

# Accelerator Controls

## Part1: CERN Accelerator Controls

CAS 2009@Divonne

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# What we will do in the next 2 hours...

- First hour:  
The good old days...  
Concept of modern controls  
Required functionality - nothing on technology  
examples for settings generation, function trimming  
and real time feedback
- Second hour (on request of the program committee):  
A fully detailed description of the CERN timing  
system (= multi accelerator operation)



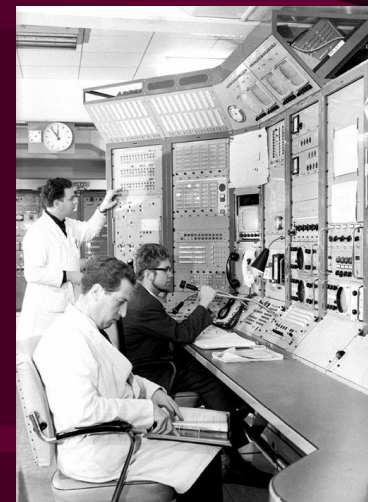
# Outline

- Controls technology (5 minutes)
  - 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

Examples for:

static and dynamic control, real time feedback

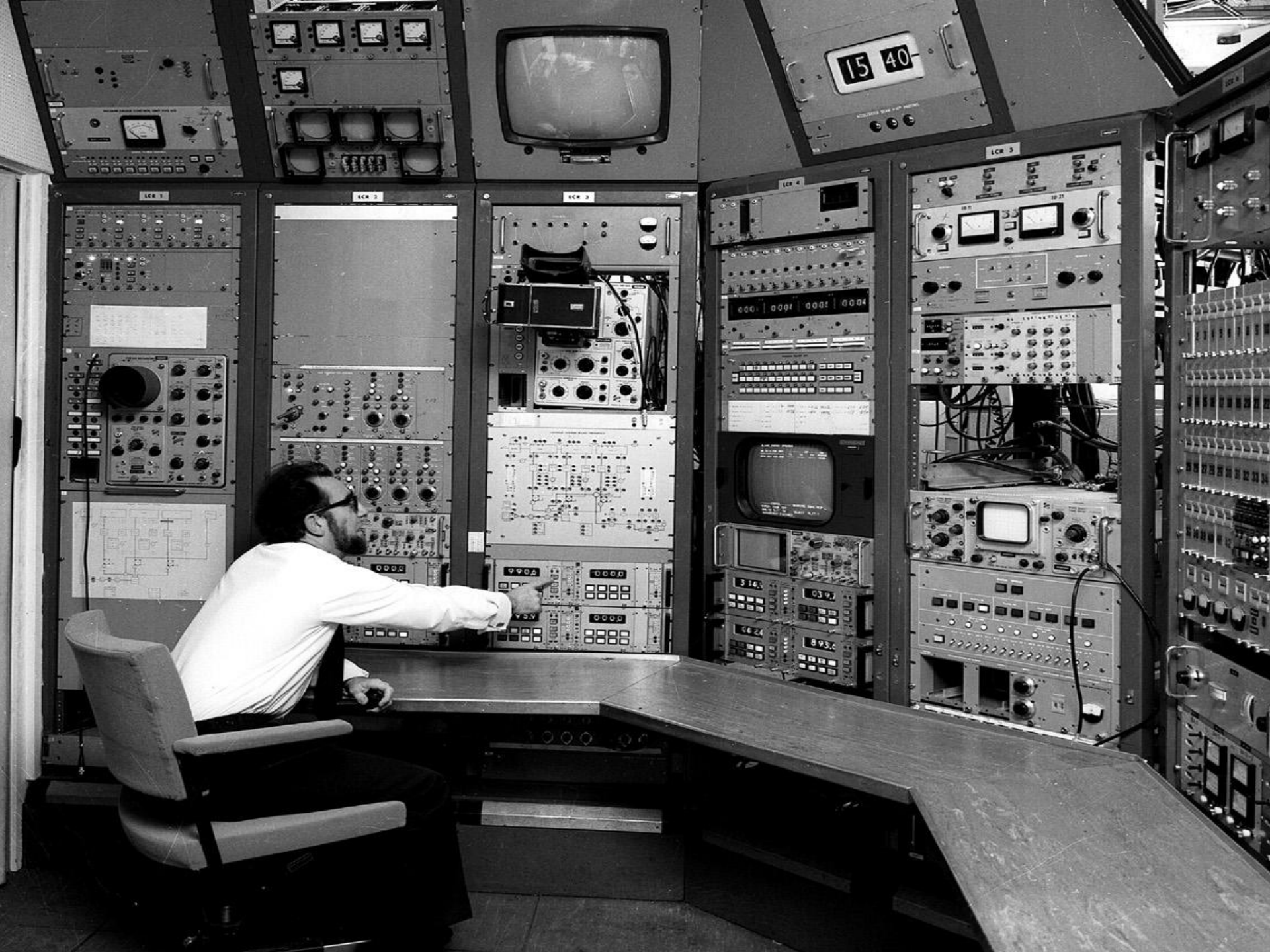




# Controls technology

- ...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

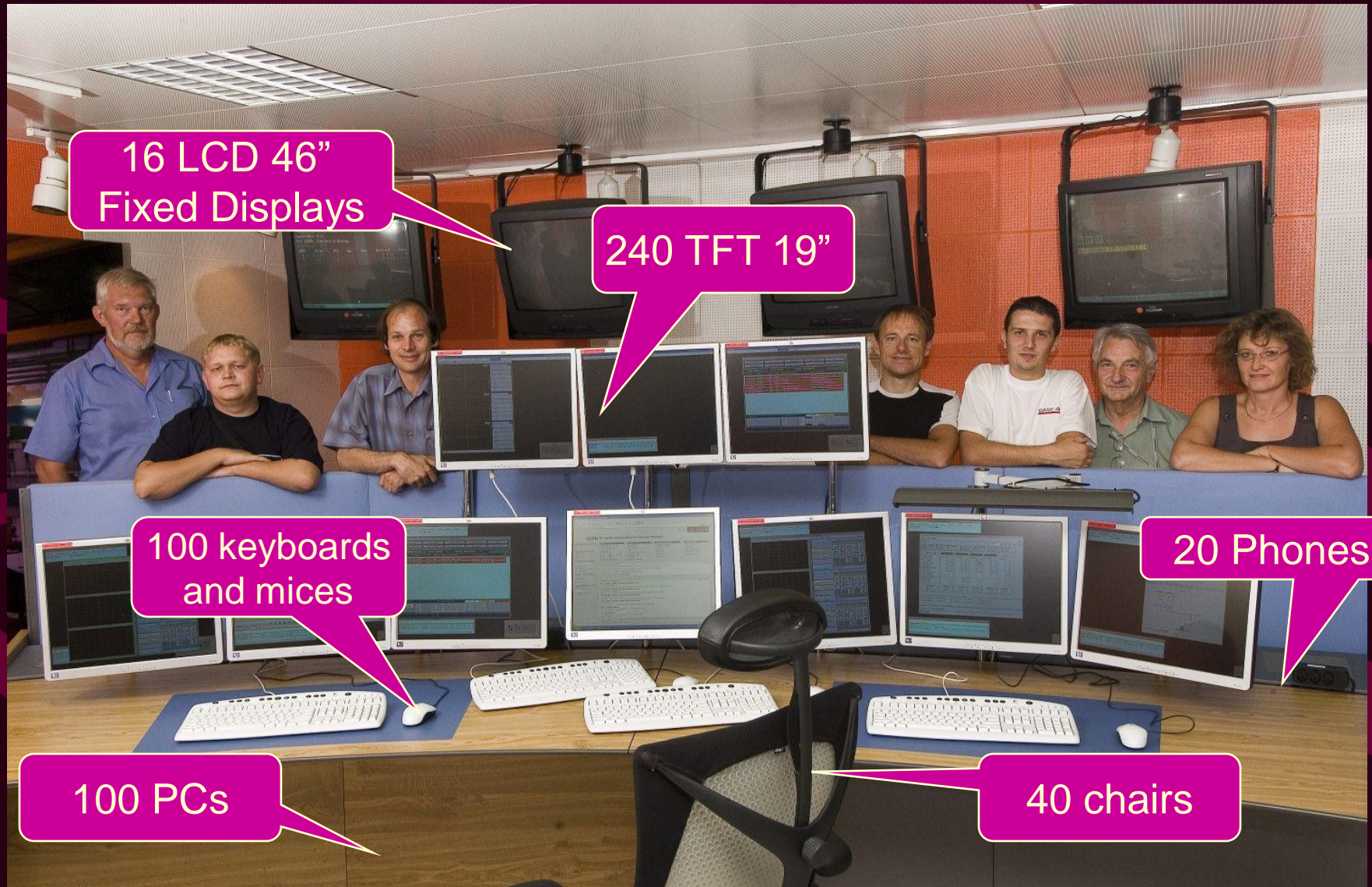
# The New CERN control center, ready spring 2006







# CCC (=CERN Control Center) Working Place



16 LCD 46"  
Fixed Displays

240 TFT 19"

100 keyboards  
and mices

20 Phones

100 PCs

40 chairs





# 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 interfaes, 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,
- 3-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)



...and an uncountable number of

The image displays a complex multi-window software interface for accelerator control. Key components include:

- Equipment Management:** Windows for 'Equip State' and 'Filtering on TIB' showing device names (MCIAS8260, MCIAS8320), status (OFF), and commands (READ\_TABLE, OCCURRENTS).
- Beam Control & Monitoring:** 'SPS Manual Trim V2.0-2004' windows for various sequences (S653v1, S954v3, S546v1) and 'SDDS logging monitor' for data recording.
- Optics & Diagnostics:** 'Optics display' section with 'SPS OPTICS DISPLAY' and 'BLM BPM' (Beam Loss Monitor / Beam Position Monitor) data.
- Data Visualization:** 'SDDS Default View' showing a 2D image of the beam spot, and several plots including a 'cycle selector' graph showing current vs. time, a 2D image plot, and two histograms.
- System Configuration:** 'Active Selection' window for 'SPSRING / S546v1 / SPS.USER.LHC546 : 0-20550 ms'.



# Technical Services

All we need even before thinking of injecting beam:

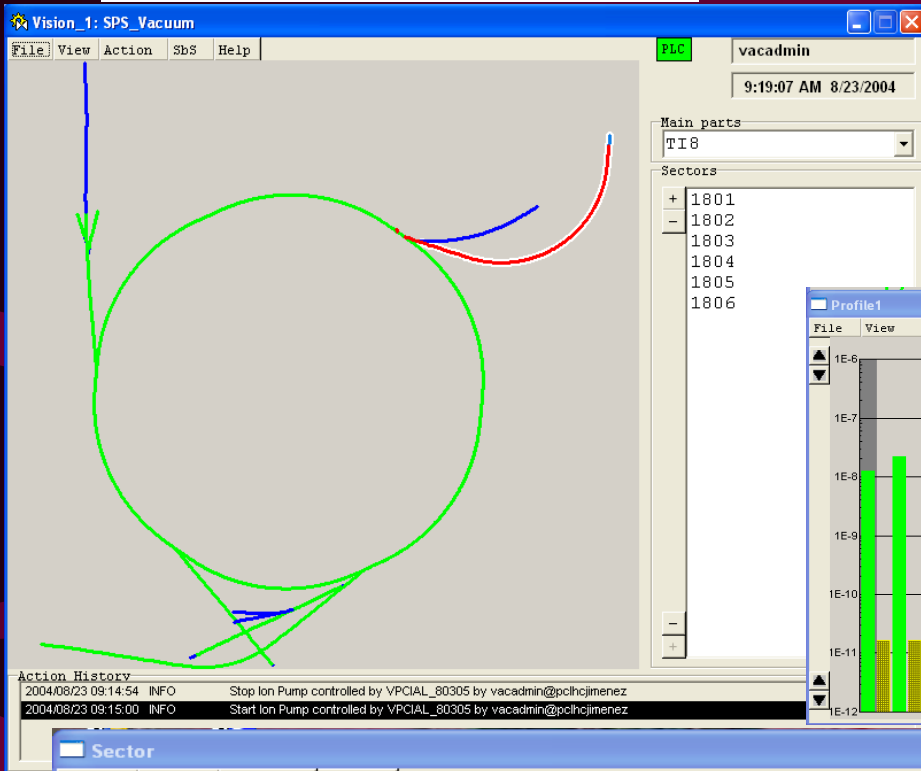
- Electrical supplies
- Uninterruptible Power Supplies (UPS),  
Arret Urgence Generale (AUG)
- Cooling & Ventilation
- Cryogenics systems
- Vacuum systems
- Access System (Personal Safety)
- Interlock Systems (Material Safety)  
i.e. powering interlocks, quench protection system
- General services  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



