COMMISSIONING OF AN ACCELERATOR:

TOOLS AND MANAGEMENT

Amor NADJI

SOLEIL SYNCHROTRON

EPAC08, Genoa, Italy, 23rd – 27th June 2008

OUTLINE

- ❑ COMMISSIONING STRATEGY
- ❑ PRE-BEAM PREPARATION
- ❑ GETTING THE FIRST BEAM
- ❑ FIRST OPTICS STUDIES
- ❑ ROLE OF THE DIAGNOSTICS & CONTROLS
- ❑ TOP LESSONS
- ❑ CONCLUSIONS

❖In this talk, I will relate my own experience of the commissioning of **SOLEIL**, as well as some information collected from other accelerators recently or being commissioned, **DIAMOND**, **JPARC**, **LCLS**, **LHC**, **SNS**, and **SSRF**.

AKNOWLEDGEMENTS

R. Bailey (CERN), Z. Dai (SSRF), P. J. Emma (LCLS), J. D. Galambos and S. D. Henderson (SNS), R. Bartolini and, Vince Kempson (DIAMOND), and Tadashi Koseki (J-PARC, KEK).

SOLEIL accelerator physics group and J.-M. Filhol.

COMMISSIONING STRATEGY

- Commissioning: actions for checking and tuning an accelerator in order to meet its specifications.

- After years of calculation, construction and tests.

- Pressure to reach the goal as fast as possible BUT

  Take time for a sound understanding of the accelerator functions and a safe operation of the equipment.

Definition of the Objectives,
Organization of the Coordination
and Preparation of the Tools.

PHASING THE COMMISSIONING

- The standard approach encloses 5 STAGES:

  - Pre-Beam preparation
  - Getting the first beam
  - Beam-Based hardware and software checkout
  - First optics studies
  - High current intensity operation

- Some commissioning considerations are specific to different types of accelerator.

PRE-BEAM PREPARATION

☛ Avoid (at any price) the commissioning with beam to be plagued by different technical problems.

Clear aim to commission/fix/test everything that can be: before beam.

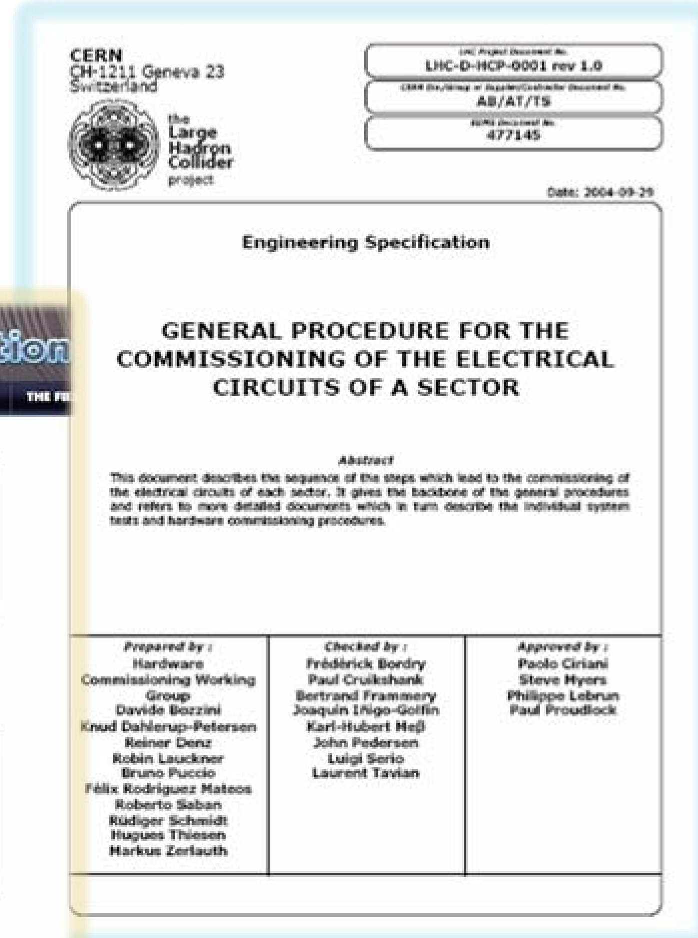
➢ A comprehensive and thorough Hardware Commissioning.

➢ Systems implicated include:

- Survey / Alignment
- Cooling
- Vacuum
- Cryogenics plant
- Electrical connections
- Magnets
- Pulsed magnets
- Power supplies
- Machine protection
- Safety interlocks
- Timing system
- Controls
- Diagnostics
- RF systems

Procedure and Documentation

- Design the procedures
- Evaluate the resources needed
- Build the necessary environment (documentation, test folders, analysis tools, logbooks)



CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC-D-HCP-0001 rev 1.0

AB/AT/TS

477145

Date: 2004-09-29

Engineering Specification

GENERAL PROCEDURE FOR THE COMMISSIONING OF THE ELECTRICAL CIRCUITS OF A SECTOR

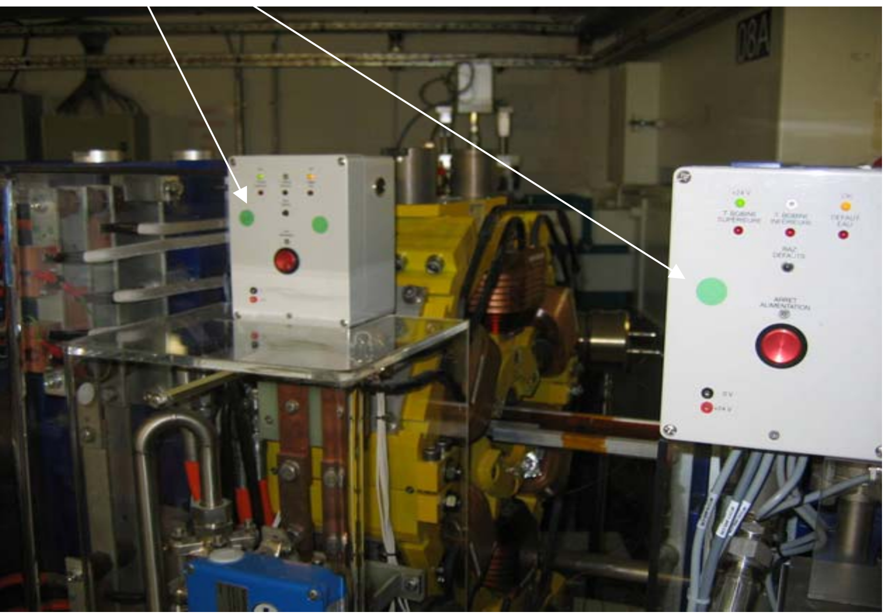
Abstract

This document describes the sequence of the steps which lead to the commissioning of the electrical circuits of each sector. It gives the backbone of the general procedures and refers to more detailed documents which in turn describe the individual system tests and hardware commissioning procedures.

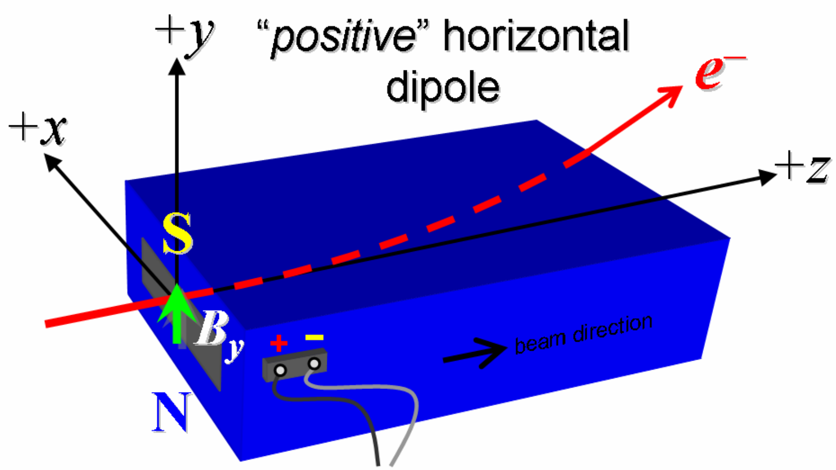
Prepared by :	Checked by :	Approved by :
Hardware Commissioning Working Group Davide Bozzini Knud Dahlerup-Petersen Reiner Denz Robin Lauckner Bruno Puccio Félix Rodriguez Mateos Roberto Saban Rüdiger Schmidt Hugues Thiesen Markus Zerlauth	Frédérick Bordry Paul Cruikshank Bertrand Frammery Joaquin Iñigo-Golfin Karl-Hubert Meß John Pedersen Luigi Serio Laurent Tavian	Paolo Ciriani Steve Myers Philippe Lebrun Paul Proudlock

LHC HWC Web Site:http://hcc.web.cern.ch/hcc/

Green stickers to validate the polarity of the magnet (SOLEIL)



Check the wiring (LHC)



Use of graphics for checking (LCLS)

Could only be revealed by the beam:

- Aperture limitations

- Polarity errors (if not identified during the control)

Lattice Modeling (1)

- A very accurate on-line optics modeling tested and ready for use before the start-up.

- Databases of the measured magnets used for a complete and trustworthy (non-)linear model.

- Good quality of magnetic measurements is then fundamental.

- Take into account:

additional focusing effects coming from magnets fringing field, gradient due to curved trajectory in BM and difference between entrance and exit edge, magnetic fields overlap between neighboring magnets...

Lattice Modeling (2)

SOLEIL : optimized bare lattice $\nu_x = 18.20$ $\nu_z = 10.30$

❖ Additional focusing effects deduced from magnetic measurements (Field mapping of 10 BM)

- BM fringing field
  - L = 0.1607 m
  - $\Delta\nu_z = -7.6\ 10^{-2}$
- Gradient due to curved trajectory
  - $\Delta B/B = +2.2\ 10^{-4}$ at x = +20 mm
  - $\Delta\nu_z = -8.5\ 10^{-2}$
- Difference between entrance and exit edges
  - $\Delta\theta = 0.3$ mrad (0.017°)
  - $\Delta\nu_z = +2.2\ 10^{-3}$

Compensation:

The 10 quadrupole families are used to restore:

Tunes
Optical Function Symmetry
Chromaticity shift

Lattice Modeling (3)

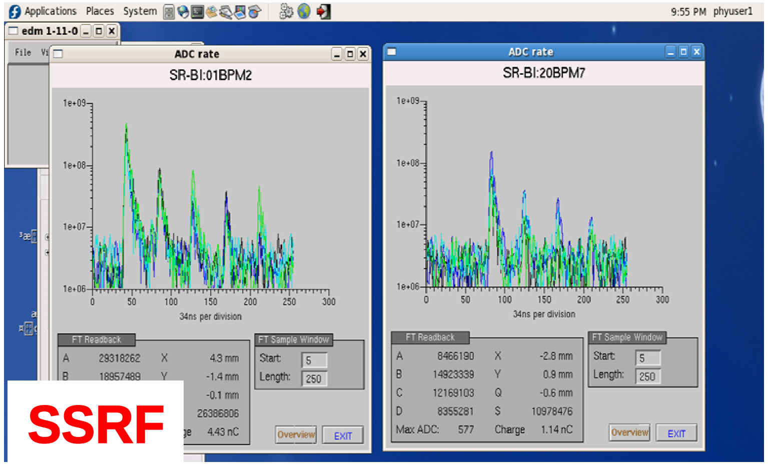
- During the first days, the correction of the beam trajectory, the tune adjustment, and the variation of the chromaticities will rely on the model response matrices.

