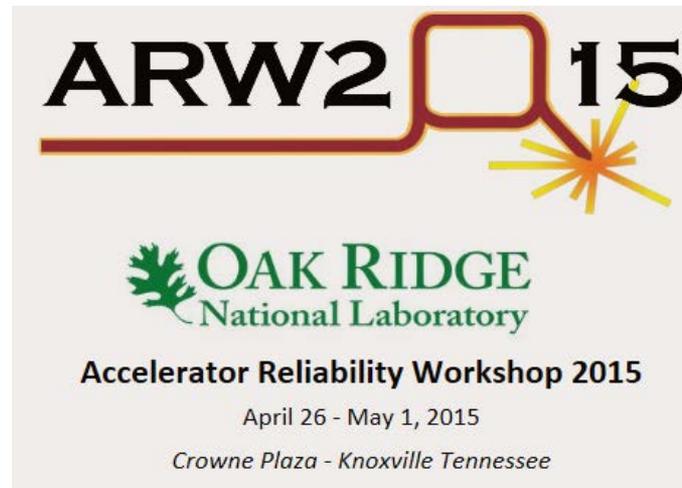


Vacuum System Reliability Illustrated with LHC

V. Baglin

CERN TE-VSC, Geneva



Reliability engineering,

The ability of a system or component to perform its **required functions under stated conditions** for a **specified period** of time [1].

[1] Institute of Electrical and Electronics Engineers (1990) IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. New York, NY ISBN 1-55937-079-3

- A system must be **think / produced to be reliable before** being operated
- I will introduce the **main action** taken in order a vacuum system is **reliable during** operation

OUTLINE

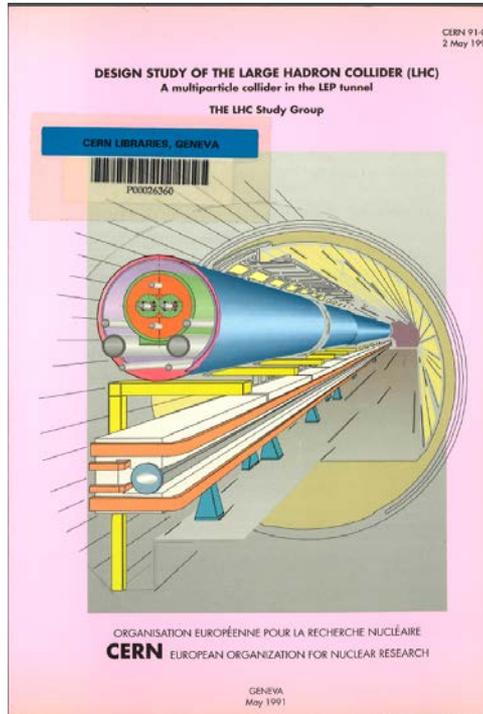
1. Study, Design, Procurement & Installation
2. Operation
3. Repair, Consolidation & Upgrade
4. Summary

1. Study, Design, Procurement & Installation

LHC from Study to Project

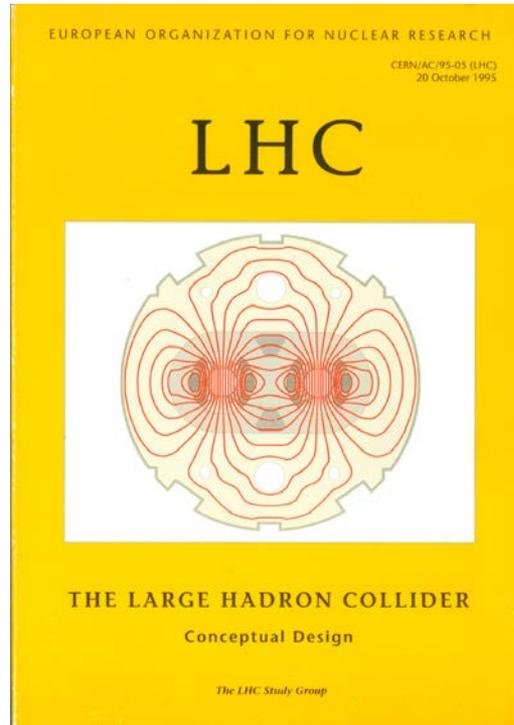
- **Communication** & release of **Official** documents and books **is mandatory** to share pertinent information across the project

Design study



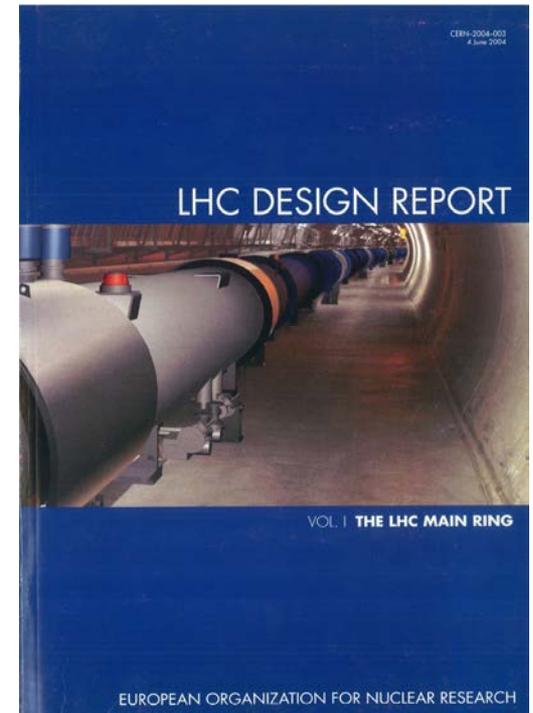
1991

Conceptual design



1995

Design project



2004

LHC Project

- Defining and understanding the machine parameters impacting the vacuum system was a crucial part of the project

CERN
CH-1211 Geneva 23
Switzerland



LHC Project Document No.
LHC-PM-ES-0002.00 rev.1.1

CERN Div./Group or Supplier/Contractor Document No.
AC/TCP

EDRS Document No.
100513.00 rev. 1.1

Date: April 8, 1999

Engineering Specification

**GENERAL PARAMETERS FOR EQUIPMENT
INSTALLED IN THE LHC**

Abstract

A number of design parameters and operational scenarios are used in many documents (Project Notes, Project Reports, Market Surveys, Technical Specifications, etc.) either directly, or for calculating safety margins or defining test procedures for machine components. The present document is a compilation of these parameters with a reference to a document or other sources where more detailed information can be found. Equipment installed in the experimental areas has not been considered.

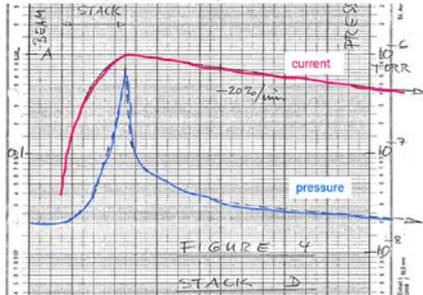
<i>Prepared by :</i>	<i>Checked by :</i>	<i>Approved by :</i>
Paul Cruikshank Paul Proudlock Germana Riddone Roberto Saban Rüdiger Schmidt	Wolfgang Erdt Jean-Pierre Gourber Oswald Gröbner John Pedersen Alain Poncet Günther Rau Felix Rodriguez-Mateos Norbert Siegel Graham Stevenson Laurent Tavlan Carlo Wyss	Lyndon Evans Paul Faugeras Philippe Lebrun Pierre Lefèvre Thomas Taylor



	Design	
	Nominal	Ultimate
Energy [TeV]	7	
Luminosity [$\times 10^{34} \text{ cm}^{-2} \cdot \text{s}^{-1}$]	1.0	2.3
Current [mA]	584	860
Proton per bunch [$\times 10^{11}$]	1.15	1.7
Number of bunches	2808	
Bunch spacing [ns]	25	
Normalised emittance [$\mu\text{m} \cdot \text{rad}$]	3.75	
β^* [m]	0.55	
Total crossing angle [μrad]	285	
Critical energy [eV]	44.1	
Photon flux [ph/m/s]	$1 \cdot 10^{17}$	$1.5 \cdot 10^{17}$
SR power [W/m]	0.22	0.33
Photon dose [ph/m/year]	$1 \cdot 10^{24}$	$1.5 \cdot 10^{24}$

Expertise: Intersecting Storage Rings

- Discovery of :
 - Vacuum Stability and pressure runaway



First documented pressure bump in the ISR
E. Fischer / O. Gröbner / E. Jones 18/11/1970

- Beam induced multipacting

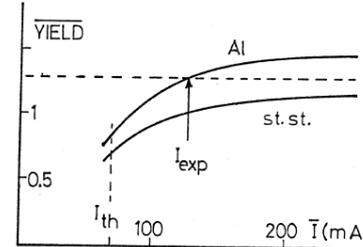


Fig. 4. Average secondary electron yield for aluminium and stainless steel obtained from figs. 2 and 3 and assuming uniformly distributed electrons. As seen from the observed threshold, I_{exp} , the calculation overestimates the yield by about 30%. With this correction, stainless steel should not multipactor in the ISR.

O. Gröbner,
Proc X Int. Conf. High Energy Accel, Protvino 1977

- Application of glow discharge cleaning as a remedy
- In the ISR, two cold bore were also operated during ~ 5 years in order to prepare the use of superconducting magnets for the future !

- Vacuum stability
- Condensation of gas
- ...

→ Development of laboratory studies, cleaning methods, surface science etc.

IEEE Transactions on Nuclear Science, Vol. NS-24, No. 5, June 1977
A VACUUM COLD BORE TEST SECTION AT THE CERN ISR
C. Benvenuti, R. Calder, M. Milleret
CERN
Geneva, Switzerland

Summary
A 2 m helium cooled vacuum test section has been inserted into the CERN ISR to investigate problems molecules are adsorbed as ions than secondary molecules are released (beam pumping).
In the CERN ISR, in which, for geometrical reasons,

