CERN Power Converters

- Operation
- Consolidation
- LHC design % reliability
- Hardware commissioning status

Frédérick Bordry
CERN Power Converter Group Leader

Content

- Operation organisation
- MTBF and MTTR
- Consolidation strategy
- Design of the LHC power converters:
  - Design principle: N+1 strategy, reliability and MTTR objectives,…
  - Operation strategy
- LHC hardware commissioning

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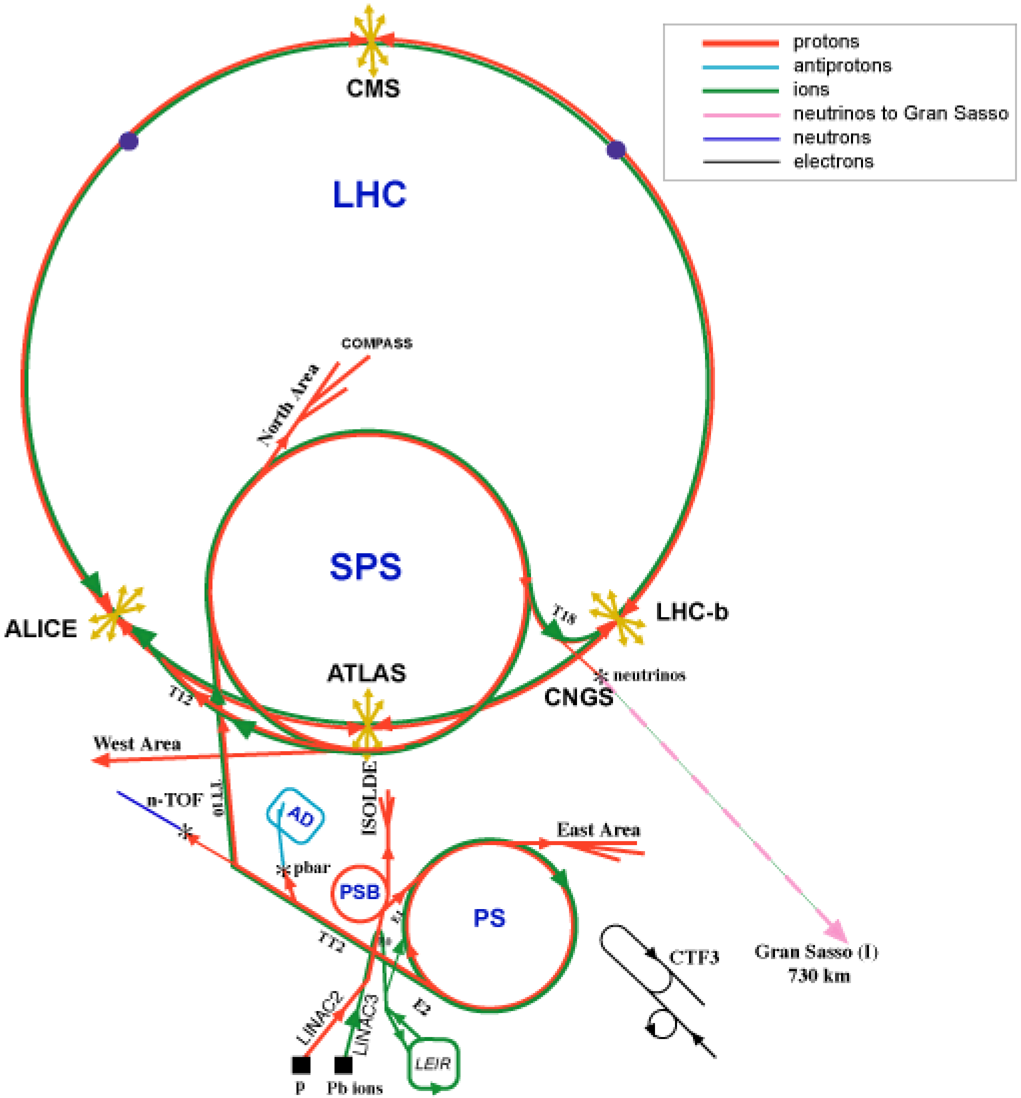
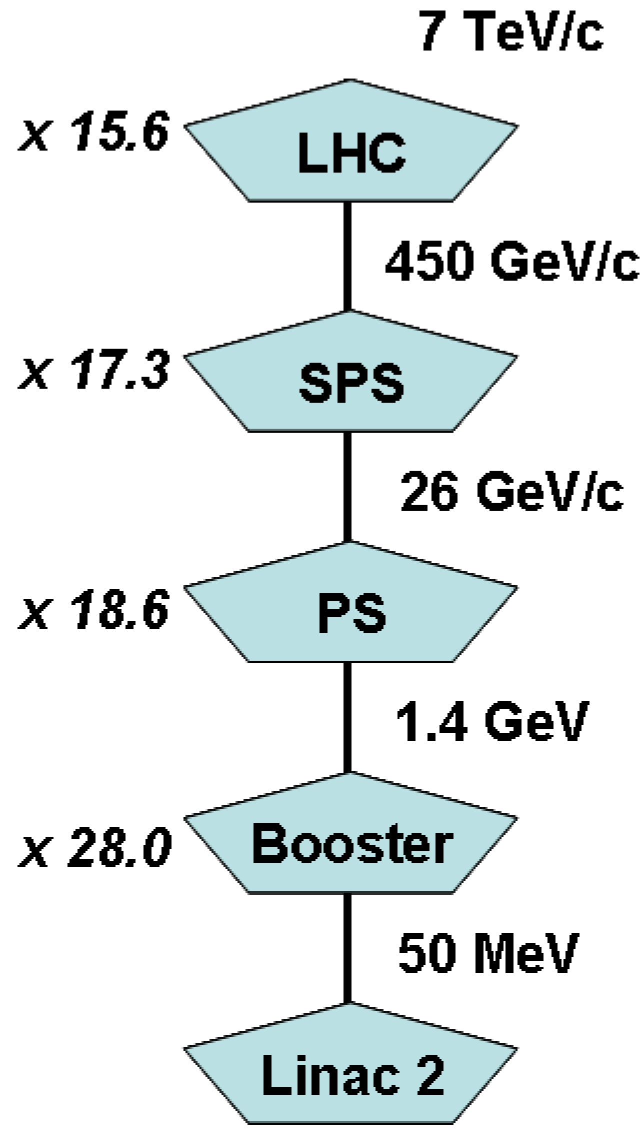
The CERN accelerator network





Long operation experience at CERN

Power Converter operation and maintenance

- Large geographical dispersion for the equipments
- > 4500 power converters with a large spectrum of age and technologies (few kW to hundreds of MW)
- Limited and difficult access to the equipments
- Availability is crucial [A= MTBF/(MTBF+MTTR)]

Logging and analysis of MTTR and MTBF

SPS since 1976

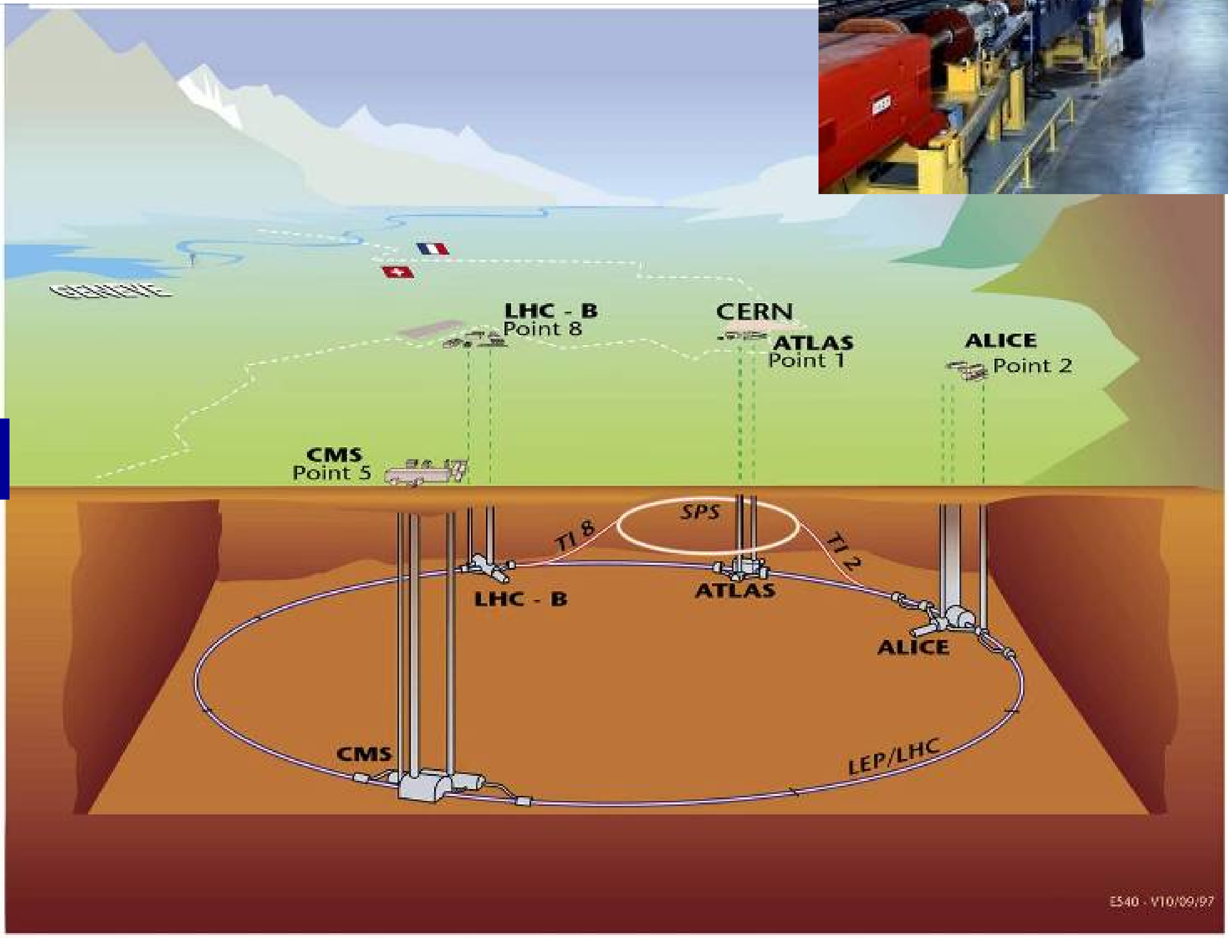
PS since 1959

AD since 1972

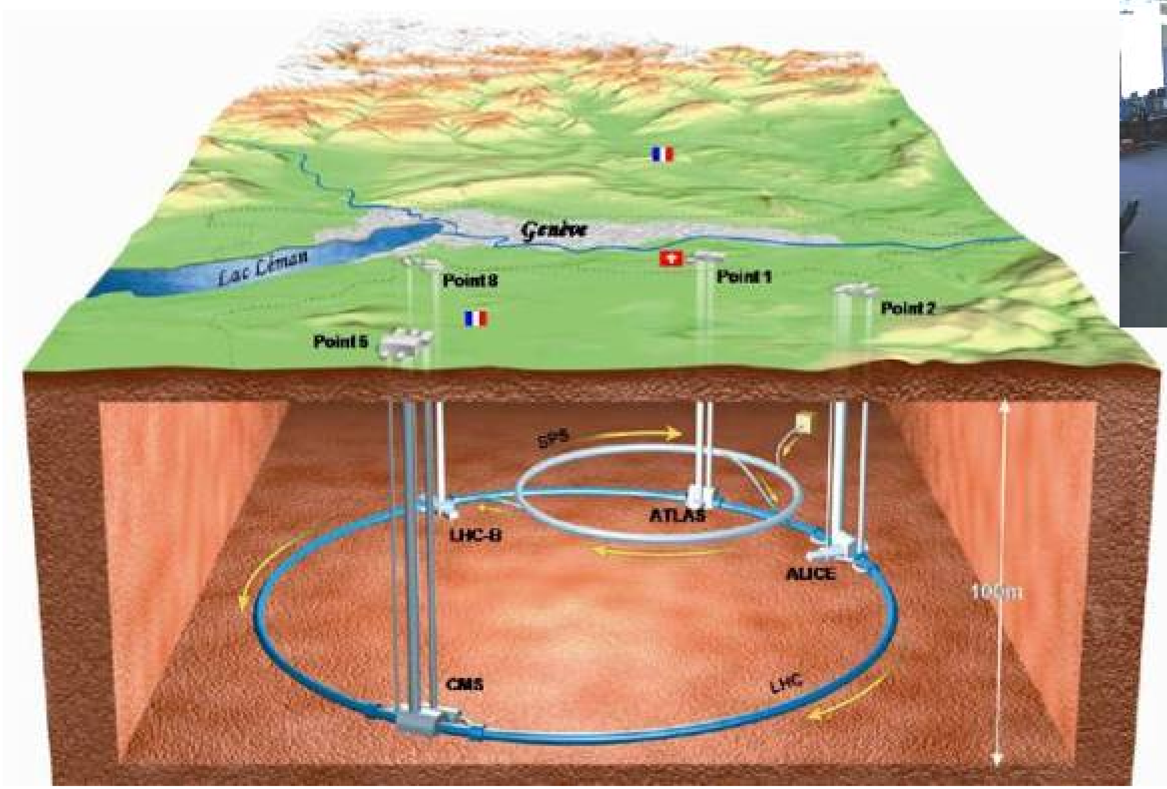
SPS since 1976

LEIR since 2005

LEP from 1989 to 2000



Power Converter operation and maintenance



CERN Control Centre

Al the accelerators are in continuous operation around the clock during more than 7 months

15th November | **1st March** | **1st April** | **15th November**

Shut down for maintenance | Commissioning | **Operation period 24h/24h**

POwer Converter Group (AB-PO)

The Power-Converter group is responsible for design, procurement or construction, installation, commissioning, operation and maintenance of all power converter systems for the present and future accelerators at CERN

~65 staffs

Group Leader AB/PO

- **Section AB/PO-TC** – Thyristors Converters – 10 Eng.&Tech
- **Section AB/PO-MPC** – Main Power Converters – 9 Eng.&Tech
- **Section AB/PO-PH** – Pulsed and High Voltage Converters – 9 Eng.&Tech
- **Section AB/PO-SC** – Switch Mode Converters – 9 Eng.&Tech
- **Section AB/PO-HP** – High Precision Measurement – 6 Eng.&Tech
- **Section AB/PO-CC** – Converter Control – 10 Eng.&Tech
- **Section AB/PO-IEE** – Integration Exploitation and Electronics Production – 13 Eng.&Tech

Power Converters (few KVA to hundreds of MVA): TC, MPC, PH, SC

Metrology: HP

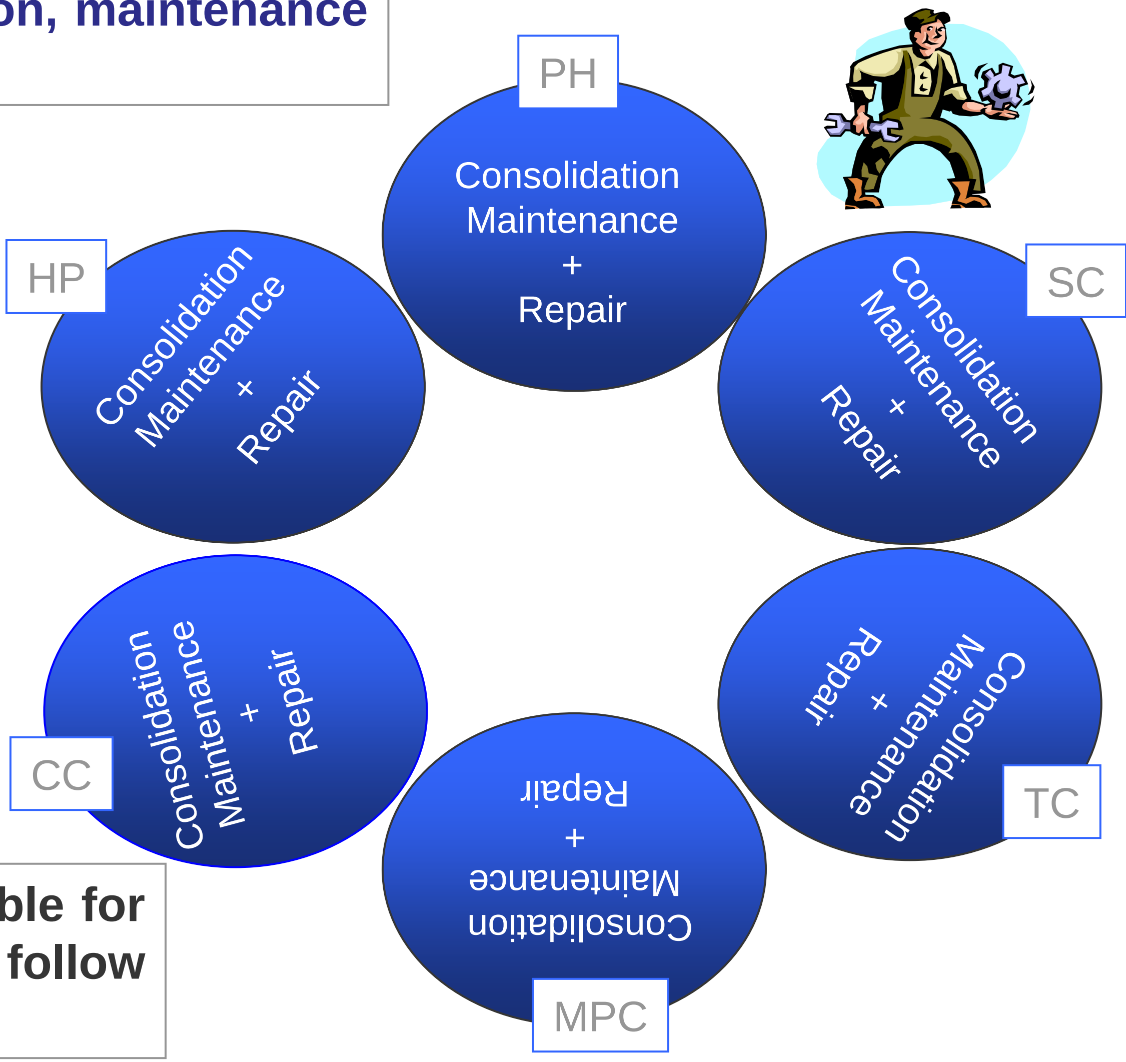
Remote Control: CC

Logistical Support: IEE

Industrial support: ~20 persons: engineers, technicians, electro-mechanics,…

Operation and maintenance: no dedicated section

According to their technology domains, each section follows the consolidation, maintenance and repair of its facilities.