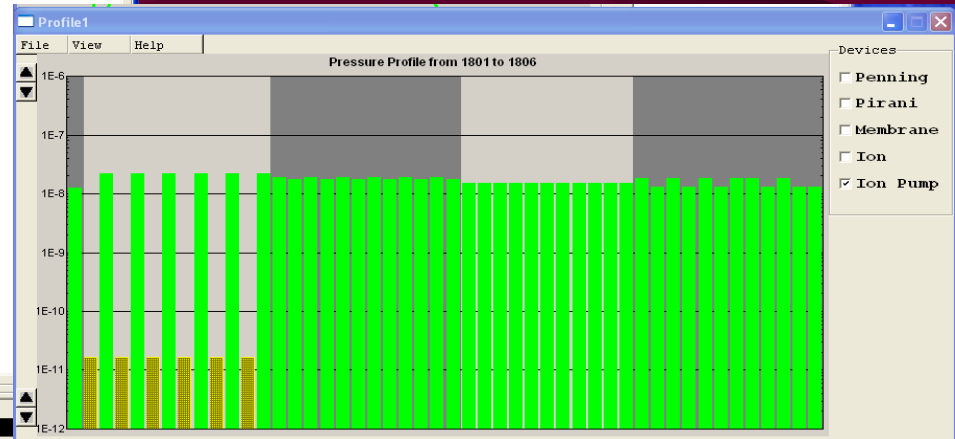


# The “look and feel” of all these systems example: vacuum system for LHC transfer line

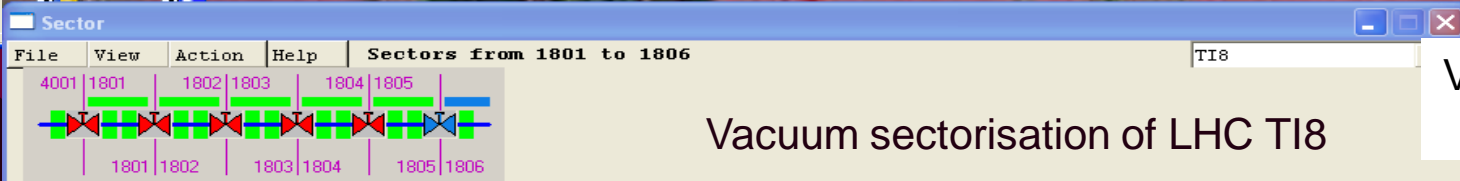
Synoptic of the SPS Complex



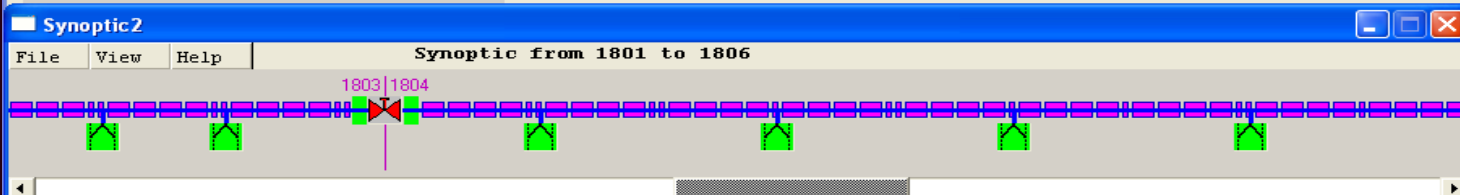
Pressure profile in LHC TI8



Vacuum sectorisation of LHC TI8

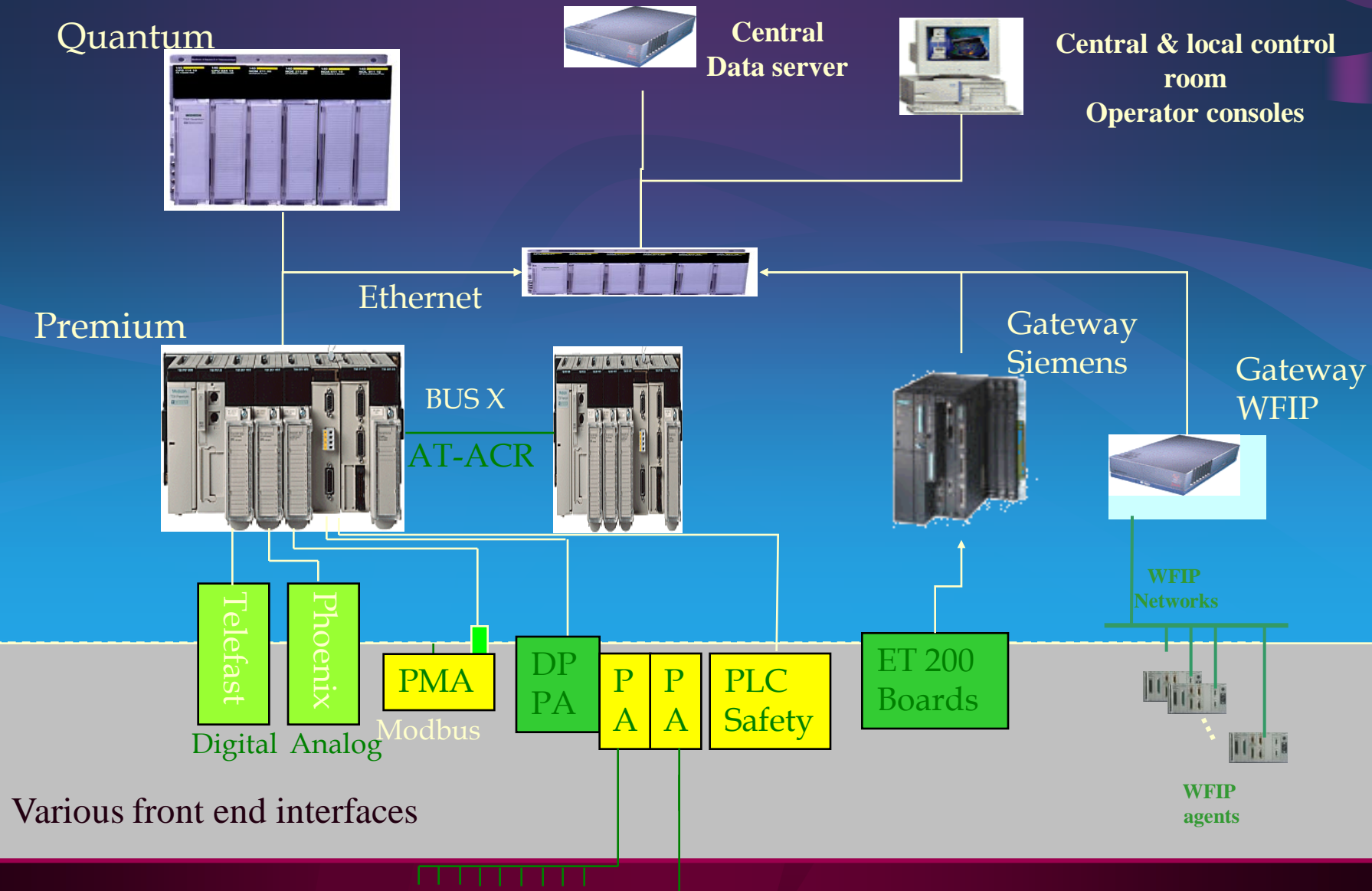


Vacuum layout of LHC TI8





# A typical implementation



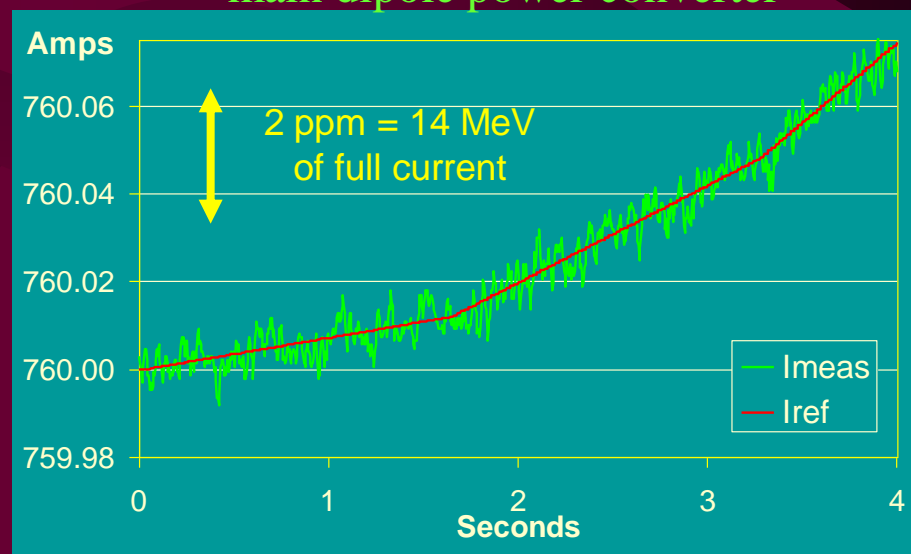


# Finally: Beam Control

- 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

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	HWName	Status	Command	Parameter	Value
BCT	M CIAH8260	OFF	[M] READ-TABLE		
BLM	M CIAH8320	OFF	[M] PCCURRENTS		
BPM	M CIAH8340	OFF	[R] DETAILED-STATUS		
BTV	M CIAH8400	OFF	[R] EVLIST		
MUGE F	M CIAH8420	OFF	[R] MAG-CONNECTION		
VIDEO_SWITCH	M CIAH8480	OFF	[R] READ-CHECK-FUNCT		
	M CIAH8500	OFF	[R] READ-POLARITY		
	M CIAH8560	OFF	[R] TEMPERATURE		
	M CIAH8580	OFF	[S] STATUS		
	M CIAH8640	OFF	[L] LOAD-FUNCT		
	M CIAH8660	OFF	[L] LOAD-ZERO-FUNCT		
	M CIAH8720	OFF	[L] LOAD-TEST-FUNCT		
	M CIAH8740	OFF	[W] CONNECT-MAG-1		
	M CIAV8010	OFF	[W] CONNECT-MAG-2		
	M CIAV8070	OFF	[W] HARD-INIT		
	M CIAV8130	OFF	[W] INIT-ACQ		
	M CIAV8150	OFF	[W] INIT-SOFTWARE		
	M CIAV8210	OFF			
	M CIAV8230	OFF			
	M CIAV8290	OFF			
	M CIAV8310	OFF			

Select All

Execute

Console

Running tasks

09:04:37 - Executing command STATUS on cycle S653v1.C1044.CO on MBI8160M-M, MBI8160M-M, MBIAV8110M, MBIBV8774M, M CIAH8020, M CIAH8080, M CIAH8100, M CIAH8160, M CIAH8180, M CIAH8240, M CIAH8260, M CIAH8320, M CIAH8340, M CIAH8400, M CIAH8420, M CIAH8480, M CIAH8500, M CIAH8560, M CIAH8580, M CIAH8640, M CIAH8660, M CIAH8720, M CIAH8740, M CIAV8010, M CIAV8070, M CIAV8130, M CIAV8150, M CIAV8210, M CIAV8230, M CIAV8290, M CIAV8310, M CIAV8370, M CIAV8390, M CIAV8450, M CIAV8470, M CIAV8530, M CIAV8550, M CIAV8610, M CIAV8630, M CIAV8690, M CIAV8710, M CIAV8770, M CIBH8040, M QID8010, M QID8030, M QID8710M, M QID8730, M QID8750, M QID8770, M QIF8020, M QIF8700M, M QIF8720, M QIF8740M, M QIF8760, M MSIB8813M

Executing command STATUS on cycle S653v1.C1044.CO on MBI8160M-M, MBI8160M-M, MBIAV8110M, MBIBV8774M, M CIAH8020, M CIAH8080, M CIAH8100, M CIAH8160, ...



# Generic Measurement

Equip State

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 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