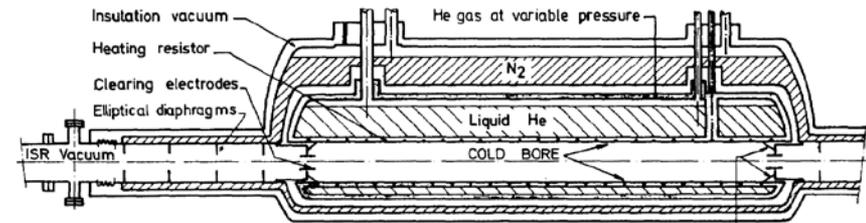
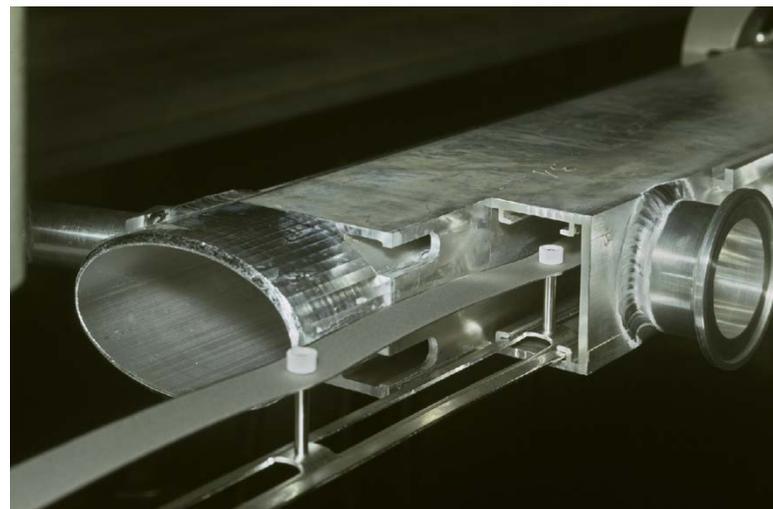
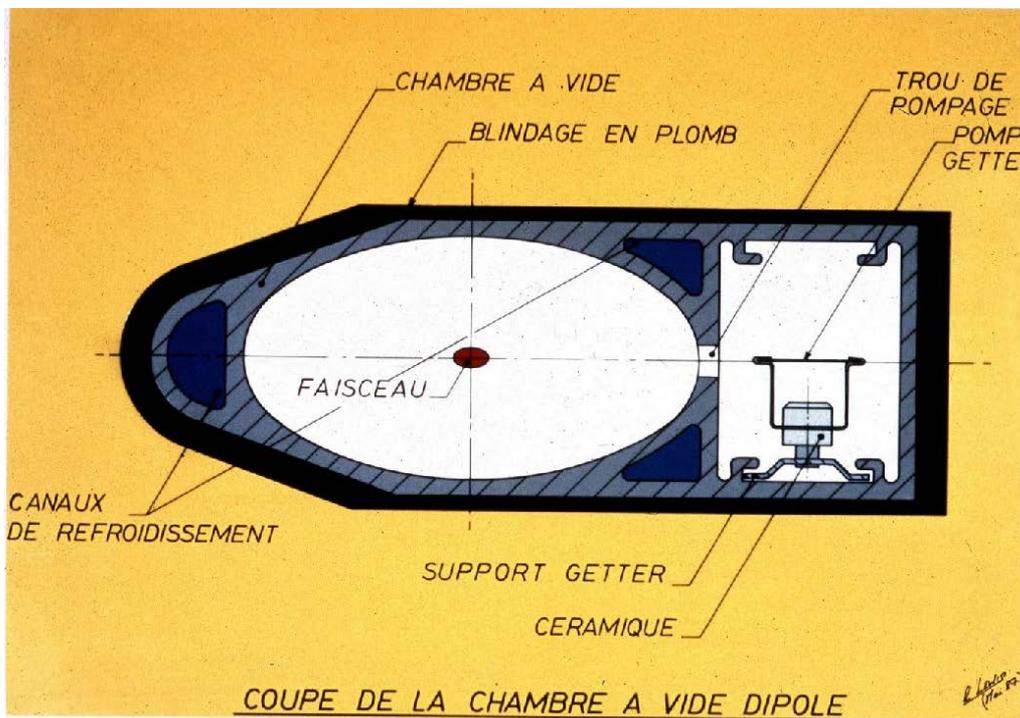
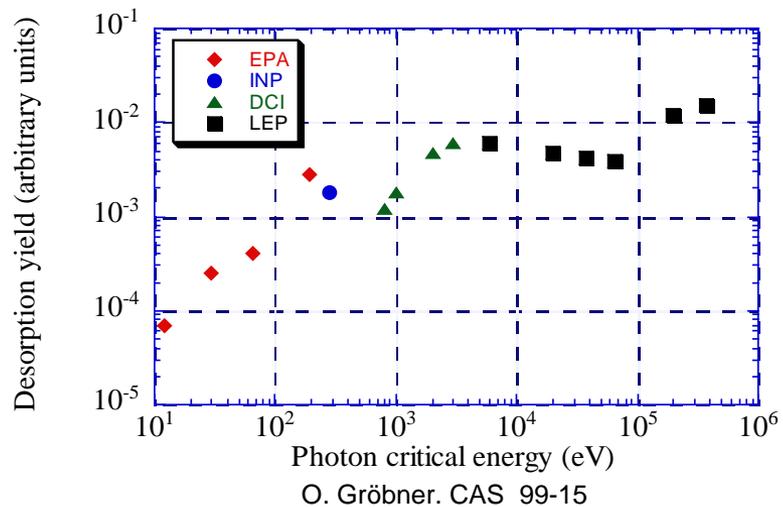


Fig. 2. Cold-Bore Cryostat - Schematic Outline.

More Expertise: Large Electron Positron Collider

- Synchrotron radiation in LEP:
 - From 6 to 660 keV critical energy
 - Gas desorption studies
- Innovative pumping system
 - Antechamber with NEG pumping strip
 - Water cooled and lead shielded



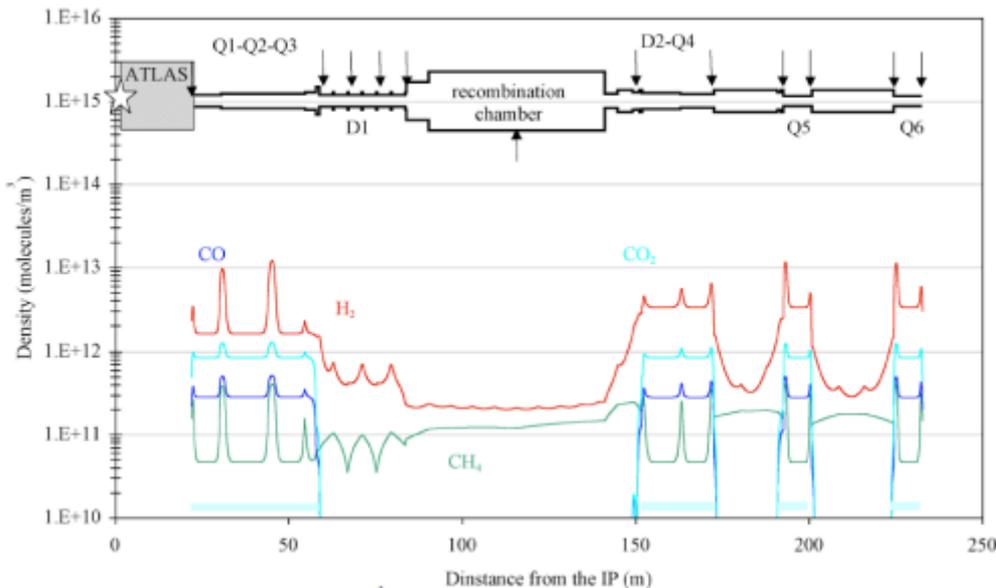
(CERN LEP Vacuum group)

LHC Design Value : a Challenge with p Beams

- **Life time limit** due to nuclear scattering ~ 100 h
 - $n \sim 10^{15} \text{ H}_2/\text{m}^3$
 - $\langle P_{\text{arc}} \rangle < 10^{-8} \text{ mbar H}_2 \text{ equivalent}$
 - ~ 80 mW/m heat load in the cold mass due to proton scattering

$$\tau = \frac{1}{\sigma c n} \quad P_{\text{cold mass}} = \frac{I E}{c \tau}$$

- **Minimise background** to the LHC experiments



	H2_eq / m3	mbar
$\langle \text{LSS}_{1 \text{ or } 5} \rangle$	$\sim 5 \cdot 10^{12}$	10^{-10}
$\langle \text{ATLAS} \rangle$	$\sim 10^{11}$	10^{-11}
$\langle \text{CMS} \rangle$	$\sim 5 \cdot 10^{12}$	10^{-10}

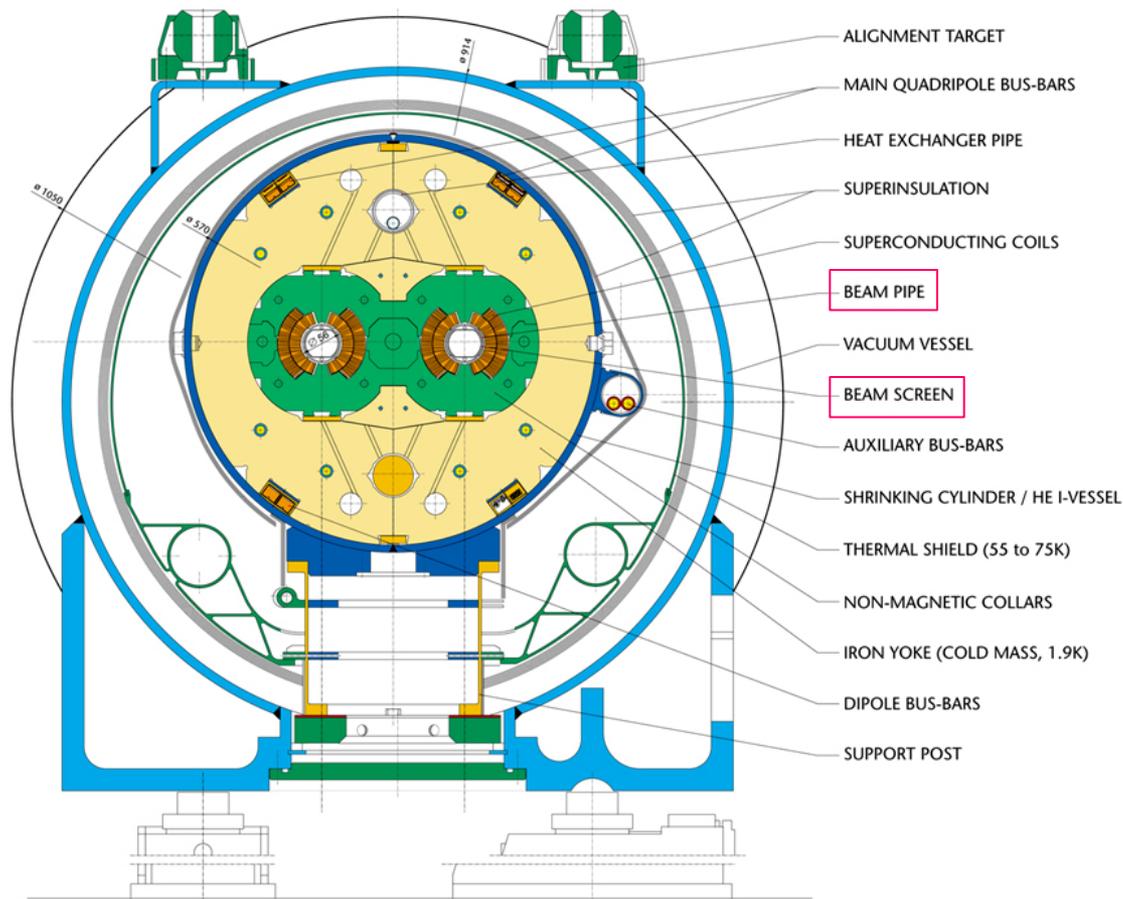
A. Rossi, CERN LHC PR 783, 2004.

→ Predicting LHC vacuum performances with models

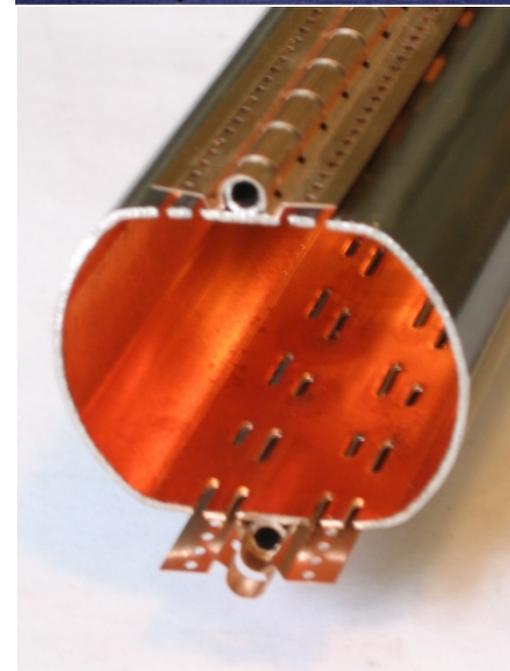
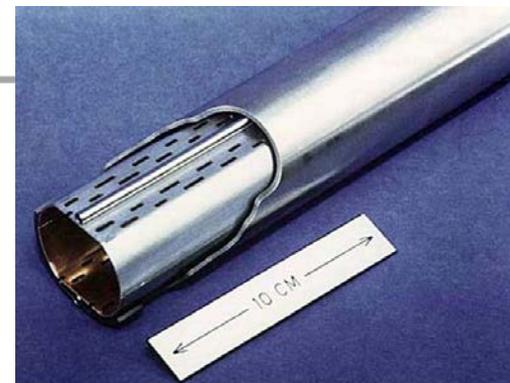
LHC Dipole Vacuum System

- Cold bore (CB) at 1.9 K which ensures leak tightness
- Beam screen (BS) at 5-20 K which intercepts thermal loads

