CERN

LHC Run 1:
qu'est ce qui c'est bien passé, qu'est ce qui c'est mal passé et leçons pour le futur

V. Baglin pour le groupe TE-VSC

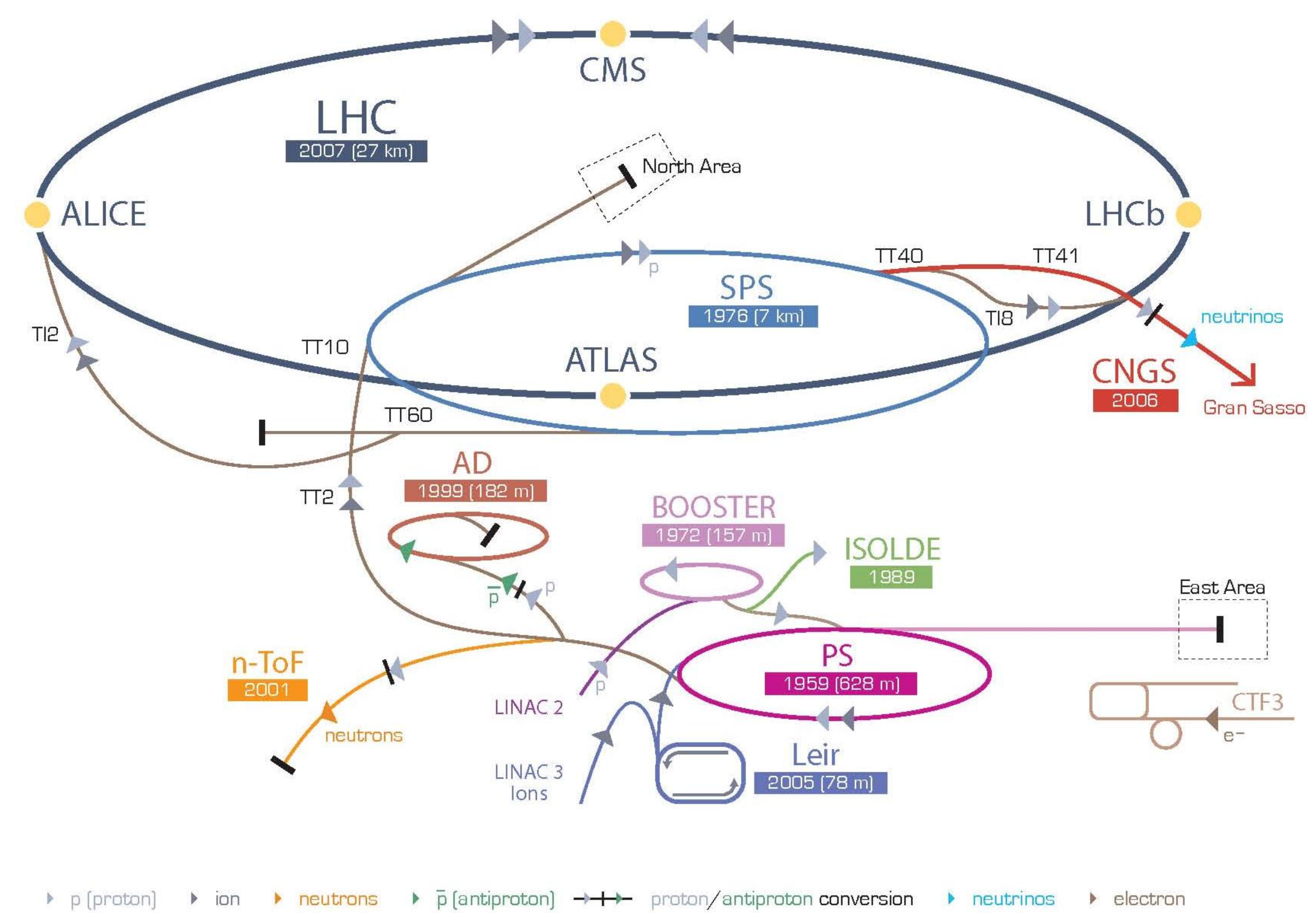
CERN TE-VSC, Geneva

Outline

1. Introduction au LHC
2. Système vide faisceau
3. Difficultés rencontrées pendant l'installation
4. Démarrage du système vide faisceau
5. Consolidations et améliorations
6. Résumé

1. Introduction au LHC

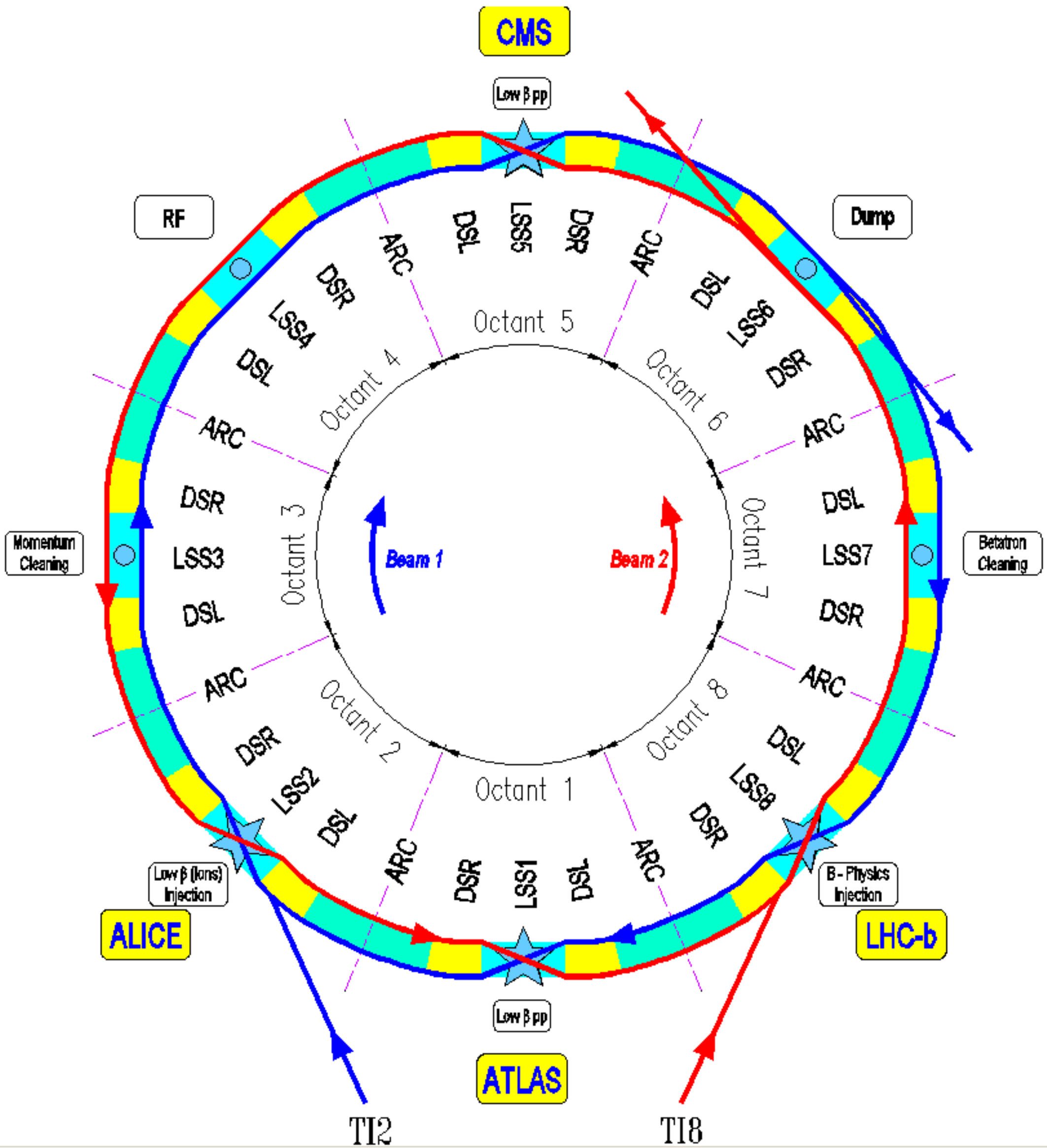
CERN Accelerators Complex



LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

LHC Layout



CMS
Low β pp
RF
Dump
Momentum Cleaning
Betatron Cleaning
Low β (Ions) Injection
B - Physics Injection
ALICE
LHC-b
Low β pp
ATLAS
TI2
TI8
Octant 1
Octant 2
Octant 3
Octant 4
Octant 5
Octant 6
Octant 7
Octant 8
Beam 1
Beam 2
LSS1
LSS2
LSS3
LSS4
LSS5
LSS6
LSS7
LSS8
ARC
DSR
DSL

LHC layout : Some numbers

Item	Length (m)	% wrt to total
Ring circumference	26 642.1	100
<arc length>	~ 2810	84
<LSS length>	~ 515	16
Total length under vacuum	52 232	

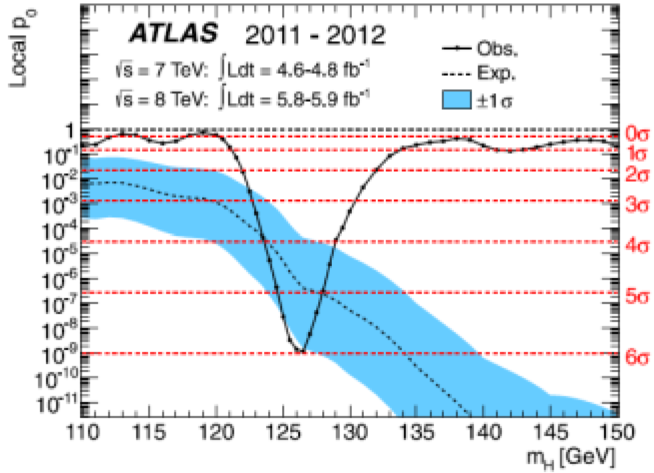
LHC Current Parameters

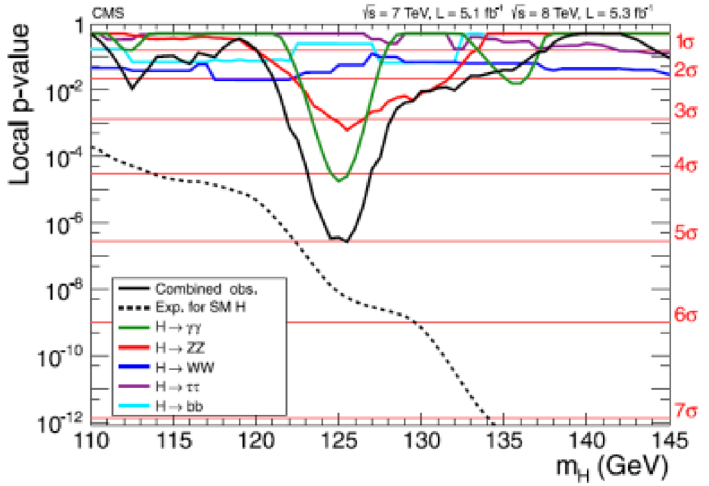
	Design		Commissioning		
	Nominal	Ultimate	2010	2011 (Fill 2256)	2012 (Fill 3250)
Energy [TeV]	7		3.5	3.5	4
Luminosity [$x10^{34}$ $cm^{-2}.s^{-1}$]	1.0	2.3	0.02	0.36	**0.75**
Current [mA]	584	860	80	362	420
Proton per bunch [$x10^{11}$]	1.15	1.7	1.2	1.45	**1.6**
Number of bunches	2808		368	1380	1378
Bunch spacing [ns]	25		150 (75-50)*	50 (25)*	50 (25)*
Normalised emittance [μm.rad]	3.75		~ 3	~ 2.3	~ 2.2
β * [m]	0.55		3.5	1	0.6
Total crossing angle [μrad]	285		240	240	290
Critical energy [eV]	44.1		5.5		8.2
Photon flux [ph/m/s]	$1\ 10^{17}$	$1.5\ 10^{17}$	$0.06\ 10^{17}$	$0.3\ 10^{17}$	$0.4\ 10^{17}$
SR power [W/m]	0.22	0.33	0.002	0.01	0.02
Photon dose [ph/m/year]	$1\ 10^{24}$	$1.5\ 10^{24}$	$1\ 10^{21}$	$1\ 10^{23}$	$1.4\ 10^{23}$

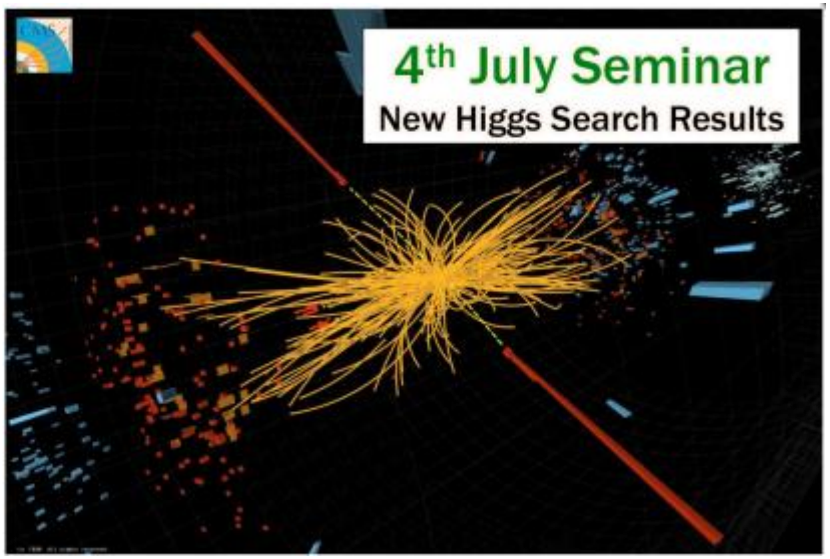
* During MD periods

4th July 2012: SM BEH Boson Discovery

ATLAS and CMS discovered a new boson in the mass region ~ 125-126 GeV/c²







Nobel Prize 2013

The Laureate during the announce the 4^{th} of July 2012

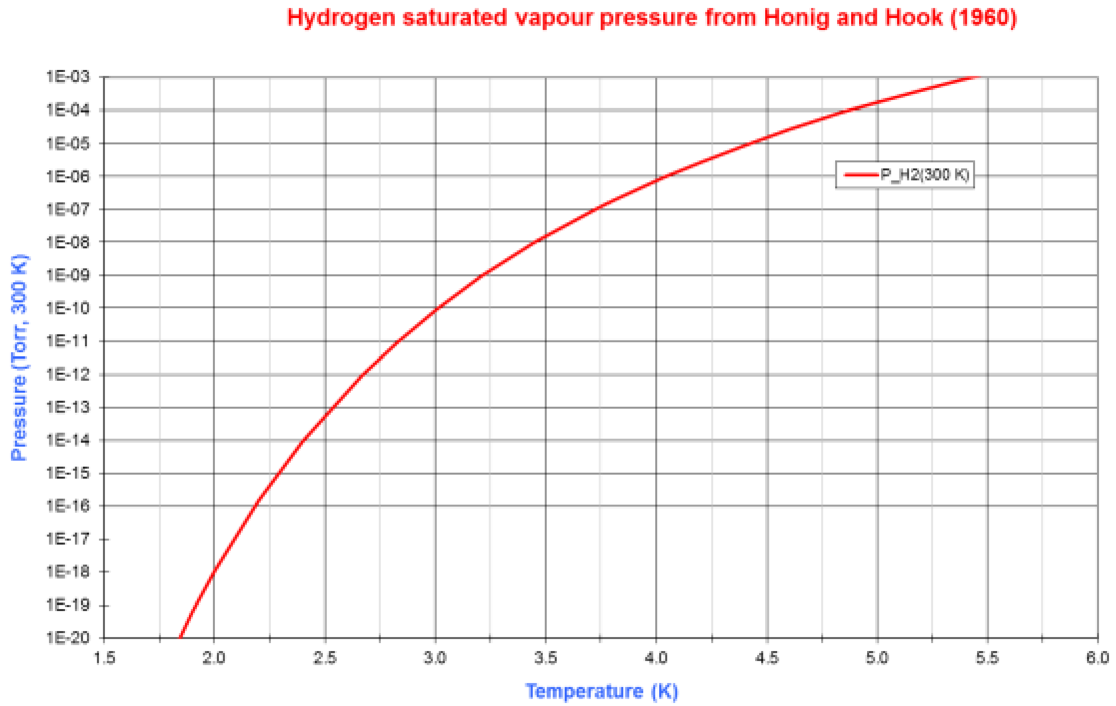
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

2. Système vide faisceau

Introduction

- Without beam, the LHC vacuum system static pressure is in the UHV-XHV range

- In principle, inside a leak tight cryogenic vacuum system operating at 1.9 K, the pressure level is defined by the hydrogen vapour pressure (<< 10^{-19} Torr)



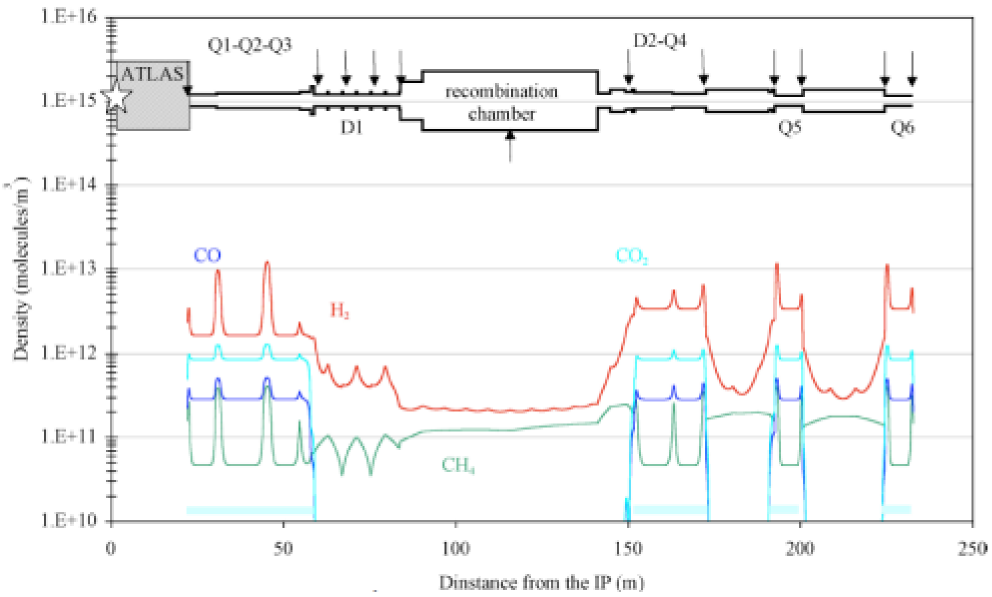
- With circulating beam, the LHC vacuum system dynamic pressure is dominated by 3 sources :
  - SR stimulated molecular desorption
  - Electron stimulated molecular desorption
  - ion stimulated molecular desorption

Design value : a challenge with circulating beams

- Life time limit due to nuclear scattering ~ 100 h
  - n ~ 10^{15} H_2/m3
  - $\langle P_{arc} \rangle < 10^{-8}$ 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



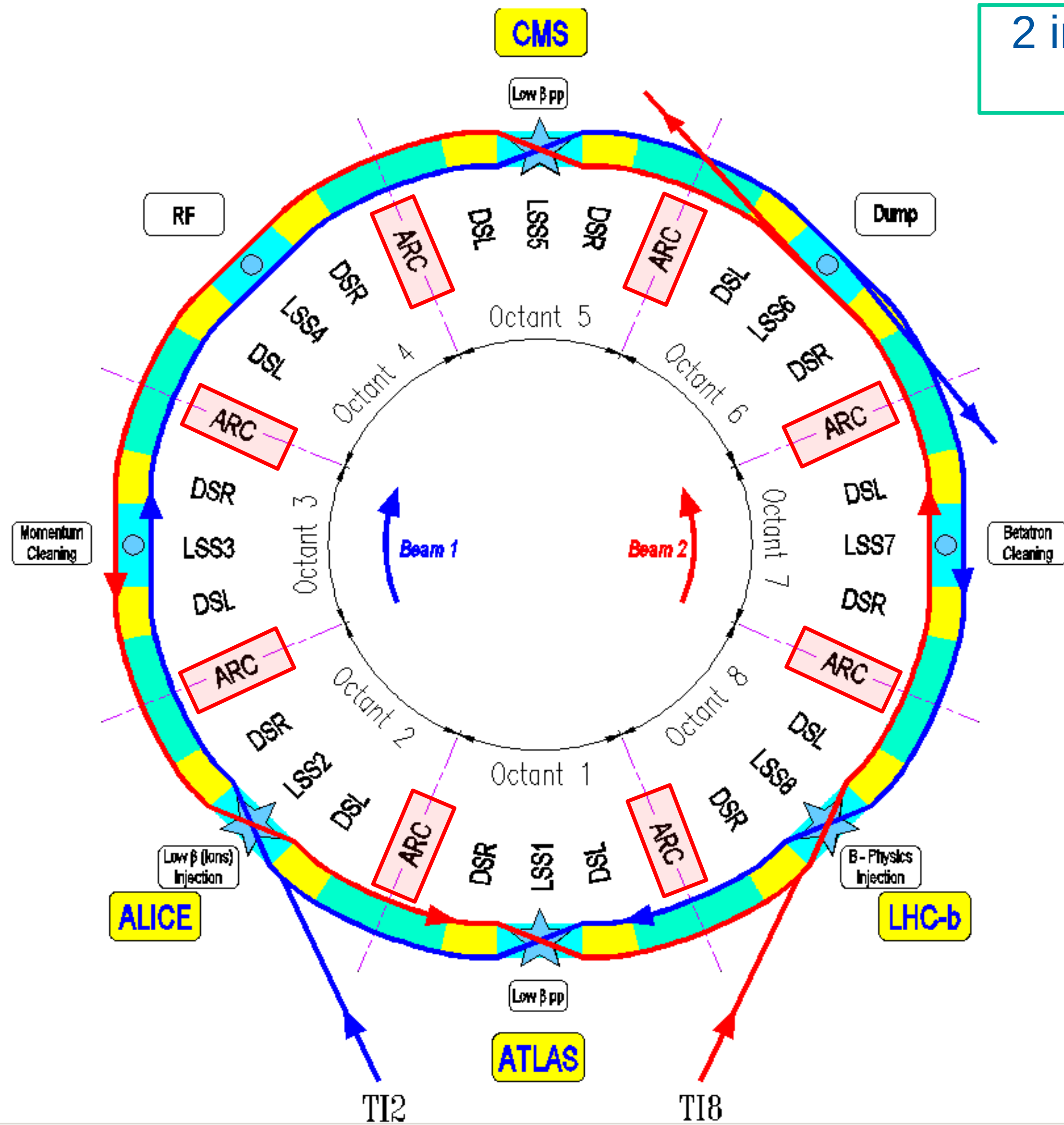
	H2_eq / m3	mbar
$\langle LSS_{1\ or\ 5} \rangle$	~ 5 10^{12}	10^{-10}
<ATLAS>	~ 10^{11}	10^{-11}
<CMS>	~ 5 10^{12}	10^{-10}

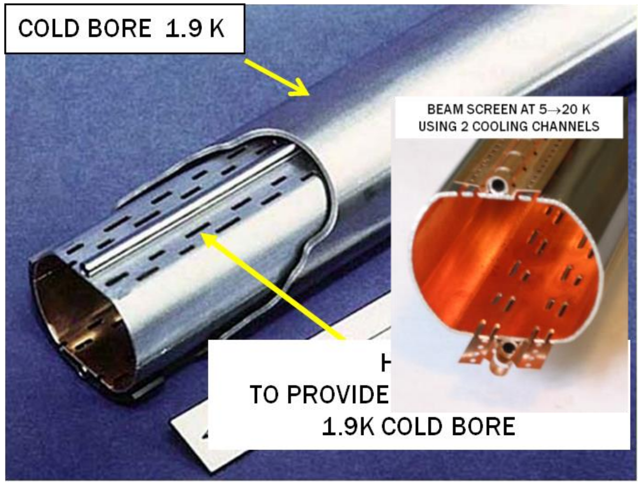
A. Rossi, CERN LHC PR 783, 2004.