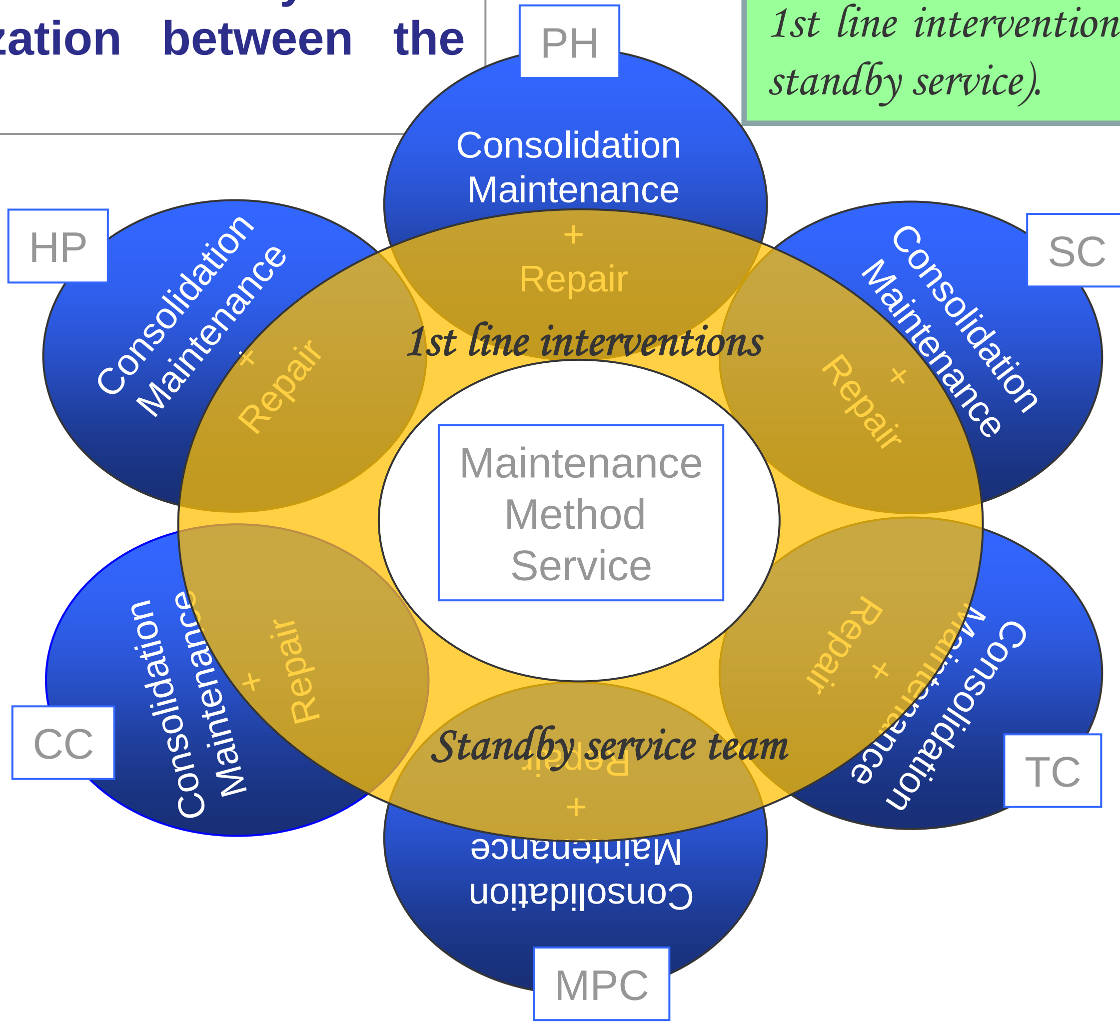
This sharing of tasks promotes feedback from maintenance to design and vice versa

The designers are also responsible for equipment operation which they follow everyday behaviour.

Operation and maintenance: no dedicated section

- **Standby service team (members are coming from all the sections) is responsible for the 1st line interventions on all the systems.**
- **Cross-fertilization between the sections**

The “Maintenance/Method Service” gives logistic support for the operation and maintenance (database, elogbook, spare part managements,…) and coordinates the 1st line interventions (management of the standby service).



The AB-PO equipment data-base

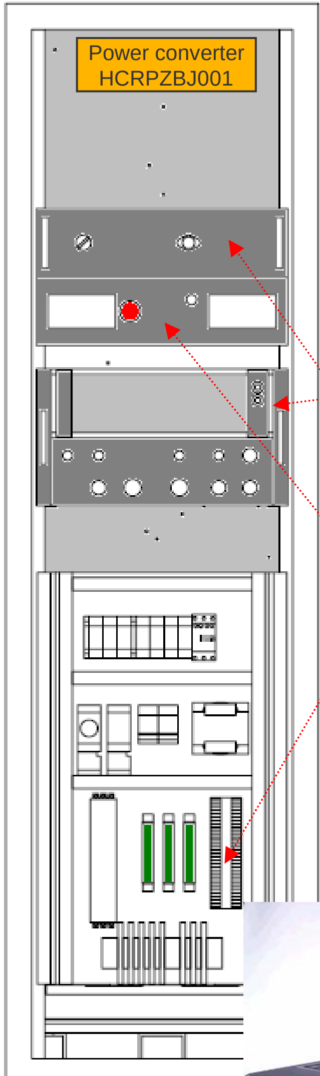
Report - Microsoft Internet Explorer

Address: http://webh02.cern.ch/Converters-Databases/net/equipments/report.aspx?Complex=CNGS&ID_Specialist=164&Power_Supplies=ON

Equipments List - 48 record(s) - Complex=CNGS&ID_Specialist=164&Power_Supplies=ON

Complex	Machine	Eqp Name	Status	Building Name	Building Number	Room	Eqp Type	Model	Eqp Code	CERN Serial Number	Manufacturer Serial Number	Installation Date	Comments	Position	Holder	Responsible1	Responsible2	Pique Phon
CNGS	CNGS (TT41)	COD-019702	Spare	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019702		26/11/2004		RA 0418		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	COD-019707	Spare	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019707		26/11/2004		RA 0418		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	COD-019709	Spare	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019709		08/02/2006		RA 0418		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	COD-027789	Spare	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00027789		26/11/2004		RA 0418		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	MDGH4102	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019711		26/11/2004		RA 0417		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	MDGH4106	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019698		26/11/2004		RA 0417		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	MDGH4108	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019706		26/11/2004		RA 0417		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	MDGH4112	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019697		26/11/2004		RA 0417		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	MDGH4114	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019705		26/11/2004		RA 0417		Yves Jacquemard	Loic De Oliveira	16039
CNGS	CNGS (TT41)	MDGH4118	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019704		26/11/2004						
CNGS	CNGS (TT41)	MDGV4103	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019682		07/02/2006						
CNGS	CNGS (TT41)	MDGV4105	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019681		26/11/2004						
CNGS	CNGS (TT41)	MDGV4109	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00027820		26/11/2004						
CNGS	CNGS (TT41)	MDGV4111	Installed	BB4	921	Hall	CONVERTER	Ncod	HCRPJAH000	00019710		26/11/2004						

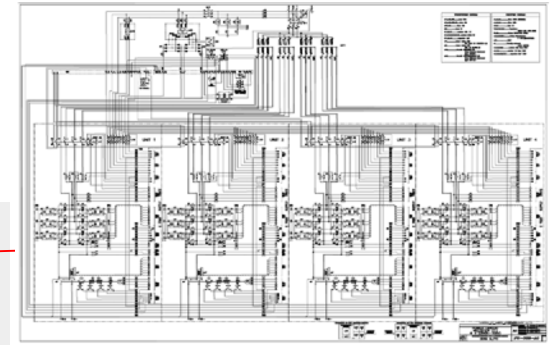
Operational documentation

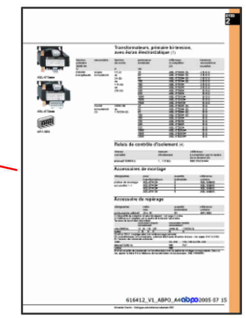


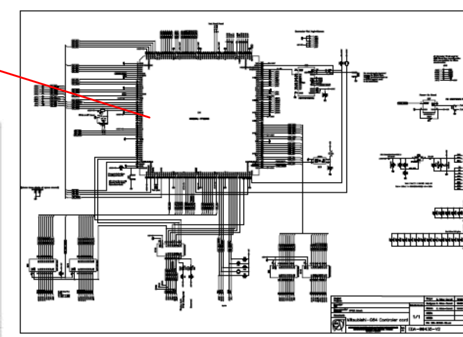
This Equipment code is given for each type of equipment or component.

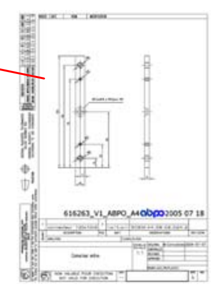
An EDMS tree represents the power converter structure

- DC
  - Switching
    - HCRPZBJ001 : S50T : Power Converter GEREG Switching
      - HCREHAR002 : GEREG
      - HCRYAAC001 : Output Contactor Base Plate
      - HCREHBA001 : Base plate 50Hz
      - HCRLAAL001 : Self DC Filter
      - HCRYAAD000 : Switching Plate
      - HCRPCAB001 : Power Module
      - HCREHBB001 : Front Panel
        - HCRBPAA000 : Command Panel Card
        - HCRUAAF000 : Ampermetre et Voltemetre
      - HCRTNAT001 : Transformateur d'intensite (50A/1A)
      - HCRTMAB000 : Power Transformer



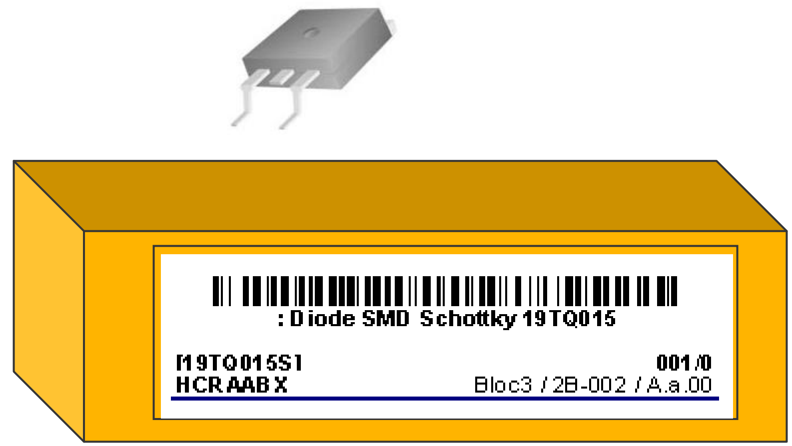






All AB-PO operational documentation can be extracted from EDMS and stored in a USB -Key

The spare parts: codification



HCRAAGS001-00000001

HCRBSBS00E-CR000057

Auxiliary operational spare parts storage

- All the equipment spare parts in the PS and SPS complex buildings have been inventoried

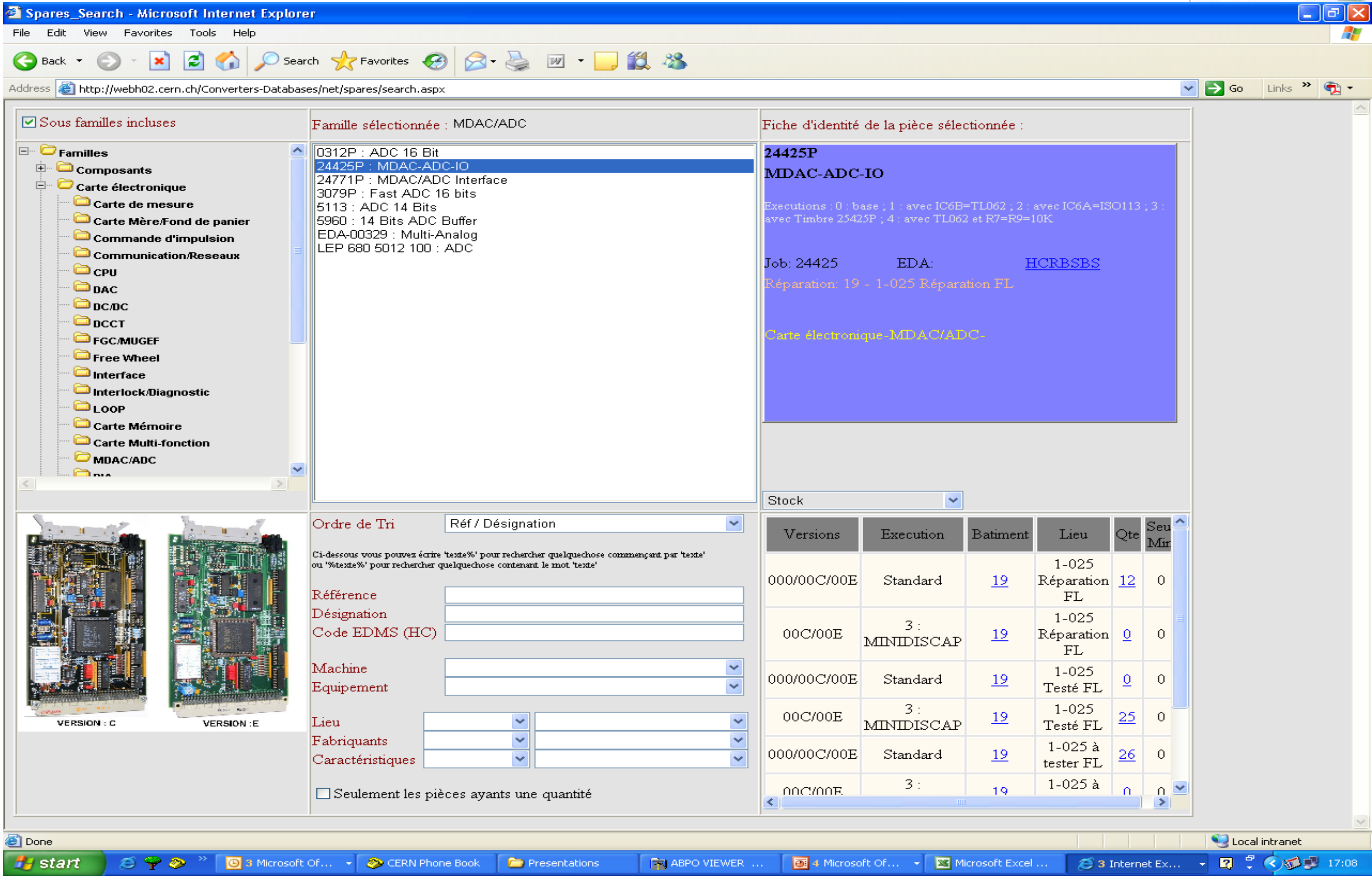
- 5900 type references / 55000 components identified and stored,
- Components are visible and manageable from the e-catalogue and the e-LogBook