LHC DIPOLE : STANDARD CROSS-SECTION



CERN AC/DI/MM - HE107 - 30 04 1999



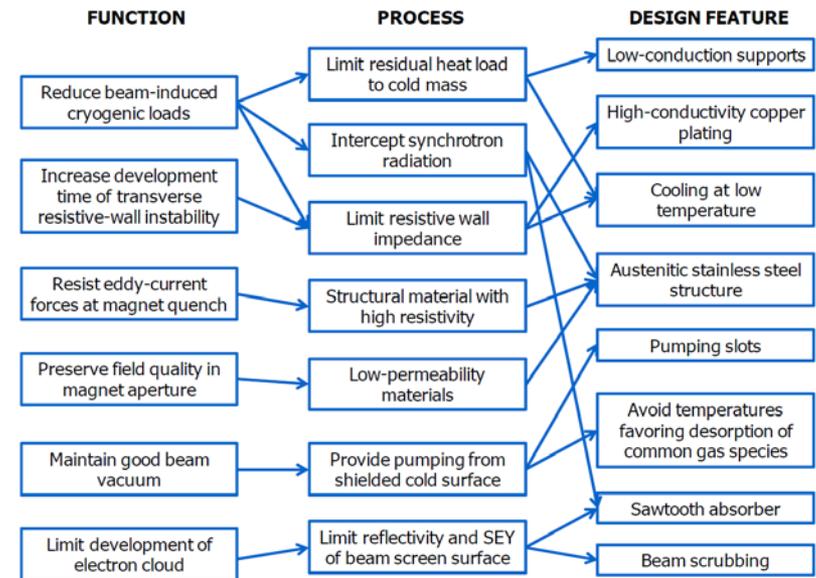
New System: LHC Beam Screens

- An **innovative and complex** system, produced at several 10 km scale !
- **Intercept the heat load** induced by the circulating beam
- Operate between 5 and 20 K
- Pumping holes to **control the gas density**



Courtesy N. Kos CERN TE/VSC

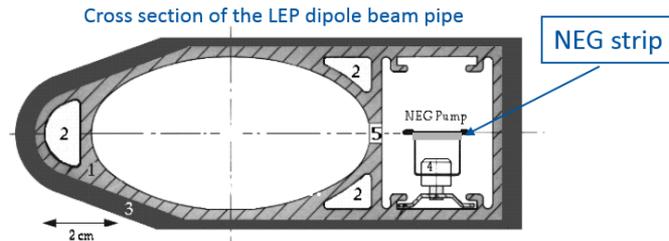
Functional design map of beam screen



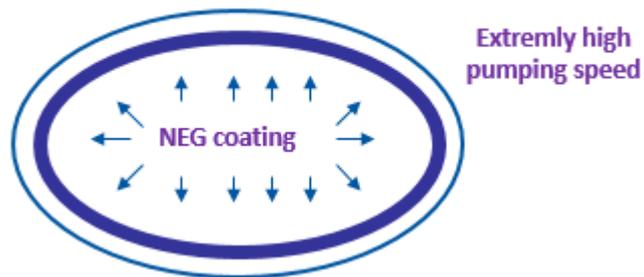
P. Lebrun *et al.*, ICEC 2012

New System: NEG film coating

- **Invention** of low activation temperature ($\sim 200^{\circ}\text{C}$) **getter film**
=> **full** pumping across the beam pipe
- Some vacuum chambers were constructed and getter coated ...
~ 1 200 vacuum chambers produced



Cross section of an LHC warm dipole beam pipe



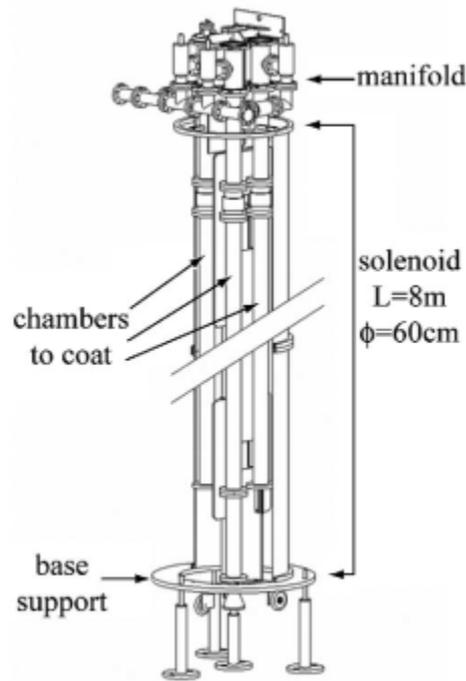
C. Benvenuti *et al.*



Courtesy R.Veness and P. Chiggiato

NEG Coating System: Industrialised Process

- Ti-Zr-V is coated by **magnetron sputtering** with Kr gas
- ~ 1 μm thick
- All room temperature vacuum chamber including the experimental beam pipe are coated with Ti-Zr-V
- Performances are validated by XPS on **witness sample**



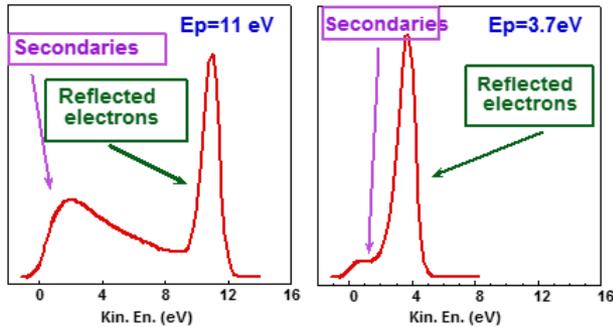
P. Costa Pinto, P. Chiggiato / Thin Solid Films 515 (2006) 382-388

Base Line Validation

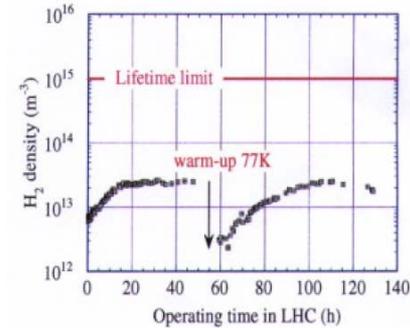
- Many studies conducted over ~ a decade with experts all around the world, some examples:

Material performance qualification

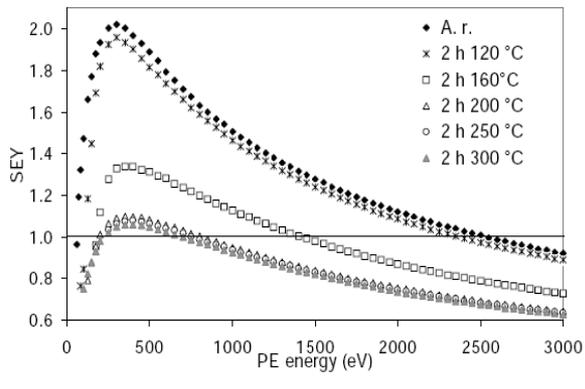
System performance qualification



R. Cimino, I.R. Collins, *App. Surf. Sci.* 235, 231-235, (2004)

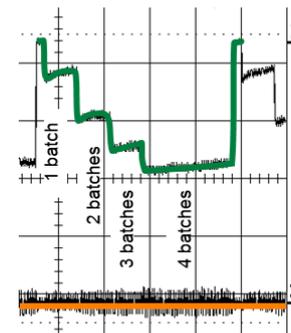


V. Anashin *et al.*, *J. Vac. Sci. Technol. A* 14(4) (1996) 2618



C. Scheuerlein *et al.* *Appl. Surf. Sci.* 172(2001)

Reference unbaked
Stainless Steel
ID 156mm - 5V PU



NEG - activated 250°Cx2h + saturated
rectangular - 100 mV PU
A. Rossi, *Proc. Ecloud'04*

Design of components / assemblies

- Design **review** (conceptual, detailed, production readiness ...)
- During LHC procurement, the LHC-VAC group internally reviewed all **technical specifications** and **drawings** :
 - ensure compatibility across the vacuum system
 - allows optimisation across components and performance (standardisation)
 - use quality class (class A, approval circuit after control 1&2)
- **Rule: rejects** components, including in-kind, which do not meet VACUUM DESIGN APPROVAL
 - **Do's and don'ts** (just a few important ones from LHC design and experience)
 - No halogenated fluxes
 - No cold demountable joints
 - Helium envelopes are all-metal
 - Joining techniques need to be validated (materials, welding, DT)
 - No dye penetrant testing
 - Minimise thin wall components.
 - Combine RT leak and pressure test of components
 - Decide a policy for cold testing of critical components
 - Keep non-vacuum group manufacturing under control – assign a vac link person
 - Don't allow deliveries until tightness certification is approved
 - Minimise number of welds to be tested in the tunnel
 - Many, many more
 - ...

➔ Technical specification & drawing validation

➔ State of the art material, cleaning methods, procedures

Quality Assurance Plan

- Allows to share information in a global way producing the right component

Date: 2013-11-04

ENGINEERING CHANGE REQUEST

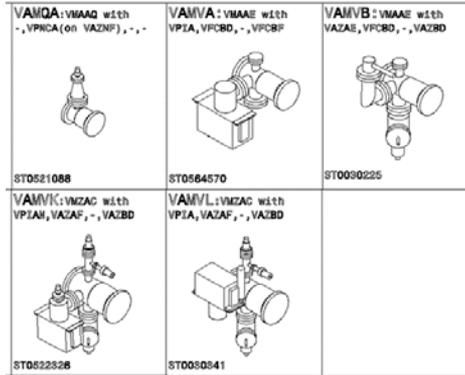
Vacuum Pilot Sectors in the LSS8

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

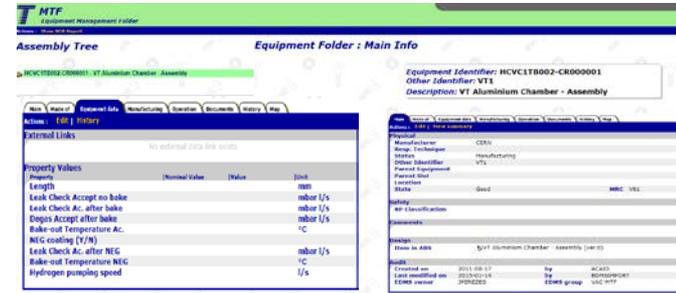
The vacuum pilot sectors provide detailed information for the understanding of the vacuum dynamics stimulated by synchrotron radiation and electron cloud. It opens the possibility, on a day by day basis, to carefully monitor and analyse pertinent beam vacuum parameters for the LHC operation. With this ECR the VSC group requests to allocate the space between Q5L8 and Q4L8 from -163.51 m to -145.18 m on the left of IP8 to dedicated vacuum instrumentation as described below.