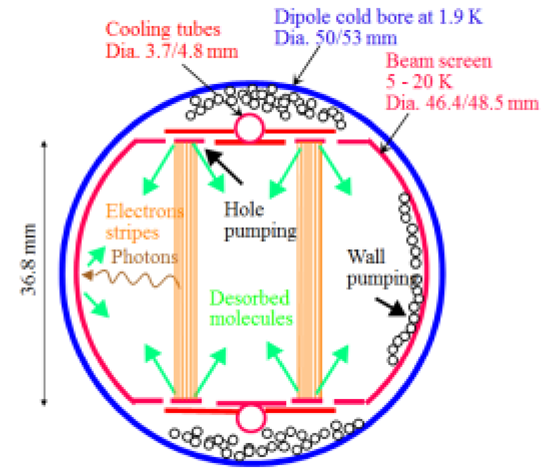
3.1 Système vide à température cryogénique

Cryogenic Beam Vacuum

2 independent beam pipes per arc:
8 arcs of 2.8 km each







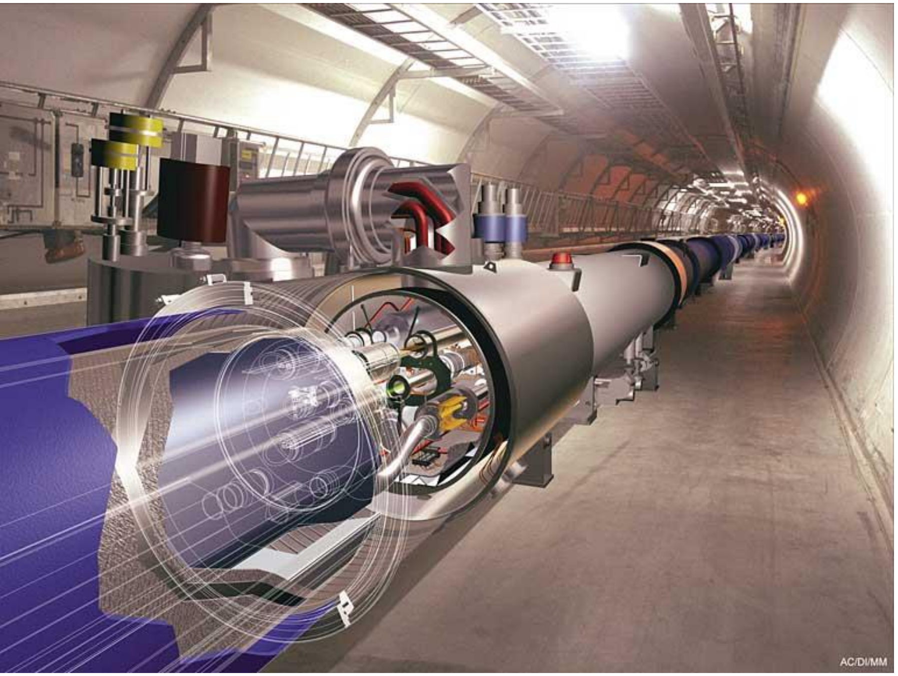
Arc : Some Numbers

Item	Total
Vacuum sectors (cryogenic)	16
Vacuum sector valves	32
Roughing valves (arc)	844
Ion pumps	0
Bayard Alpert gauges	0
Penning gauges (arc)	108
Pirani gauges	108

Item	Length (m)
Unbaked Arc @ cryo T	~ 45 000

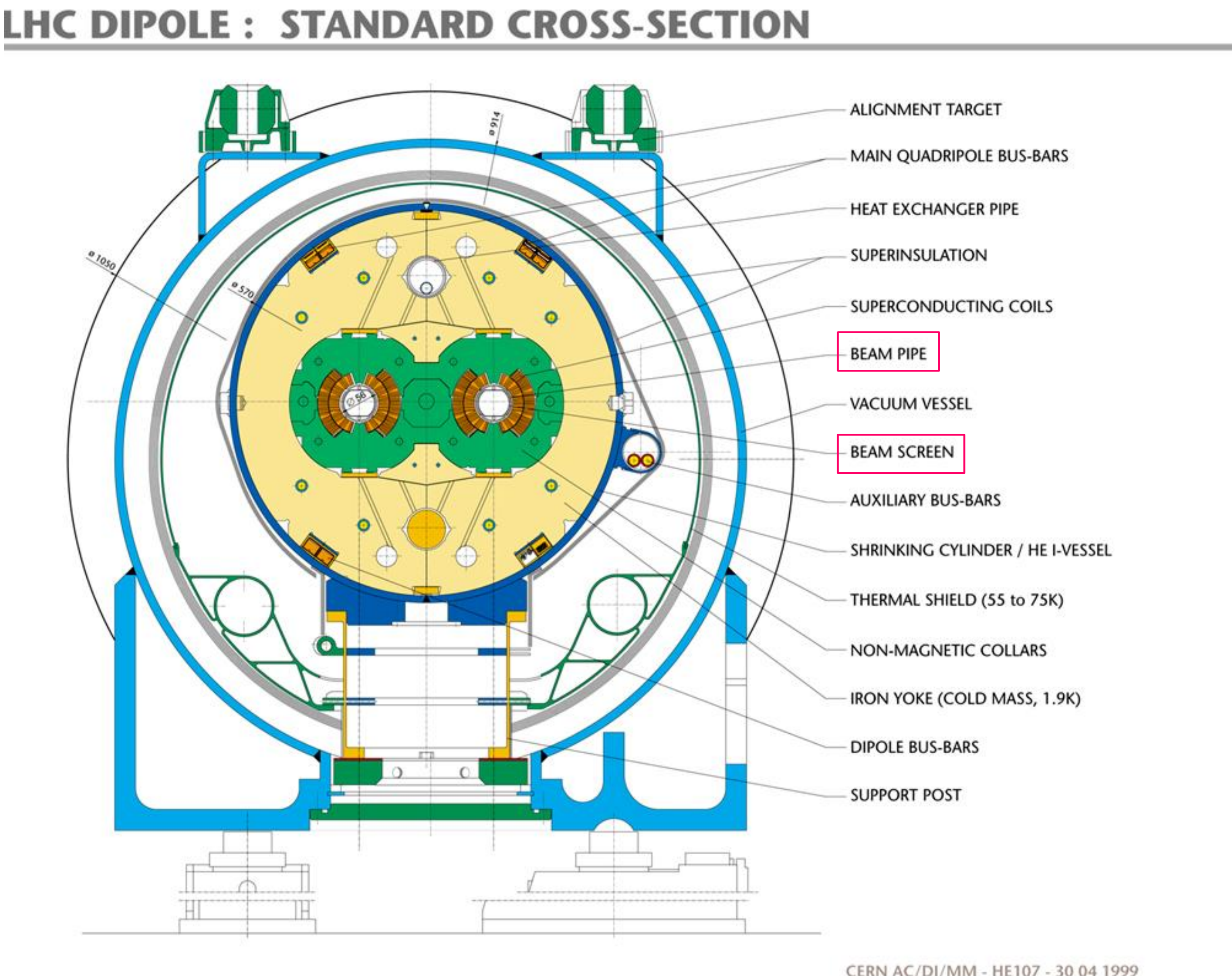
LHC : Superconducting Technology

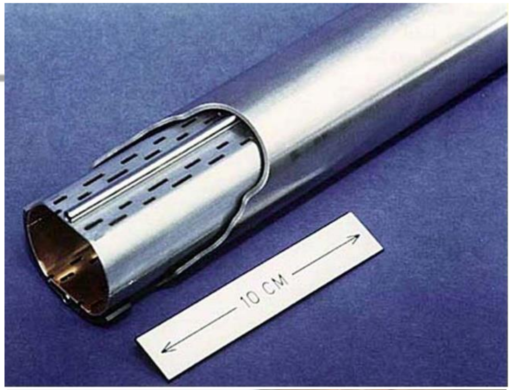
- Cryogenic vacuum system inside the arc
- A beam screen is housed inside the cold bore held at 1.9 K



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 and acts as a screen





Courtesy N. Kos CERN AT/VAC

LHC Vacuum System Principle

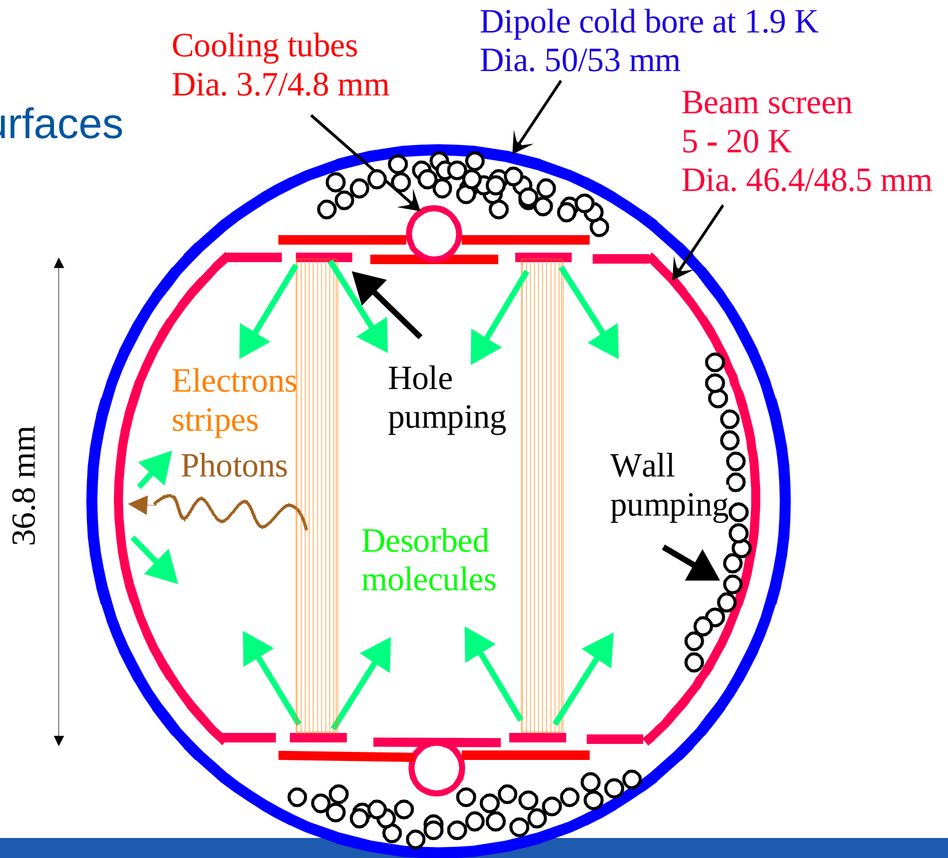
- Molecular desorption stimulated by photon, electron and ion bombardment
- Desorbed molecules are pumped on the beam vacuum chamber
- 100 h beam life time (nuclear scattering) equivalent to ~ 10^{15} H_2/m^3 (10^{-8} Torr H_2 at 300 K)

In cryogenic elements

- Molecular physisorption onto cryogenic surfaces (weak binding energy)

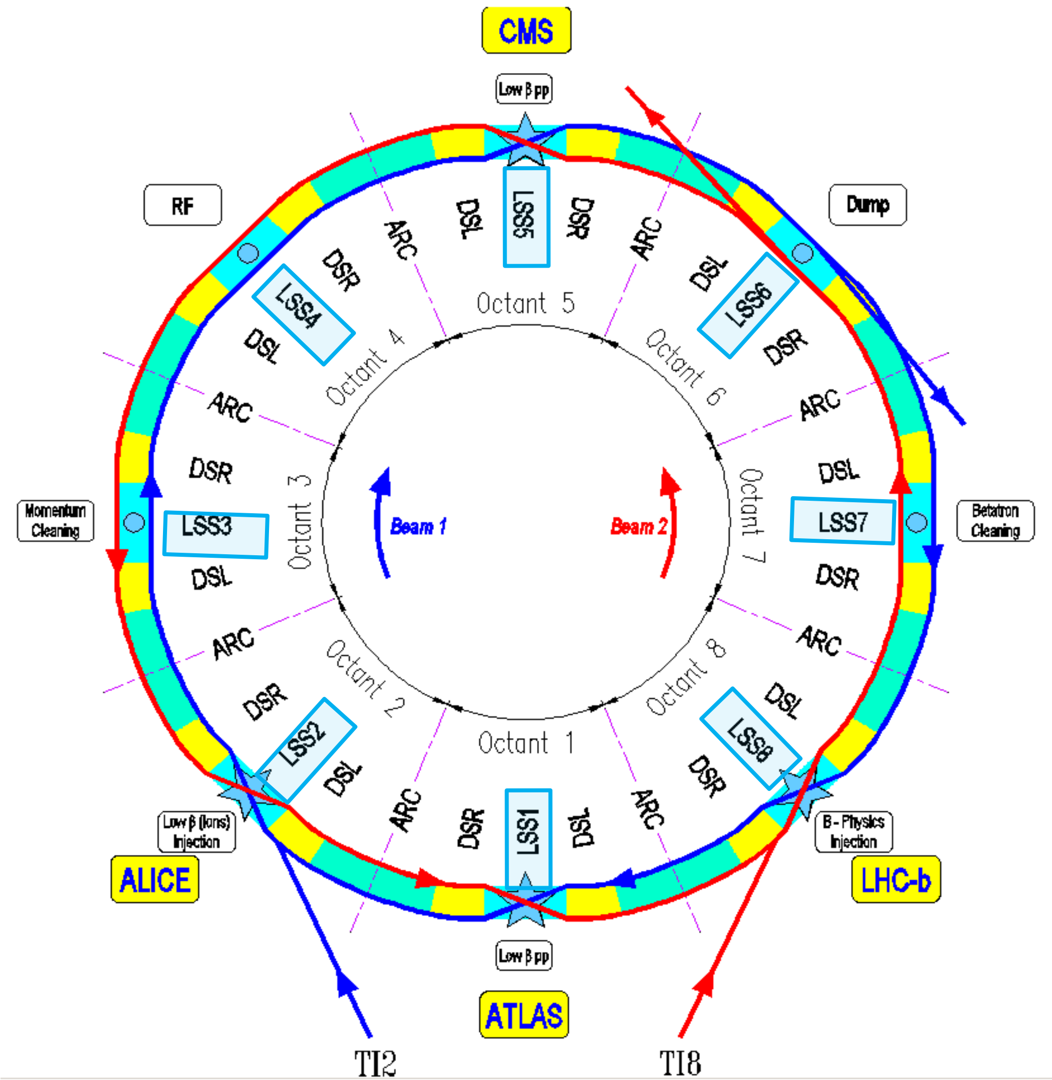
- Molecules with a low recycling yield are first physisorbed onto the beam screen (CH_4, H_2O, CO, CO_2) and then onto the cold bore

- H_2 is physisorbed onto the cold bore



2.2 Système vide à température ambiante

Room Temperature Beam Vacuum



6 km of RT beam vacuum in the long straight sections

Extensive use of NEG coatings

Pressure $<10^{-11}$ mbar after vacuum activation

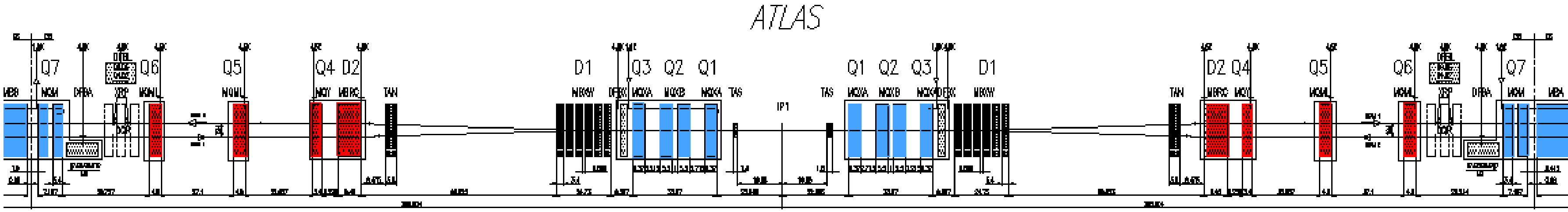
LSS: Some Numbers

Component	Total
Vacuum sectors (cryogenic / RT)	84 / 185
Vacuum sector valves (all LHC)	295
Roughing valves (LSS)	309
Ion pumps (special /30 / 60 / 400 l/s)	12 / 550/ 168 / 49
Bayard Alpert gauges (LSS)	178
Penning gauges (LSS)	502
Pirani gauges (LSS)	289

Item in LSS	Length (m)	% wrt to total
SAM @ cryo T	~ 1 365	19
LSS @ RT baked	~ 1 000	14
LSS @ RT with baked NEG	~ 4 800	67
Total length under vacuum	7 227	100

- ~ 85 % of the baked vacuum system is NEG coated

LHC Long Straight Section Vacuum System



- Focusing inner triplets located around experiments operate at 1.9 K
- Matching sections operate at 4.5 K

} Beam screens

- Other components operate at room temperature

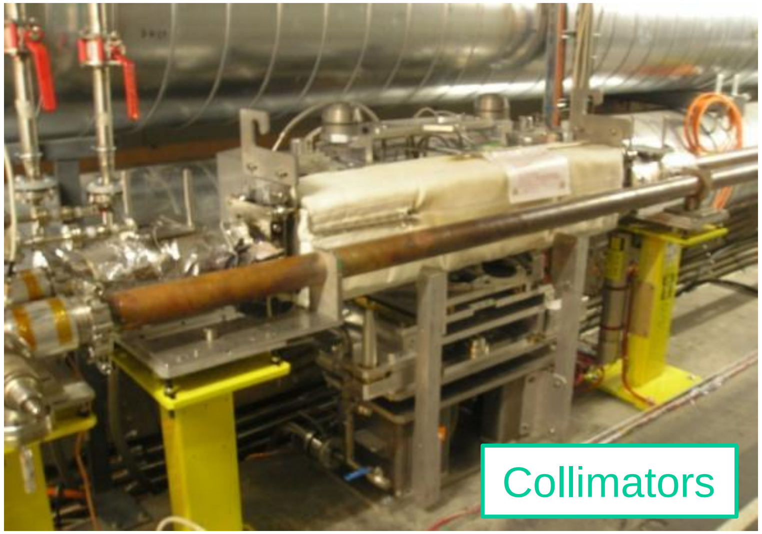
<u>"Combined" sector in both side of each experiment</u>
Both beams circulates in the same beam pipe

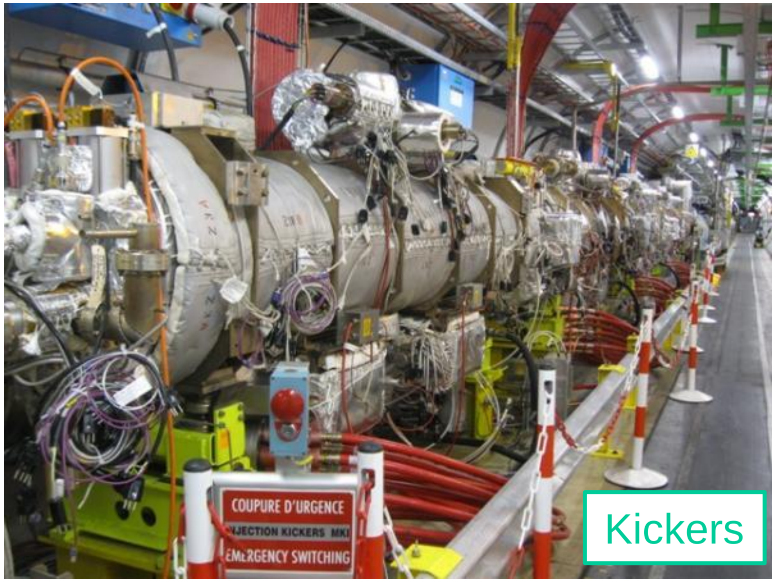
<u>"Twin" sector</u>
Beams circulate in different beam pipes

