operation”
 - in case of the LHC the main dipoles are superconducting → the field model is more complicated than a simple look-up table
-next slides



Available data for LHC magnets

- warm measurements on the production:
 - all (superconducting) MB, MQ, MQM, MQY:
 - main field integral strength
 - higher order geometric harmonics
 - all (superconducting) MBX, MBR_x, MQX_x
 - **warm measurement on MQTL so far at CERN**
 - most (superconducting) lattice corrector and spool pieces
 - all (warm) MQW
 - a sample (5 to 10) of other warm insertion magnets (MBXW, ... measured at the manufacturer before delivery)
- cold measurements on:
 - a high fraction of MB and MQ in standard conditions
 - special tests (injection decay and snap-back, effect of long storage) on 15...20 MB
 - a sample of MQM and MQY
 - ≈ 75 % of MBX, MBR_x
 - 100 % of MQX_x (Q1, Q2, Q3)
 - a limited sample of lattice correctors and spool pieces

example of integral dipole field in an LHC dipole



The *field model*

- general decomposition in error sources, with given functional dependency on

$t, I, dI/dt, I(-t)$ geometric C_n^{geom}

→ DC magnetization from persistent currents C_n^{MDC}

→ iron saturation $C_n^{saturation}$

→ decay at injection C_n^{decay}

→ snap-back at acceleration C_n^{SB}

→ coil deformation at high field C_n^{def}

→ coupling currents C_n^{MAC}

→ residual magnetization $C_n^{residual}$

- linear composition of contributions:

higher values
higher variability
higher uncertainty



smaller values
smaller variability
smaller uncertainty

$$C_n = C_n^{geom} + C_n^{MDC} + C_n^{saturation} + C_n^{decay} + C_n^{SB} + C_n^{def} + C_n^{MAC} + C_n^{residual}$$



Use of data

- The data will be used to:
 1. set injection values
 2. generate ramps
 3. forecast corrections (in practice only for MB's or IR quads)

on a magnet *family* basis

- *Families* are magnet groups powered in series, i.e. for which an *integral transfer function* (and, possibly, *integral harmonics*) information is needed. Example: the MB's V1 line in a sector (154 magnets)



MB injection settings in sector 7/8

- From field model:

$$TF = 10.117 \text{ (Tm/kA)}$$

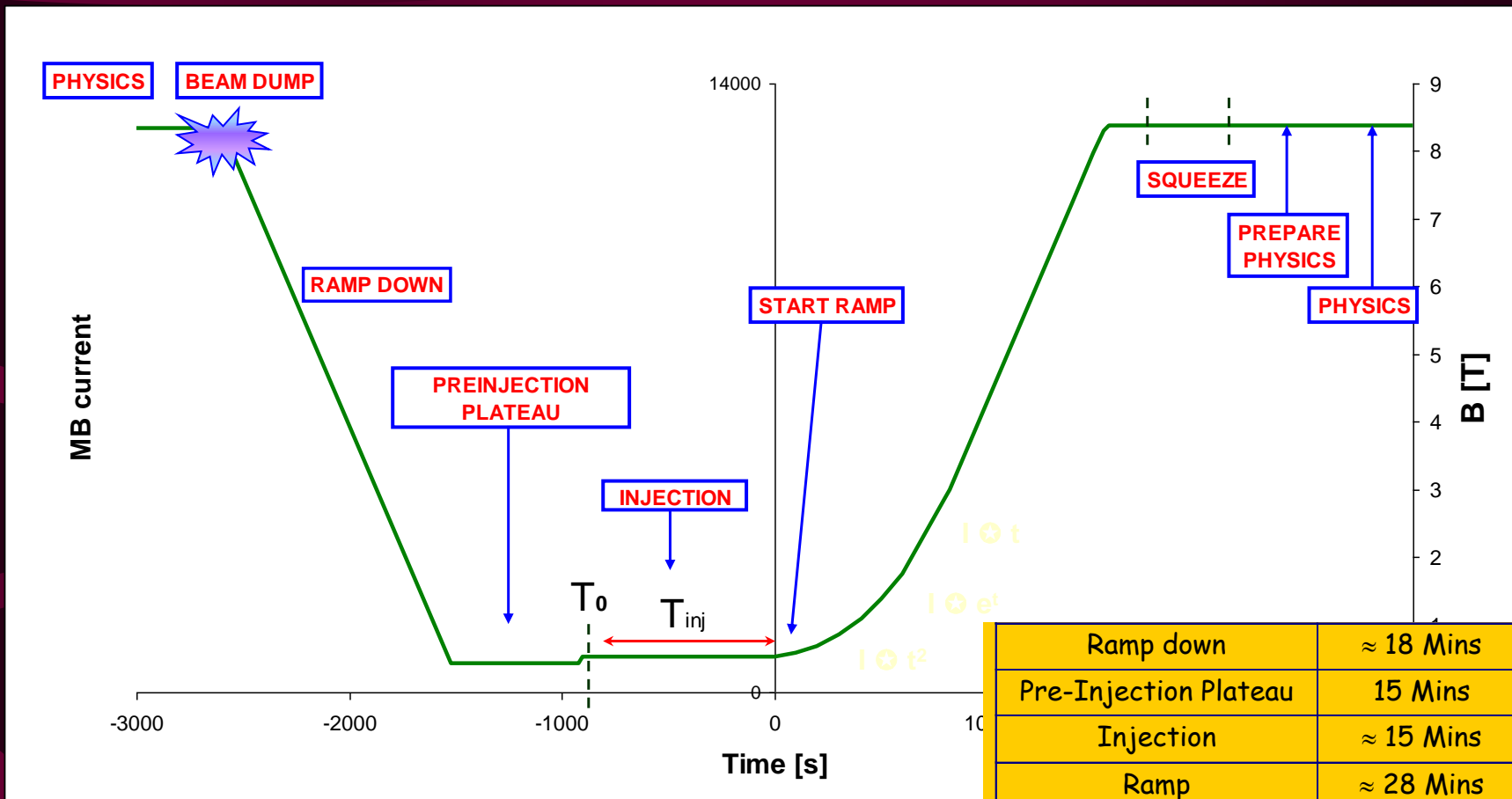
- Required integrated field strength in sector 78 for an injection at 450 GeV from SPS : 1189.2 T m

$$\rightarrow I = 763.2(5) \text{ A}$$

= this corresponds to the first step in the discussed sequence

The Control system receives and stores this setting and makes it available for trimming

