

# Accelerator Controls



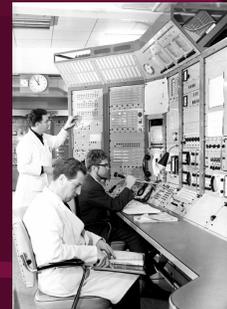
CAS 2011- Chios Greece

Hermann Schmickler



## 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





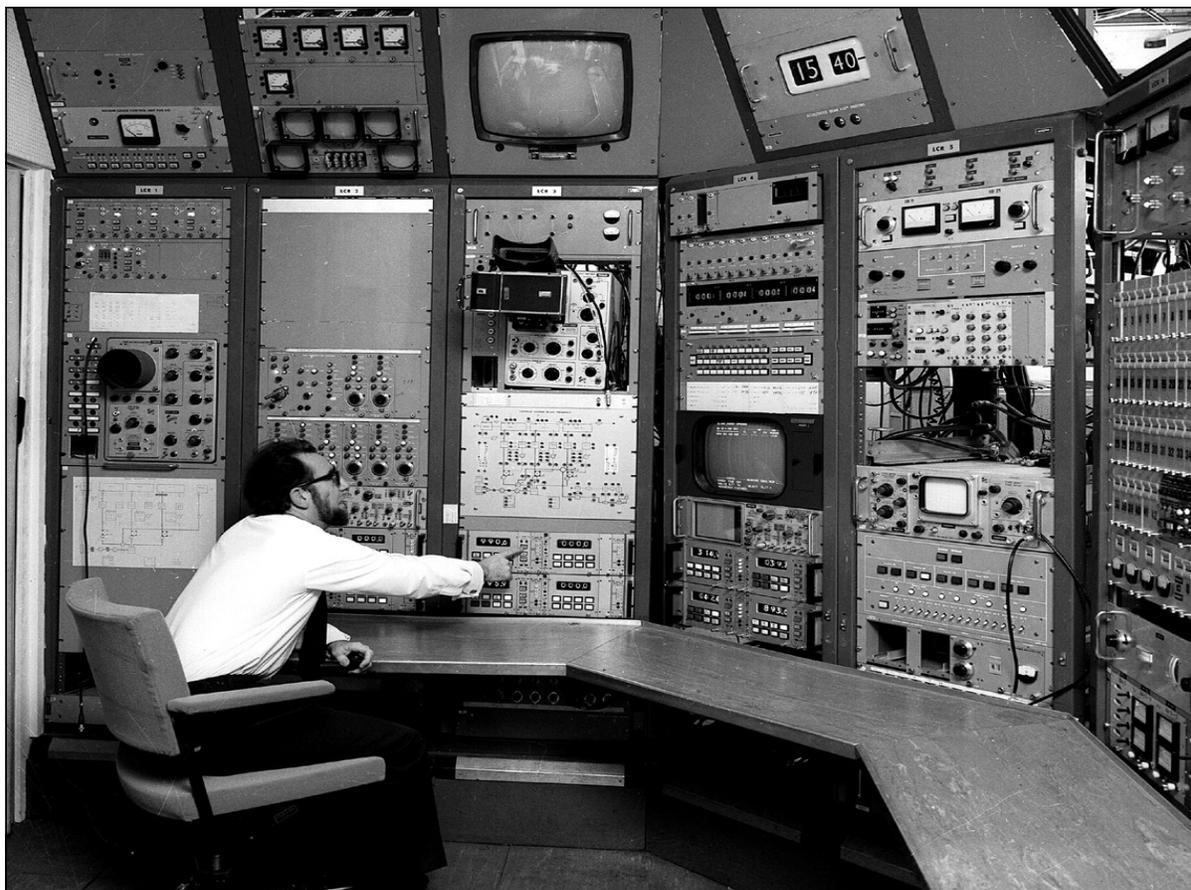
## Controls technology

- ...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.



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## 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

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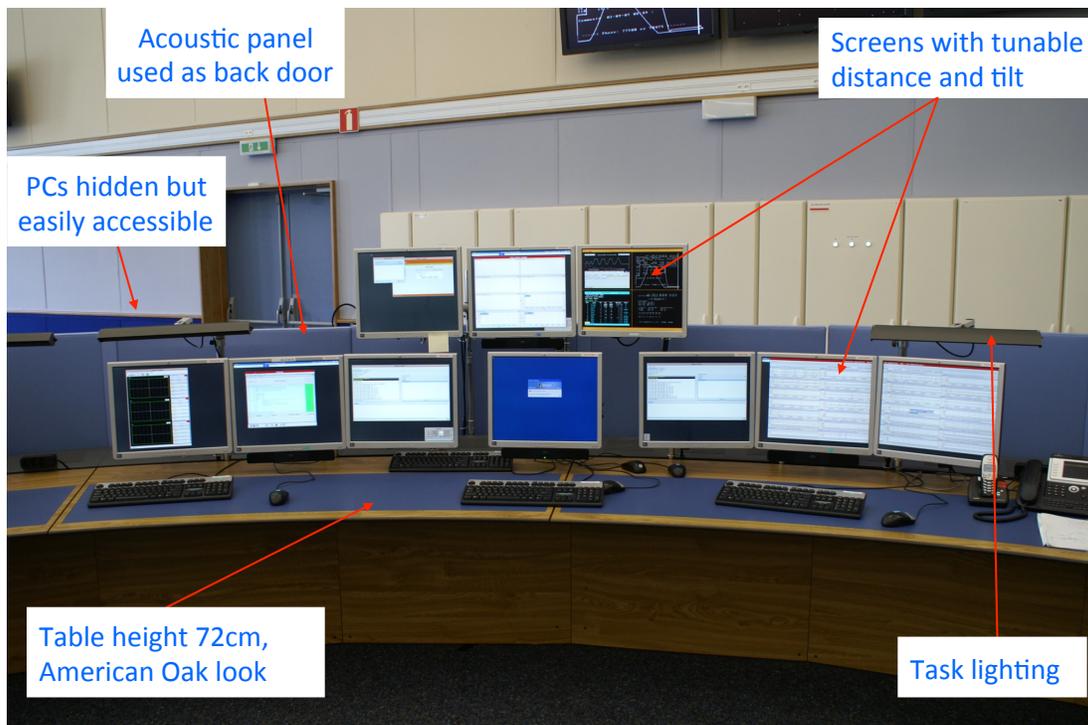




# Inside CCC



# 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, electrivity, RF power control, BT power control)
  - Supervisory Control and Data Acquisition Systems (SCADA) for commands, graphical user interfaees, 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)

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## 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 ??





# 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)

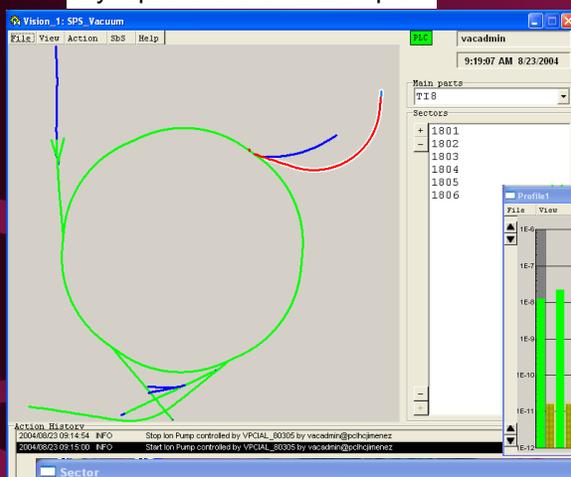
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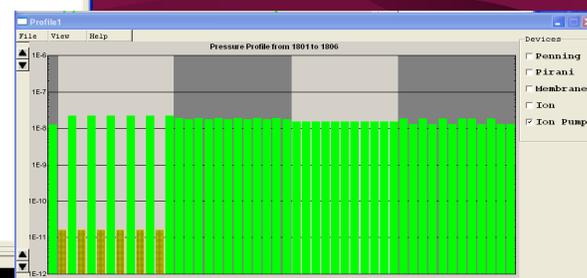