Standard Components Installed Inside LSS

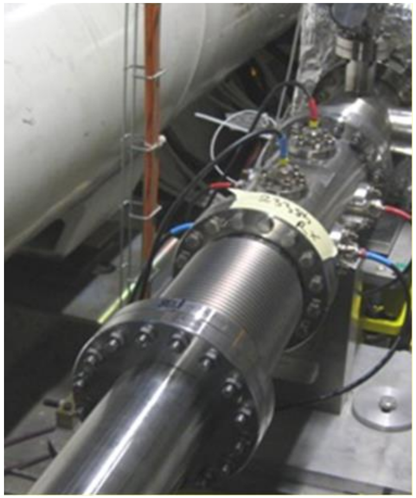
- Warm magnets, kickers, septum, collimators, beam instrumentation …


Warm magnets

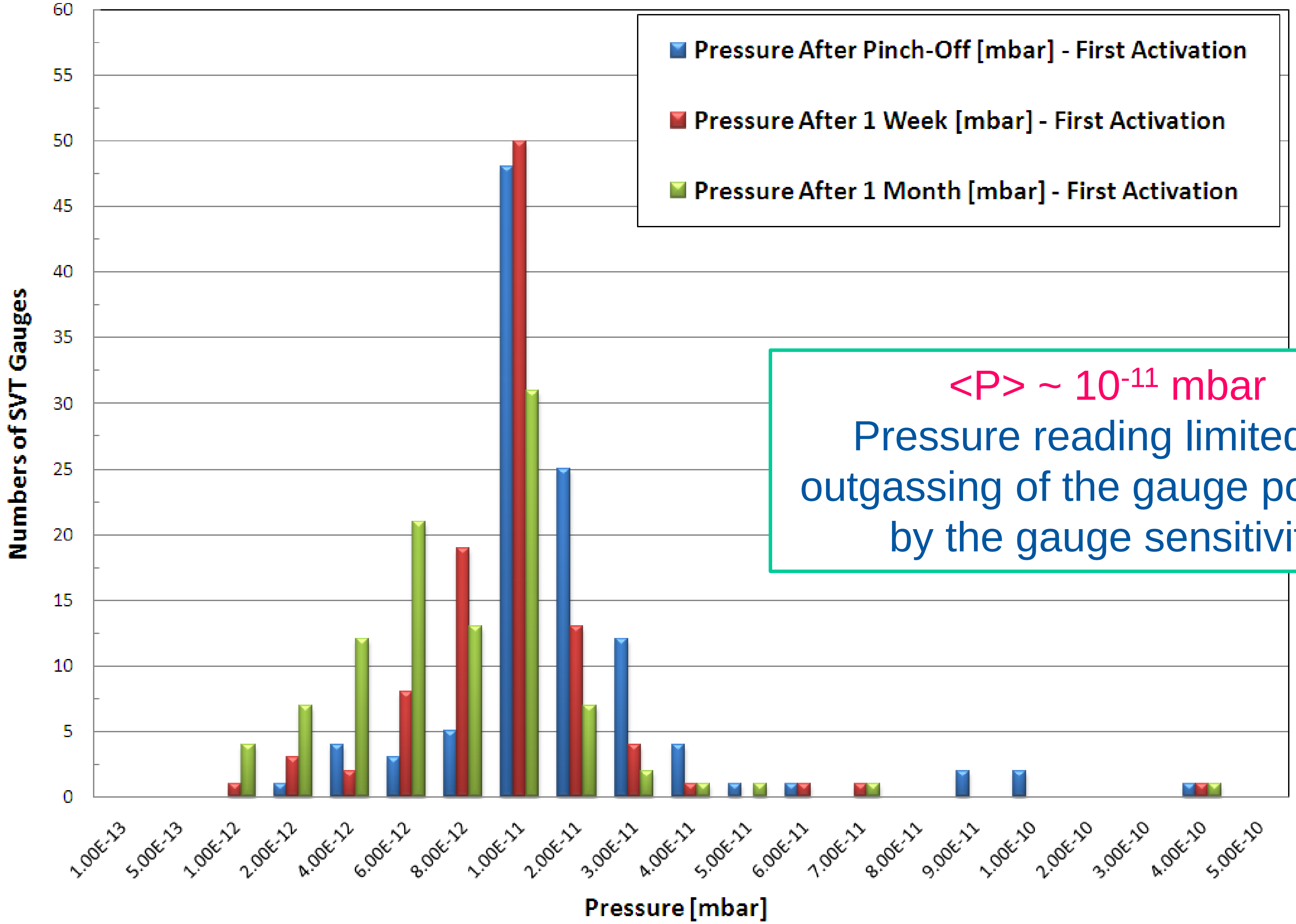

Collimators



Kickers


Beam Instrumentations

Performances of RT Vacuum Sectors

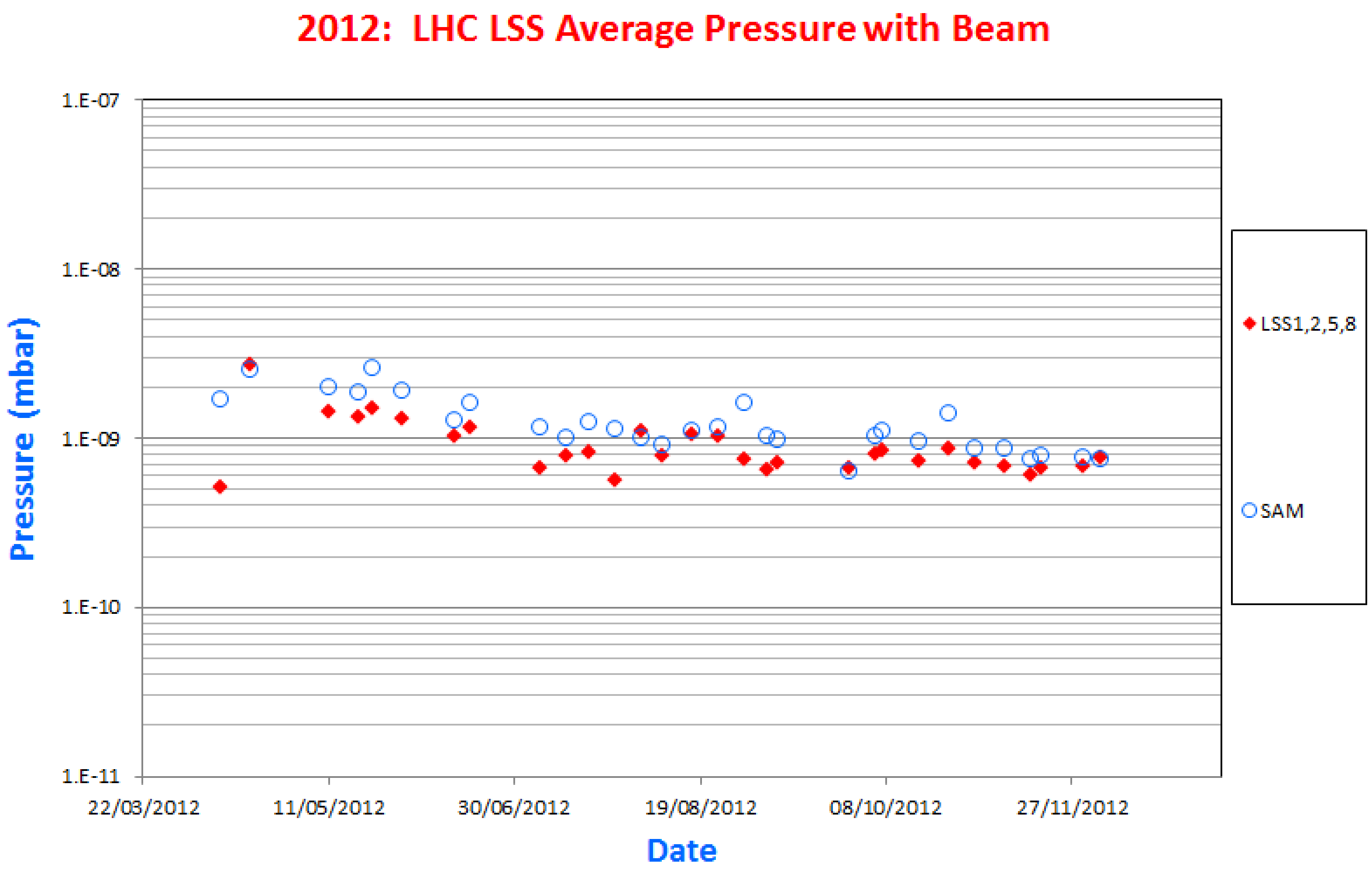


<P> ~ 10^{-11} mbar
Pressure reading limited by outgassing of the gauge port and by the gauge sensitivity

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

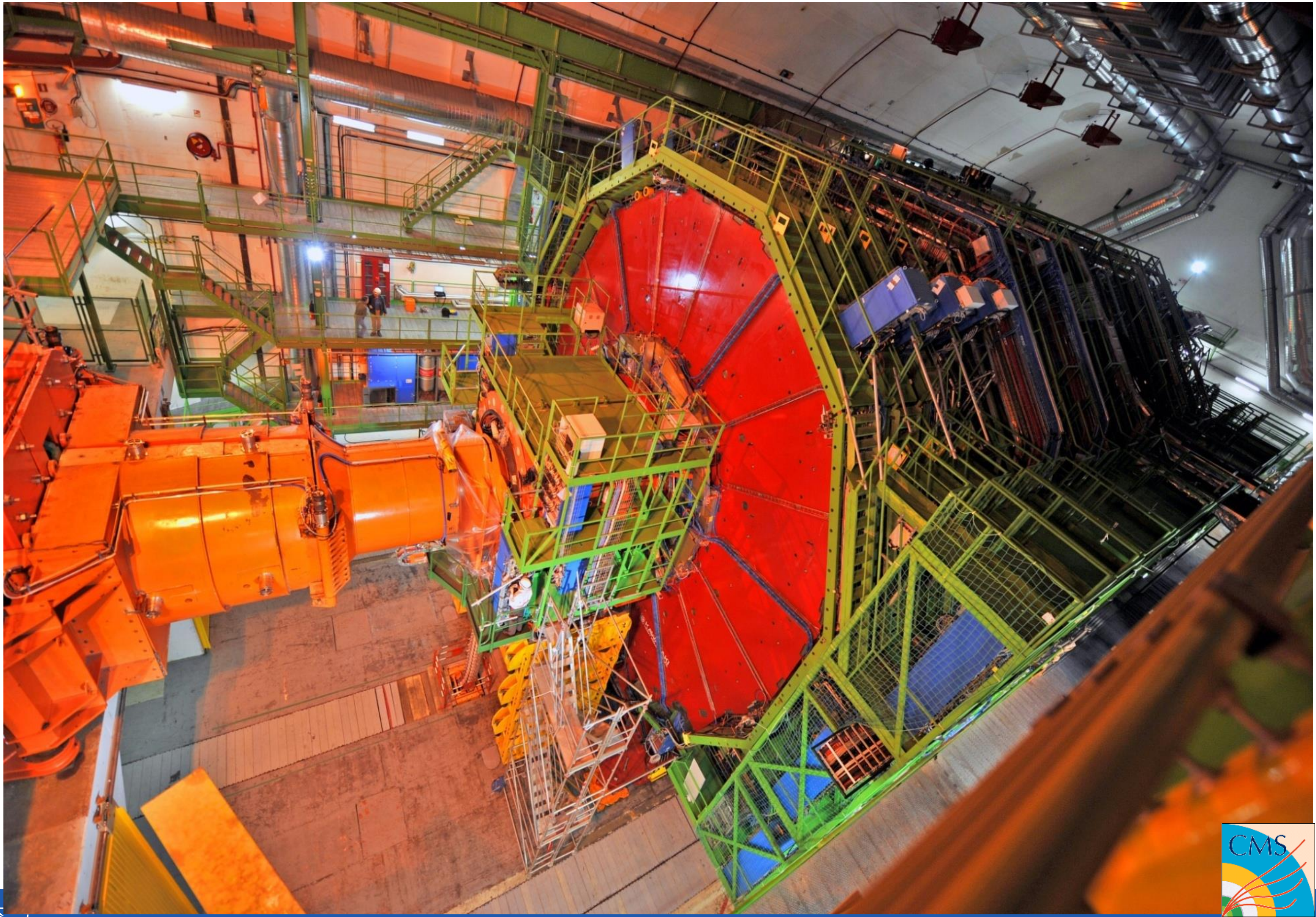
LSS: Performances with Beams

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



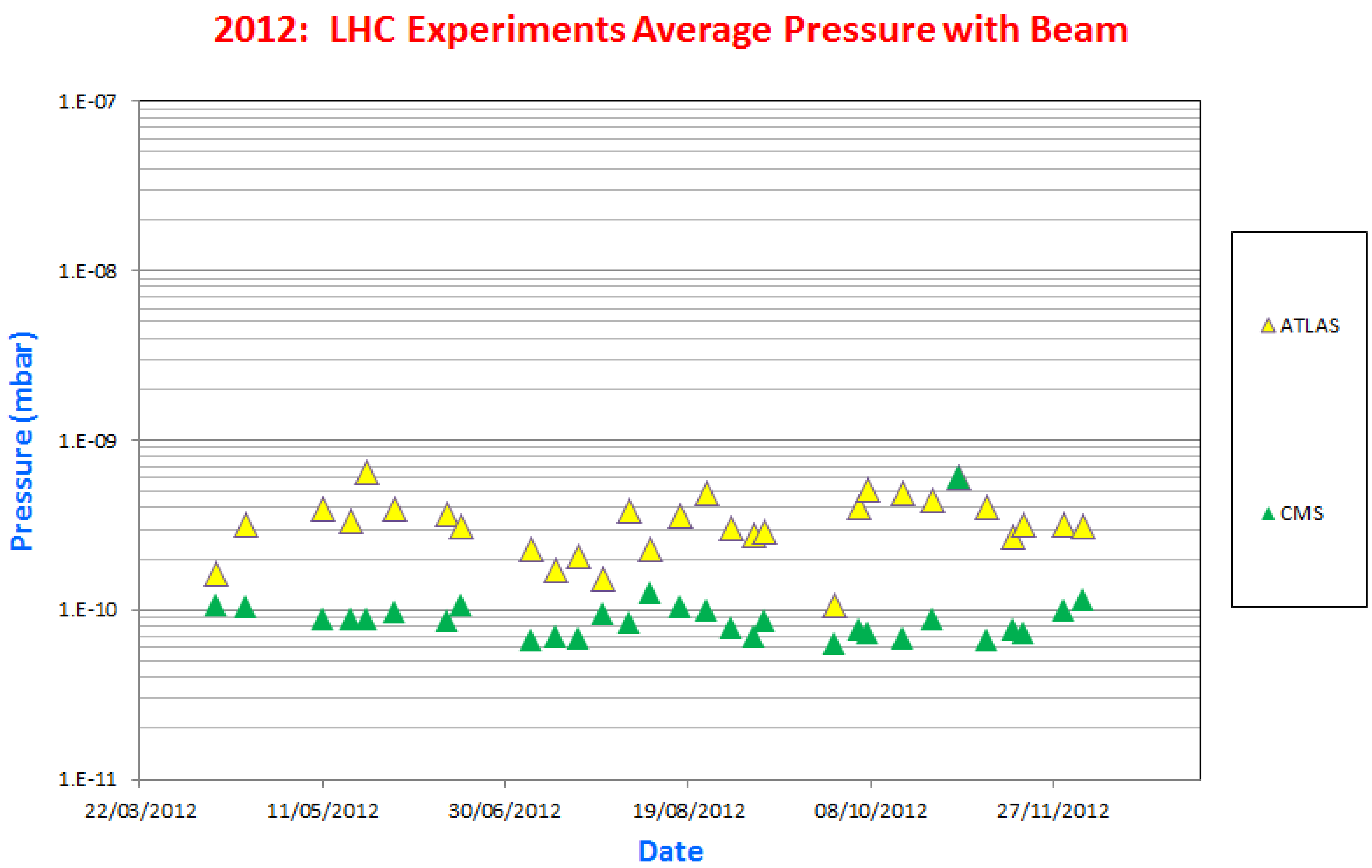
Beam Pipe Installation in ATLAS Before Closure

CMS Closed and Ready for Beam



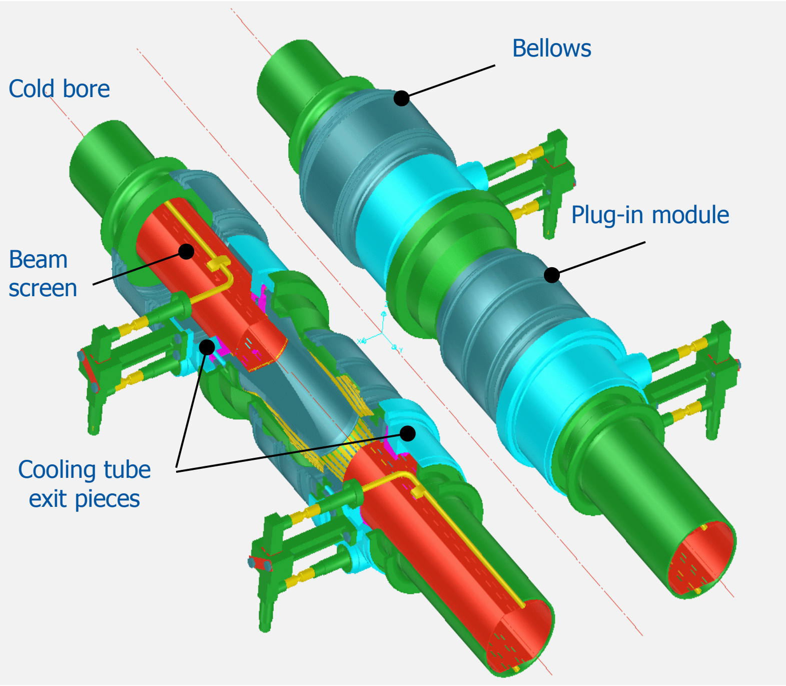
LHC Experiments: Performances with Beams

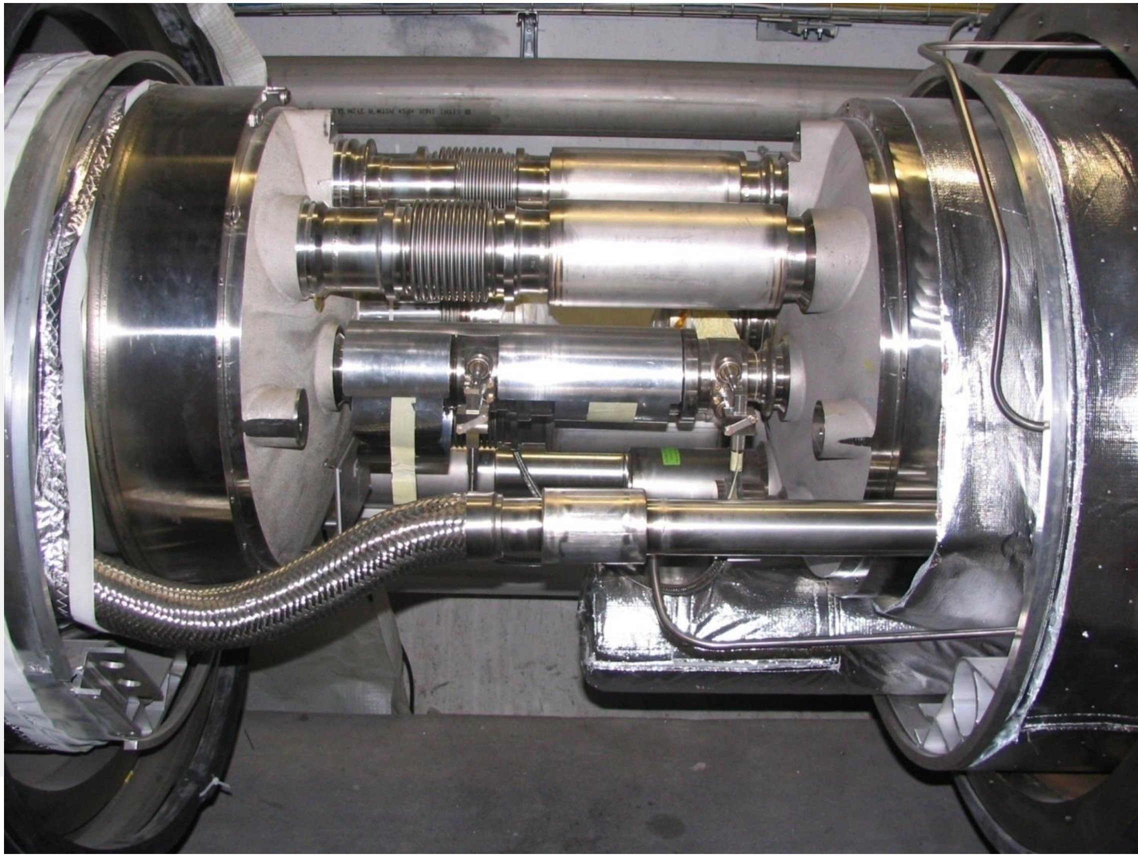
- Constant pressure during the year, here, dominated by extremities (VAX area)
- $<P_{exp}> \sim 2\ 10^{-10}$ mbar