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

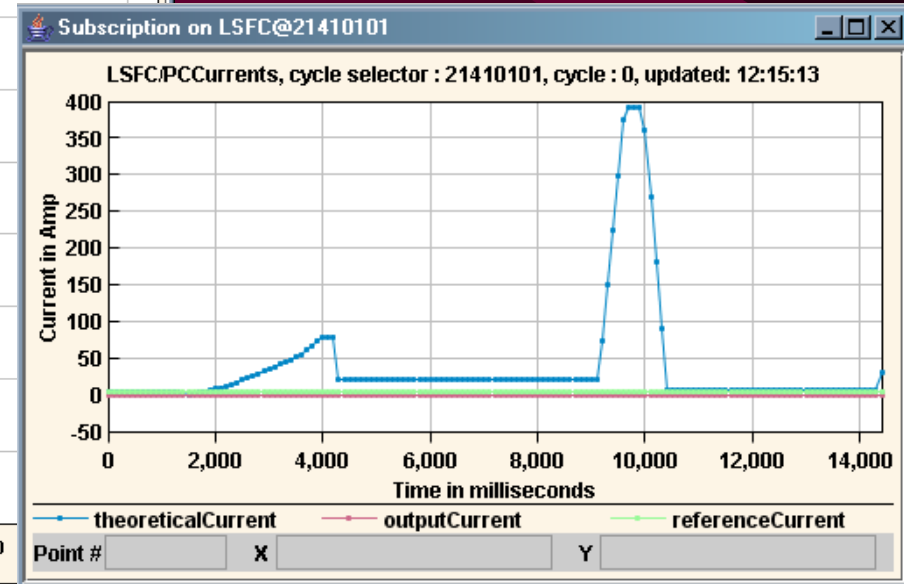
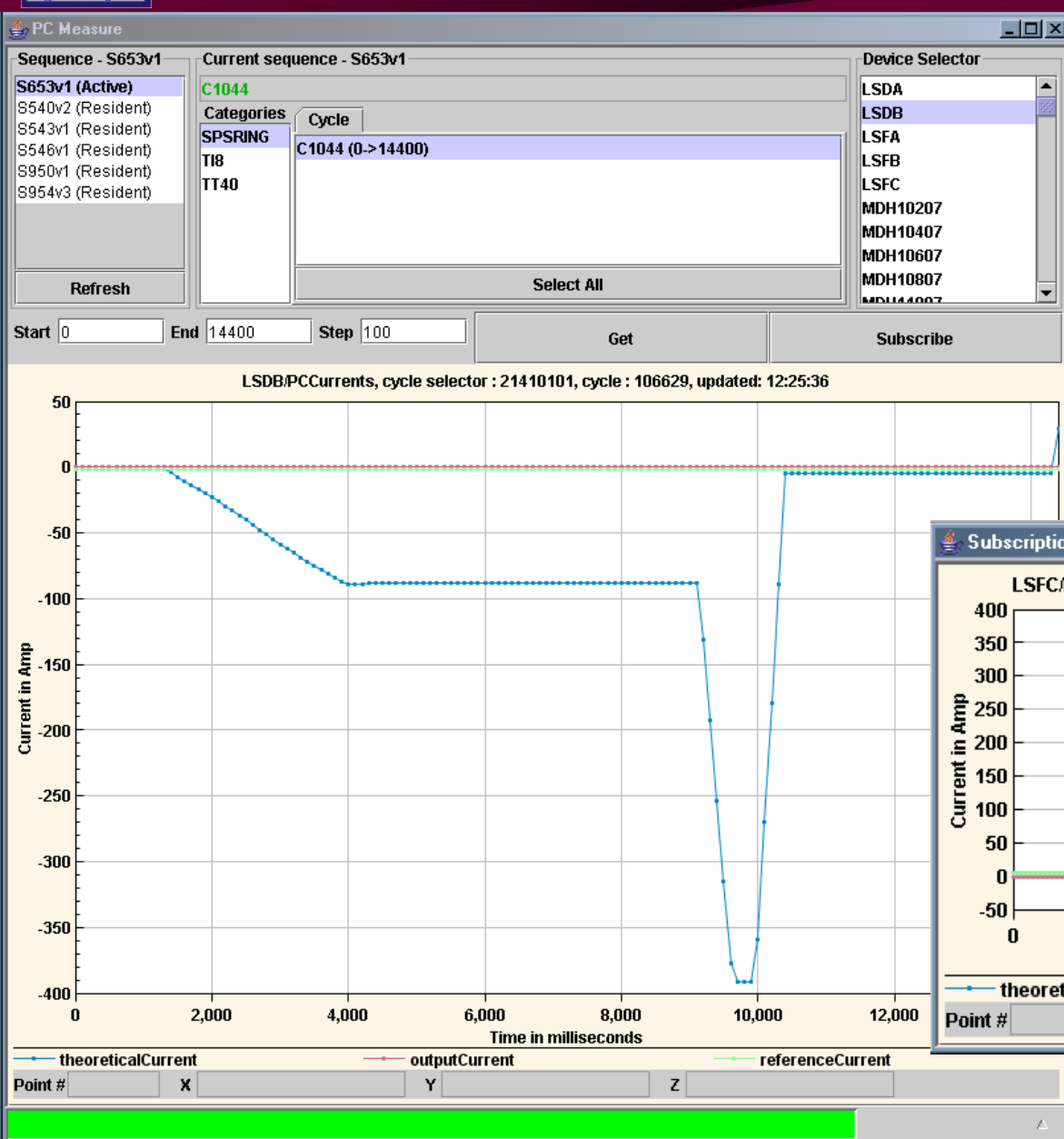
16:24:59 - Executing command PCCURRENTS on cycle

Executing command PCCURRENTS on cycle S653v1.C1044.C0 on



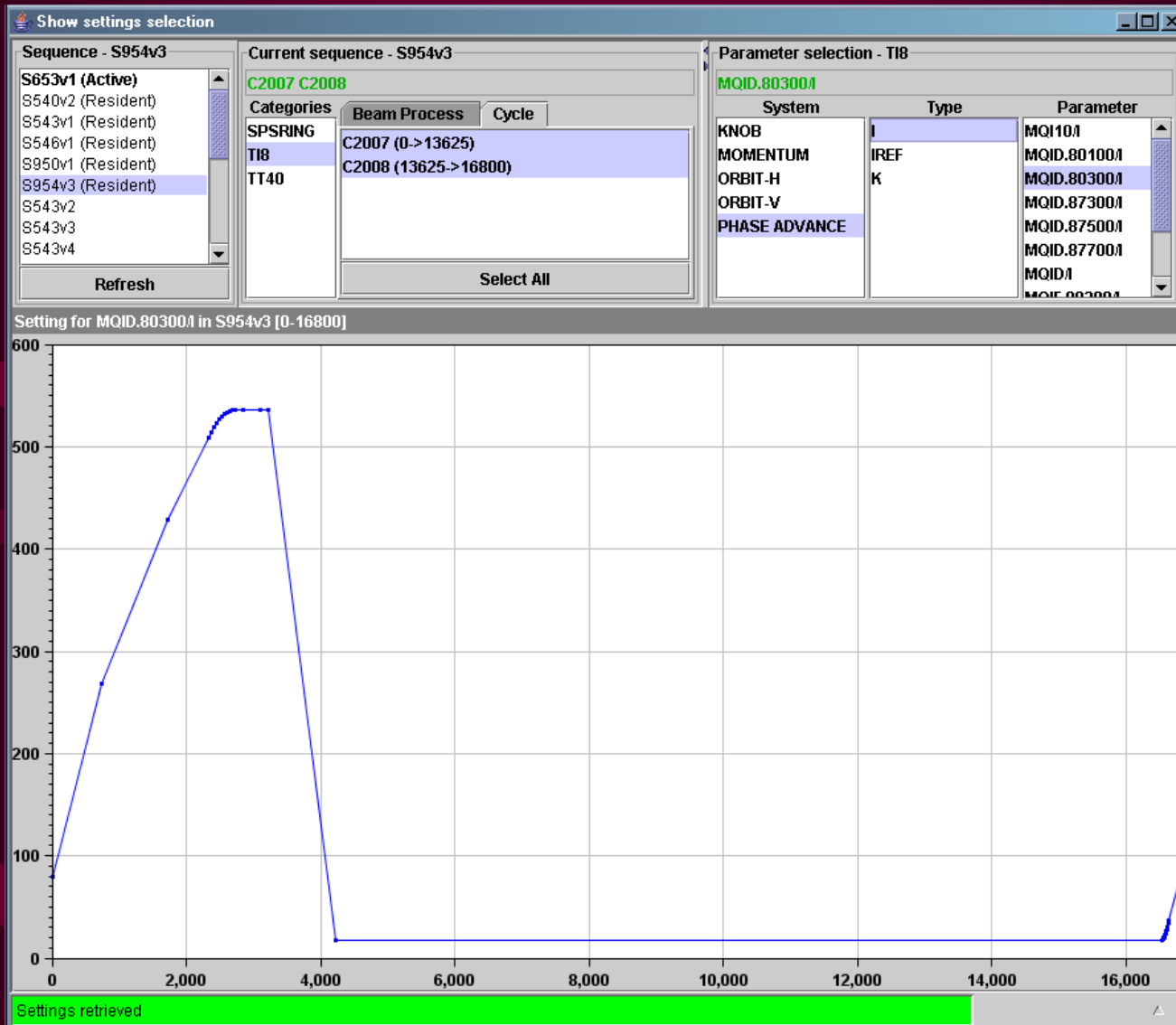


# Measurement of power converters





# 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)

Cycle

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

current reference

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

Current sequence - S546v1

TI8

Categories

- SPSRING
- TI8
- TT40

Beam Process

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

Refresh

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 @ MCAIV.85504 - f = 1.00
- 24-10-2004 @ 22:38:51 : Single kick @ MCAIV.85504 - f = 1.00
- 24-10-2004 @ 22:39:21 : Single kick @ MCAIV.85504 - f = 1.00

Load Add trim comment Quit

Views

S546v1.TI8.BP3->MCAIV.85504.K : 25/11/04 16:16:03

VALUE

- Trim
- Trim Point
- Abort
- Trim History
- Send to Hardware
- Undo last trim
- Ready

Ready



# 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

H Pos(um)

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

Monitor H

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

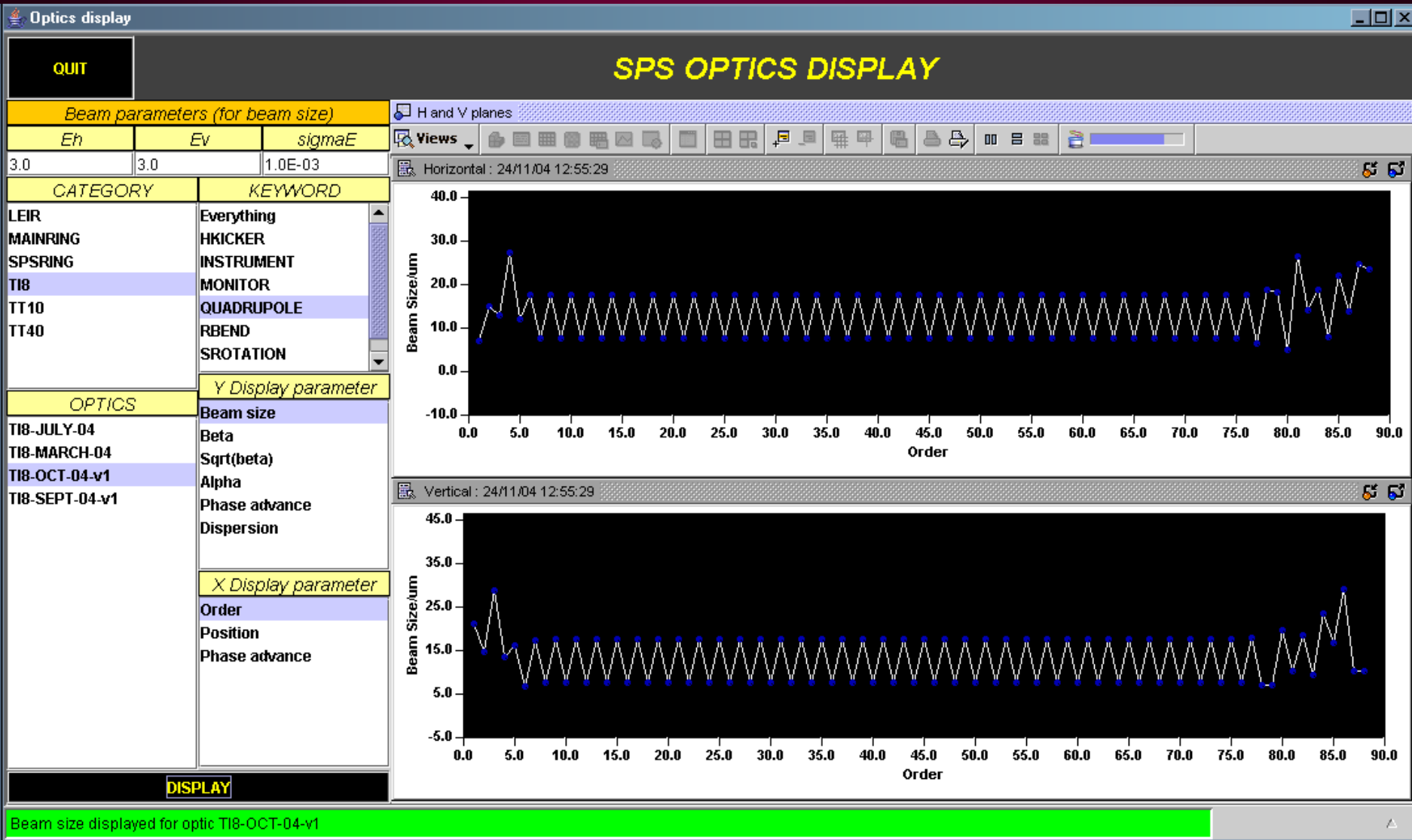
V Pos (um)

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

Monitor V



# Optics Display







# 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.japc.ParameterException: Error -132 : StartTime exceeds cycleLength
Caused by:
    cern.japc.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

