CERN

# Vacuum System Reliability Illustrated with LHC

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CERN TE-VSC, Geneva

ARW2015

OAK RIDGE National Laboratory

Accelerator Reliability Workshop 2015

April 26 - May 1, 2015

*Crowne Plaza - Knoxville Tennessee*

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

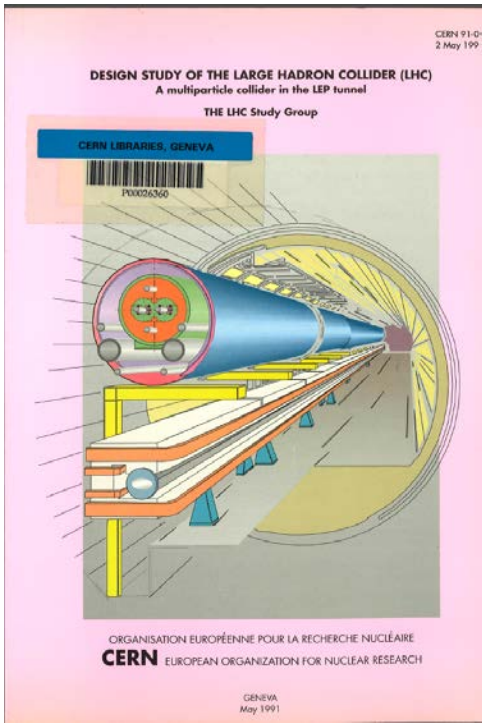
1. Study, Design, Procurement & Installation
2. Operation
3. Repair, Consolidation & Upgrade
4. Summary

# 1. Study, Design, Procurement & Installation

# LHC from Study to Project

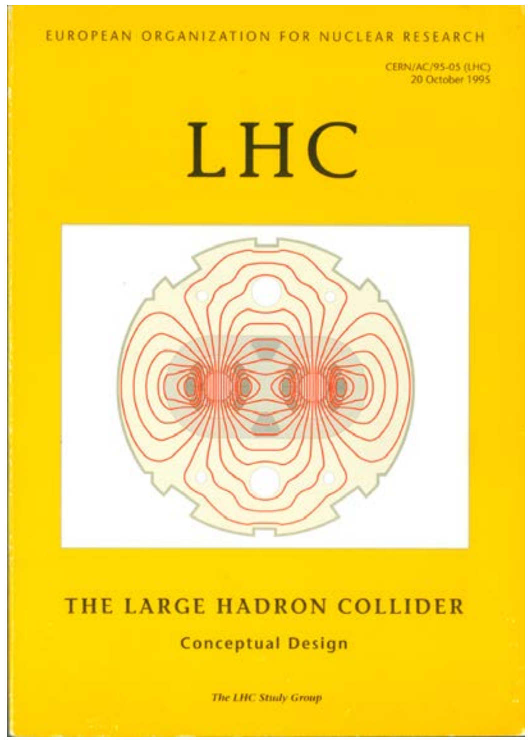
- Communication & release of Official documents and books is mandatory to share pertinent information across the project

Design study



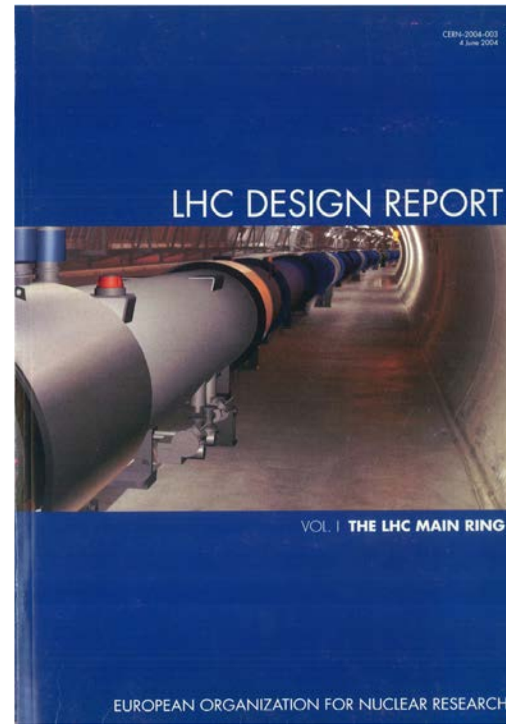

1991

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

the **Large Hadron Collider** project

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

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

EDMS Document No. **100513.00 rev. 1.1**

Date: April 8, 1999

**Engineering Specification**

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


*Abstract*

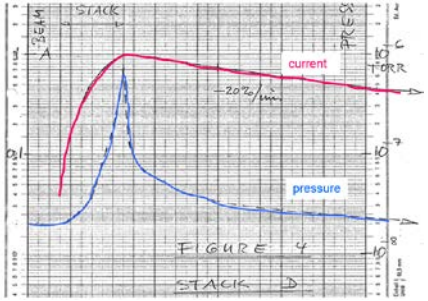
A number of design parameters and operational scenarios are used in many documents (Project Notes, Project Reports, Market Surveys, Technical Specifications, etc.) either directly, or for calculating safety margins or defining test procedures for machine components. The present document is a compilation 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.


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

| | Design | |
|---|---|---|
| | Nominal | Ultimate |
| Energy [TeV] | 7 | |
| Luminosity [$x10^{34}$ $cm^{-2}.s^{-1}$] | 1.0 | 2.3 |
| Current [mA] | 584 | 860 |
| Proton per bunch [$x10^{11}$] | 1.15 | 1.7 |
| Number of bunches | 2808 | |
| Bunch spacing [ns] | 25 | |
| Normalised emittance [μm.rad] | 3.75 | |
| β * [m] | 0.55 | |
| Total crossing angle [μrad] | 285 | |
| Critical energy [eV] | 44.1 | |
| Photon flux [ph/m/s] | $1\ 10^{17}$ | $1.5\ 10^{17}$ |
| SR power [W/m] | 0.22 | 0.33 |
| Photon dose [ph/m/year] | $1\ 10^{24}$ | $1.5\ 10^{24}$ |

# 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

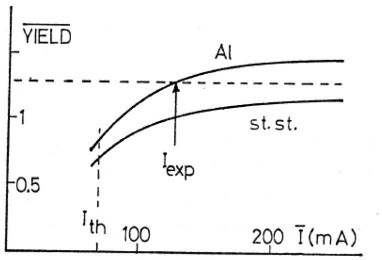
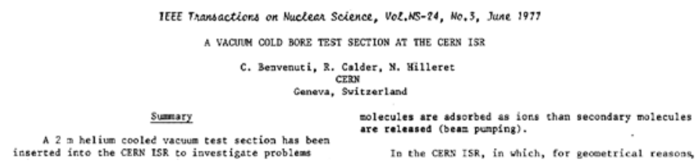



Fig. 4. Average secondary electron yield for aluminium and stainless steel obtained from figs. 2 and 3 and assuming uniformly distributed electrons. As seen from the observed threshold, $I_{exp}$, the calculation overestimates the yield by about 30%. With this correction, stainless steel should not multipactor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



IEEE Transactions on Nuclear Science, Vol.NS-24, No.3, June 1977

A VACUUM COLD BORE TEST SECTION AT THE CERN ISR

C. Benvenuti, R. Calder, N. Hilleret
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,

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

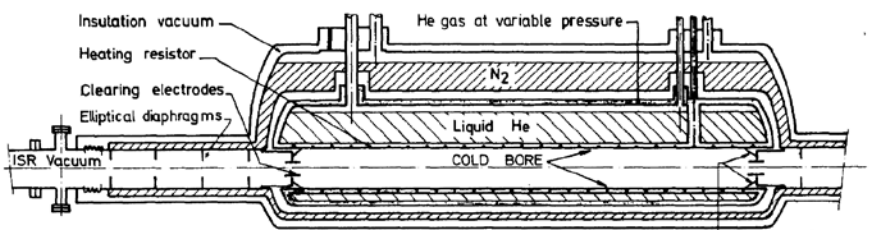
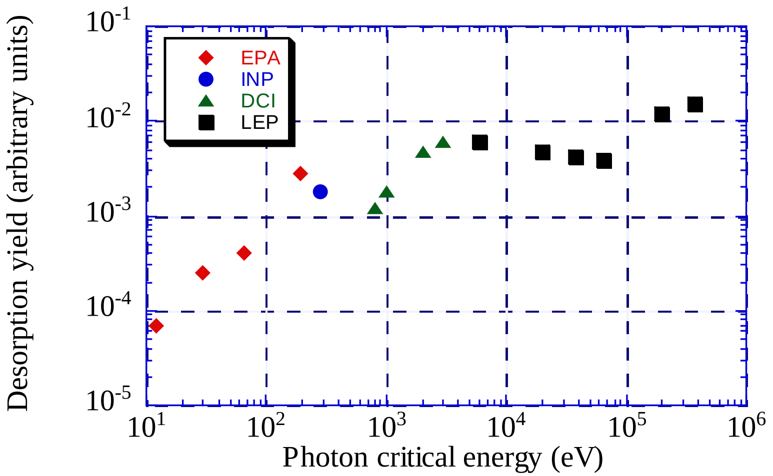



Fig. 2. Cold-Bore Cryostat - Schematic Outline.

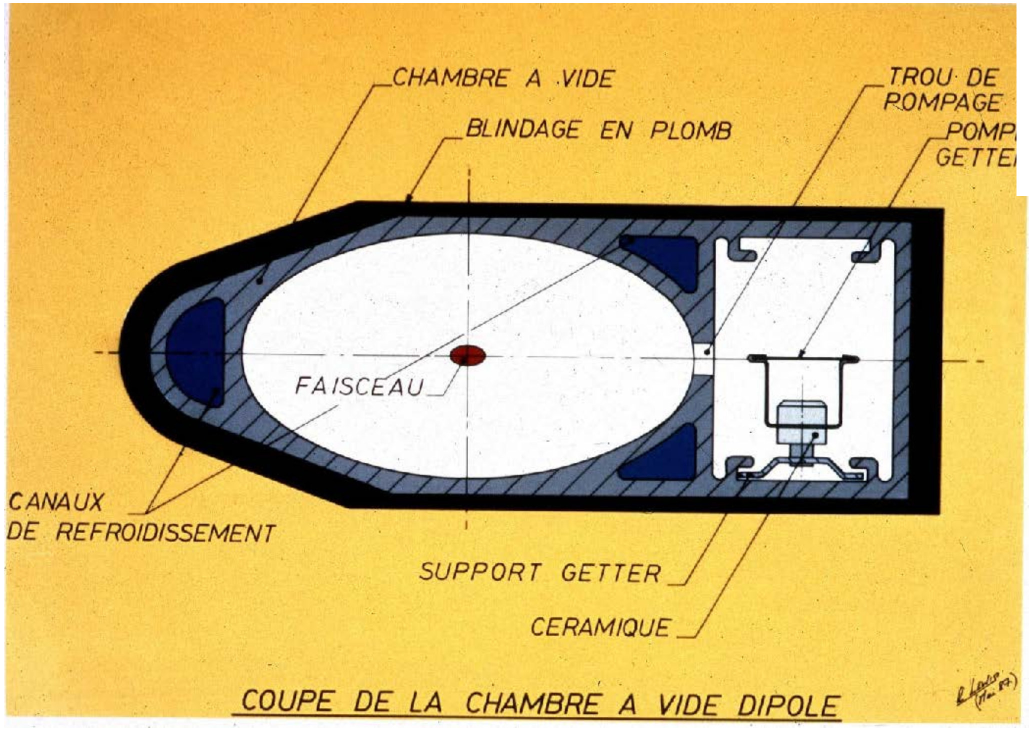
# More Expertise: Large Electron Positron Collider