3. Difficultés rencontrées pendant l'installation

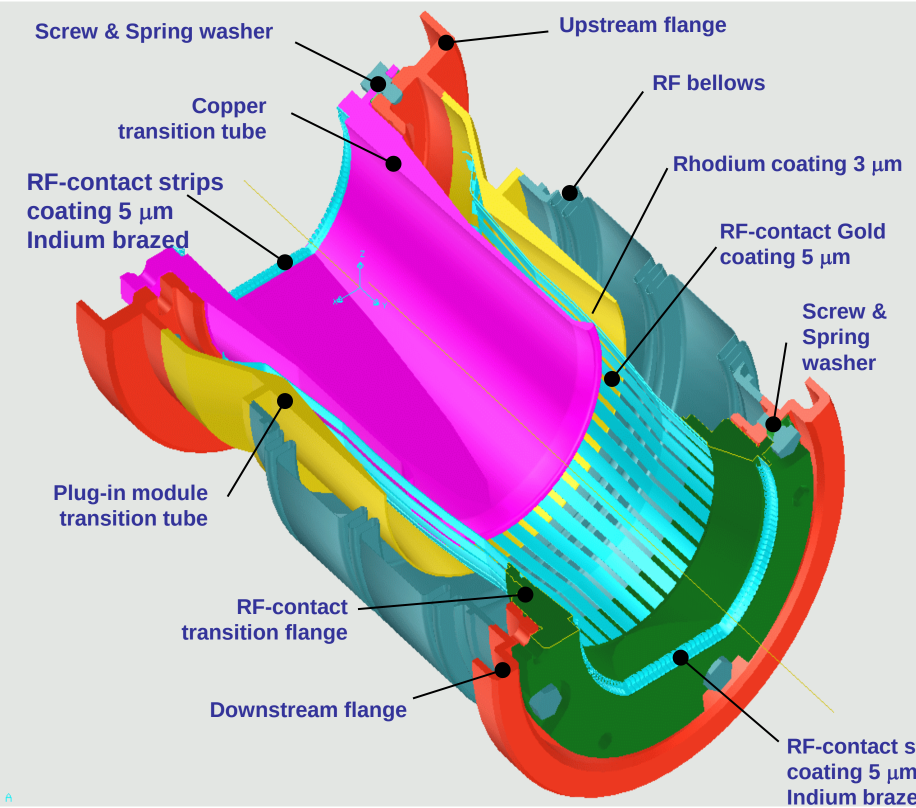
Dipole-Dipole Interconnection



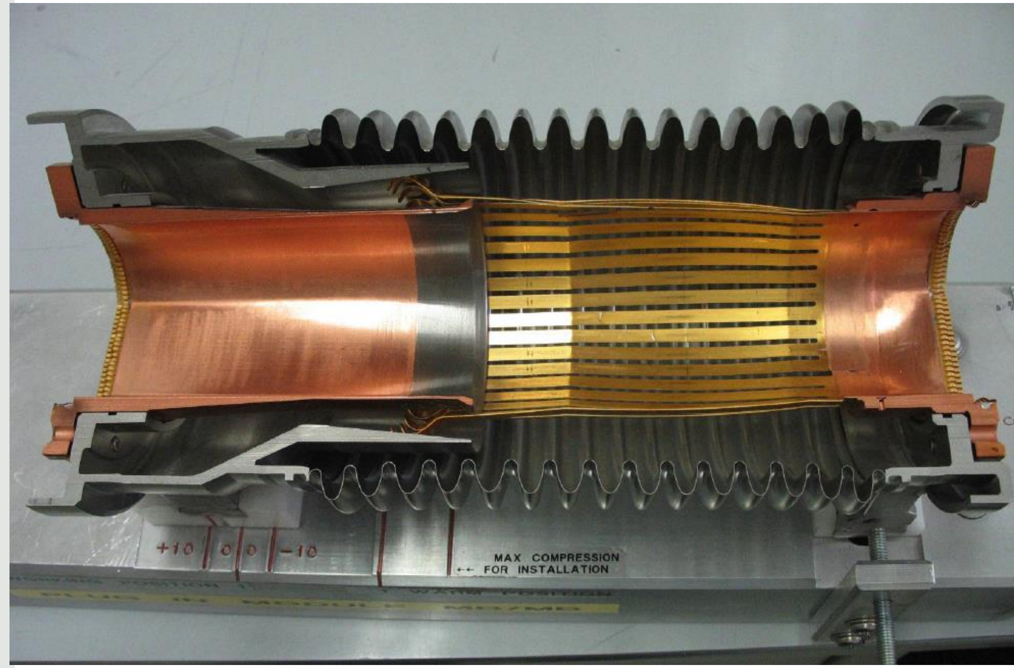


Plug-in Modules with RF Fingers

- Last installed component to interconnect superconducting magnets (~ 1 700 PIM)
- RF bridge made of sliding RF fingers (Au coated to avoid cold welding)
- < 0.1 mOhm contact resistance, Rh coatiing (i.e. 3 mOhm/RF finger)



Room temperature position



Courtesy R. Veness

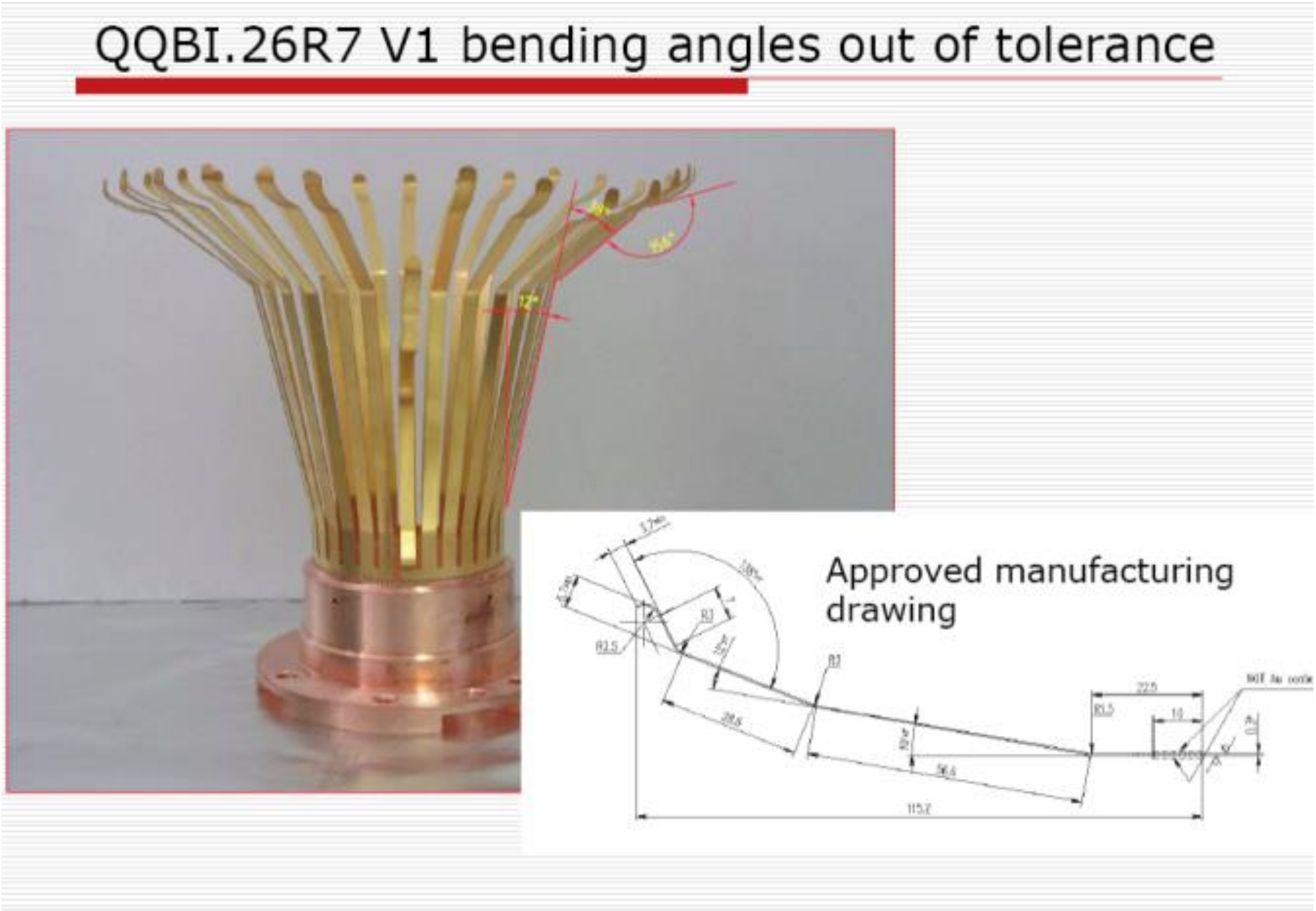
Working position at cryogenic temperature

August 2007

- After warm-up of sector 7-8
  - A buckled PIM was discovered in interconnect QQBI.26.R7
  - Was really found by chance!

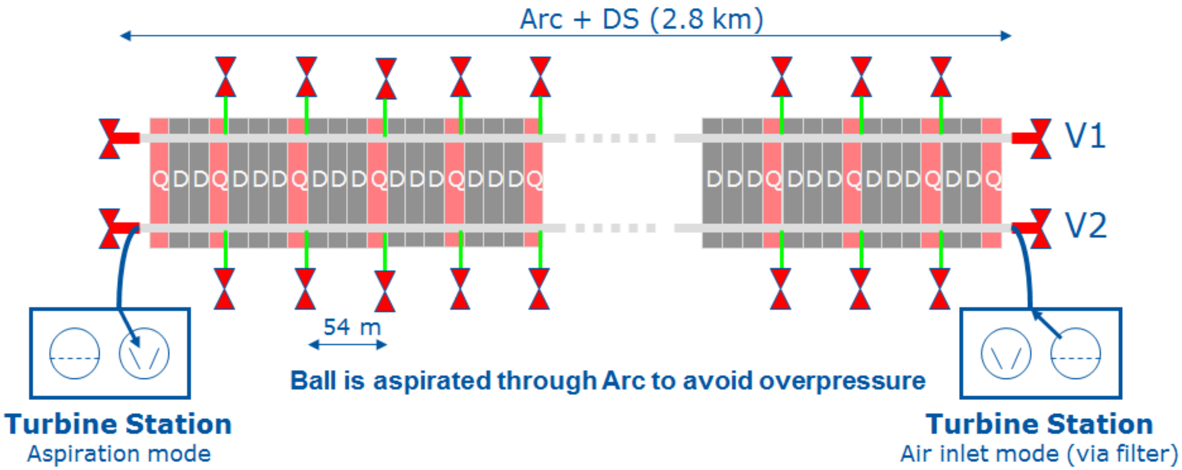
Why buckling ?

- Non conformity during manufacturing
- Not properly documented => Lesson: respect of Quality Assurance is a MUST

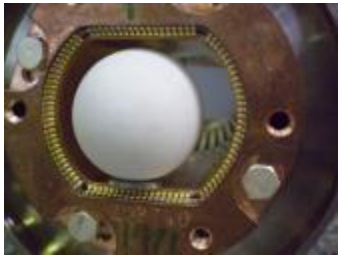


The consequence: RF ball emitter

- Identification of critical PIM :
  - Repair / consolidation when possible
  - ~ 1 mm longitudinal shift of quadrupole to gain margin
- Maintain arc below 130 K during stand-by period
- Recurrent observation after each warm up of arc with:
  - RF ball
  - Tomography
  - Endoscopes



RF ball



RF ball inside PIM

A buckled PIM

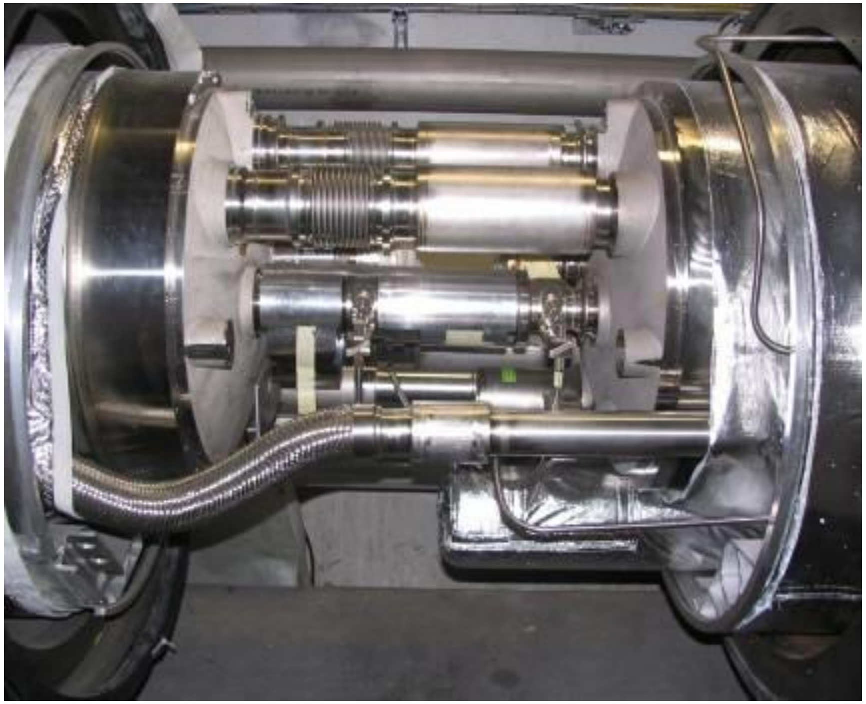
The Sector 3-4 incident (just before the 1st ramp)

19th September 2008 at 11:18.36

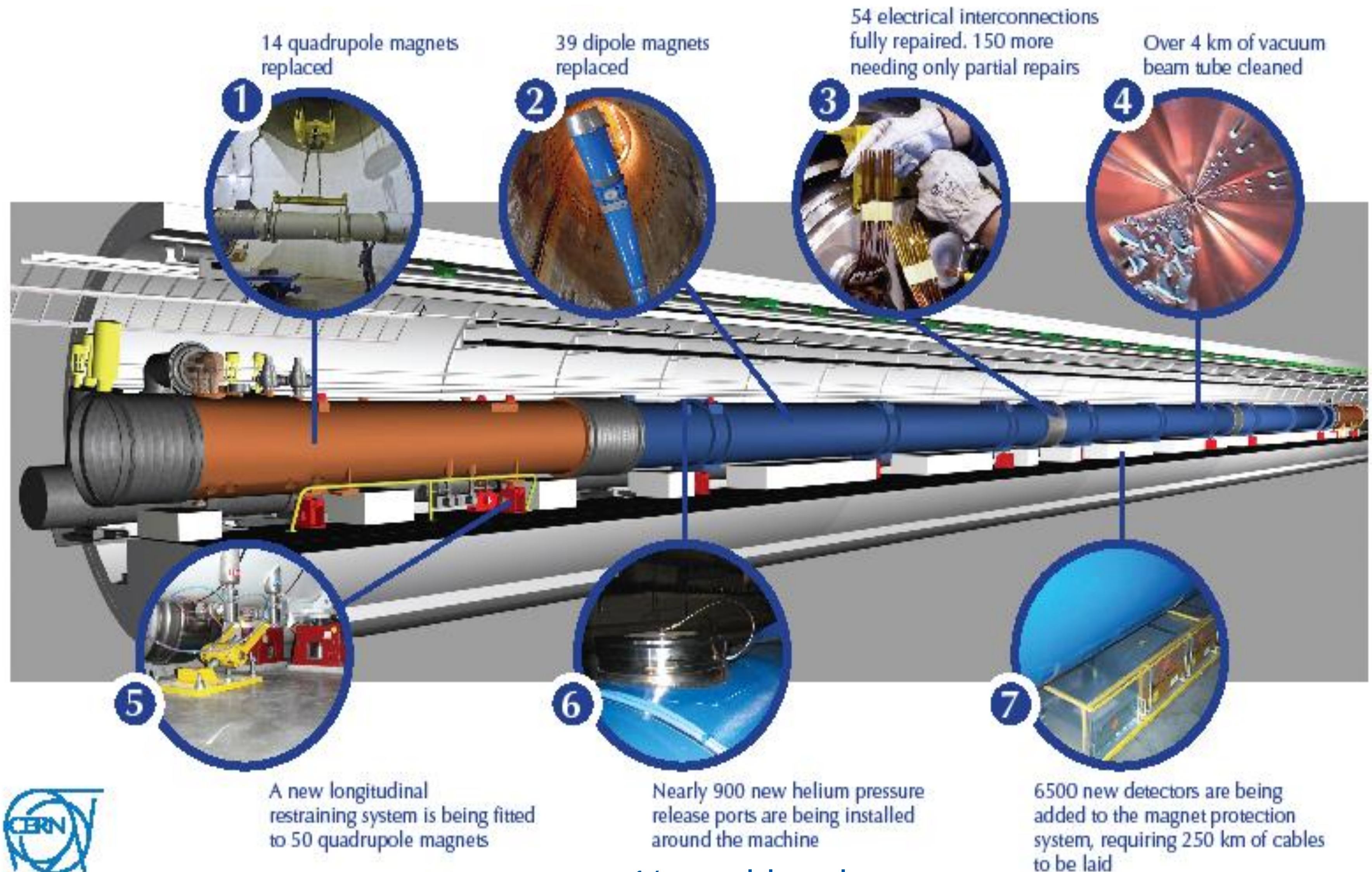
last test of the last sector: 7kA (4TeV) towards 9.3 kA (5TeV)

Electrical arc at 8.7 kA in the interconnection

Rupture of bellows, expansion of liquid Helium with superinsulation debris



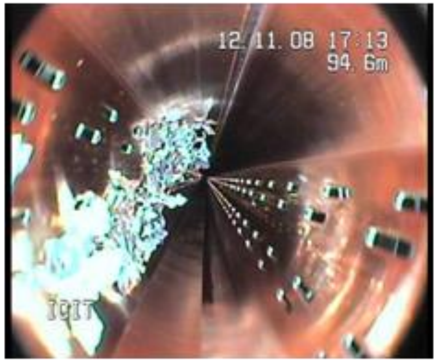
The LHC repairs in detail



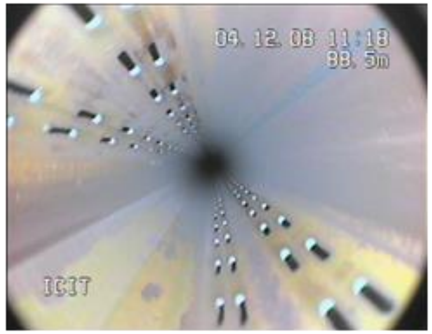
½ machine done

Beam Vacuum Recovery

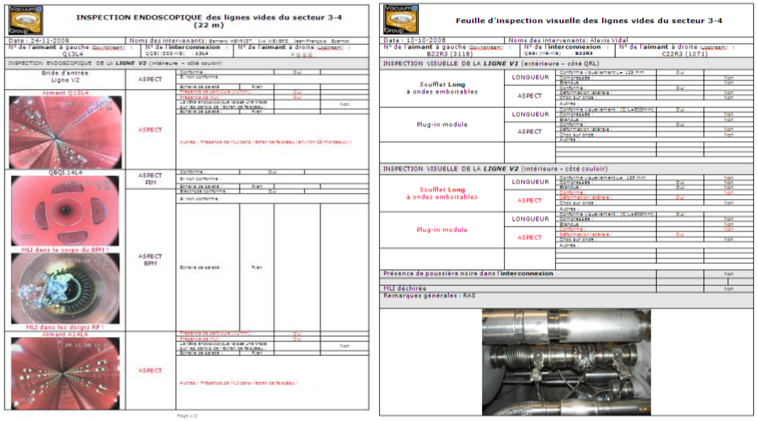
- Following S34 incident, 6 km of vacuum chambers where cleaned during 6 months



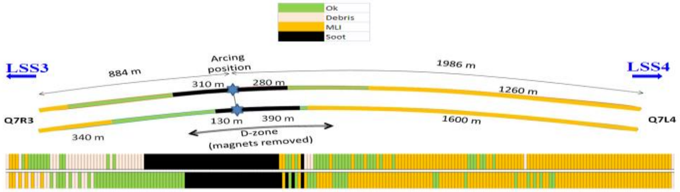
Example of A10L4.V2 beam screen polluted with super insulation debris



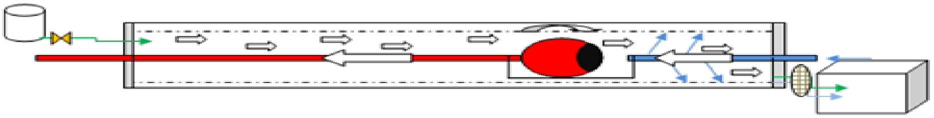
Example of Q19R3.V2 beam screen polluted with soot.



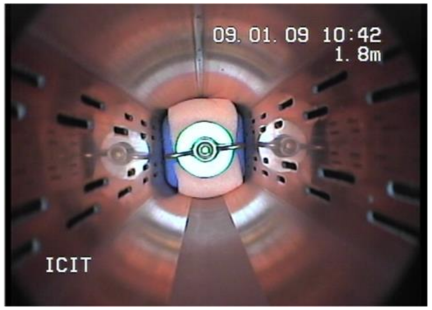
Examples of endoscopy and interconnection reports.



Debris distribution along sector 3-4.



Nozzle and endoscope inserted in a beam aperture subjected to automatic pumping/venting cycles

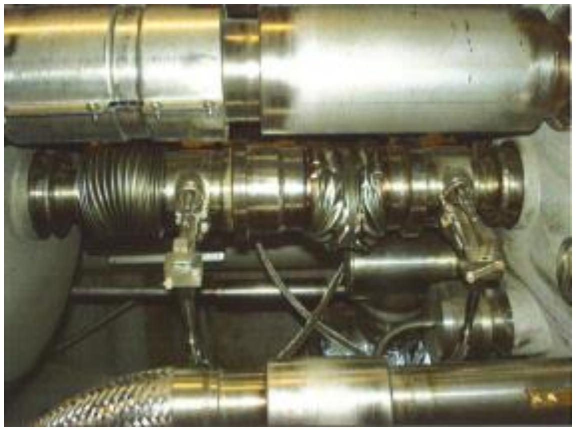


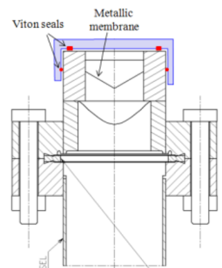
The cleaning with a dry foam-plug.