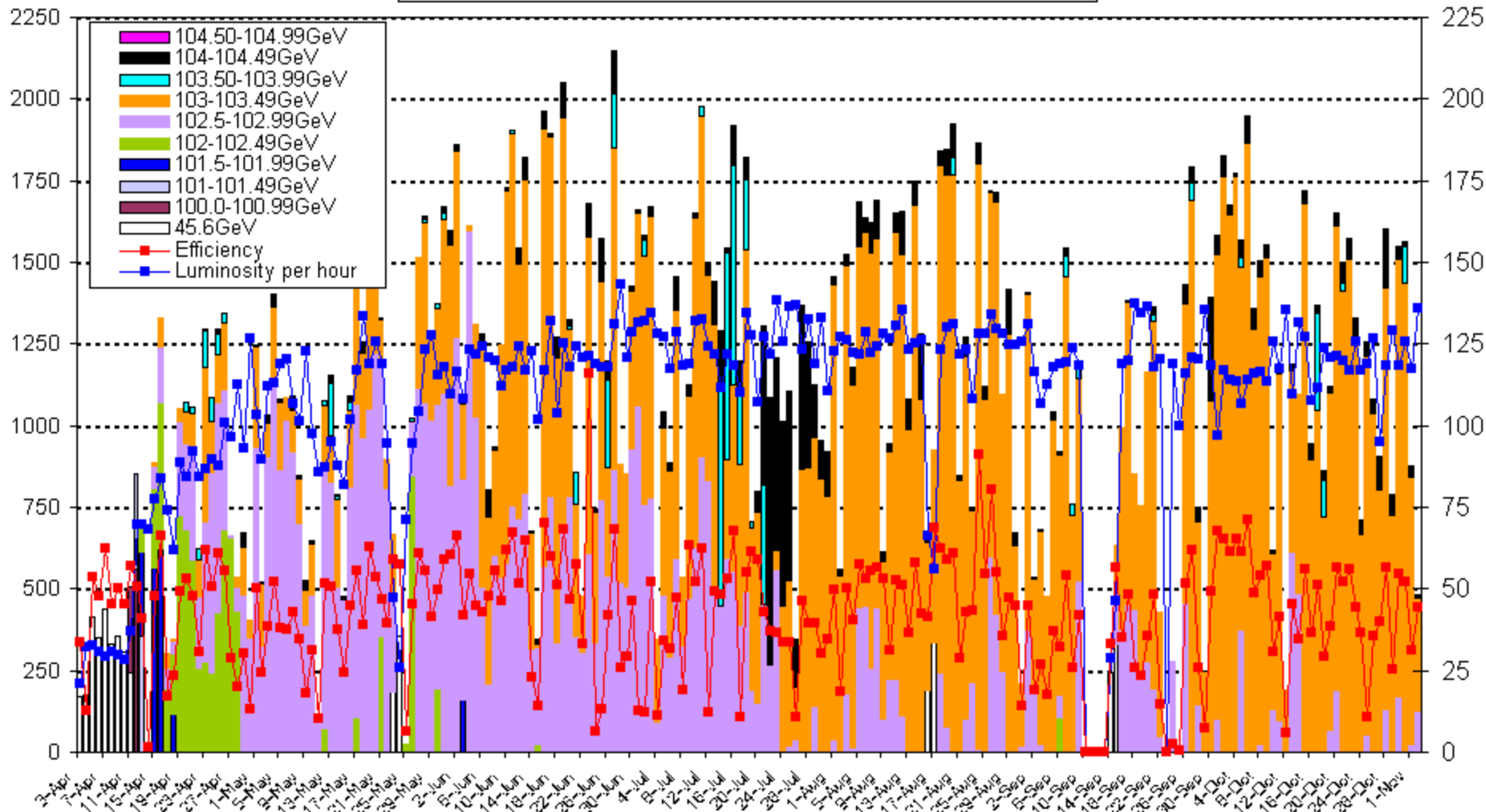


# Statistics

nb-1

Integrated luminosity per day in 2000

nb-1/hour & %



Data hauled from database automatically at end of fill



# Retrieval of archived measurements

The screenshot displays 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.ClassGlobalCommaactionList.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 main pane displays a list of files, each named "BTVI\_LSS4.41831#getImage" followed by a date and time stamp and a ".sdds" extension. The files are arranged in three columns, showing a chronological sequence from 09\_48\_47 to 10\_32\_52.



# Browser & Viewer

SDDS Browser

File Options

SDDS root directory: \\hpdepotopdata4\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

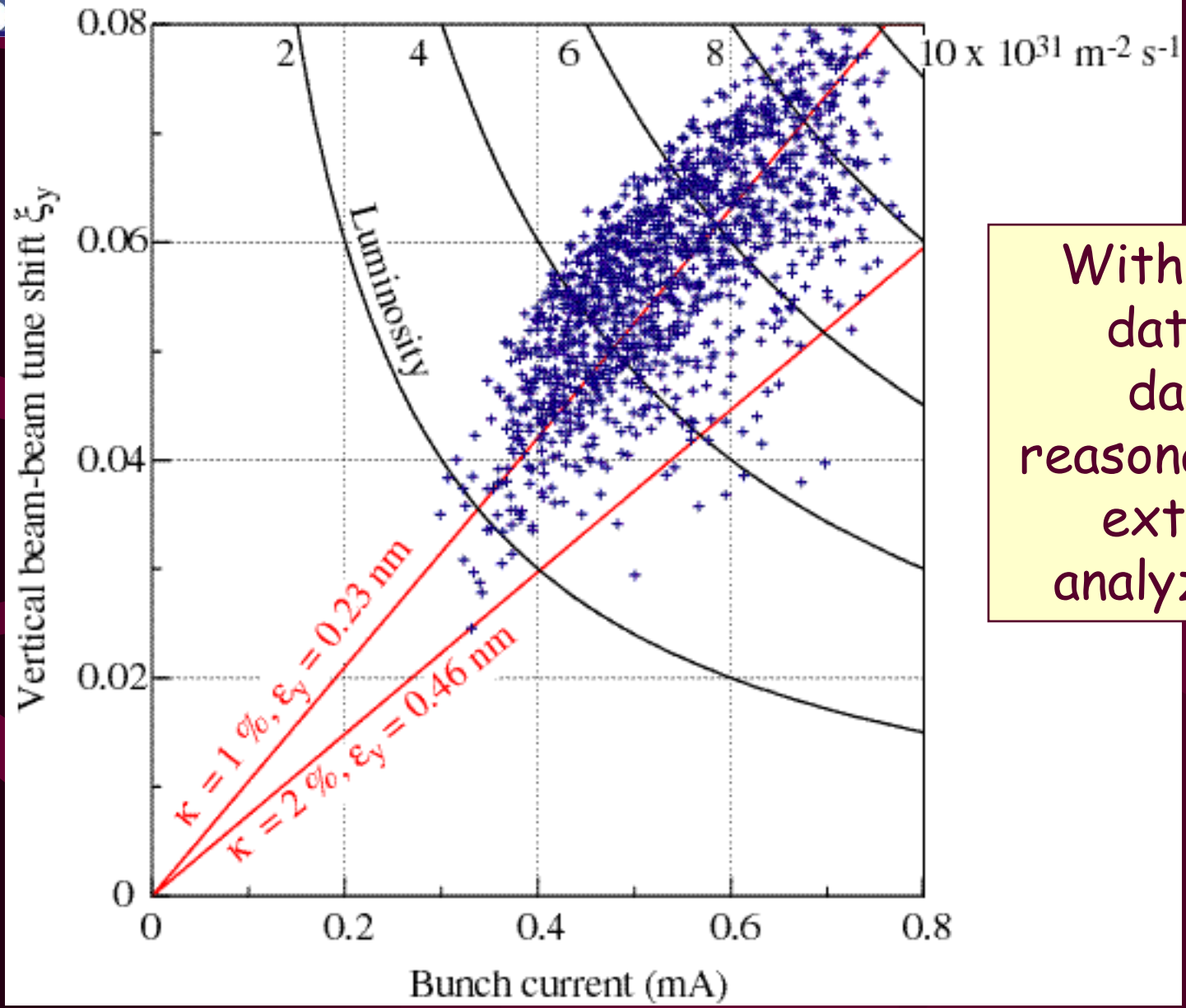
BTVI\_T18.84404 @ Cycle sdds.19:19:56 Update 13:07:48 925

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





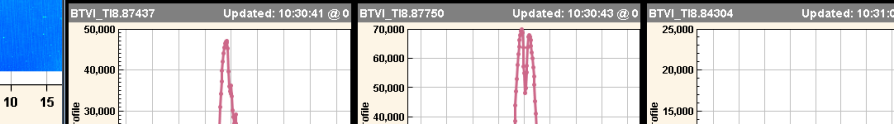
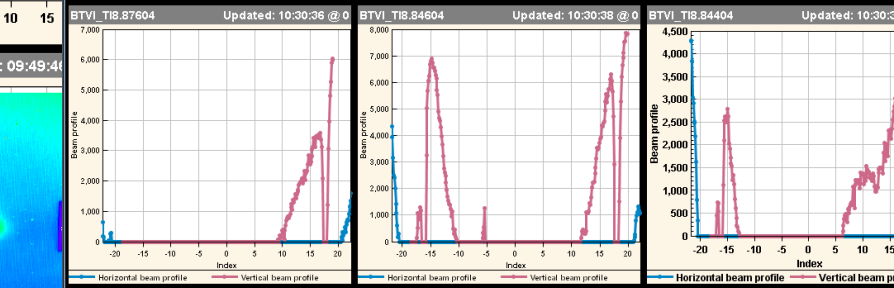
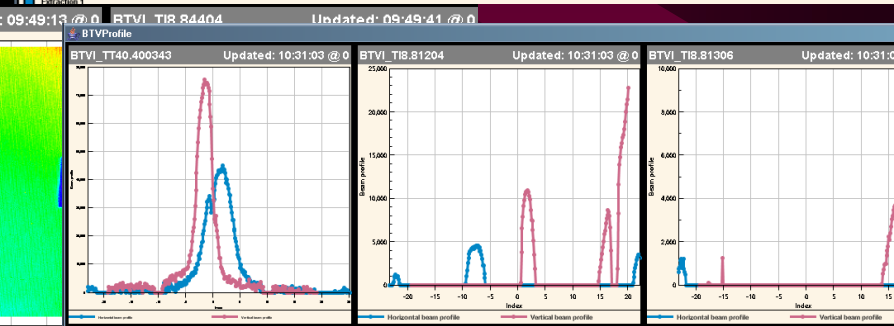
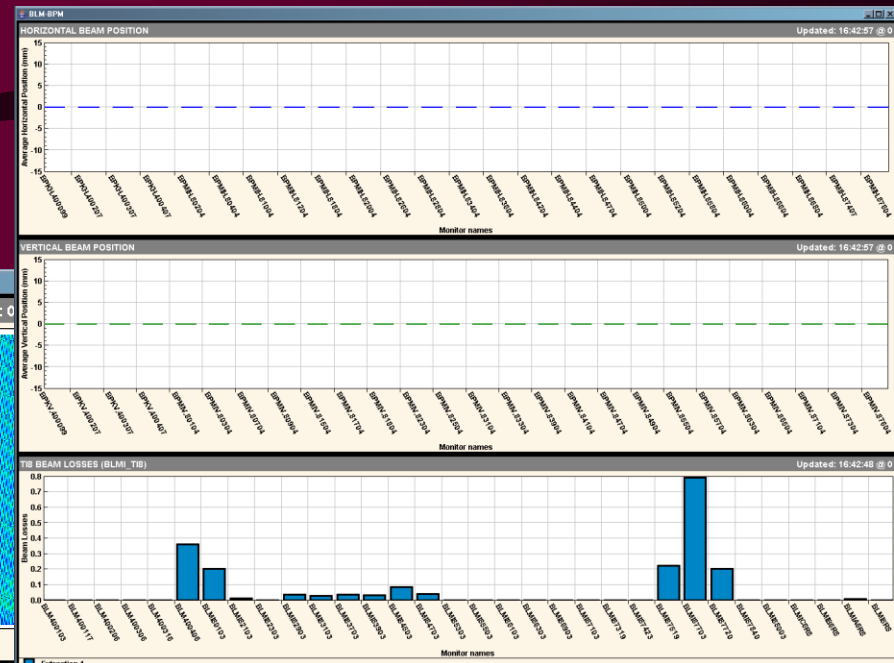
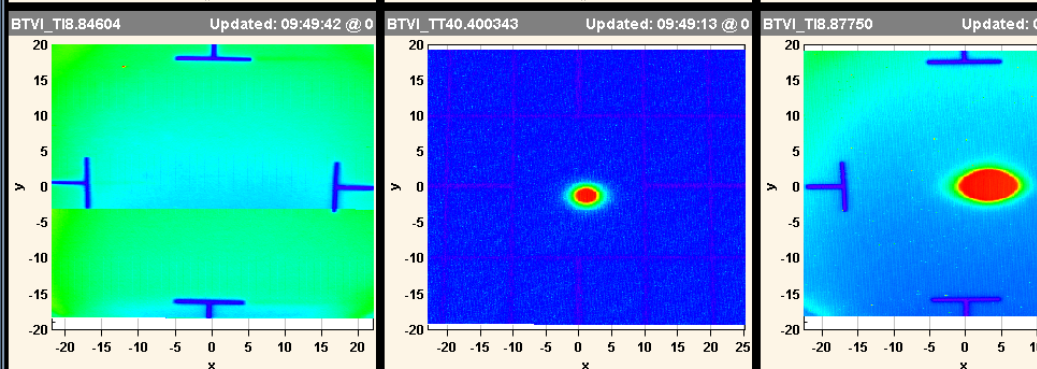
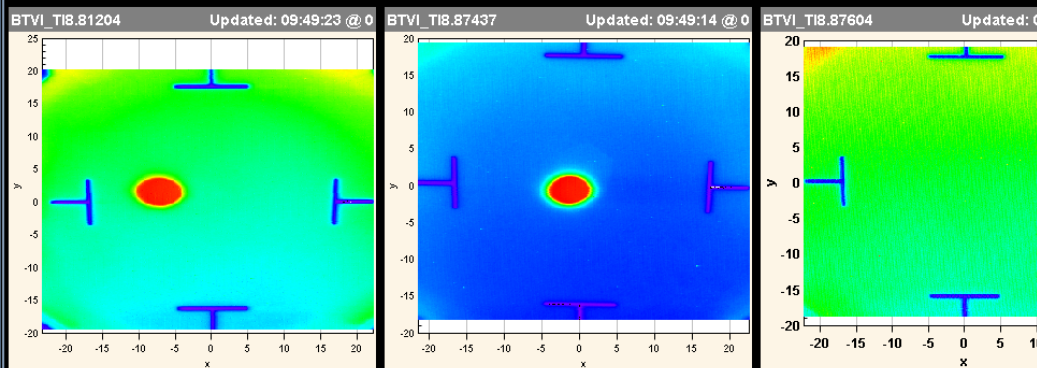
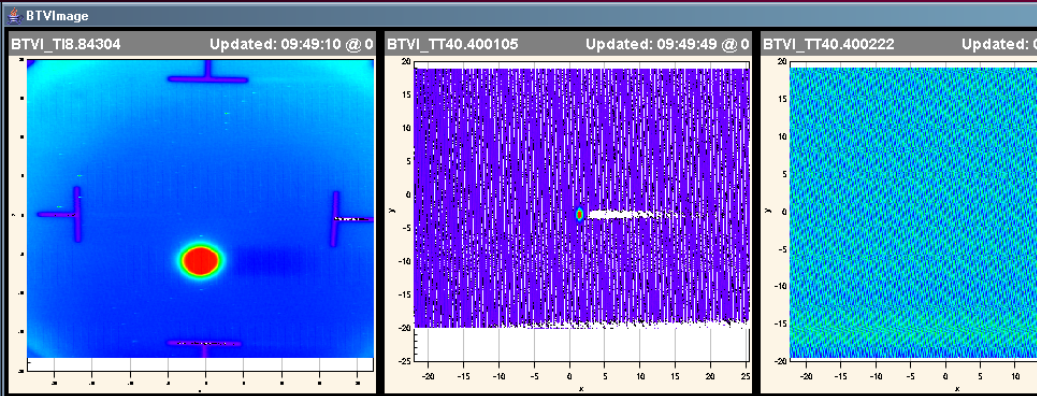
# Dedicated Video (FAST) Signals (LEP)