  - ➡ facilitate the circulation of the first beam
  - ➡ provide accurate snapshot input for off-line or on-line evaluation

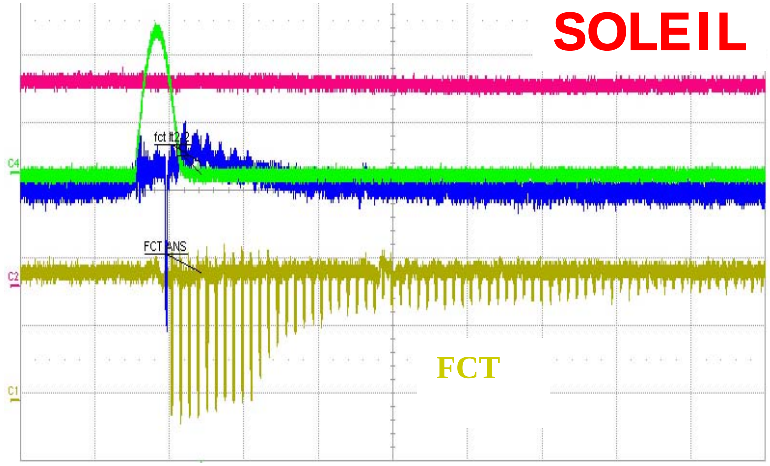
- Essential for the protection of the accelerator equipment.

  ➡ Example: The highly destructive power of the LHC beam, operating mainly in a superconducting environment, places stringent demands on the beam parameter control.

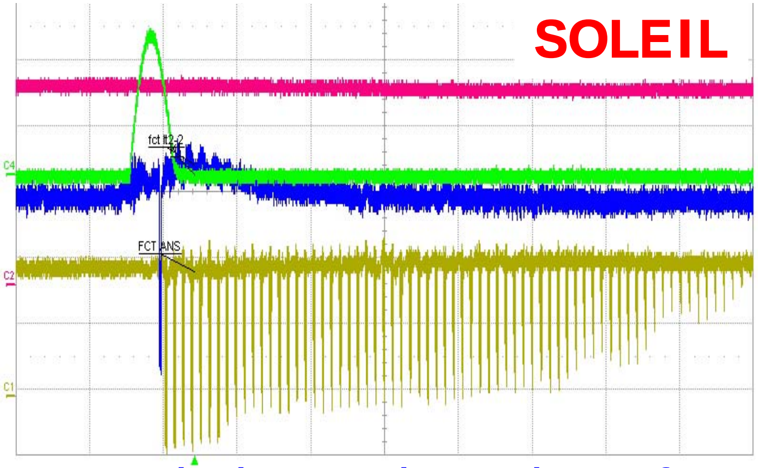
GETTING THE FIRST BEAM



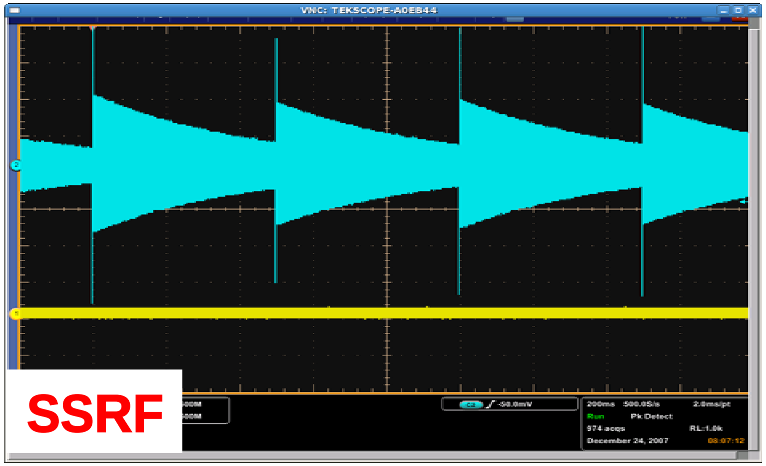
SSRF Storage Ring 5 first turns



50 turns with sextupoles and RF OFF

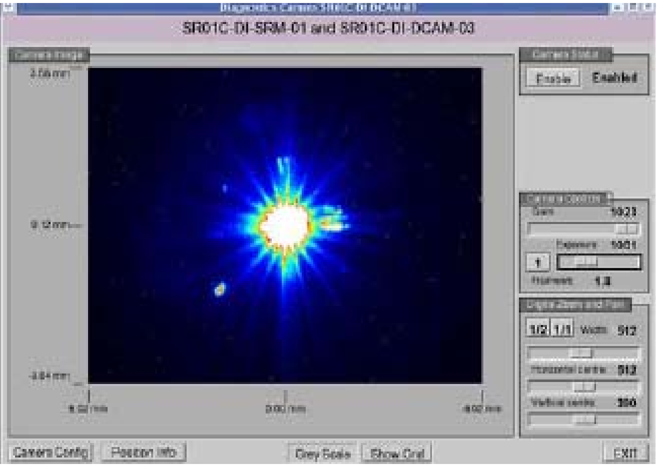


transmission and number of turns
improving after powering the sextupoles

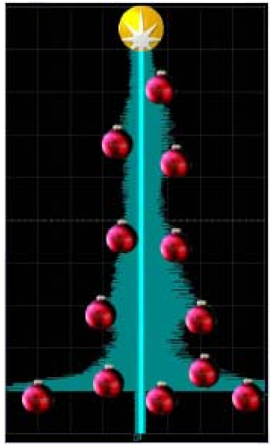


Stored beam

Unique, Exceptional, Historical, and highly emotional event!



DIAMOND



SOLEIL

SSRF

BEAM-BASED HARDWARE AND SOFTWARE CHECKOUT

- BPM offset measurements.
- BPM and Corrector polarity checking and calibration.
- Aperture scans.
- Orbit, current, radiation, instability,... interlocks.
- Machine protection validation.
- Optimizing and automating tune measurements.
- Calibration of the beam size measurement instrument.
- Calibrating the thresholds of the Beam Loss Monitors.
- Debugging and optimizing the main high level applications.

FIRST OPTICS STUDIES

Check and Correct the optics of the accelerator

- Beam Based Alignment
- Optimize RF frequency (circumference measurement)
- Response Matrices (orbit, tune, chromaticity)
- Beta functions at quadrupole locations and at BPMs
- Dispersion function
- Beam emittance and dimensions
- Betatron and synchrotron tunes
- Natural and corrected chromaticity
- Global and local coupling
- Momentum compaction factor
- Bunch length
- Energy spread
- Beam lifetime
- Momentum acceptance and dynamic aperture
- Effect of Insertion Devices
- …

LOCO code

- It is a (standard) tool for restoring the linear optics.

$$\sum_{i,j} \frac{\left(M_{\exp,ij} - M_{cal,ij}\right)^2}{\sigma_i^2}$$ is minimized in iterative process.

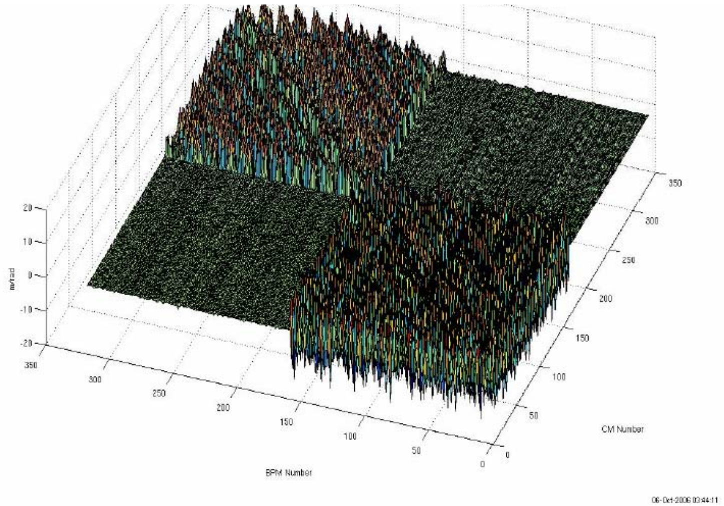
- Fits many parameters in an optics model, including quadrupole gradients, BPM and corrector calibrations.

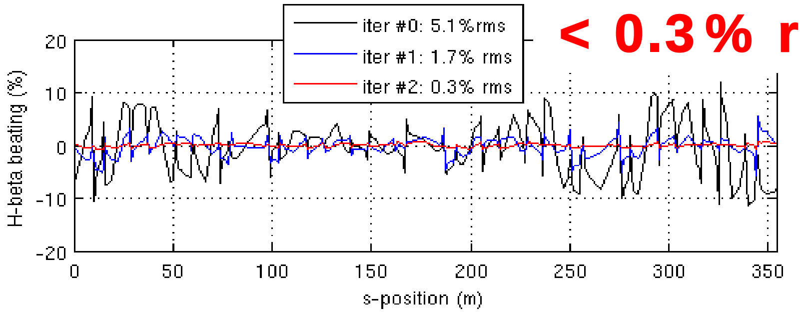
- Constraints for large machines: the large number of BPMs and correctors, the available computer memory, and CPU time.

- A response matrix using 120 BPMs and 56 correctors in both planes takes typically 25 min at SOLEIL. 896 parameters are used in the fitting.

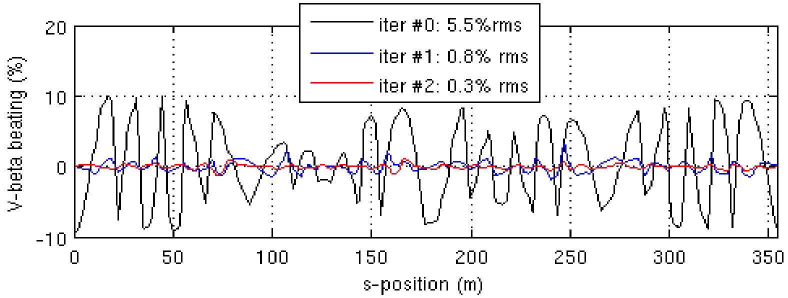
Some results after LOCO correction

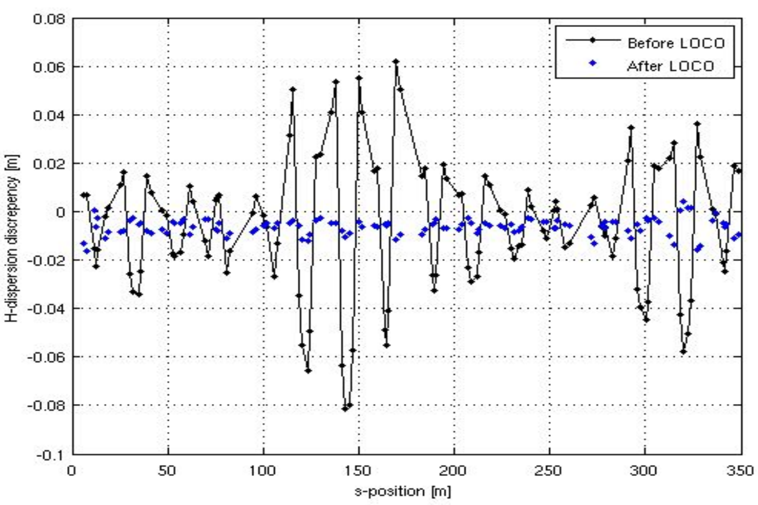
Full coupled orbit response matrix.