<p>PREPARED BY: Name Dept/Grp G. Bregliozzi TE-VSC V. Baglin TE-VSC B. Henrist TE-VSC</p>	<p>TO BE CHECKED BY: Name Dept/Grp G. Bregliozzi TE-VSC V. Baglin TE-VSC B. Henrist TE-VSC</p>	<p>TO BE APPROVED BY: Name Dept/Grp</p>
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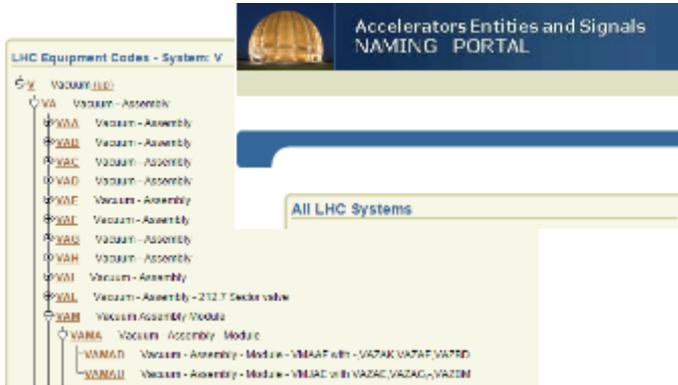
Engineering Change Request



Standard components Libraries



Equipment Management Folder



Naming Convention



LHC layout database

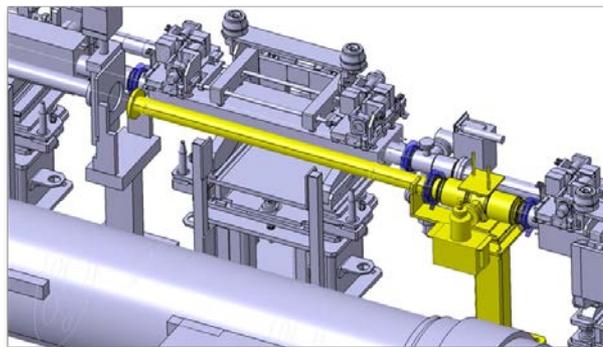


Vacuum Layout

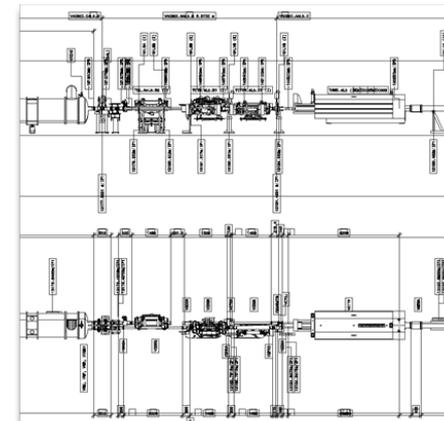
- Define components, produce data based drawings and SCADA systems, ease installation and optimise future intervention (e.g. in radioactive areas)

Part	Ref	Theme	Component	LSS	Beam	DCUM	Length	Designation	Description	Comment
208	313	NEG upgrade	Assembly module	S	BALS.R	R	13180.812	278.5	VANVE.4LS.R	check
209	303	CL4	Vacuum module	S	BALS.B	R	13180.302	300	VANVF	module in the machine, instrumentation changing
210	276	NEG upgrade	Assembly module	S	BALS.B	R	13180.302	290	VANVF with VGRS.VANVAPRCA.VANVF	no
211	261	CL4	Vacuum chamber	S	BALS.R	R	13180.372	1747	VCDRL	replace VCDGR-VMDRA

Vacuum layout database



Integration studies

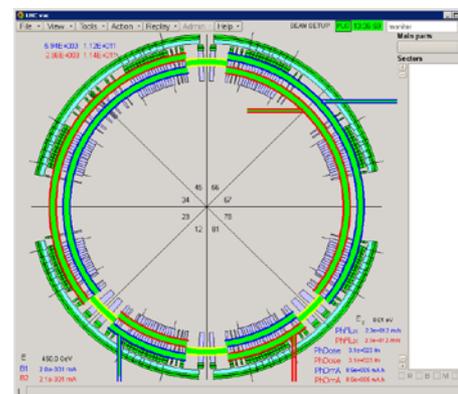
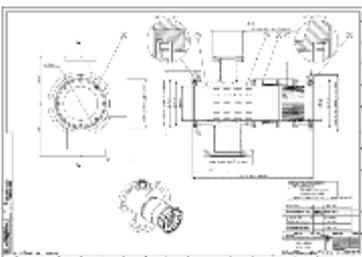


Installation drawings

Updated 14072014 VB

Part	Ref	Theme	Component	LSS	Beam	DCUM	Length	Designation	Description	Comment
208	313	NEG upgrade	Assembly module	S	BALS.R	R	13180.812	278.5	VANVE.4LS.R	check
209	303	CL4	Vacuum module	S	BALS.B	R	13180.302	300	VANVF	module in the machine, instrumentation changing
210	276	NEG upgrade	Assembly module	S	BALS.B	R	13180.302	290	VANVF with VGRS.VANVAPRCA.VANVF	no
211	261	CL4	Vacuum chamber	S	BALS.R	R	13180.372	1747	VCDRL	replace VCDGR-VMDRA

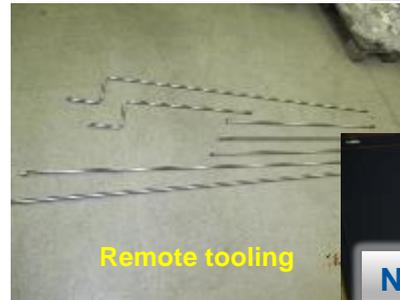
New components
Production & follow up



SCADA

Infrastructure and Material

- Adapted stores, components, tools and **storage management** are mandatory

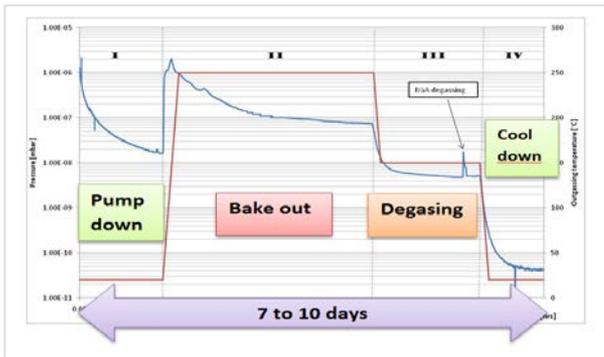


Vacuum Acceptance Tests

• Prior installation **all** (several thousands) **equipment** have been baked and **validated at the surface** before installation in the tunnel:

- functional test
- leak detection
- residual gas composition
- total outgassing rate

➔ Logistics, scheduling, coordinating & official reporting



2 ALFA Roman pot stations (XRPA) connected to TB1 in B113

Equipment for test by LSS sector for LSS

Legend: Equipment Tested To test Not

last update: 04/09/2014

Wk open sector	Wk close sector	Wk activate sector	Wk test surface	Year	Building	LSS Sector	Line	Reason/Nature work	Equipment 1	Equipment 2	Equipment 3	Equipment 4	
10	11	11	7	2013	r/h	5	AS5	Blue	Repair 1 VM with RC	4 x Modules pilot sector	4 x NEG Dusted chambers (already tested)	2 VADN + 2 VPNA	2 SVT + 4 x 1/2 mo
11	13	14	8	2013	r/h	3	A413	Red	Repair 1 VM with RC	2 x VADN + 2 x VPNA	1 x VPA		
11	21	22	8	2013	r/h	5	A555	Blue	Repair 1 VM with RC	1 x VPA			
12	13	14	9	2013	113	2	A412	Both	TD/ New layout	2 x VADN	1 x VPB	1 x VPA	1 x VMBSD
12	13	15	9	2013	113	3	IP1	Red	Repair 1 VM with RC	4 x VADN (avec VPNA)	2 x VPA		

Site Actions: Browse Documents Library

Vacuum Reports > Documents > All Documents -
Share a document with the team by adding it to this document library.

Home Operation Vacuum Reports Pipet Service Experiments Long Straight Sections Arca and stand alone Shutdown Stores LSS Activities Report TE Home VSC Home

Code Name	Destination
Raman Pot ALPHA	B7K1.B
Raman Pot ALPHA + BMSA	A7L1.R
Raman Pot ALPHA + BMSA	A7K1.B
VMGFA	B2.B / 6B3.B
VMGSP	B2.B
VDCDC/VCCDD	LSS 4L2 and 4L2
Echamillon cable BPH	
Ferrite T12-11R Skyworks	LHC TCTP
Below module for collimator	TCS estimator
BPH cable	TCTP collimators LHC
BPH/SLCS12.B1 & BPH/SLAS2.B1	point 2
PT150 cables	TCTP collimators LHC
PT180	LHC
PT160	LHC
TCSF jaw	LHC point 6
Curved BPH tables	
	Raman pot for ATLAS
Ferrite for VHTSA	LHC, LSS2, LSS5, A412, A442, A488, A418
Clickop and CIC jaw bloc	TCS and TCTP collimators
Kapton cable	LHC
	C4R5
Curved BPH tables	TCTP collimators
BPH cables pre-series lot n°2	TCTP collimators LHC

Key Filters: Apply Clear

Modified: On

Recycle Bin All Site Content

TEC Technology Department

Depositing member: Gregory Cattenoz

Depositing member: Gregory Cattenoz

Comments

Page 1 of 4

Vacuum acceptance report

UHV Vacuum degassing test of VMZAS and VMZAK modules for the LHC

UHV Compatible

RGA analysis and degassing rate are compliant for use in the beam vacuum system of the LHC.

UHV not Compatible

Prepared par: Gregory Cattenoz
Reviewed par: Giuseppe Dragalinzi
Approved par:

G. Cattenoz et al., IPAC 2014

Examples of tested parts



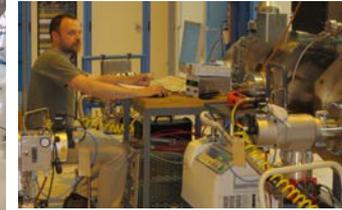
VPIAN test



NEG cartridge



BTVSS.6R8



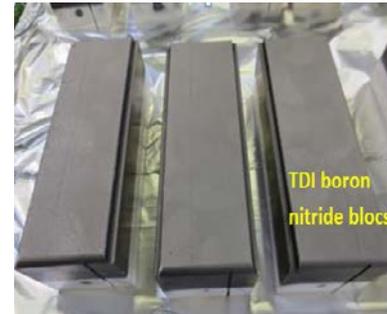
VMBGD - TDI sectorisation



Collimator test bench



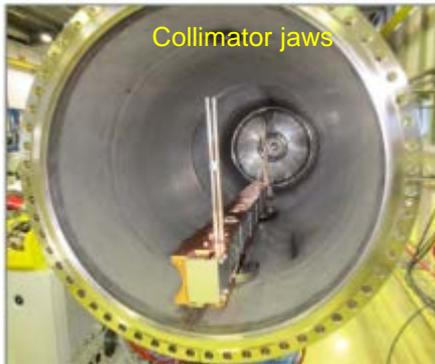
MKI Oven test facility B.867



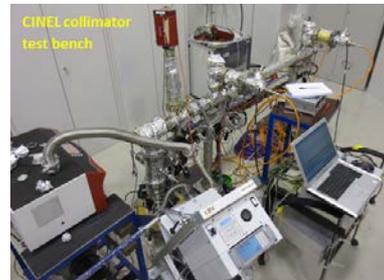
TDI boron nitride blocs



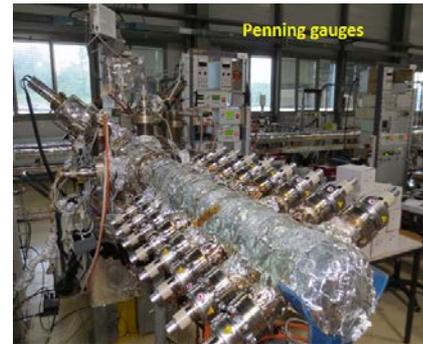
VM NEG copper inserts



Collimator jaws



CINEL collimator test bench



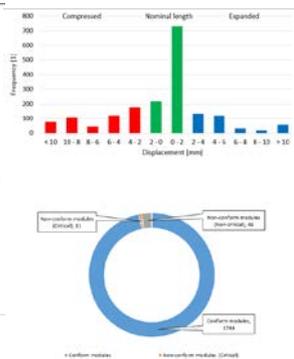
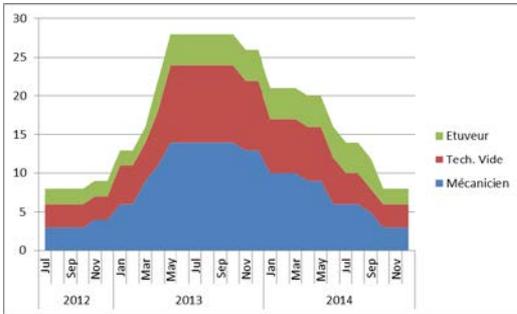
Panning gauges



ATLAS VC1AP (G. Lanza)

Installation and Quality Control

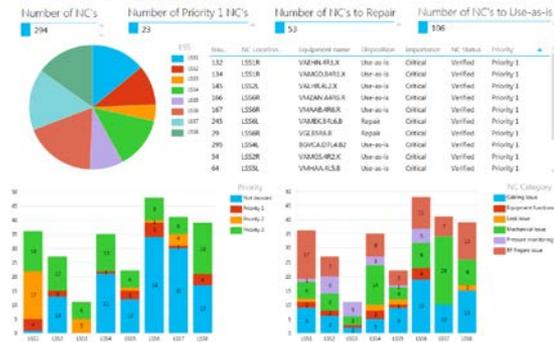
- Expert teams dedicated to **specific tasks**, logistic included
- Industrial support coordinated by CERN staff



J. Sestak *et al.*, IPAC 2015

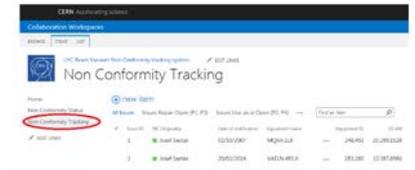
LHC Beam Vacuum Non Conformities status wk11

This report shows the overall status of LHC Non Conformity Database. In the charts, please select the data type you are looking for. The data are going to be filtered automatically. To view that the issue details are wanted please use linked Issue ID on the report page: <https://exp0000011.cern.ch/beam/vacuum/NC/NC1>

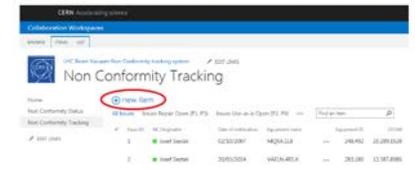


How to report a new issue?