## The “look and feel” of all these systems example: vacuum system for LHC transfer line

Synoptic of the SPS Complex

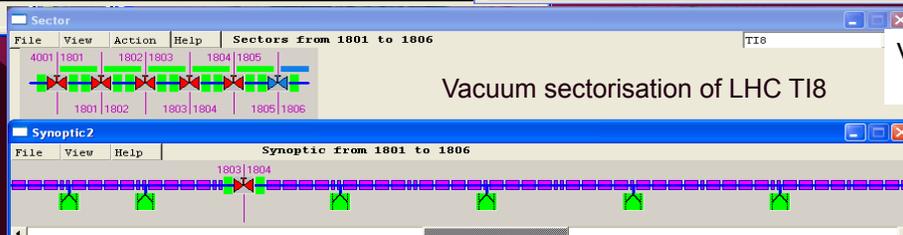


Pressure profile in LHC TI8



Vacuum sectorisation of LHC TI8

Vacuum layout of  
LHC TI8

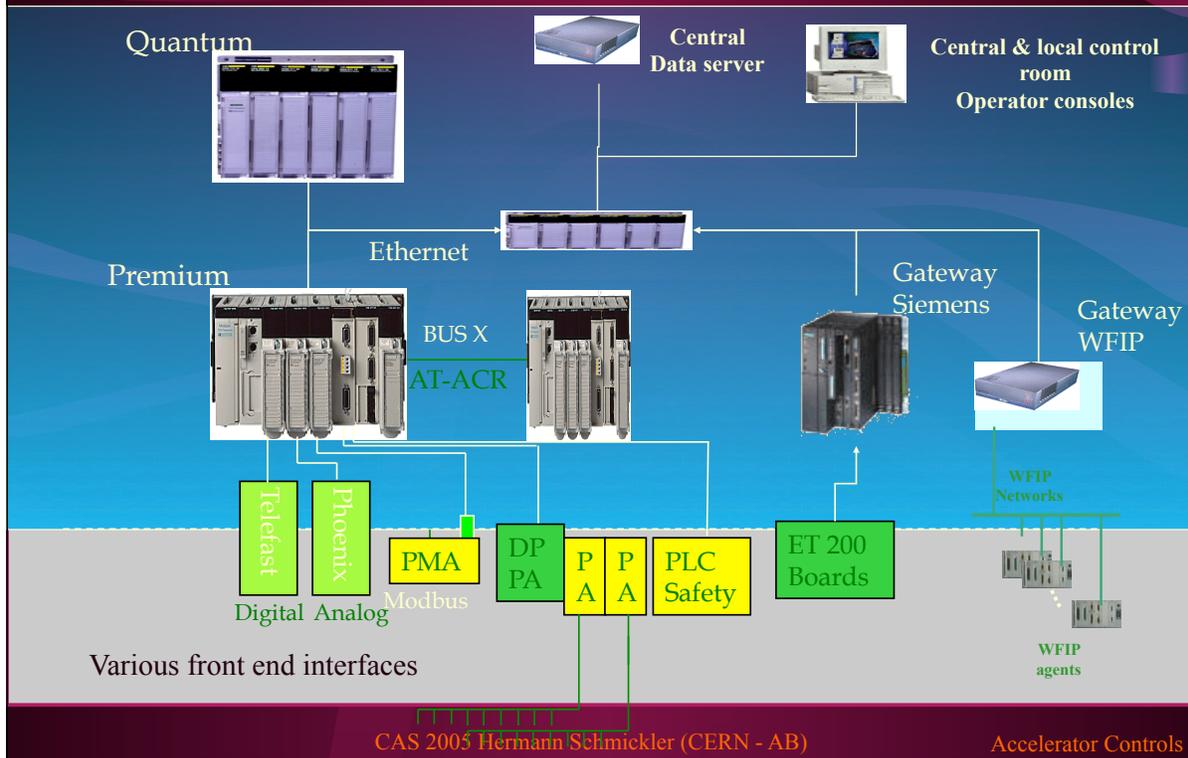


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I.Laugier AT-VAC



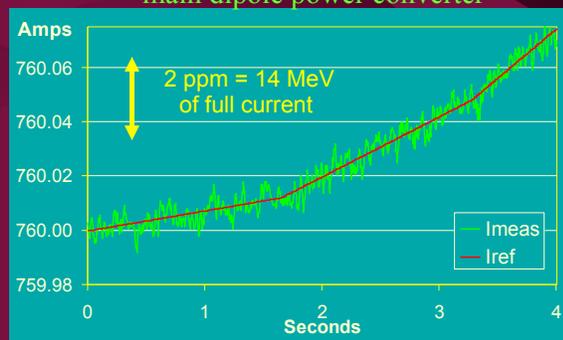
# A typical implementation



# 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...



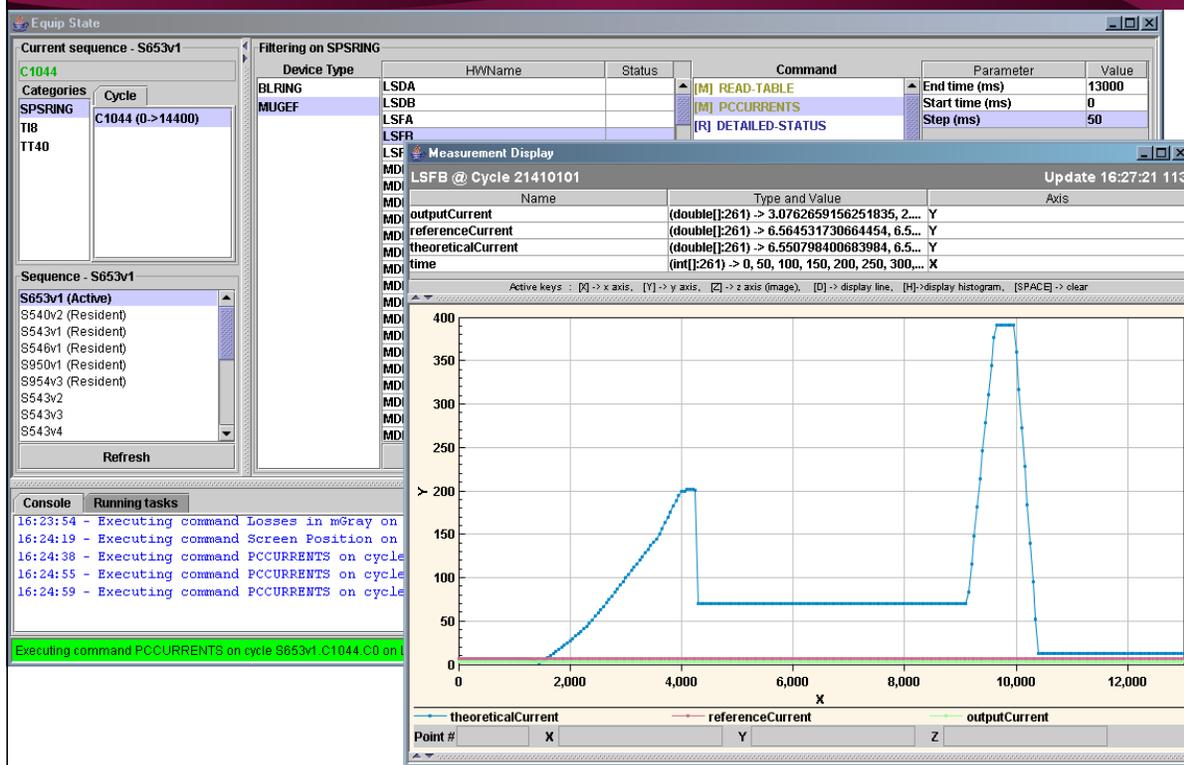
# Generic Equipment Control

The screenshot displays the 'Equip State' window with the following components:

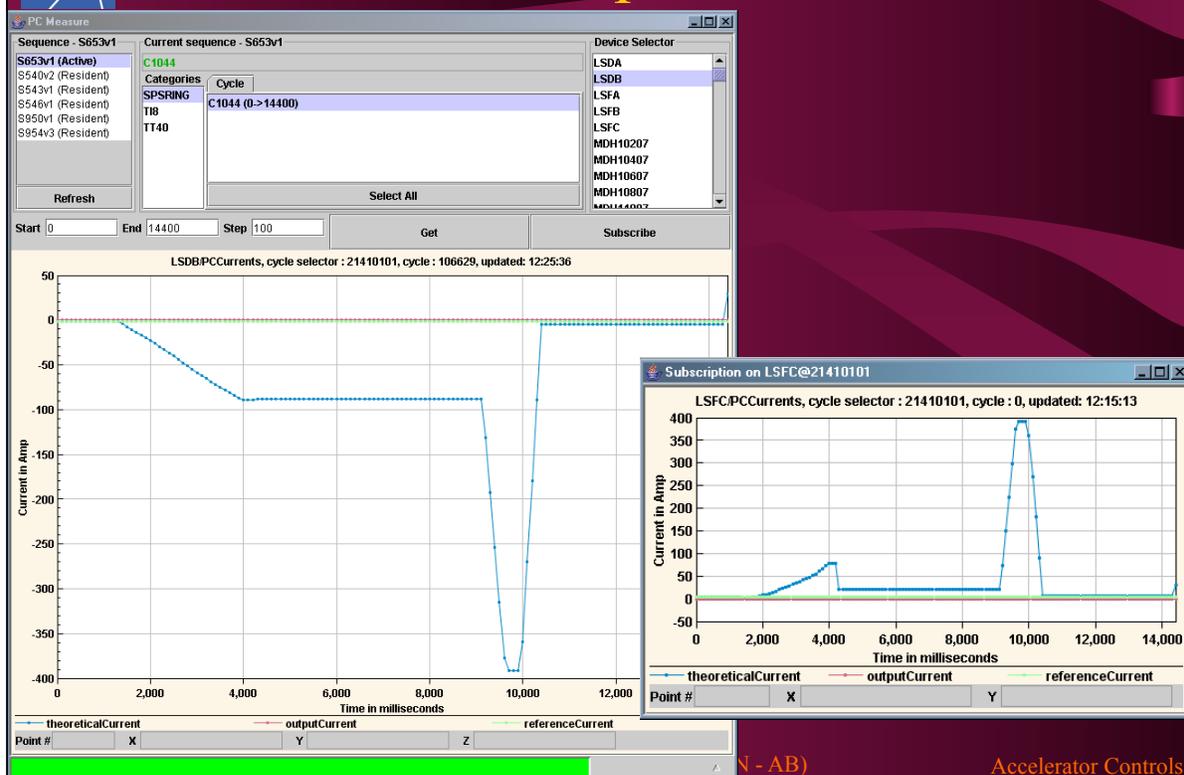
- Current sequence - S653v1**: Shows cycle C1044 (0->14400) and categories SPSRING, T18, and TT40.
- Sequence - S653v1**: Lists active and resident equipment like S540v2, S543v1, S546v1, S950v1, S954v3, S543v2, S543v3, and S543v4.
- Filtering on T18**: A table listing device types and hardware names with their status.
- Command**: A list of available commands such as READ-TABLE, PCCURRENTS, DETAILED-STATUS, EVLIST, MAG-CONNECTION, READ-CHECK-FUNCT, READ-POLARITY, TEMPERATURE, STATUS, LOAD-FUNCT, LOAD-ZERO-FUNCT, LOAD-TEST-FUNCT, CONNECT-MAG-1, CONNECT-MAG-2, HARD-INIT, INIT-ACQ, and INIT-SOFTWARE.
- Console**: Shows the execution of the STATUS command on cycle S653v1.C1044.CO on various equipment units.



# Generic Measurement

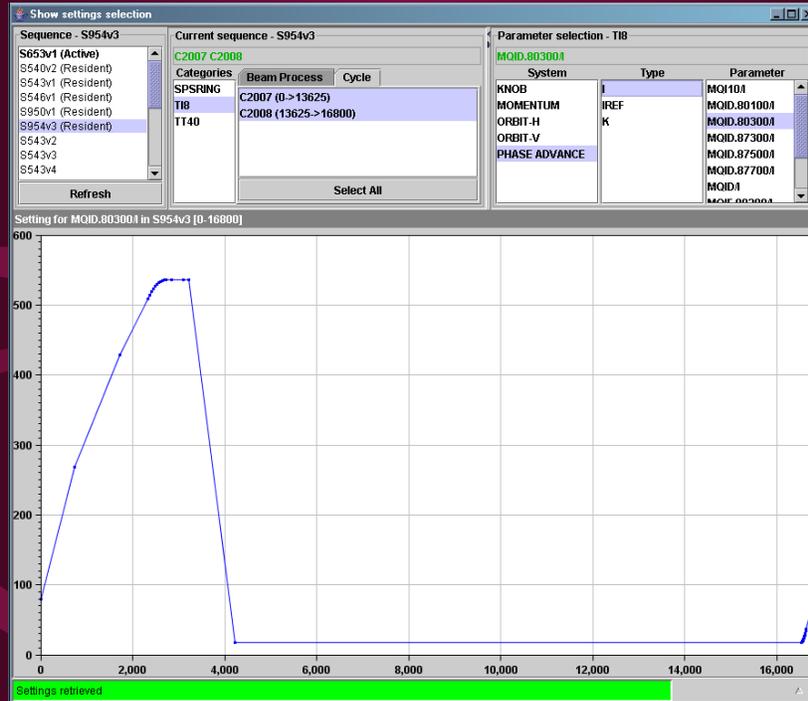


# Measurement of power converters





# Visualization of the settings

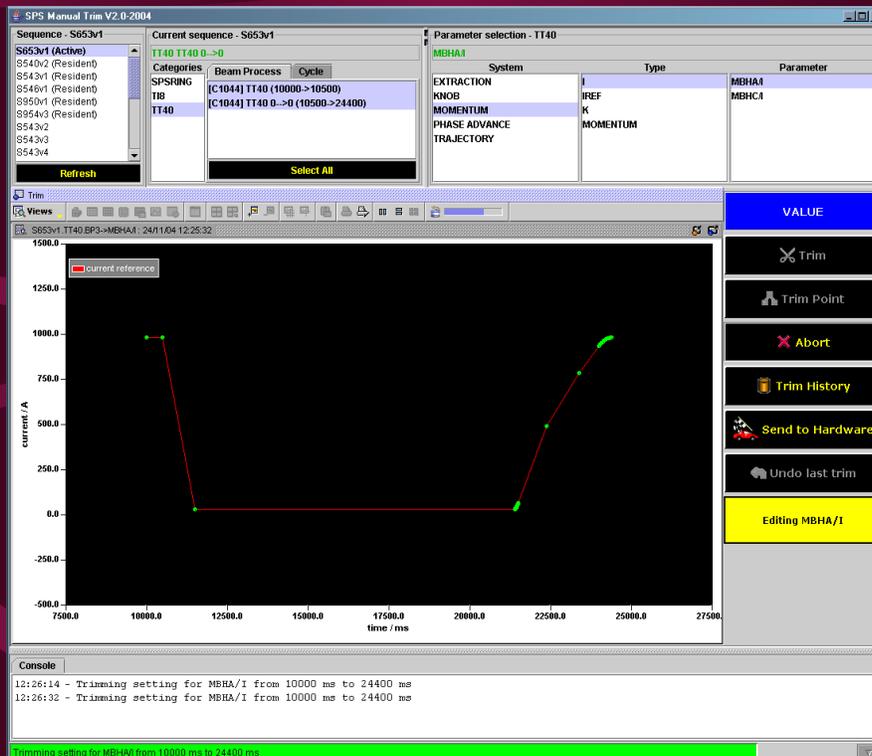


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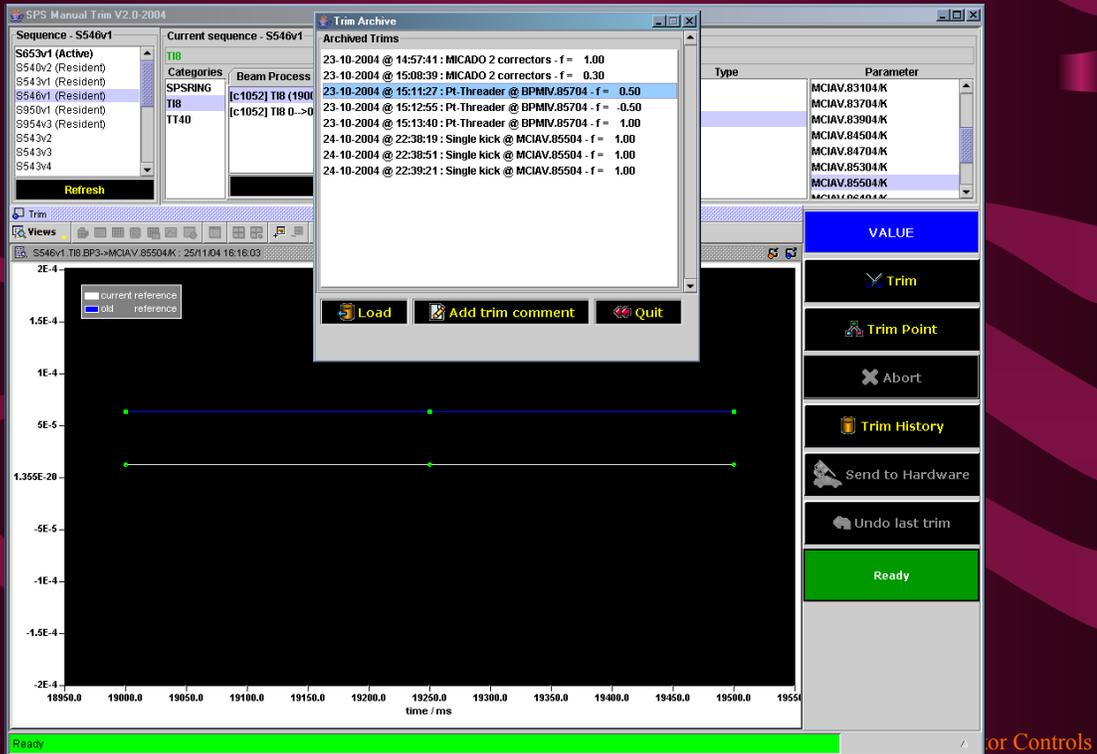
# Trim