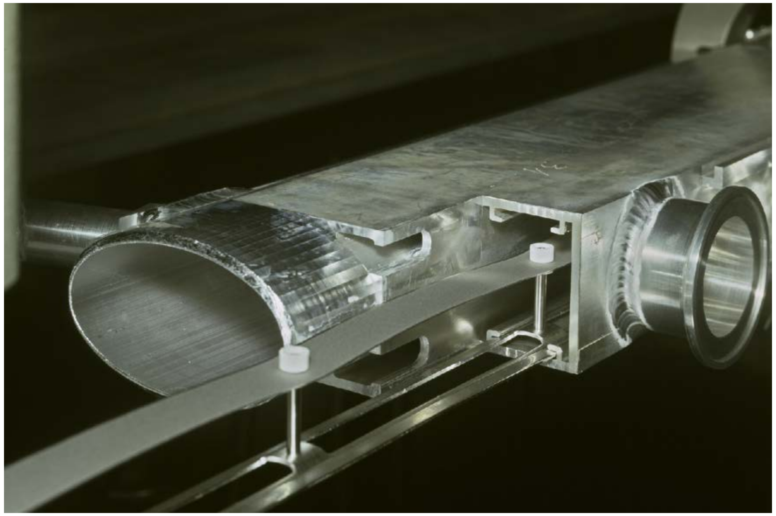
- Synchrotron radiation in LEP:
  - From 6 to 660 keV critical energy
  - Gas desorption studies

- Innovative pumping system
  - Antechamber with NEG pumping strip
  - Water cooled and lead shielded




O. Gröbner. CAS 99-15



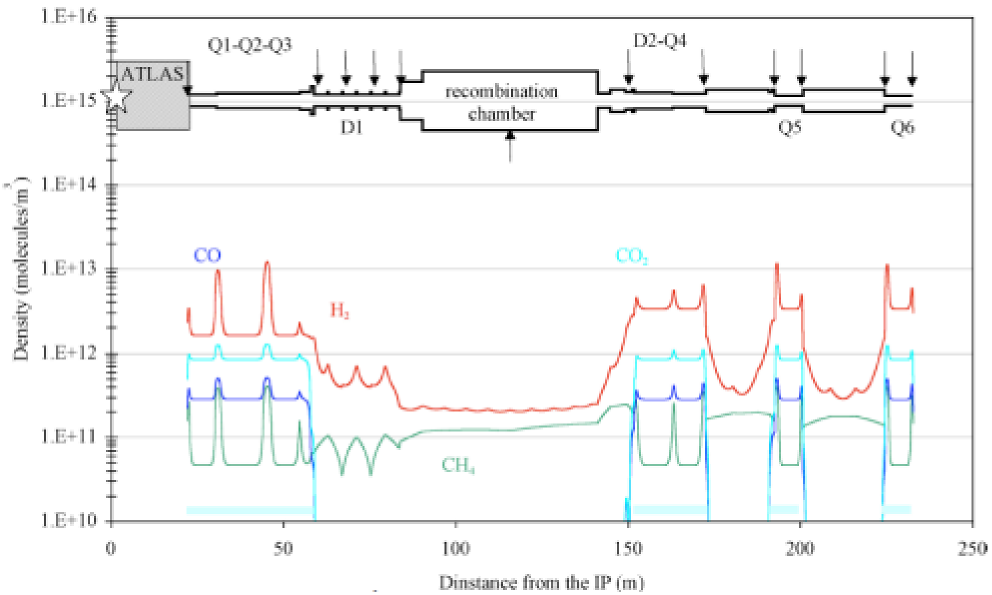
(CERN LEP Vacuum group)

# LHC Design Value : a Challenge with p Beams

- Life time limit due to nuclear scattering ~ 100 h
  - n ~ $10^{15}$ $H_2$/m3
  - <$P_{arc}$> < $10^{-8}$ mbar $H_2$ equivalent
  - ~ 80 mW/m heat load in the cold mass due to proton scattering

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

- Minimise background to the LHC experiments



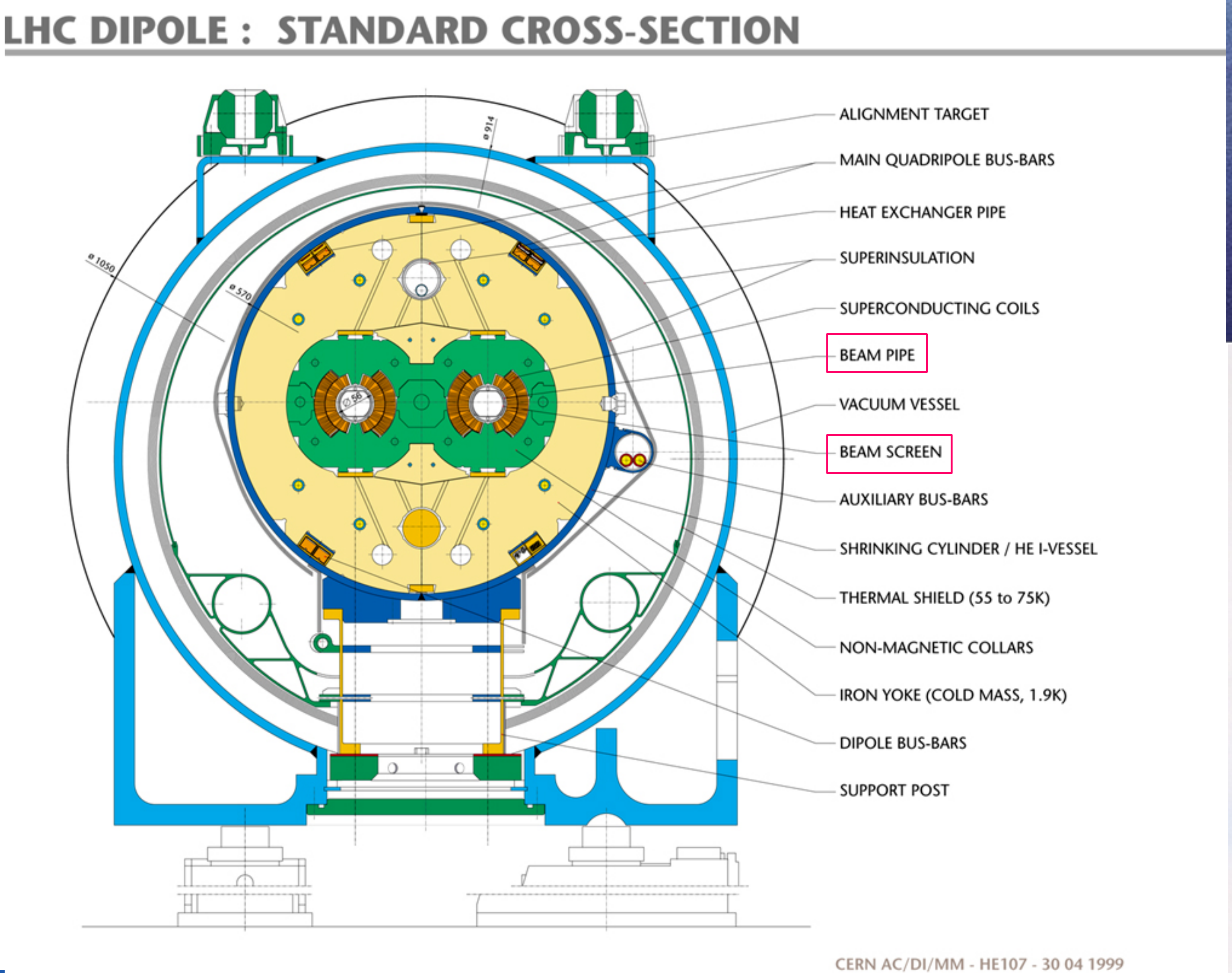

| | H2_eq / m3 | mbar |
|---|---|---|
| <$LSS_{1\ or\ 5}$> | ~ 5 $10^{12}$ | $10^{-10}$ |
| <ATLAS> | ~ $10^{11}$ | $10^{-11}$ |
| <CMS> | ~ 5 $10^{12}$ | $10^{-10}$ |

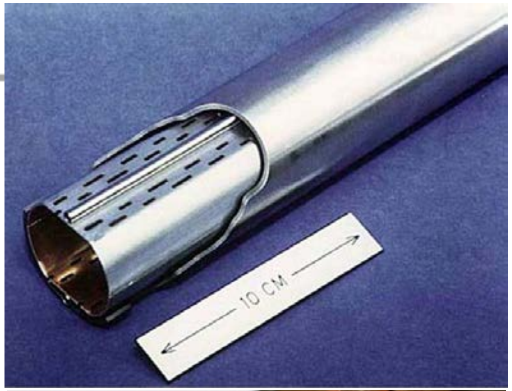
A. Rossi, CERN LHC PR 783, 2004.

➔ 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



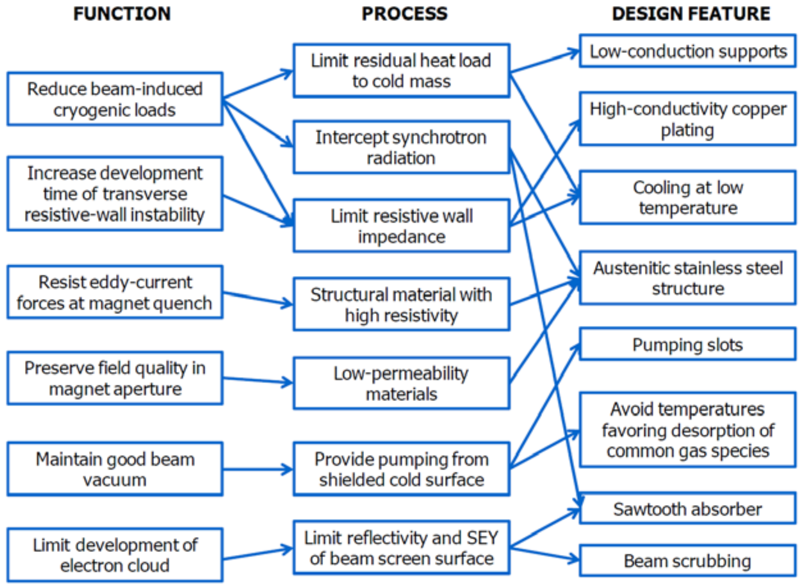

Courtesy N. Kos CERN AT/VAC

# 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

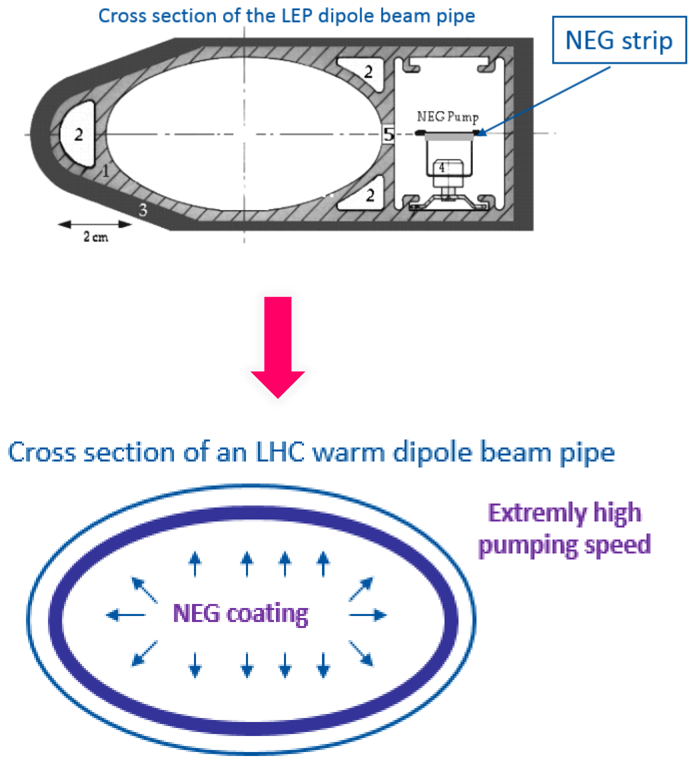

## Functional design map of beam screen




P. Lebrun *et al.*, ICEC 2012

# New System: NEG film coating

- Invention of low activation temperature (~ 200ºC) getter film
  => full pumping across the beam pipe
- Some vacuum chambers were constructed and getter coated …
  ~ 1 200 vacuum chambers produced