Data sampled at slower rate  
 → logging database



# Fixed Displays Large screens in CCC)





# Now we take a closer look:

## Ex: Settings generation for the main bend MB

- warm magnets:

- 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) Magnetic Model (or calibration curve) refined by momentum measurement in receiving machine
- 6) Other cycle history handled as trim and rollback utility (i.e. “cold machine after shutdown”, “warm machine after 1 day of permanent operation”)

- cold magnets:

things are more complicated...next slides



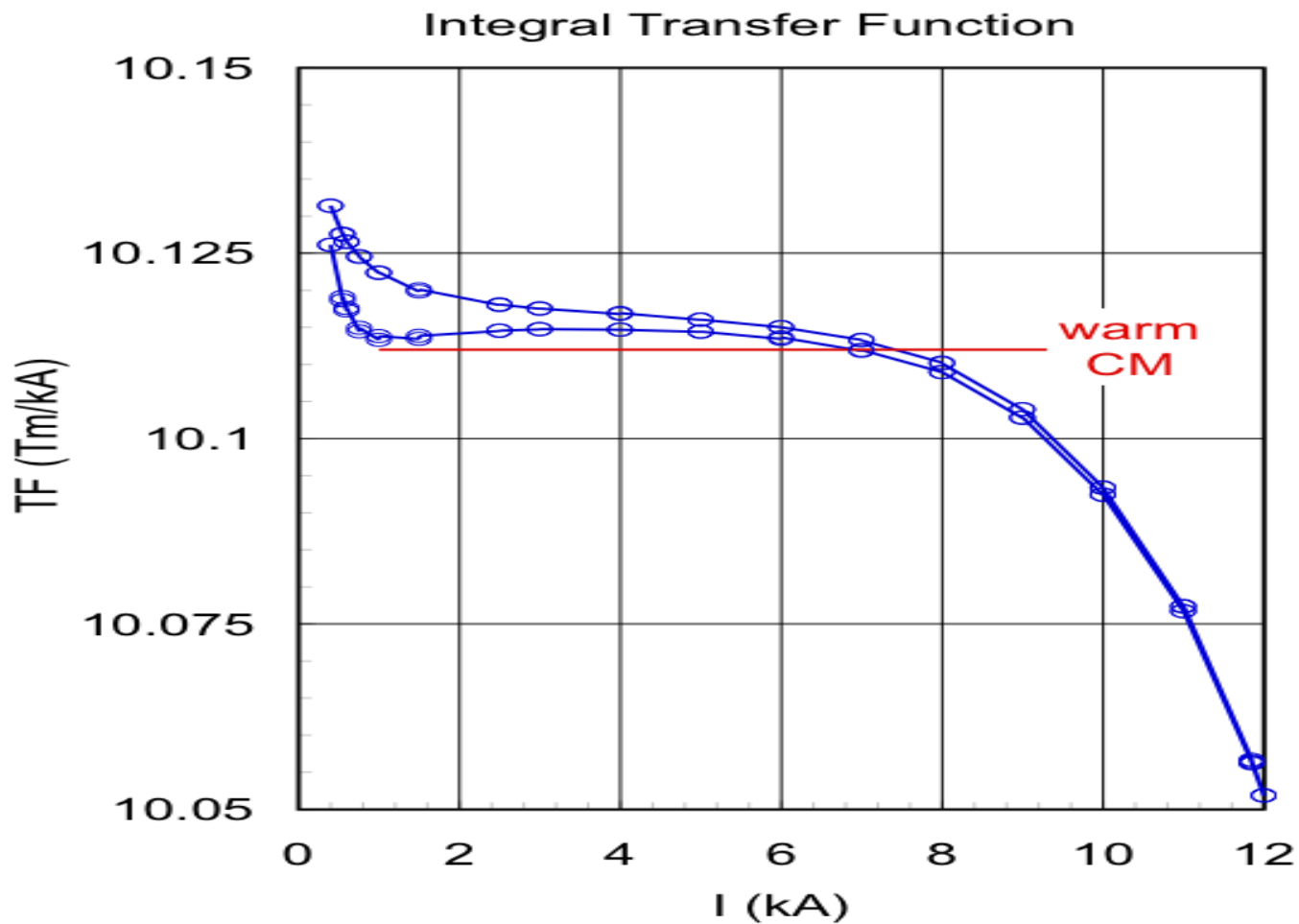


# Available data for LHC magnets

- warm measurements on the production:
  - all (superconducting) MB, MQ, MQM, MQY:
    - main field integral strength
    - higher order geometric harmonics
  - all (superconducting) MBX, MBR<sub>x</sub>, MQX<sub>x</sub>
  - **warm measurement on MQTL so far at CERN**
  - most (superconducting) lattice corrector and spool pieces (about 90% of data available)
  - all (warm) MQW
  - a sample (5 to 10) of other warm insertion magnets (MBXW, ... measured at the manufacturer before delivery)
- at the present rate, cold measurements on:
  - $\approx 20\%$  of MB and  $\approx 20\%$  of 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
  - $\approx 75\%$  of MBX, MBR<sub>x</sub>
  - 100% of MQX<sub>x</sub> (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 - 1/5

- Determine the current  $I$  in the MB to obtain a given integrated field  $B \, dl$  over the sector (as specified by LHC control system). Algorithm:

*only if cold data is missing*

→ retrieve warm transfer function  $TF_W^M$  for each magnet in the sector

→ apply warm-cold scaling  $f_{TF}$  and offset  $\Delta_{TF}(I)$  and obtain the cold transfer function  $TF_C^M$

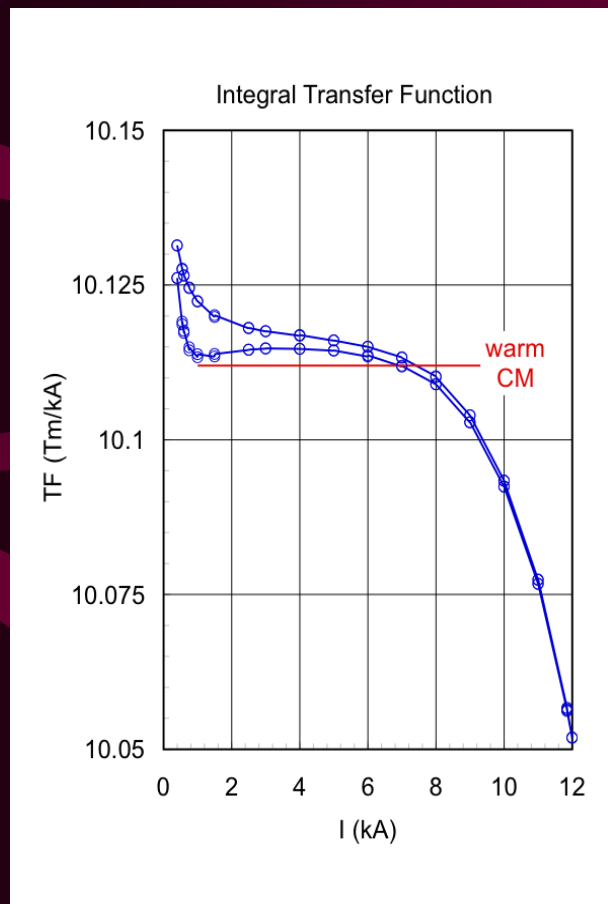
$$TF_C^M(I) = f_{TF} TF_W^M + \Delta_{TF}(I)$$

→ integrate the  $TF_C^M$  over the sector

$$TF_C(I) = \sum_M TF_C^M(I)$$

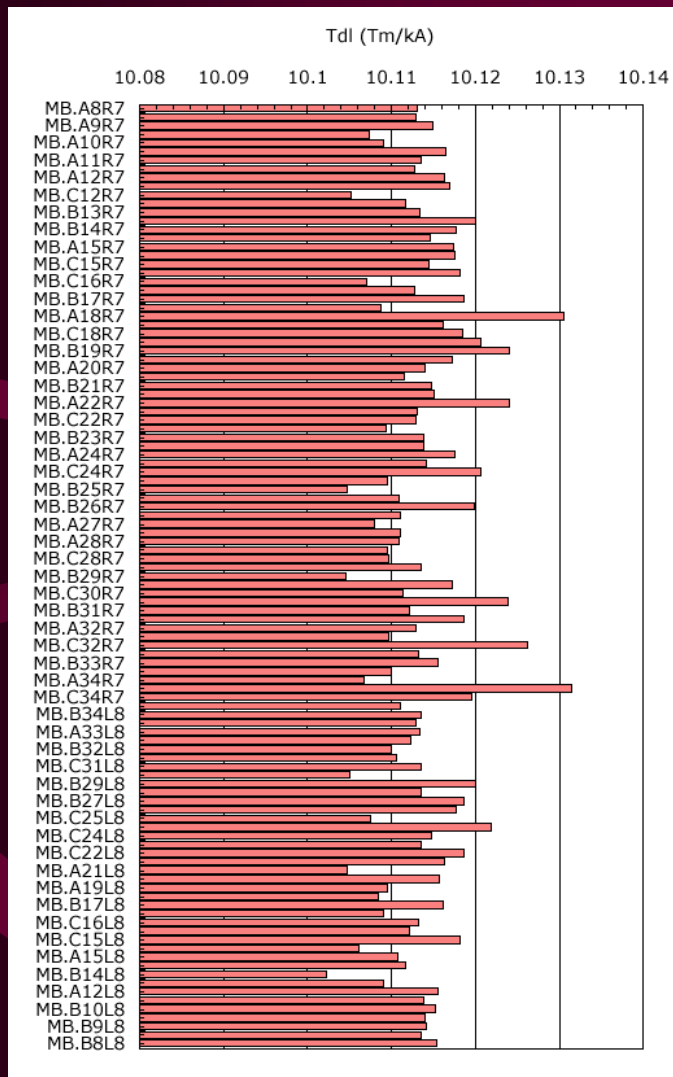
→ compute the current by inversion of the (non-linear)  $TF_C$

$$I = (TF_C(I))^{-1} B \, dl$$





# MB Injection settings - 2/5



- Warm and cold magnetic data is stored in a database containing separate entries for:
  - warm data
  - cold data
    - injection
    - flat-top
  - warm/cold offsets
    - injection
    - flat-top
  - components in cold conditions
    - geometric
    - persistent currents
    - decay and snap-back
    - saturation