1. Go to the Non Conformity Tracking page.



2. Click 'new item'.



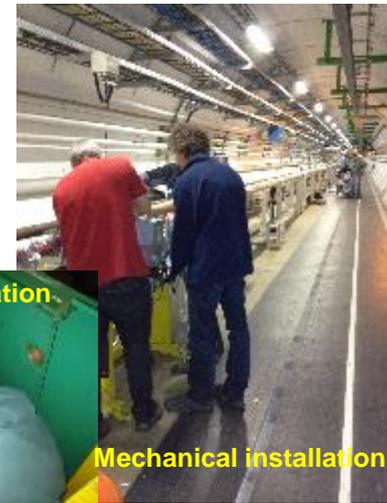
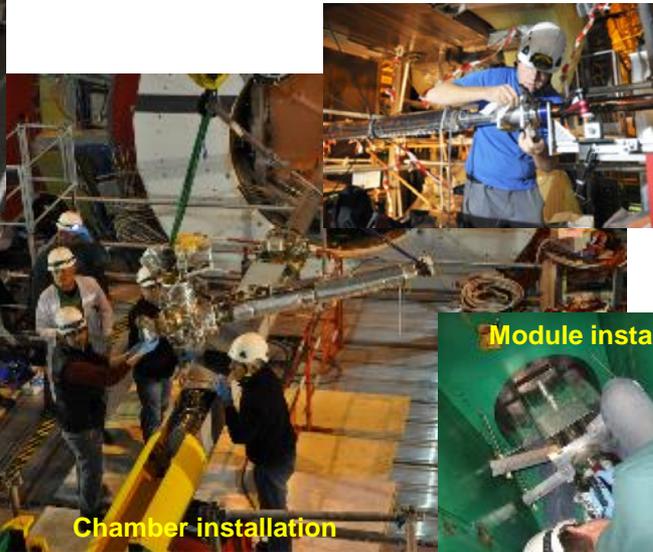
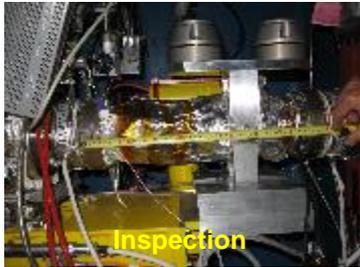
3. Fill the mandatory fields and click Save.

NC Originator *

Number of the nonconformity issue

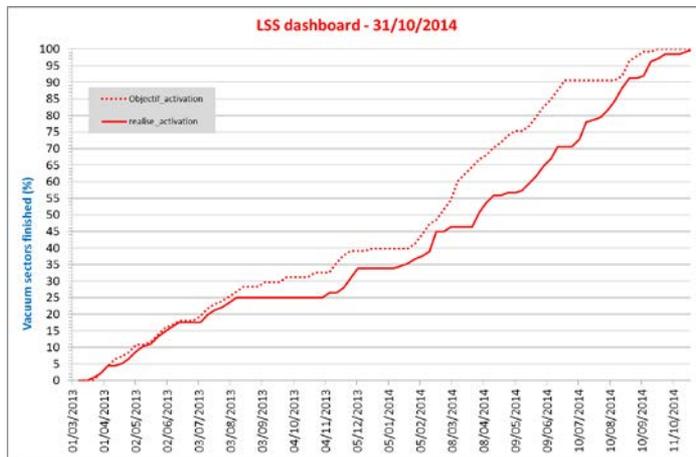
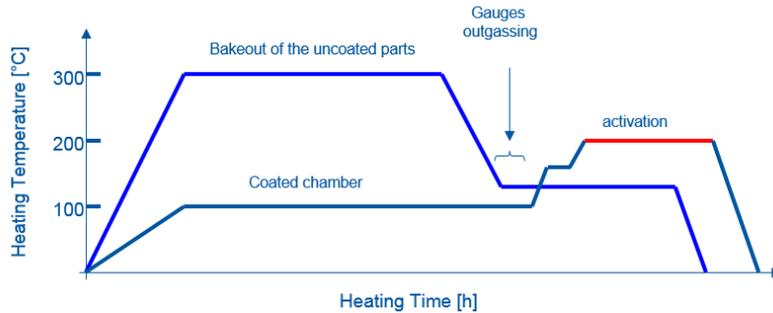
Date of notification *

Equipment name *



Commissioning of the NEG coated vacuum system

- Bake out of stainless steel part first
- Followed by NEG activation



- ➔ Specific procedure for NEG activation
- ➔ Activity reports
- ➔ Progress & performance charts

CERN CH-1211 Geneva 23 Switzerland

TE Technology Department

TE-VSC

Document No.

Date: 15/11/2011

Vacuum procedure

Bake-out and NEG vacuum activation of the LSS vacuum sectors

Abstract
This document presents the procedure for the bake-out and NEG vacuum activation of the Long Straight Sectors (LSS) for the Long Shutdown 1 (LS1) of the LHC.

Prepared by: Giuseppe Bealozzi Giuseppe.Bealozzi@cern.ch	Checked by: Gregory Cattaneo Gregory.Cattaneo@cern.ch Giulia Lanza Giulia.Lanza@cern.ch Nicolas Zelko Nicolas.Zelko@cern.ch	Approval Leader: Vincent Baglin Vincent.Baglin@cern.ch
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Approval List:

CERN CH-1211 Geneva 23 Switzerland Dep./Group: TE-VSC

Vacuum NEG Activation of LSS Vacuum Sectors of LHC

Description

LSS Sector Beam

Start date: 10/05/2014

End date: 13/06/2014

Operator 1: N. Thaus

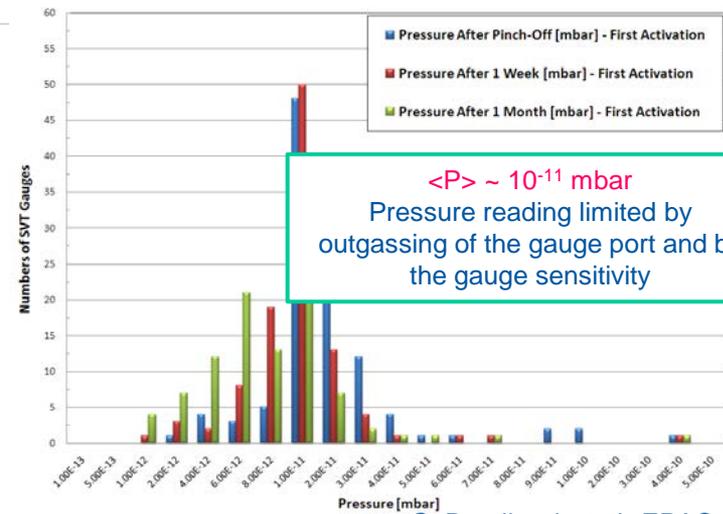
Operator 2: Operator 3:

Start Dosimeter Value (mSv): 0

First day: Bake-out of not NEG coated equipment

- Control that all the manual metal valves in the LSS vacuum sector and magic box are open.
- Control that sector valves are closed.
- Control that the wear sector are under vacuum: $P < 1$ mbar
- Control that all the bake-out racks are present in PVSS
- Perform an RGA scan of the sector in Faraday mode and attach a picture of the scan file if pressure $< 9E-7$ mbar

Attachments: A/PRL 8 before bakeout.jpg (130 KB), A/PRL 8 before bakeout.jpg (257 KB)



$\langle P \rangle \sim 10^{-11}$ mbar
Pressure reading limited by outgassing of the gauge port and by the gauge sensitivity

G. Bregliozzi et al., EPAC Genoa, 2008

2. Operation

Vacuum Monitoring – Stand-By

- **General** monitoring : check status of components, record of machine status
- Stand-by with **specific duties**: answer to control room request, act on simple intervention, assist expert teams during complicate / delicate interventions
- Stand-by must be **trained** !

CERN
CH-1211 Geneva 23
Switzerland



LHC Project Document No.
CERN Div./Group or Supplier/Contractor Document No.
TE/VSC
EDMS Document No.
1503404

Date: 11-12-2014

TE-VSC Procedure

Procedure for the Operation Follow-up of the LHC and Injector Complex Vacuum Systems

Abstract

This document describes the tools and procedures for the daily follow-up of the LHC and all injector vacuum systems, which are required to guarantee an optimum efficiency of all systems. It is dedicated for use in the new Vacuum Monitoring Room (VMR). Based on the present vacuum control system, a step-to-step procedure is given to survey the status of all machines comprising the LHC and the complete proton and heavy ion injector chain. The majority of the vacuum systems are controlled with PVSS. A table with acronyms can be found in the Annex.

Author:	Checked by:	Approved by:
Eric PAGE, TE-VSC Edgar MAHNER, TE-VSC Ludovic MOURIER, TE-VSC Jose De La GAMA, TE-VSC Germana RIDDONE, TE-VSC	Paul Cruikshank SLs	Paolo Chigiato

Procedures

Monitoring report

Author: Francois Bellieres | Date: 26/09/2014

Summary of observations and interventions

Piquet 1: Francois Bellieres | Piquet 2: Esa Paju | VC: None

Report type: Monitoring report (Daily) | Duration: 1.5 h | Status: Closed

Action required on machine

Beam V.LHC Ins V.LHC SPS PS Booster LINAC AD ISO

Detailed description

1.1. LHC Insulation vacuum:

1.1.1. LHC cryogenic system logbook:
LS1 no monitoring required

1.1.2. LHC operation logbook:
LS1 no monitoring required

1.1.3. Control of pumping grooves and valves:
VPGFH.355.4RB.Q
VPGFE.201.5R3.Q

Daily and weekly Reports

Piquet report

Author: Jose Antonio Somoza | Date: 28/08/2014

Summary of observations and interventions

Piquet 1: Berthold Jenninger | Piquet 2: Jose Antonio Somoza | VCR Staff: None

Report type: Piquet report (Weekly) | Duration: 0 h | Status: Closed

Concerned machine

Beam V.LHC Ins V.LHC SPS PS Booster LINAC AD ISOLDE Other

Detailed description

Important

Tout faciliter la prise en compte des rapports de piquet dans les statistiques, merci de préciser les dates suivantes pour chaque intervention dans la mesure du possible :

1. Date d'intervention
2. Heure d'appel de la CCC
3. Machine, zone
4. Equipement concerné, origine du problème
5. Présence d'interlock ou non
6. Type d'intervention (sur place ou à distance)
7. Temps d'intervention & temps de perte faisceau

To improve the availability of the information used for the statistics please specify the details below for each intervention if it is possible :

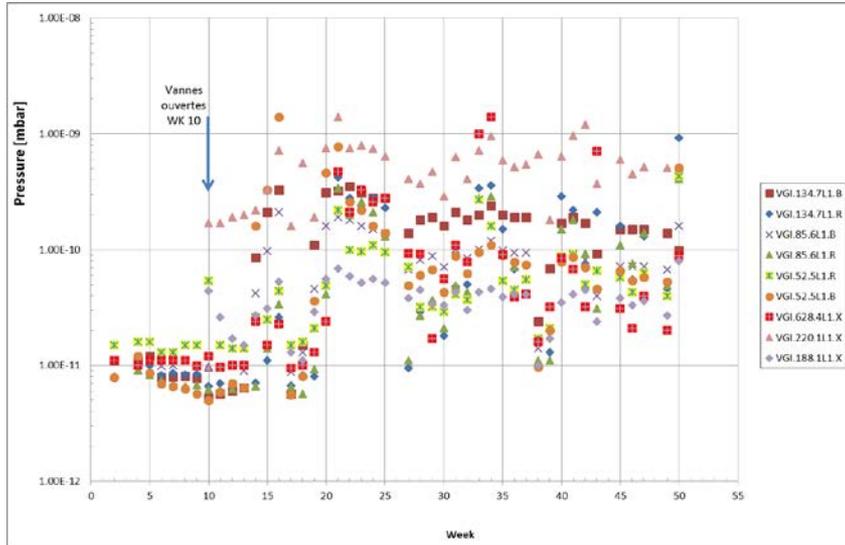
1. Date of intervention
2. Time of CCC call
3. Machine, zone
4. Affected equipment, problem source
5. Interlock
6. Intervention type (on site or remote)
7. Intervention time & beam lost time

No phone call from the CCC. No intervention during the Piquet's week.
NAS.