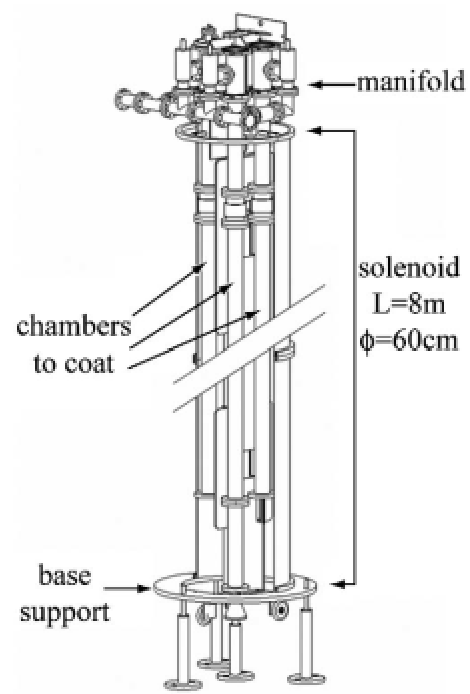


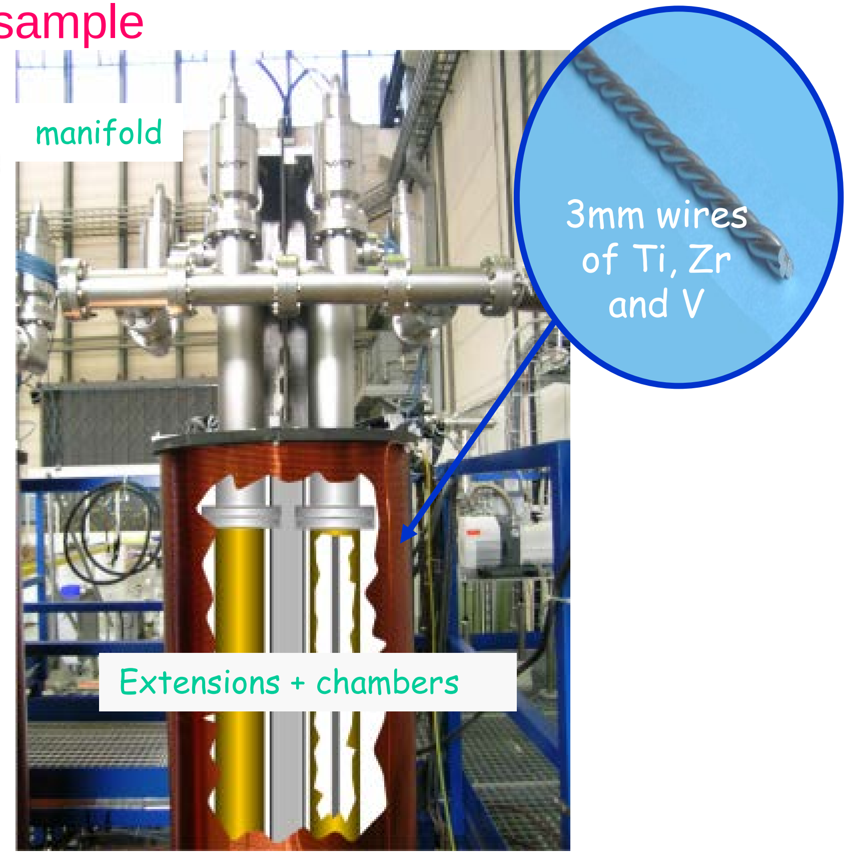

C. Benvenuti *et al.*

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 valided by XPS on witness sample

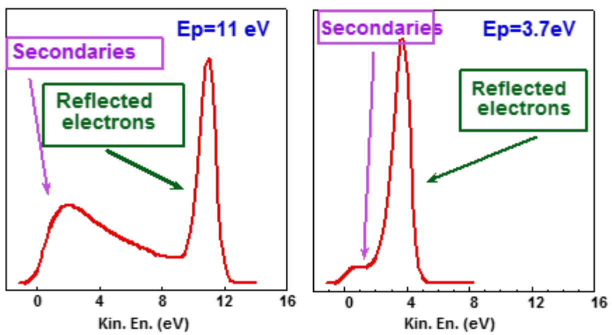




P. Costa Pinto, P. Chiggiato / Thin Solid Films 515 (2006) 382-388

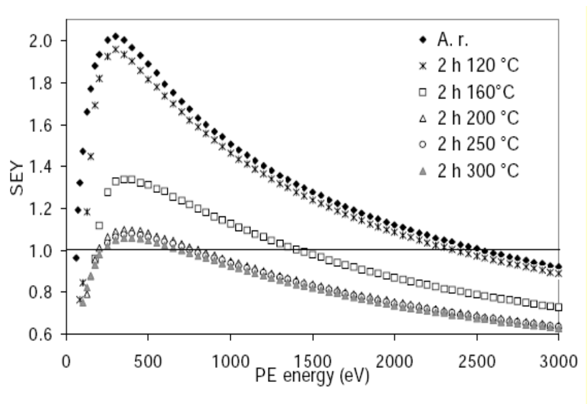
# Base Line Validation

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

## Material performance qualification

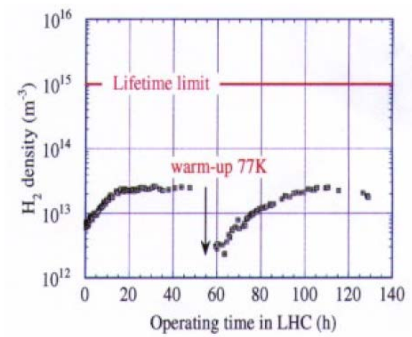



R. Cimino , I.R. Collins, App. Surf. Sci. 235, 231-235, (2004)




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

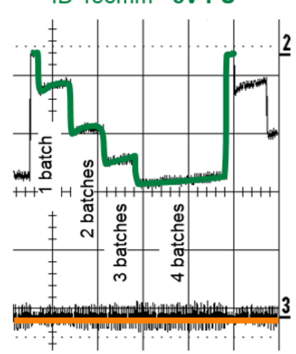
## System performance qualification




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

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

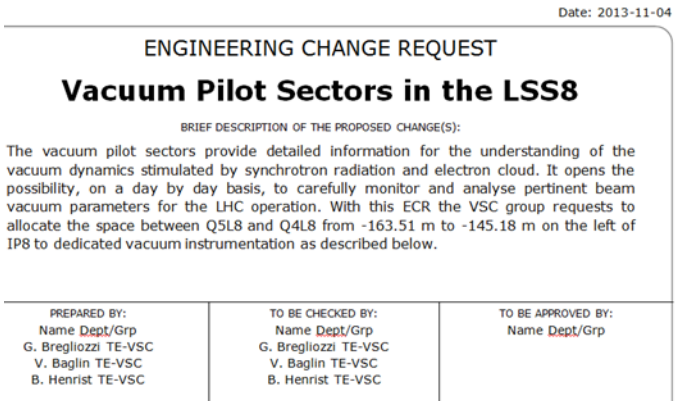
- Design review (conceptual, detailed, production readiness …)
- During LHC procurement, the LHC-VAC group internally reviewed all technical specifications and drawings :
    - ensure compatibility across the vacuum system
    - allows optimisation across components and performance (standardisation)
    - 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

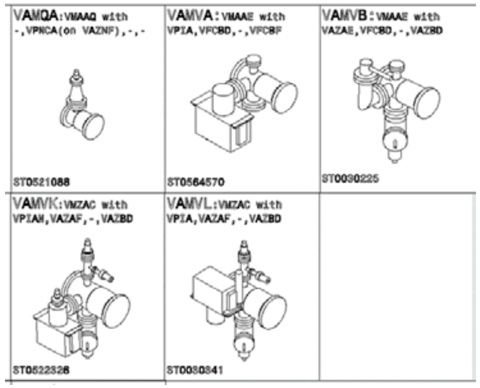
**Vacuum Pilot Sectors in the LSS8**

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

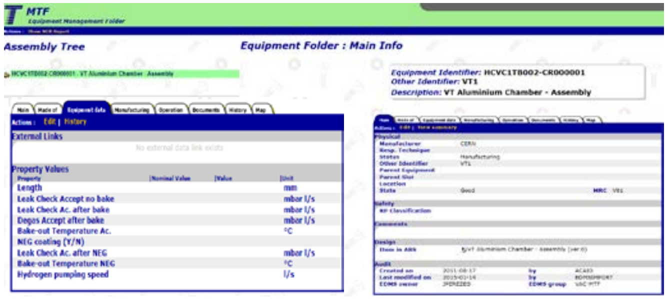
The vacuum pilot sectors provide detailed information for the understanding of the vacuum dynamics stimulated by synchrotron radiation and electron cloud. It opens the possibility, on a day by day basis, to carefully monitor and analyse pertinent beam vacuum parameters for the LHC operation. With this 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.

| PREPARED BY: | TO BE CHECKED BY: | TO BE APPROVED BY: |
|---|---|---|
| Name Dept/Grp<br>G. Bregliozzi TE-VSC<br>V. Baglin TE-VSC<br>B. Henrist TE-VSC | Name Dept/Grp<br>G. Bregliozzi TE-VSC<br>V. Baglin TE-VSC<br>B. Henrist TE-VSC | Name Dept/Grp |

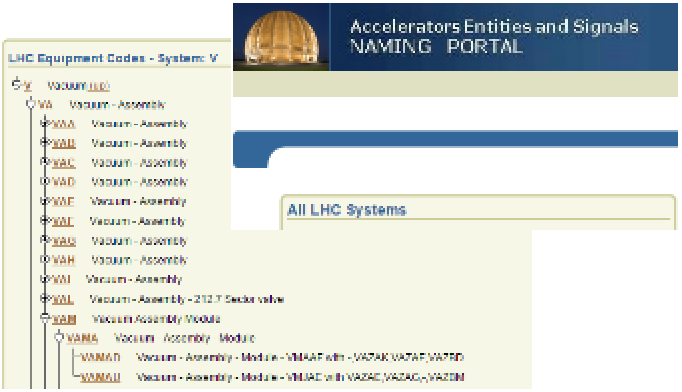
Engineering Change Request




Standard components Libraries




Equipment Management Folder

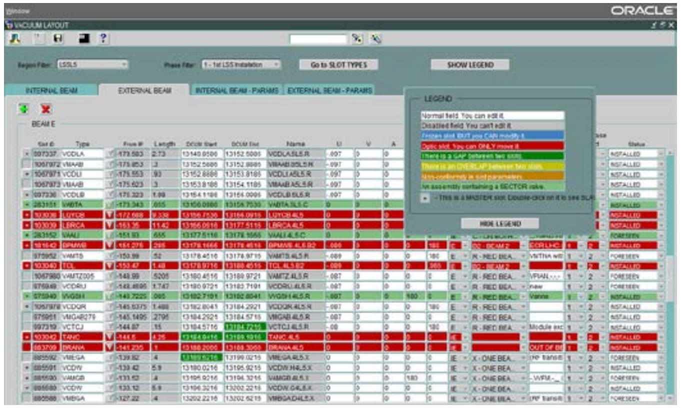



Naming Convention

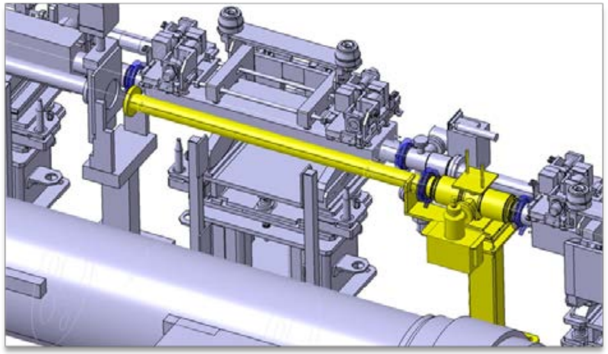

LHC layout database

# Vacuum Layout

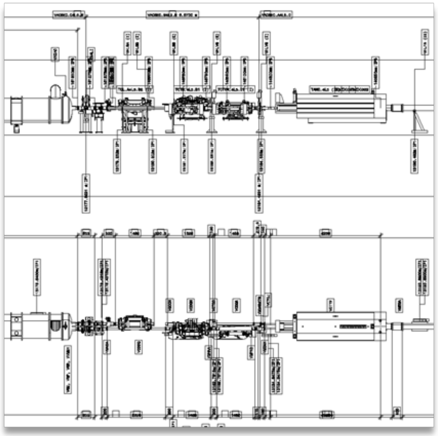
- Define components, produce data based drawings and SCADA systems, ease installation and optimise future intervention (e.g. in radioactive areas)