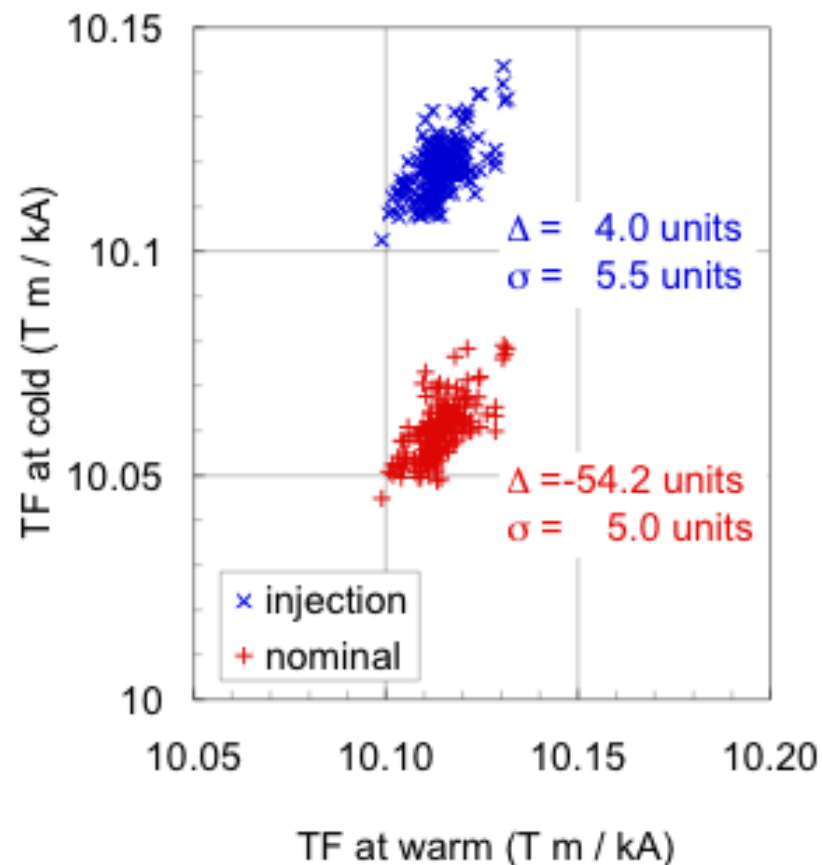


# MB injection settings - 3/5

- warm/cold correlation based on production accumulated so far.
- computed in July 2004 on approximately 100 magnets
- offsets are stable, standard deviation acceptable and comparable with expected measurement accuracy

$$f_{TF} = 1.00 \text{ (-)}$$

$$\Delta_{TF} = 5.5(6) \text{ (mT m/kA)}$$







# MB injection settings - 4/5

NAME	FUNCTION	Polarity	Magnet
LQTAC.7R7	Q7R7	V1F/V2D	
LBARA.8R7	A		3026
LBBRB.8R7	B		1031
LQTBB.8R7	Q8R7	V1D/V2F	
LBARA.9R7	A		3050
LBBRC.9R7	B		1044
LQTEC.9R7	Q9R7	V1F/V2D	
LBARA.10R7	A		1052
LBBRB.10R7	B		1032
LQTBB.10R7	Q10R7	V1D/V2F	
LBARA.11R7	A		3022
LBBRA.11R7	B		1034
LQTCH.11R7	Q11R7	V1F/V2D	
LBARA.12R7	A		2018
LBBRA.12R7	B		1010
LBARB.12R7	C		2039
LQATH.12R7	Q12R7	V1D/V2F	
LBBRA.13R7	A		3041
LBARA.13R7	B		1013
LBBRC.13R7	C		
LQATM.13R7	Q13R7	V1F/V2D	
LBARA.14R7	A		3030
LBBRA.14R7	B		1004
LBARB.14R7	C		2015
LQATH.14R7	Q14R7	V1D/V2F	
LBBRA.15R7	A		3020
LBARA.15R7	B		3010
LBBRC.15R7	C		1022
LQATQ.15R7	Q15R7	V1F/V2D	
LBARA.16R7	A		
LBBRA.16R7	B		1008
LBARB.16R7	C		3028
LQATH.16R7	Q16R7	V1D/V2F	
LBBRA.17R7	A		2008
LBARA.17R7	B		3055
LBBRC.17R7	C		1035
LQATM.17R7	Q17R7	V1F/V2D	
LBARA.18R7	A		3006
LBBRA.18R7	B		1021
LBARB.18R7	C		2029
LQATH.18R7	Q18R7	V1D/V2F	
LBBRA.19R7	A		2004
LBARA.19R7	B		1045
LBBRC.19R7	C		2009
LQATQ.19R7	Q19R7	V1F/V2D	
LBARA.20R7	A		3054
LBBRA.20R7	B		2002
LBARB.20R7	C		3043
LQATH.20R7	Q20R7	V1D/V2F	
LBBRA.21R7	A		3014
LBARA.21R7	B		1012
LBBRC.21R7	C		1024

LQATM.21R7	Q21R7	V1F/V2D	
LBARA.22R7	A		3007
LBBRA.22R7	B		1023
LBARB.22R7	C		2020
LQOAG.22R7	Q22R7	V1D/V2F	
LBBRA.23R7	A		3042
LBARA.23R7	B		1014
LBBRC.23R7	C		1038
LQASE.23R7	Q23R7		
LBARA.24R7	A		
LBBRA.24R7	B		
LBARB.24R7	C		
LQOAG.24R7	Q24R7		
LBBRA.25R7	A		
LBARA.25R7	B		
LBBRC.25R7	C		
LQOAR.25R7	Q25R7		
LBARA.26R7	A		
LBBRA.26R7	B		
LBARB.26R7	C		
LQOAG.26R7	Q26R7		
LBBRA.27R7	A		
LBARA.27R7	B		
LBBRC.27R7	C		
LQASE.27R7	Q27R7		
LBARA.28R7	A		
LBBRA.28R7	B		
LBARB.28R7	C		
LQOAG.28R7	Q28R7		
LBBRA.29R7	A		
LBARA.29R7	B		
LBBRC.29R7	C		
LQOBF.29R7	Q29R7		
LBARA.30R7	A		
LBBRA.30R7	B		
LBARB.30R7	C		
LQOAM.30R7	Q30R7		
LBBRA.31R7	A		
LBARA.31R7	B		
LBBRC.31R7	C		
LQOAV.31R7	Q31R7		
LBARA.32R7	A		
LBBRA.32R7	B		
LBARB.32R7	C		
LQOAG.32R7	Q32R7		
LBBRA.33R7	A		
LBARA.33R7	B		3023
LBBRC.33R7	C		2041
LQOBJ.33R7	Q33R7	V1F/V2D	
LBARA.34R7	A		2016
LBBRA.34R7	B		1003
LBARB.34R7	C		3025
LQOAM.34R7	Q34R7	V1D/V2F	

LBBRA.34L8	C		1025
LBARA.34L8	B		2017
LBBRC.34L8	A		3005
LQOBF.33L8	Q33L8	V1F/V2D	
LBARA.33L8	C		3021
LBBRA.33L8	B		2050
LBARB.33L8	A		2523
LQOAM.33L8	Q33L8	V1D/V2F	

LBBRA.21L8	B		2007
LBARB.21L8	A		2036
LQATH.20L8	Q20L8	V1D/V2F	
LBBRA.20L8	C		1015
LBARA.20L8	B		2028
LBBRD.20L8	A		2003
LQATO.19L8	Q19L8	V1F/V2D	
LBARA.19L8	C		1011
			3061
			1036
			3012
			2042
			2006
			2056
			3003
			3063
			3009
			2014
			3058
			3018
			2031
			3038
			3065
			3002
			3029
			1017
			1133
			3034
			3066
			3019
			3053
			1030
			3062
			3036
LBBRF.9L8	A		
LQNCB.8L8	Q8L8	V1D/V2F	
LBARE.8L8	B		3051
LBBRI.8L8	A		3016
LQNF1.7L8	Q7L8	V1F/V2D	

- The magnet installation sequence is determined at the Magnet Evaluation Board (MEB), based on constraints on:
  - geometry
  - field quality
  - other (quench, non-conformities, ...)
- The information is collected in an installation map, recorded in the Manufacturing and Test Folder (MTF)

We know which magnet is where we can build integral field information



# MB injection settings - 5/5

- average transfer function at injection for sector 78 (extrapolated from 109/154 magnets allocated)
- warm/cold extrapolation for 44/109 magnets (65 cold measured)

$$TF_1 = 10.117(5) \text{ (T m/kA)}$$

$$TF_2 = 10.117(1) \text{ (T m/kA)}$$

- current in sector 78 for an injection at 450 GeV from SPS (1189.2 T m)

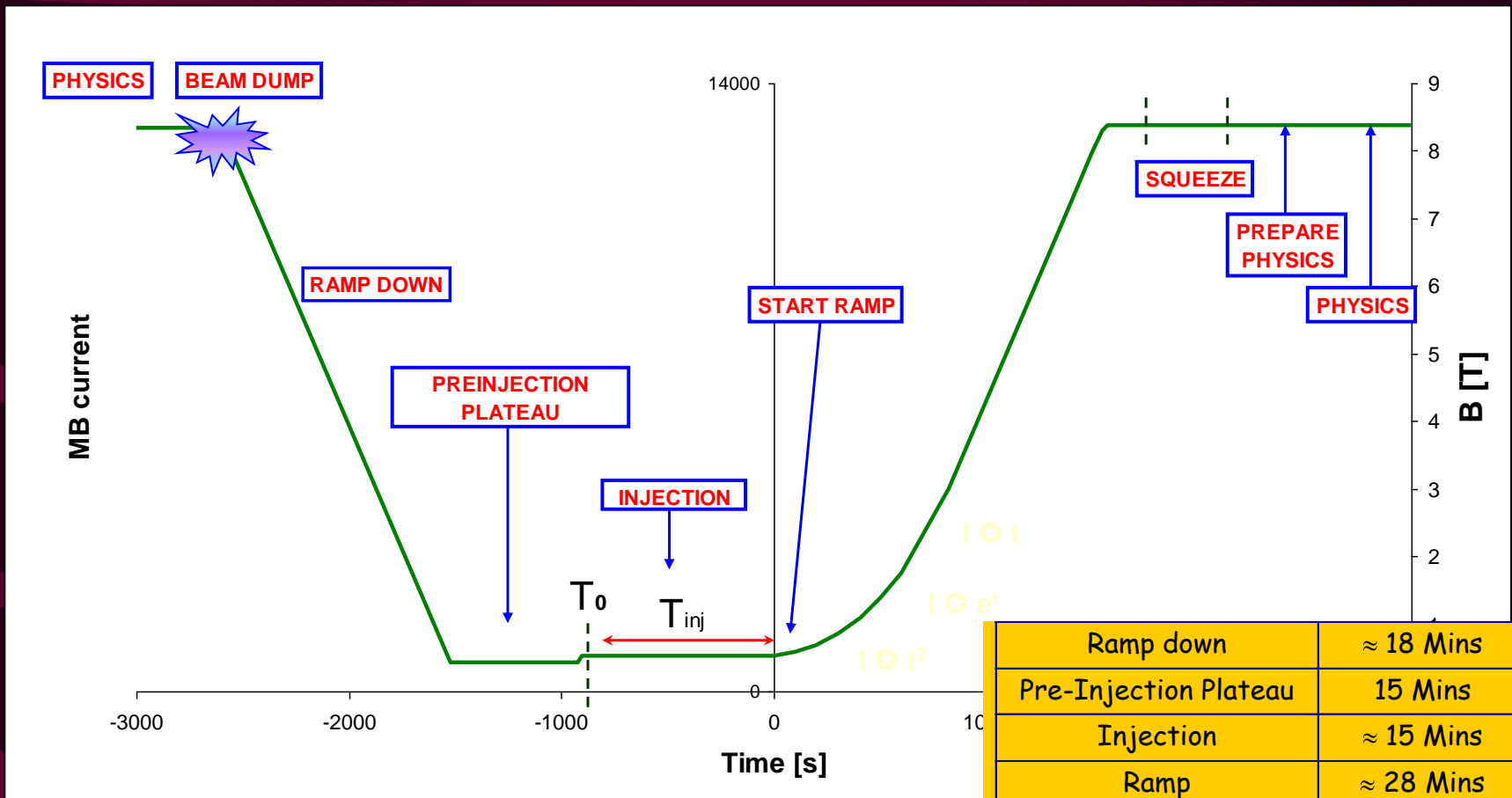
$$I = 763.2(5) \text{ A}$$

= this corresponds to step 1 in the discussed sequence

The Control system has to help generating these settings and then stores this setting and makes it available for trimming