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# Trim history

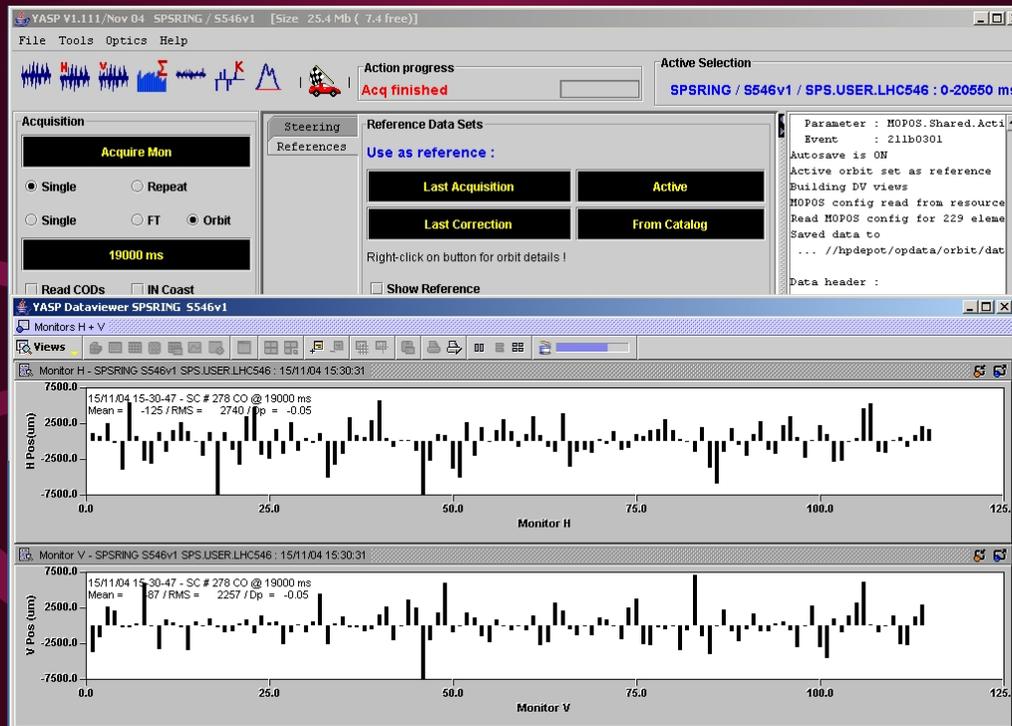


# Supporting Tools for Operation

- 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

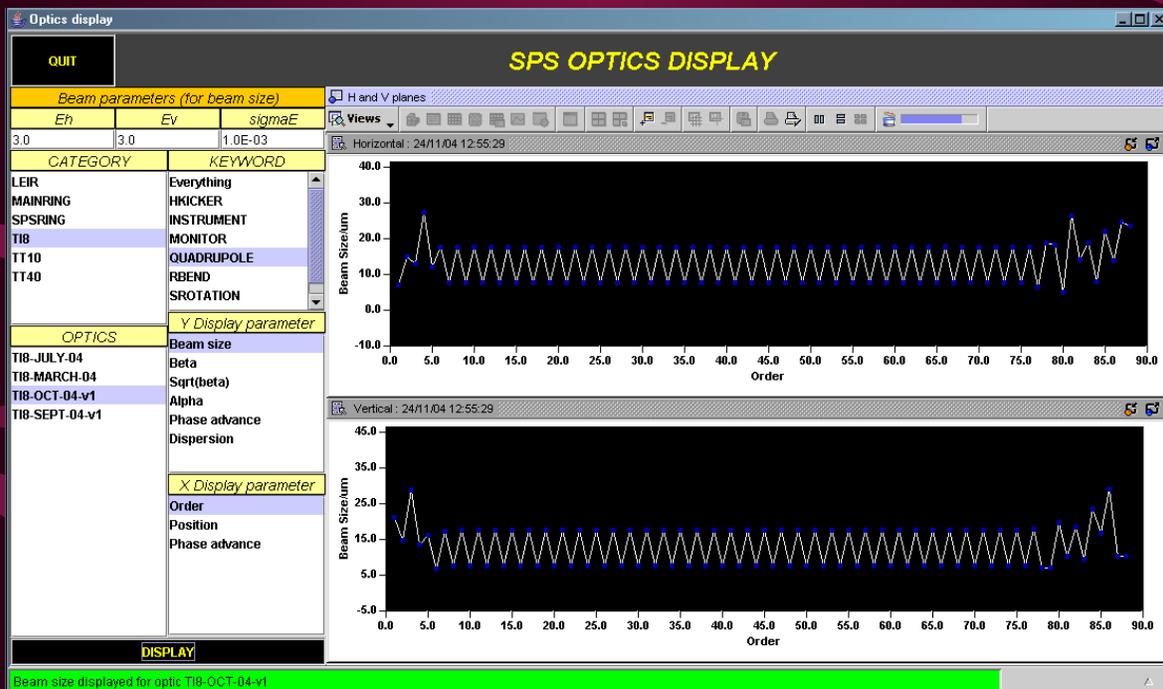


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# Optics Display



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# Logging & Monitoring

SDDS logging monitor

Configuration File: dslacsoft-sdds-writer\srlacsoft-sdds-writer\SDDSConfig.xml TIB

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	11:30:38	34772
STEP_1.gpsbb4P3N		