Vacuum layout database

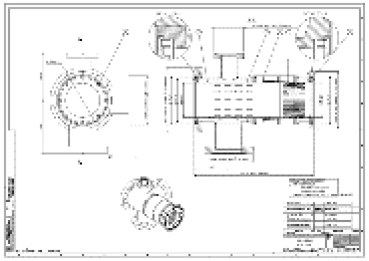


Integration studies

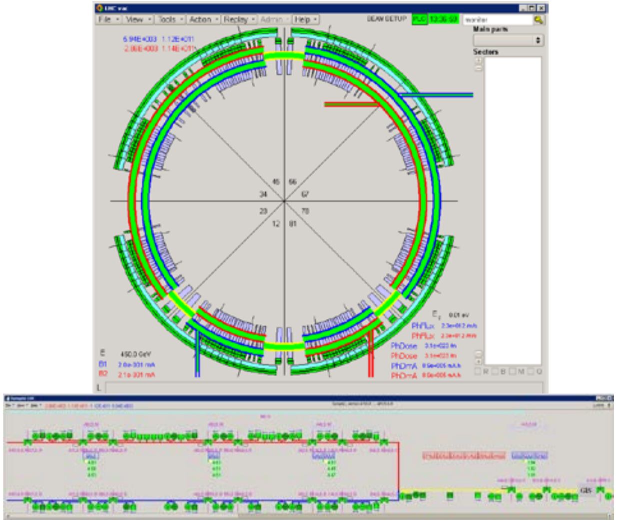


Installation drawings

| B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LBV component's order for LS1 | | | | | | | | | |
| | | Updated | 14/07/2014 | VB | | | | | | | |
| Ref V | Ref EP | Theme | Component | LSS | Sector | Beam | DCUM ( | Lenght (mm | Designation | Description | Comment |
| 208 | 313 | NEG upgrade | Assembly module | 5 | B4L5.R | R | 13180.812 | 279.5 | VAMVE.4L5.R | VPIAN/VPNCA_,_-,VVFMF | check |
| 209 | 103 | TCL4 | Vacuum module | 5 | B4L5.B | B | 13180.902 | 300 | VAMWF | VMJAF with-,VGRB,VPIAN/VPNCA,VVFMF | module in the machine, instrumentation changing |
| 210 | 276 | NEG upgrade | Assembly module | 5 | B4L5.B | B | 13180.902 | 280 | VAMWF.4L5.B | VMJAF with-,VGRB,VPIAN/VPNCA,VVFMF | na |
| 211 | 161 | TCL4 | Vacuum chamber | 5 | B4L5.R | R | 13180.972 | 1747 | VCDRU | Chambre ID80 DN100-QCF100 | remplace VCDQN+VMDNA |