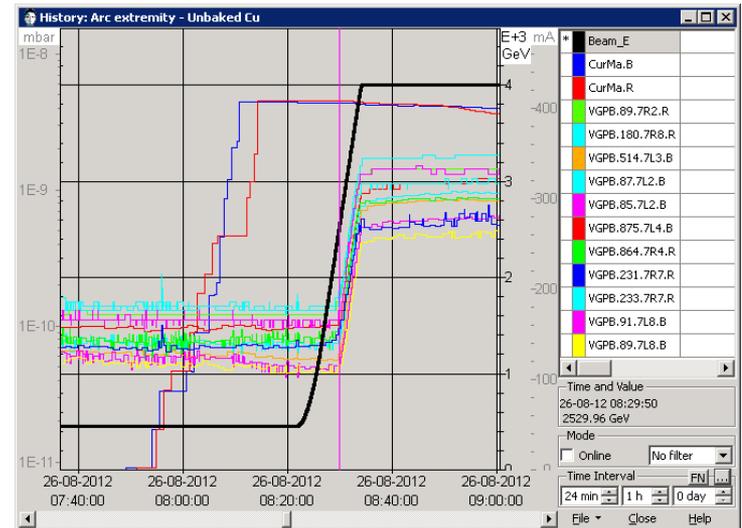


Pressure Follow-Up

- Expert monitoring: check general trends and track / resolve specific issues, follow daily and detailed machine operation



General trends



Interlocks records

Type	Name	Date	VACSEC.....	Equipment	Sector valve	Short description	DESCR
Interlock	VGSW.122.4I2.C 30th of November 2012	30/11/2012 14:05	A4I2.X	TDI.4I2.C	VGSW.122.4I2.X	Beamdump of fill 3348 triggered by ALICE BIC	The b which
Interlock	VGSW.819.5R4.B 10th of September 2012	10/09/2012 21:51	E5R4.B	BWS.5R4.B	VGSW.819.5R4.B	Beamdump of fill 3053 triggered due to air leak on BWS	The b trigge
2nd Interlock	VGST.232.7R7.B 26th of August 2012	26/08/2012 22:30	A7R7.B	VGPB.231 & 233.7R8.B	VGST.232.7R7.B	Beamdump of fill 3006 triggered due to sparking on RF fingers	Pressi
Interlock	VGST.232.7R7.B 26th of August 2012	26/08/2012 02:30	A7R7.B	VGPB.231 & 233.7R8.B	VGST.232.7R7.B	Beamdump of fill 3003 triggered due to sparking on RF fingers	Pressi
Interlock	VGST.232.7R7.B 16th of August 2012	16/08/2012 16:20	A7R7.B	VGPB.231 & 233.7R8.B	VGST.232.7R7.B	Beamdump triggered by VGPB	Possi
Interlock	VGSF.221.1R8.X 20th of July 2012	20/07/2012 02:00	Both VAX in IP8	VGPB.122 & 219.1R8.X	VGSF.221.1R8.X	Beamdump triggered by VGPB	Possi

Tracking interlocks

LHC fill history table with columns: Fill number, Filling scheme, Electron cloud, Laboratory, Fill-LHC, Date, Name, Short description, Modified, Modified by.

Fill number	Filling scheme	Electron cloud	Laboratory	Fill-LHC	Date	Name	Short description	Modified	Modified by
3350	50ns_1374_1368_6_1262_1440p12i1	1.64			02/11/2012	FI 3350	1374 ns - Primary ions at QRRS during ramp (as regularly observed) - Dump on quills 9s after colliding scraper lamp - F.U.S. touch with XRF area inducing pressure rise as seen on VGI.77.6L1.B together with quills and quills	03/12/2012 03:23 PM	Vincent Bagnin
3348	50ns_1374_1368_6_1262_1440p12i1	1.42			30/11/2012	FI 3348	6-24 s - Bad injection leading to ALICE triggering dump. 246 ns 100.0	03/12/2012 05:21 PM	Vincent Bagnin
3314	50ns_1374_1368_6_1262_1440p12i1	1.49			30/05/2012	FI 3114	1374 ns - Collid at HX220 - VGE = 3.7e-9 mbar - Error = 2e-9 mbar - Comparison with BE 2544 of 26/02/2011 - 597_Correk = 1e-9 mbar	02/12/2012 01:32 PM	Vincent Bagnin
3087	50ns_769_72_5_48_360p3i1	1.47			26/09/2012	FI 3087	Region after T03 and HX220 exchange. - Deacceleration det BC is visible at HX220	28/09/2012 05:49 PM	Vincent Bagnin
3045	50ns_1374_1368_6_1262_1440p12i1	1.64			08/09/2012	FI 3045	Pressure excursion up to 3e-8 mbar at HX220 during ramp. The origin is probably the backscat - HX220 detected perfectly with very pressure excursion up to 2e-10 mbar at the same time	15/09/2012 11:42 AM	Vincent Bagnin
3044	50ns_1374_1368_6_1262_1440p12i1	1.67			06/09/2012	FI 3044	Pressure excursion up to 3e-8 mbar at HX220 during ramp. The origin is probably the backscat - HX220 detected perfectly with very pressure excursion up to 2e-10 mbar at the same time	10/09/2012 12:13 PM	Vincent Bagnin
3006	50ns_1374_1368_6_1262_1440p12i1	1.66			16/08/2012	FI 3006	Beam dump at VGST.232.7R7.B with interlock level set at 1e-9 mbar while pressure reading on P030 is 1e-7 mbar - Issue with PVSS sampling	27/08/2012 04:27 PM	Vincent Bagnin
2976	50ns_1374_1368_6_1262_1440p12i1	1.49			16/07/2012	FI 2976	Low pressure rise observed made (cosmo right side of ALICE) - T02L = 1.1e-8 mbar	16/09/2012 09:17 AM	Vincent Bagnin
2965	Inject and dump	14.0			14/03/2012	FI 2965	450 GeV only - T02L was aligned following previous fill (T02L violation with proton beams (1x10 p) as a function of injection conditions) - Delta_P = 1e-8 - Delta_P = 1e-8 - T02L = 1.5 M0/s per mbar	15/08/2012 11:23 AM	Vincent Bagnin
2964	T02 25 alignment	18.0			14/03/2012	FI 2964	450 GeV only - angular alignment at T02L with probe Beams (1x10 p) - Delta_P = 1e-8 - Delta_P = 1e-8 - T02L = 1.5 M0/s per mbar	15/08/2012 10:51 AM	Vincent Bagnin
2957	50ns_1374_1368_6_1262_1440p12i1	1.35			13/09/2012	FI 2957	CMS aligned 0.07	13/09/2012 08:05 PM	Gulra Lanza

Fill by fill monitoring

Operation Follow-Up: Checking Design

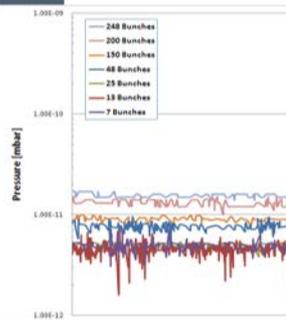
- **Checking** that the system behave **as expected**: example synchrotron radiation induced gas desorption

First Observation of Synchrotron Radiation: Aug-2010



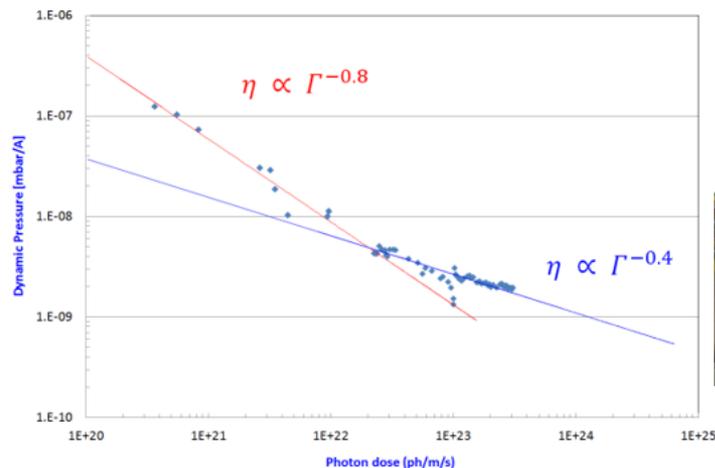
- Pressure rise during the beam energy ramp

- Dynamic pressure increases with beam current
- $\Delta P = 2 \cdot 10^{-10}$ mbar



Cleaning Effect under SR

- Arc extremity's vacuum gauges : unbaked Cu and cryogenic beam screen
- Reduction by **2 orders of magnitude** since October 2010



- 2 trends :
 - Room temperature
 - Cryogenic temperature



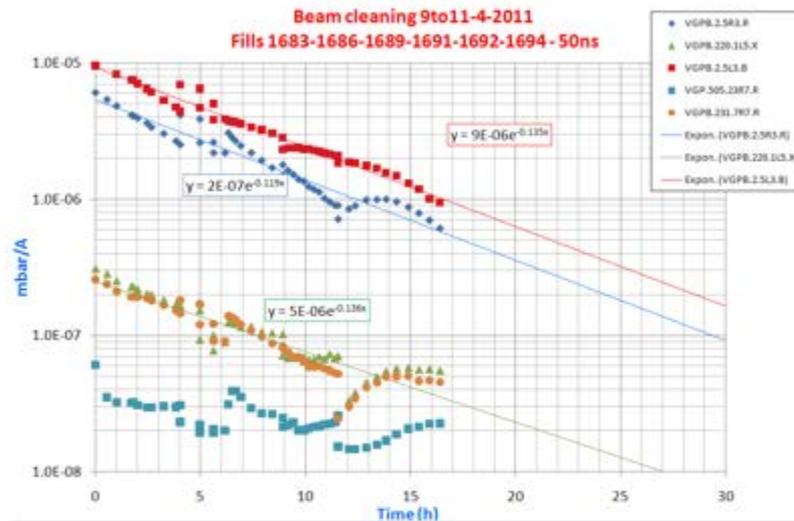
- Inside the arc, at 5-20 K, $\Delta P < 10^{-10}$ mbar (i.e. **below detection limit**)
- The photodesorption yield at **cryogenic temperature** is estimated to be $< 10^{-4}$ molecules/photon

Operation Follow-Up: Expertise

- Assisting the control room during important phase of the commissioning: scrubbing run periods

2011 Scrubbing Run with 50 ns Bunch Spacing

- As expected, strong pressure reduction with time were observed



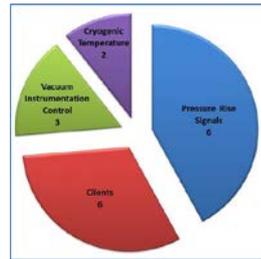
- Which allowed to fill-in the machine with nominal parameters the 7-12-2012 with 25 ns bunch spacing