...and now we have to ramp the whole lot



Ramp down	≈ 18 Mins
Pre-Injection Plateau	15 Mins
Injection	≈ 15 Mins
Ramp	≈ 28 Mins
Squeeze	< 5 Mins
Prepare Physics	≈ 10 Mins
Physics	10 - 20 Hrs



All routine operation based on a Semi-automatic sequencer

- Reproducibility
- Reduced scope for error

Sequencer Execution GUI (PRO) : 1.1.3

Sequencer Feedback Help

▼ RBA: lhcop

LHC NOMINAL SEQUENCE (B1_B2) SQUEEZE 2ND PART TO LOWBETA

LHC NOMINAL SEQUENCE (B1 & B2)

- ▶ PREPARE LHC FOR INJECTION (ALL BUT PCS)
- ▶ INJECTION PROBE BEAM
- ▶ INJECTION PHYSICS BEAM
- ▼ PREPARE RAMP
 - ▶ ENABLE POST MORTEM EVENTS
 - ▶ FORCE SBF TO FALSE
 - ▶ SWITCH OFF ABORT GAP CLEANING
 - ▶ RF CHECKS: WATCHDOG&FREQ B1/B2 LINKED
 - ▶ PREPARE FEEDBACKS FOR THE RAMP
 - ▶ ENSURE INJECTION IS NOT POSSIBLE
 - ▶ DISABLE INJECTION CLEANING
 - ▶ INJECTION COLLIMATORS OUT
 - ▶ HANDSHAKE END OF INJ - SM&BM = PREPARE RA
 - STOP FIDEL TRIMMING
 - CALCULATE FIDEL RAMP CORRECTIONS
 - ▶ INCORPORATE INJECTION TRIMS INTO THE RAMP
 - ▶ TRIM ADT NORMALIZED GAINS TO RAMP VALUES
 - ▶ SWITCH TUNE FB ON
 - MAKE LHC.USER.RAMP RESIDENT
 - ▶ LOAD RAMP SETTINGS IN PC&RF FGC
 - ▶ ARM LONGITUDINAL BLOW-UP
 - ▶ LOAD CLEANING & DUMP PROTEC COLL RAMP SE
 - ▶ CHECK INJ-PROT OUT COLL INTERLOCKED OUT

PREPARE_RAMP

- ▼ PREPARE RAMP
 - ▶ ENABLE POST MORTEM EVENTS
 - ▶ FORCE SBF TO FALSE
 - ▶ SWITCH OFF ABORT GAP CLEANING
 - ▶ RF CHECKS: WATCHDOG&FREQ B1/B2 LINKED
 - ▶ PREPARE FEEDBACKS FOR THE RAMP
 - ▶ ENSURE INJECTION IS NOT POSSIBLE
 - ▶ DISABLE INJECTION CLEANING
 - ▶ INJECTION COLLIMATORS OUT
 - ▶ HANDSHAKE END OF INJ - SM&BM = PREPARE RAMP
 - STOP FIDEL TRIMMING
 - CALCULATE FIDEL RAMP CORRECTIONS
 - ▶ INCORPORATE INJECTION TRIMS INTO THE RAMP
 - ▶ TRIM ADT NORMALIZED GAINS TO RAMP VALUES
 - ▶ SWITCH TUNE FB ON
 - MAKE LHC.USER.RAMP RESIDENT
 - ▶ LOAD RAMP SETTINGS IN PC&RF FGC
 - ▶ ARM LONGITUDINAL BLOW-UP
 - ▶ LOAD CLEANING & DUMP PROTEC COLL RAMP SETTINGS
 - ▶ CHECK INJ-PROT OUT COLL INTERLOCKED OUT
 - END SUBSEQUENCE BREAK