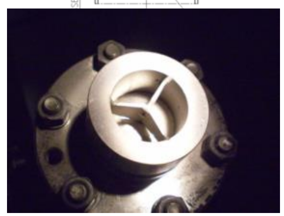
V. Baglin, EPAC 2010

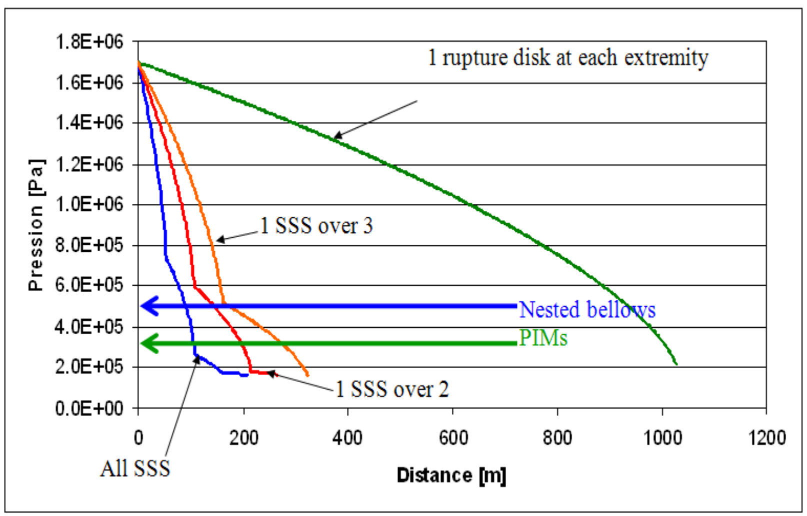
The Lesson: Arc Beam Vacuum Consolidation

- ~ 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









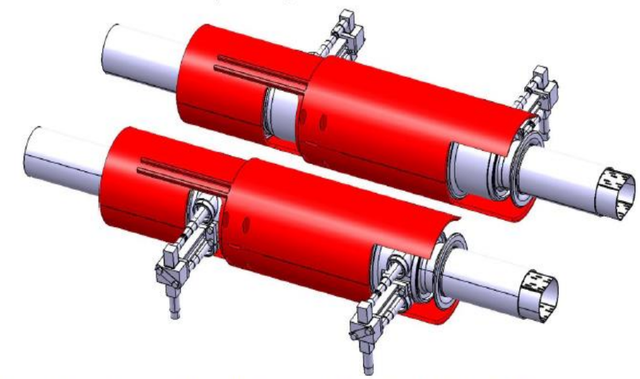
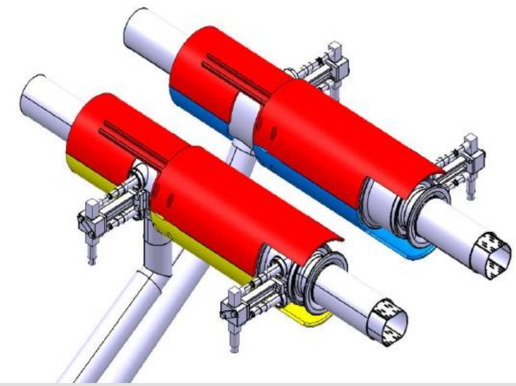


Fig. 1 Protective half shells for the MB-MB or MB-SSS interconnections

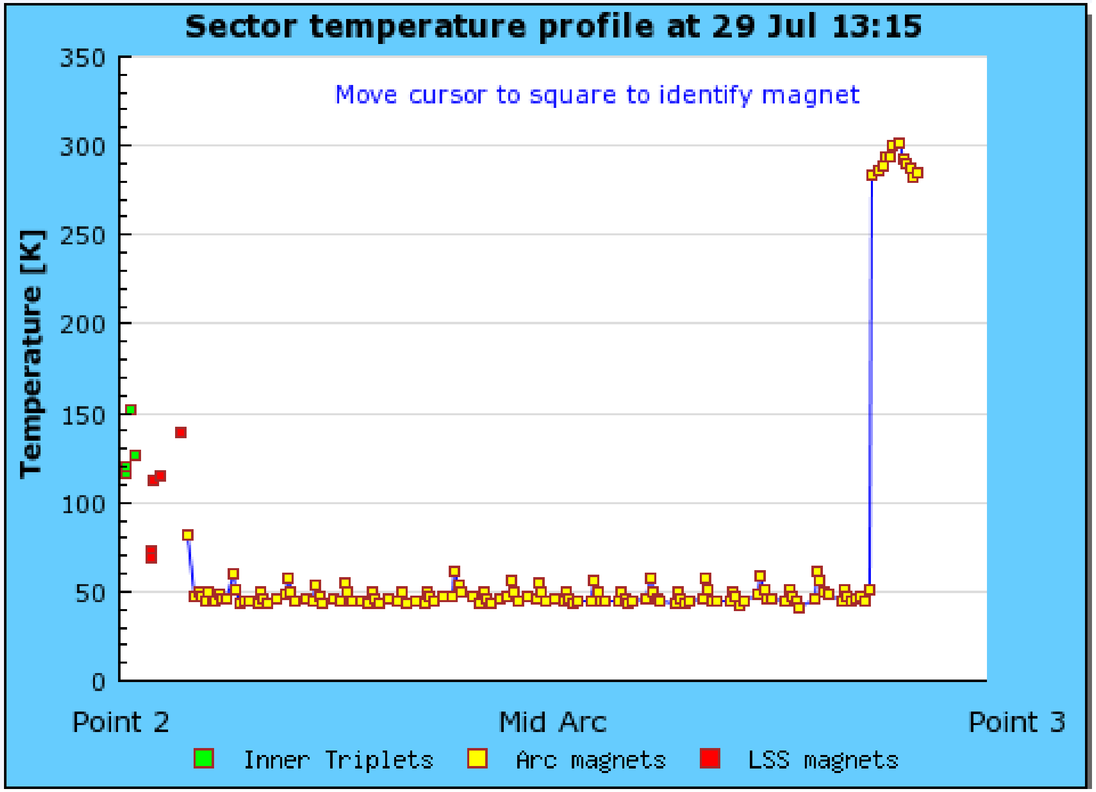


Protective half-shells for cryomagnet interconnections

Courtesy C. Garion

Cooling Pipe Repair with Arc at Cryogenic Temperature

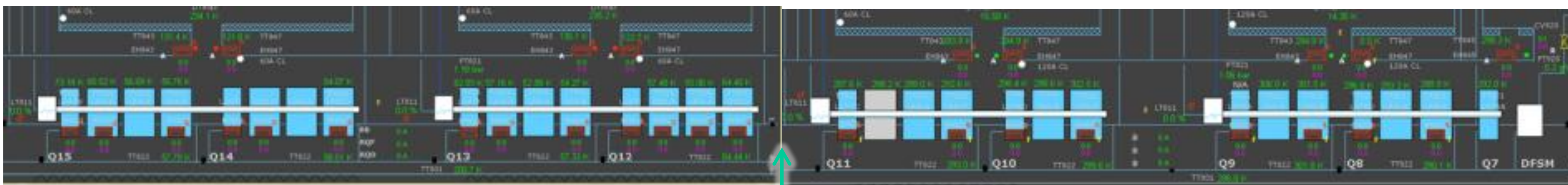
- S23 – July 2009
  - A He leak of ~0.3 mbar.l/s appeared in insulation vacuum sector VACSEC A7L4.M the 11th of July.
  - This sector starts at Q7L3 and finishes at the vacuum barrier at Q11L3
  - A partial warm up to 300 K of the arc was decided to repair the leak



Faulty cooling circuit
Located in distribution feedbox DFBA

Cooling Pipe Repair with Arc at Cryogenic Temperature

- S23 – July 2009
  - The PIM located between A12L3 and Q11L3 will be subjected to a gradient of temperature with a high risk of buckling. The PIM's name is QBQI.12L3
  - The other PIMs between Q11L3 and Q7L3 will be at room temperature
  - The remaining arc's PIMs will have their temperature increasing from 50 to 120 K during the intervention.
  - After repair of the DFBA's cooling pipe endoscopic inspection of QBQI.12L3 PIMs is required to check its conformity.
  - Beam vacuum was vented with Neon and then the PIM located in QQBI.9L3 was cut to allow the endoscopy.



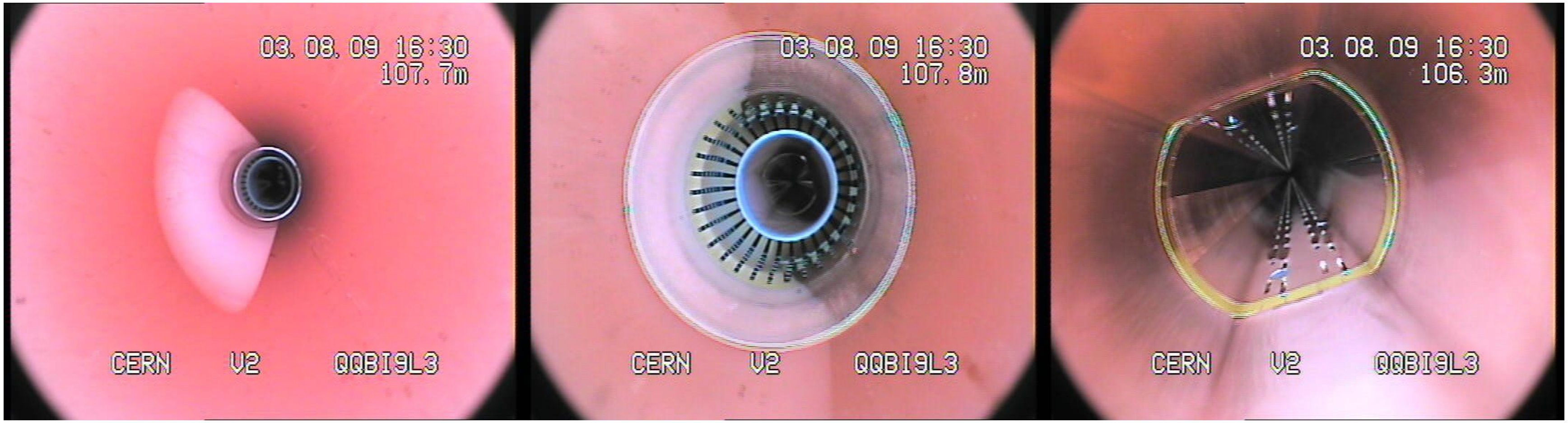
Rest of the arc with cells at 60 K

PIM QBQI.12L3

Cells at 300 K

Cooling Pipe Repair with Arc at Cryogenic Temperature

- S23– July 2009
  - Endoscopy result : all PIMs from Q7 till QBQI.12L3 were conform: Great !
  - But we forgot to inject ultra-pure Neon, we injected only 99.999 % Neon:
    - Result ~ 250 Torr.l of impurities were injected in the arc during venting as shown by the ice

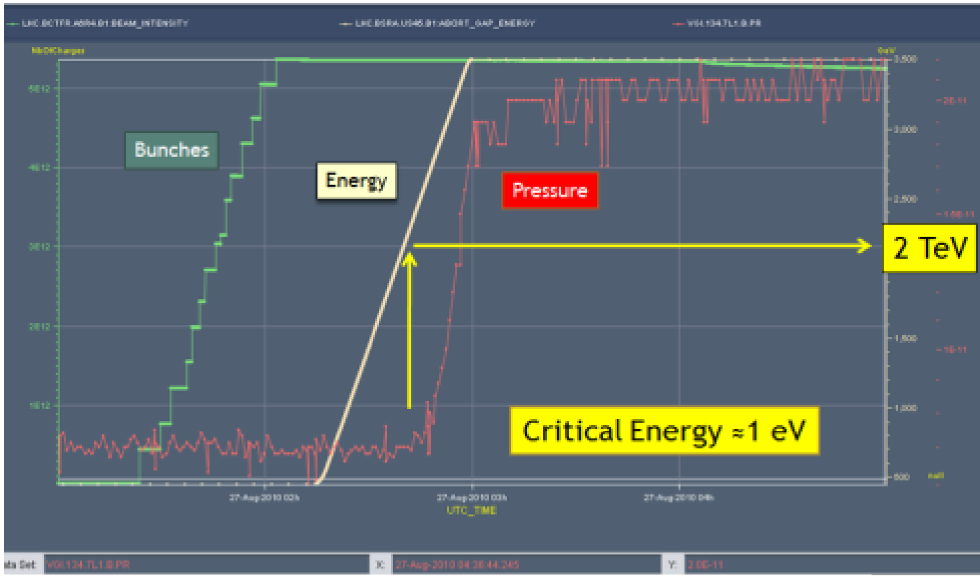


- We kept nevertheless the arc cold and observed a nice gas released during the next warm up of the arc !
- Fortunately, during those time, LHC was not operating with large current !
- Lesson : you need also a bit of luck !
- NB: a similar repair was done in S81 which was vented with ultrapure Ne.

4. Démarrage du système vide faisceau

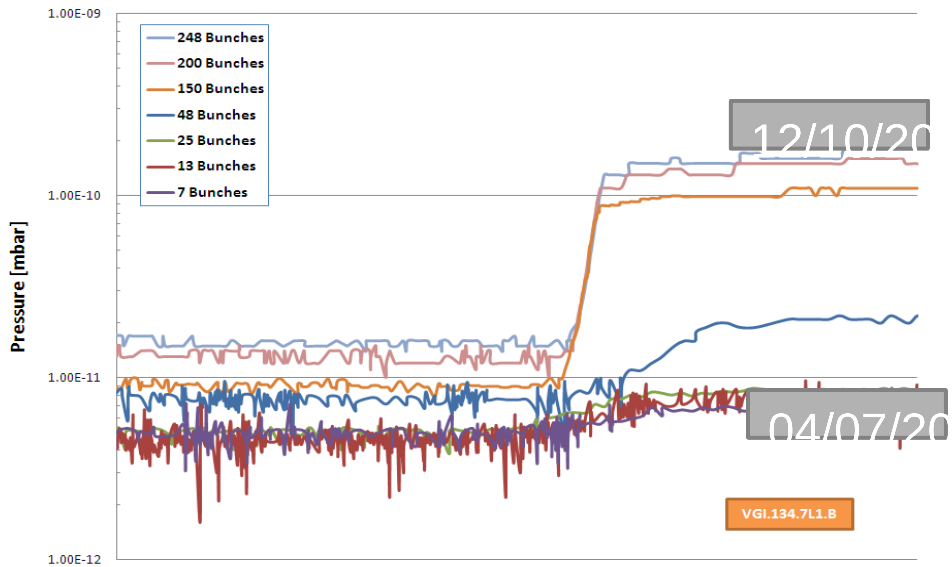
4.1 Photodesorption moléculaire: comme attendu

First Observation of Synchrotron Radiation: Aug-2010



- Pressure rise during the beam energy ramp

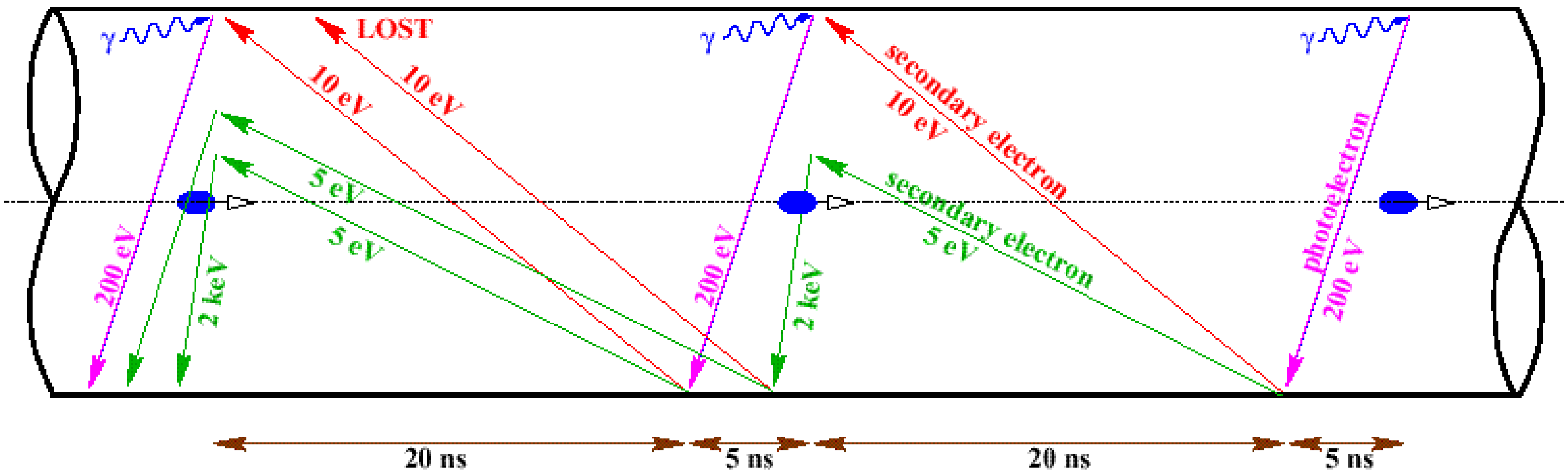
- Dynamic pressure increases with beam current
- DeltaP = 2 10^{-10} mbar



4.2 Nuage d'électron:

comme attendu

Mecanism in LHC



Schematic of electron-cloud build up in the LHC beam pipe.

F. Ruggiero *et al.*, LHC Project Report 188 1998, EPAC 98

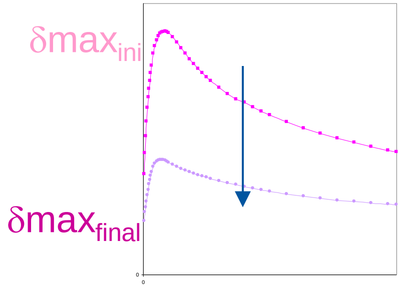
- Key parameters:
  - beam structure
  - bunch current
  - vacuum chamber dimension
  - secondary electron yield
  - photoelectron yield
  - electron and photon reflectivities

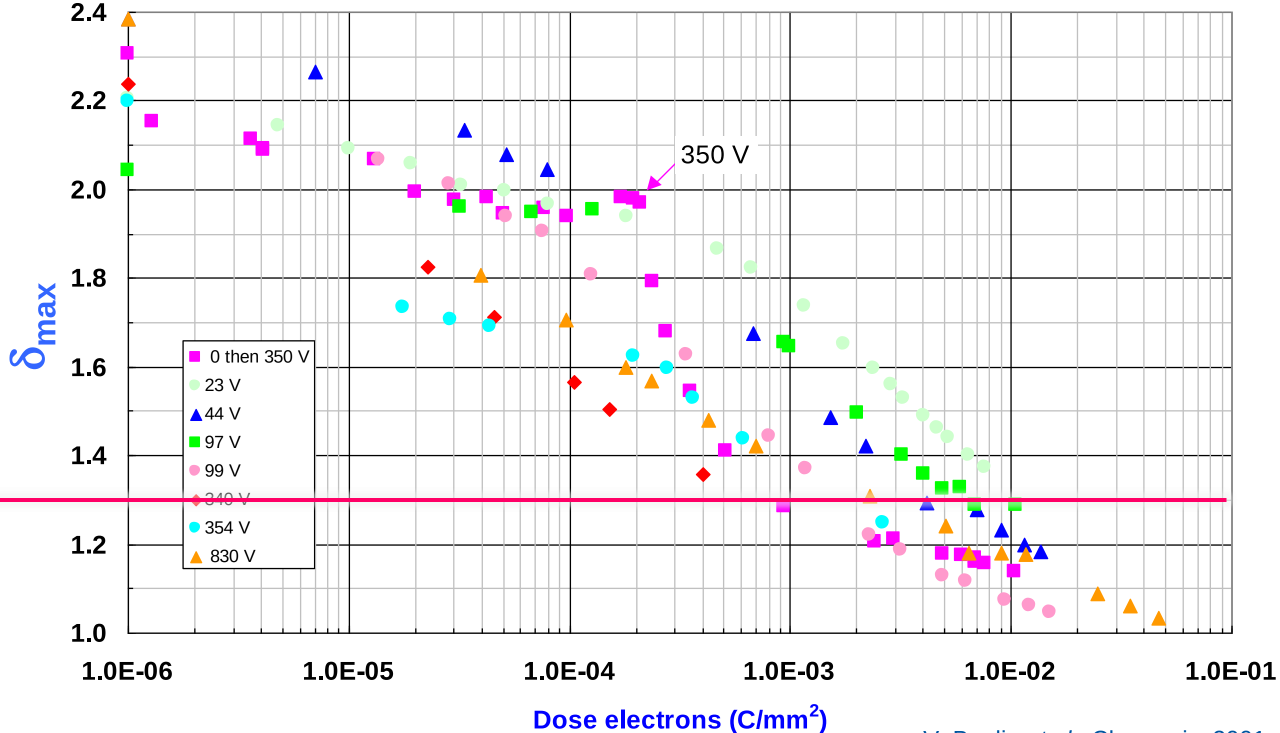
  …

$$P = \frac{Q + \eta_{Electrons}\dot{\Gamma}_{Electrons}}{S}$$

LHC : Scrubbing of the Surface

- Photoelectrons produced by SR are accelerated towards the test sample
- Reduction of SEY under electron irradiation is observed
- 1 to 10 mC/mm² is required
- Growth of a carbon layer (AES, XPS)