2748 2748

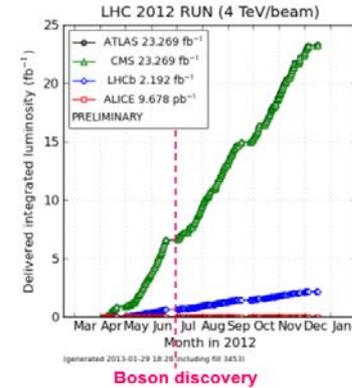
Global Performance with Beams

- Vacuum level with beams is **within specifications**
- 17 beam dumps in 2012 following sector valve closure, for a total turnaround time of 52 h

2012: Integrated Luminosity ~ 23 fb⁻¹
(2011: 5 fb⁻¹)



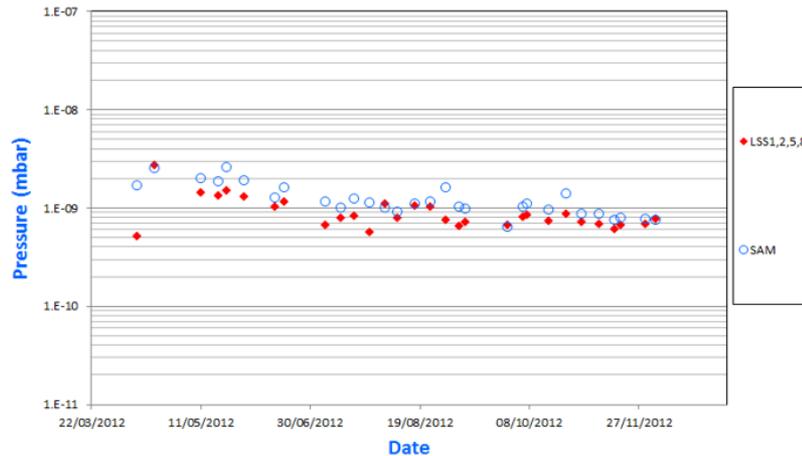
G. Lanza, Proc Evian 2012.



Long Straight Sections

- Reduction throughout the year while increasing beam intensities from 200 to 400 mA
- $\langle P_{LSS} \rangle \sim 7 \cdot 10^{-10}$ mbar

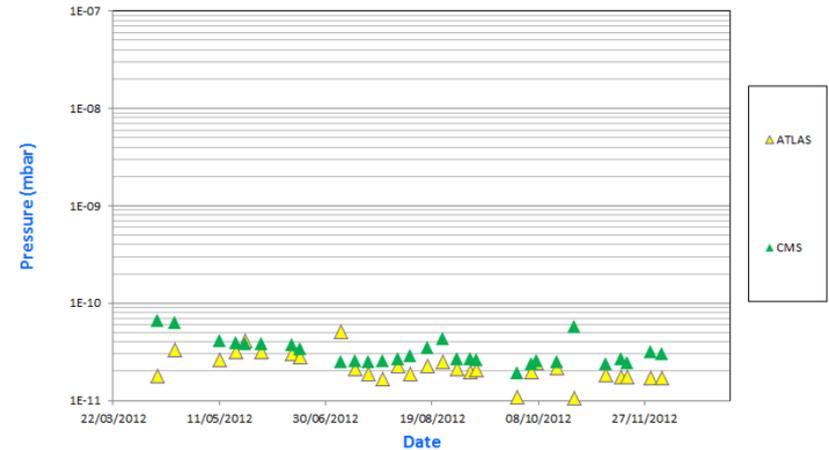
2012: LHC LSS Average Pressure with Beam



LHC Experiments

- Almost constant pressure during the year
- $\langle P_{LHC\ Experiments} \rangle \sim 3 \cdot 10^{-11}$ mbar

2012: LHC Experiments Average Pressure with Beam (IP only)



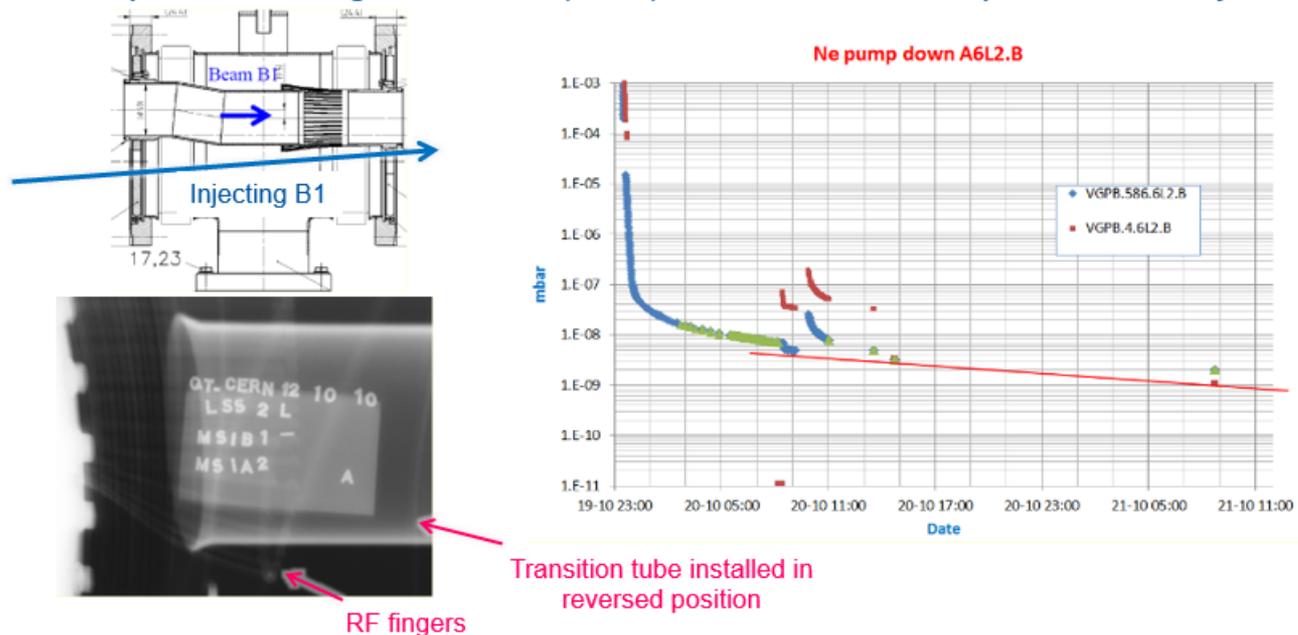
3. Repairs, Consolidation & Upgrade

Fast Intervention: Ne venting

- Allow to reduce the recovery time minimising the impact of vacuum performance:

October 2010: Injection Septa in A6L2.B

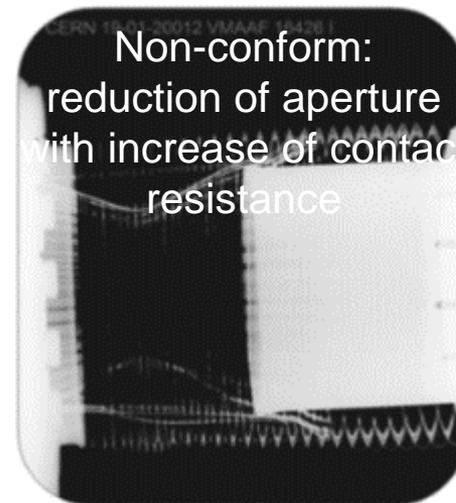
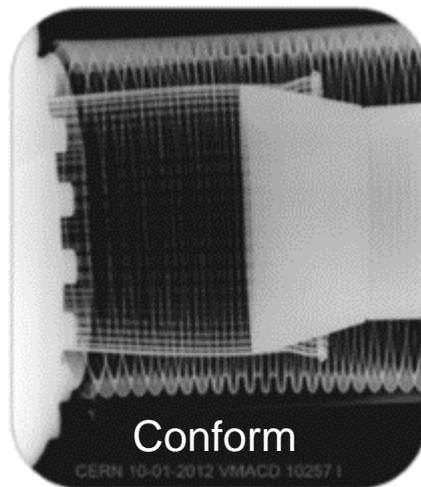
- Reverse mounting of a vacuum module during installation
 - Unfortunately, that was the injection area so RF fingers started to be damaged by the incoming beam. A bump was needed to inject properly into LHC !
- Ultra-pure Ne venting 19-10-2010 (wk42), allowed to resume operation in 3 days



Fast recovery following RF bridge repair: operation resumed in 3 days

Repair of Non-Conformities (2013-14)

- As a consequence of the previous repair, a **systematic X-ray** analysis of all the vacuum modules was done: 1800 X-rays were taken during 2 years.
- The **repair** of 96 non-conform vacuum modules (~ 5% of the total) was needed to **restore machine impedance** and to **avoid pressure spikes/excursion** (*i.e.* avoid beam dumps).
- 52 RT vacuum sectors impacted out of which 29 are opened during LS1 **on purpose** (~ 200 kCHF manpower)



Courtesy A. Vidal, J-M. Dalin EN-MME

- ➔ Identify and classify the non-conformities
- ➔ Repair them !

Pumping System Consolidation

- Consolidation of pumping scheme, main activities :
 - reduce **background** to the experiments:
 - NEG coating of RF bridges inserts located inside and in the vicinity of the LHC experiments
 - 180 inserts to replace
 - **minimise impact of radiation** onto the personnel:
 - installation of remotely powered NEG cartridge as complementary lumped pumping system in collimators areas
 - 190 D400 NEG cartridges to install

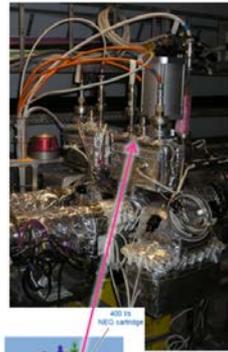


Figure 2: Schematic of the collimator area with installed NEG cartridges (180 Torr and 400 Torr).



Figure 1: D400 NEG cartridge with DN 35 CF flange

Table 1: Pump Characteristics

D400		
Alloy Type	St 172®	
Alloy Composition	ZrVFe	
Getter Mass (g)	45	
Getter Surface (cm ²)	380	
Pumping speed (l/s)	H ₂	400
	CO	180
Sorption Capacity (Torr l)	H ₂	900
	CO	0.9

- Pumping speed multiplied by ~ 10
- Can be **remotely** re-activated

➔ Identification and consolidation of weak points

Specific Instrumentation

Vacuum Pilot Sectors



NEG Pilot Sectors

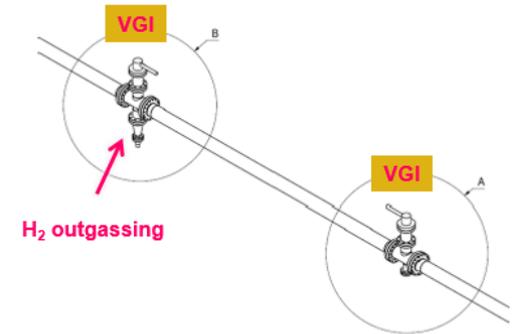
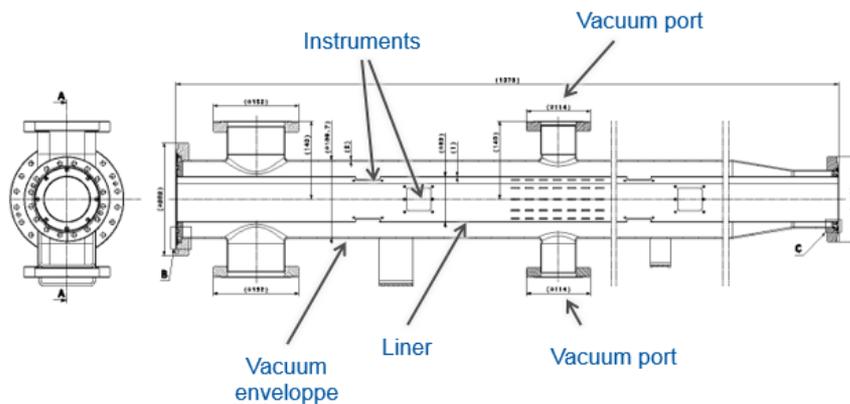
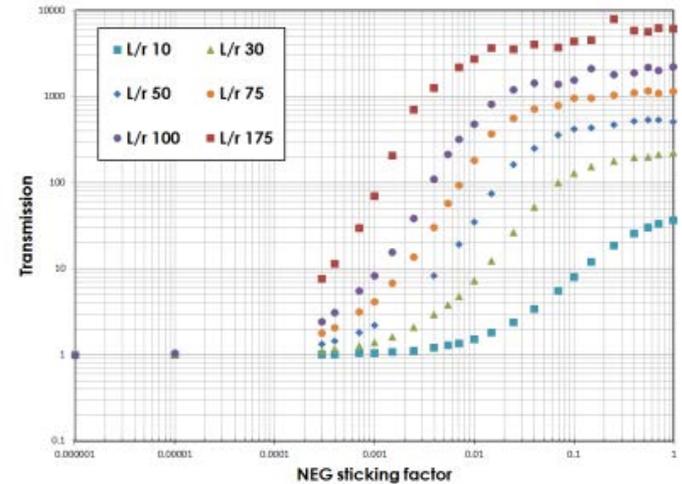