The main operational spare parts storage

- 1400 type references
- 17900 components

Local management system installed

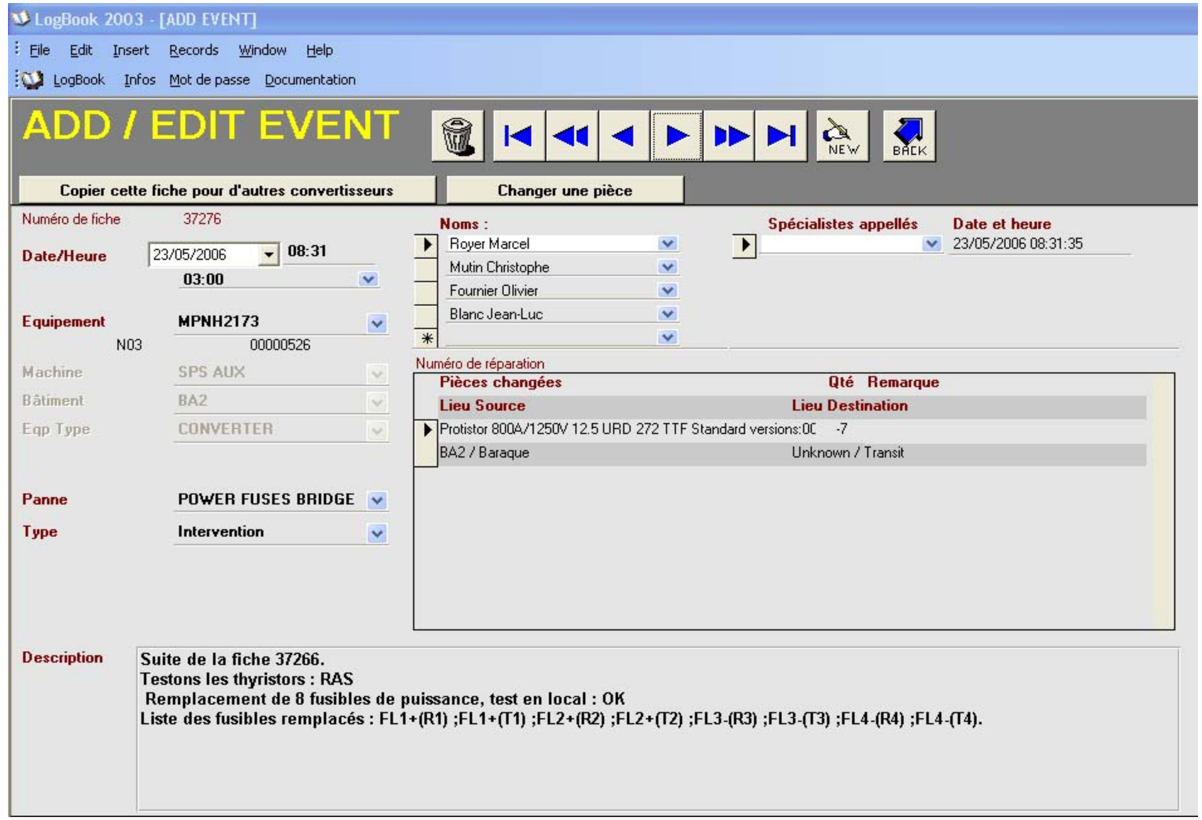
E-catalog AB-PO: example



E-logbook AB-PO: intervention form

- They are checked and discussed, one-by-one, at the “standby service” meetings held every Monday morning.
- Each expert receives automatically an E-mail whenever an intervention form is created, concerning an equipment under his responsibility (database link)
- They can be filled and accessed from the web,

AB-PO Logbook



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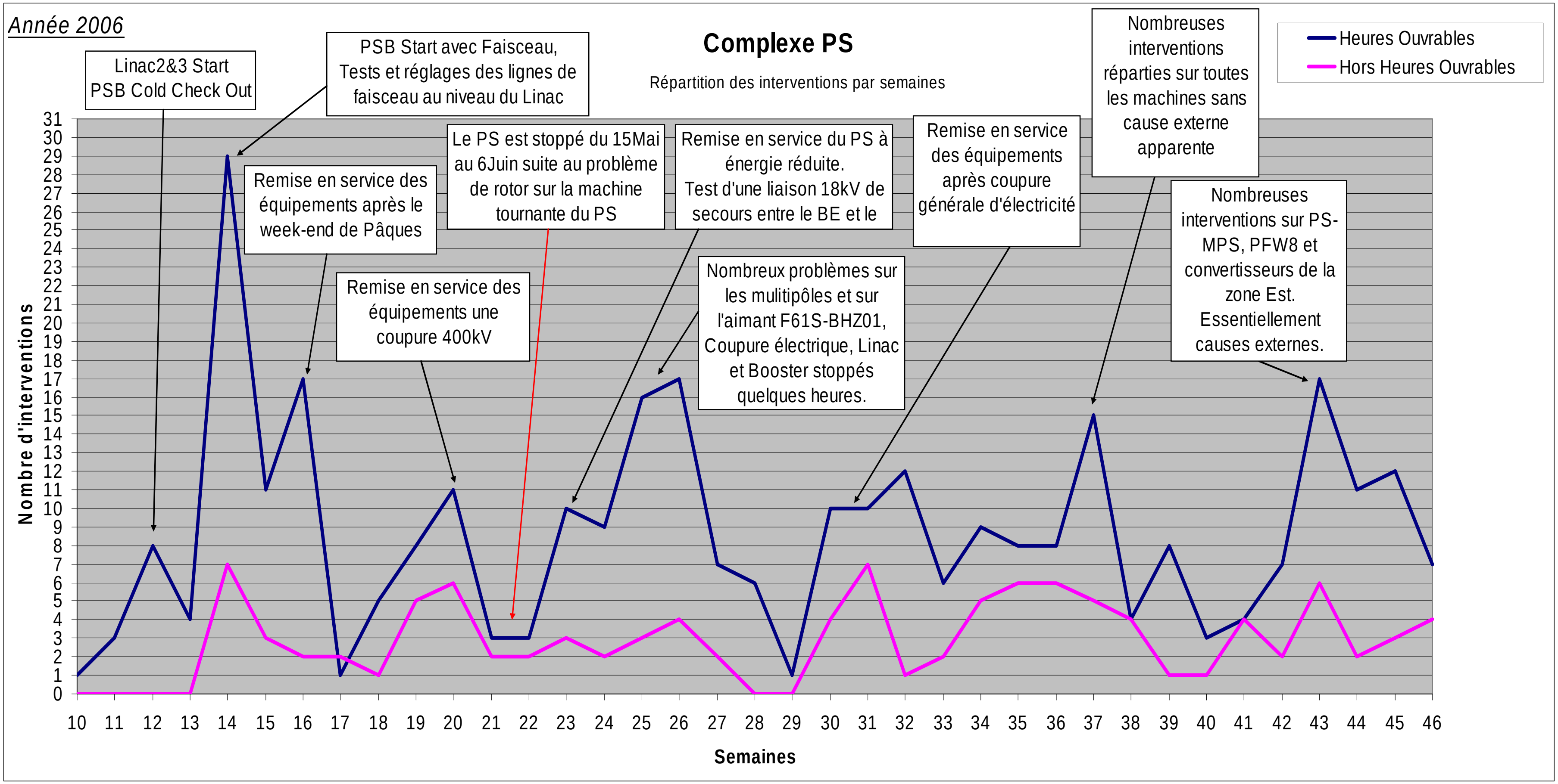
Breakdown of every week at PS complex in 2006

Statistics are directly extracted from the "Elogbook" filled by any person who makes an intervention on operational equipment



Measured MTTR around 1h.

Measured MTBF between 40'000h to 300'000h according to the power converter types and ages.

Courtesy of C. Mugnier

Statistics: MTBF evolution since 2004 (without 2005)

MTBF Calculation (Hours)	a) Linac 2&3				b) Booster + PSB-Isolde				c) PS + FT16			
	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults
Year 2007	82037	61528	15	5	49248	24901	45	44	38472	15553	38	56
Year 2006	75662	44354	17	12	40226	20479	56	54	34592	10330	43	101
Year 2004	73623	56300	13	4	80890	44297	23	19	19055	13101	66	30

MTBF Calculation (Hours)	d) Zone Est + FT61				e) CTF3				f) AD			
	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults
Year 2007	12545	7923	24	14	55726	41131	31	11	42613	21915	18	17
Year 2006	14723	5745	16	25	70226	48768	25	11	21244	11848	29	23
Year 2004	17056	7995	15	17					16592	14088	45	8

MTBF Calculation (Hours)	g) North Area				h) SPS + Transferts			
	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults
Year 2007	15451	9712	88	52	56231	19757	39	72
Year 2006	10502	6677	103	59	110257	32158	21	51
Year 2004			0	0			0	0

Right

To be followed

Too Low

MTBF Calculation (Hours)	Total PS Complex (a + b + c + d + e + f)				Total SPS Complex (g+h)			
	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults	MTBF Conv.	MTBF Total	Conv. Faults	Context Faults
Year 2007	47645	25620	171	147	29985	15172	127	124
Year 2006	44160	19936	186	226	32424	17182	124	110
Year 2004	33003	22277	162	78			0	0

2005: year without beams due to LHC construction

Courtesy of C. Mugnier

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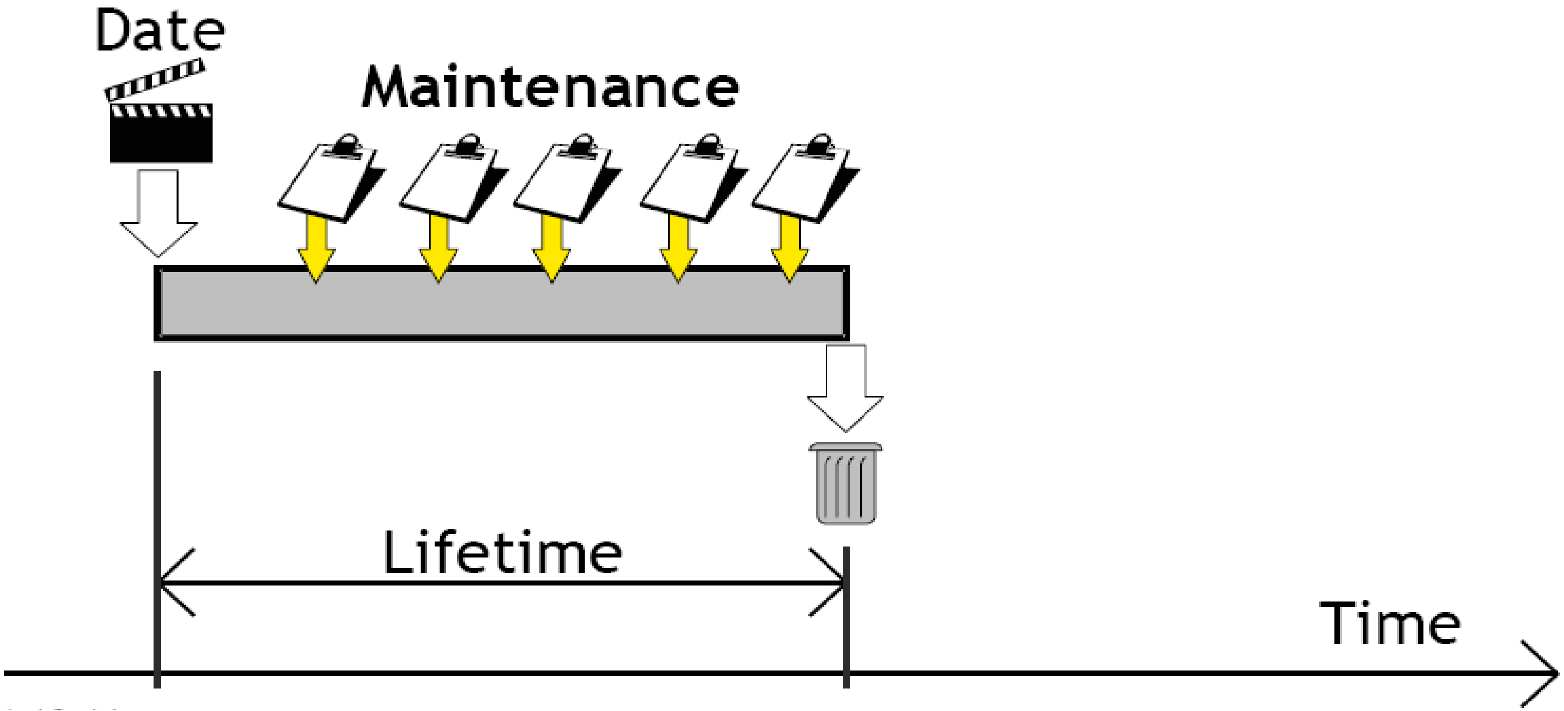
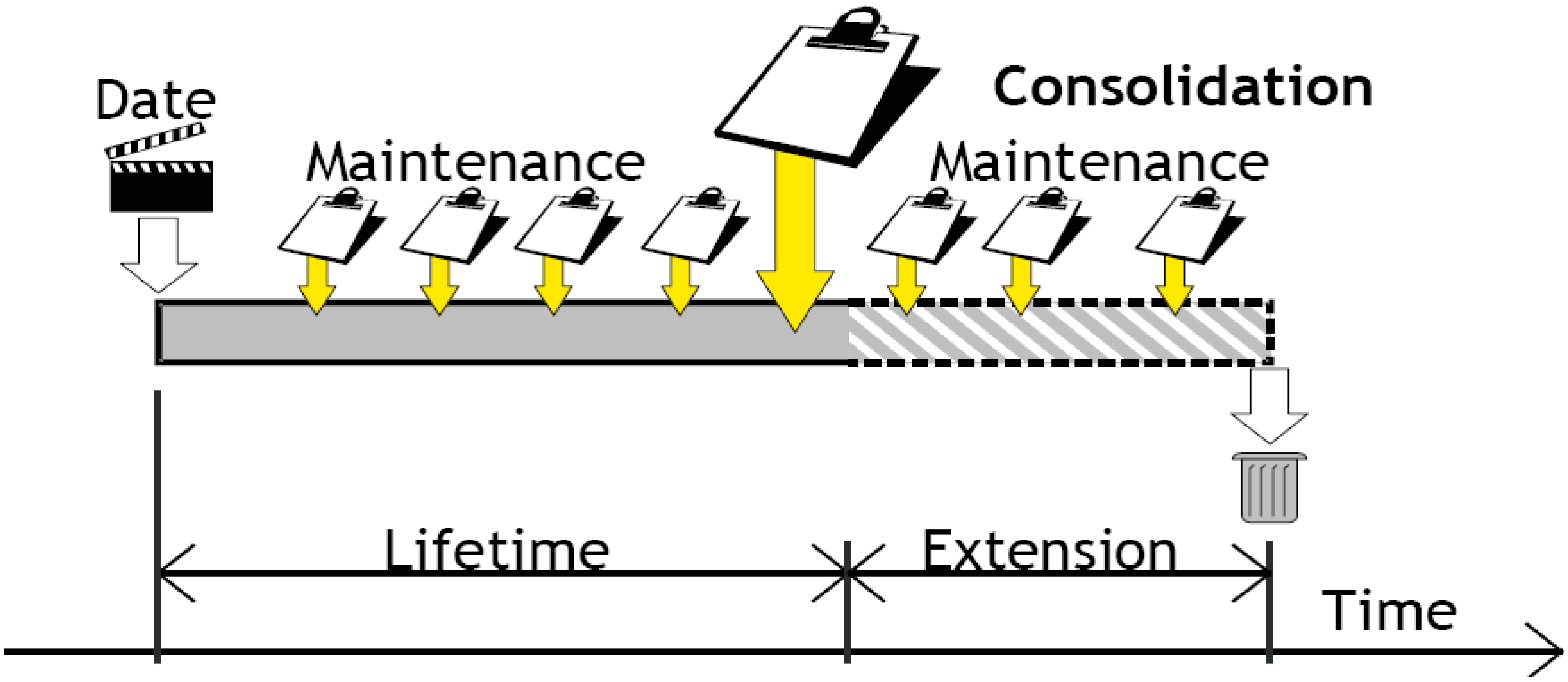
Operation budget: curative and preventive maintenance

Maintenance: all routine recurring actions required to maintain a facility, system, building, structure or equipment in good working order or in a specified operating state or in serviceable condition throughout its initially expected lifetime.



Consolidation budget

Consolidation: all actions performed on a facility, system, building, structure or equipment in order to either extend its initially expected lifetime or to add new capabilities.