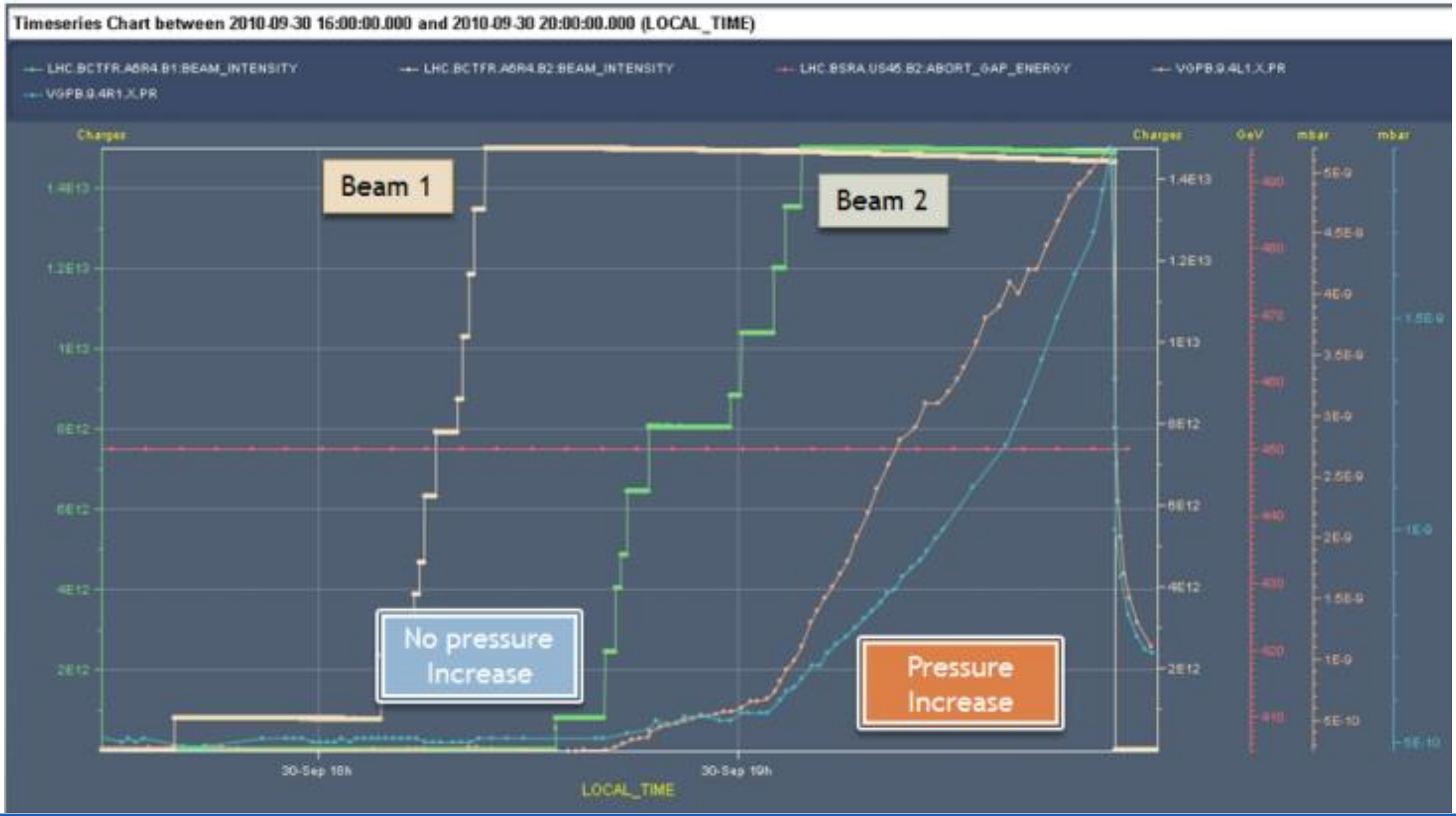


LHC design: δmax ~ 1.2

V. Baglin *et al.*, Chamonix, 2001

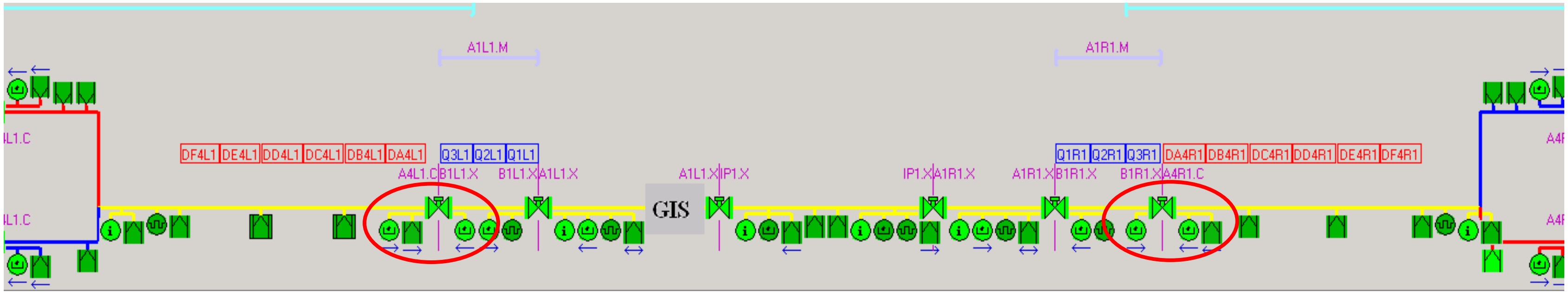
First Observation of Electron Cloud : 29-9-2010

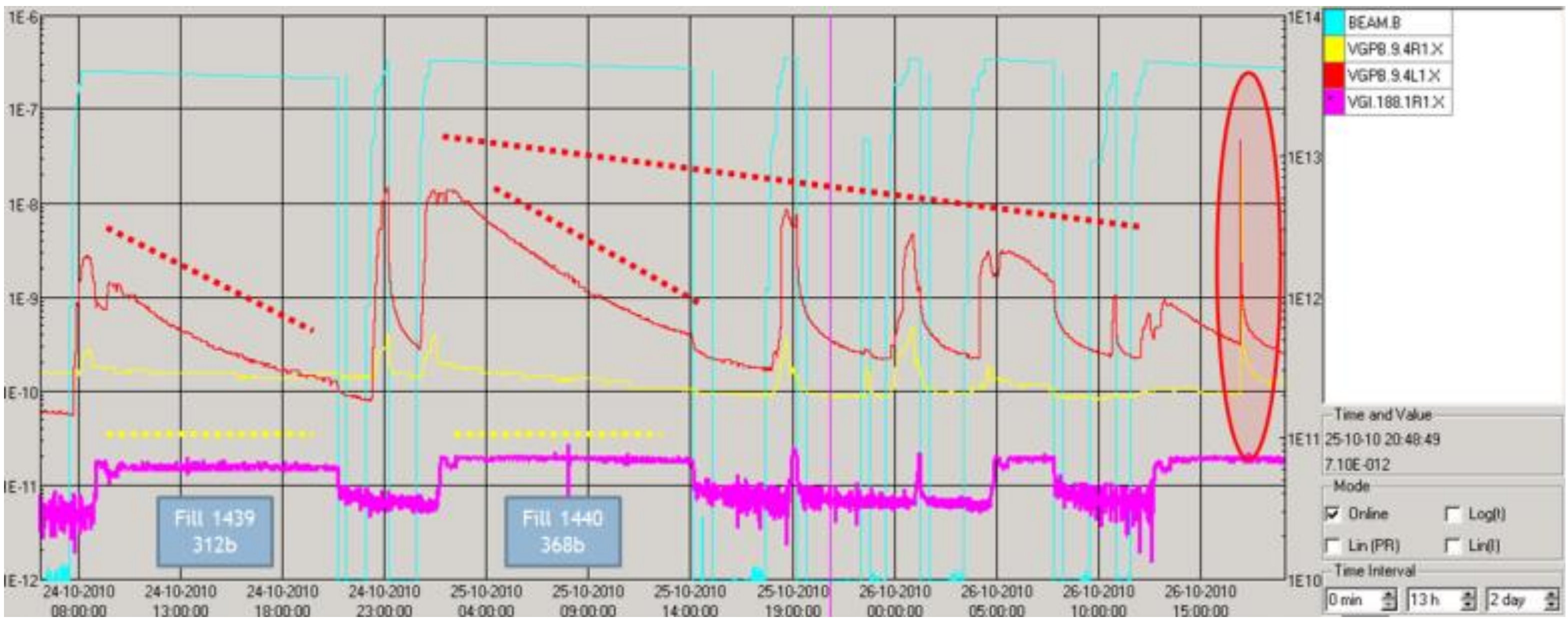
- After first successful injections of bunch trains (22/9), pressure rise appeared rapidly
  - At 450 GeV : no SR so no PSD
  - Delta_P = 5 10^{-9} mbar
  - Dynamic pressure observed ONLY in common beam pipes where the 2 beams circulates in opposite direction . The 2 beams are needed to trigger the phenomenon.



First Observation of Electron Cloud : 29-9-2010

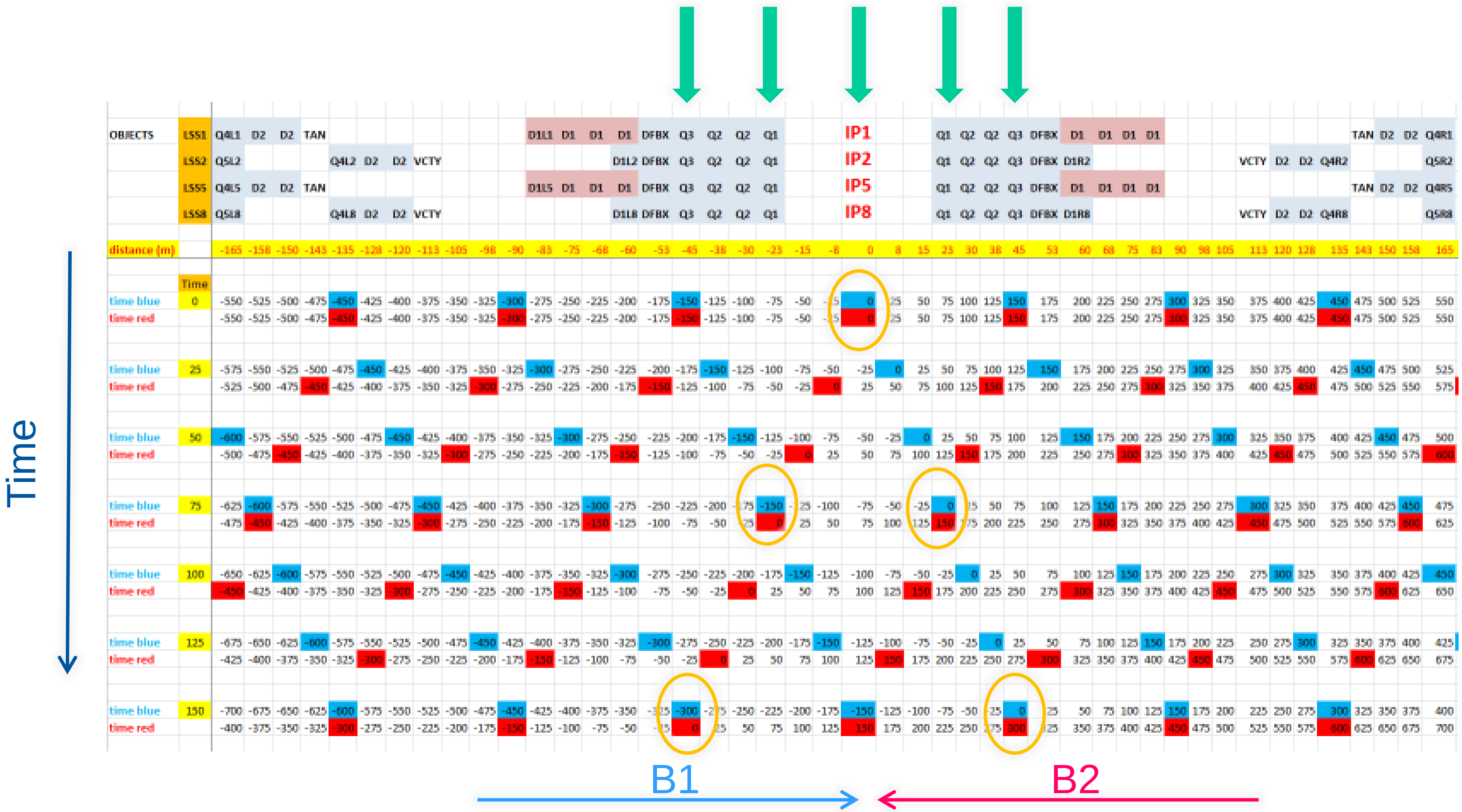
- 368 bunches of 1.2 10^{11} ppb spaced by 150 ns
  - Why a build-up with 150 ns spaced beams (45 m spacing) ?





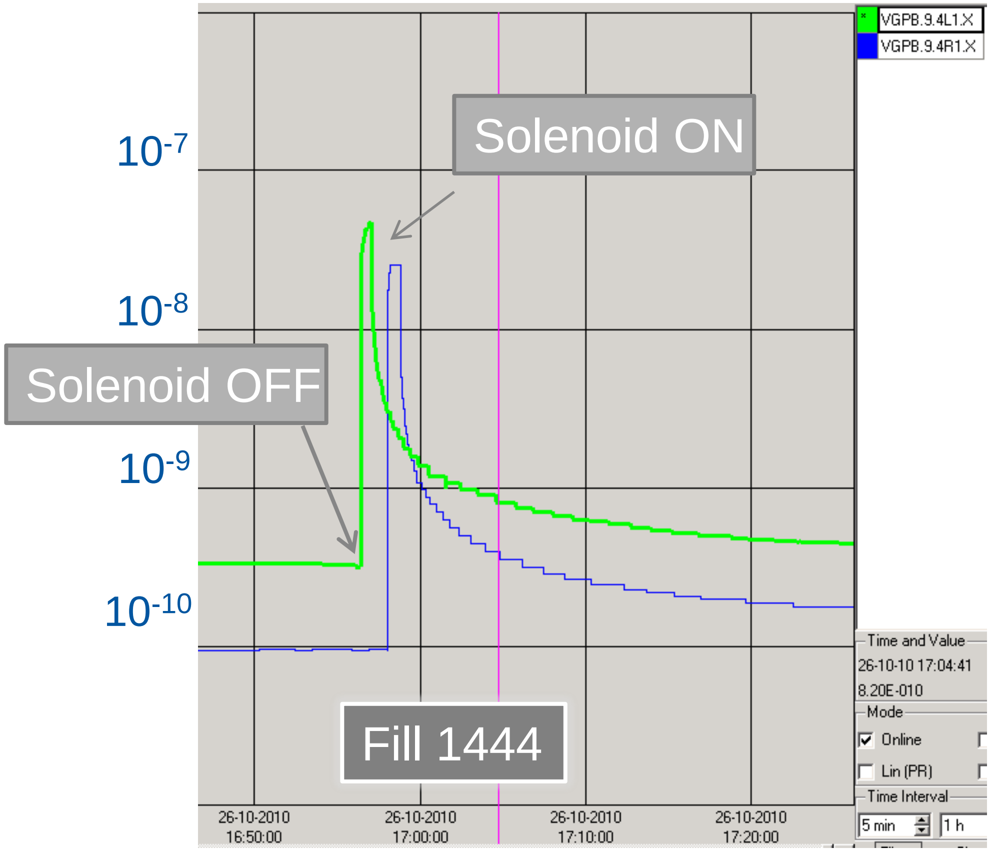
First Observation of Electron Cloud : 29-9-2010

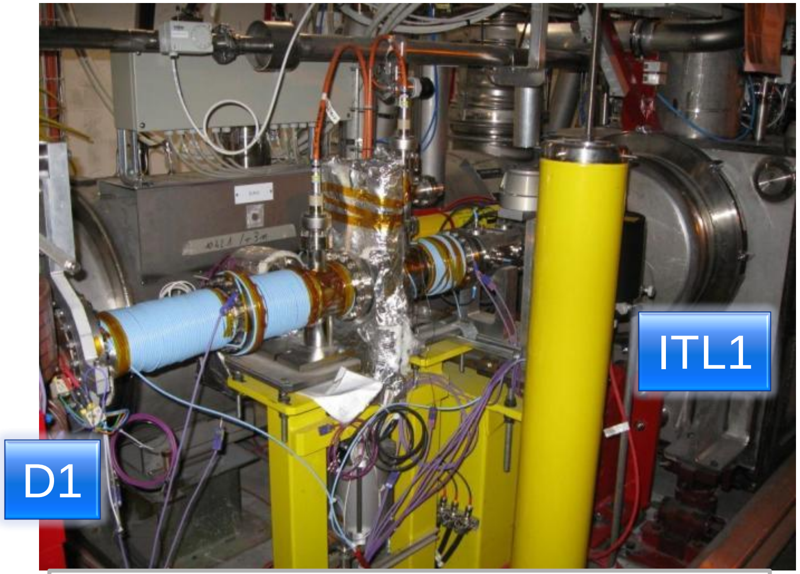
- Bunch spacing by 150 ns = 45 m
  - So the 2 opposite bunches which interacted at IP, will encounter again another bunch at multiples of ½ bunch distance i.e. 22.5, 45, 67.5, 90 m etc.



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 ….

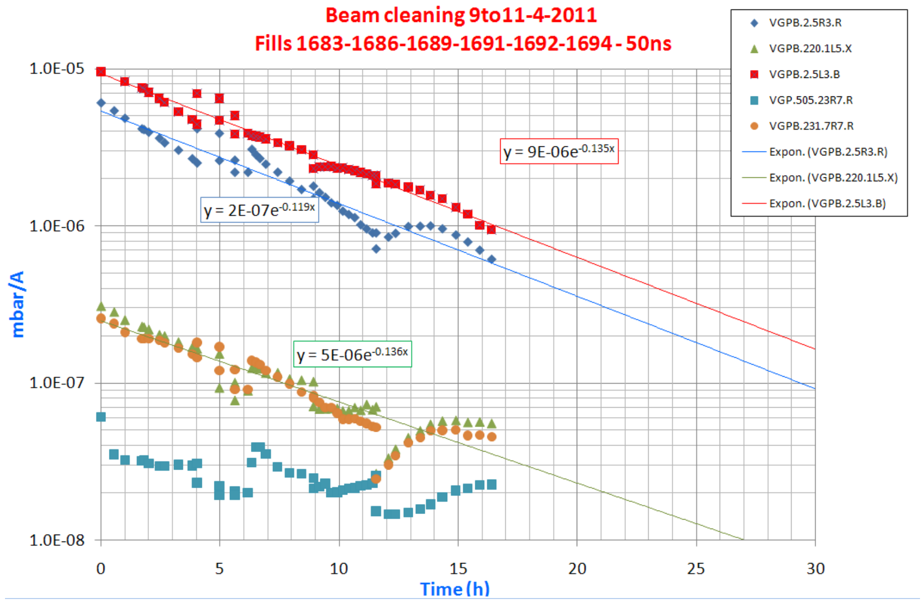




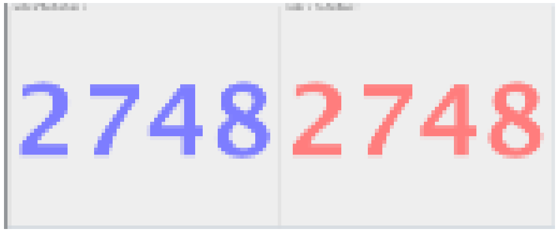
Magnetic field of solenoid≈ 20 Gauss

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

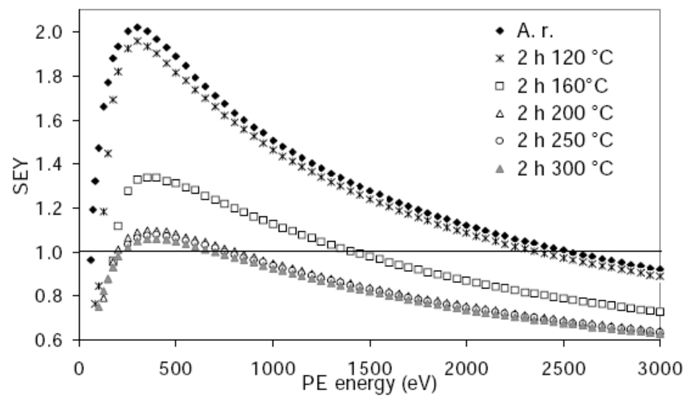


No multipacting in NEG chambers : ID80

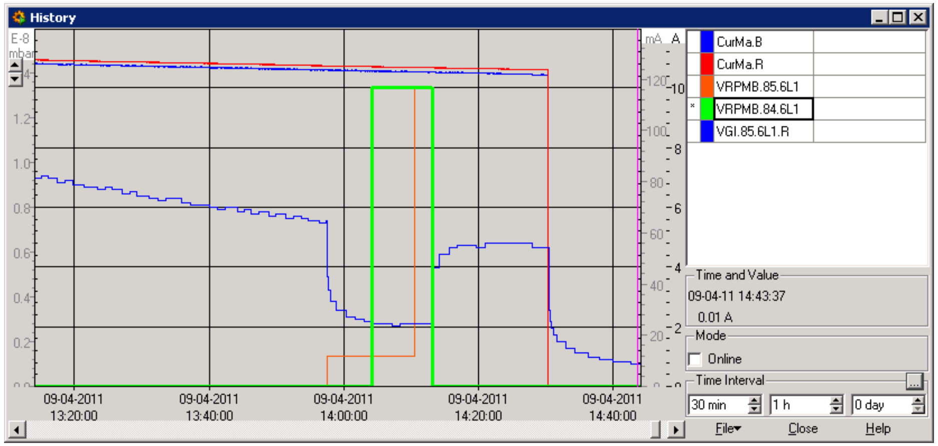
- With the solenoids we could also demonstrated the absence of electron cloud build up in the NEG coated vacuum chambers

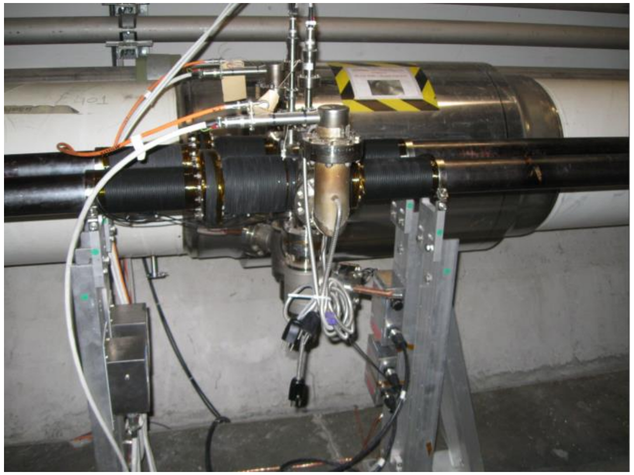
A real fairy tale of understanding !

