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2nd BrightnESS Best Practice Workshop:

Installation aspects of large-scale In-Kind projects

Hardware Commissioning

The LHC Experience

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www.europeanspallationsource.se

This is a 9 years old story

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Commissioning is about Machine Protection *(and safety)*

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Main lesson learnt after 15 years working on this:

Everybody knows about machine protection and safety

Everybody knows about commissioning

… especially management

Explanation:

everybody thinks she/he has done it before and

everybody thinks her/his system is the most critical one and needs a better protection

everybody thinks it's easy

Commissioning is about Machine Protection *(and safety)*

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The general opinions above may be true when it comes to:

- Small projects
- Large projects built with well-known technology systems

But they become dangerous when dealing with

- Large projects with unique technology systems
- Complex high dependability protection systems
- Large projects 'running late'

Specially devoted team, leadership, methods and tools are essential for the implementation of a reliable machine protection system and the safe and efficient commissioning of the machine

Commissioning is about Machine Protection *(and safety)*

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Why Commissioning and Protection?

The commissioning of a machine not only concerns the protection systems but it shall be focused on them:

- ✓ Commissioning may be completed without all the systems tested (some things can be postponed to operational campaign), however,
- ✓ Commissioning cannot be completed until all the required protection systems have been validated

It is a simple sequence:

- ✓ First you check your safety net
- ✓ Then you can start playing

How to validate a protection system:

1. Risk Zero Validation: dry-runs, simulations.
2. Moderated Risk Validation: progressive validation from zero to nominal hazard.

The commissioning of a complex high dependability system requires a mix of (1) and (2) and a clear set of rules and policies to avoid increasing the accepted risk

The hardware commissioning of CERN's Large Hadron Collider is a good example.

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The LHC Hardware Commissioning was a 6-year long project

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The LHC Hardware Commissioning started its field activities during 2005 when first beam was planned for end of 2007 or beginning of 2008.

However, planning of activities, preparation of quality and tests procedures, specification of IT tools and gathering of a commissioning team started two years before in 2003

LHC Commissioning overlapped with machine installation during the first years and beam operation during 2008 and 2009

Machine was geographically divided in 8 sectors that could be treated 'almost' independently from each other from the cryogenics and magnet powering point of view. The LHC commissioning was therefore transformed in the commissioning of 8 different accelerators. This eased the overlap with installation and the distribution of resources

The LHC Hardware Commissioning Team delivered the machine to Operations for first beams on 10 Sept 2008

The LHC Hardware Commissioning team was in charge of all field and control room activities

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The LHC Commissioning Team coordinated the:

Individual System Tests (IST) of the machine systems

Electrical Quality Assurance Test (ElQA) at room temperature

Machine pressure and leak tests

Machine cooldown

ElQA tests at cold

Powering Interlock tests at Zero Risk

Powering Interlock tests at Moderate Risk

Powering Tests of the superconducting magnets at cold including magnet first trainings

Machine dry-runs

Hand-over to machine operation

So… what did we need?

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- ✓ A commissioning coordination team (which does not need to be the Operations team) with enough authority in the offices and in the field
- ✓ An approved set of test and commissioning procedures
- ✓ A schedule and resource allocation plan
- ✓ A commissioning-adapted machine protection system
- ✓ A management that receives regularly reports and set the goals but does not interfere in the procedures
- ✓ IT tools for execution, coordination, information, follow-up and QA

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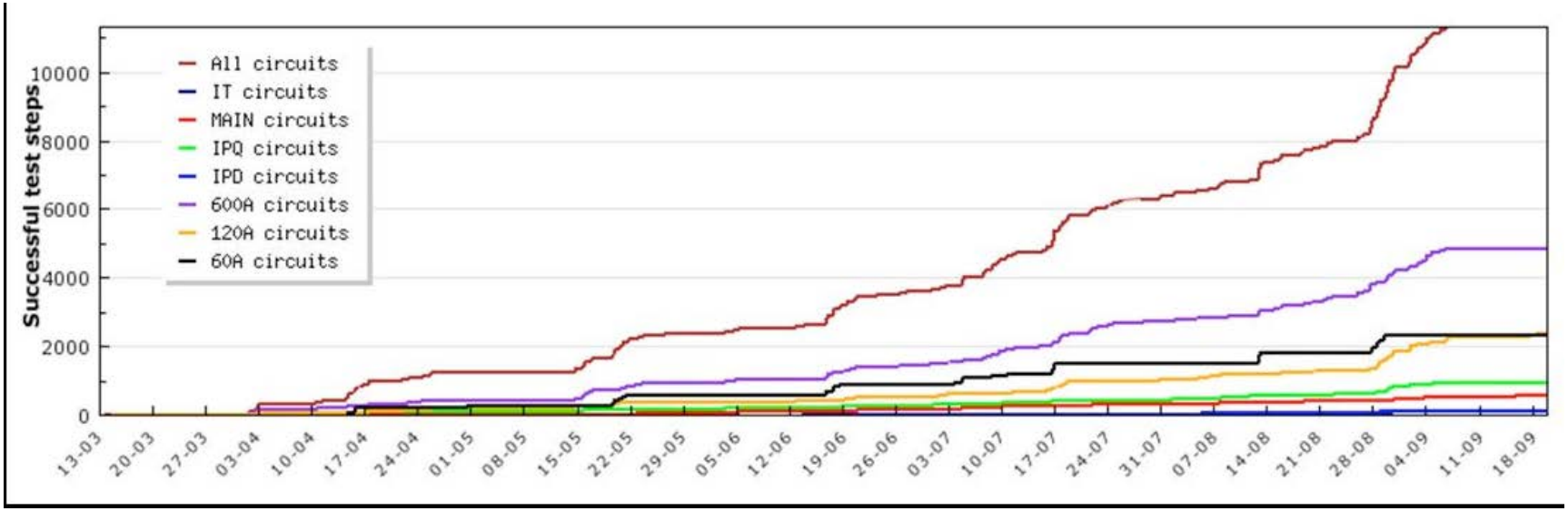
Schedule and Progress Monitoring