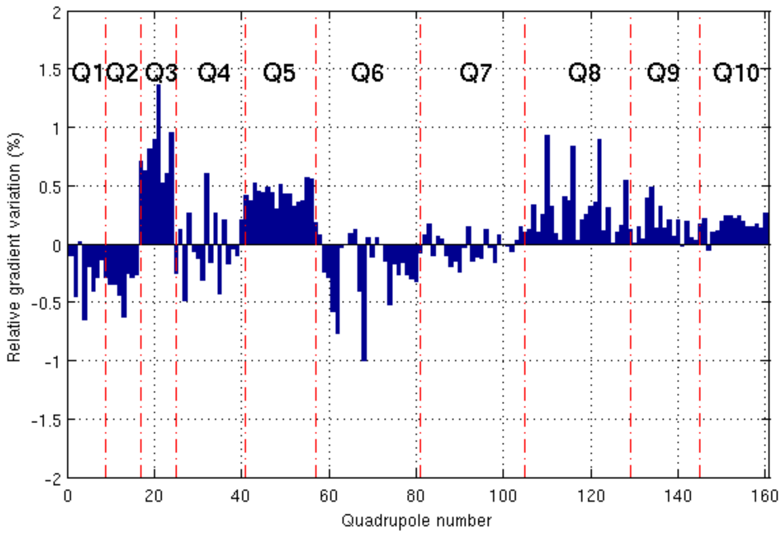




< 0.3 % rms

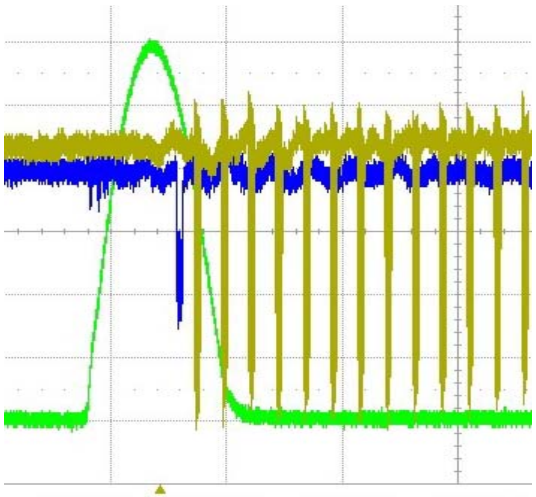






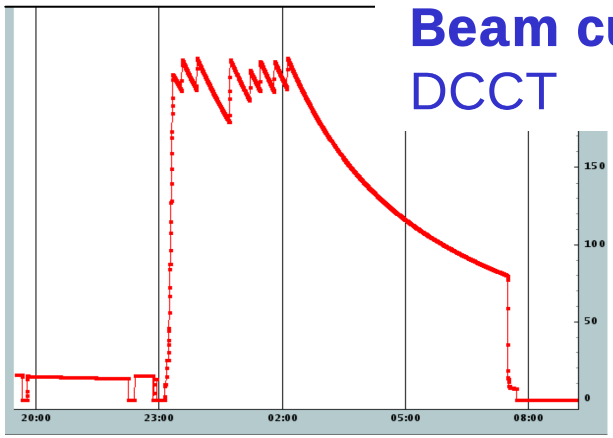
ROLE OF THE DIAGNOSTICS

➢ It is certain that excellent beam diagnostics make beam commissioning much easier. Ears and eyes in the control room.



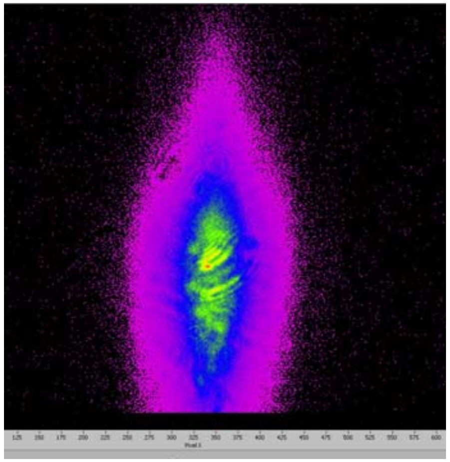
Beam current:

FCT (Turn by turn)



Beam current:

DCCT



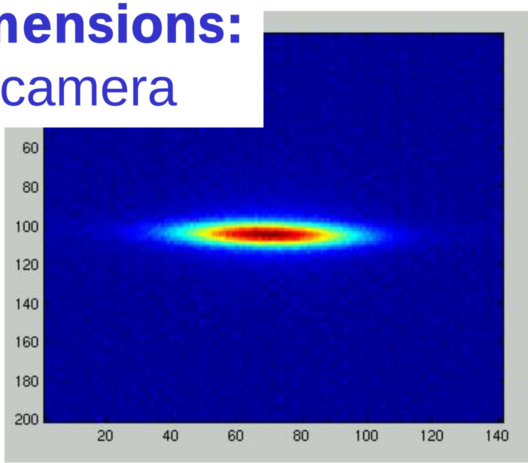
vertical beam excitation

Beam behaviour:

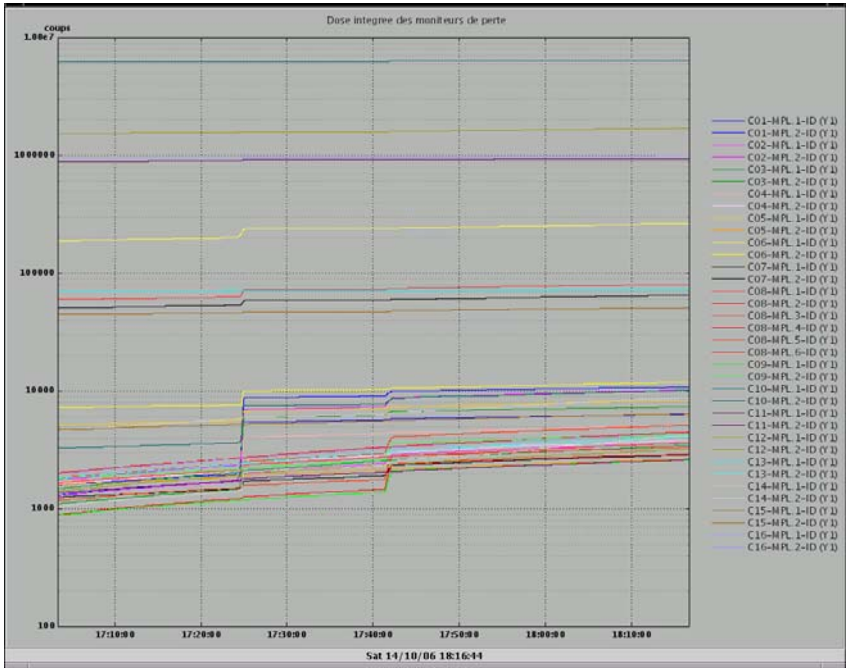
a visible light monitor

Beam dimensions:

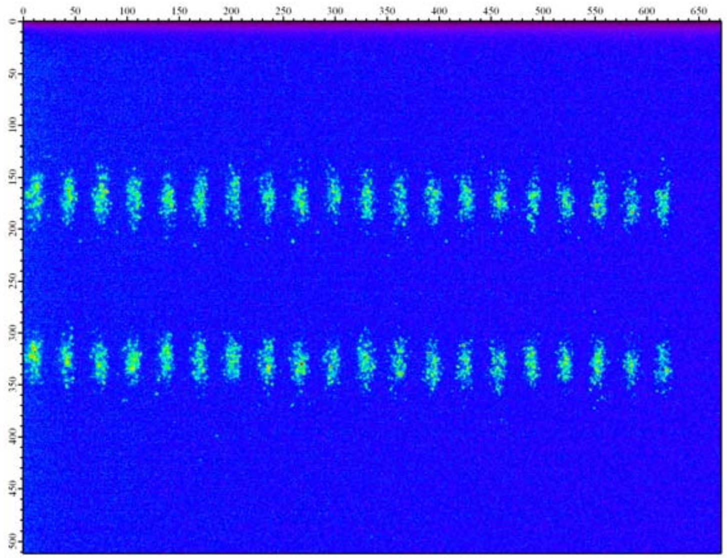
a pinhole camera



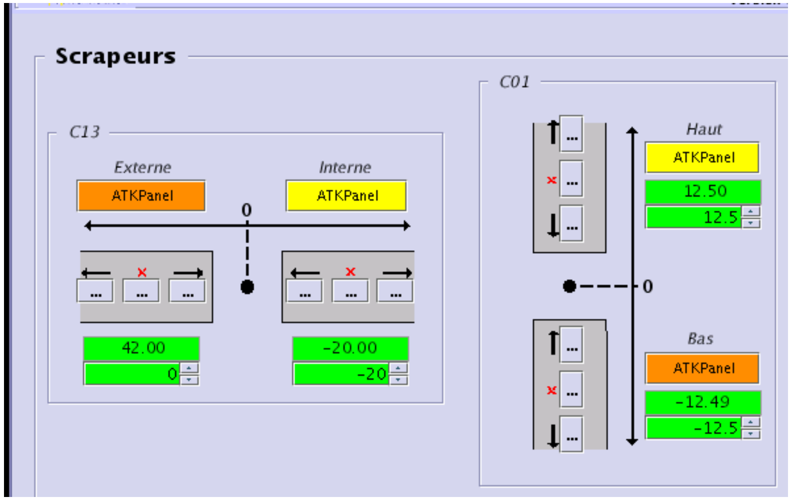
Beam Loss monitors:



Bunch length: a streak camera

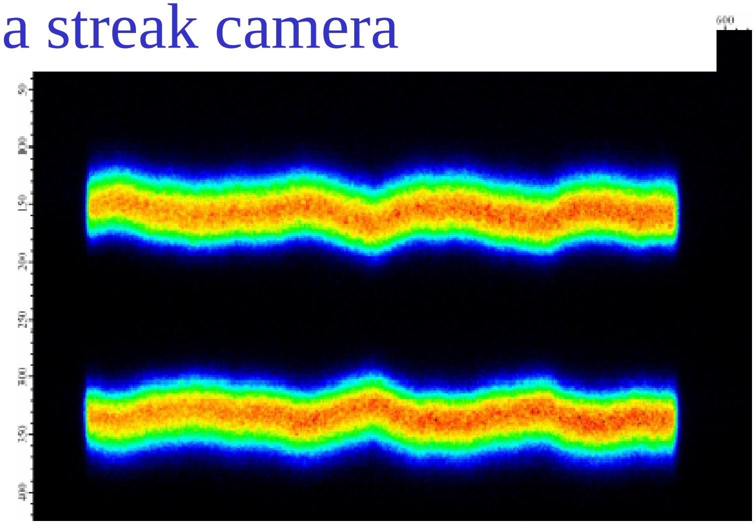


Kill the beam, acceptance: Scrapers



Longitudinal instabilities:

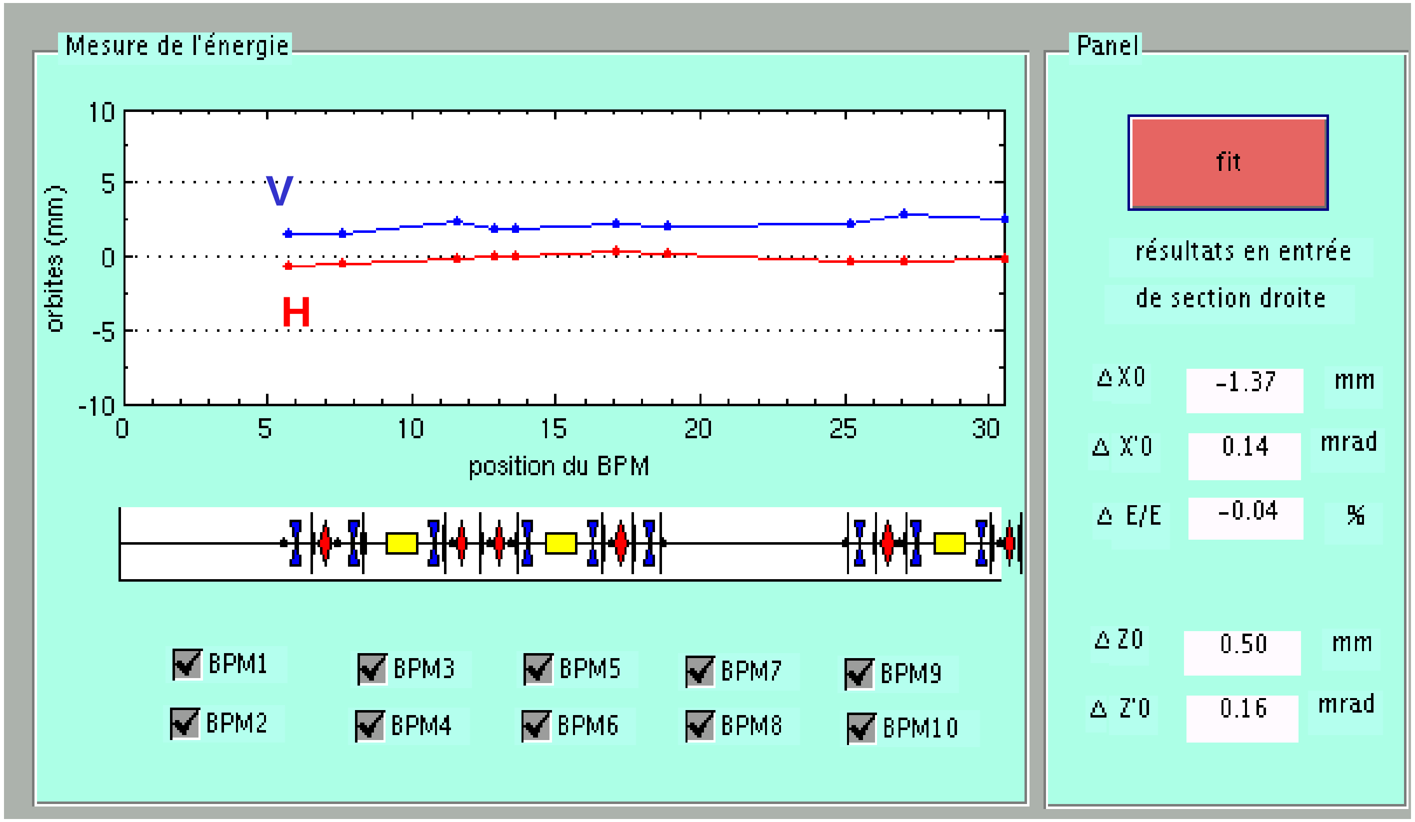
a streak camera



TURN-BY-TURN BPMS

(LIBERA BPM ELECTRONICS)

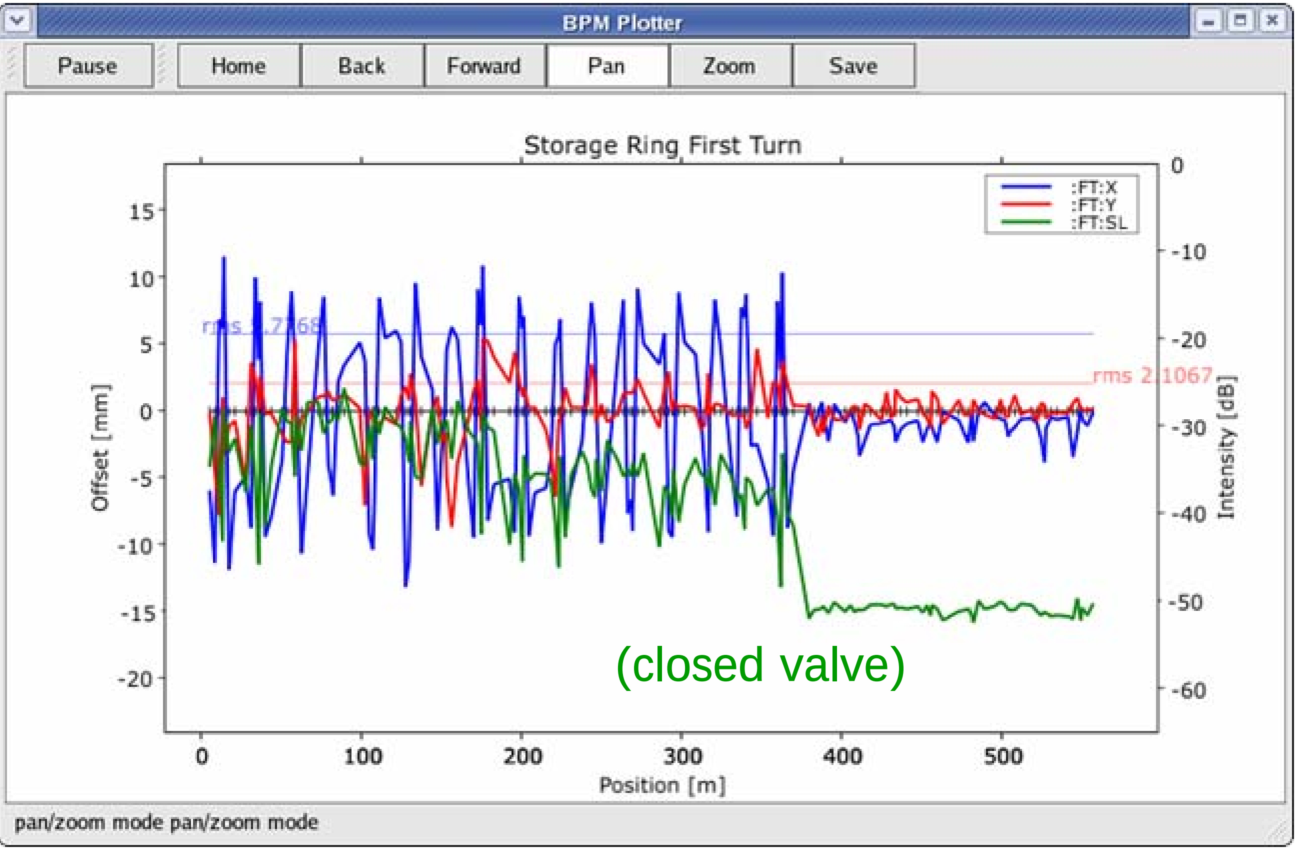
- Successfully used for the setting of the Bending Magnet current and for the tuning of the first turn.



TURN-BY-TURN BPMS

(LIBERA BPM ELECTRONICS)

❖ Allowed to understand quickly that some magnets were connected in the opposite direction, and helped investigate the location of obstacles in the beam path.



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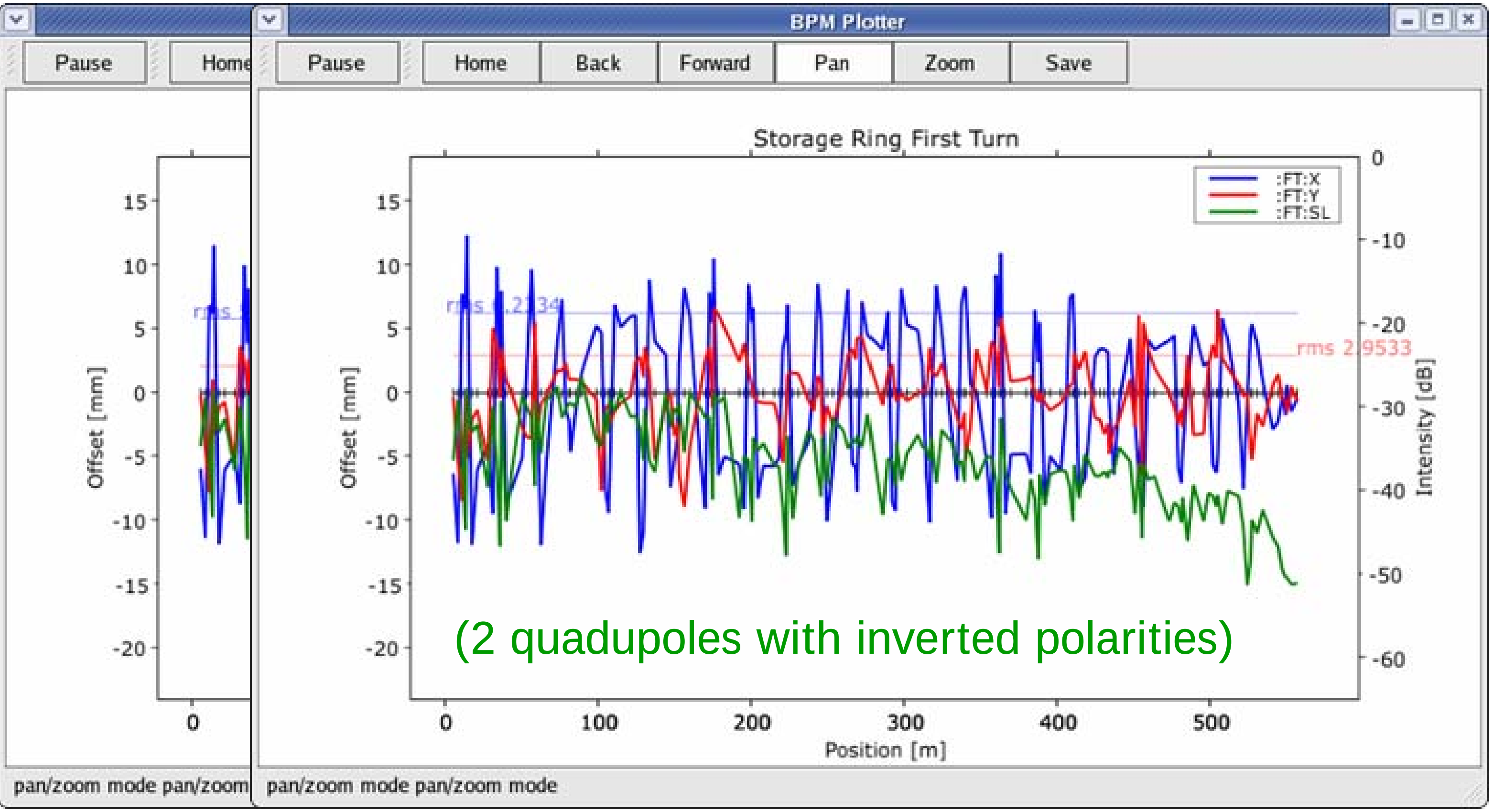