SUSPENDED

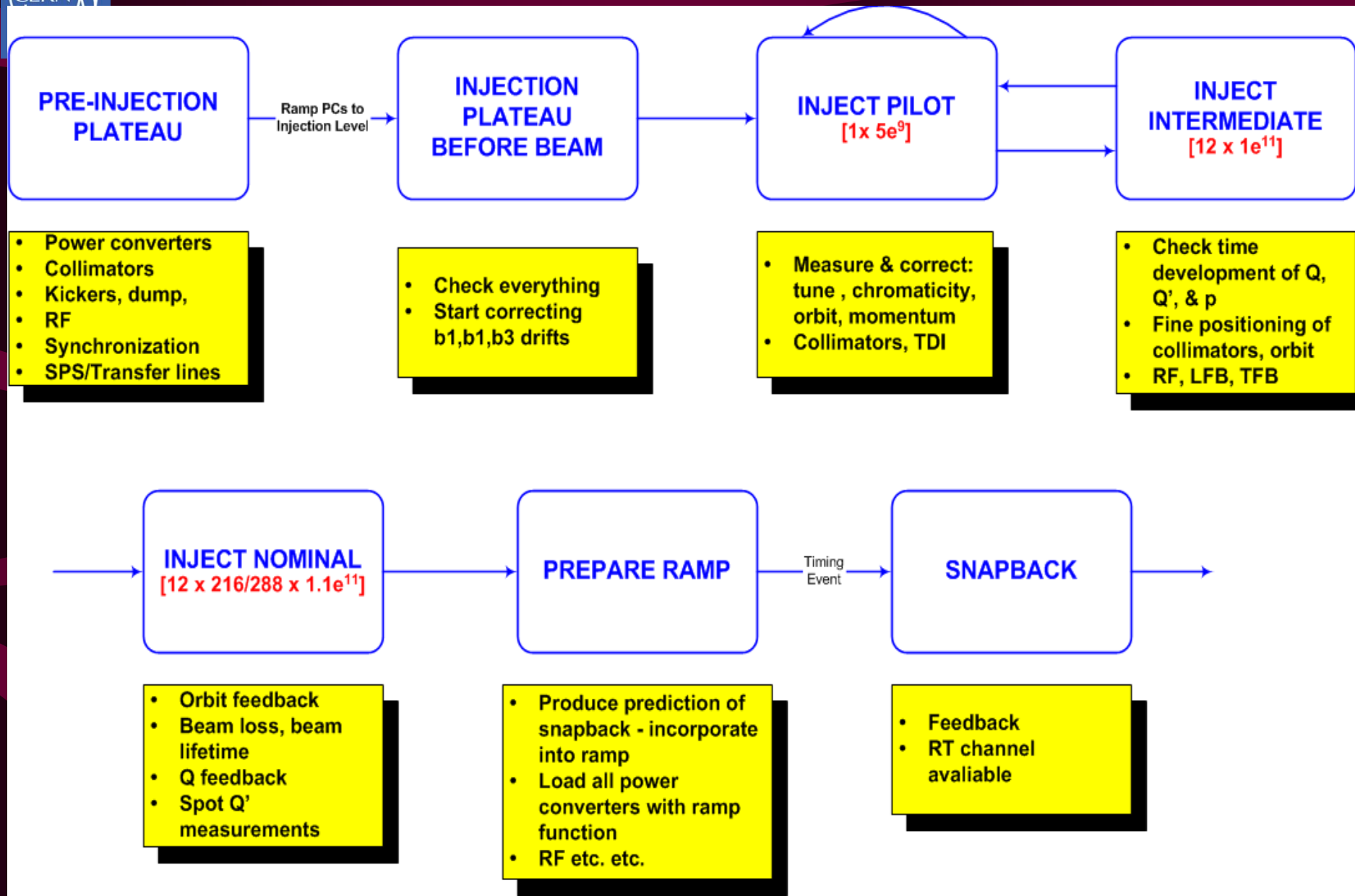
Run Suspend Step Skip Stop

Console Details Result

New RBA token received: will be used from the next step: RBAToken
[serial=0x1a32fd53;authTime=2011-09-07@14:27:19;endTime=2011-09-07@22:26:19;application=AppPrincipal[name=LHC Sequencer GUI, critical=false, timeout=-1];location=LocationPrincipal[name=CCC-LHC, address=172.18.200.124, auth-reqd=false, def-user=null];user=UserPrincipal[name=lhcop, roles=[[DIAMON-Operator, LHC-Operator, OP-Daemon, SPS-Operator, SeqHwcOperator, SeqLhcOperator, SeqSpsOperator]]];extra=null]

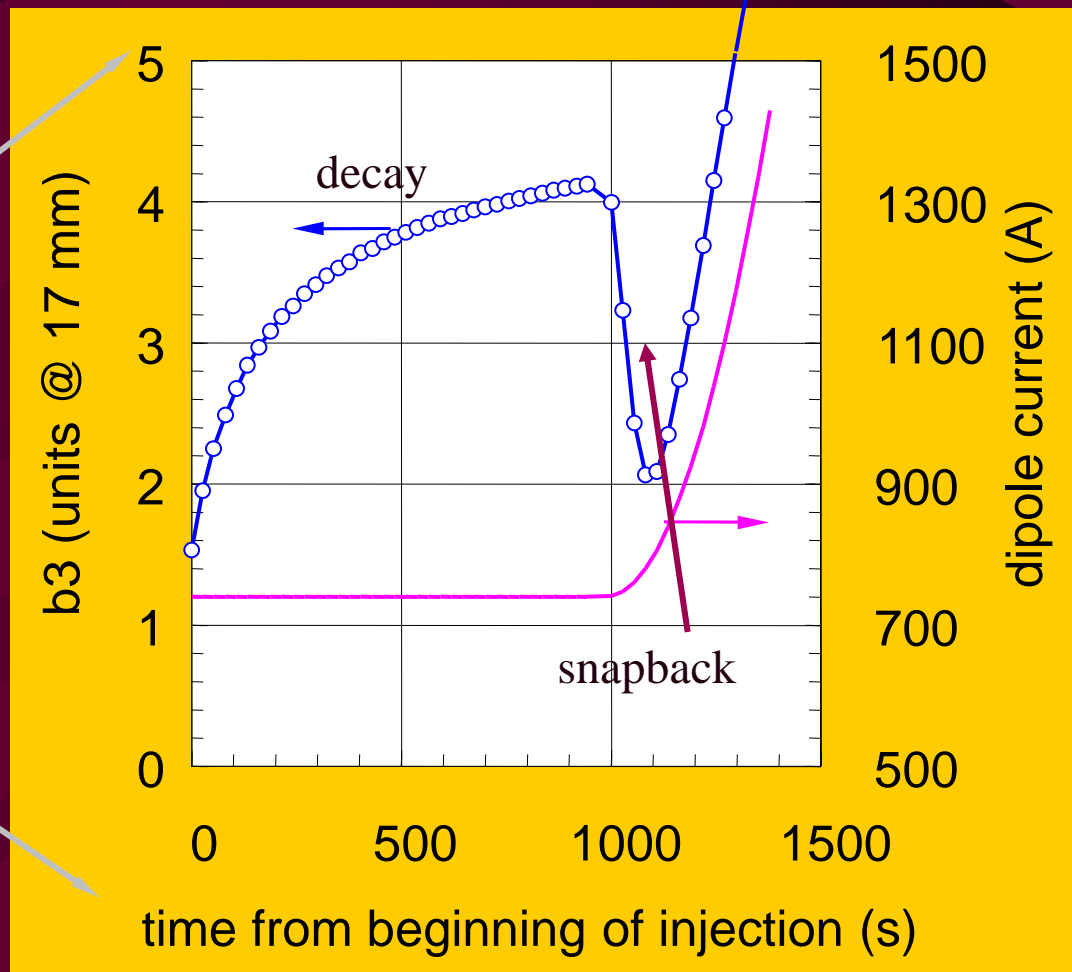
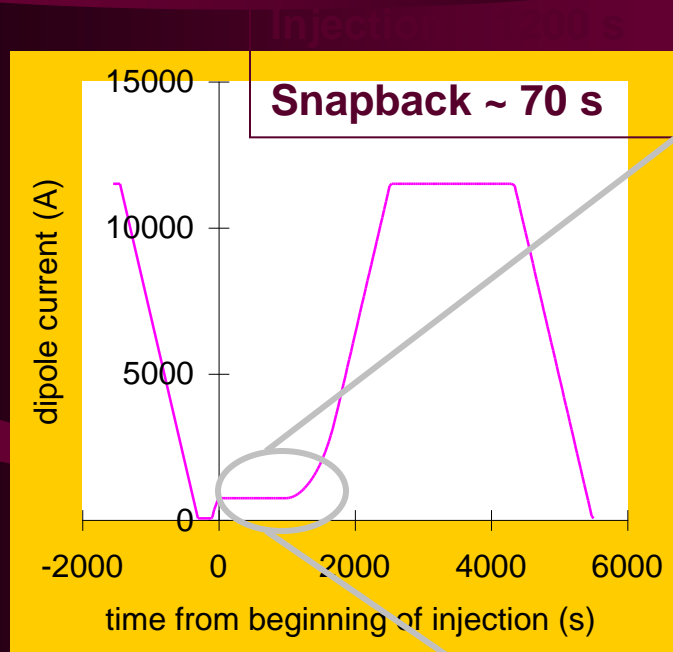
Server logs

```
onSequenceRemoved(). SequenceId = SM_CHECKS-RAMP-SQUEEZE@418@20110907141519807
onSequenceRemoved(). SequenceId = SM_CHECKS-ADJUST-STABLE_BEAMS@426@20110907143632143
Sequence prepared : SequenceId = PREPARE_RAMP @428@20110907154659254
```