Risk analysis

Risk: the combination of the probability of an event and its consequences (Guide ISO 73)

(ISO/IEC Guide 73:2002 definition 3.1.1 “Risk management – Vocabulary – Guidelines for use in standards”)

Note: the term “risk” is generally used only when there is at least the possibility of negative consequences

- Risk identification
- Risk assessment
- Risk treatment
- Risk control

Risk score : RS = P x I

Probability of failure of the equipment (frequency)

Impact : impact in case of failure (Duration I_D, Financial I_F, Safety/environment I_S, Reputation I_R)

The product of both factors determines a value of the effects (gravity, consequences) of breakdown of failure, called **Risk Score**

$$\mathbf{RS = P \times I}$$

$$I = Max\ (I_D\ ;\ I_F\ ;\ I_F\ ;\ I_S\ )$$

Probability of failure of the equipment

P

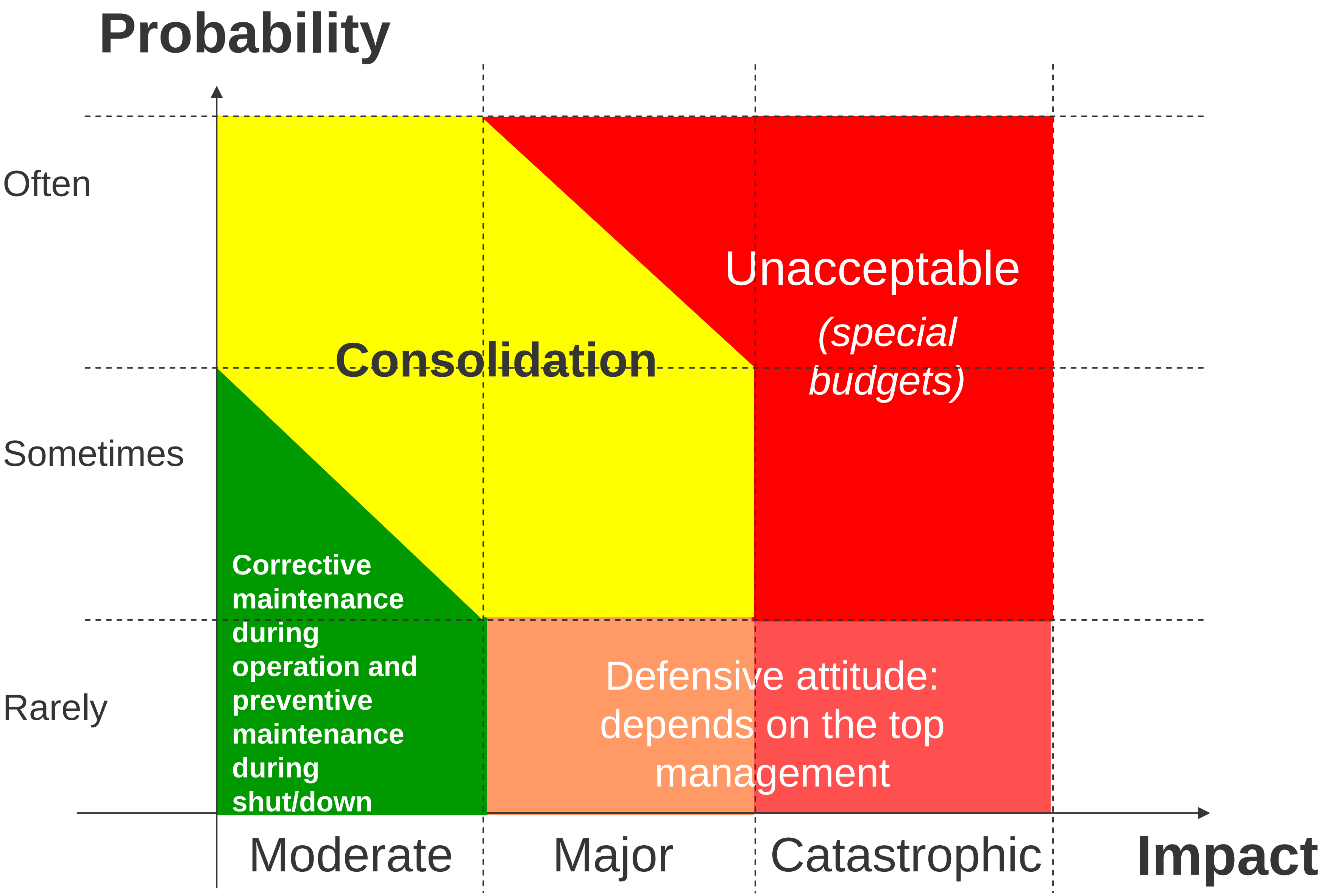
- **1** = **Rare**, i.e. less than once in 25 years ;
- **2 = Possible**, i.e. once in 5 to 10 years ;
- **3 = Likely**, i.e. once in 2 to 5 years ;
- **4 = Frequent**, i.e. about once a year ;

Impact on the CERN’s scientific objectives in case of failure

I_O

- **1** = **Insignificant**, i.e. 1 day of **loss of physics** or less
- **2 = Moderate**, i.e. between 1 day and 1 week of loss of physics
- **3 = Major**, i.e. up to few (3 to 5) weeks, major impact on scientific objectives
- **5 = Catastrophic**, i.e. no more operation, failure to meet scientific objectives for the year

Risk management



Risk analysis: Consolidation program

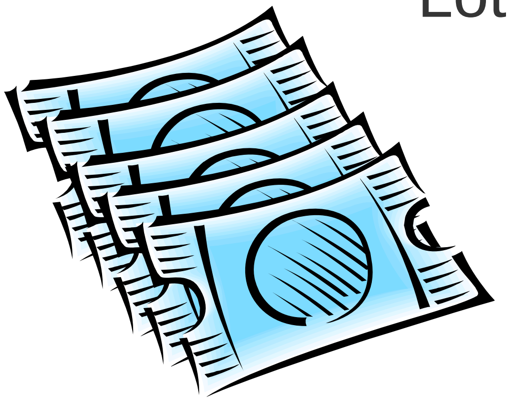
- Identifying all the systems that need to be consolidated.
- Estimation of the Risk Score (RS) before and after the consolidation or risk mitigation (spare increase, open contract, agreement with other labs or companies,…)
- Because budgets are limited, identifying those that should have priority.

qry_AllSystems_byΔRS 08/10/2004

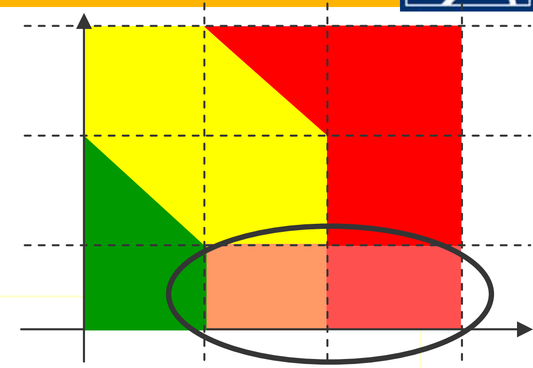
Label	Holder	RS	RS'	RS*	RS**	ΔRS	ΔRS'	ΣP	ΣP*	ΔP	ΣM	ΣM*	ΔM	ΔP+M
Power Converter of PS Main Ring	FREDERICK.BORDRY@CERN.CH (AB-PO)	15	13.5	4	3.6	-11	-9.9	21	11.2	-9.8	1400	3120	172 0	495
Septum SEH31 Feedthrough Oil	VOLKER.MERTENS@CERN.CH (AB-BT)	15	13.5	4	3.6	-11	-9.9	14	0	-14	350	100	-25 0	-2000
Quadrupoles Q120 of PS East Experiemental Area	WILLI.KALBREIER@CERN.CH (AT-MEL)	12	2.4	2	.4	-10	-2	1.4	0	-1.4	175	200	2 5	-150
Continuous Transfer (present version)	VOLKER.MERTENS@CERN.CH (AB-BT)	12	3.6	4	1.2	-8	-2.4	.7	0	-.7	70	400	33 0	242.5
Slow Ejection SMH57 Power Converter of PS Experimental Area	JEAN-PIERRE.ROYER@CERN.CH (AB-PO)	12	1.2	4	.4	-8	-.8	0	1.2	1.2	560	300	-26 0	-110
Proton Distributor Electronics of the PS and PSB	VOLKER.MERTENS@CERN.CH (AB-BT)	12	12	4	4	-8	-8	.7	0	-.7	0	150	15 0	62.5
Quadrupole Jacks of SPS	DAVID.SMEKENS@CERN.CH (AT-MEL)	8	5.6	1	.7	-7	-4.9		0			65		
PFW (Pole Phase Winding) Power Converters of PS	JEAN-PAUL.BURNET@CERN.CH (AB-PO)	8	7.2	1	.9	-7	-6.3	.7	4.35	3.65	70	700	63 0	1086.25
Internal Beam Dump of the PS	ENRICO.CHIAVERI@CERN.CH (AB-ATB)	9	8.1	2	1.8	-7	-6.3	0	4	4	360	600	24 0	740
Horn Pulser High Current Ignitron	VOLKER.MERTENS@CERN.CH (AB-BT)	9	.9	2	.2	-7	-.7	1.4	0	-1.4	350	230	-12 0	-295
Dipole M105 and Quadrupole 74-75 of PS East Experiemental Area	WILLI.KALBREIER@CERN.CH (AT-MEL)	9	1.8	2	.4	-7	-1.4	1.4	0	-1.4	175	300	12 5	-50
Sieve of the PS	ENRICO.CHIAVERI@CERN.CH (AB-ATB)	8	3.6	2	.9	-6	-2.7	0	.4	.4	0	50	5 0	100
Main Quadrupoles of the SPS North Experiemental Area	DAVID.SMEKENS@CERN.CH (AT-MEL)	8	2	2	.5	-6	-1.5	.7	3	2.3	105	950	84 5	1132.5
PS Main Magnets	THOMAS.ZICKLER@CERN.CH (AT-MEL)	12	10.8	6	5.4	-6	-5.4	7	3	-4	1400	18980	1758 0	17080
HT Converters for Linac2 RF	JEAN-PIERRE.ROYER@CERN.CH (AB-PO)	8	8	2	2	-6	-6	0	.7	.7	0	300	30 0	387.5
Gamma Transition Power Converters of PS	JOEL.LAHAYE@CERN.CH (AB-PO)	8	7.2	2	1.8	-6	-5.4	.7	1.2	.5	70	500	43 0	492.5
Main Quadrupoles of the TT60, TT40 and LHC TI2 and TI8	DAVID.SMEKENS@CERN.CH (AT-MEL)	8	3.6	2	.9	-6	-2.7	.4	2	1.6	60	200	14 0	340
Power Conerters of TT2	ANDRE.BEURET@CERN.CH (AB-PO)	8	5.6	2	1.4	-6	-4.2	7	7.9	.9	875	2000	112 5	1237.5
PSB Main Magnets	WILLI.KALBREIER@CERN.CH (AT-MEL)	6	6	1	1	-5	-5	1.4	1	-.4	175	300	12 5	75
Kicker Oil System of the PS	VOLKER.MERTENS@CERN.CH (AB-BT)	8	8	4	4	-4	-4	1.4	0	-1.4	350	160	-19 0	-365
Proton Distributor Generator of the PS and PSB	VOLKER.MERTENS@CERN.CH (AB-BT)	6	6	2	2	-4	-4	.7	0	-.7	70	200	13 0	42.5
HV Cables of the Septa of the PS and PSB	VOLKER.MERTENS@CERN.CH (AB-BT)	8	4	4	2	-4	-2	.7	0	-.7	105	550	44 5	357.5
Main Dipoles and Main Quadrupoles of the SPS Main Ring	DAVID.SMECKENS@CERN.CH (AT-MEL)	12	8.4	8	5.6	-4	-2.8	1.4	.8	-.6	1750	2200	45 0	375
Ejection Kicker Feedthrough of the PS and PSB	VOLKER.MERTENS@CERN.CH (AB-BT)	6	6	2	2	-4	-4	0	0	0	0	40	4 0	40
Controls Infrastructures of the SPS	BERTRAND.FRAMMERY@CERN.CH (AB-CO)	8	2	4	1	-4	-1	1.4	.6	-.8	0	500	50 0	400
Multipole/Dipole Power Convereters of the PSB	VALERIE.MONTABONET@CERN.CH (AB-PO)	4	4	1	1	-3	-3	7	5.8	-1.2	0	800	80 0	650
Low Energy Correction Converters for the PS	VALERIE.MONTABONET@CERN.CH (AB-PO)	4	3.6	1	.9	-3	-2.7	7	2.5	-4.5	0	500	50 0	-62.5
Dipole Steering Converters of Linac2 and Linac3	JEAN-PIERRE.ROYER@CERN.CH (AB-PO)	4	4	1	1	-3	-3	.7	.8	.1	700	200	-50 0	-487.5
Magnet Interlock System of the SPS and TT40, TT60	BERTRAND.FRAMMERY@CERN.CH (AB-CO)	6	4.2	3	2.1	-3	-2.1	2.1	.6	-1.5	350	200	-15 0	-337.5
Analog Observation System (NAOS) of the PS Complex and SPS	BERTRAND.FRAMMERY@CERN.CH (AB-CO)	6	6	3	3	-3	-3	2.8	1.4	-1.4	210	500	29 0	115
∫Bdl & Q Strips of PS	ANDRE.BEURET@CERN.CH (AB-PO)	4	3.6	2	1.8	-2	-1.8	1.4	1.1	-.3	700	300	-40 0	-437.5
Transformers of SPS Power Converters	ANDRE.BEURET@CERN.CH (AB-PO)	3	2.1	1	.7	-2	-1.4	0	4.1	4.1	0	2100	210 0	2612.5
Fault Protection and Surveillance of the Kickers of the PS	VOLKER.MERTENS@CERN.CH (AB-BT)	4	4	2	2	-2	-2	2.1	0	-2.1	0	320	32 0	57.5
Tekelec Convertors of Linac2, Linac3 and PS	ANDRE.BEURET@CERN.CH (AB-PO)	4	4	2	2	-2	-2	.7	5.8	5.1	350	2500	215 0	2787.5
Power Supply Interface for Multipole Magnets of the PSB	BERTRAND.FRAMMERY@CERN.CH (AB-CO)	4	4	3	3	-1	-1	0	0	0	0	220	22 0	220
Thyristor Bridges of SPS Power Converters	ANDRE.BEURET@CERN.CH (AB-PO)	3	2.1	2	1.4	-1	-.7	0	1.45	1.45	0	960	96 0	1141.25
Halogen Cables of the PCR	BERTRAND.FRAMMERY@CERN.CH (AB-CO)					0		0	0	0	0	0	0	0
AD vacuum components	PIERRE.STRUBIN@CERN.CH (AT-VAC)					0						185		

Decision ? Defensive attitude: depends on the top management

Lottery Game

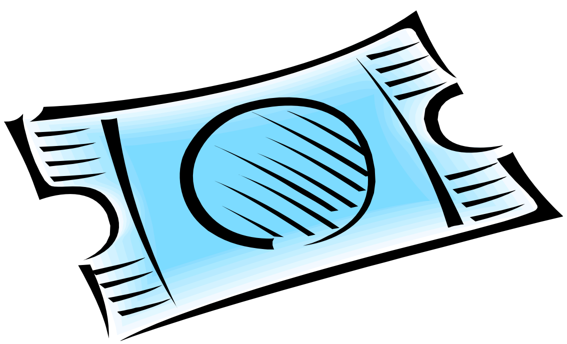


1000 €
with p=1/2



You have 1600 tickets
Gain estimation = 1600 x 1000/2 = 800’000 €

Are you ready to sell your tickets for 400’000 € ?