Optimization of the powering tests of the LHC superconducting circuits. Particle Accelerator Conference 2009, Vancouver, Canada, 04 - 08 May 2009, pp.WE6RFP049, M.Solfaroli et al.

Schedule and Progress Monitoring

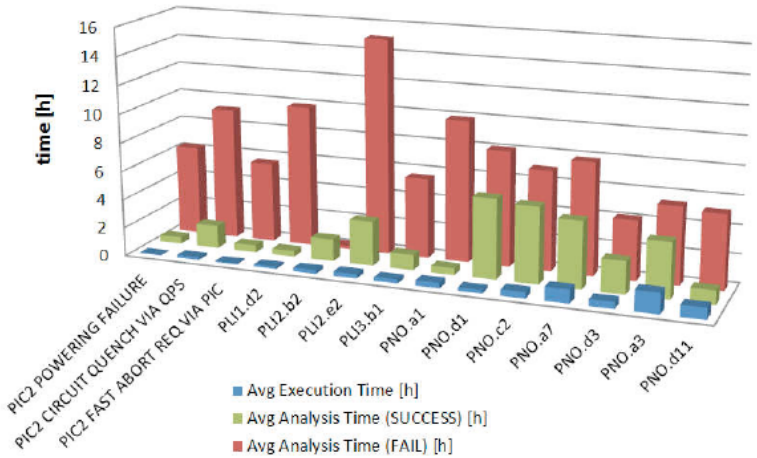


Figure 4: Average analysis times.

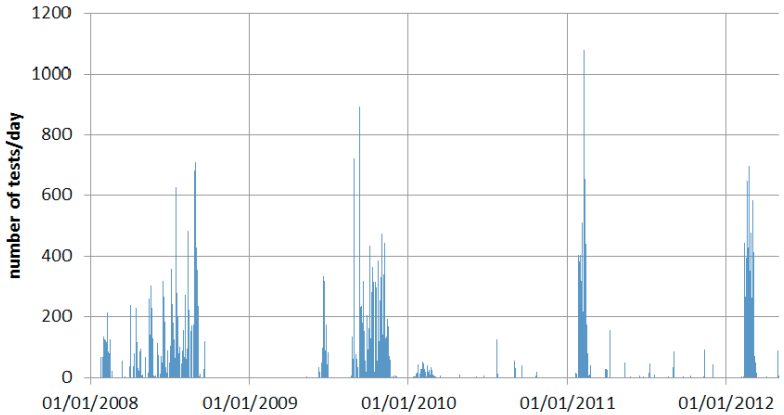


Figure 3: Executed tests per day between 01 Jan 2008 and 30 April 2012.

Automated Execution and Tracking of the LHC Commissioning tests. CERN ATS-2012-205 - K.Fuchsberger et al.

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Information Tools

DATA ACQUISITION SYSTEM	PURPOSE	Acquisition Rate	Data Volume	Importance for operation
SCADA supervisory systems	**Real-time supervisory tools** (Java, PVSS)	On change	> 10s of kB-MB / day, local archive, then sent to long term storage	High – Used daily for supervision of MPS systems
DIAMON	**Diagnostic and monitoring of controls infrastructure**	infrequent	Few 10s of changes per day	Medium, used for online monitoring of controls infrastructure, power supplies, FE processes, ….
ALARM System	**Alarms service** (for technical infrastructure,..)	infrequent	> 10.000 Alarms per day	Not used (yet), no efficient alarm filtering available …
Measurement Database	Continuous Logging of equipment system	**Few Hz**	> GB /day, kept for 7 days only	High - Not used for MPS (identical concept as Logging DB)
Logging Database	Logging system for equipment systems, slower response time	On change, but typically <1Hz	**> 100 GB / day**, kept for LHC lifetime	Very High – Used daily for performance evaluation
Post Mortem	**Transient data analysis** after powering or beam dump events	**>kHz/MHz**, < intervals around interesting events	> 1 GB / beam dump event, kept for LHC lifetime	Very High – Used daily for performance evaluation

Courtesy of Markus Zerlauth (CERN)

picHMI_1: picHMI

PIC SUPERVISION v5.6

LHC Powering Interlocks System

12:09:17 AM 03/25/2010

Point 4

CMS
Point 5

Point 6

ALICE
Point 2

ATLAS
Point 1

LHCb
Point 8

CIP MASKED INFO

CRYO_START	NOT Masked
CRYO_MAINTAIN	NOT Masked
CRYO_OK_ISA	NOT Masked
QPS_OK	NOT Masked
UPS_OK	NOT Masked
AUX3_OK	NOT Masked
CRC_OK	Masked