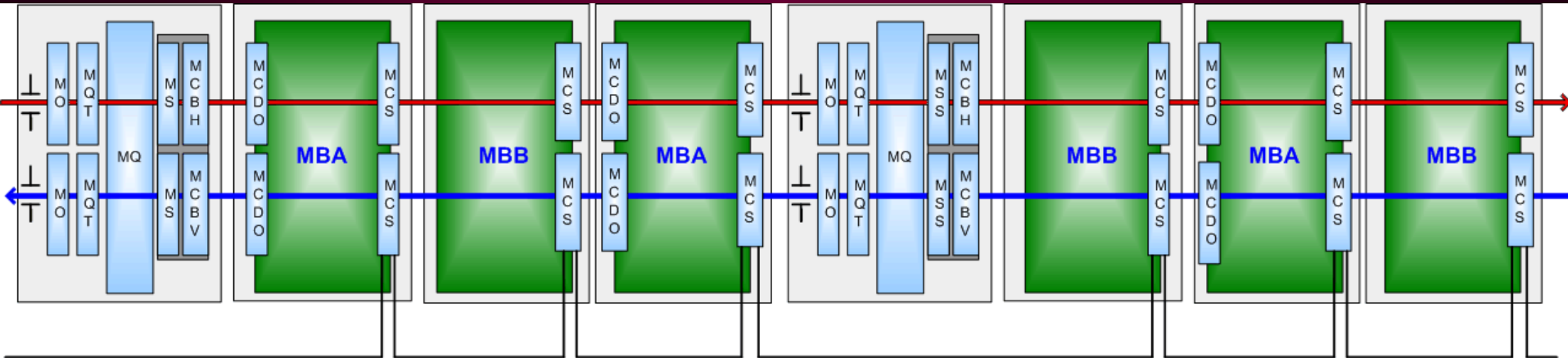


A very frightening problem...



Parameter	Nominal tolerance	Limit on $b_n(\text{MB}) - \text{Inj.}$	Approx. Decay	Parameter swing
Q'	$Q' \approx 2 \quad \Delta Q' \approx \pm 1$	± 0.02	1.7	$\Delta Q' \approx +71/-64$

Correction elements



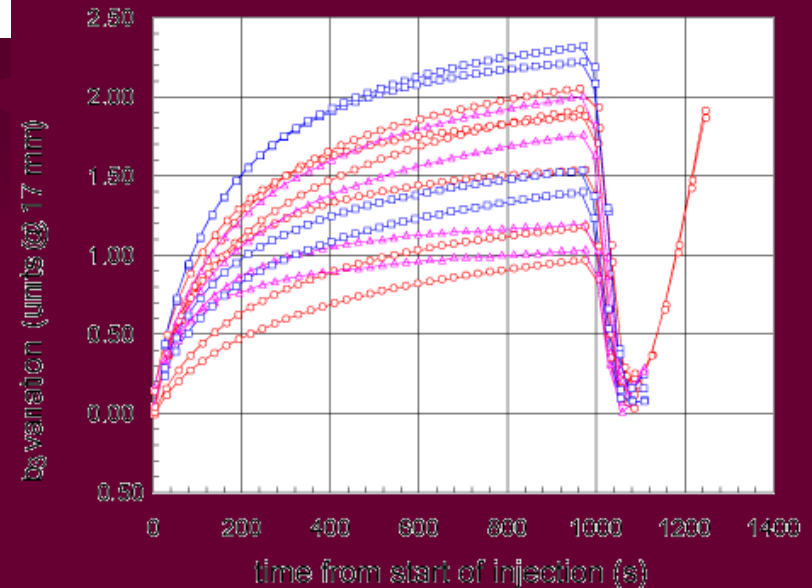
RCS.A78B2.UA83

Per aperture:

154 MCS sextupole spool pieces powered in series.

77 MCO & MCD spool pieces powered in series.

Therefore we're working on the average per sector per aperture



Dynamic effects - correction

Per sector per aperture:
magnitude of errors at t_0
and time evolution of $b_n(t)$
during decay has been
measured

$$b_n(t)$$

$$I_{MB}(t)$$

Based on this
corrections applied as
a function of time
during the injection
plateau

Δb_n applied as trim

Decide to ramp

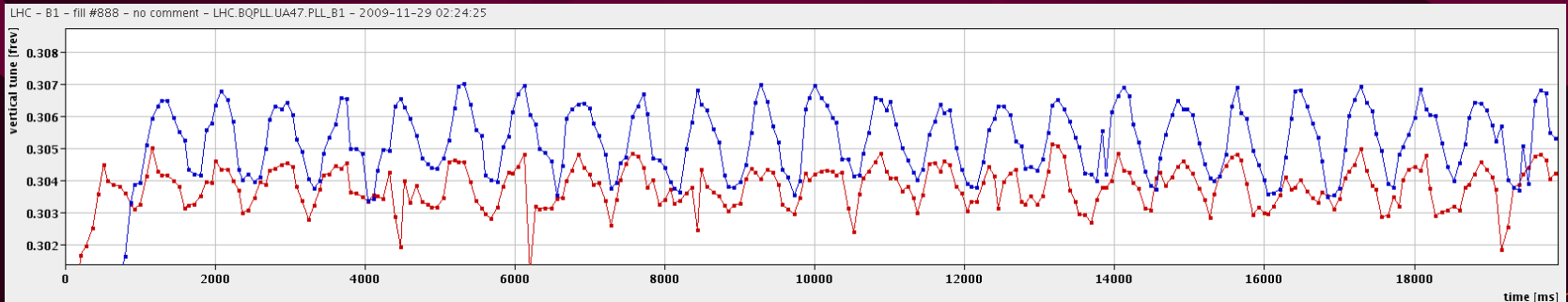
Start ramp

After time t_{inj} a
prediction of the
snapback is
required.
Download.



Q' - control

- Extract sextupole change in dipoles from slow Q' measurements & b_3 corrections during injection to give Δb_3 and thus ΔI .
- Just before ramping:
 - Extract total b_3 correction
 - Invoke fit for snapback prediction
 - Convert to currents
 - Incorporate into ramp functions & download
- Functions invoked at ramp start by standard timing event
- Occasionally follow chromaticity over ramp by measurements and verify that the incorporation of the trims is still valid.
 - Extract from measurements deviation from constant chromaticity
 - invert function and calculate corresponding correction function
 - make this function available in the control system as additional trim (experts only)





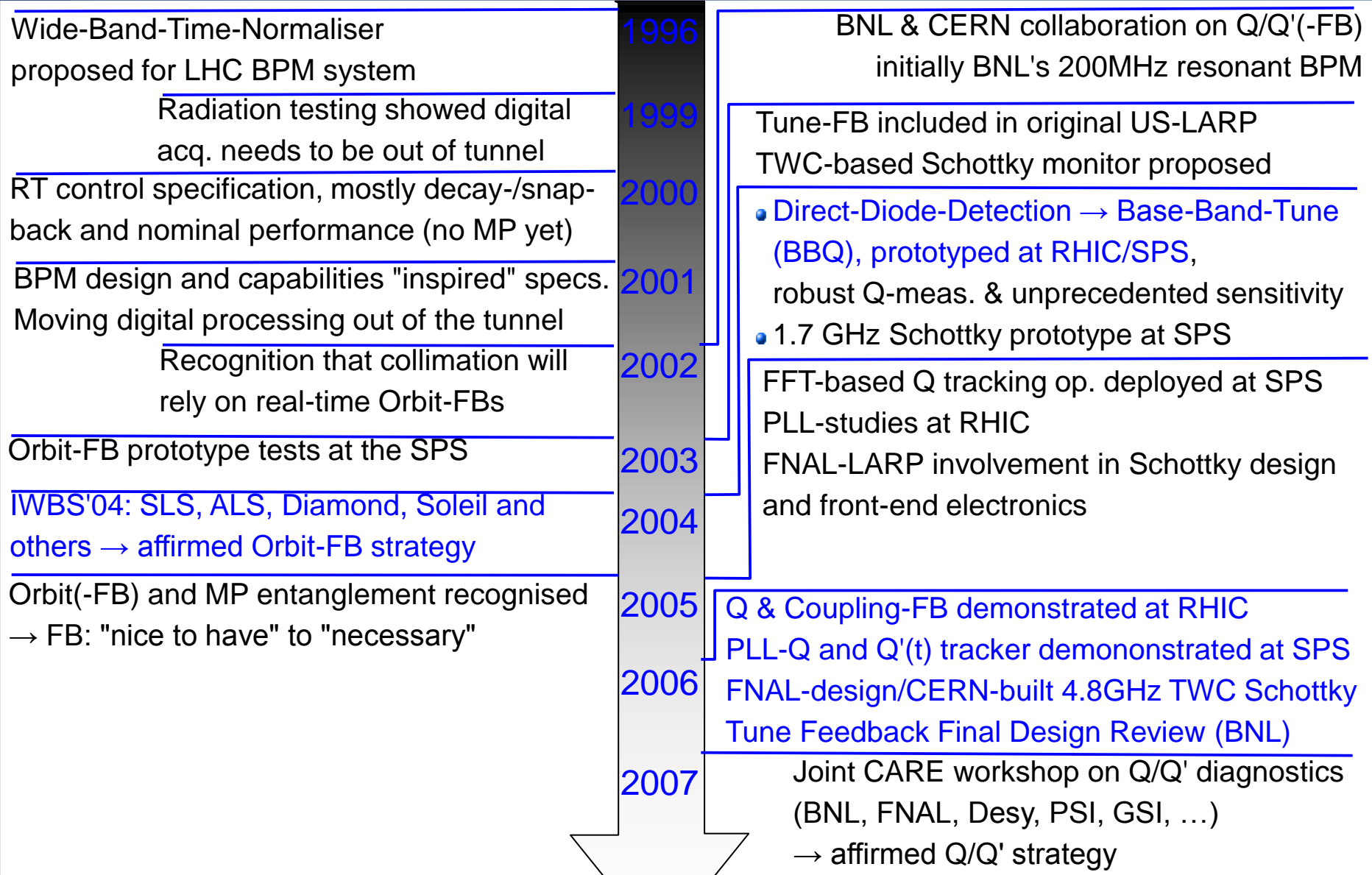
...and if all this is not enough: real time feedbacks on beam parameters