Secondary Electron Yield



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



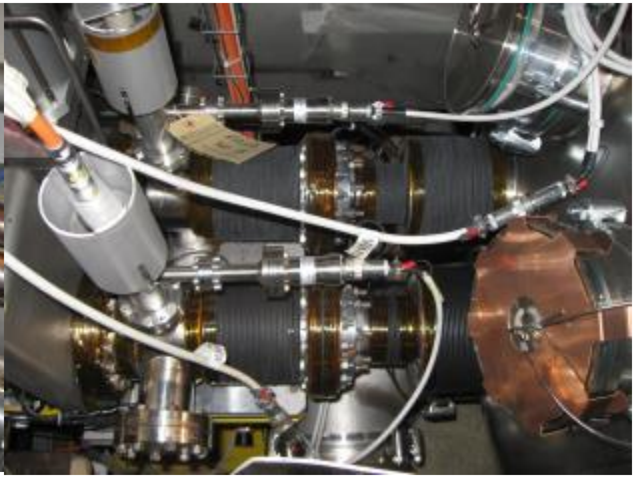
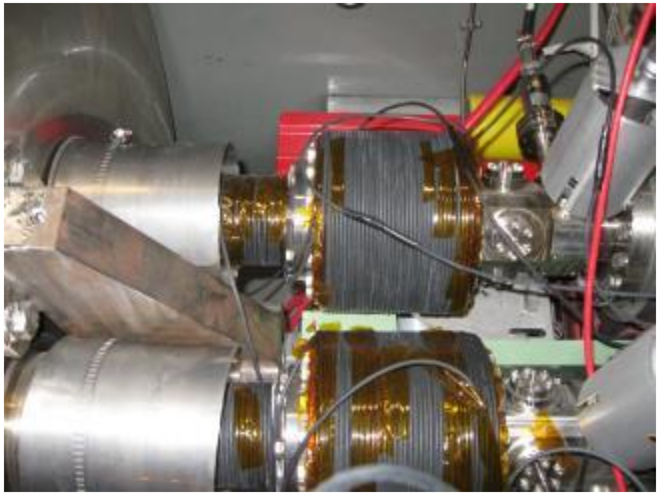


- Switching ON (to 10 A) the solenoids around NEG beam pipe has no effect on the pressure reading (VRPMB.84.6L1)
- Switching ON to 1 A (~6 G) the solenoid around the warm module decreases the pressure from 7 to 3 10^{-9} mbar (VRPMB.85.6L1).

But ….

- Our colleagues from the machine operation and physics groups had a clever idea :
  - Installing a solenoid <u>everywhere</u> in the machine to mitigate electron cloud !

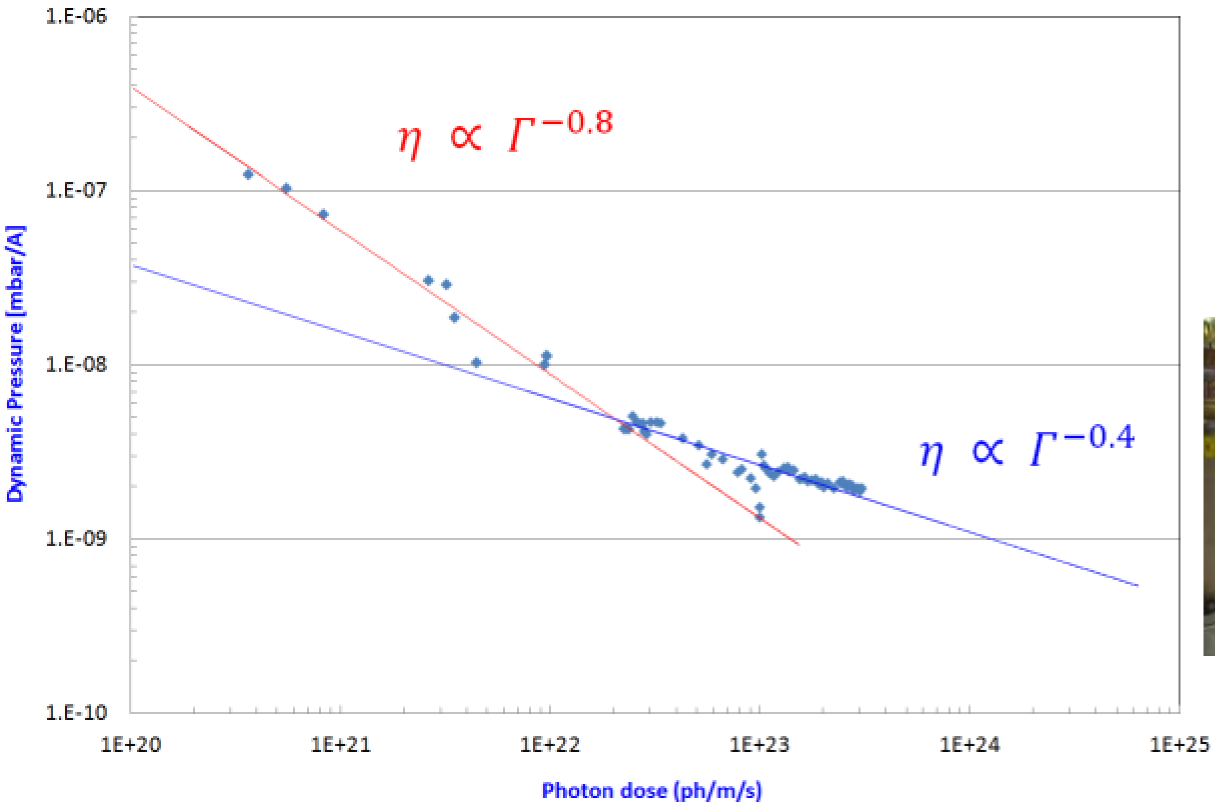
- So, in Nov 2010, we had to proposed the installation of solenoids around experimental areas i.e. 20 km of cable to wound around vacuum chambers !
  - ~ 350 man.days of work, so 2 teams during ~ 4 months !

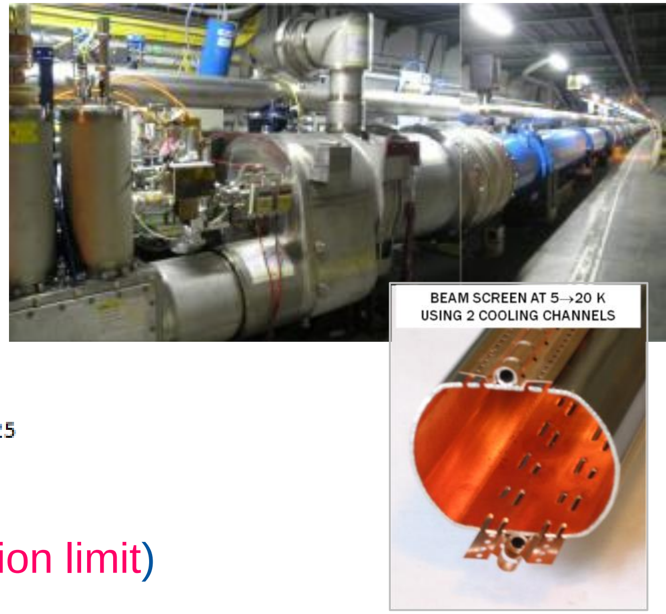
4.3 Performances obtenues

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

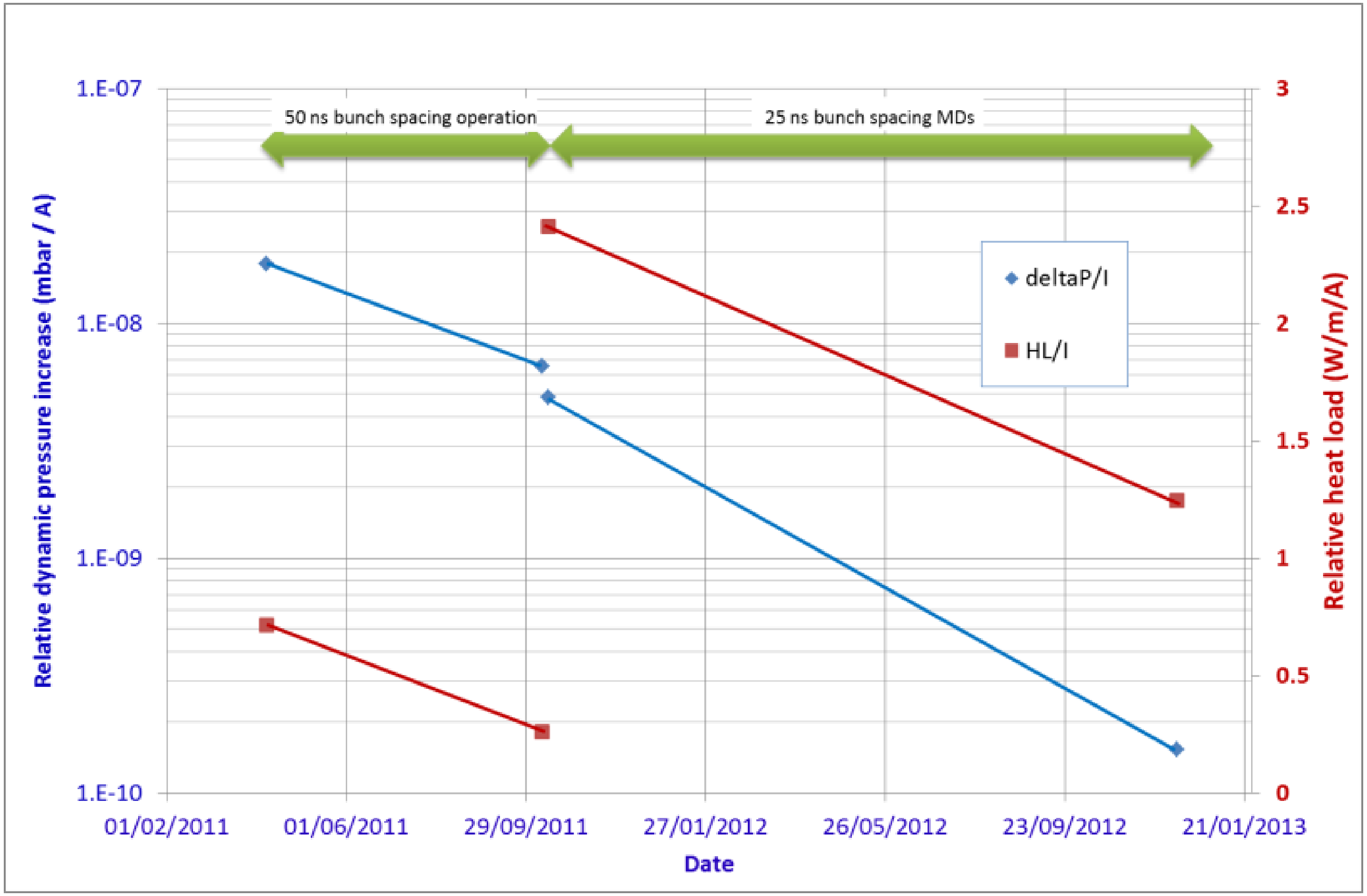


- Inside the arc, at 5-20 K, deltaP < 10^{-10} mbar (i.e. below detection limit)

- The photodesorption yield at cryogenic temperature is estimated to be < 10^{-4} molecules/photon

Beam Scrubbing / Conditionning

- Measurements in the arc
- Dynamic pressure : reduction of 2 orders of magnitude since 2011

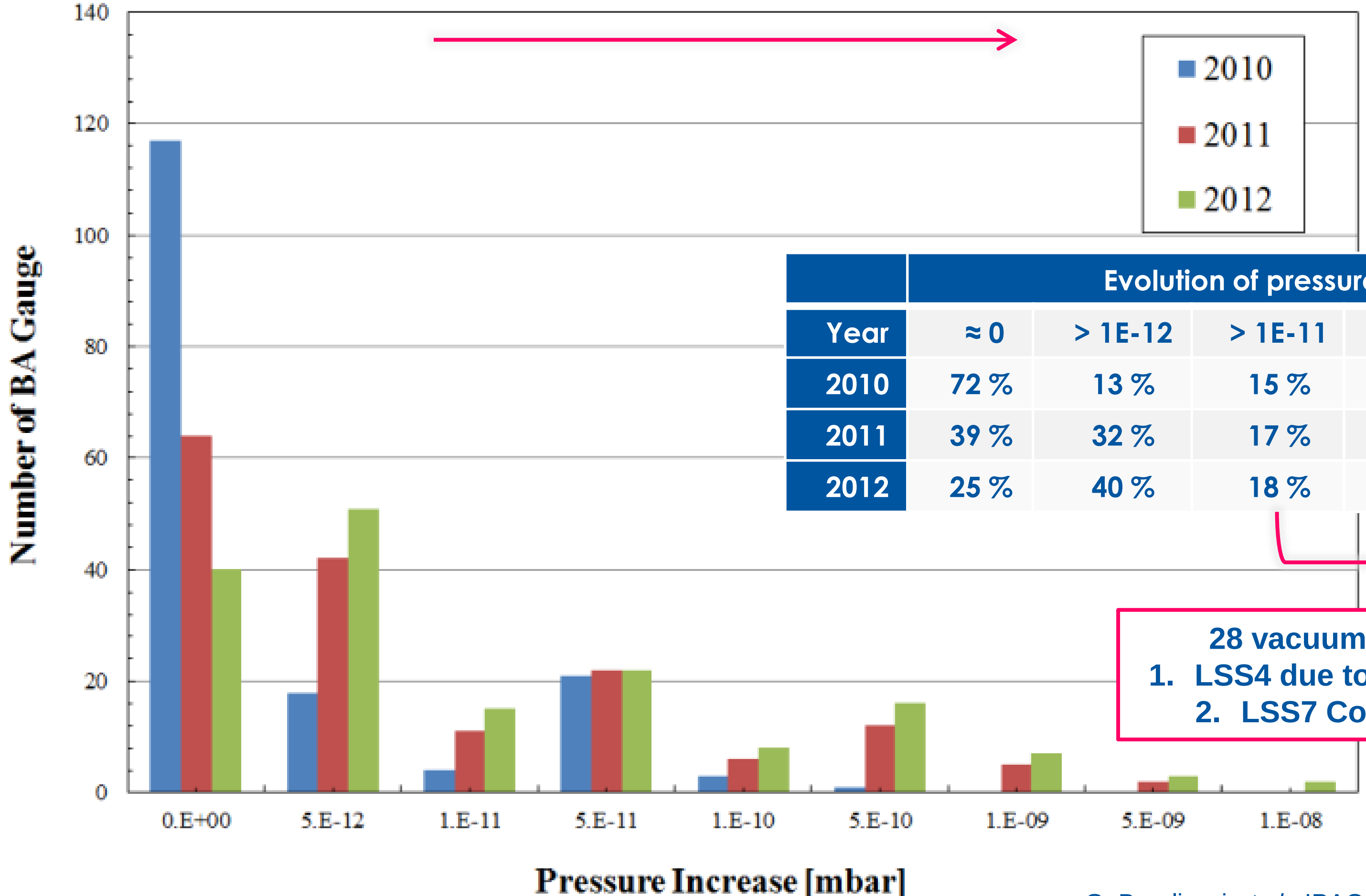


- The electron desorption yield at cryogenic temperature is estimated to be < 5 10^{-4} molecules/e

Evaluation of NEG coating ageing in LHC

- With time, the static pressure in vacuum sector degrades due to partial saturation of the NEG coating

Pressure increase ≈ NEG losing performances



	Evolution of pressure [mbar]				
Year	**≈ 0**	**> 1E-12**	**> 1E-11**	**> 1E-10**	**> 1E-9**
2010	72 %	13 %	15 %	1 %	0 %
2011	39 %	32 %	17 %	11 %	1 %
2012	25 %	40 %	18 %	14 %	3 %

28 vacuum sectors mainly in:
1. **LSS4 due to component exchange**
2. **LSS7 Collimator outgassing**

G. Bregliozzi *et al.*, IPAC Shangai, 2013

NEG coating ageing in LHC : example around collimators

- The NEG starts to be saturated due to the collimator outgassing.

- Since 2 ion pumps are located around the collimator, the NEG saturation speed is strongly reduced when the apparent pumping speed of the NEG at the collimator level is negligible as compared to the pumping speed of the ion pump

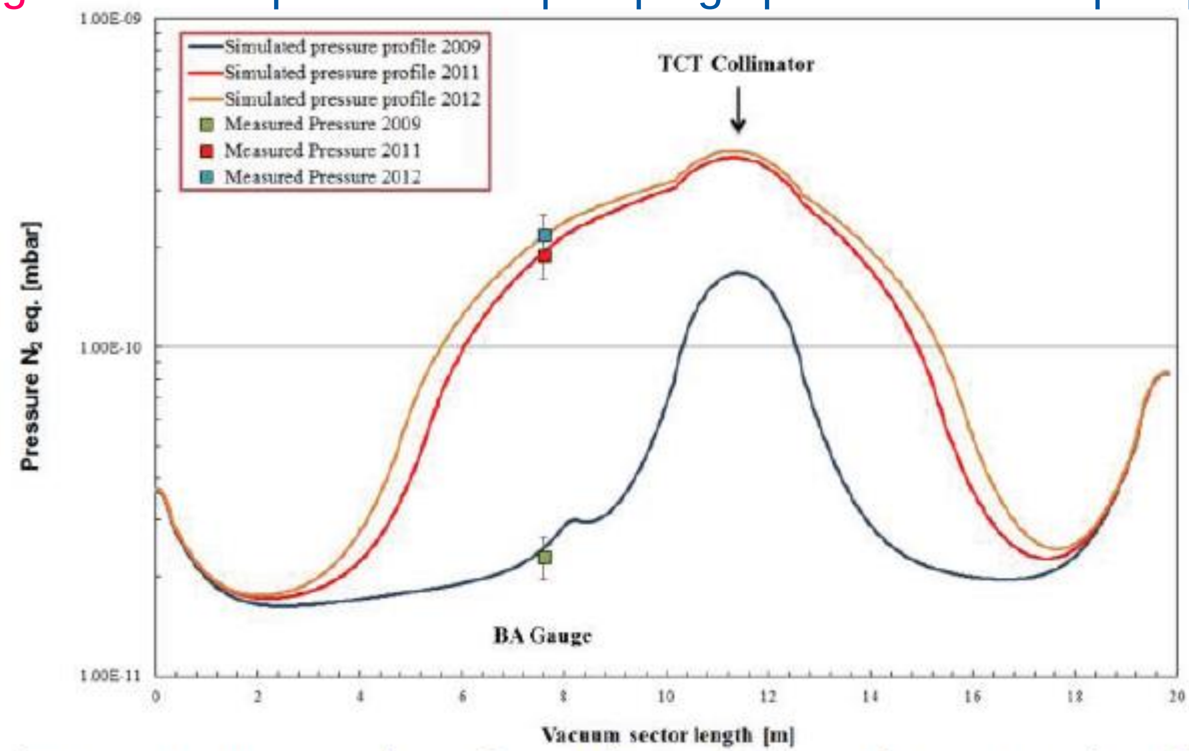


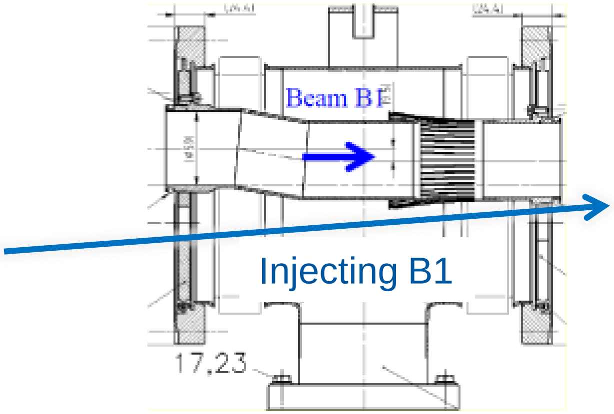
Figure 4: Example of static pressure increase in the vacuum sector A5R5.B.