POST MORTEM INFO

TRIGGER	LAST ACQUITC
Multiple triggers	24/03/2010 17:17:15

CIRCUITS INFO

LOCKS	36
SUPER LOCKS	6

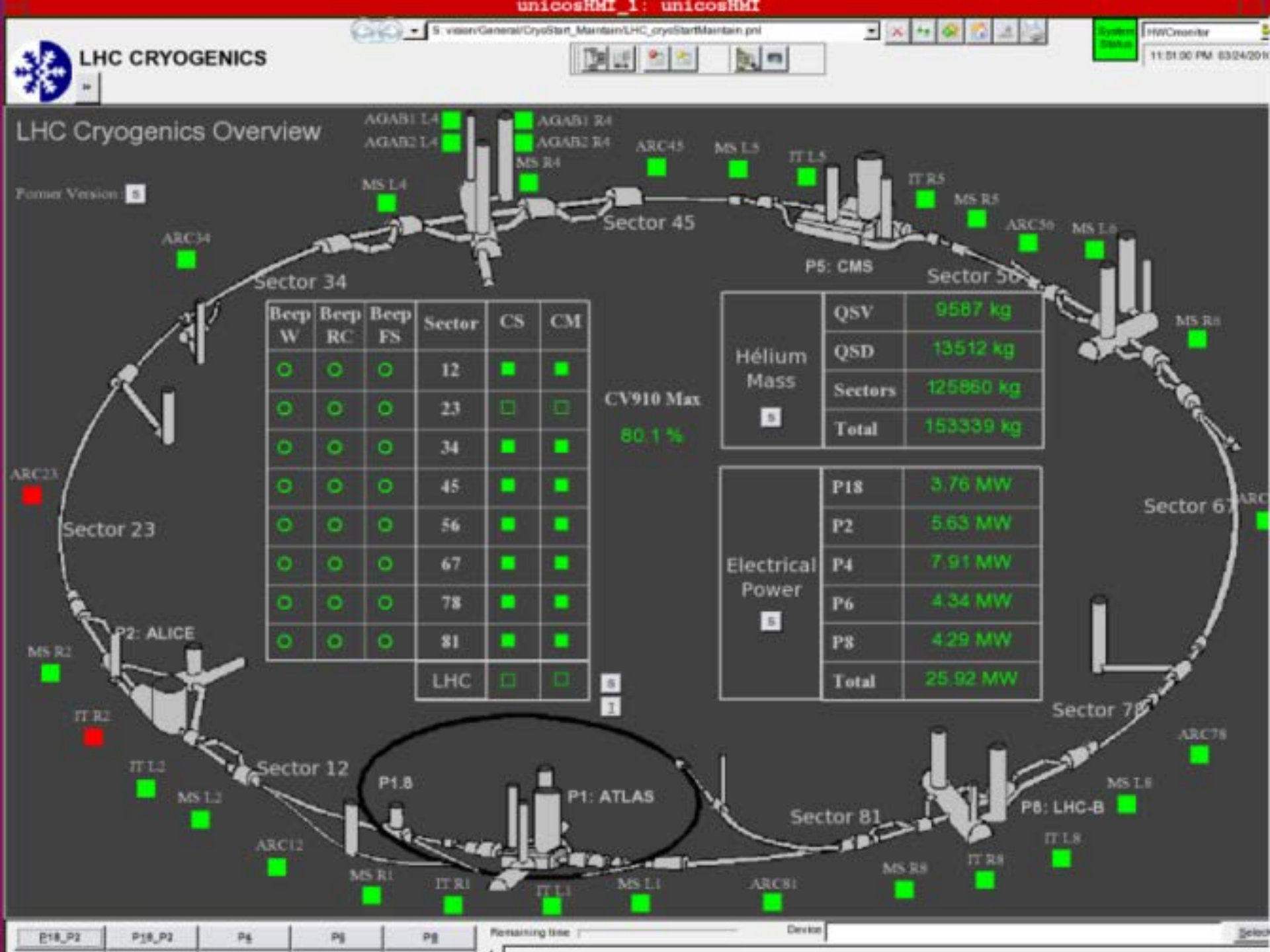
	812	923	034	145	256	667	678	081
PPSSA	Permit	Permit	Permit	Permit	Permit	Permit	Permit	Permit
SECTOR ACCESS	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed

Remaining time

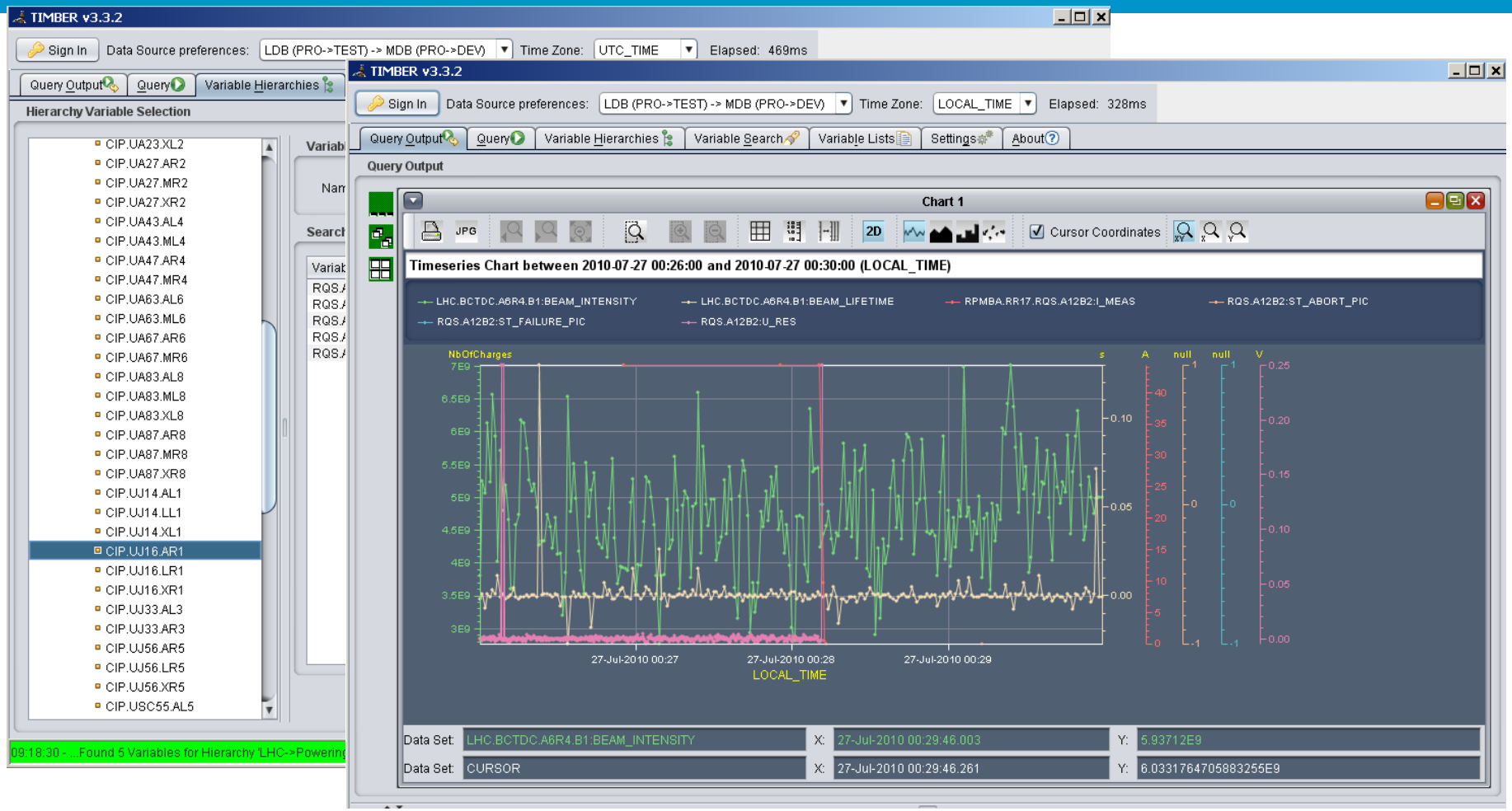
Device

Select

Actions Logbook

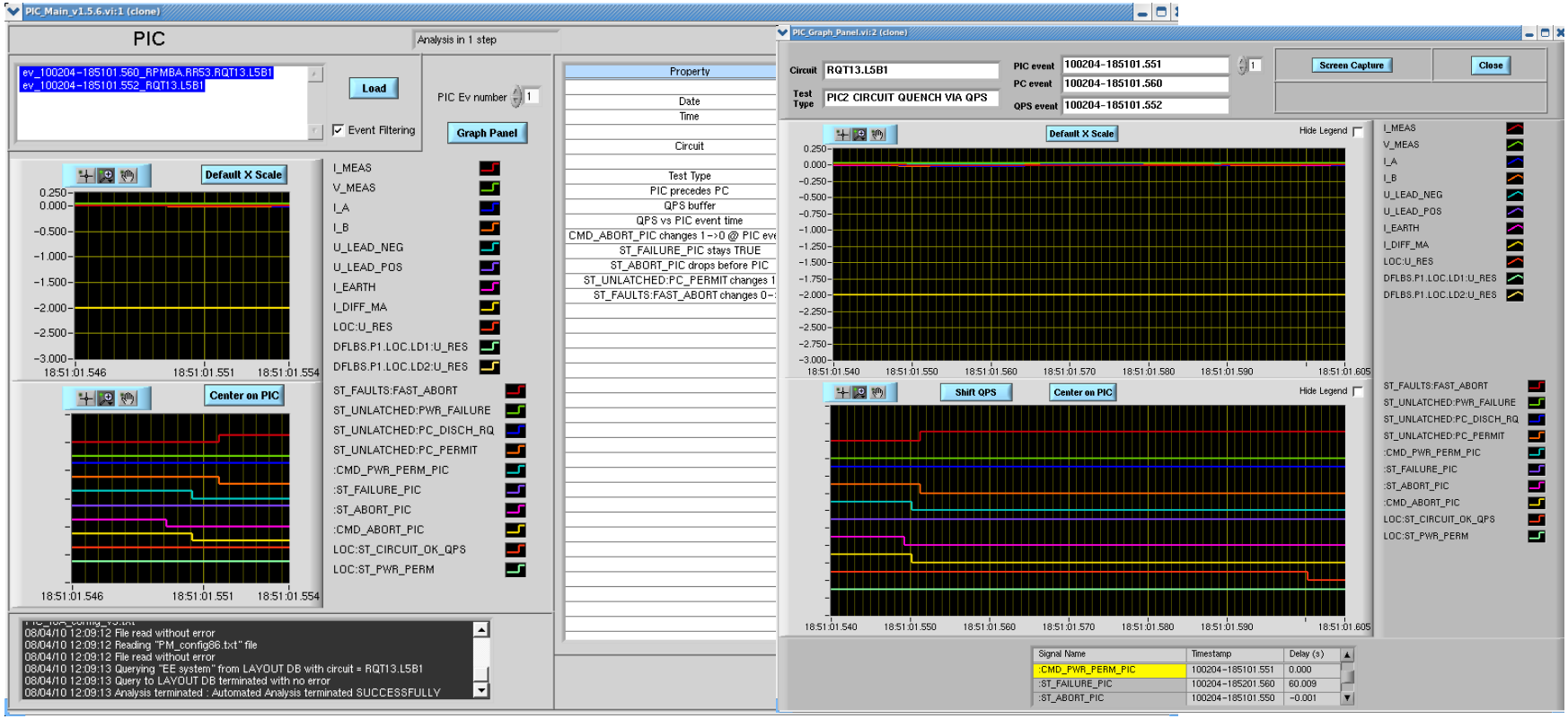

unicosHMI_1: unicosHMI
LHC CRYOGENICS
LHC Cryogenics Overview
Former Version
Sector 34
Sector 45
Sector 56
Sector 67
Sector 78
Sector 81
Sector 12
Sector 23
P5: CMS
P2: ALICE
P1: ATLAS
P1.8
P8: LHC-B
ARC34
ARC45
ARC56
ARC78
ARC81
ARC12
ARC23
MS L4
MS R4
MS L5
MS R5
MS L6
MS R6
MS L8
MS R8
MS L1
MS R1
MS L2
MS R2
IT L5
IT R5
IT L8
IT R8
IT L1
IT R1
IT L2
IT R2
AGAB1 L4
AGAB2 L4
AGAB1 R4
AGAB2 R4
Beep W
Beep RC
Beep FS
Sector
CS
CM
12
23
34
45
56
67
78
81
LHC
CV910 Max
80.1 %
Hélium Mass
QSV
9587 kg
QSD
13512 kg
Sectors
125860 kg
Total
153339 kg
Electrical Power
P18
3.76 MW
P2
5.63 MW
P4
7.91 MW
P6
4.34 MW