New components
Production & follow up



SCADA

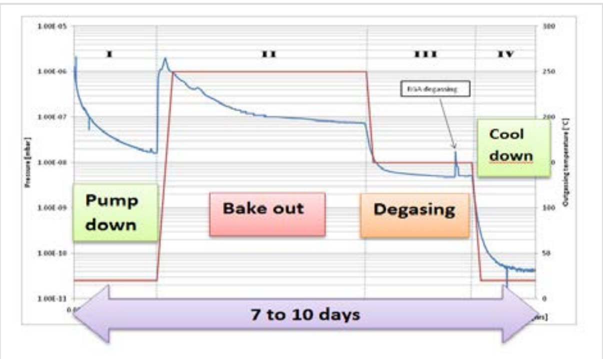
# Infrastructure and Material

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

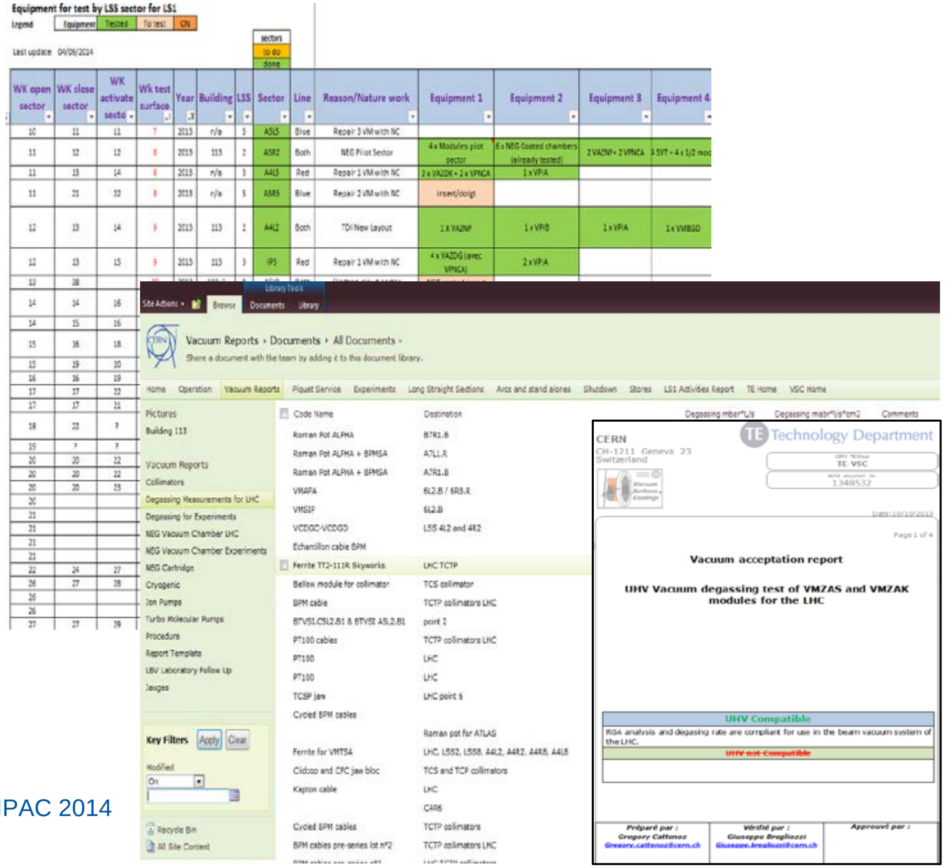
# Vacuum Acceptance Tests

- 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

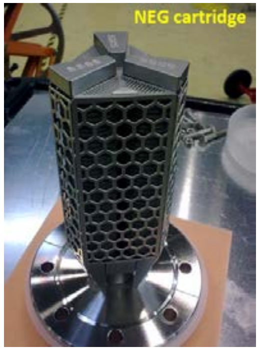



2 ALFA Roman pot stations (XRPA) connected to TB1 in B113

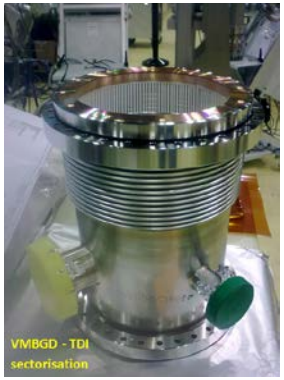



G. Cattenoz *et al.*, IPAC 2014

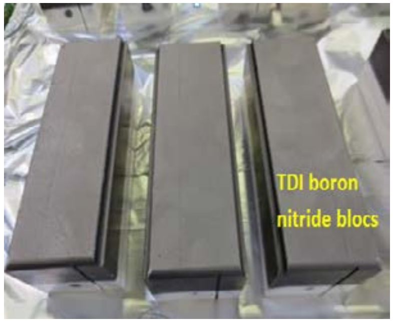
# Examples of tested parts

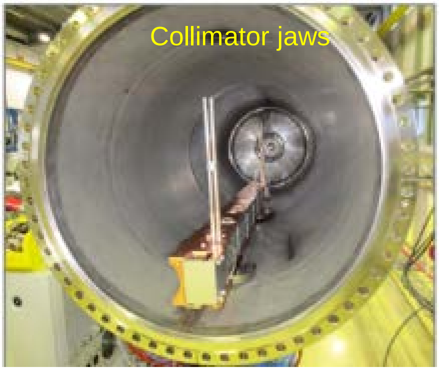


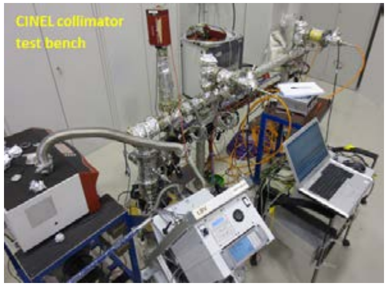




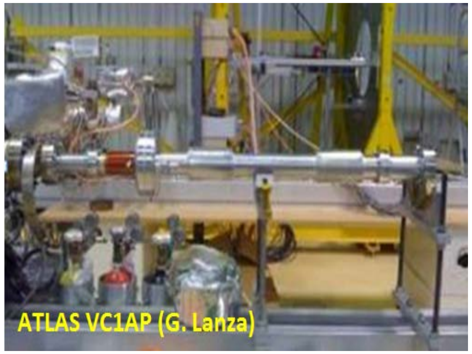







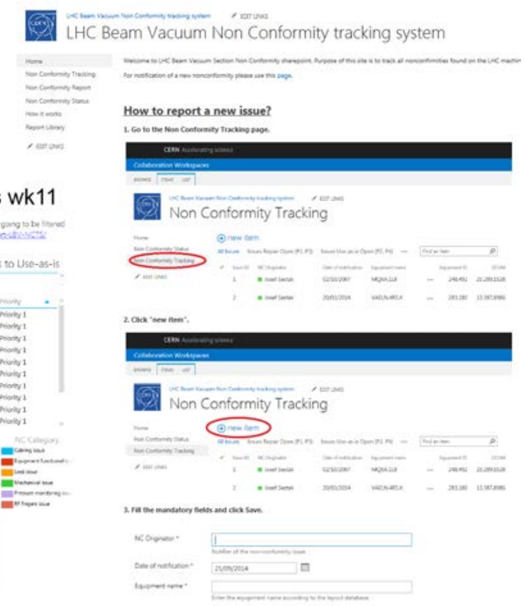



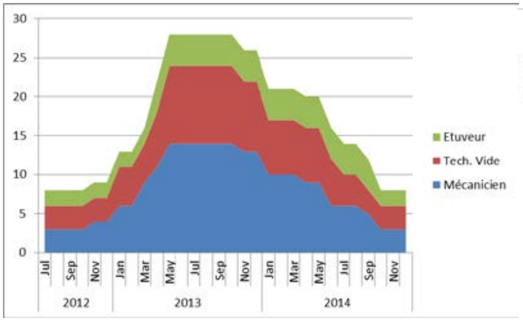


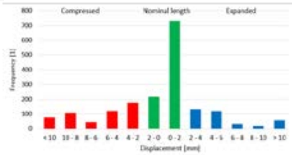


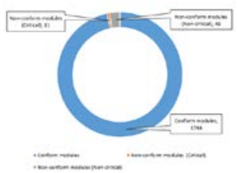
# Installation and Quality Control

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

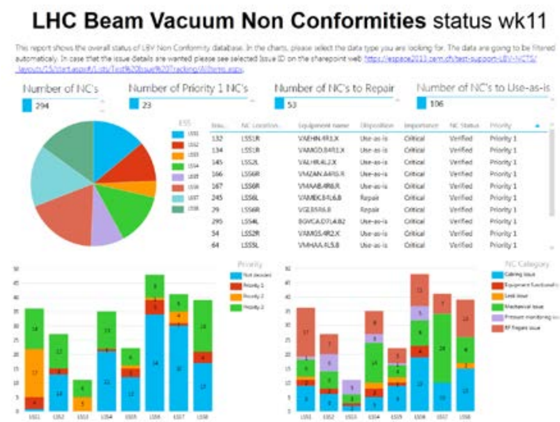


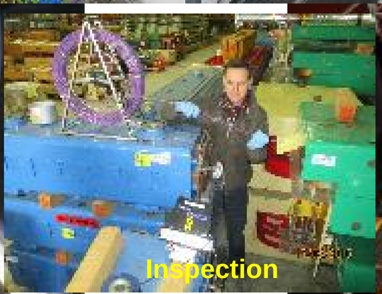



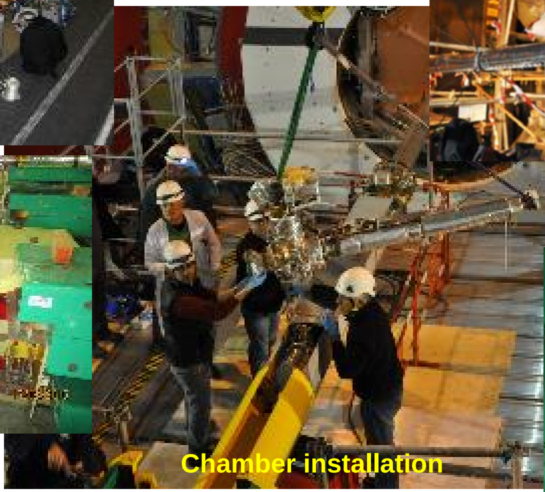
J. Sestak *et al.*, IPAC 2015





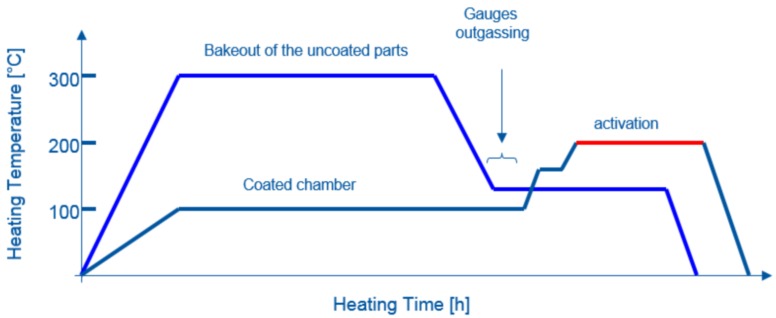


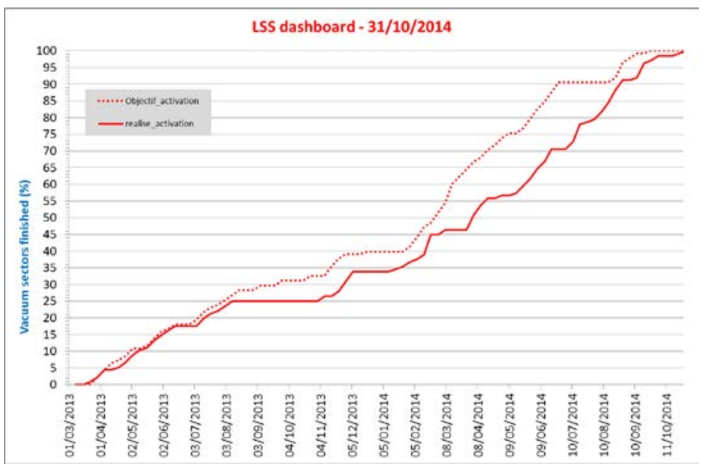



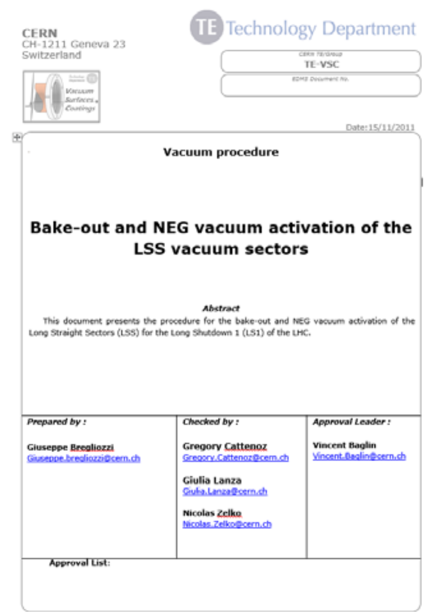




# Commissioning of the NEG coated vacuum system

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



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TE Technology Department

TE-VSC

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 : | Checked by : | Approval Leader : |
|---|---|---|
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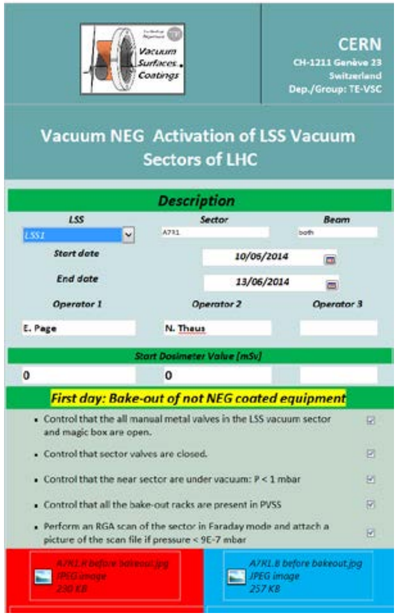
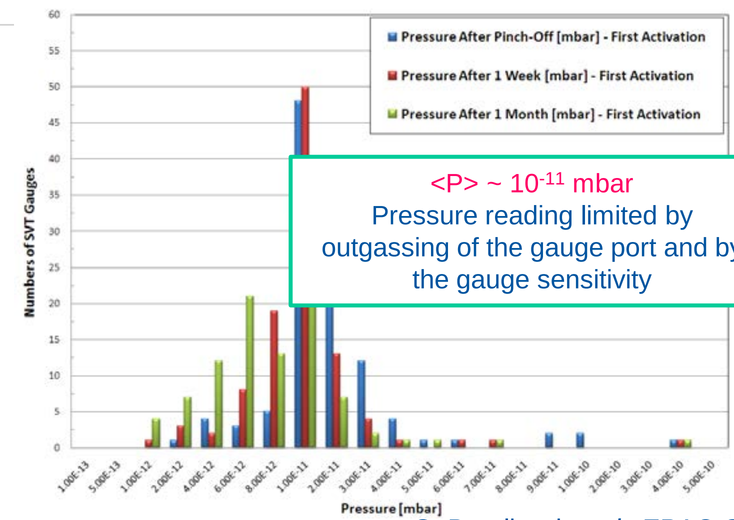
Approval List:




<P> ~ $10^{-11}$ mbar
Pressure reading limited by outgassing of the gauge port and by the gauge sensitivity

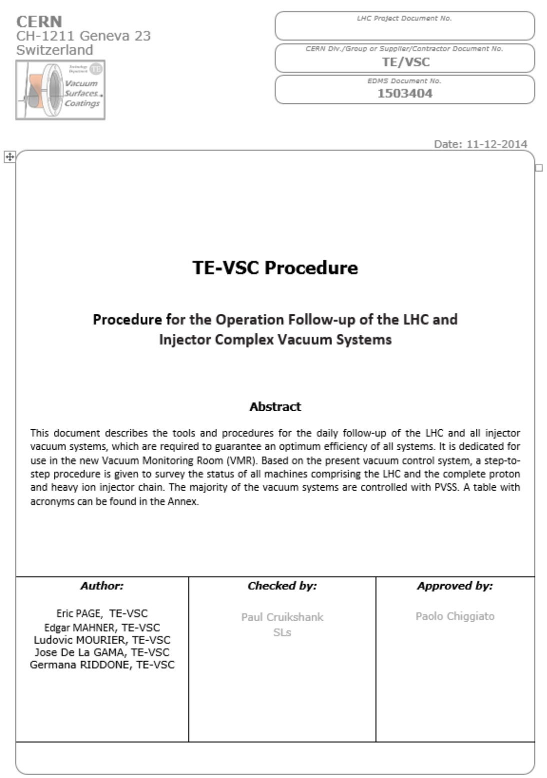
G. Bregliozzi *et al.*, EPAC Genoa, 2008

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

# 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**

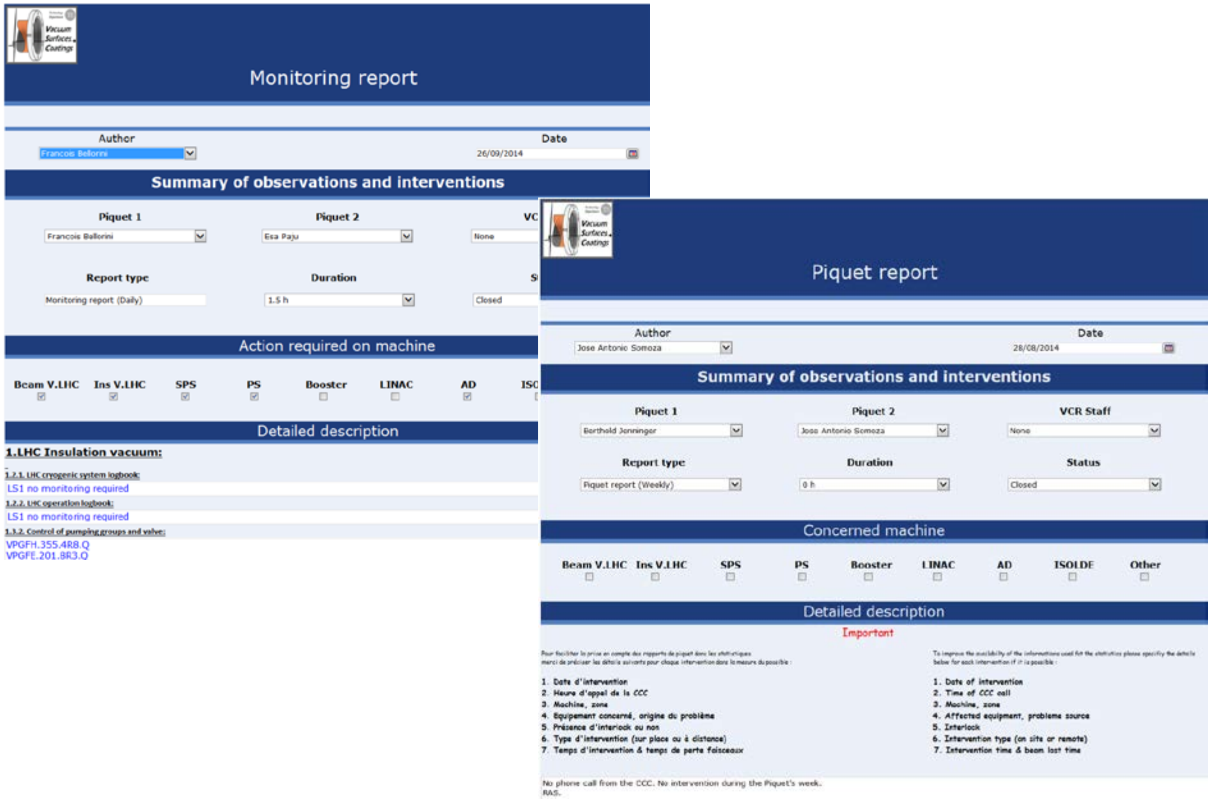
**Procedure for the Operation Follow-up of the LHC and Injector Complex Vacuum Systems**

**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<br>Edgar MAHNER, TE-VSC<br>Ludovic MOURIER, TE-VSC<br>Jose De La GAMA, TE-VSC<br>Germana RIDDONE, TE-VSC | Paul Cruikshank<br>SLs | Paolo Chiggiato |