# ...and now we have to accelerate 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



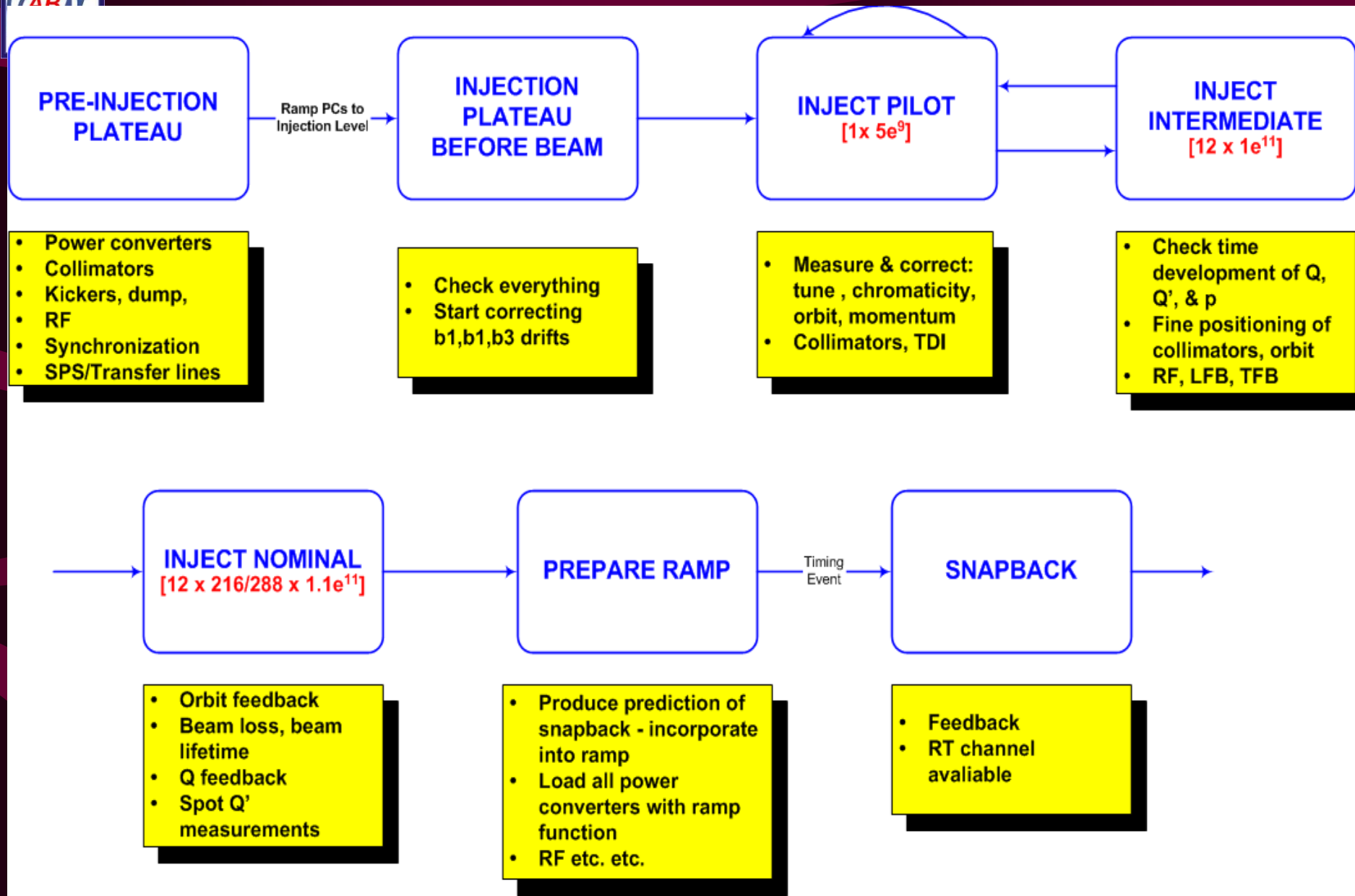
## Semi-automatic sequencer for LEP

- Reproducibility
- Reduced scope for error

Action	V	Func	
Run		***** CHANGE MODE TO	
Run		Load RF GVC Cds Data	
Run		Put PCs to IDLE	
Run		Fire Beam Dump (Please Do This)	test2
Run		Reset Beam Dump Interlocks	test2
Run		Turn WIGGLERS ON (new & improved)	test2
Run		Set QSC di/dt to 4 A/s	test2
Run		Set QSCs to 300A (slowly)	test2
Run		Degauss Magnets	test2
Run		Switch on GVC	test2
Run		Download RF Ramp	test2
Run		Set GVC vector	test2
Run		Enable GVC for RAMP	test2
Run		Disable Automatic RF unit Switch ON	test2
Run		Disable Automatic RF Setpoints	test2
Run		Create Breakpoint Settings	test2
Run		Mini Initialise ZLs (quick)	test2

Step   Run   STOP

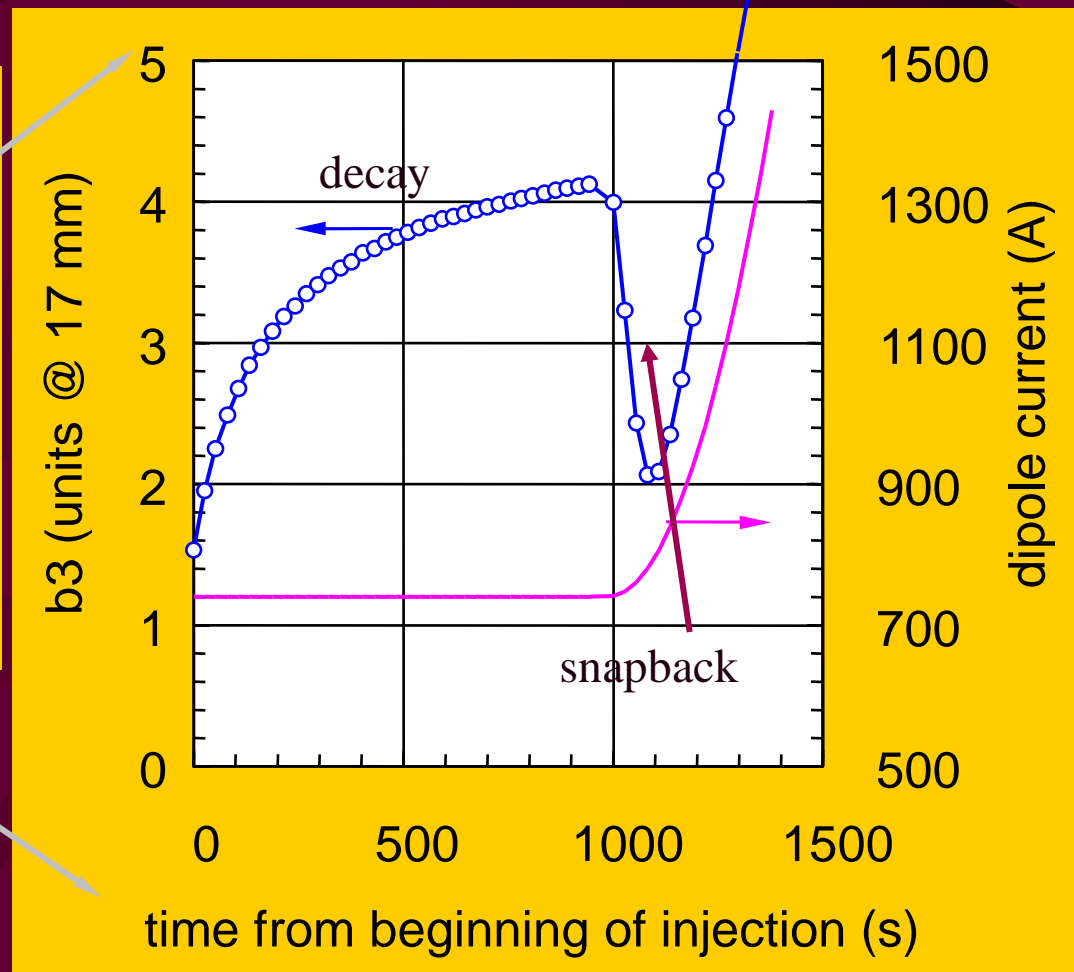
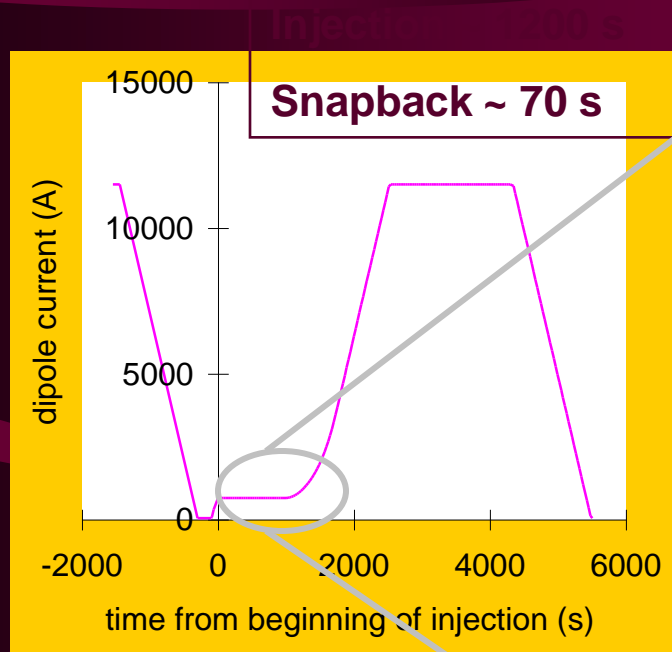
Typical turn-around: ~ 45 minutes







# The most frightening problem...



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



# Chromaticity

- The measured chromaticity is the sum of:

$$Q'_{total} = Q'_{meas} = Q'_{natural} + Q'_{lattice-sext} + Q'_{b3-dipole} + Q'_{b3-spool} + Q'_{b3-other}$$

→ Correct natural with lattice sextupoles

→ Would aim to balance  $Q'$ - $b_3$ -dipole with  $Q'$ - $b_3$ -spool

→ Watch other (e.g. insertion quads – own correctors)

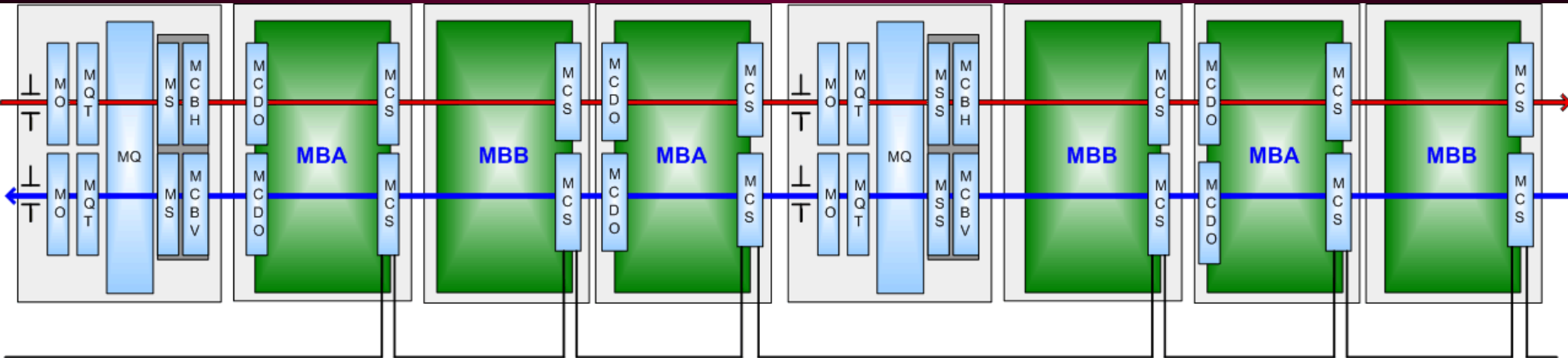
- Signature of improperly compensated  $b_3$  error is clear:

→ 0.1 unit  $b_3$  → +3/-3.5  $Q'h/Q'v$

- We should be able to measure periodically on injection plateau to verify corrections.



# Correction elements



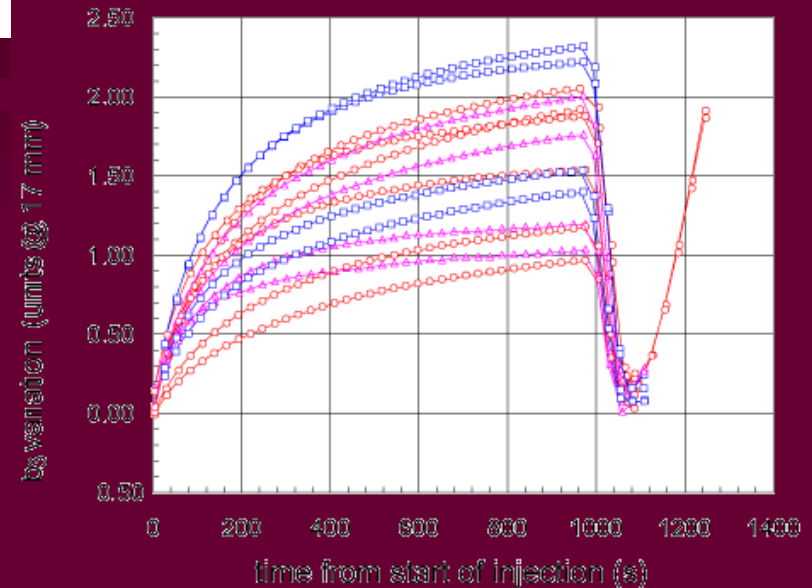
RCS.A78B2.UA83

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





# Requirements

- Static errors → controls database
- Eddy currents → controls database
- Transfer functions → controls database
  - Note:  $I$ ,  $I(t)$  downloaded to front-ends
  - $K$  to  $B$  to  $I$ ,  $I(t)$  done at high level via transfer function look-up
- Hysteresis model
  - to deal with reversing the direction of the current in e.g. the MCS.  
This causes crossing of the hysteresis loop with a potentially large chromaticity shift – going to have deal with this control system side

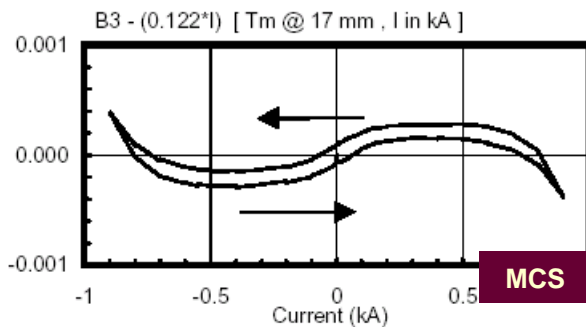


Figure 3 : Field strength of a MCD corrector : difference between the strength and straight line giving the average to enlighten the hysteresis due to persistent currents.