P8
4.29 MW
Total
25.92 MW
P18_P2
P18_P2
P6
P6
P8
Remaining time
Device

Test Analysis Tools



Courtesy of Markus Zerlauth (CERN)

Test Analysis Tools



The LHC Installation and Commissioning

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CIRCUIT NAME	LAST PASSED TEST	TESTS EXEC	LAST EXEC	SUC	UNDER EXEC	EXECUTION PLAN								
ROD.A34B1	PIC2 TEST HW LINKS	9 / 14 (64%)	PCS	N	_	PCL	PCC.5	PIC2	PCS	PLI3.b1	PNO.d3	PNO.b1	PNO.a3	PIC2 GPM
ROD.A34B2	PLI3.b1	11 / 14 (78%)	PNO.d3	N	_	PCL	PCC.5	PIC2	PCS	PLI3.b1	PNO.d3	PNO.b1	PNO.a3	PIC2 GPM
ROF.A34B1	PIC2 TEST HW LINKS	9 / 14 (64%)	PCS	N	_	PCL	PCC.5	PIC2	PCS	PLI3.b1	PNO.d3	PNO.b1	PNO.a3	PIC2 GPM
ROF.A34B2	PCS	10 / 14 (71%)	PCS	Y		PCL	PCC.5	PIC2	PCS	PLI3.b1	PNO.d3	PNO.b1	PNO.a3	PIC2 GPM