- Time resolved measurements
 - LHC orbit: minimum 10 Hz
 - LHC betatron tunes: some Hz
 - LHC chromaticities: Hz
 - Data centralization and computation of corrections (including error handling, dynamic change of twiss parameters...)
 - Feedback of corrections to power converters
- Nice Problem for the instrumentation group



LHC Feedback Success has a long Pedigree: Years of Collaboration, Development and leveraged Experience

Real-Time Beam Control at the LHC, Ralph Steigler @ CERN, FNAL, New York, NY, 2011-03-30

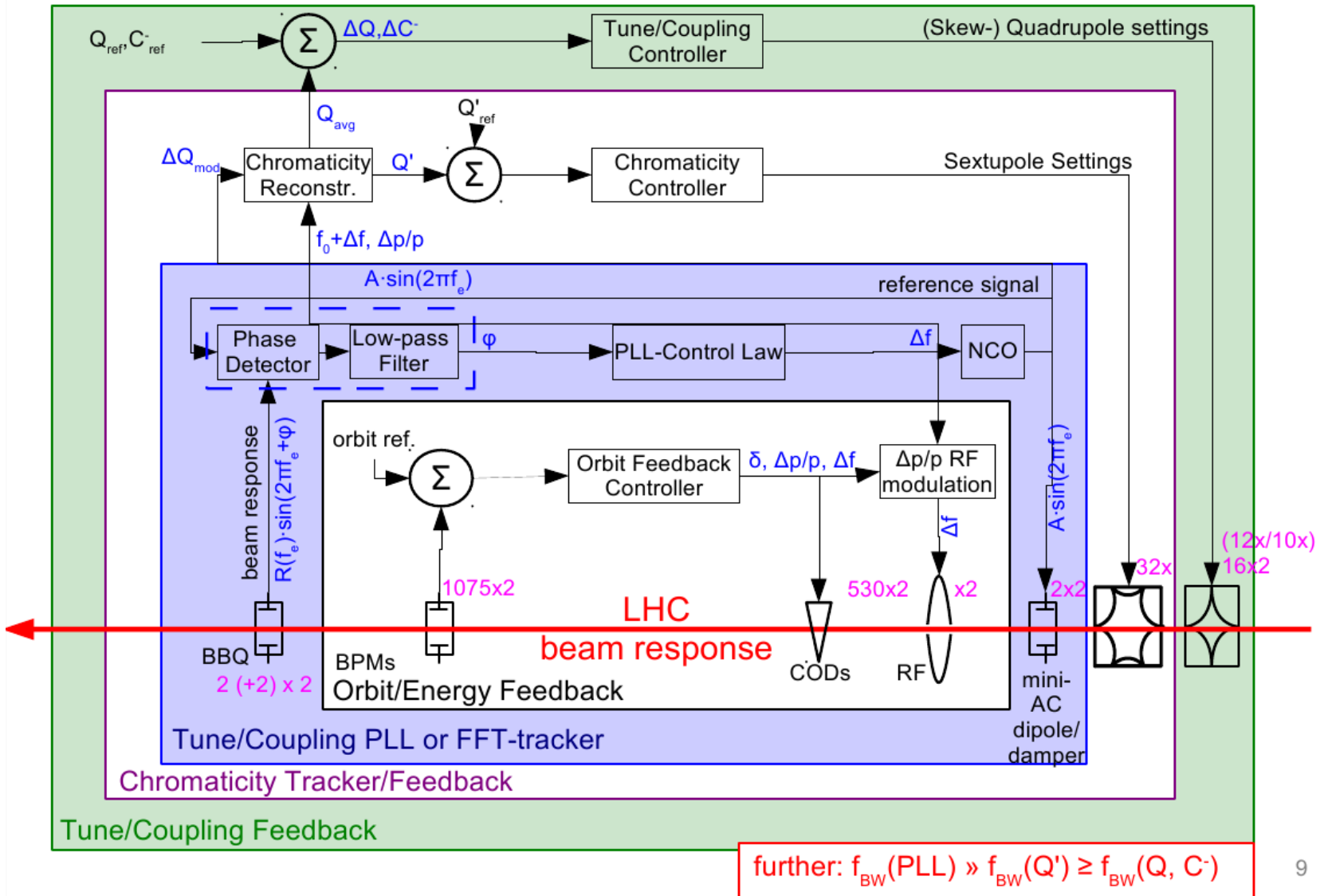