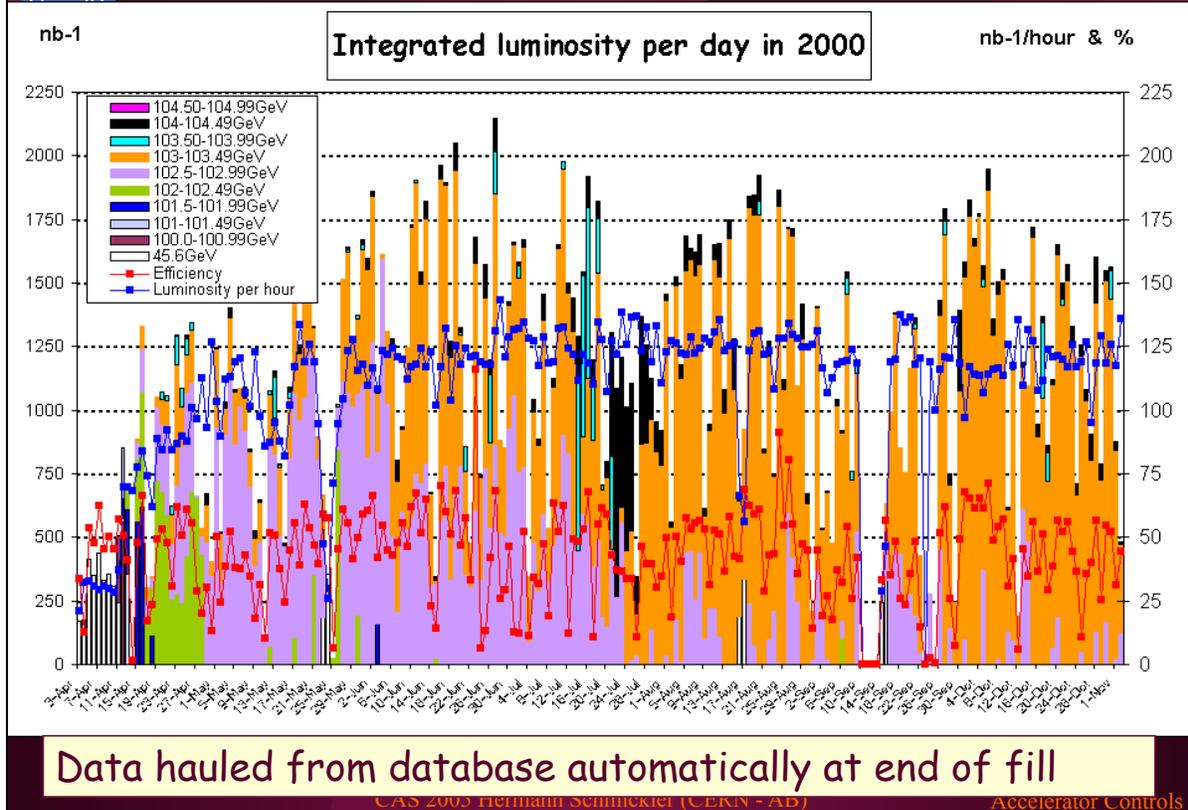
Console

```
11:30:40 - Start monitoring parameter [MSE4183M/PCCurrents]
11:30:40 - Exception occurred: [MSE4183M/PCCurrents]asynchronous operation on MSE4183M/PCCurrents@21890301 failed
cern.jgpc.ParameterException: Error -132 : StartTime exceeds cycleLength
Caused by:
cern.jgpc.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





# Retrieval of archived measurements

Address: \\hdepot\opdata4\SDDS\_LOGGING\23\_10\_04\BTV\_LSS4.41831\getImage

Files:

- BTV\_LSS4.41831\getImage\_09\_48\_47.10048.sdds
- BTV\_LSS4.41831\getImage\_09\_49\_11.10049.sdds
- BTV\_LSS4.41831\getImage\_09\_49\_40.10050.sdds
- BTV\_LSS4.41831\getImage\_09\_50\_09.10051.sdds
- BTV\_LSS4.41831\getImage\_09\_50\_37.10052.sdds
- BTV\_LSS4.41831\getImage\_09\_51\_06.10053.sdds
- BTV\_LSS4.41831\getImage\_09\_51\_35.10054.sdds
- BTV\_LSS4.41831\getImage\_09\_52\_04.10055.sdds
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- BTV\_LSS4.41831\getImage\_10\_05\_01.10082.sdds
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- BTV\_LSS4.41831\getImage\_10\_06\_28.10085.sdds
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- BTV\_LSS4.41831\getImage\_10\_31\_54.10138.sdds
- BTV\_LSS4.41831\getImage\_10\_32\_23.10139.sdds
- BTV\_LSS4.41831\getImage\_10\_32\_52.10140.sdds



# Browser & Viewer

SDDS root directory: \\hdepot\opdata4\SDDS\_LOGGING\23\_10\_04

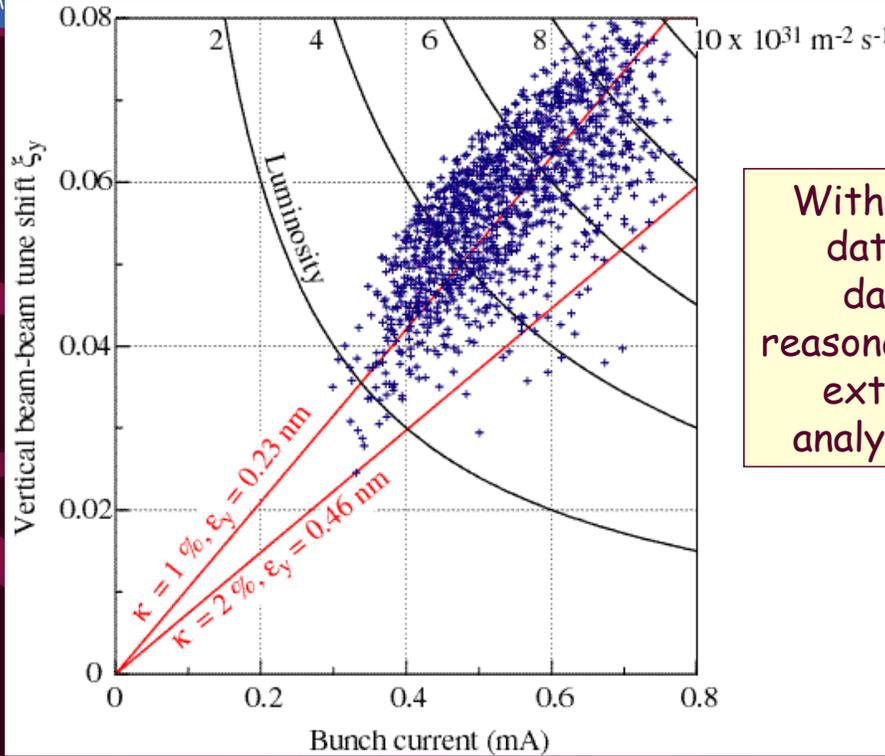
Parameters:

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

Active keys: [0] -> x axis, [1] -> y axis, [2] -> z axis (image), [D] -> display line, [H] -> display histogram, [SPACE] -> clear



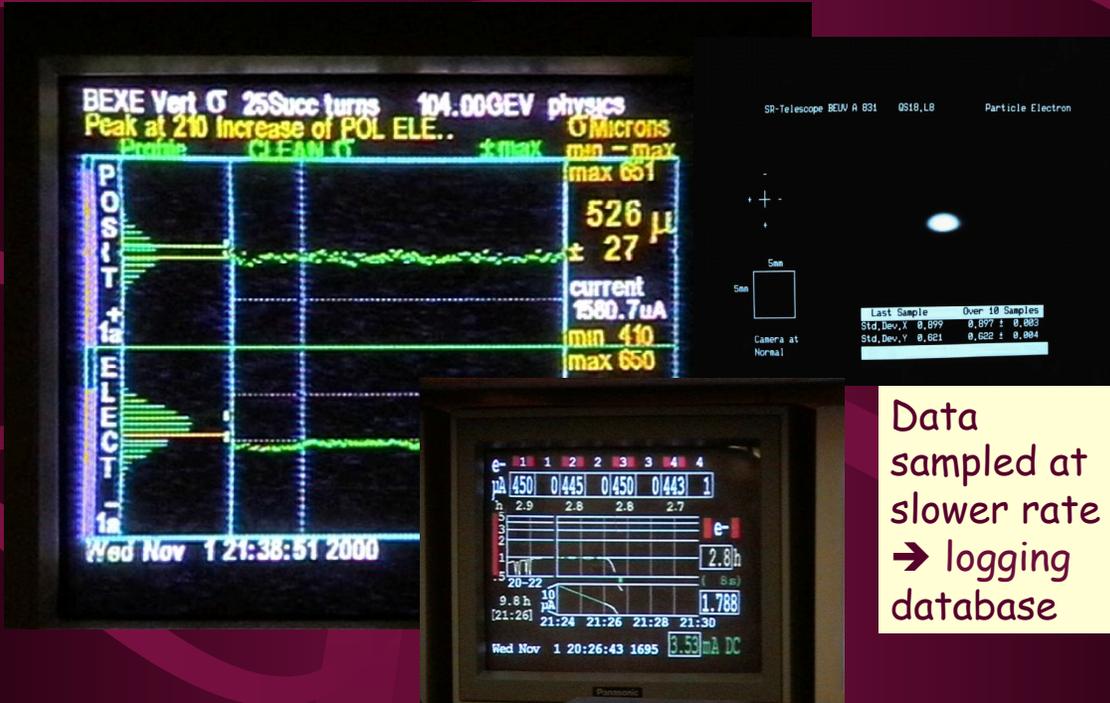
# DATA EXTRACTION → POST RUN ANALYSIS



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



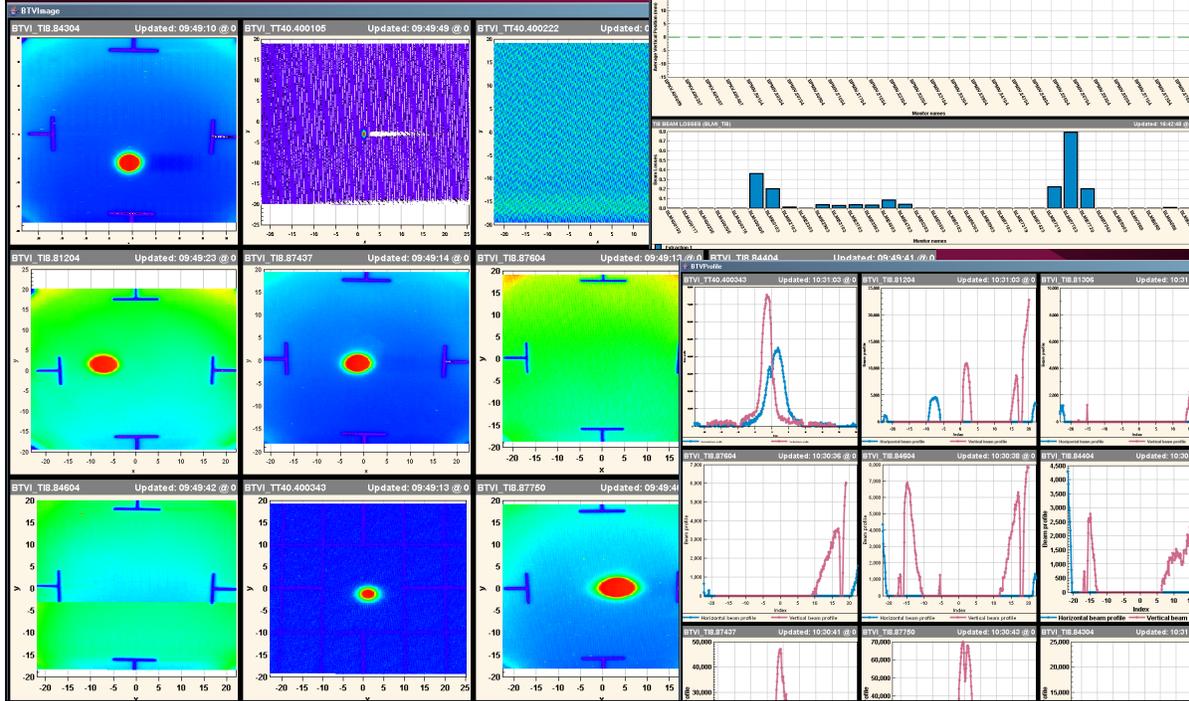
# Dedicated Video (FAST) Signals (LEP)



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

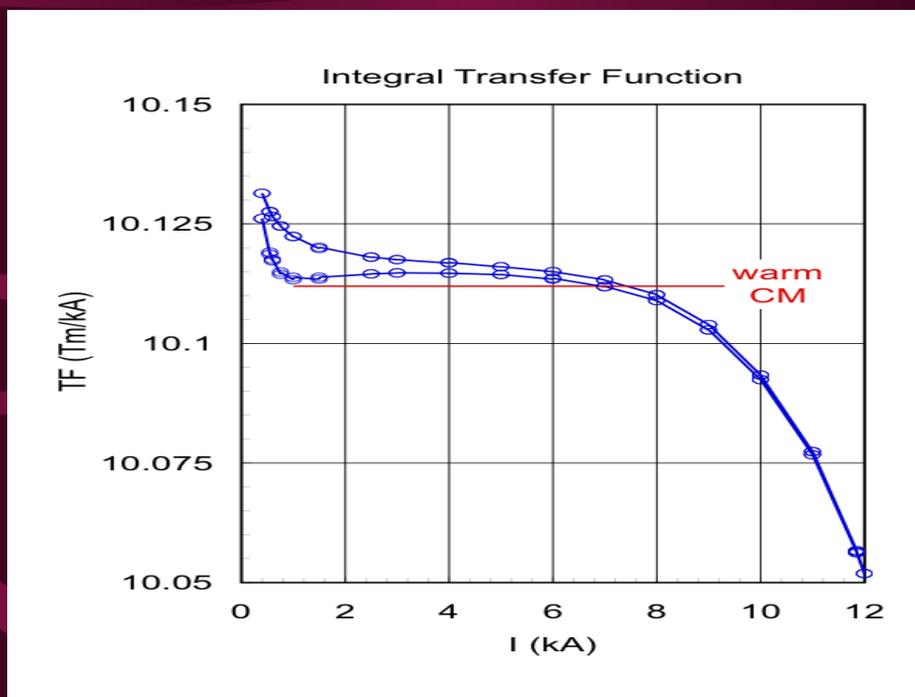


# Available data for LHC magnets

- warm measurements on the production:
  - all (superconducting) MB, MQ, MQM, MQY:
    - main field integral strength
    - higher order geometric harmonics
  - all (superconducting) MBX, MBRx, MQXx
  - 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
  - $\approx 75\%$  of MBX, MBRx
  - 100 % of MQXx (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:

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

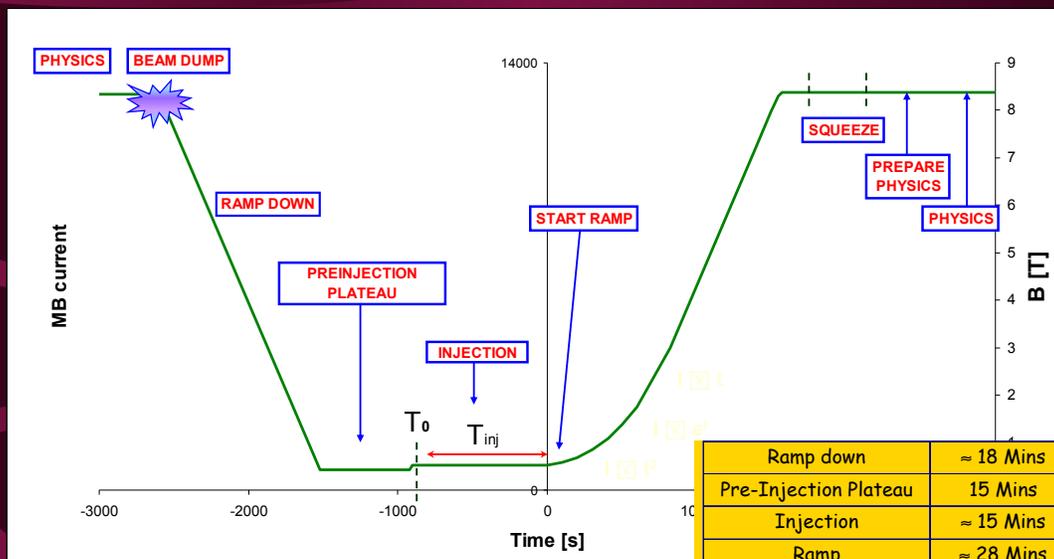
- Required integrated field strength in sector 78 for an injection at 450 GeV from SPS : 1189.2 T m

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

= 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 Feedback Help  
Sequencer Execution GUI (PRO) : 1.1.3

RBAt hcop

LHC NOMINAL SEQUENCE (B1 & B2)

- 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

PREPARED

Run Suspend Step Skip Stop

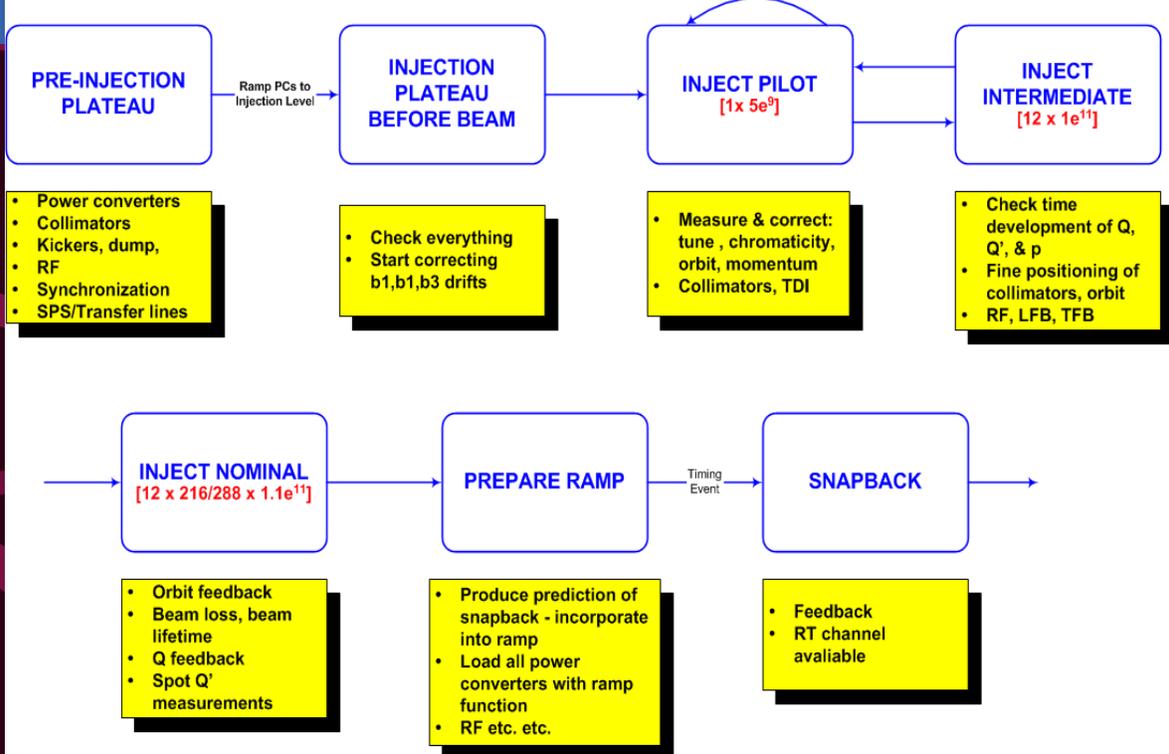
Console Details Result