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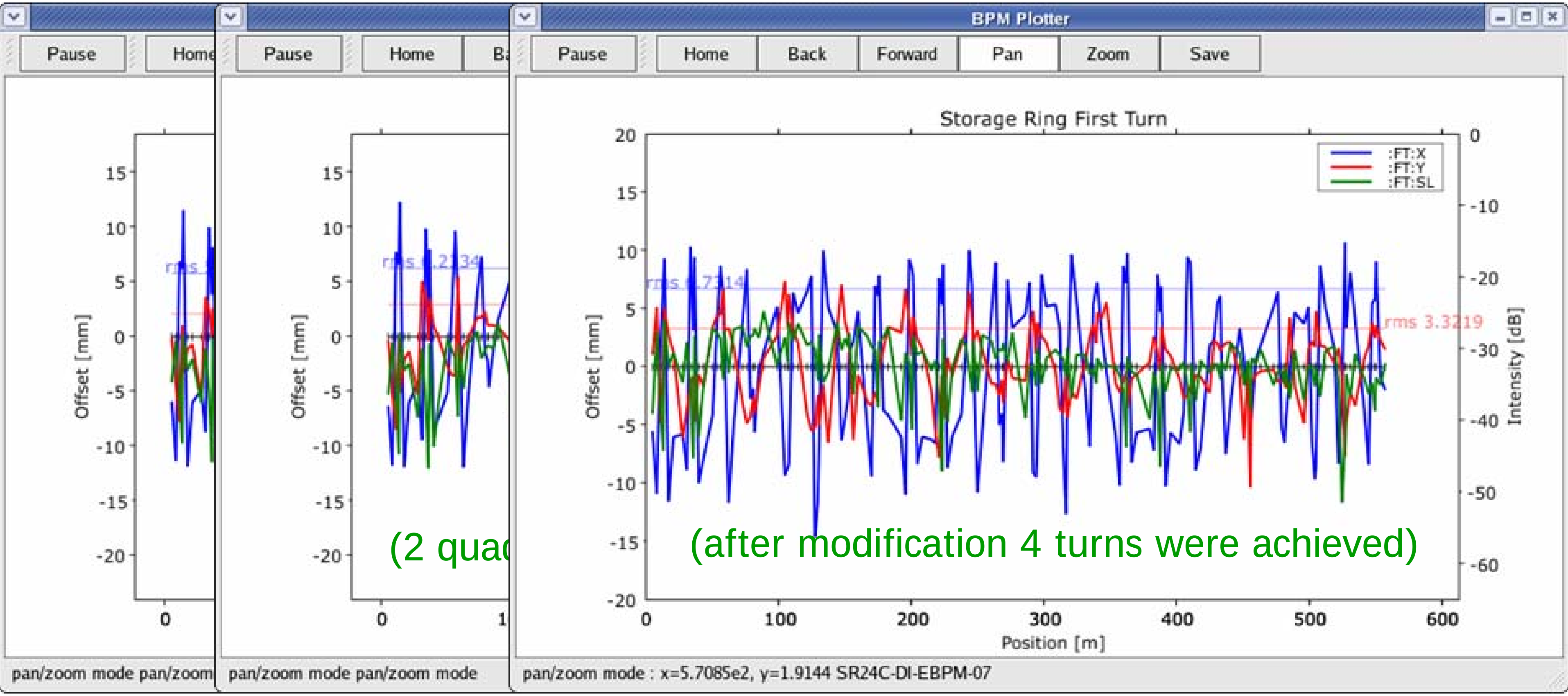
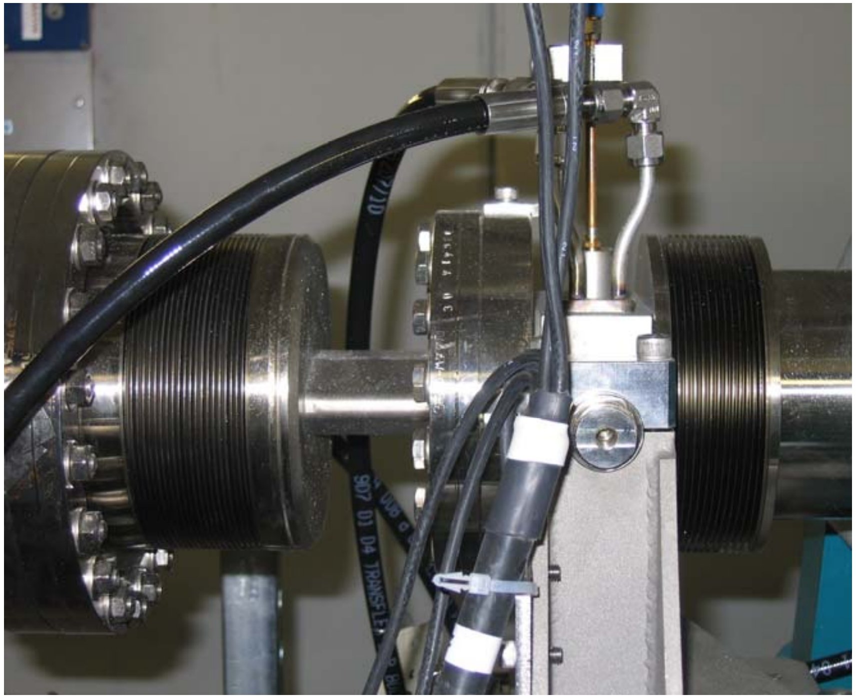


(Courtesy of R. Bartolini (**DIAMOND**))

Obstacles in the vacuum vessels

- **Problem of obstacle reducing the beam stay clear aperture**



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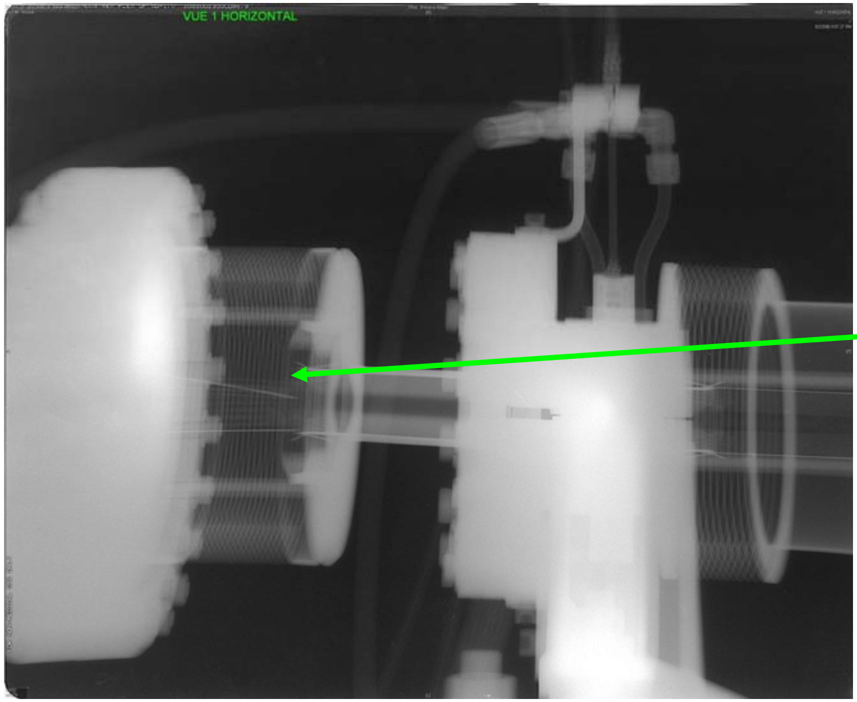
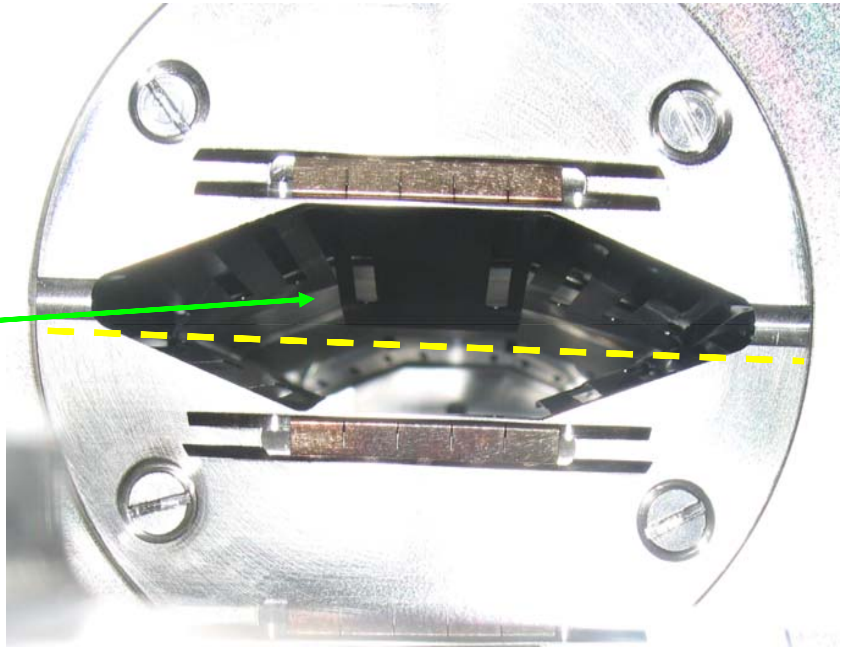




RF finger at 1.5 mm from the beam axis

Systematic bad mounting of RF Fingers in the short straight sections.

ROLE OF CONTROLS

➢A control system: « computing tool » dedicated to the implementation of distributed systems, heterogeneous and oriented control/command.