2009 – the year we established collisions: Q/Q'- & Orbit FBs operational

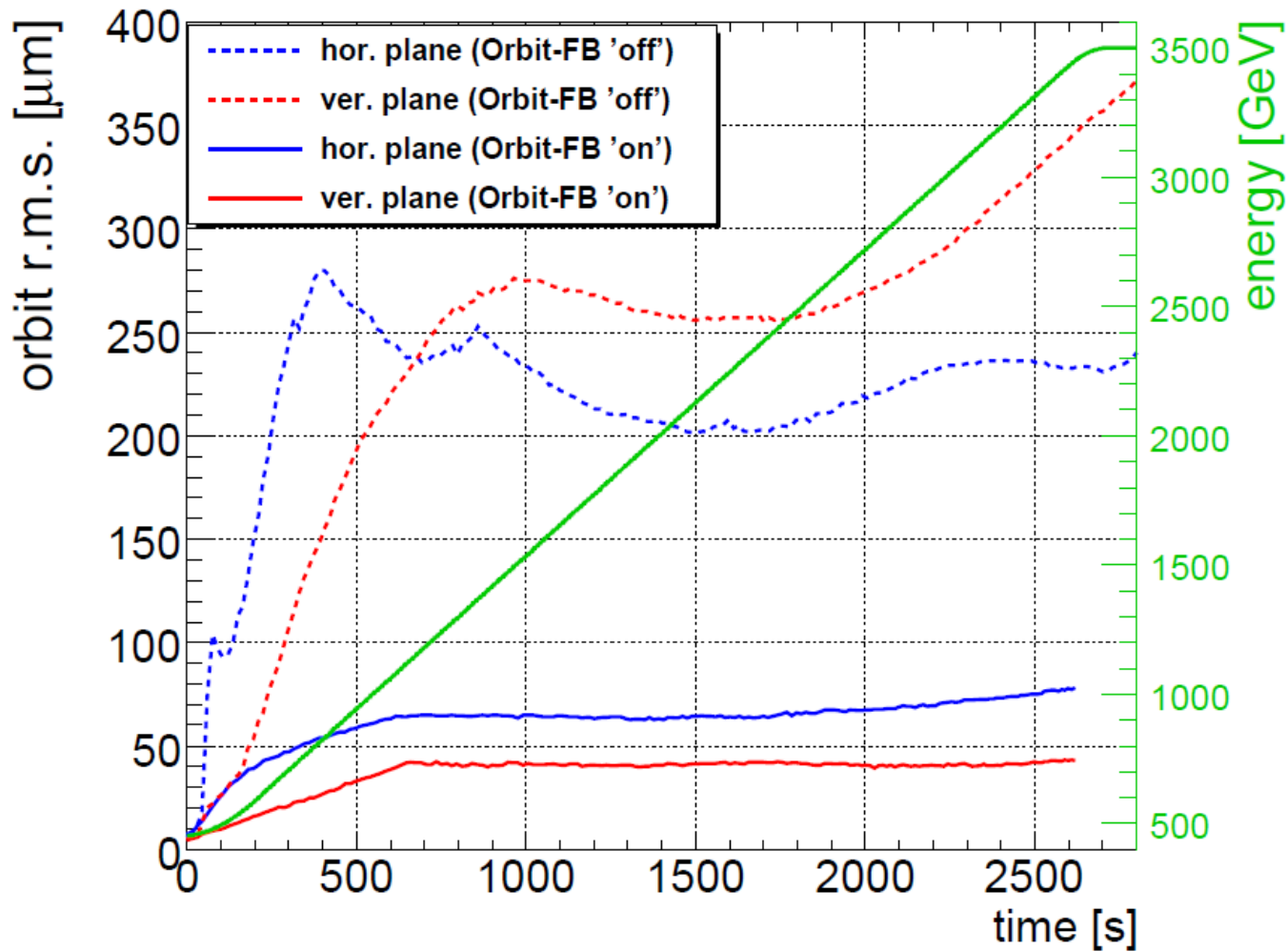


To avoid inherent Cross-Talk between FBs... ... Cascading between individual Feedbacks

Real-Time Beam Control at the LHC, Ralph Steierwagen@CERN.ch, New York, NY, 2011-03-30



- Orbit feedback used routinely and mandatory for nominal beam



- Typical stability: 80 (20) μm rms. globally (arcs)
- Most perturbations due to Orbit-FB reference changes around experiments



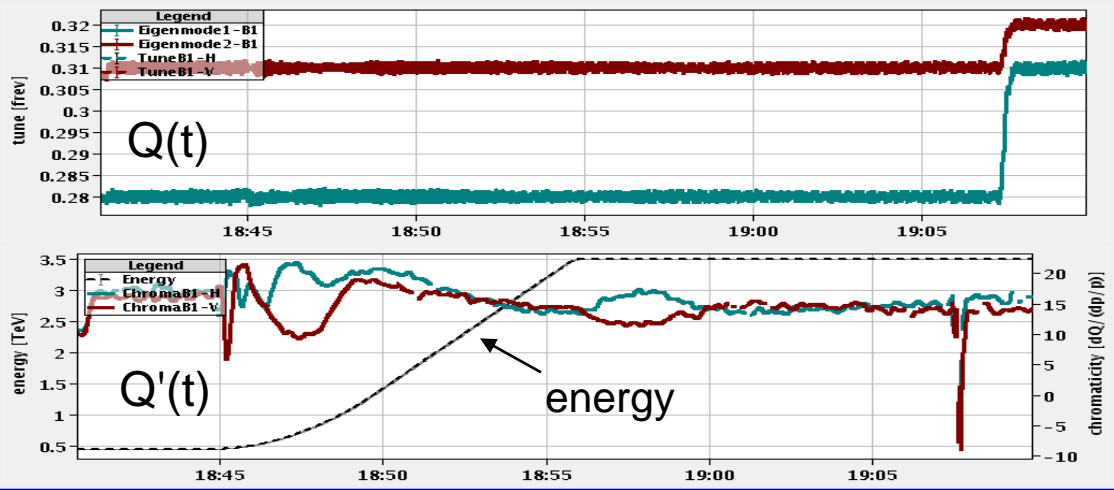
Typical Q/Q'(t) Control Room View 2010 Statistics: Out of 191 Ramps...