1’600’000 €
with p=1/2

You have 1 ticket
Gain estimation = 1’600’000 x ½ = 800’000 €

Are you ready to sell your tickets for 4

Content

- Operation organisation
- MTBF and MTTR
- Consolidation strategy
- Design of the LHC power converters:
  - Design principle: N+1 strategy, reliability and MTTR objectives,…
  - Operation strategy
- LHC hardware commissioning

LHC Power Converters

PC-V 6·4 : General Information

Last_modif 24/3/2003

Optics version	Type	Eq.Code	Current kA	Voltage Steady V	Boost V	Peak V		Module I mod kA	I tot kA	Mains Input Peak kW	Peak kVA	Losses Water kW	Air kW	Dimensions Length m	Depth m	Height m	Equiv. No. Racks	Provisional Quantity
6·4	01	RPTE	13.000	10	±180	190			16.250	2680.6	3540.0	157.9	52.6	10.8	1.8	2.0	36.00	8
6·4	02	RPHE	13.000	13	±5	18				264.9	288.0	27.8	3.1	4.2	0.9	2.0	7.00	16
6·4	03	RPHF	8.000	6	±2	8				78.2	85.0	12.8	1.4	3.0	0.9	2.0	5.00	20
6·4	04	RPHG	6.000	6	±2	8				58.7	63.8	9.6	1.1	2.4	0.9	2.0	4.00	132
6·4	05	RPHH	4.000	6	±2	8				39.1	42.5	6.4	0.7	2.4	0.9	2.0	4.00	40
6·4	10	RPMB	0.600	±8	±2	10					9.1	2.1	0.2	0.6	0.9	1.0	0.50	330
6·4	11	RPMC	0.600	±35														24
6·4	12	RPMB	0.600	8														70
6·4	13	RPMC	0.600	35														2
6·4	14	RPLB	0.120	±8														290
6·4	15	RPMC	0.120	±35														10
6·4	16	RPLA	0.060	±2														752
6·4	20	RPTL	0.650	160														3
6·4	21	RPTF	0.810	450														4
6·4	22	RPTG	0.810	950														4
6·4	23	RPTM	1.000	600														2
6·4	24	RPTI	6.500	950														2
6·4	25	RPTN	1.000	±180														3
6·4	30	RPTJ	20.000	±26														1
6·4	31	RPHK	20.500	18														1
6·4	32	RPTH	33.000	170	0													1
6·4	40	RPTK	0.040	100000	0	100000	1	0.040	0.040	4240.1	5300.9	180.1	60.0					4

Total Current required **1861 kA**

Steady State Input **63018 kW**

Peak Input **85906 kW**

Total Number of PCs **1719**

Number of Converters: > 1700

Total Current :1860 kA

Steady State Input : 63 MW

Peak Input : 85 MVW

Underground volume ≅ 1700 m3

Surface volume ≅ 300 m3

LHC power converters: Operation Strategy

Large number of converters (>1700) and high current (up to 20kA)

Underground installation (difficult access, no “walking” surveillance,...)

Ultra high precision: ppm (part per million) level

- **Modular approach to reduce the MTTR** (Mean Time To Repair)

  Spare modules in dedicated location, replacement and “off-line” repair

- **Careful design to get a high MTBF** (Mean Time Between Failures)

  MTBF > 100’000 h

  (first year MTBF ≅ 10’000 h ; other accelerator experience)

  - **1-Q high-current converters : n + 1 sub converter strategy**
  - **No systematic replacement of failed closed-orbit corrector converters**

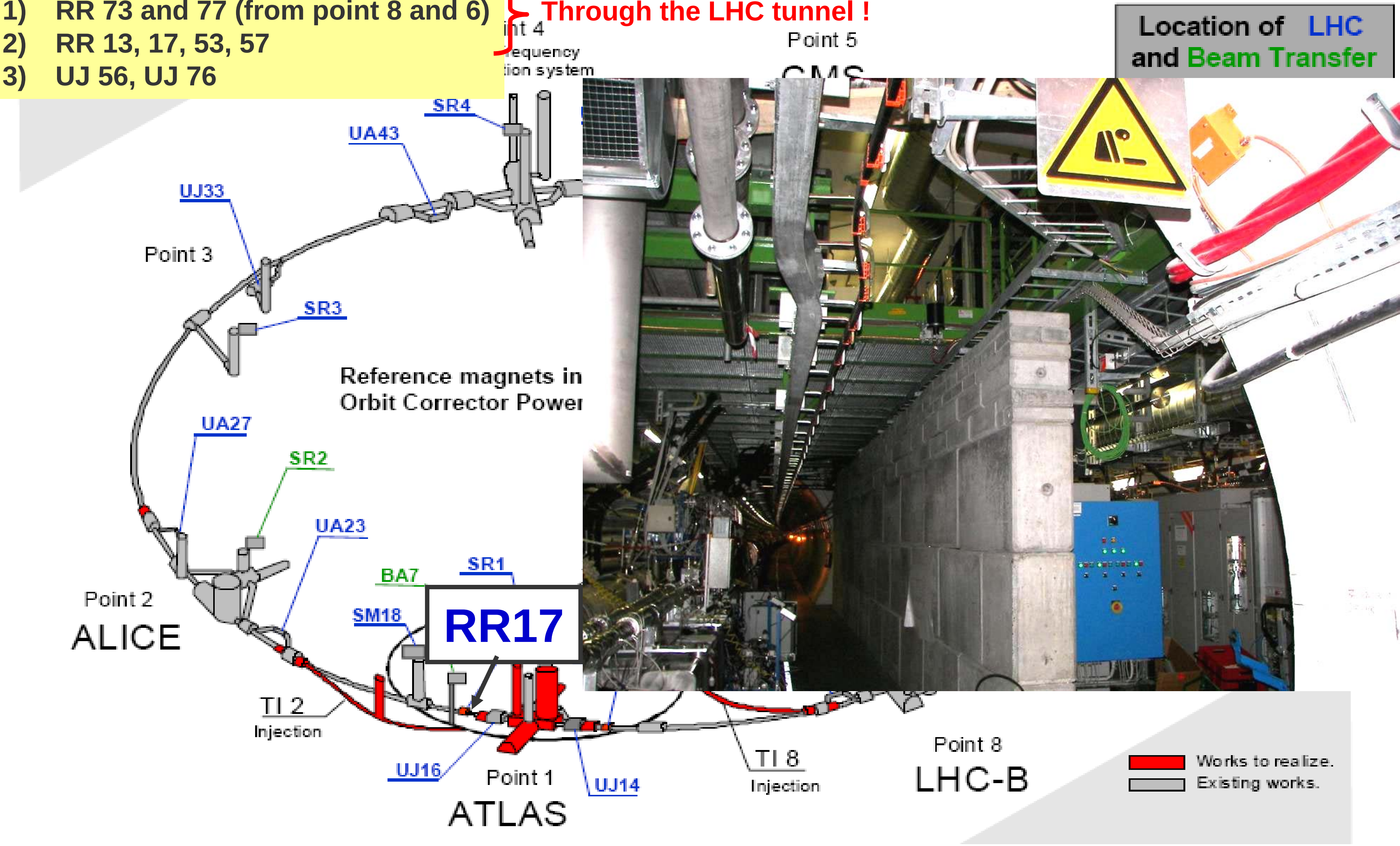
- **On-line inventory tracking for reliability and maintenance**

Massive underground installation

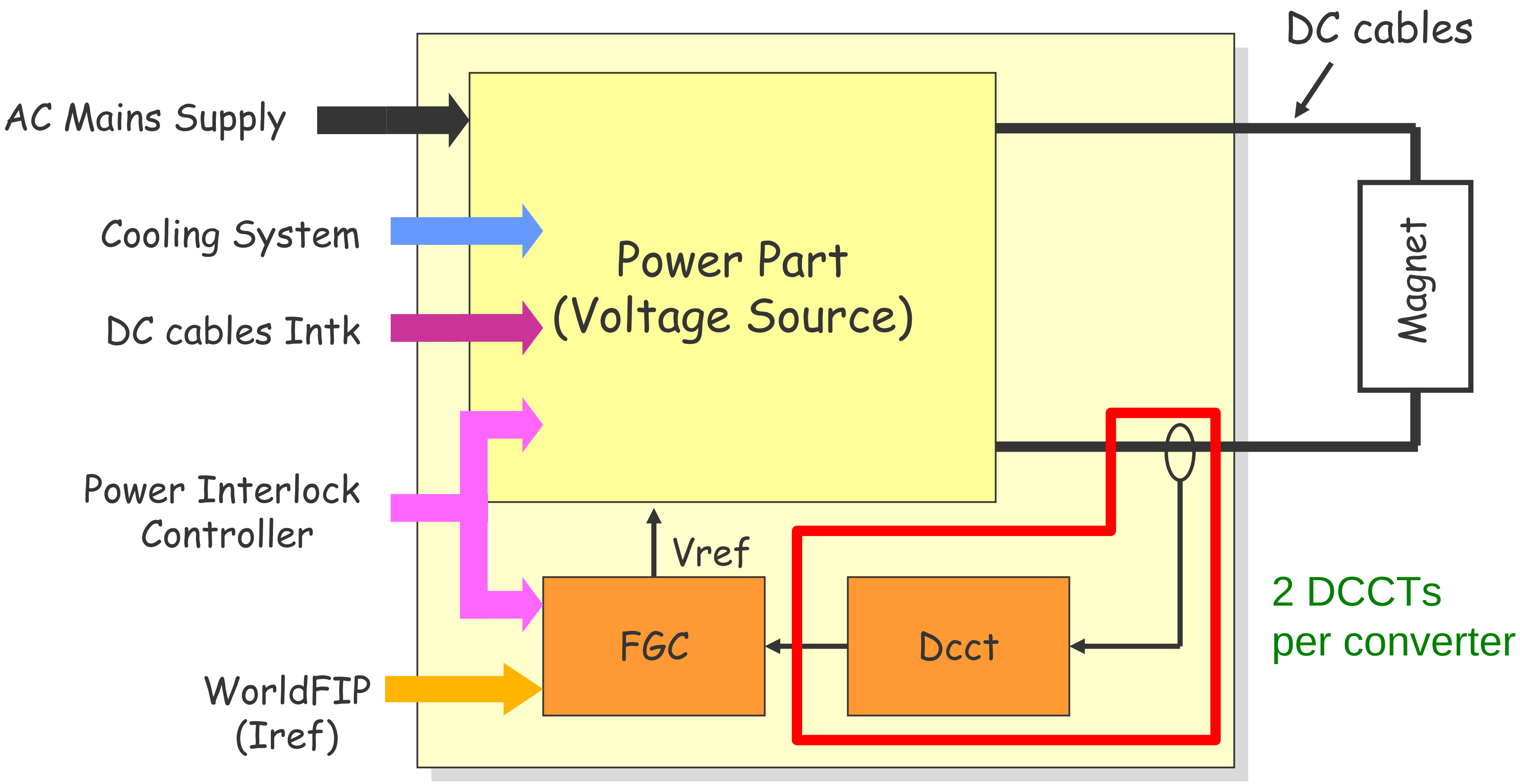
Difficult access:

1) RR 73 and 77 (from point 8 and 6)
2) RR 13, 17, 53, 57
3) UJ 56, UJ 76

Through the LHC tunnel !



LHC Power Converter : current source

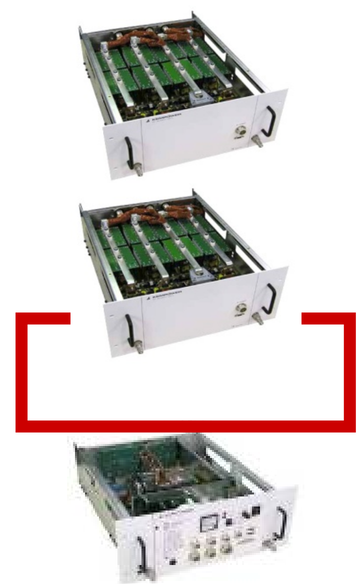


Each power converter there are two DCCTs. With digital current regulation, the FGC is able to automatically change to the second DCCT for regulation, if the first one fails. Some types of DCCT failures can be detected and signalled. Other failures are of such character that it will be impossible to tell which one of the two DCCTs has failed. This strategy should minimise the downtime in case of a DCCT failure.

In line with other power equipment, the DCCTs are of modular design to minimise the intervention time.

The only lengthy operation is the change of a DCCT head (this operation could take up to 5 hours for the high current DCCTs) but it should be very rare (one change every 3 years). ***LHC Design report***

Systematic Modular Approach to reduce the MTTR



[2kA, 8V]

Spare strategy: example

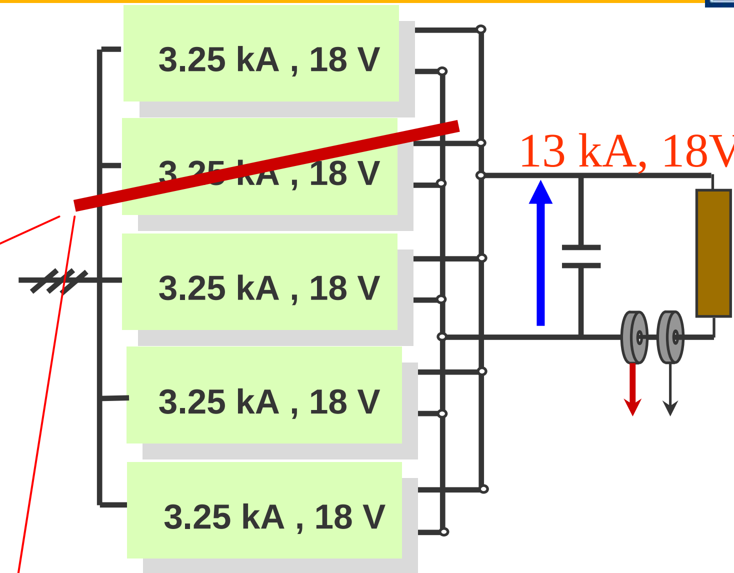
Spare components	Quantity
Power semiconductors	5% of the total number
Inverter semiconductor driver	5% of the total number
Magnetic components: transformers, inductors etc	5% of the total number
Power capacitors	5% of the total number
Power resistors (≥ 3Watts)	5% of the tota l number
Complete electronics boards (fully tested)	3% of the total number
Fuses	5% of the total number
Flow switch	10
Auxiliary power module	5
DC/DC power supply	5
Common control electronics crate	5

- ✓ 16 converters
- ✓ 2 complete spare converters: 1 installed in test hall (used as test bed) and 1 in storage)
- ✓ Spare modules ordered with production contract (~5 %)
- ✓ Spare parts ordered with production contract

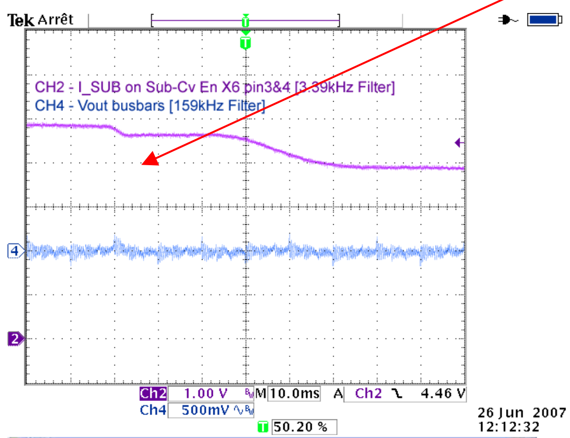
Converter Operation during a sub-converter failure