Figure 1: Pilot sector schematic



B. Henrist *et al.*, IPAC 2015



Pressure ratio yields the NEG sticking factor

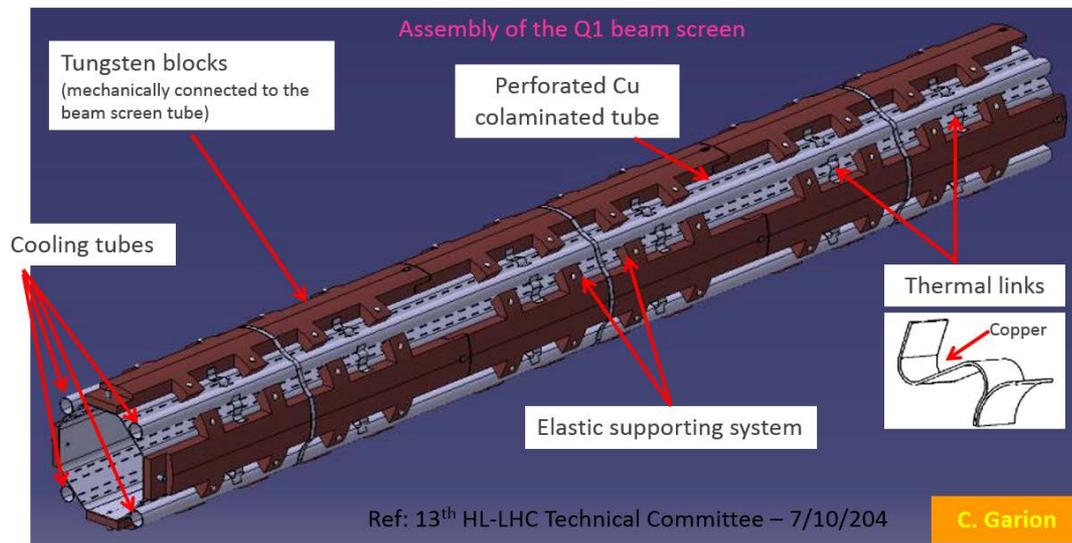
➔ Improve the understanding of the LHC vacuum system with dedicated diagnostic

Upgrade to HL-LHC

- **Integration of several functions** in a single object of the low beta insertion (inner triplet):
 - beam screen functionalities
 - anti-multipactor coating
 - cold mass shielding

Impact of debris onto IT+D1: shielded beam screen

- Operating temperature : 40 -60 K
- 16 mm absorbers in Q1, 6 mm absorbers from Q2 to D1



- Design studies underway
- Mechanical analysis : impact of quench, heat transfer, supporting system
- Tests with tungsten prototypes



VSC Seminar, December 5th 2014. CERN 19

C. Garion *et al.*, IPAC 2015

4. Summary

Summary

- Availability is a **constant concern** during the life of a system
- **Availability of the LHC vacuum system relies on :**
 - Group Expertise (which must be maintained and continued to be developed)
 - New concepts
 - Studies
 - Design
 - Production & installation follow up: Quality Assurance Plan is a must
 - General monitoring / support by stand-by
 - Fill by fill and daily monitoring / support by experts
 - Repair, consolidation and upgrade of the system
- All these activities are based on **many** technical, engineering and scientific **skills which must be available** for the project to ensure availability !

Credits & Acknowledgments

- The slides presented here are the fruit of the work of many CERN and external collaborators who participated to the design and installation of the LHC vacuum system under the successive directions of A.G. Mathewson, O. Gröbner and P. Strubin
- Credits and warm thanks should be address also to J M. Jimenez and P. Chiggiato for their constant support and to the TE-VSC-LBV team for its investment and fantastic commitment during installation of the LHC, RUN1 and the Long Shutdown 1.

Thank you for your attention !!!





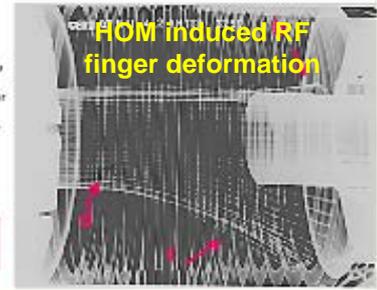
Superinsulation harvest



LHC: repair at cold or how to bring ice in the beam tube

Typical default, DCUM 3259.3524

Left side
Side view (only from corridor to TBL)
Metallic noise due to loose spring when filling vacuum chamber
RF fingers bending due to broken spring
Aperture reduced?
Non Conform
Spring was broken between May and November 2011.



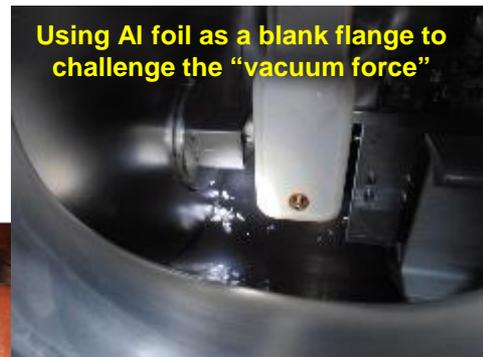
QQBI.26R7 line V2



Increasing contact impedance at the price of buckling

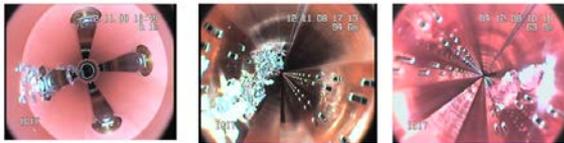


LHC: the most expensive brazing machine

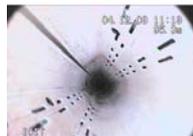


Using Al foil as a blank flange to challenge the "vacuum force"

Beam Screens with MLI and Fibers

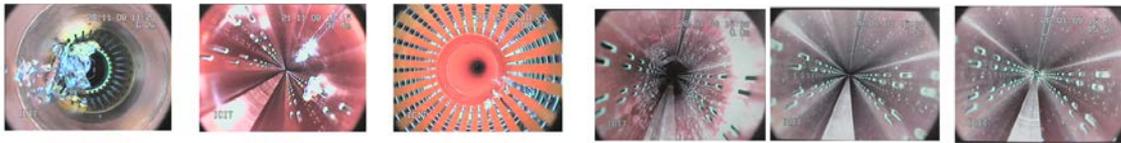


Beam screens with soot in tunnel : C19R3



C19R3.V2 before cleaning

Sector 3-4 incident: soot and superinsulation debris along ~ 6 km !



QBQJ 14L4.V2 A13L4.V1 QBQJ 12L4.V1 entrance mid end



Still RF fingers ...



Back up slides



Operation: Solenoids, a non-base line system

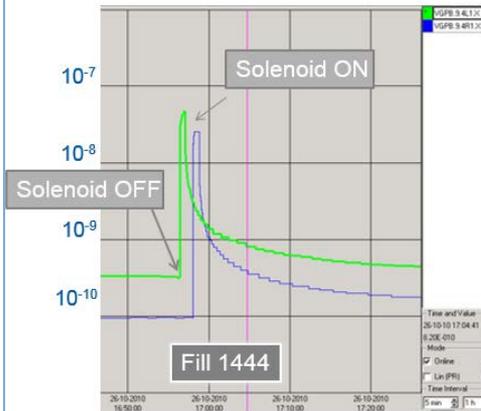
- Using expertise to solve unexpected issues: **electron cloud with 150 ns bunch spacing** (in common beam pipes) !

- Using creativity to reduce background in the experiments:

wrapping solenoids to increase the amount of anti-multipactor treated beam pipe length from 10 to 11 %

First Observation of Electron Cloud : 29-9-2010

- The position at 45 m from the IP is the **longest unbaked area** (operating at RT) in LHC, so the first candidate to trigger electron cloud



Magnetic field of solenoid= 20 Gauss

But

- Our colleagues from the machine operation and physics groups had a clever idea :
 - What about installing a solenoid everywhere in the machine to mitigate electron cloud !**
- So, in Nov 2010, we had to propose the installation of solenoids around experimental areas i.e. **20 km of cable to wound around a vacuum chamber !**
 - ~ 350 man-days of work, so 2 teams during ~ 4 months !**



Arc Beam Vacuum Consolidation

- Following sector 3-4 incident in September 2009
- ~ 850 rupture disk installation at each arc's quadrupole (SSS) to mitigate bellows buckling in case of he inrush
- Protective half-shells in case of arcing

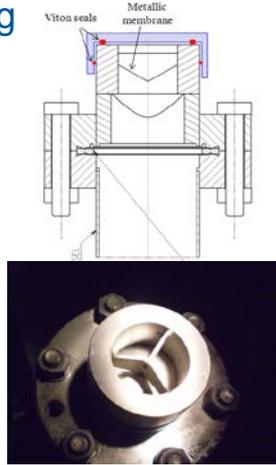
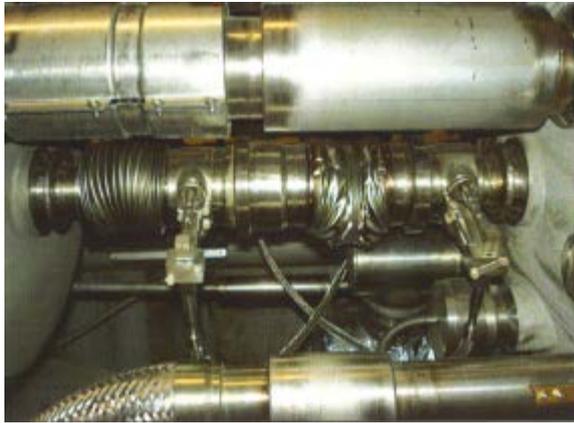
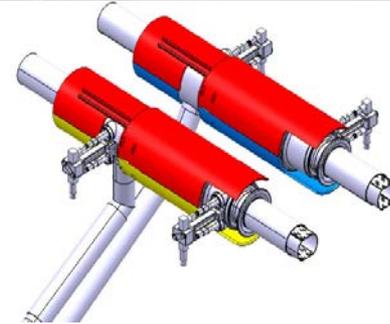
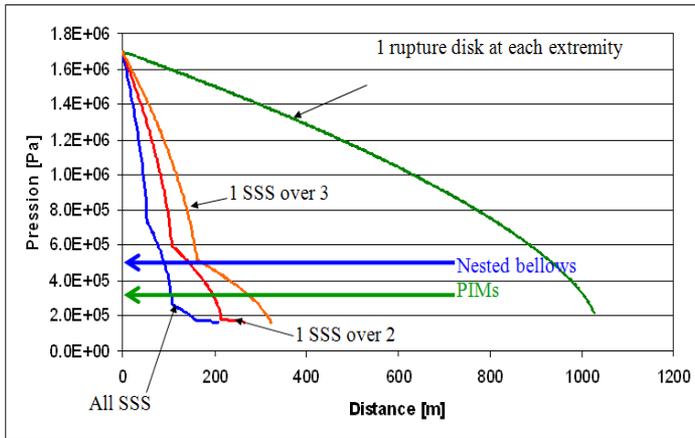


Fig. 15



Protective half-shells for cryomagnet interconnections

Courtesy C. Garion



→ Protection of the system against co-lateral damaged