CIRC. NAME	CIRC. TYPE	P.SUBS	CIRC.LOC	TEST NAME	START TIME	END TIME	CIRCUIT COMMENTS	SUCCS	MTF	OPERATOR
RSF1.A81B2	600A EE	A81	UA87	PNO.a3	27-JUN-08 20:48:45	27-JUN-08 21:18:35	; [no errors]]; [no warnings]]; PMA comments = MTF_Creator PM_path to MTF file Signed By: automated PCS_Analysis Signed By: mpojer	Y	T	msolfaro
RSF2.A81B2	600A EE	A81	UA87	PNO.a3	27-JUN-08 20:46:26	27-JUN-08 21:16:55	; [no errors]]; [no warnings]]; PMA comments = MTF_Creator PM_path to MTF file Signed By: automated PCS_Analysis Signed By: mpojer	Y	T	msolfaro
RQTF.A81B1	600A EE	A81	UA87	PNO.d3	27-JUN-08 20:44:00	27-JUN-08 21:21:21	; [no errors]]; [no warnings]]; PMA comments = MTF_Creator PM_path to MTF file Signed By: automated CROWBAR Analysis Quench during discharge, but test OK. Signed By: mpojer CROWBAR Analysis Sequence OK but Quench during discharge Signed By: bdubois	Y	T	msolfaro
RCS.A81B2	600A EE	A81	UA87	PNO.a3	27-JUN-08 20:40:06	27-JUN-08 21:07:48	; [no errors]]; [no warnings]]; PMA comments = MTF_Creator PM_path to MTF file Signed By: automated PCS_Analysis Signed By: mpojer	Y	T	msolfaro
RQTF.A81B2	600A EE	A81	UA87	PNO.a3	27-JUN-08 20:32:43	27-JUN-08 20:37:50	; [errors: Wait timed out;Wait timed out;Wait timed out;]; [no warnings]]	N	T	msolfaro
RQ8.L1	IPQ	A81	RR13	PCC.4	27-JUN-08 20:24:58	27-JUN-08 20:28:23	; [errors: Failed to reach ON_STANDBY on [RPHGA.RR13.RQ8.L1B1, RPHGA.RR13.RQ8.L1B2];Failed to reach ON_STANDBY on [RPHGA.RR13.RQ8.L1B1, RPHGA.RR13.RQ8.L1B2];Failed to reach ON_STANDBY on [RPHGA.RR13.RQ8.L1B1, RPHGA.RR13.RQ8.L1B2];]; [no warnings]]; PMA comments = MTF_Creator PM_path to MTF file Signed By: automated Manual_sign Signed By: bfavre	N	T	msolfaro

RQTL8.R3B2	PCS	10 / 12 (83%)	PCS	N	_	PCL	PCC.5	PIC2	PCS	PNO.d3	PNO.a3	PIC2 GPM		

Information Management within the LHC Hardware Commissioning Project. Particle Accelerator Conference 2009, Vancouver, Canada, 04 - 08 May 2009, pp.FR5REP008 – A. Marqueta et al.

Courtesy of Alvaro Marqueta (IFMIF/EVEDA)

Main lessons learts (before the ´event´)

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- ✓ First rule of commissioning is NO SHORTCUTS
- ✓ Planning, prediction and simulations are necessary BUT… Things often do not go as expected. Plans need to be re-done and this is only possible if we have the proper:
  - Knowledge of the systems
  - Knowledge of the procedures
  - Semi-automatic execution and analysis tools
  - Crystal-clear role allocation
- ✓ Show-stoppers are not exceptions but common challenges to face during commissioning. Demotivation or negative thinking shall not be tolerated.
- ✓ Information tools for internal and external use are essential.
- ✓ No commissioning activity should be done in a corner. Do as many things as possible in the main control room. Nobody `owns´ a system.
- ✓ Human factors: people get tired and over-confident. This can be minimized by:
  - Efficient and optimized commissioning procedures (avoid useless boring tests)
  - Automatic tools wherever possible: execution and test analysis and validation
  - Attractive information tools
  - Forcing people to move between the field, the offices and the control rooms

September 10th, 2008

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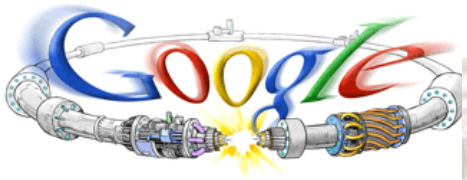

September 10th, 2008
First beams circulating

2008 | 2009

September 19th, 2008

September 10th, 2008
First beams circulating

2008	2009	2010	2011	2012

September 19th, 2008
The ‘Helium Leak’