[13kA,18V] converter :
(4+1) x [3.25kA,18V] subconverters

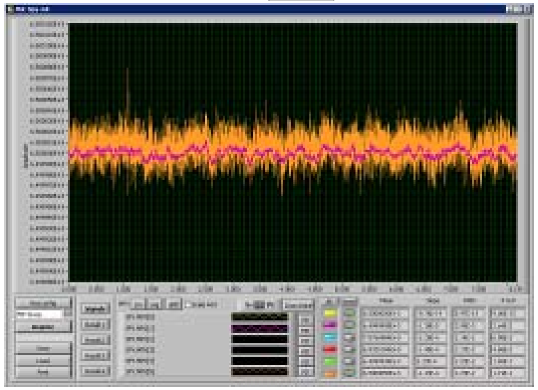
Tests during 7-8 hardware commissioning



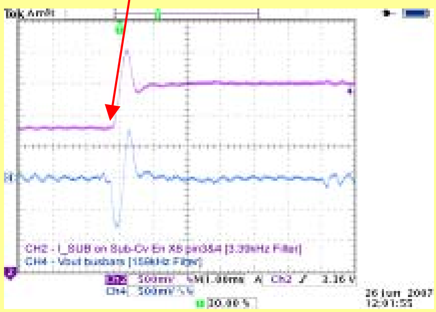
Restart of sub-converter 2

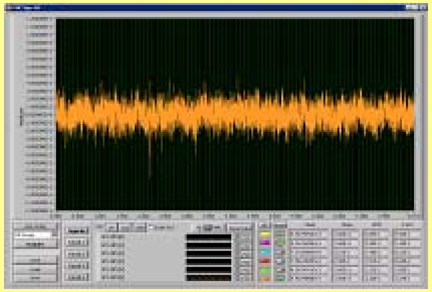


6500 A



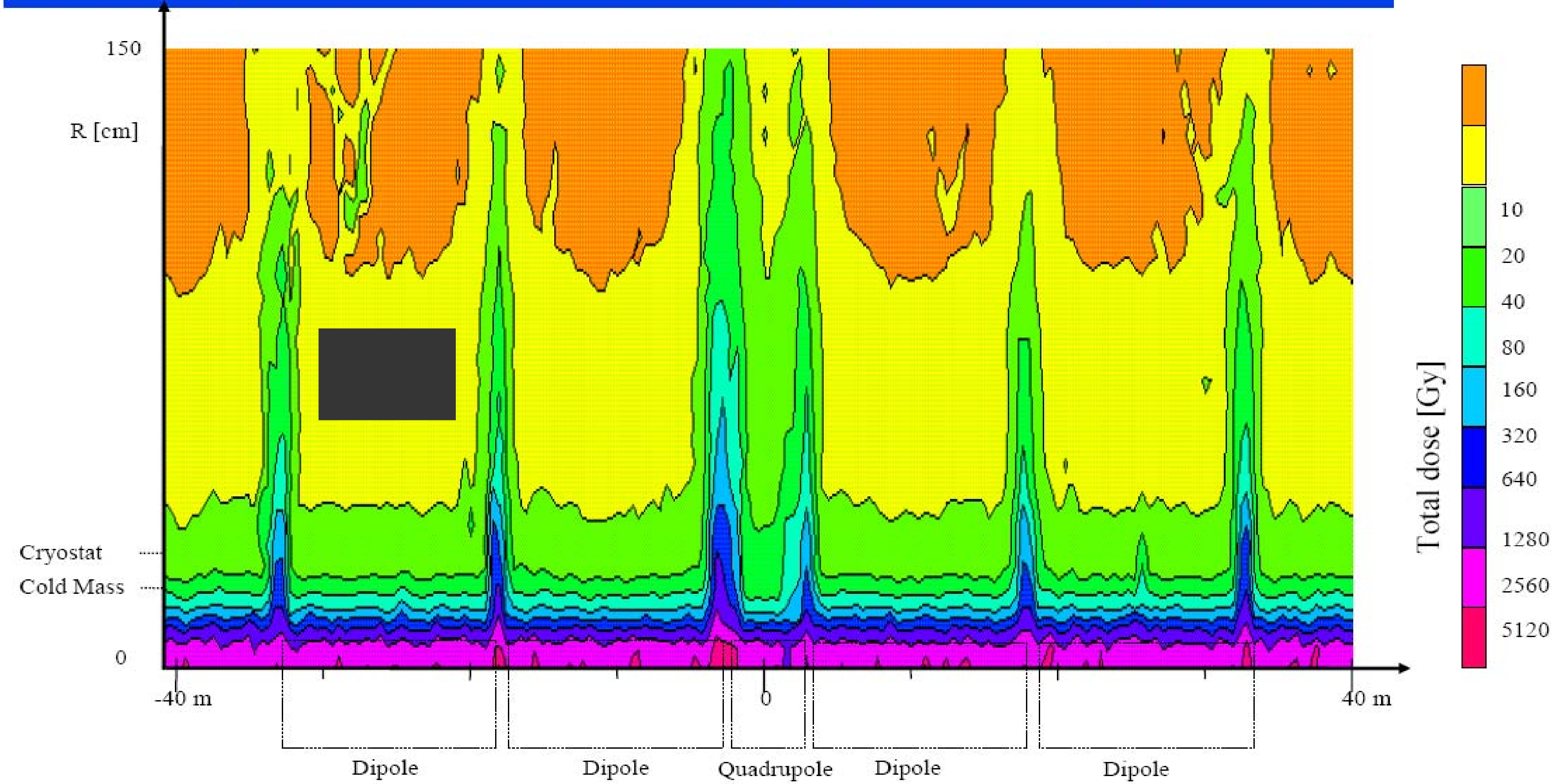
I_MEAS = About 1-2ppm pk-pk





At injection current : 760 A

Longitudinal Dose Map (10 Years)



One year:		
Dose :	2-10	Gy
Neutron fluence:	5×10^{11}	cm^{-2}
Hadron fluence :	4×10^{10}	cm^{-2}

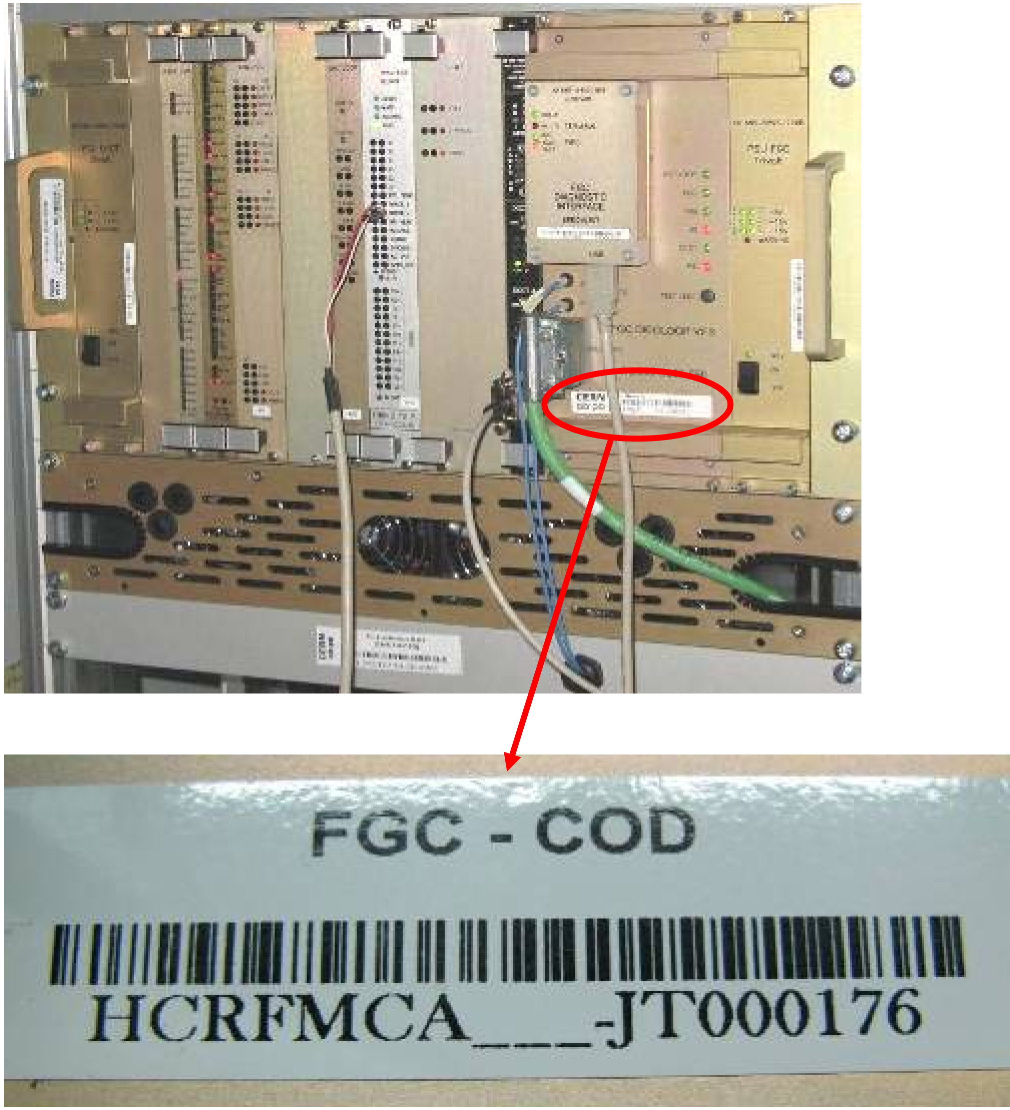
Orbit Corrector PCs
4*[60A,8V]

Σ752 converters around the LHC

High reliability :
MTBF : > 100 ’000 h
=> 1 converter breakdown every 4 days
=> One campaign every 2 or 3 months

Components Inventory

- ✓ **All LHC components have barcodes to allow tracking as INB (Installations nucléaires de base)**
- ✓ **Most electronic components also have a machine readable Maxim/Dallas 1-wire ID device**
- ✓ **> 40’000 components in the LHC powering system are identified in this way**



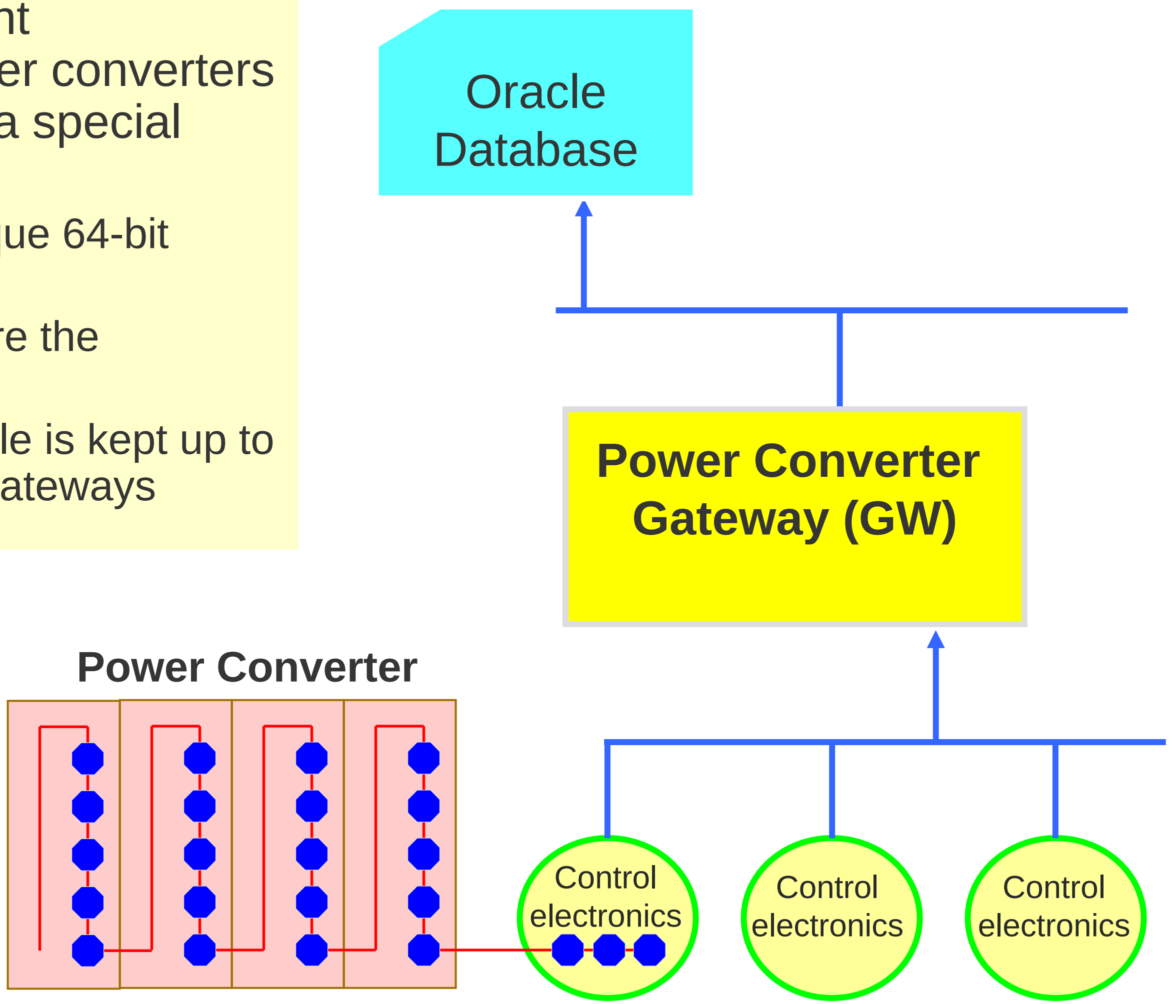
Courtesy of Q. King

Identity management

DALLAS 1-Wire Chip for LHC power converter modules

All electronics boards, current transducers, ADCs and power converters Modules are identifiable via a special Dallas-ID bus

- All Dallas chips have a unique 64-bit number
- In some cases they measure the temperature
- Complete inventory in Oracle is kept up to date automatically by the Gateways
- About 40’000 items will be tagged within the complete LHC powering system
- Module Identity will be central to inventory management

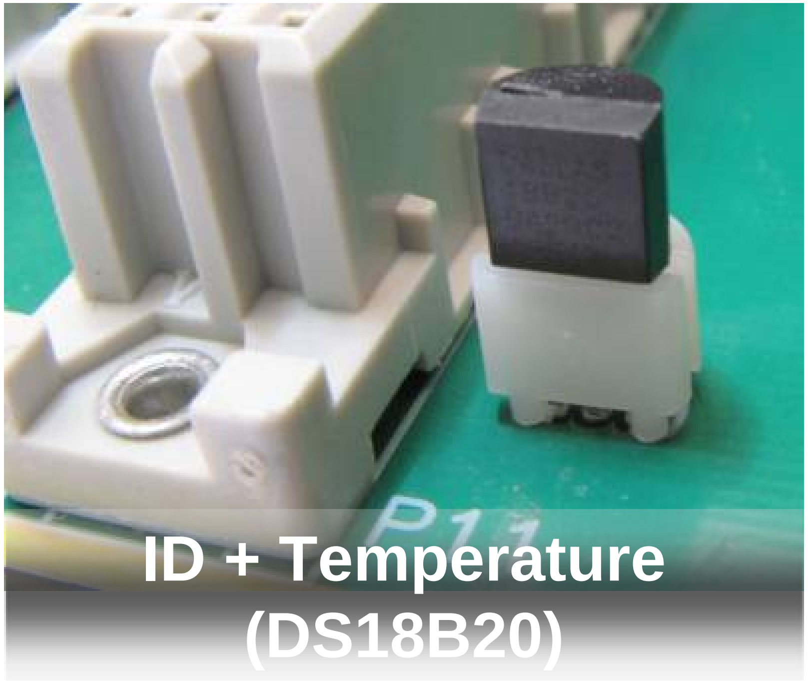


Courtesy of Q. King

Components Inventory

Many different Maxim/Dallas 1-wire devices are available (ADCs, RAMs, switches, etc…) but we use only two:

- **DS1401 ID only**
- **DS18B20 ID + Temperature**



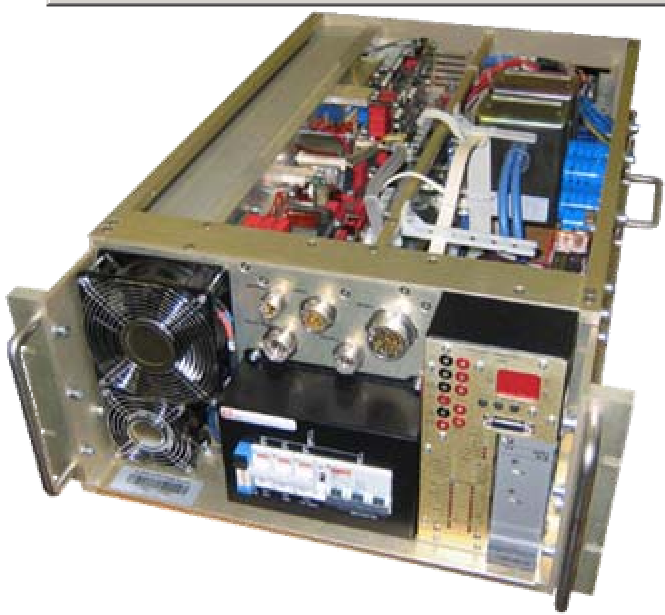
- IDs are unique 64 bit values laser etched during the fabrication, e.g.:
  - EB00000A6F11B001
  - A3000000A2B5DD28
- Byte 1 is a checksum
- Byte 8 is the device type:
  - **01 = ID only (DS2401)**
  - **28 = ID + Temperature (DS18B20)**

Courtesy of Q. King

On-line remote components Inventory: 120A converter example

RPLB.UA67.RCBYV5.R6B1

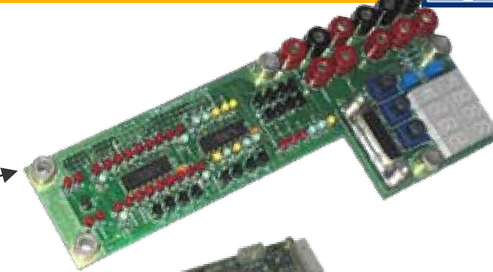
```
PLD VERSION: 5
CODE (BOOT): 130
CODE (MP):   274
NAME:        RPLB.UA67.RCBYV5.R6B1
LABEL:       PC:[120A 10V 4Q] CRWB:120A DCCT:120A Mode:DC
FIP_ID:      CFC-SR6-RR6D:8
;id.vs
A:
   0: 0900000A40E14401  0.00 HCRAAUL001-EP463784 VS Board:[120A 10V 4Q] 4QLS...
   1: 04000009E3305401  0.00 HCRAAUP001-EP466716 VS Board:[120A 10V 4Q] Fron...
   2: 6E00000B48B0AC01  0.00 HCRFBKA___-GL001675 FGC2 DIM-550 Diagnostic Int...
   3: 6800000A40F8E201  0.00 HCRAARX001-EP463417 VS Board:[120A 10V 4Q] Inpu...
   4: 0B00000B444DF201  0.00 HCRAAUW001-EP462170 VS Board:[120A 10V 4Q] Digi...
   5: 9500000A40ABFE01  0.00 HCRAAWT001-EP000235 CRWB Board:[120A 10V 4Q] Cr...
   6: C700000B4599E101  0.00 HCRAASG001-EP465453 VS Board:[120A 10V 4Q] HF P...
   7: D300000B35773101  0.00 HCRAASC001-EP465002 VS Board:[120A 10V 4Q] HF P...
   8: 37000009E227ED01  0.00 HCRMLB____-EP000202 Power Module:[120A 10V 4Q]
   9: CF00000A5A54EB01  0.00 HCRAAUK001-EP464209 VS Board:[120A 10V 4Q] 4QLS...
B:
;
States: LK.NL.FS.FO      Iref:     0.00  Vref:      0.00 VS:  -0.000049  Tout:30.25
F/W:HPTVEFI/IMSIFLRGC Imeas:    -0.00  Vmeas:     0.65 VI:  -0.000112  Tin: 22.00
I/S:DCP/PNABM-UDFCF dIrefdT:    0.00  Ierr:      0 mA Id:      -1 mA  Cpu:46:48%
Ref:                 Range:     0.00 ->        0.00  Trun:       0    Trem:      0
```