```
New RBA token received: will be used from the next step: RBA token
[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=/172.16.200.124, auth-
req=false, def-user=null);user=UserPrincipal(name=lhcop, roles=[DIAMON-Operator, LHC-Operator, OP-Daemon, SPS-
Operator, SeqHwOperator, SeqLhcOperator, SeqSpsOperator]);extra=null]
```

Server logs

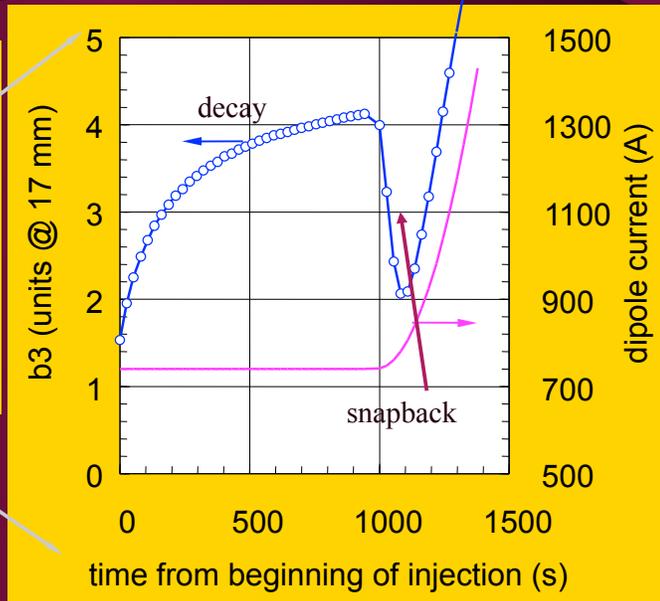
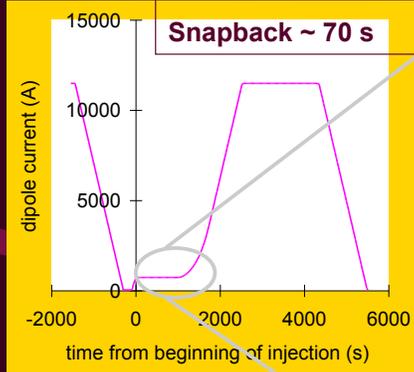
```
onSequenceRemoved() SequenceId = SM_CHECKS-RAMP-SQUEEZE@418@20110907141519807
onSequenceRemoved() SequenceId = SM_CHECKS-ADJUST-STABLE_BEAMS@426@20110907143632143
Sequence prepared : SequenceId = PREPARE_RAMP @428@20110907154659254
```

Accelerator Controls





# A very frightening problem...



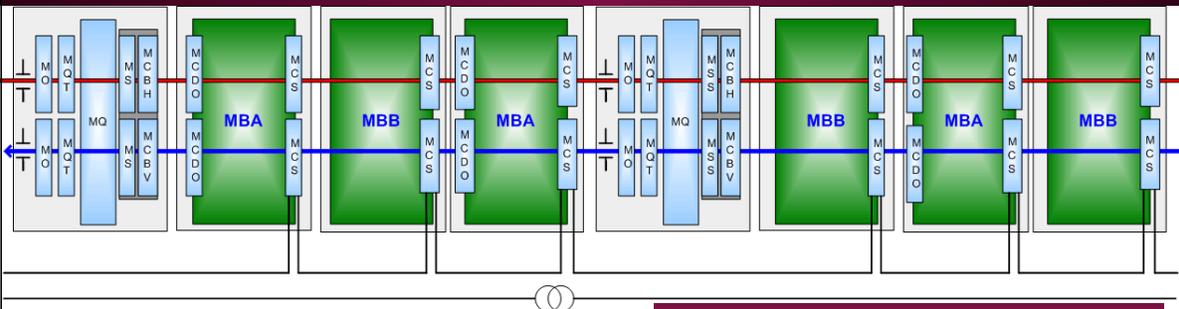
Parameter	Nominal tolerance	Limit on $b_n(\text{MB}) - \text{Inj.}$	Approx. Decay	Parameter swing
$Q'$	$Q' \approx 2 \Delta Q' \approx \pm 1$	$\approx 0.02$	1.7	$\Delta Q' \approx +71/-64$

CAS 2005 Hermann Schmickler (CERN - AB)

Accelerator Controls



# Correction elements



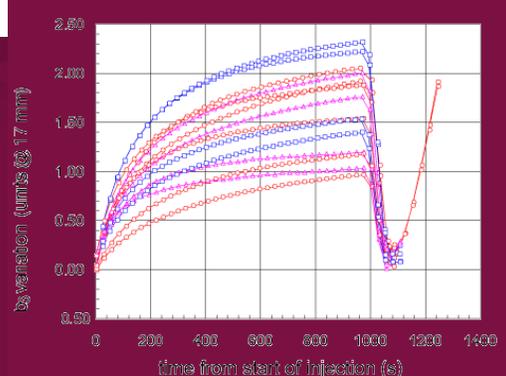
RCS.A78B2.UA83

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



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Accelerator Controls



# 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

$$b_n(t)$$

$$I_{MB}(t)$$

$\Delta b_n$  applied as trim

Decide to ramp

Start ramp

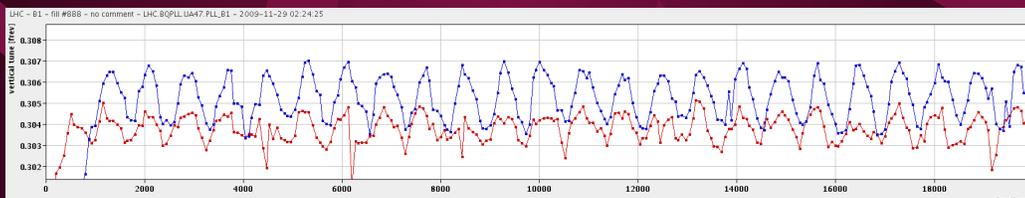
After time  $t_{inj}$  a  
prediction of  
the snapback is  
required.  
Download.

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



# Q' - control

- 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  $b_1$  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: [Reinhold.Stampanoni@CERN.ch](mailto:Reinhold.Stampanoni@CERN.ch), New York, NY, 2011-03-30

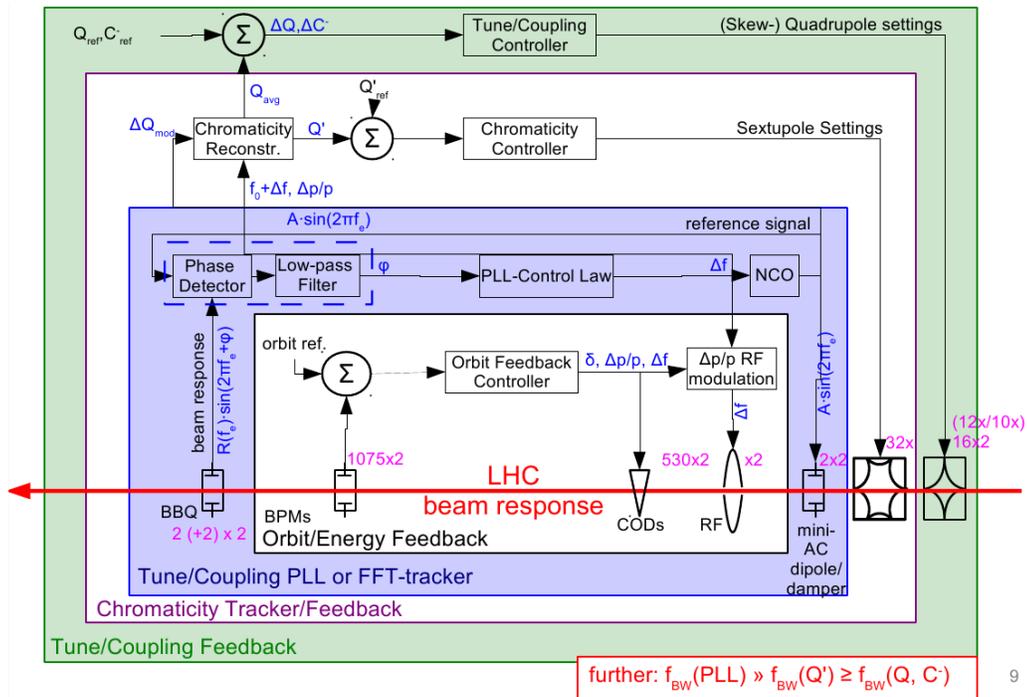
Wide-Band-Time-Normaliser proposed for LHC BPM system	1996	BNL & CERN collaboration on Q/Q'(-FB) initially BNL's 200MHz resonant BPM
Radiation testing showed digital acq. needs to be out of tunnel	1999	
RT control specification, mostly decay-/snap-back and nominal performance (no MP yet)	2000	Tune-FB included in original US-LARP TWC-based Schottky monitor proposed
BPM design and capabilities "inspired" specs. Moving digital processing out of the tunnel	2001	• Direct-Diode-Detection → Base-Band-Tune (BBQ), prototyped at RHIC/SPS, robust Q-meas. & unprecedented sensitivity