September 19th, 2008

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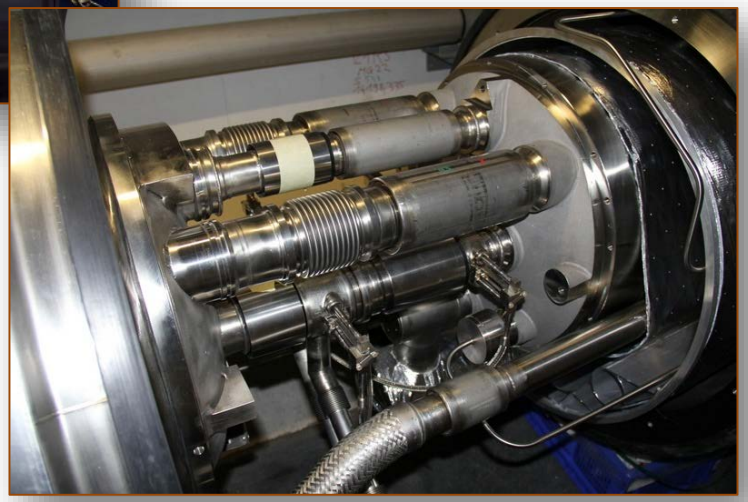
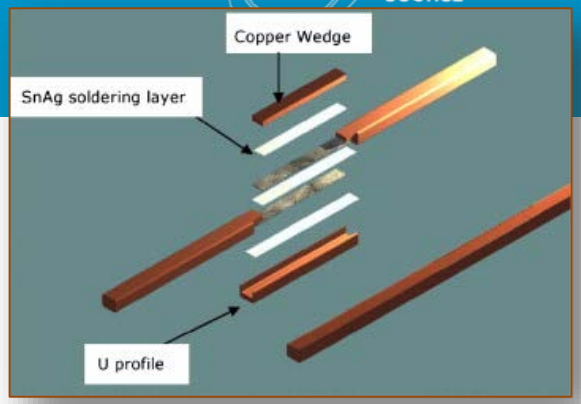
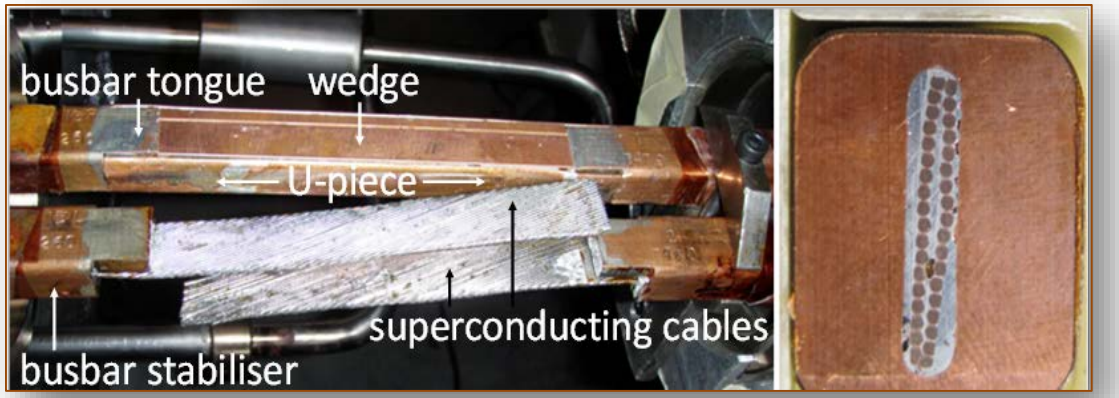
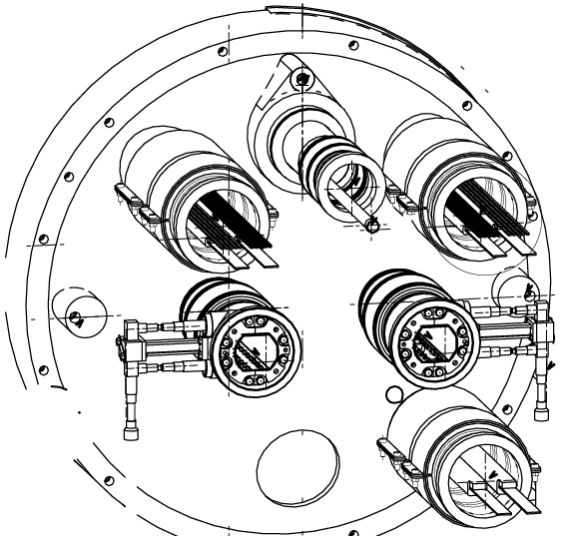
The magnet interconnects



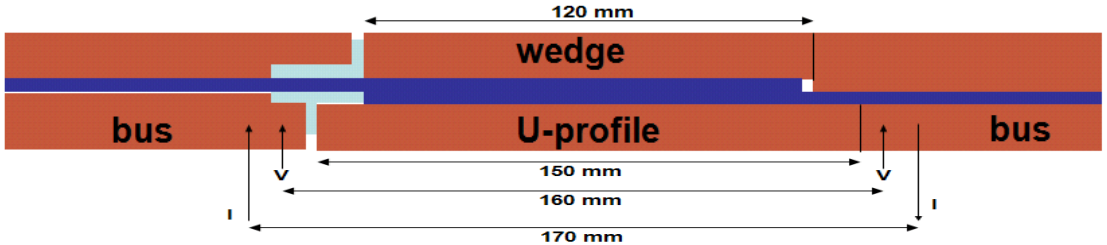


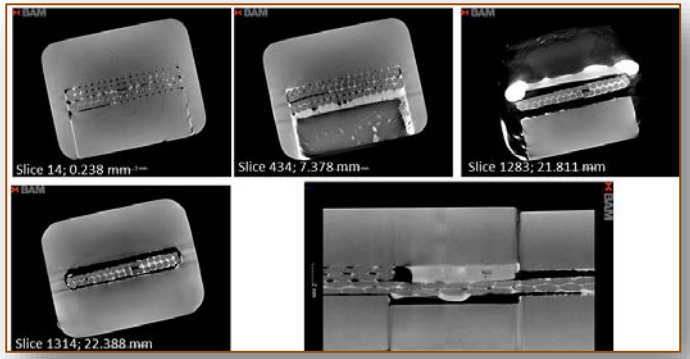
- **1695** magnet interconnects
- **10170** main superconducting splices carrying a current of about **13 kA**
- NbTi filaments surrounded by copper stabilizer filled with tin