- **Distributed Systems?**

  The system components are geographically distributed on machines connected through a computing network

- **Heterogeneous Systems?**

  A coherent whole made from heterogeneous hardware and software

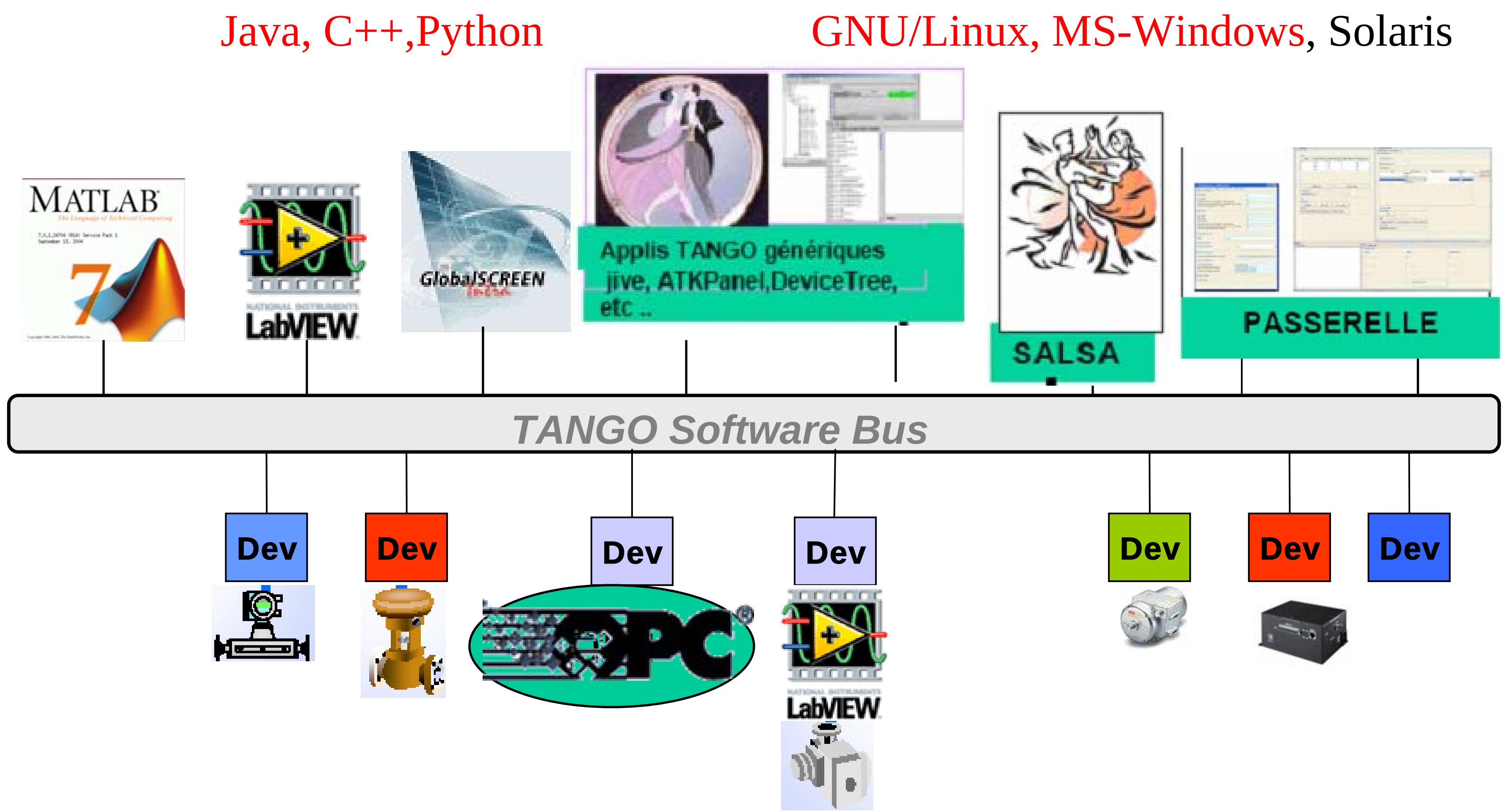
- **Oriented Systems ctrl/command?**

  Services adapted to a control system (storage, logging, alarms, ...)

➢ EPICS, TANGO and in-house built control systems.

TANGO @ SOLEIL

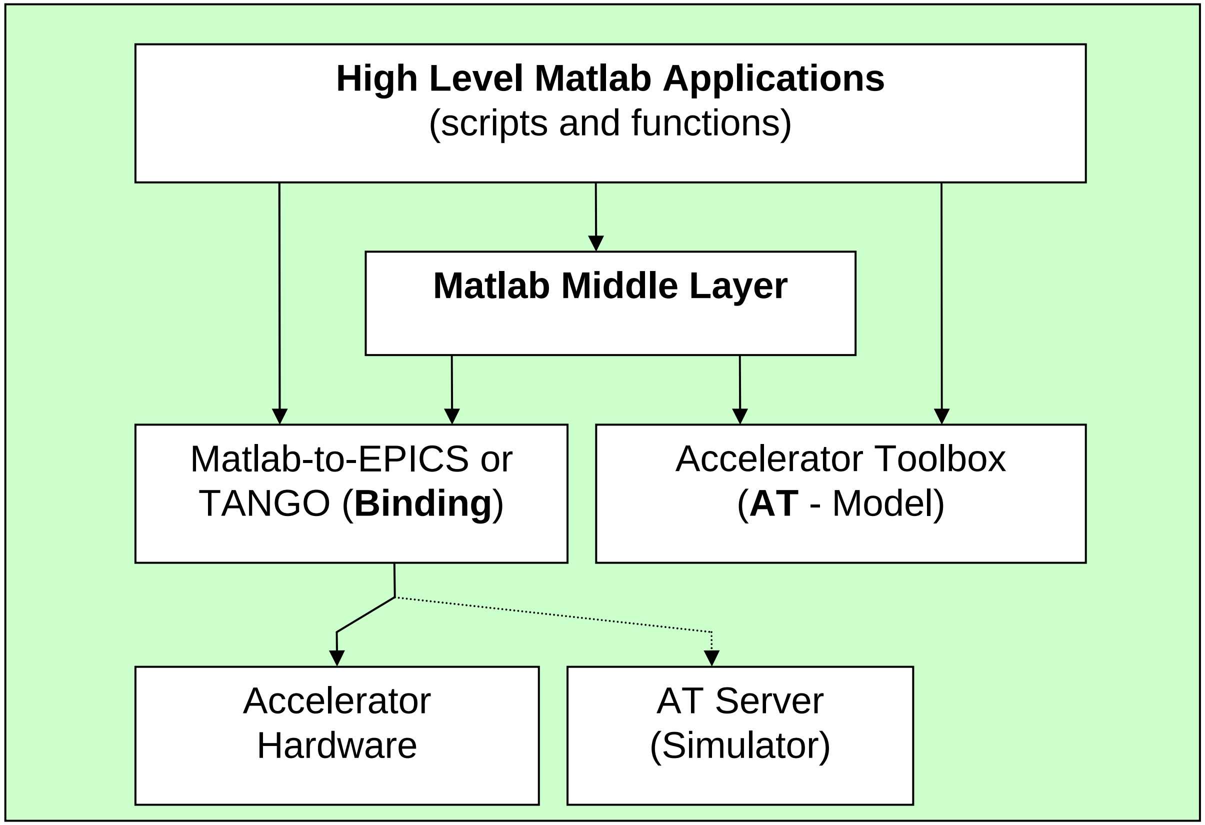
At SOLEIL, TANGO was used very successfully at full scale from Linac to Beamlines.



HIGH LEVEL APPLICATIONS

- SNS developed a Java high level application framework (XAL), which has been used also by J-PARC.

- Synchrotron light sources commissioning have benefited a lot from the **Matlab Middle Layer** applications.



Developed by

ALS and SSRL

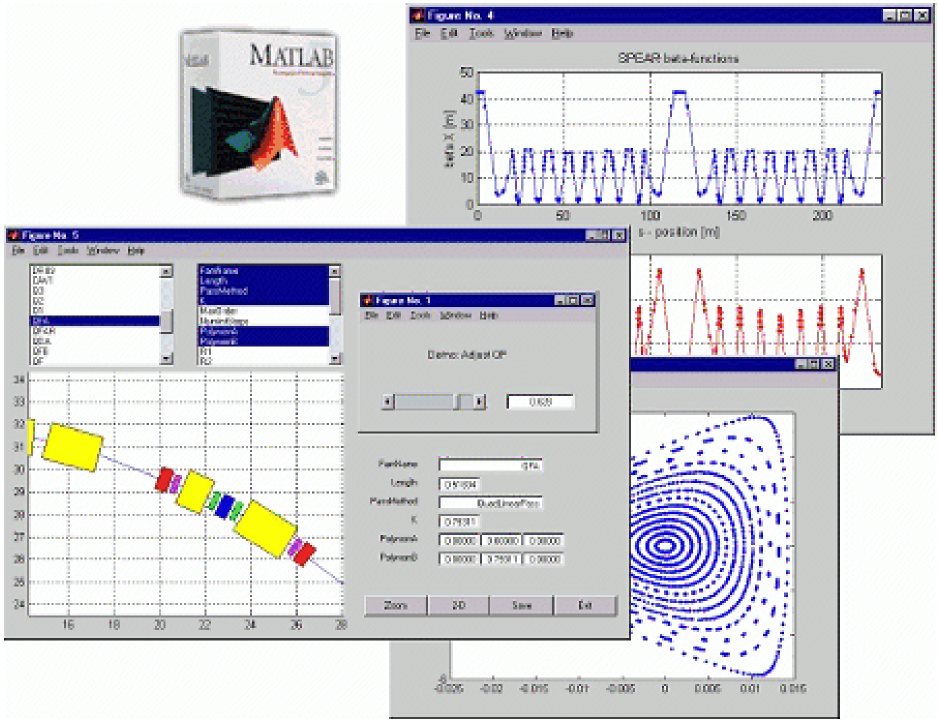
Contribution

SOLEIL

AT – Accelerator Toolbox

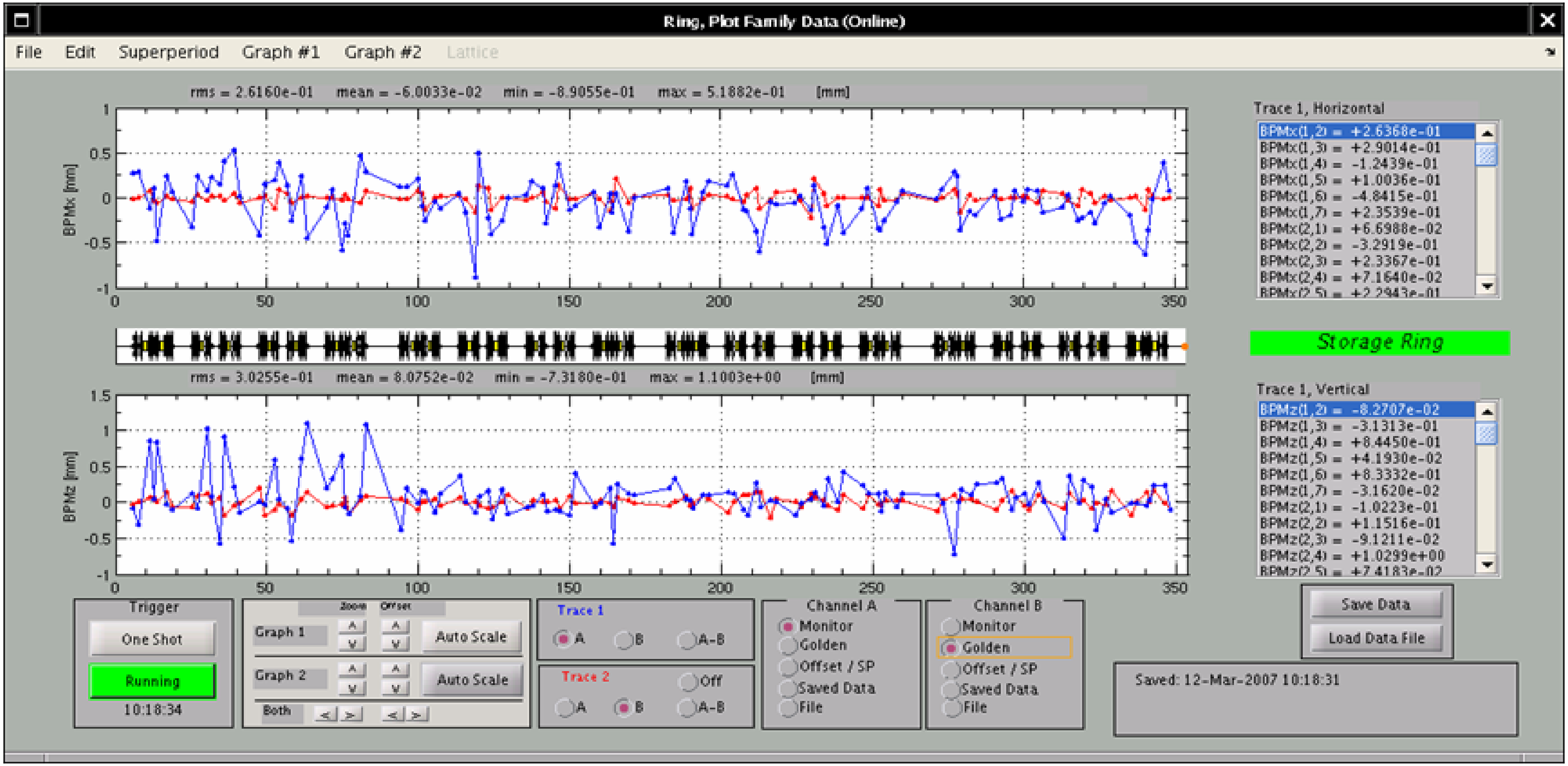
MATLAB ® Toolbox for Particle Accelerator Modeling