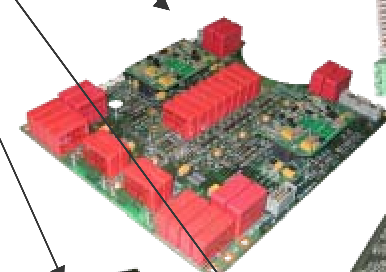


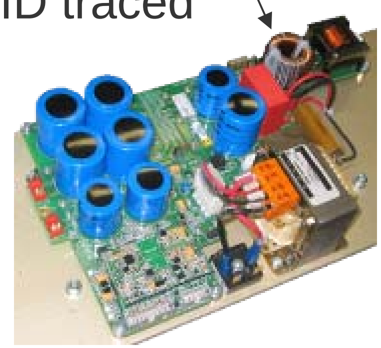
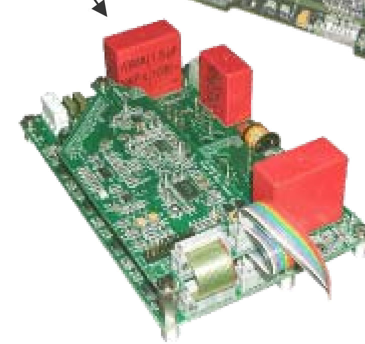
LHC120A-10V:

- 4 000 components

- 10 cards: ID traced



Diagnostic Interface

- The majority of the 1700 LHC power converters are underground in difficult to access areas
- 750 are in the tunnel, up to 2.2km from an access point
- Accurate remote diagnostics is vital if a repair team is to replace the correct module of a system that has failed
- Many converters are formed of sub-converters, each formed of power modules
- A severe failure in one sub-converter could cause a cascade in which all the others trip
- A diagnostic system is needed to reliably identify the first fault on the first module that tripped

- LHC power converter design process includes from day one the operation and the maintenance (MTTR and MTBF optimization)

- Definition of an operation strategy to minimize the MTTR (spare part management, traceability of equipments,…). To maximize the availability, both hot and cold spare systems have be addressed during the design and the production contracts.

- Design and development of remote diagnostic tools to allow remote restart of the equipment or to prepare the underground intervention (MTTR reduction).

- Technical experts involved in the design and the production are responsible of the operation and maintenance of their equipments and composed the standby service (24h service during 9 months per year)

Power converter tests before beam operation

LHC Power converters are tested before beam commissioning

- Intensive tests of the LHC power converters:
  - Parts (power source, DCCT, FGC, ADC,…)
  - Complete power converters (current source) in surface test halls (performance and 24h heat run)
  - Short-circuit tests in the underground final location
    (24h endurance test: 16h at ultimate and 8h nominal)

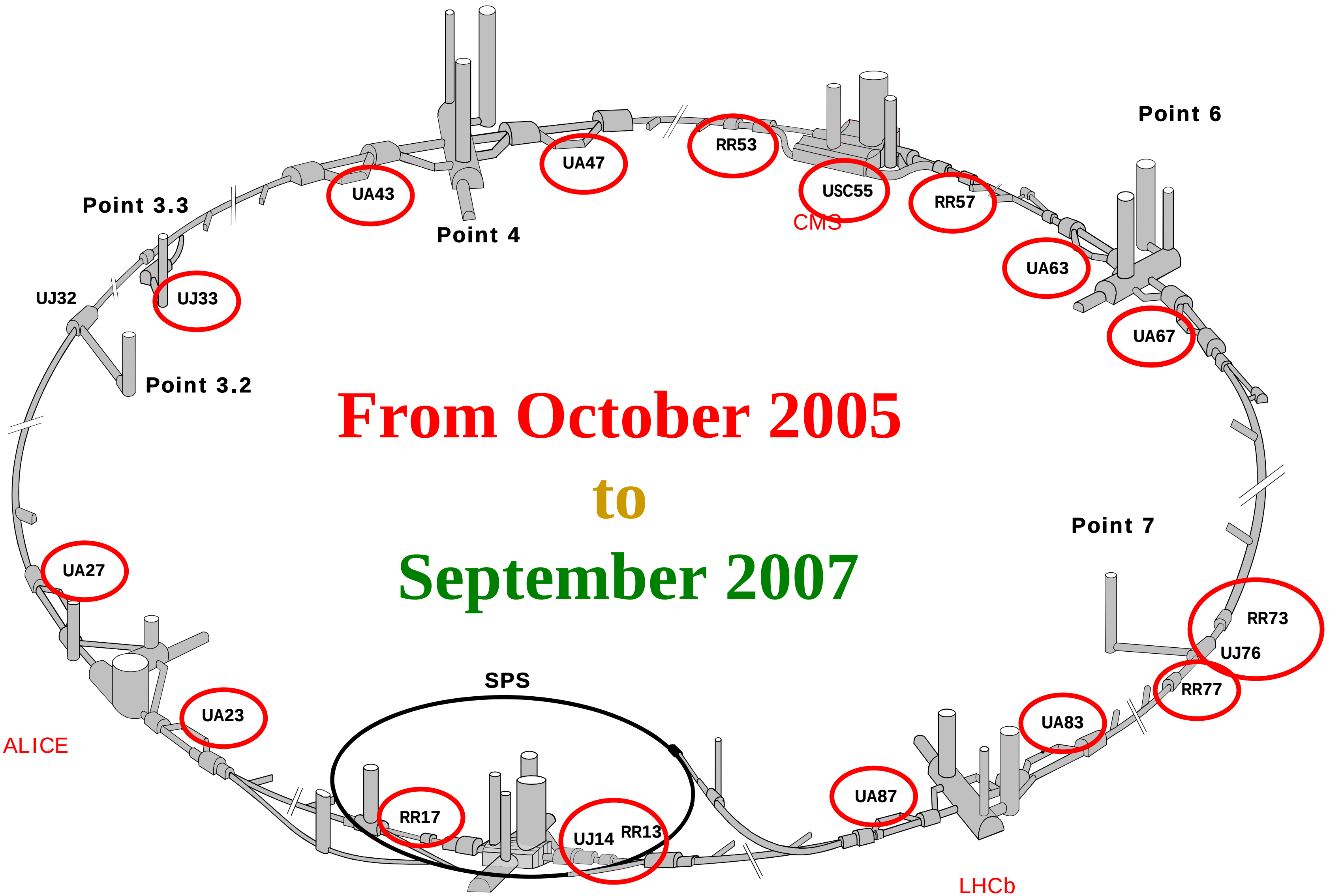
- Hardware commissioning:
  - Compatibility with QPS, PIC,… and high precision per sector
  - Ramp and squeeze functions; tracking tests; Powering Group of Circuits
  - Long run tests (8h to 24h)
  - EMC with injection kickers and with dump kickers

- a lot of early failure **("défaut de jeunesse")** has been solved (initial MTBF will be crucial at the start of LHC operation)

Content

- Operation organisation
- MTBF and MTTR
- Consolidation strategy
- Design of the LHC power converters:
  - Design principle: N+1 strategy, reliability and MTTR objectives,…
  - Operation strategy
- **LHC hardware commissioning**

Systematic short-circuits tests: full current during 24h



From October 2005

to

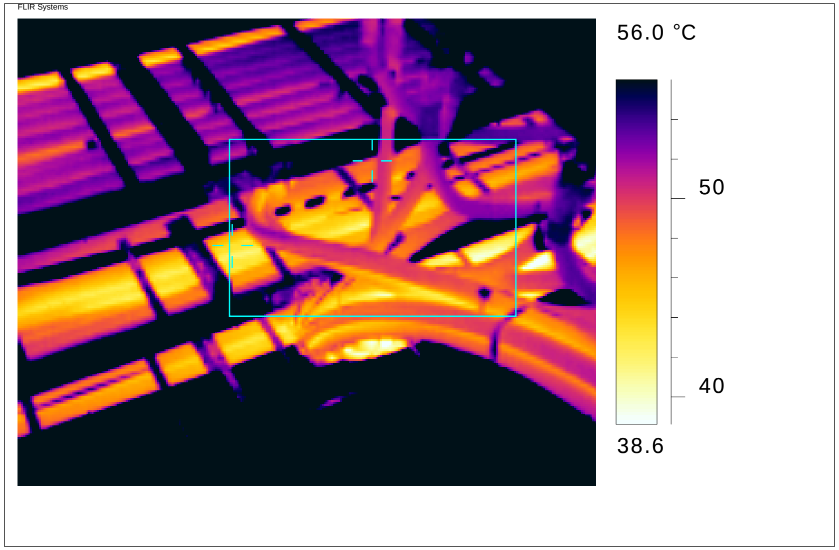
September 2007

All tests were successfully concluded by a 24h endurance test (16h at ultimate and 8h nominal)

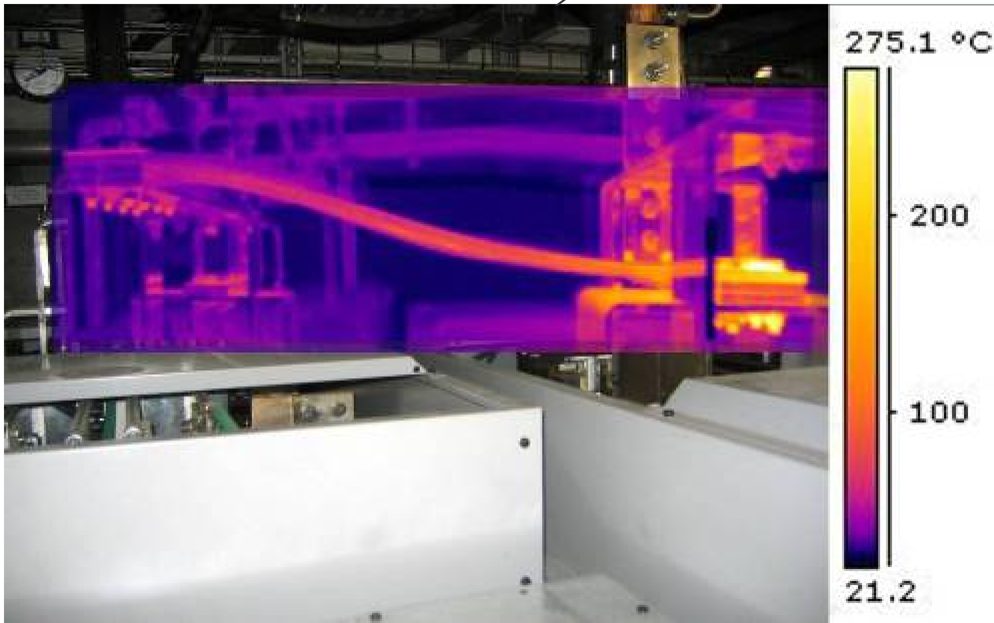
Systematic short-circuits tests: full current during 24h

early failures ("défauts de jeunesse")

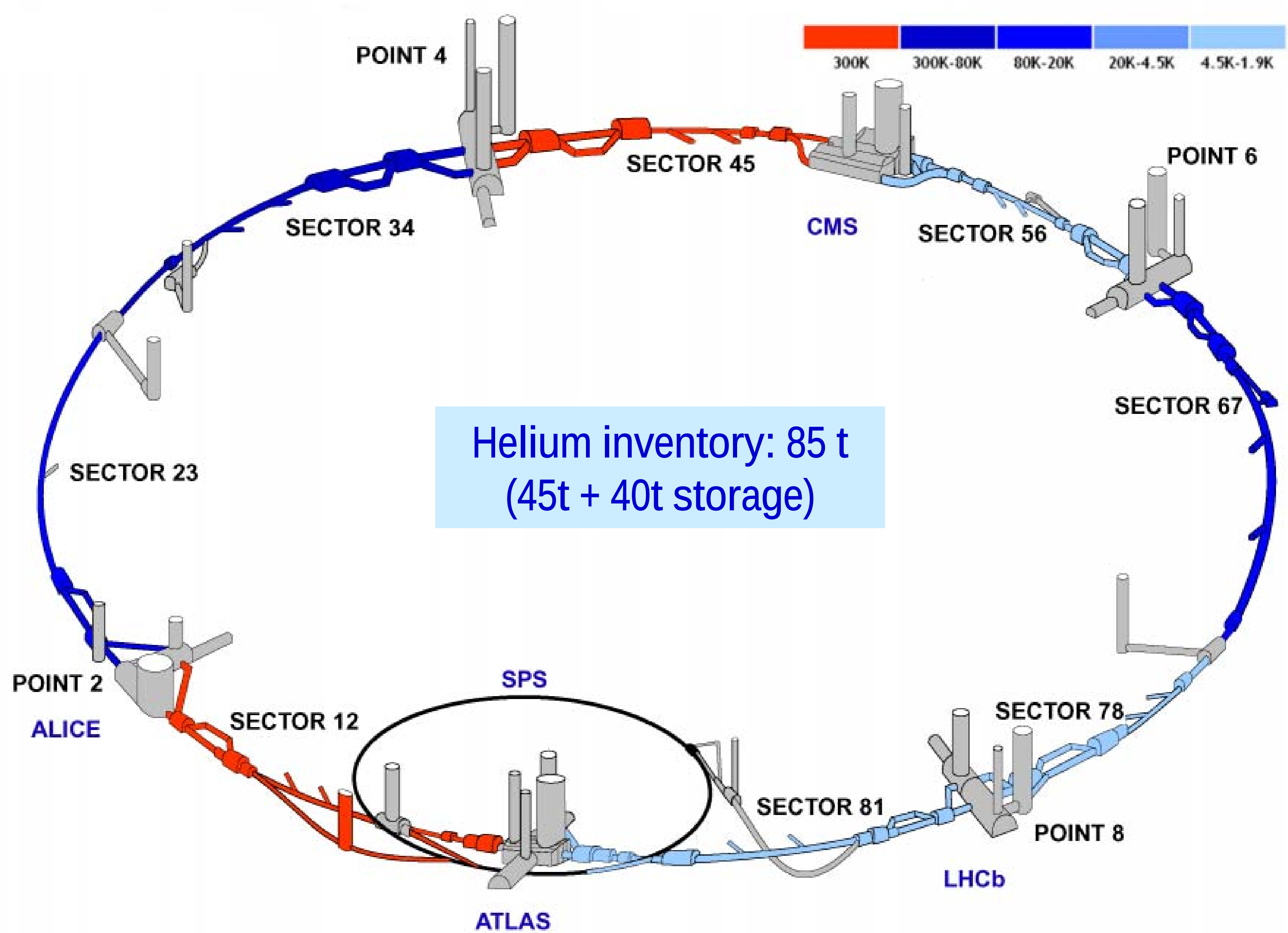
An Infra Red analysis to see what a hand cannot feel at less than 20cm !!!
Loose connection