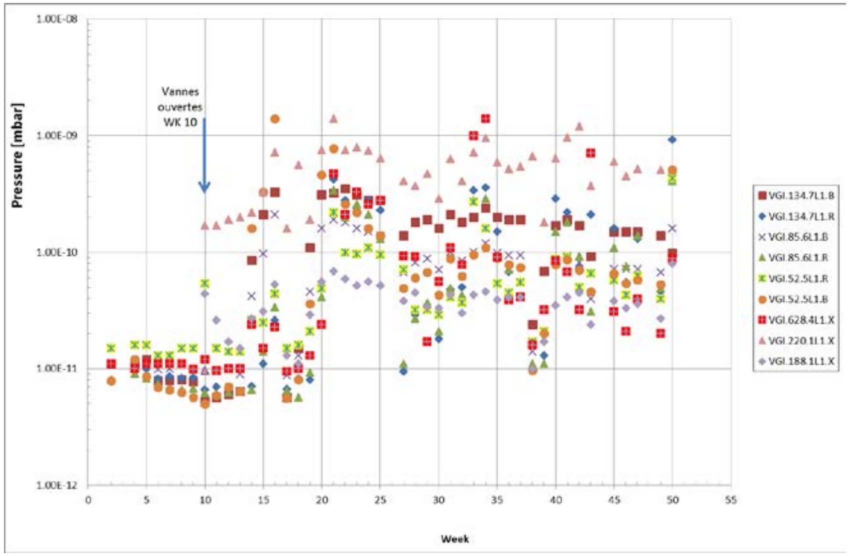
Procedures



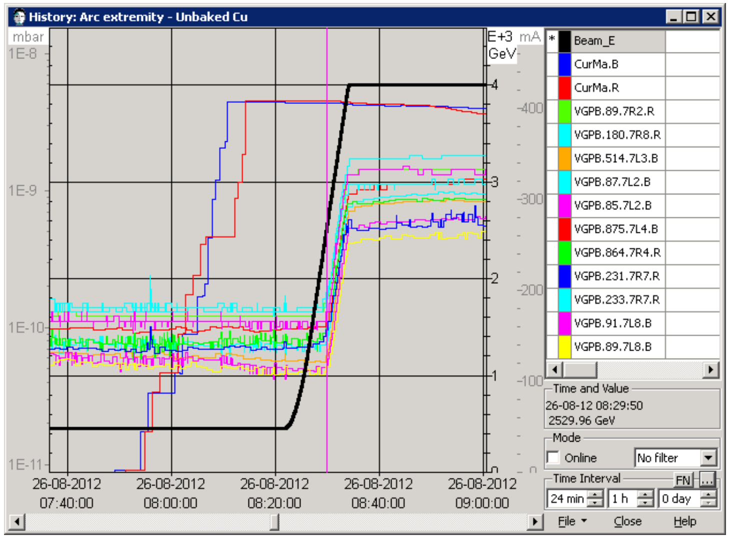

Daily and weekly Reports

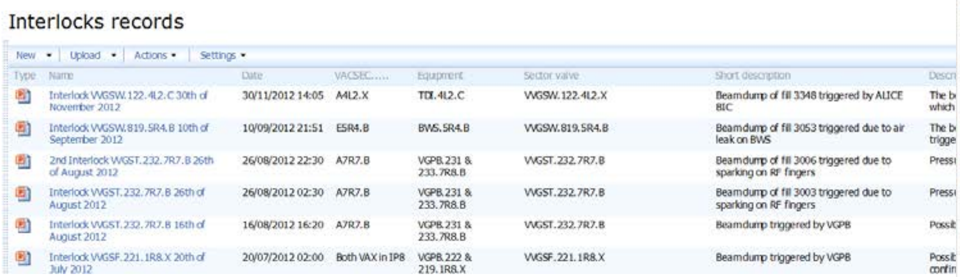
# Pressure Follow-Up

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




General trends

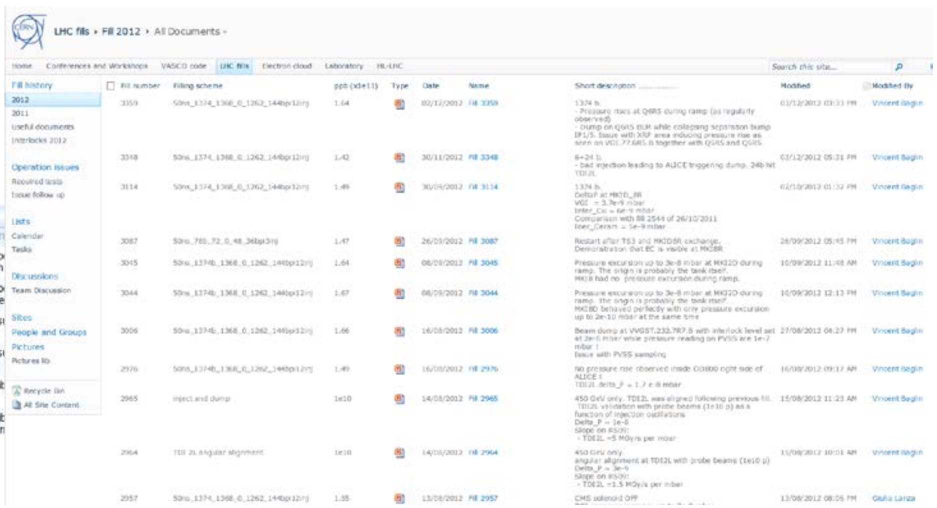




Interlocks records

New • | Upload • | Actions • | Settings •

| Type | Name | Date | VACSEC..... | Equipment | Sector valve | Short description | Descr |
|---|---|---|---|---|---|---|---|
| | Interlock VVGSW.122.4L2.C 30th of November 2012 | 30/11/2012 14:05 | A4L2.X | TDI.4L2.C | VVGSW.122.4L2.X | Beamdump of fill 3348 triggered by ALICE BIC | The b which |
| | Interlock VVGSW.819.5R4.B 10th of September 2012 | 10/09/2012 21:51 | E5R4.B | BWS.5R4.B | VVGSW.819.5R4.B | Beamdump of fill 3053 triggered due to air leak on BWS | The b trigge |
| | 2nd Interlock VVGST.232.7R7.B 26th of August 2012 | 26/08/2012 22:30 | A7R7.B | VGPB.231 & 233.7R8.B | VVGST.232.7R7.B | Beamdump of fill 3006 triggered due to sparking on RF fingers | Press |
| | Interlock VVGST.232.7R7.B 26th of August 2012 | 26/08/2012 02:30 | A7R7.B | VGPB.231 & 233.7R8.B | VVGST.232.7R7.B | Beamdump of fill 3003 triggered due to sparking on RF fingers | Press |
| | Interlock VVGST.232.7R7.B 16th of August 2012 | 16/08/2012 16:20 | A7R7.B | VGPB.231 & 233.7R8.B | VVGST.232.7R7.B | Beamdump triggered by VGPB | Possib |
| | Interlock VVGSF.221.1R8.X 20th of July 2012 | 20/07/2012 02:00 | Both VAX in IP8 | VGPB.222 & 219.1R8.X | VVGSF.221.1R8.X | Beamdump triggered by VGPB | Possib confir |

Tracking interlocks

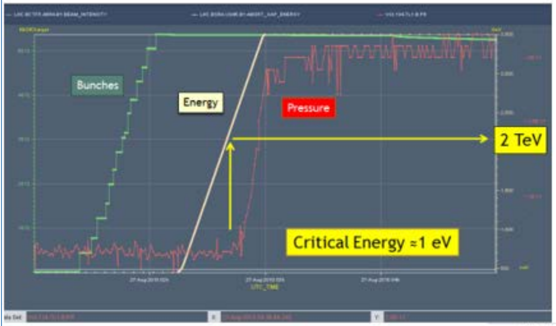



Fill by fill monitoring

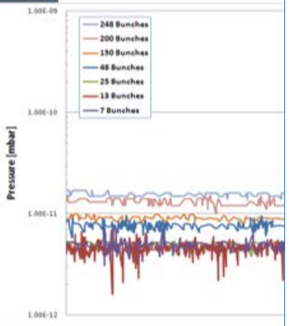
# Operation Follow-Up: Checking Design

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

## First Observation of Synchrotron Radiation: Aug-2010



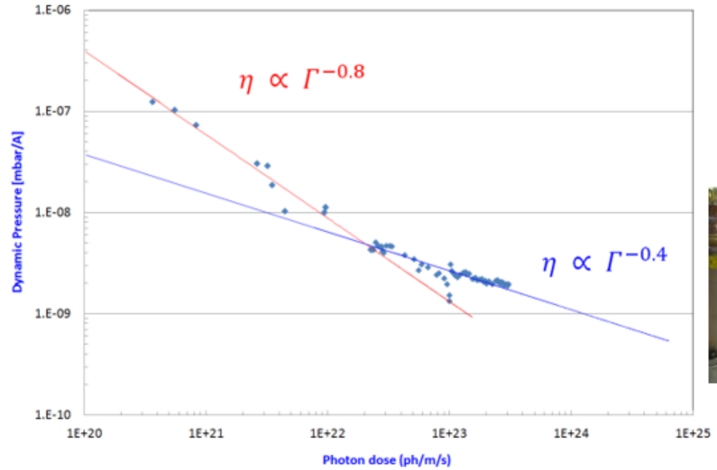

- Pressure rise during the beam energy ramp




- Dynamic pressure increases with beam current
- DeltaP = 2 $10^{-10}$ 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

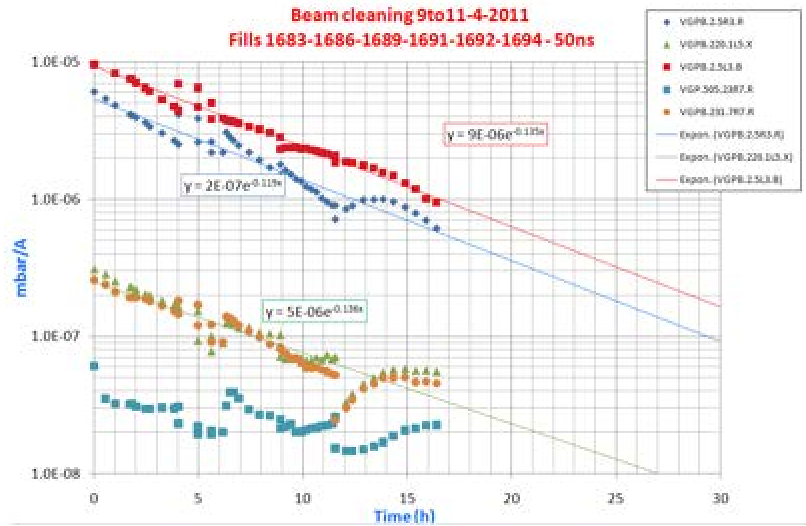

- Inside the arc, at 5-20 K, deltaP < $10^{-10}$ mbar (i.e. below detection limit)
- The photodesorption yield at cryogenic temperature is estimated to be < $10^{-4}$ molecules/photon

# 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

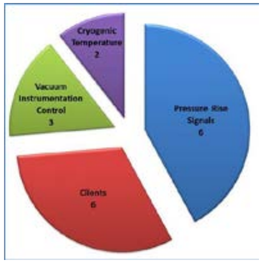
- As expected, strong pressure reduction with time were observed