Real-Time Beam Control at the LHC, [Raimo Stangorini @CERN.ch](#), New York, NY, 2011-03-30

LHC - Fill#1574
2011-03-03 19:09:51

Q1 = .309714 Qx = .310523
Q2 = .319568 Qy = .318759
|C-| = .005410 E = 3500.0 GeV
Q'x = +16.2 ± .1
Q'y = +14.0 ± .3

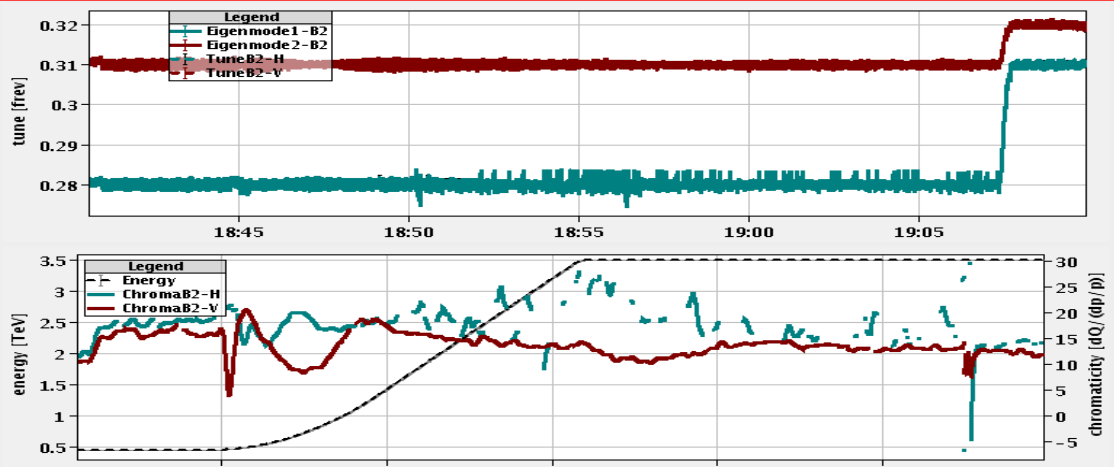
Beam 1



LHC - Fill#1574
2011-03-03 19:09:51

Q1 = .310105 Qx = .310434
Q2 = .320267 Qy = .319938
|C-| = .003598 E = 3500.0 GeV
Q'x = ???
Q'y = +11.9 ± .4

Beam 2



- ... 155 ramps with > 99% transmission, 178 ramps with > 97% transmission
- ... only 12 ramps lost with beam (6 with Tune-FB during initial 3.5 TeV comm.)
- ... “if without FBs”: 83 crossings of 3rd, 4th or C⁻ resonance, 157 exceeded $|\Delta Q| > 0.01$
- Impressive performance for the first year of operation and low-ish intensities:



Available trim functions for Qh'

Trim Editor

RBA: no token LHC OP BP

Beam Processes

Filter: RAMP_FAST_2011_JU

- RAMP_FAST_2011_JULY
- RAMP_FAST_2011_JULY@0 [START]
- RAMP_FAST_2011_JULY@0 [START]_AUGUST
- RAMP_FAST_2011_JULY@0 [START]_MD3
- RAMP_FAST_2011_JULY@0 [START]_MD3_NOM
- RAMP_FAST_2011_JULY@1020 [END]

OPERATIONAL

Parameter selection - LHCRING

System	Type Groups	Parameters
BEAM DUMP	KNOB	Filter:
BETA-BEATING	K	LHCBEAM1/QPH
BETA-STAR	K_SMOOTH	LHCBEAM1/QPV
BLM	I	LHCBEAM2/QPH
BLM IQC REF	IREF	LHCBEAM2/QPV
CHROMATICITY		Select All

Select All Select All Hierarchy Show Field(s)

Search parameter by name:

Setting part: Value Target Correction Trim History Time base: SuperCycle Cycle/Beamprocess Injection

Displayed Function: LHCBEAM1/QPH

Graph Table

Trim Abort Trim Cancel Last Trim Apply

Trim Expert Params



Available trim functions for Qv'

Trim Editor

RBA: no token LHC OP BP

Beam Processes

Filter: RAMP_FAST_2011_JU

- RAMP_FAST_2011_JULY
- RAMP_FAST_2011_JULY@0 [START]
- RAMP_FAST_2011_JULY@0 [START]_AUGUST
- RAMP_FAST_2011_JULY@0 [START]_MD3
- RAMP_FAST_2011_JULY@0 [START]_MD3_NOM
- RAMP_FAST_2011_JULY@1020 [END]

OPERATIONAL

Parameter selection - LHCRING

System	Type Groups	Parameters
BEAM DUMP	↑	Filter: [?]
BETA-BEATING	K	LHCBEAM1/OPH
BETA-STAR	K_SMOOTH	LHCBEAM1/OPV
BLM	I	LHCBEAM2/OPH
BLM IQC REF	IREF	LHCBEAM2/OPV
CHROMATICITY		Select All

Select All Select All Hierarchy Show Field(s)

Search parameter by name: [?]

Setting part: Value Target Correction

Trim History

Time base: SuperCycle Cycle/Beamprocess Injection

Displayed Function: LHCBEAM1/OPV

Time (SuperCycle)	Value
0	-18
50	-30
100	-20
150	-5
200	-2
300	1
400	2
500	3
600	4
700	5
800	6
900	7
1000	8

Graph Table

Trim

Abort Trim

Cancel Last Trim

Apply

Trim Expert Params



Summary

- Accelerator Controls is a vast activity
- Controls Hardware mainly based on commercially available products (COTS)
- Controls of beam parameters makes the link between:
 - accelerator physics
 - beam observation
 - equipment control
- ...is fun to work on...