600A cables

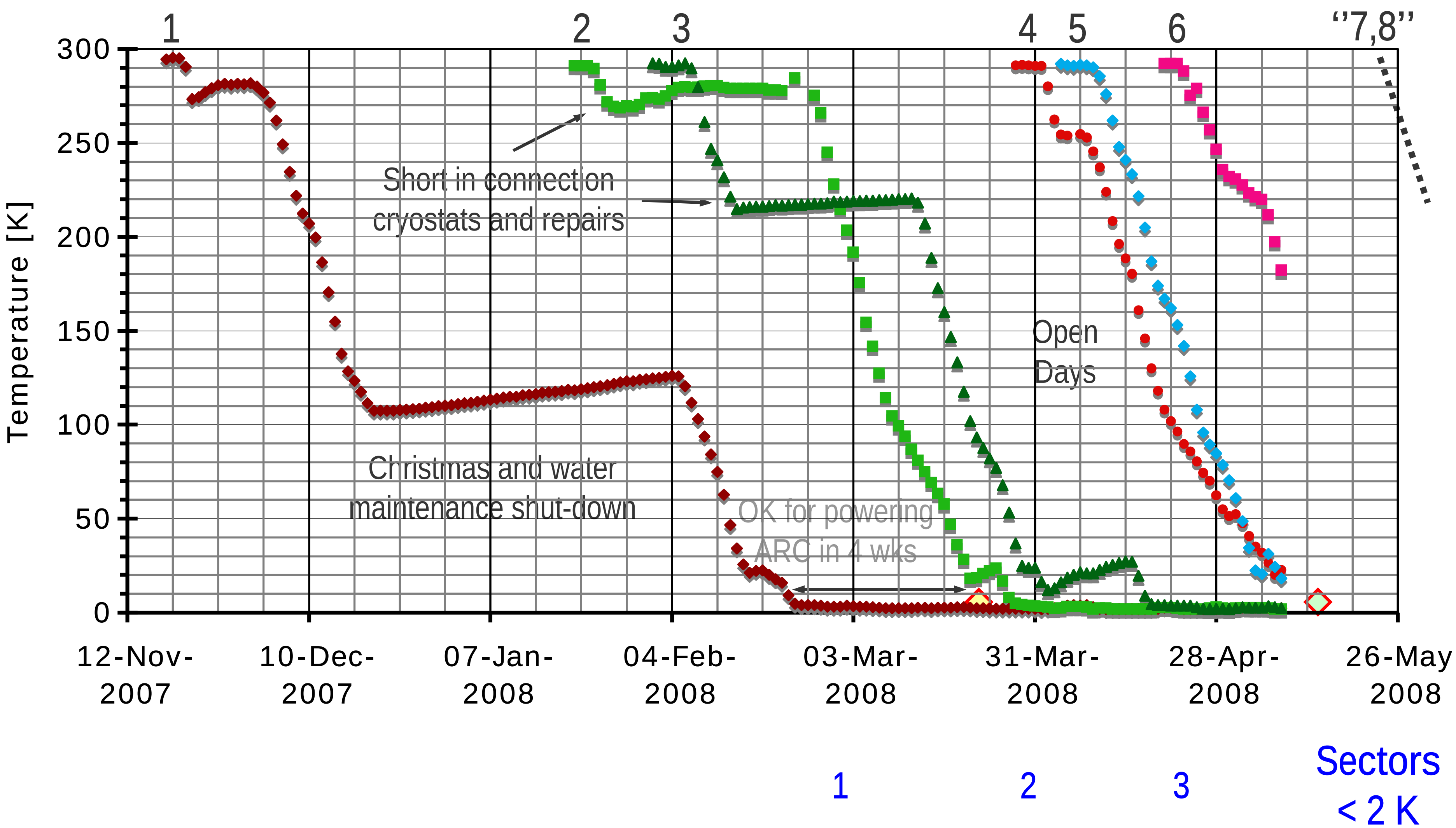


Status of the LHC (15th May 2008)



All sectors should be cold by end of May and 2K by mid of July

Cool-down of LHC sectors



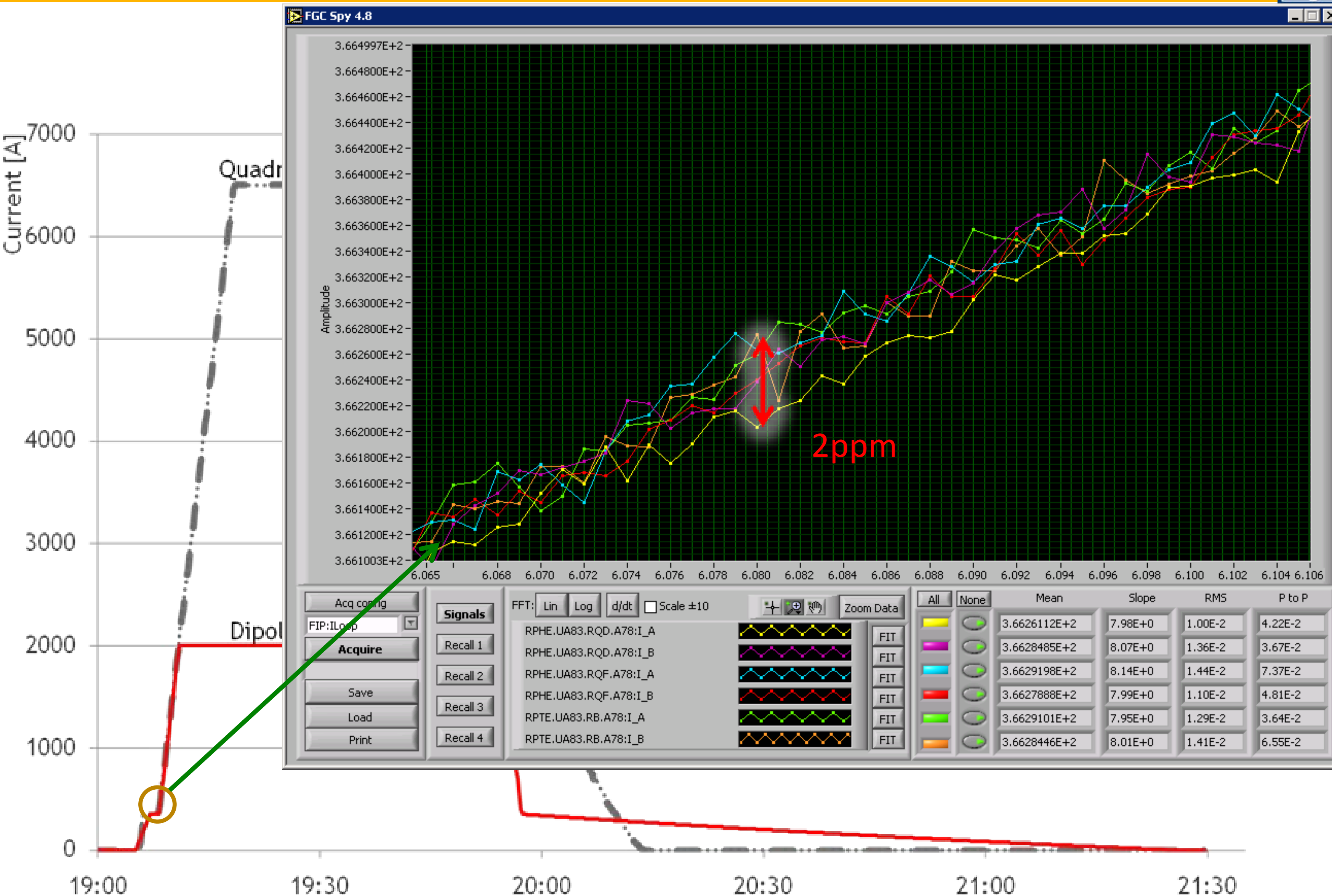
Courtesy of S. Claudet

Powering Tests: the superconducting circuits

Circuit Type	Sector								LHC
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1	
13 kA	3	3	3	3	3	3	3	3	**24**
Independently Powered Dipoles	3	2	2	3	1	0	2	3	**16**
Independently Powered Quadrupoles	14	7	6	13	12	5	7	14	**78**
600A with Energy Extraction	23	27	28	24	23	27	27	23	**202**
600A Energy Extraction in Converter	14	20	20	14	14	20	20	14	**136**
600A no Energy Extraction	16	9	2	9	9	2	9	16	**72**
80-120A Correctors	50	37	22	33	33	22	37	50	**284**
TOTAL	**123**	**105**	**83**	**99**	**95**	**79**	**105**	**123**	**812**

Circuit Type	Sector								LHC
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1	
60A Closed Orbit Correctors	94	94	94	94	94	94	94	94	**752**

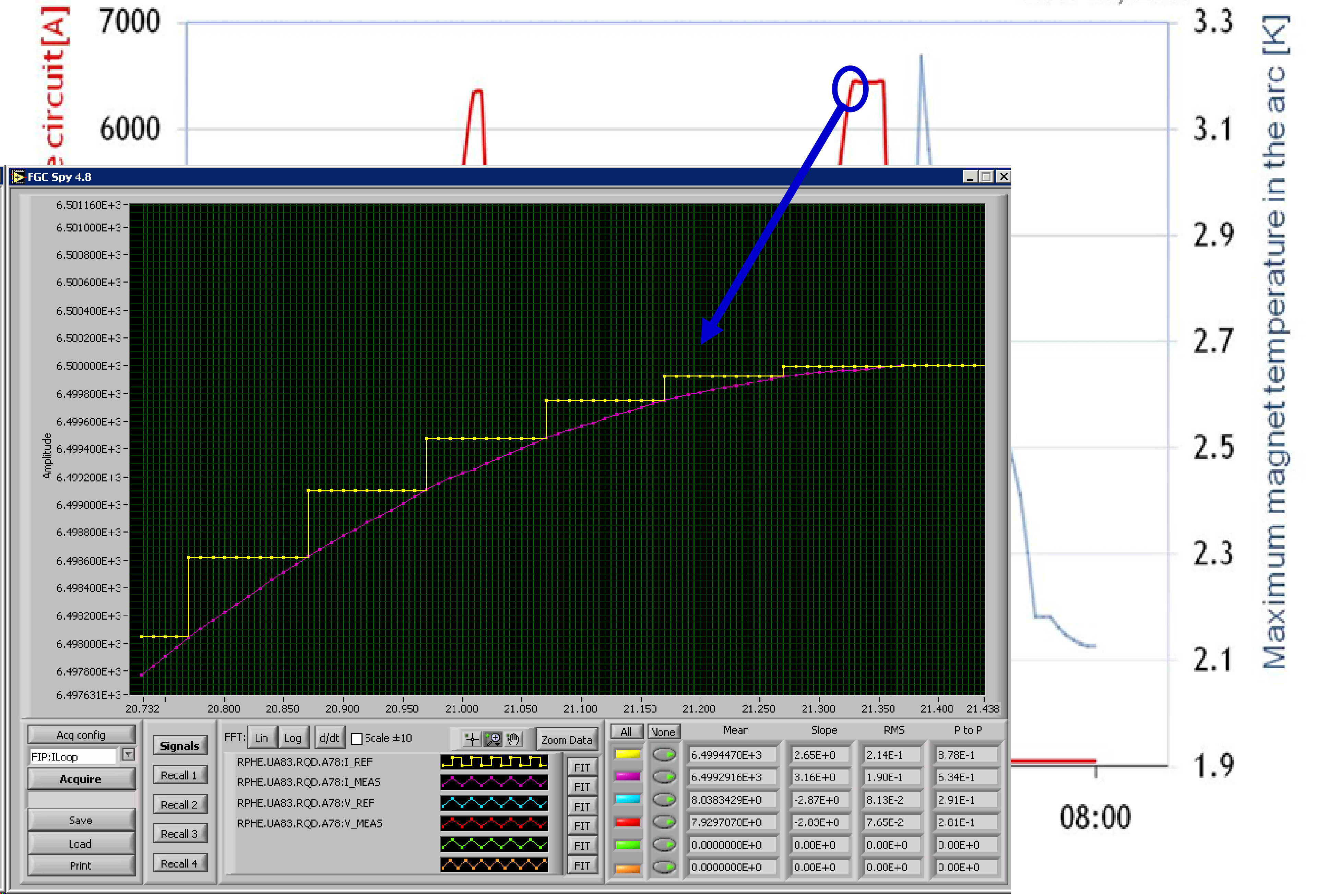
Tracking between the three main circuits of sector 78



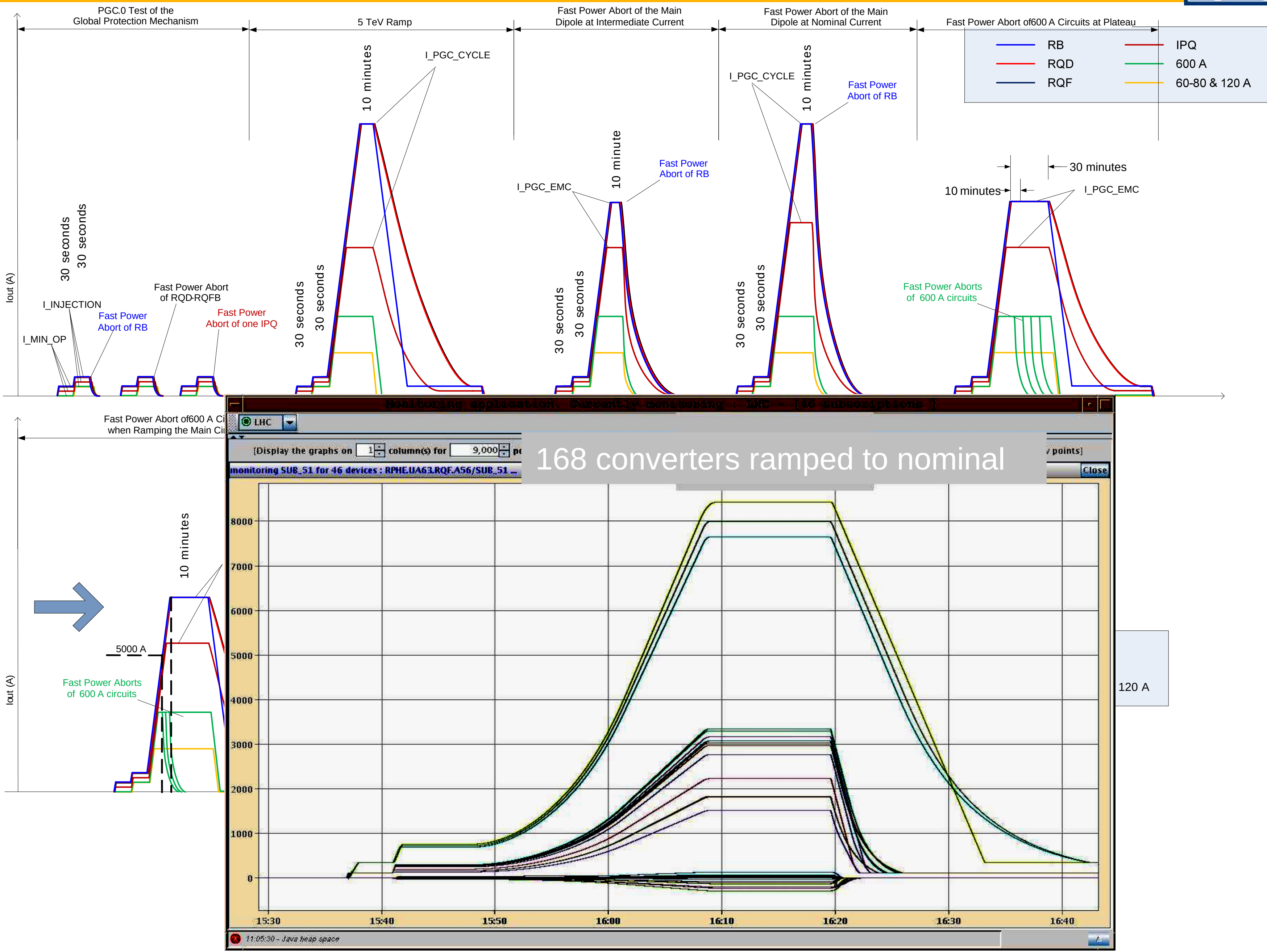
Free-wheeling : L/r ≅ 23'000 s

RQD Circuit discharge in the energy extraction system and Quench from 6.5 kA

June 21, 2007



Powering Groups of Circuits



... where are we today (powering tests of sector 56)

- A strategy, where the initial beam energy is at least 5 TeV, is proposed to gain time with the training of magnets and meet the summer deadline.
- The fact that we can easily reach that energy level has been proven both in Sector 45 and Sector 56.
- Nevertheless, we have started a quench campaign on the dipoles of Sector 56 to find out how much time we will need to get to 7 TeV. All the other circuits have been commissioned at 7 TeV

Current [A]	Equivalent Energy [TeV]	Magnet (Position)	Date
10004	5.91	3362 (A28L6) - 2245 (B29R5)	28/04/08
10227	6.04	3370 (A29L6)	28/04/08
10357	6.12	3372 (A23L6)	29/04/08
10546	6.23	3188 (A15R5)	30/04/08
10652	6.29	3368 (C32R5)	06/05/08
10714	6.33	3246 (A10L6) - 3387 (C16L6)	07/05/08
10751	6.35	3335 (A21R5)	09/05/08
10793	6.38	3337 (B8R5)	15/05/08
10834	6.40	3357 (A20L6)	16/05/08

Thank you for your attention