Accelerator Toolbox is a collection of tools to model particle accelerators and beam transport lines in MATLAB environment. It is being developed by Accelerator Physics Group at Stanford Synchrotron Radiation Laboratory for the ongoing design and future operation needs of SPEAR3 Synchrotron Light Source.

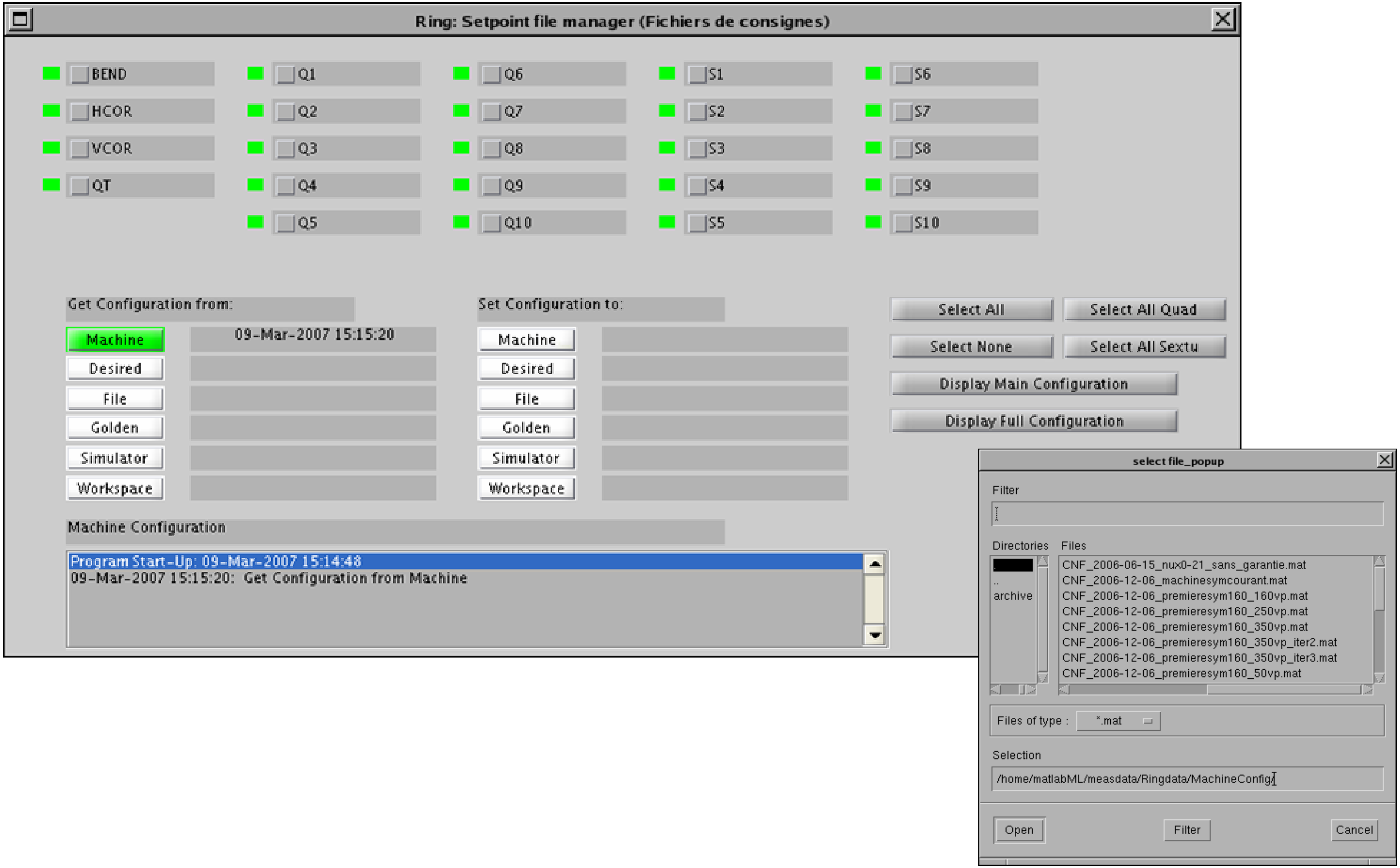


Andrei Terebilo: **www-ssrl.stanford.edu/at/welcome.html**
http://www.slac.stanford.edu/~terebilo/at/