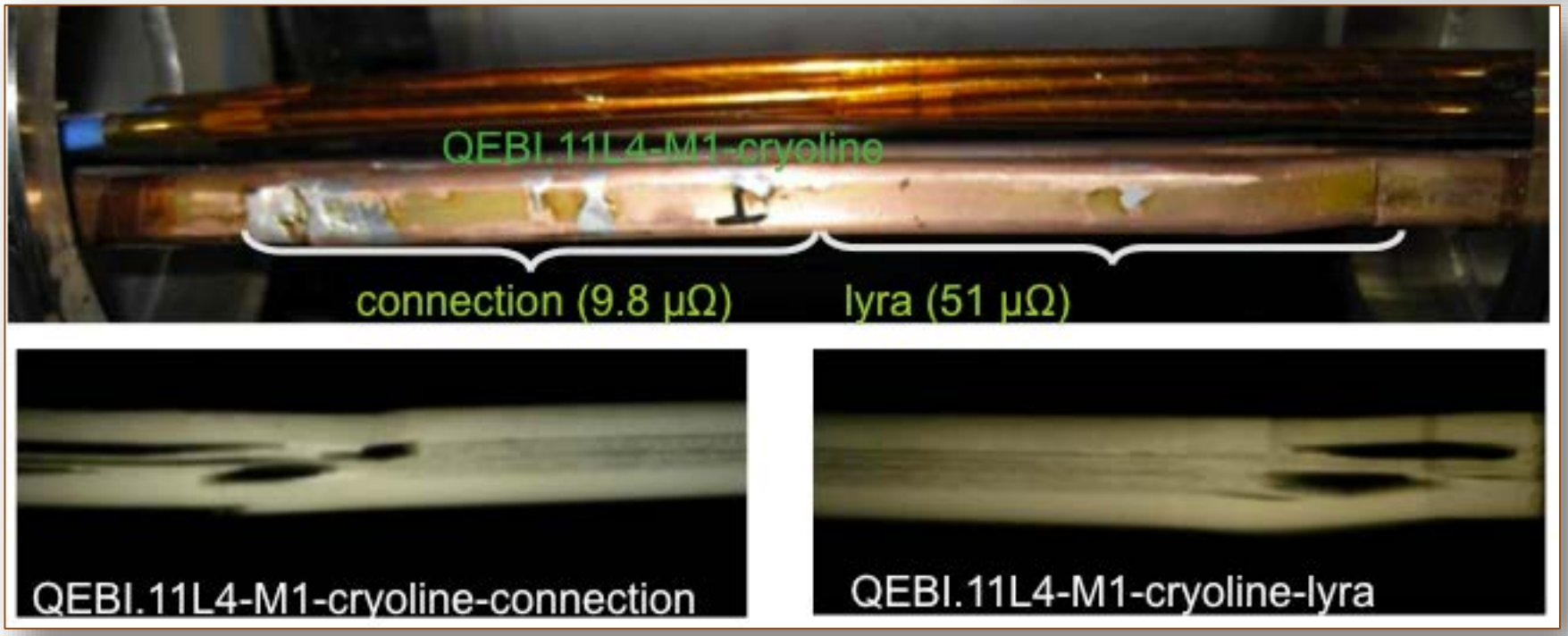




The magnets interconnects







A happy ending

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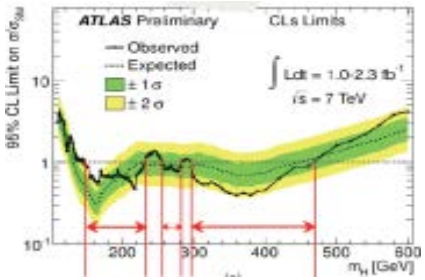
3.5 TeV

4 TeV

September 10th, 2008
First beams circulating

November 29th, 2009
Beams back

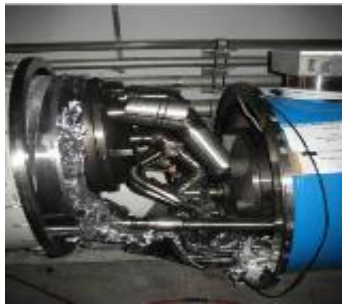


August, 2011
2.3e33, 2.6 fb^{-1}
1380 bunches

July 4th, 2012
Higgs discovery

2008

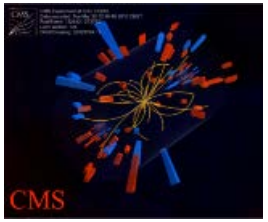
2009



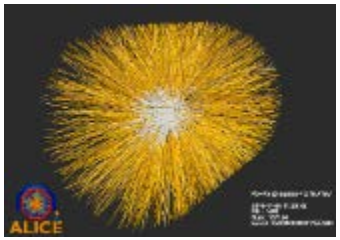
September 19th, 2008

Accidental release of 600 MJ stored in one LHC dipole magnets

March 30th, 2010
First collisions at 3.5 TeV



November 2010
Ions



7 TeV
(6.5)

Some obvious conclusions

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Commissioning of complex superconducting machines shall be oriented toward a correct validation of the machine protection systems. All the rest comes after

There are very few references on large scale commissioning of scientific instruments and especially on superconducting machines, **however**, the LHC hardware commissioning campaigns proved that industrial-like methods, strategy and tools were essential for its success… and they are scalable to new projects like ESS, ITER, IFMIF or FCC

Commissioning a multi-billion scientific project after decades of design, construction, meetings, travels, hurries… **is very difficult**. People is tired, stressed and under pressure by management…. It is very important to:

accept coordination (your system is not yours anymore)
follow procedures (no shortcuts, no cowboys)
assume responsibilities
sleep (whenever possible)
…. And keep smiling

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Thank you.

antonio.vergara@esss.se

14 June 2017

www.europeanspallationsource.se