Plus dynamic effects...



# Dynamic effects - correction

Need per sector per aperture: magnitude of errors at  $t_0$  and time evolution of  $b_n(t)$  during decay

$b_n$  

$I_{MB}$  

Control system has “linear” model of multipole behaviour  
Incorporating empirical adjustments based on previous experience

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

Decide to ramp

Start ramp

$\Delta b_n$  applied as trim

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





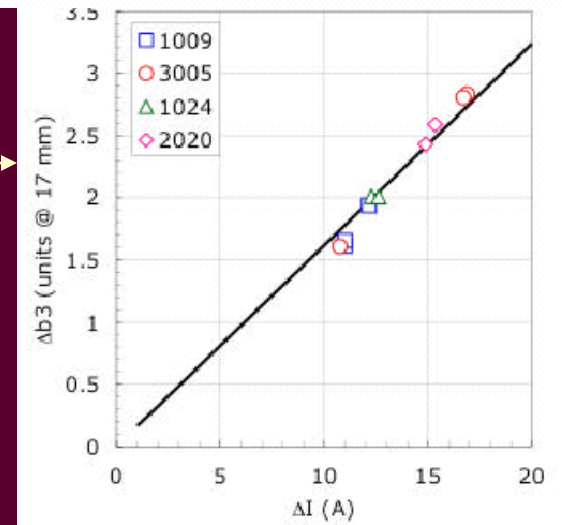
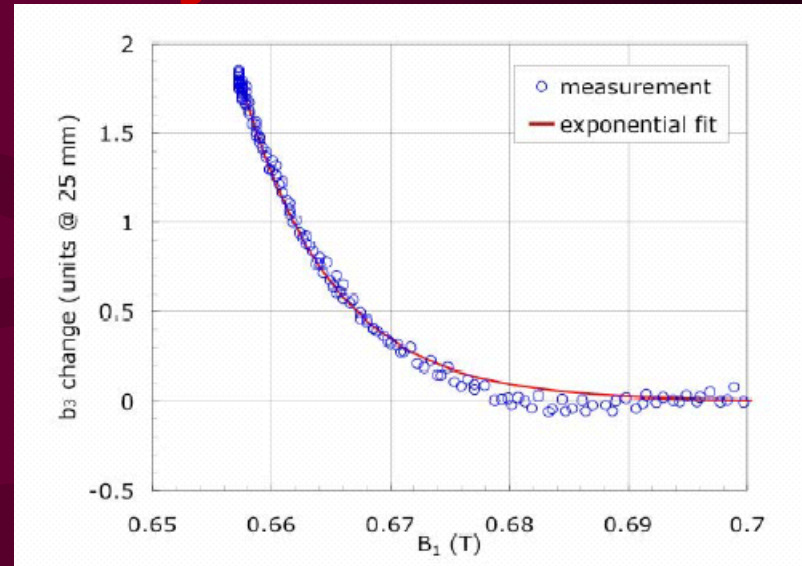
# Snapback – Q'

If  $b_3$  amplitude can be measured "on-line" the SB fit can be predicted w/out use of "multi-parameter" algorithm

- Fit snapback:

$$b_3^{snapback} \approx \Delta b_3 e^{-\frac{I(t) - I_{injection}}{\Delta I}}$$

- $I(t)$  – MB current at time  $t$
- $I_{injection}$  – injection value of current
- $\Delta b_3$  and  $\Delta I$  are fitting constants
- $\Delta b_3$  and  $\Delta I$  are correlated





# Q' - snapback

- Extract sextupole change in dipoles from slow Q' measurements &  $b_3$  corrections during injection to give  $\Delta b_3$  and thus  $\Delta I$ .
- 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



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

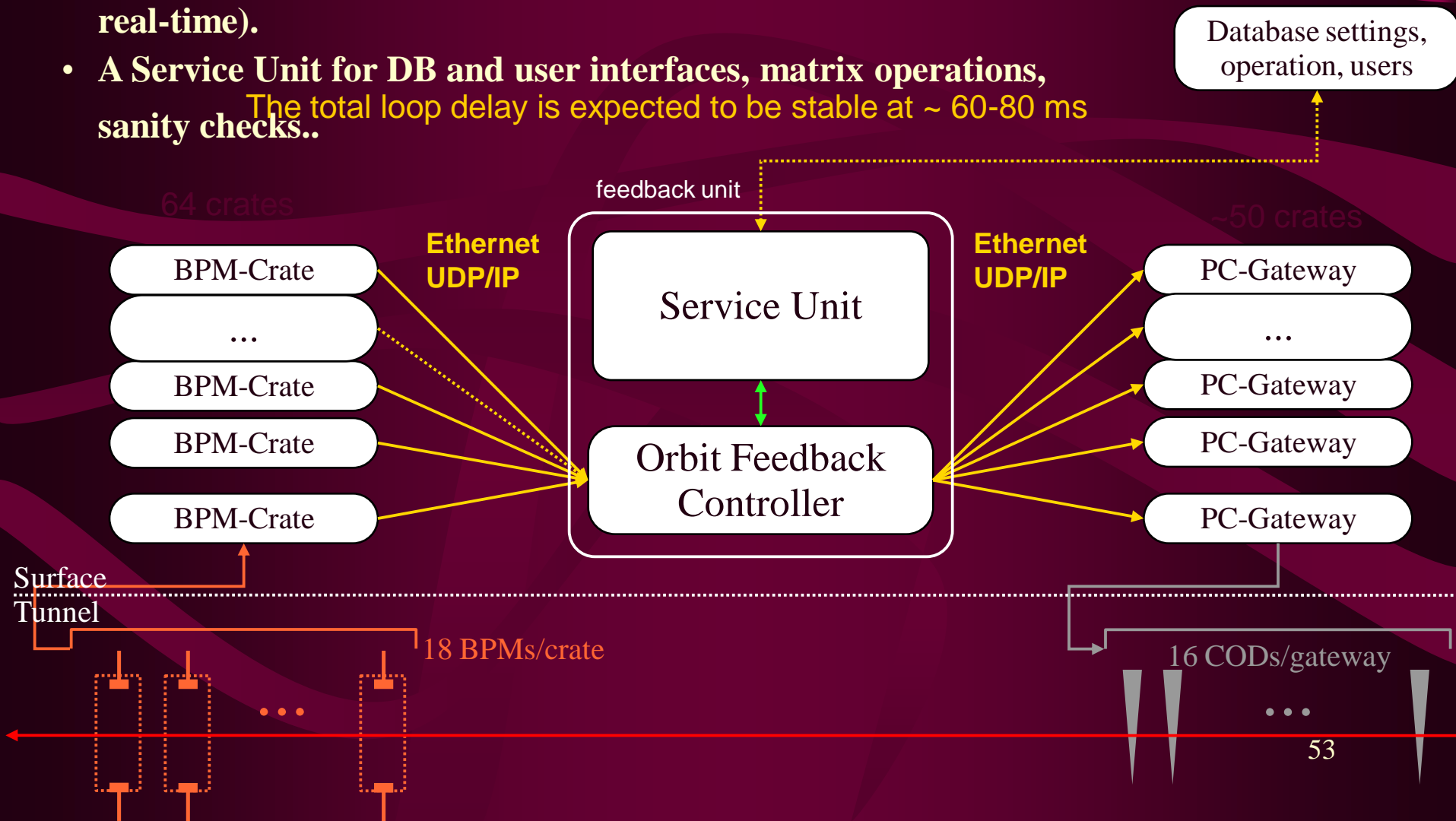
- Time resolved measurements
    - LHC orbit: minimum 10 Hz
    - LHC betatron tunes: some Hz
    - LHC chromaticities: Hz
  - Data centralization and computation of corrections (including error handling, dynamic change of twiss parameters...)
  - Feedback of corrections to power converters
- Nice Problem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



# Orbit FB Control Layout

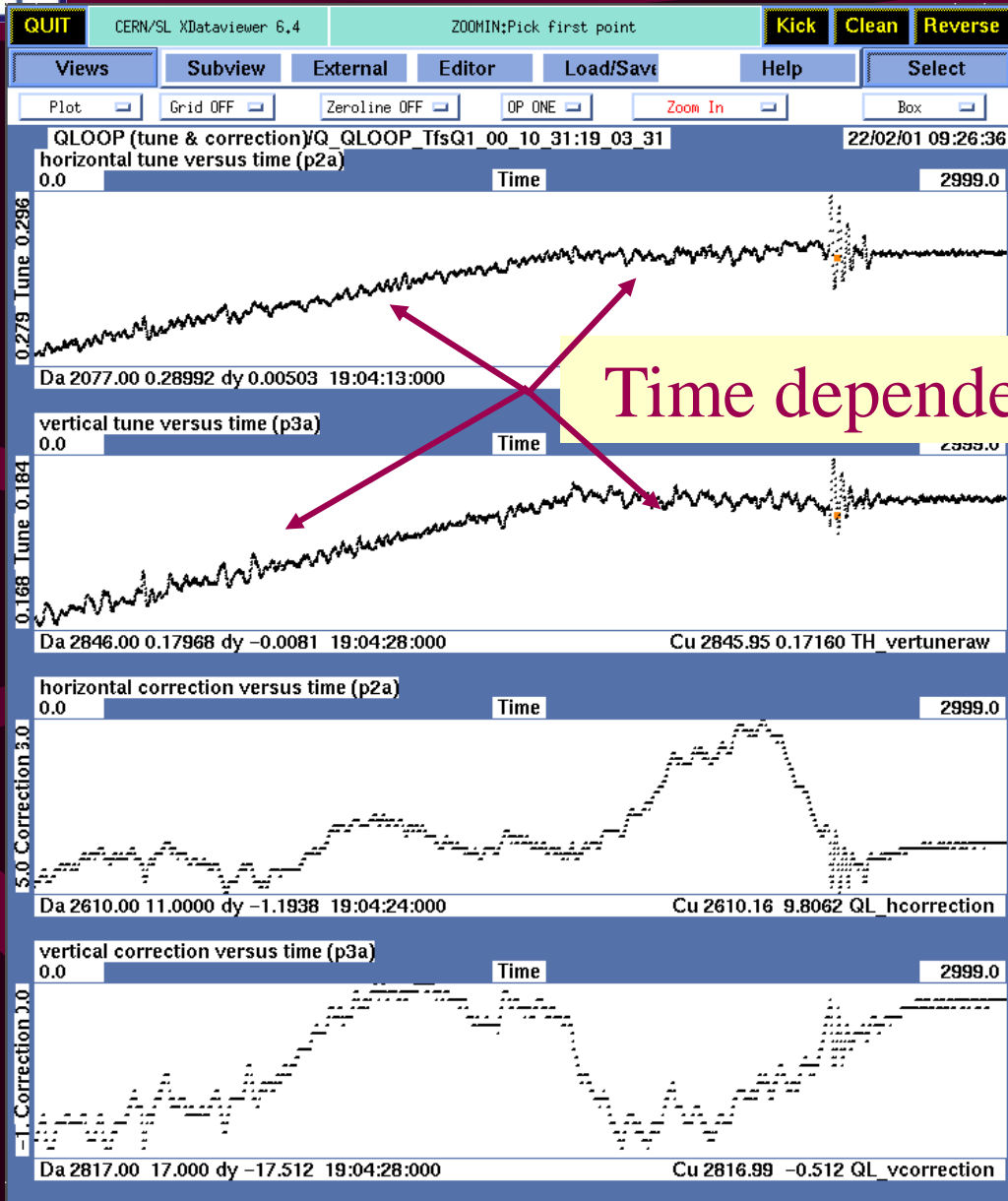
## Central FB unit has 2 functional parts

- Time-critical controller unit to compute the corrections (hard real-time).
  - A Service Unit for DB and user interfaces, matrix operations, sanity checks..
- The total loop delay is expected to be stable at ~ 60-80 ms





# LEP feedback on tunes



Time dependent reference for tunes!

QUIT Q meter -> Q-Loop

Unable to refresh Qloop Status

QLoop works in PLL mode **Fast PLL**

QLOOP Status & Settings **-> To PLL Settings**

QLoop Status (read back from Equipment)

Ref. H	0.0	Ref. V	0.0
Current Vector:	0	Stop Vector:	0
Cor. QF	0	Cor. QD	0

QLoop Settings (you can modify them !)

Use Function **LOAD NONSTANDARD FUNCTION**

**PLL->REF** **LOAD STANDARD FUNCTIONS (junk)**

**LOAD LOW CURRENT FUNCTION (< 660/bunch)**

**LOAD HIGH CURRENT FUNCTION (> 660/bunch)**

Ref. H	0.0	Ref. V	0.0
Current Vector:	0	Stop Vector:	0

Start QLOOP at: **At Start Ramp**

**read tune history** **Save long tune history buffer** **100000**

**S.O.S. : STOP QLOOP & TDAC = 0**

**(re)start qloop** **stop qloop** **stop ql & pll** **back**





# Summary 1<sup>st</sup> hour

- Accelerator Controls is a vast activity
- Controls Hardware mainly based on commercially available products (COTS)
- Controls Software an incredible suite of tools and applications mainly based on open source technologies and in majority developed at CERN
- Controls of beam parameters makes the link between:
  - accelerator physics
  - beam observation
  - equipment control
- ...and is fun to work on...