Recognition that collimation will rely on real-time Orbit-FBs	2002	• 1.7 GHz Schottky prototype at SPS
Orbit-FB prototype tests at the SPS	2003	FFT-based Q tracking op. deployed at SPS PLL-studies at RHIC
IWBS'04: SLS, ALS, Diamond, Soleil and others → affirmed Orbit-FB strategy	2004	FNAL-LARP involvement in Schottky design and front-end electronics
Orbit(-FB) and MP entanglement recognised → FB: "nice to have" to "necessary"	2005	Q & Coupling-FB demonstrated at RHIC PLL-Q and Q'(t) tracker demonstrated at SPS
	2006	FNAL-design/CERN-built 4.8GHz TWC Schottky Tune Feedback Final Design Review (BNL)
	2007	Joint CARE workshop on Q/Q' diagnostics (BNL, FNAL, Desy, PSI, GSI, ...) → affirmed Q/Q' strategy

**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 Steinhilber@CERN.ch, New York, NY, 2011-03-30



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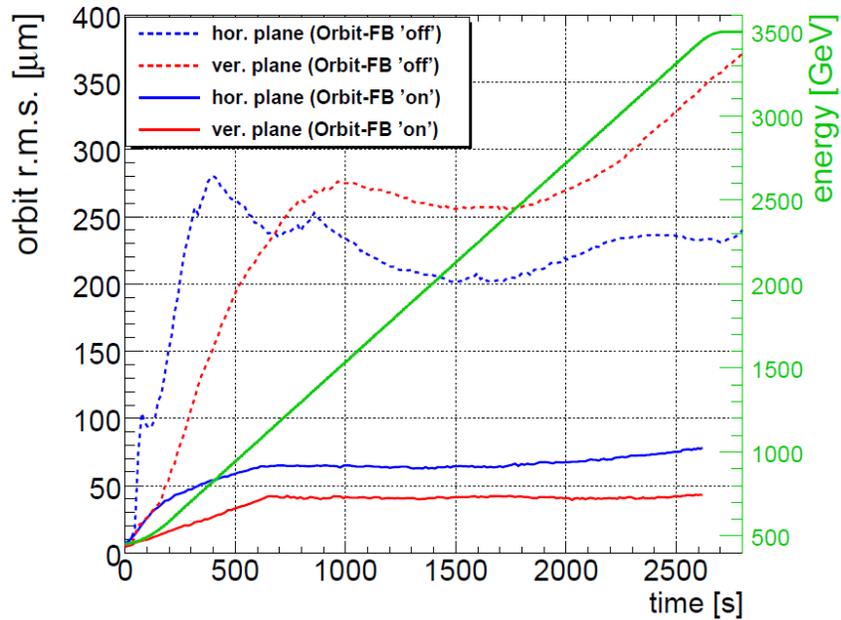
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## Orbit Feedback Performance

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

- Orbit feedback used routinely and mandatory for nominal beam



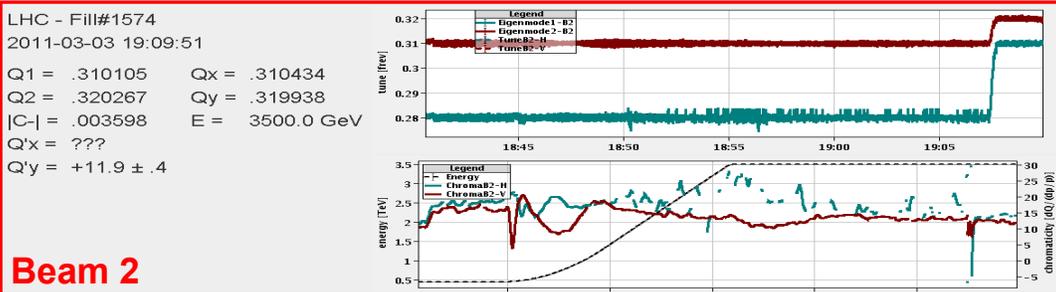
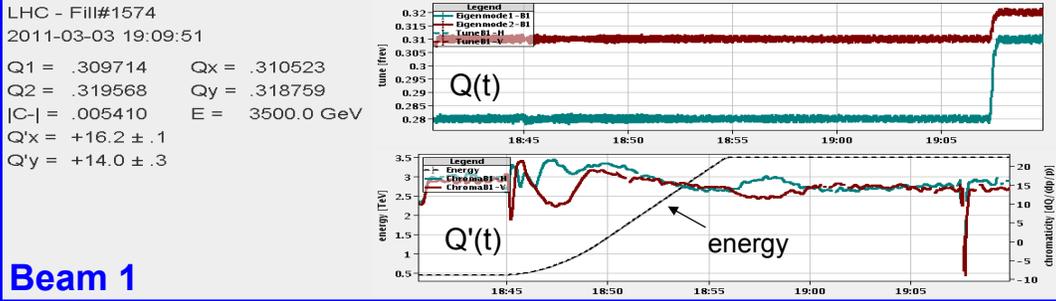
- Typical stability: 80 (20) μm rms. globally (arcs)
- Most perturbations due to Orbit-FB reference Δ changes around experiments

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

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



- ... 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 3<sup>rd</sup>, 4<sup>th</sup> or C<sup>-</sup> 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

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

Displayed Function: LHCBEAM1/OPH

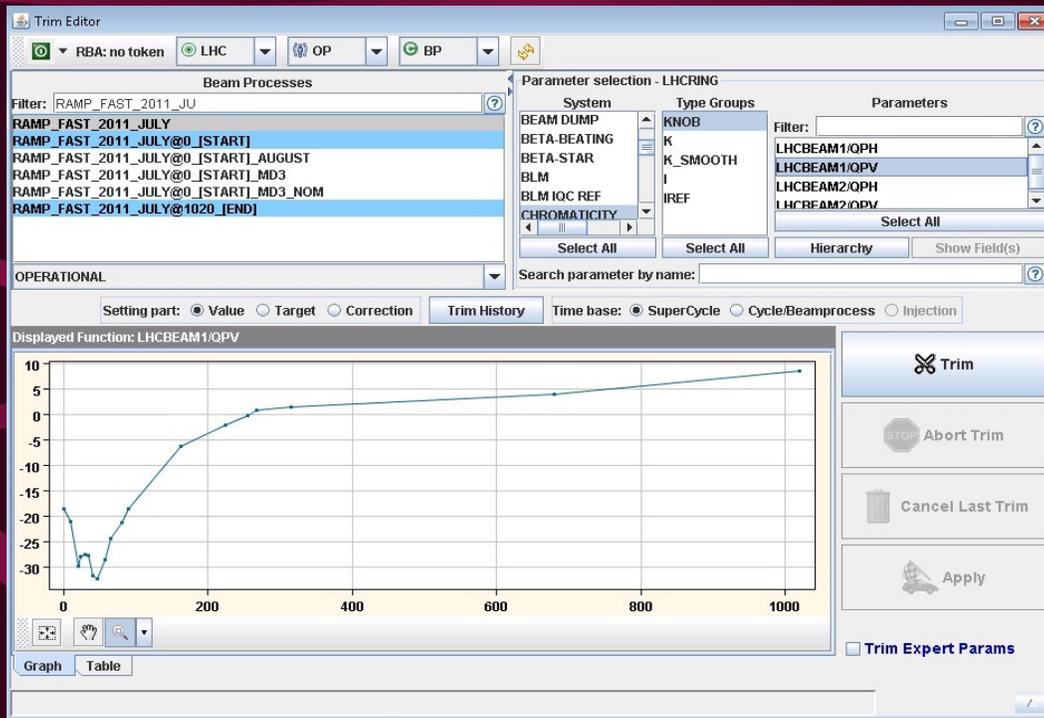
Parameter selection - LHC-RING

System	Type Groups	Parameters
BEAM DUMP	KNOB	
BETA-BEATING	K	
BETA-STAR	K_SMOOTH	
BLM	I	
BLM IOC REF	IREF	
CHROMATICITY		LHCBEAM1/OPH
		LHCBEAM1/OPV
		LHCBEAM2/OPH
		LHCBEAM2/OPV

Buttons: Trim, Abort Trim, Cancel Last Trim, Apply, Trim Expert Params



# Available trim functions for Qv'



CAS 2005 Hermann Schmickler (CERN - AB)

Accelerator Controls



## 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...

CAS 2005 Hermann Schmickler (CERN - AB)

Accelerator Controls