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

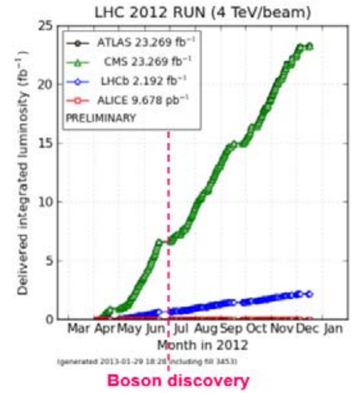
# Global Performance with Beams

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




G. Lanza, Proc Evian 2012.

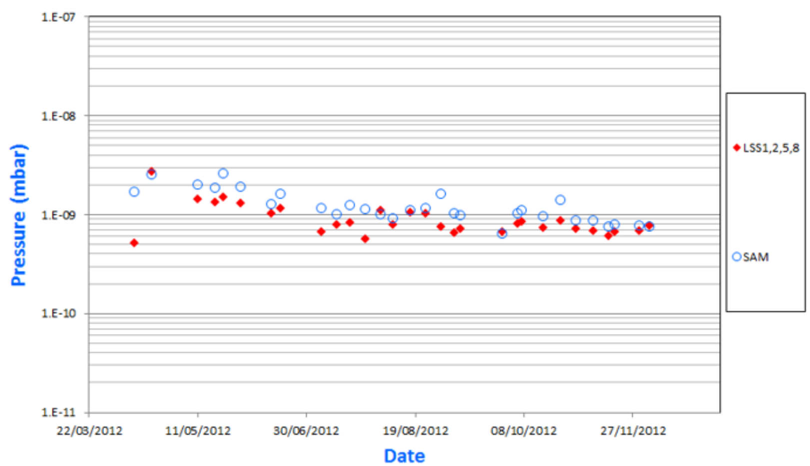
**2012: Integrated Luminosity ~ 23 $fb^{-1}$**
**(2011: 5 $fb^{-1}$)**




## Long Straight Sections

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

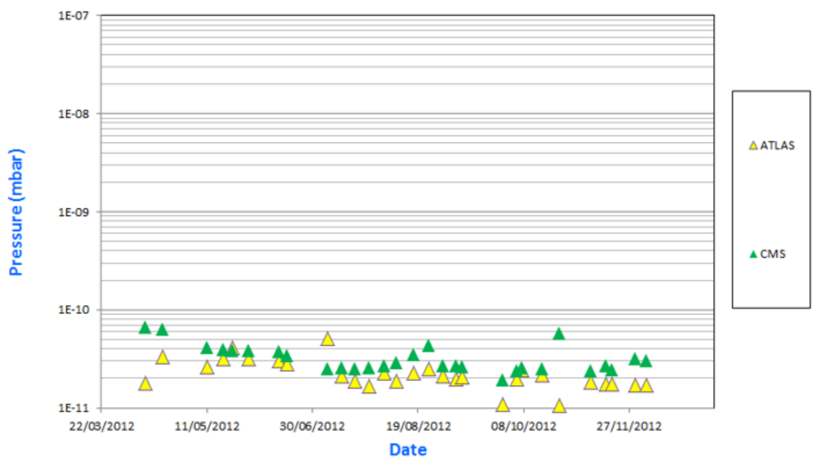
**2012: LHC LSS Average Pressure with Beam**




## LHC Experiments

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

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



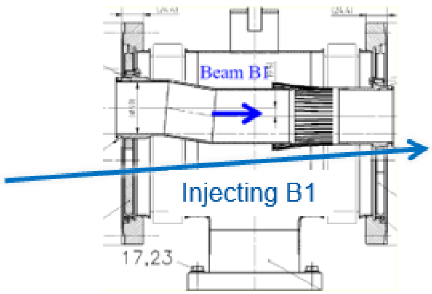
# 3. Repairs, Consolidation & Upgrade

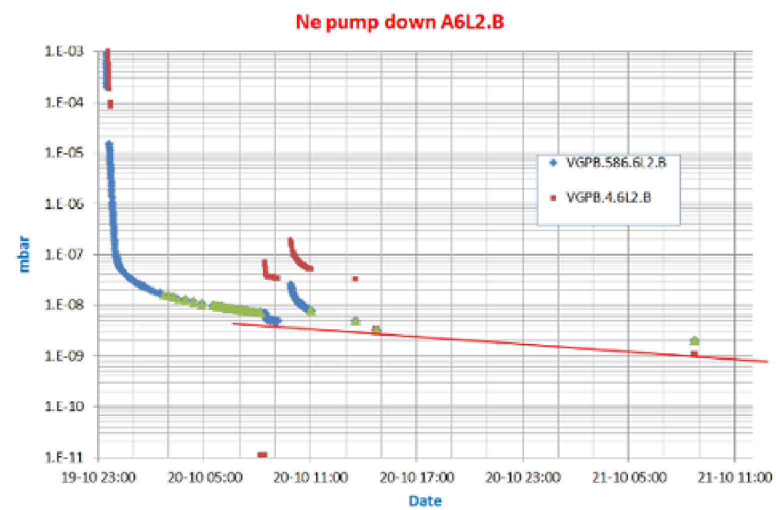
# Fast Intervention: Ne venting

- Allow to reduce the recovery time <u>minimising</u> 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




Transition tube installed in reversed position

RF fingers

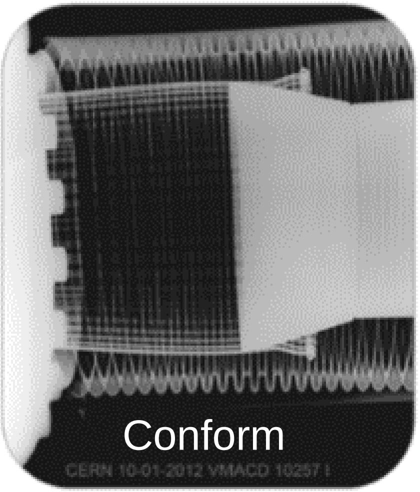
Fast recovery following RF bridge repair: operation resumed in 3 days

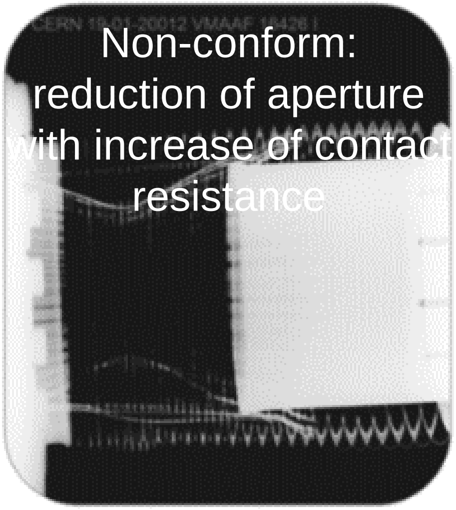
# Repair of Non-Conformities (2013-14)

- 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)



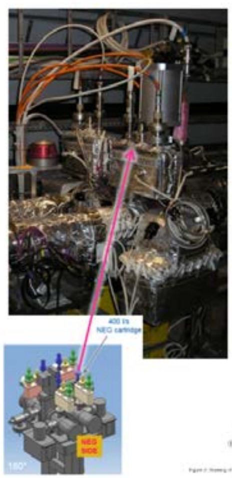



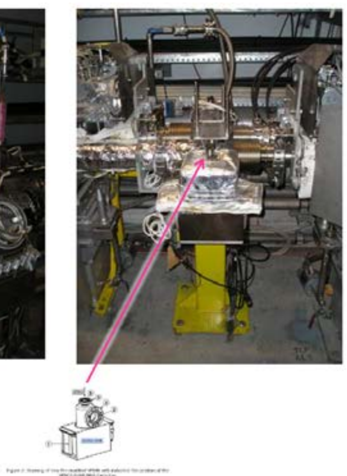

Courtesy A. Vidal, J-M. Dalin EN-MME

➔ 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



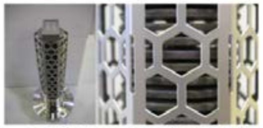


Figure 1: D400 NEG cartridge with DN 35 CF flange

Table 1: Pump Characteristics

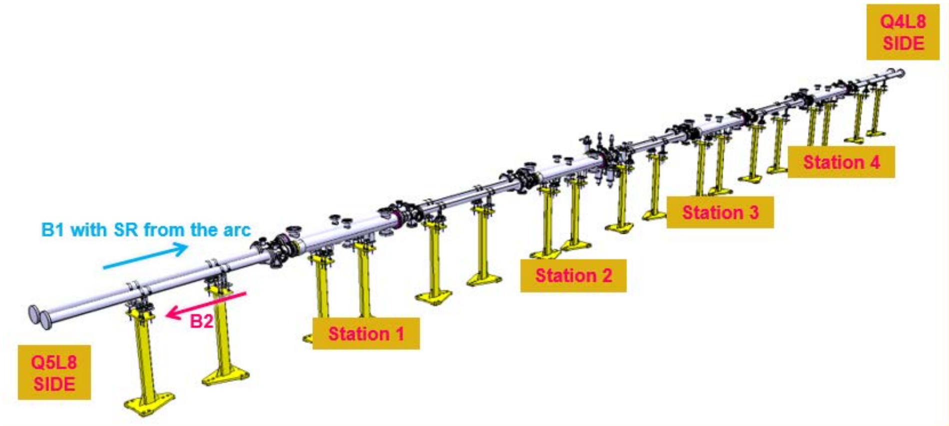
| | | D400 |
|---|---|---|
| Alloy Type | | St 172® |
| Alloy Composition | | ZrVFe |
| Getter Mass (g) | | 45 |
| Getter Surface ($cm^2$) | | 380 |
| Pumping speed (l/s) | $H_2$ | 400 |
| | CO | 180 |
| Sorption Capacity (Torr l) | $H_2$ | 900 |
| | CO | 0.9 |

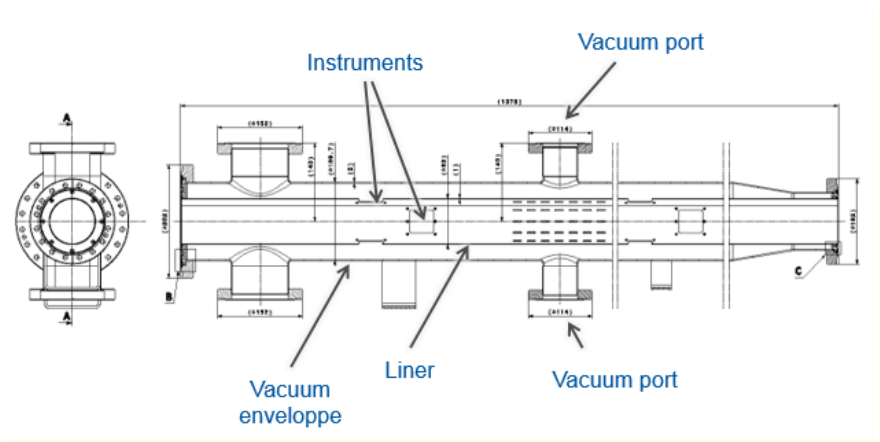
- Pumping speed multiplied by ~ 10
- Can be remotely re-activated

➔ Identification and consolidation of weak points

# Specific Instrumentation

## Vacuum Pilot Sectors




B. Henrist *et al.*, IPAC 2015

## NEG Pilot Sectors

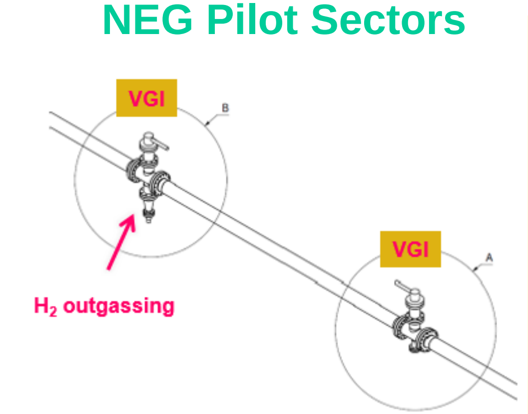
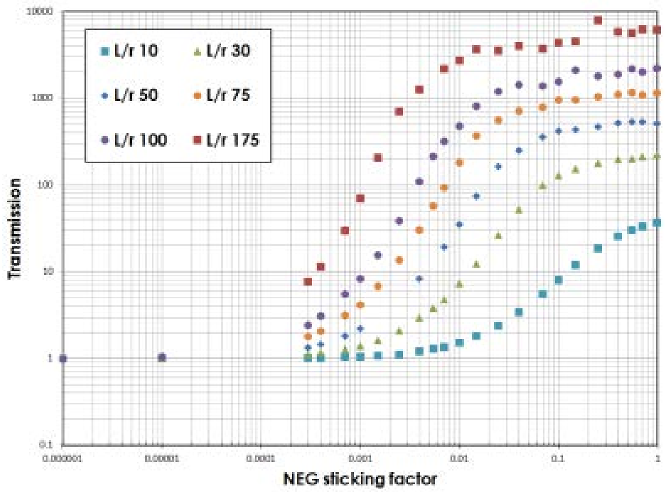