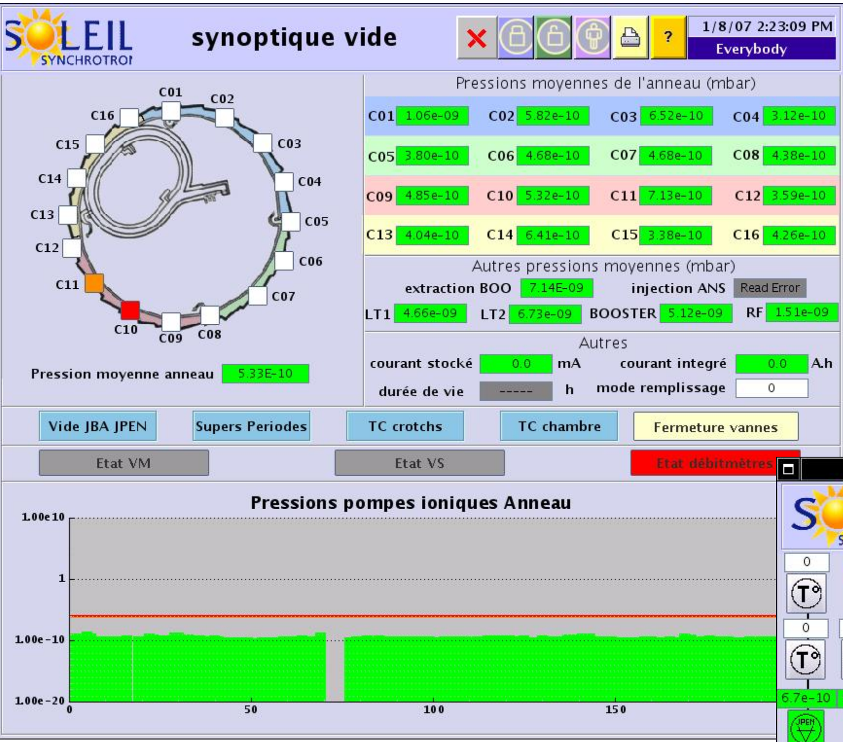
Displaying Closed Orbit

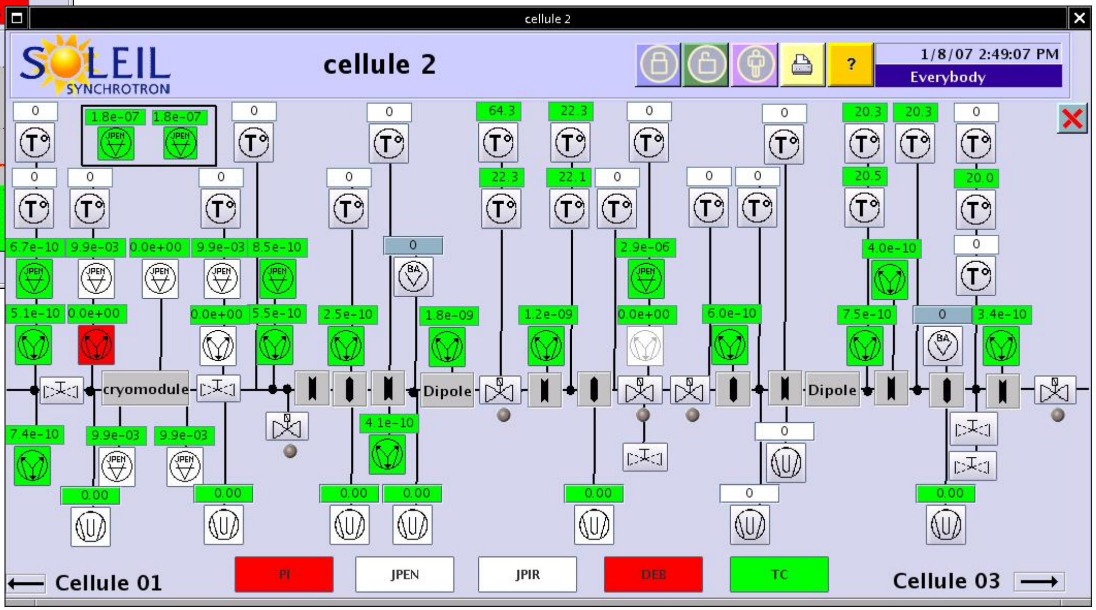


Save / Restore magnet setpoints



Vacuum System

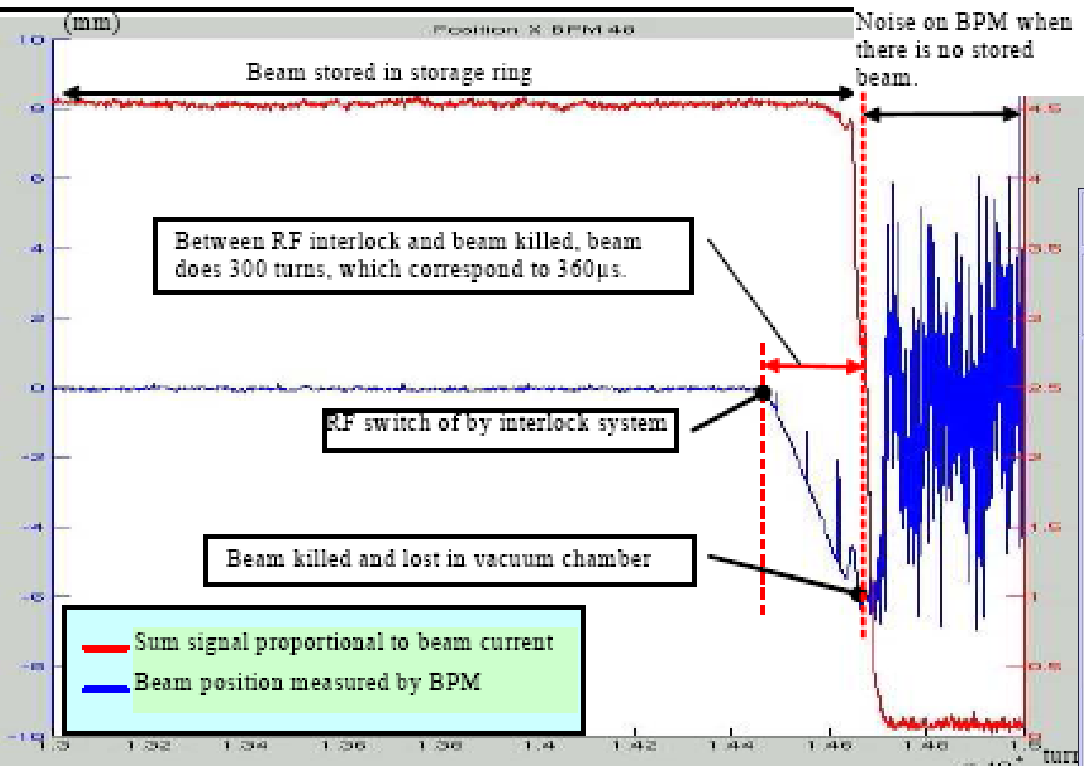


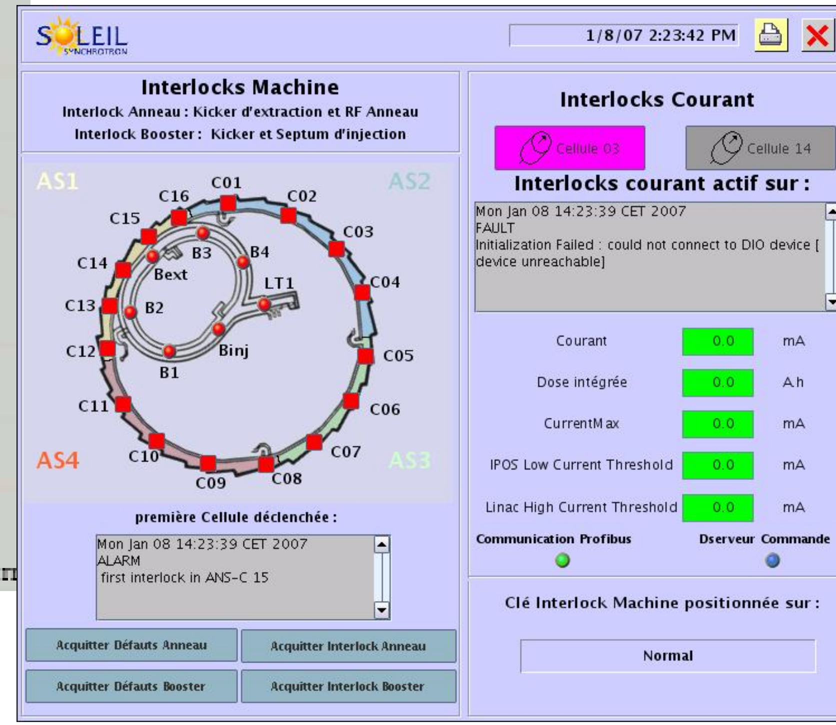


- 239 flowmeters
- 70 gauges
- 201 ion pumps
- 95 valves
- 327 thermocouples

✓Average pressure
✓Global state of a cell
✓Grouped command for closing all valves

Capacity to understand unexpected beam losses (postmortem systems, Machine Protection system)





Electronics logbook: machine (operation, vacuum, ID groups, BLs)

File Edit View Go Bookmarks Tools Help

http://elog:8081/cahier_machine/ Go

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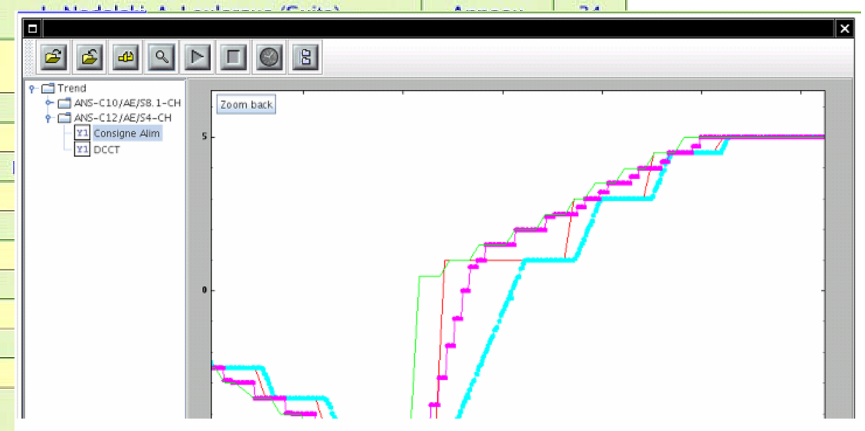
Responsable du livre de bord : groupe Physique Machine, Page 1 sur 3 ELOG

Créer | Chercher | Sélectionner | Importation CSV | Configuration | Aide

Détail | Résumé | Arborescence Afficher les entrées sur Toutes les entrées 41 Entrées

Aller à la page 1, 2, 3 Suivante Tous

Icone	Date	Sujet	Auteur	Accélérateur	ID
	06/06/06, 00:24	TOP-UP maison toutes les 10s avec 10 - 16 mA de 3H à 6H du matin	P. Lebasque, A. Loulergue	Anneau	41
	05/06/06, 16:46	Shift d'apès-midi du 5 juin 2006	R. Nagaoka+J.C. Denard+P.Marchand + A. Loulergue	Anneau	40
	05/06/06, 08:23	session machine lundi 5 juin 2006 7h - 15h	A. Nadji, MP. Level, P. Brunelle	Anneau	39
	05/06/06, 05:12	shift 23h - 7h de dimanche 4 au lundi 5 juin	JM Filhol, MA Tordeux et Alex reste un peu	Anneau	38
	04/06/06, 17:09	Shift 15 h - 23 h du 4 juin dimanche 2006	A. Loulergue + R. Nagaoka	Anneau	37
	04/06/06, 09:16	dimanche 4 juin: 7h - 15h	L. Nadolski, A. Madur	Anneau	36
	03/06/06, 22:28	samedi soir	A. Nadji + JM. Filhol	Anneau	35
	03/06/06, 18:47	18h50 - 23h samedi 3 juin : Correction orbite mode anneau, changement nombre d'onde			
	03/06/06, 16:54	shift 15h-18h samedi 3 juin : Correction orbite mode anneau, changement nombre d'onde			
	03/06/06, 11:04	shift 7h - 15h du samedi 3 juin			
	03/06/06, 00:18	Continuation Session 2 (shift de nuit 02 juin vendredi - 03 juin samedi)			
	02/06/06, 20:28	shift 15h-23h du vendredi 2 juin			
	02/06/06, 00:54	Session machine 23h - 7h du jeudi 1 juin 2006			
	01/06/06, 19:59	shift 15h-23h			
	01/06/06, 01:43	Session Machine 23h - 7h mercredi 31/05/06			
	31/05/06, 23:18	fichier de bump d'Alex et Amor			
	31/05/06, 19:24	session1 du protocole semaine 22 (continuation)			
	31/05/06, 00:42	Shift de Nuit 30-31 mai 2006 (test de la radioprotection)			
	30/05/06, 18:37	démarrage			
	14/05/06, 16:01	Run machien dimanche 14 mai 2006			



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ELOG V2.6.0-beta

ORGANIZATION (1)

- A coordinator with a central team is generally in charge of leading the accelerator commissioning with beam.

For round the  operation. (3 shifts of 8 hours per day)

- Not restricted to accelerator physicists but has to include, since the early stages, representatives of the technical teams.

➡allows for interdisciplinary interactions to better identify and solve encountered problems

ORGANIZATION (2)

- **Necessary training**
  - Global view of main equipment operation
  - Radiation safety
  - High level applications
  - Other systems control software

- **Detailed plan**
  - Step by step
  - Necessary condition for each step
  - Goal for each step
  - Possible trouble in each step
  - Backup solution
  - Flexible

ORGANIZATION (3)

- A detailed protocol for each shift.
- Shift crews.
- An overlap of a minimum of half an hour between two successive shift members.
- Weekly commissioning meetings.
- A meeting following each blocking point.
- Reporting progress and problems to the wider community.

LTC Dec 14th : LHC commissioning organisation

R.Bailey
M.Lamont
(O.Bruning)
(P.Collier)

Machine Coordinator
Weekly responsibility
3 needed

G.Arduini
R.Assmann
M.Giovannozzi
S.Fartoukh
J.Uythoven
J.Wenninger
F.Zimmermann

Accelerator Systems
As required
Defined responsibilities

Commissioner
Scheduled shifts years 1,2
Pool of at least 7 needed

Accelerator system
Activity 1
Activity 2
Activity n

S.Redaelli	01.06
M.Gruwe	01.06
EIC3	07.06
EIC4	07.06
EIC5	01.07
EIC6	01.07
EIC7	01.07

EIC
Scheduled shifts long term
7 needed

Operator
Scheduled shifts long term
7 needed

M.Albert
G.Crockford
R.Giachino
G.H.Hemelsoet
D.Jacquet
L.Normann
F.Pirotte
R.Suykerbuyk
E.Veyrunes

(Courtesy of R. Bailey (LHC))

Don’t neglect Infrastructure!

SOLEIL: water cooling problem due to presence of resin balls blocking the magnet filters

⇨ **Cooling repetitive interlocks**

DIAMOND: water supply and quality problems ⇨ commissioning of the Booster at 700 MeV without any cooling water at all.

LHC: Delay due to problems in QRL.

TOP LESSONS (1)

- Keep the commissioning simple, and phase it.

- Wait for completion of installation and test of equipment before moving to the commissioning.

- Make sure first order simple functions work first.

- Allocate some time in between beam commissioning shifts to analyze data and modify software or hardware.

- The availability of more than one central team member on shifts (in addition to the operator) is very useful. This helps in communicating knowledge, and combining people's skills and experiences to promote new ideas and approaches.

TOP LESSONS (2)

- A tool to easily save and restore machine settings for good tunes is imperative

- It is important to carefully document in the Electronic log book all failures of equipment and their causes, to help associated colleagues to better understand the problems and their remedies.

CONCLUSIONS

❖ The most recent commissioning of accelerators have been performed in much shorter time than it used to be before.

❖ This is due to a careful preparation of the phase before the beam, a much more detailed, extensive, and accurate modeling and analysis, a robust control system, and an excellent set of diagnostics **ready on day one.**

❖ Additionally, as it is expected in any projects, the tremendous enthusiasm enables to overcome rapidly most of the difficulties that may arise.

CONCLUSIONS

The commissioning phase is a real team effort requiring great communications and very cooperative spirits.

Thank you for listening