Figure 1: Pilot sector schematic

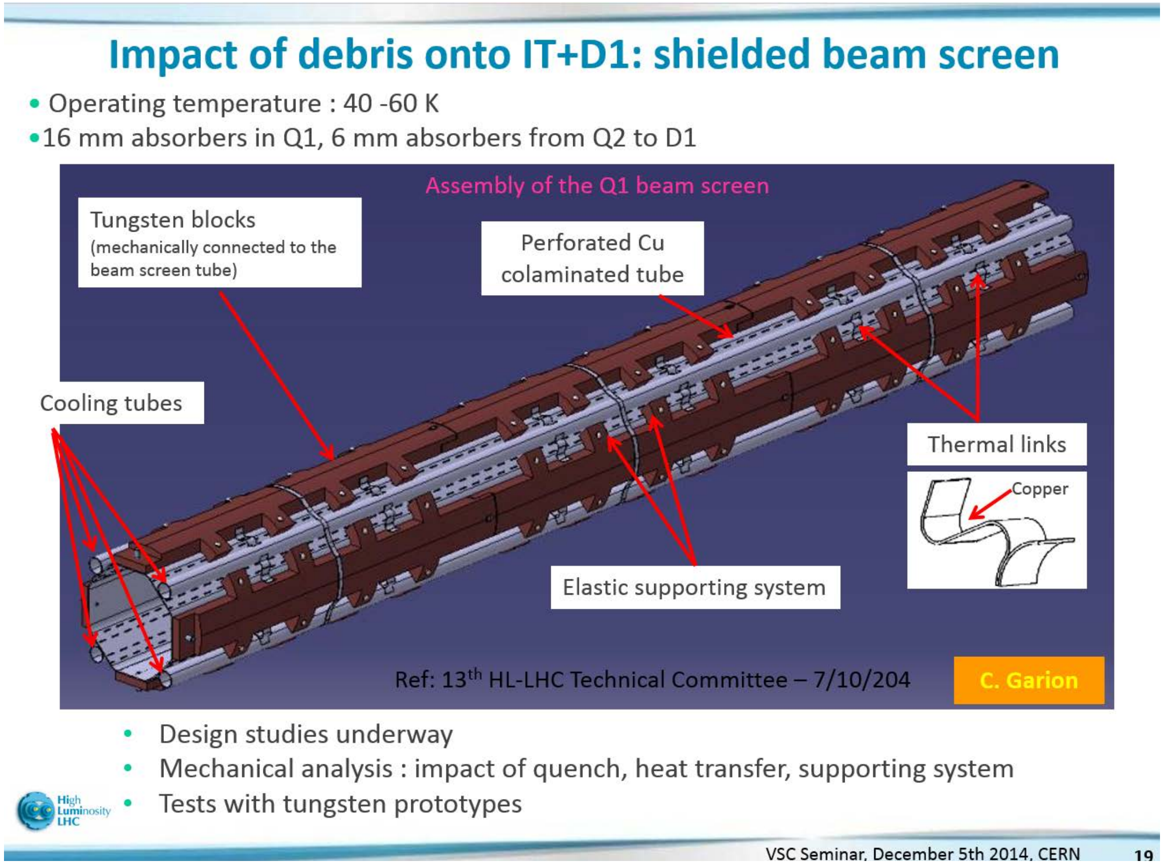



Pressure ratio yields the NEG sticking factor

→ 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




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

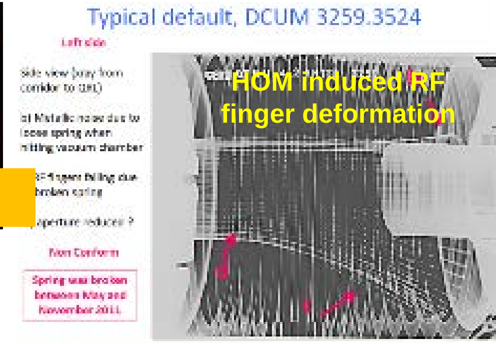

- The slides presented here are the fruit of the work of many CERN and external collaborators who participated to the design and installation of the LHC vacuum system under the successive directions of A.G. Mathewson, O. Gröbner and P. Strubin

- 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


03. 08. 09 16:30
107. 7m
03. 08. 09 16:30
107. 8m
03. 08. 09 16:30
106. 3m
LHC: repair at cold or how to bring ice in the beam tube ….

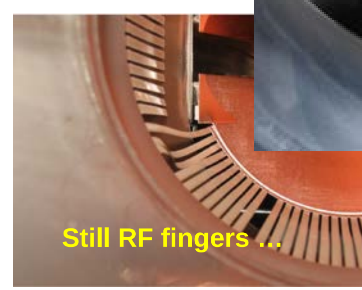

Typical default, DCUM 3259.3524
HOM induced RF finger deformation

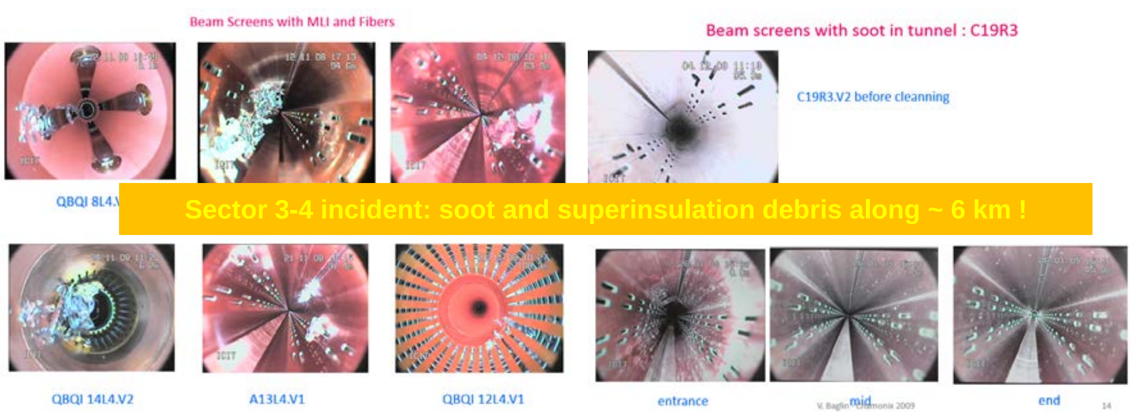

QQBI.26R7 line V2
Increasing contact impedance at the price of buckling


14. 01. 09 15:30
0. 0m
CERN TE-VSC
A vacuum cleaner to remove superinsulation


LHC: the most expensive brazing machine


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


Still RF fingers …


Beam Screens with MLI and Fibers
Beam screens with soot in tunnel : C19R3
C19R3.V2 before cleanning
Sector 3-4 incident: soot and superinsulation debris along ~ 6 km !
QBQI 14L4.V2
A13L4.V1
QBQI 12L4.V1
entrance
mid
end

# Back up slides

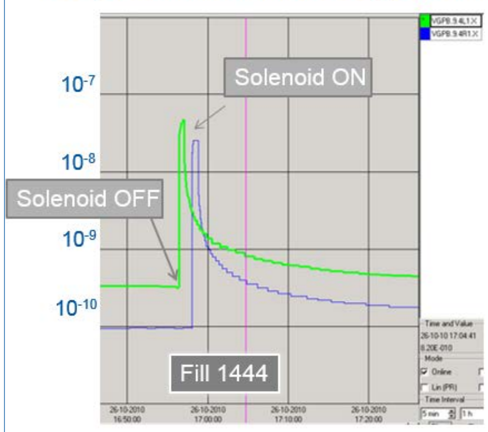
# Operation: Solenoids, a non-base line system

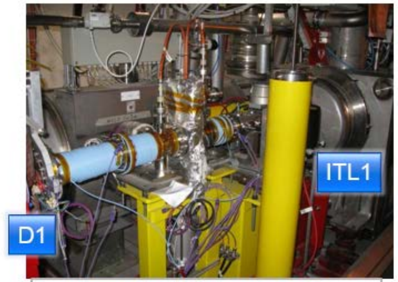
- Using expertise to solve unexpected issues:
  electron cloud with 150 ns bunch spacing (in common beam pipes) !

- 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 ….

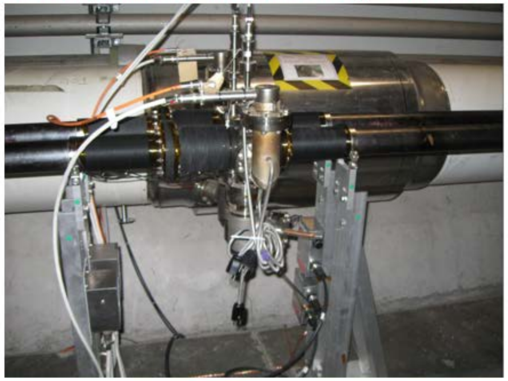


Magnetic field of solenoid≈ 20 Gauss

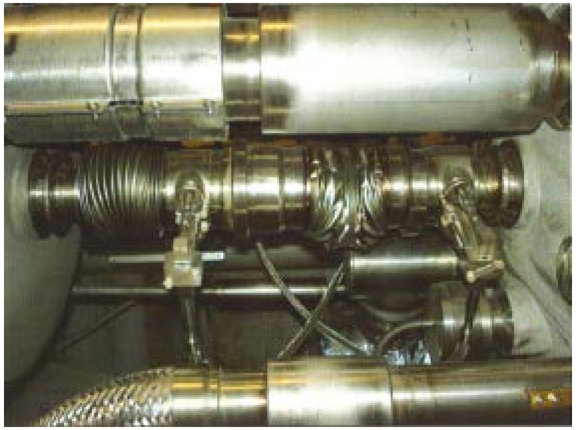
### But ….

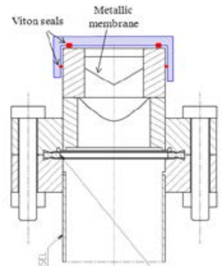
- Our colleagues from the machine operation and physics groups had a clever idea :
  - What about installing a solenoid everywhere in the machine to mitigate electron cloud !
- So, in Nov 2010, we had to proposed the installation of solenoids around experimental areas i.e. 20 km of cable to wound around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

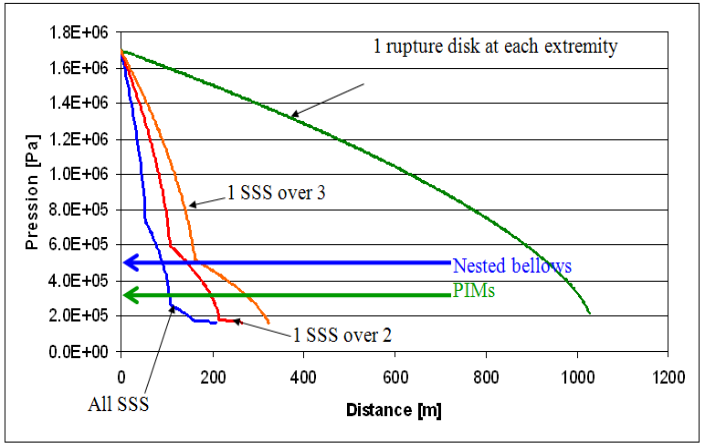


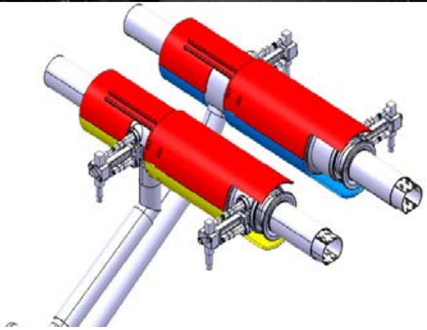
# Arc Beam Vacuum Consolidation

- 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





Protective half-shells for cryomagnet interconnections

Courtesy C. Garion

➔ Protection of the system against co-lateral damaged

CERN