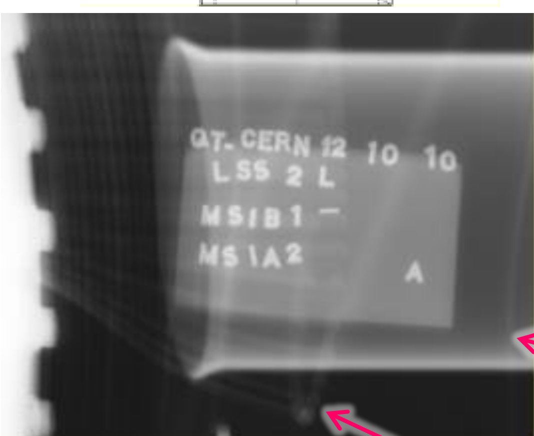
G. Bregliozzi *et al.*, IPAC Shangai, 2013

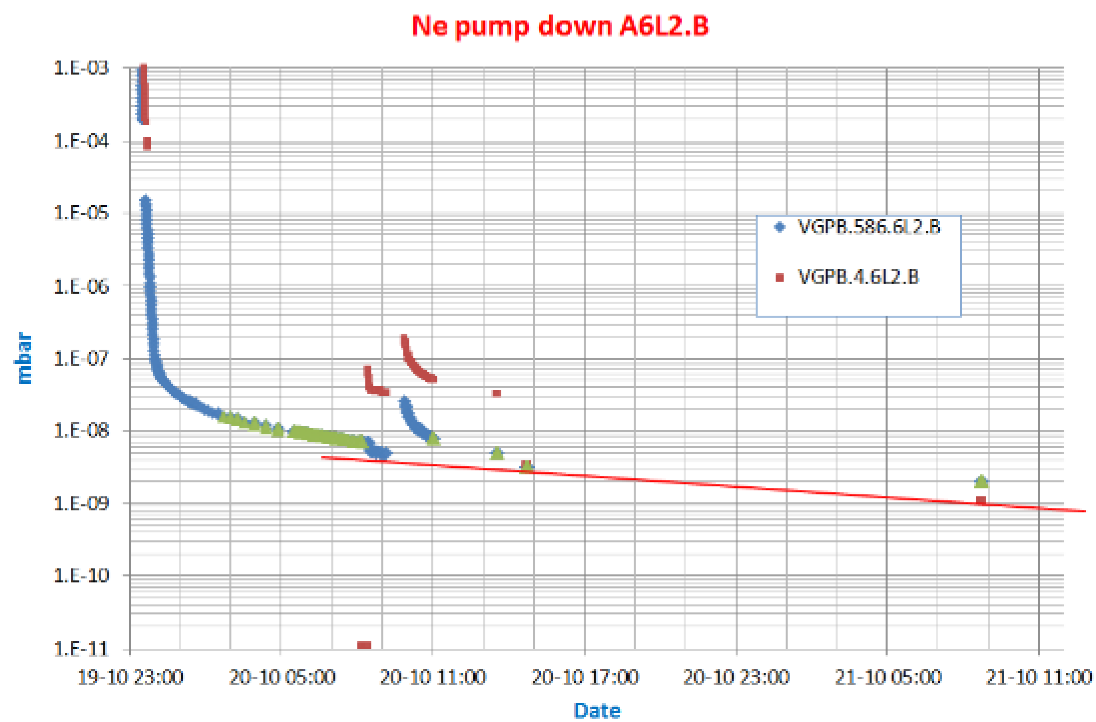
4.4 Erreurs, pannes et réparations

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





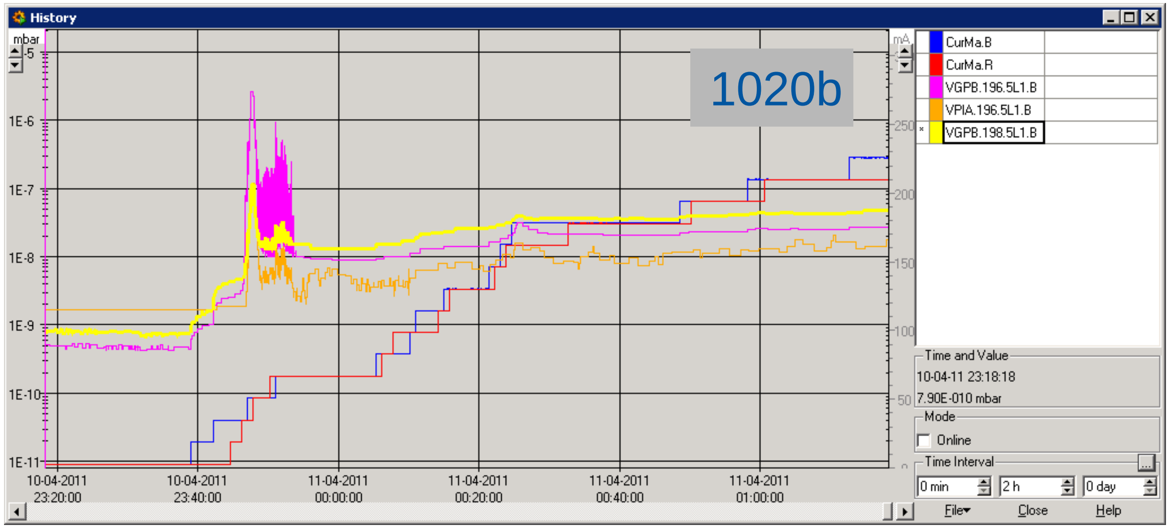


Transition tube installed in reversed position

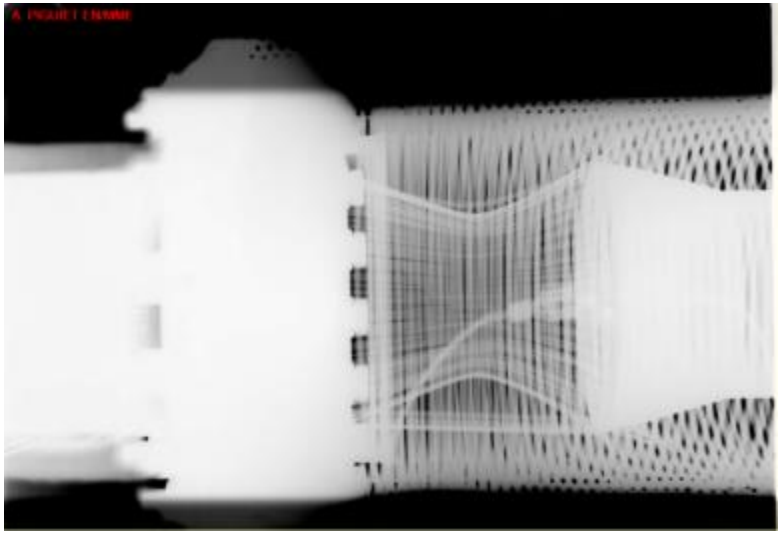
RF fingers

April 2011: Pressures around Q5L1.B

- We observed, regularly, a singular vacuum behavior in Q5L1.B : which triggered beam dump



- Is it a vacuum gauge or an ion pump which produce outgassing ?
  - In front of our ignorance, we increased the interlock level to 10^{-4} mbar !

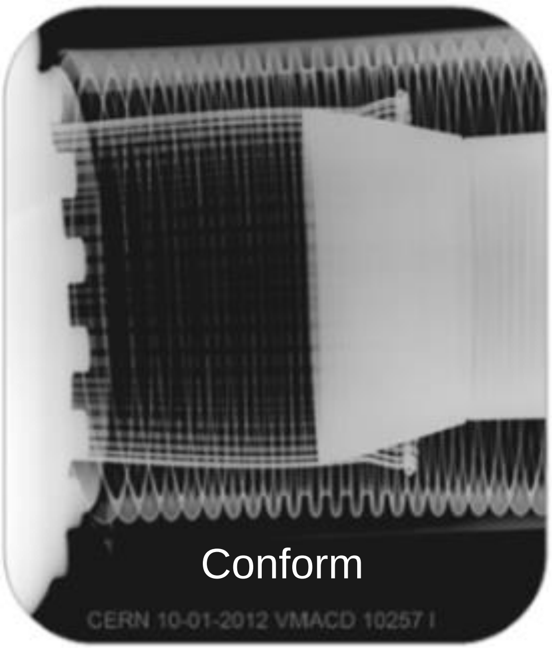


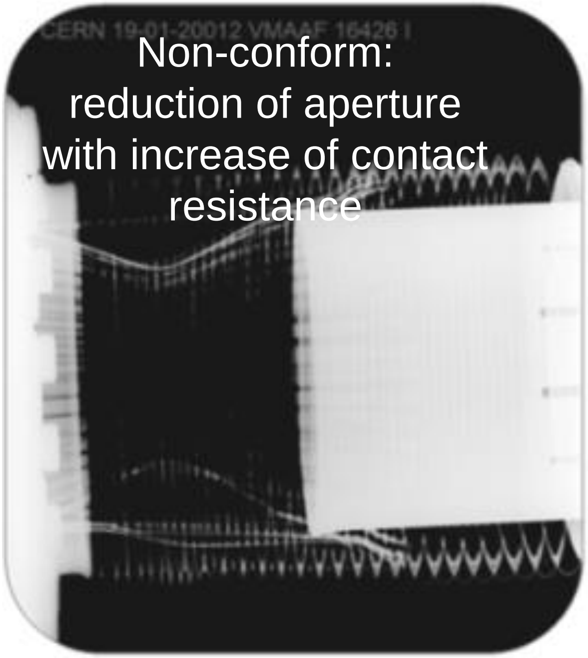
- X-ray (12/9/2011) showed a reduced aperture

- We repaired during the winter technical stop 2011-12

Fix of Non-Conformities during LS1 (2013-14)

- As a consequence of the 2 previous observations, 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 total) is needed to restore machine impedance and to avoid pressure spikes/excursion
- 52 RT vacuum sectors impacted out of which 29 are opened during LS1 on purpose (~ 200 kCHf manpower)



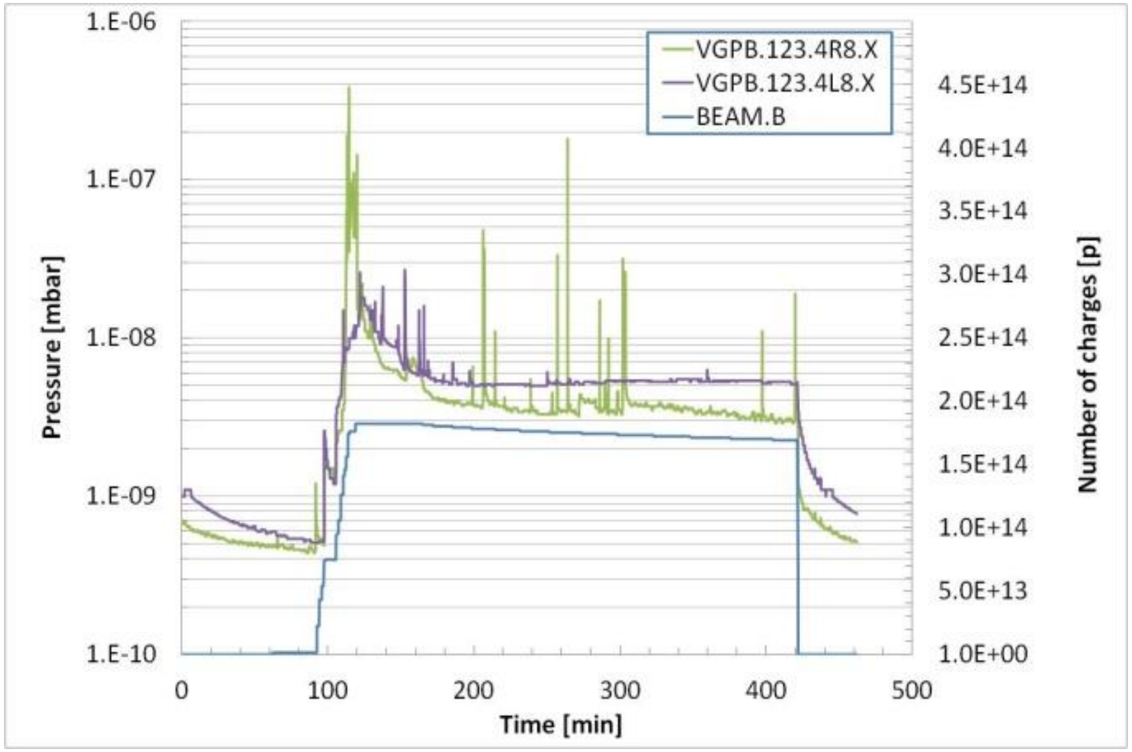


Courtesy A. Vidal, J-M. Dalin EN-MME

- LESSON : 1) Write down and execute properly the installation procedures with activity reports
  2) Implement a quality assurance team

Summer 2011 : Vacuum Modules - VMTSA

- Design extrapolated and not mechanically validated before installation in the ring
- Pressure spikes located beside inner triplets generated interlocks and background



Observed Pressure spikes during a physics fill

Vacuum Modules : VMTSA - 2011

- X-rays done in May showed a conform module, in November the module was broken
- The RF bridge was destroyed by the beam !
- 8 out of a total of 20 in LHC were damaged i.e. 40 %

Typical default, DCUM 3259.3524

Left side

Side view (xray from corridor to QRL)

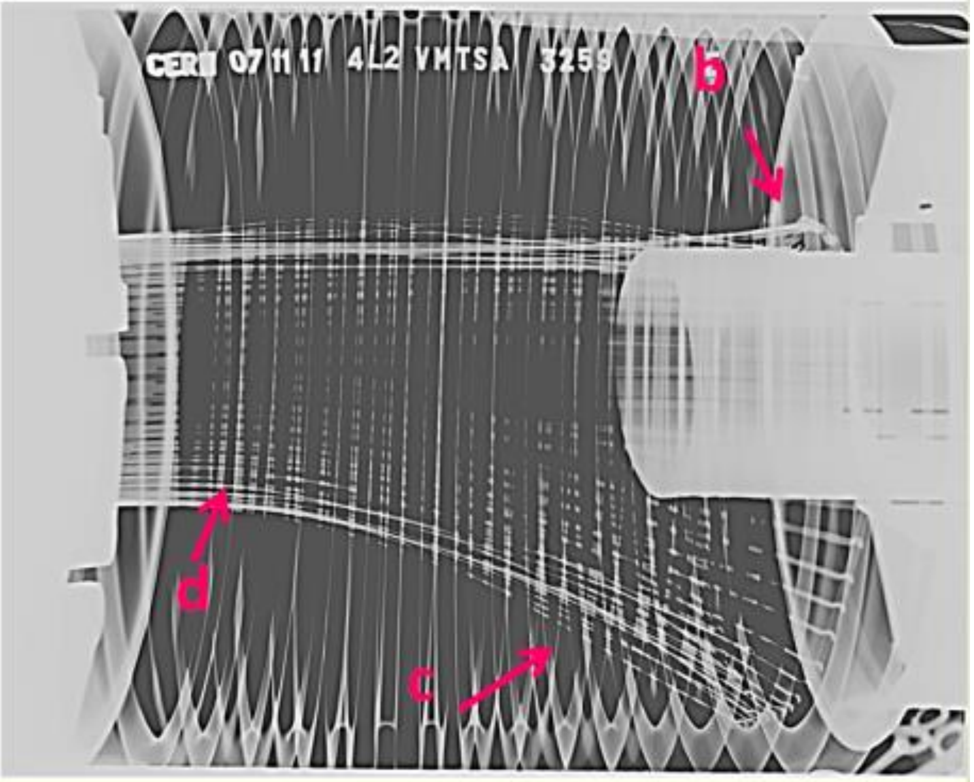
b) Metallic noise due to loose spring when hitting vacuum chamber

c) RF fingers falling due to broken spring

d) aperture reduced ?

Non Conform

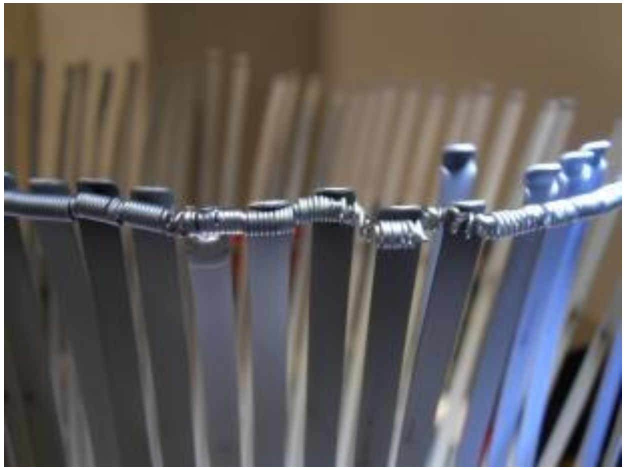
Spring was broken between May and November 2011



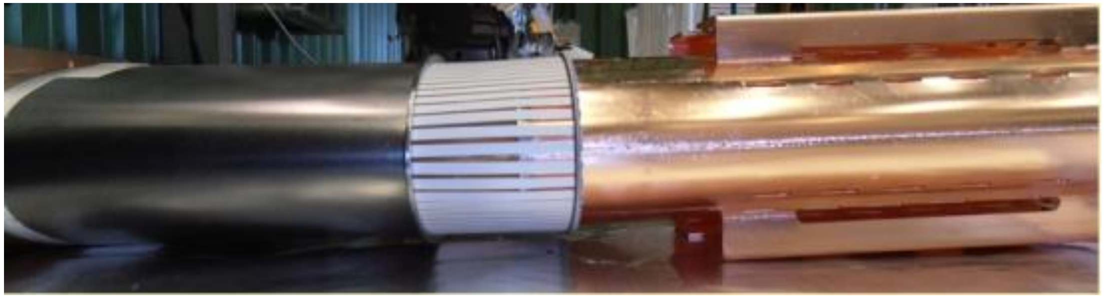
Vacuum Modules : VMTSA - 2011

- Again repair during winter technical stop 2011-12

- Permanently deformed fingers
- Spring brazed to the finger



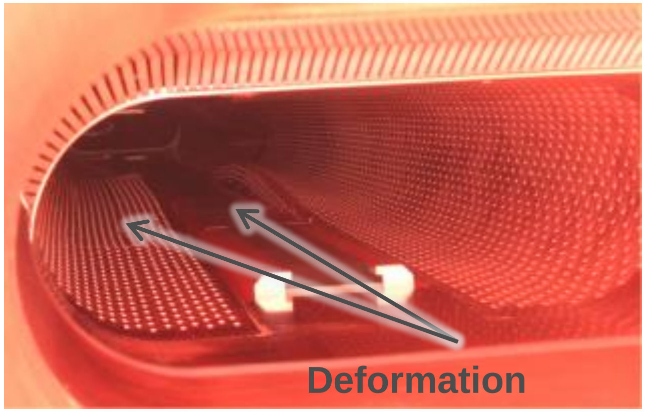
- Origin of the systematic default was identified to be due to a poor contact between the RF finger and the transition tube. The RF fingers were stiffened for 2012 consolidation.



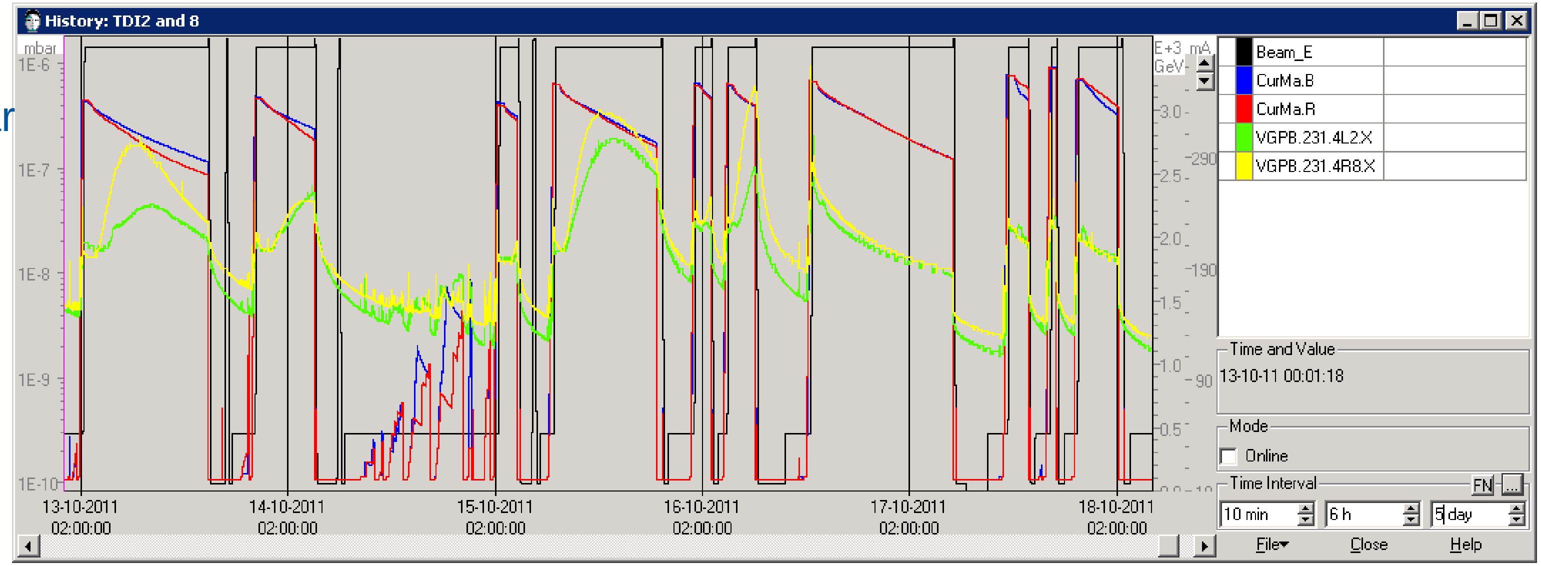
- For LS1, the layout was modified to remove the badly design module
- LESSON : always mechanically validate the design of components (even under schedule pressure)

TDI in LSS2 and 8

- A movable mask to protect ALICE during injection (Boron nitride jaw)
- Deformed beam screen observed during winter technical stop 2011-12
  - Suspected origin is a bad sliding point
  - Cu beam screen was deformed during bakeout at 300 deg
  - Consolidated TDI for LS1 with reinforced beam screen and ceramic bearings



- Beam induced thermal outgassing
  - ~ 10^{-7} mbar



ALICE : A Large Ion Collider Experiment

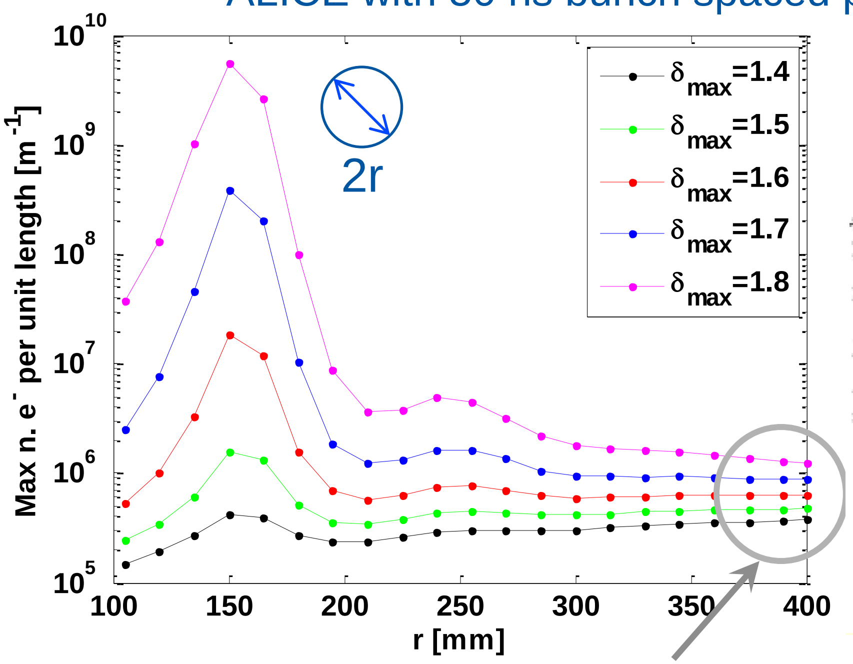
- An Ion Collider Experiment which make physics with protons as well !

  => Do not be naïve like me and simply trust the name of an experiment !

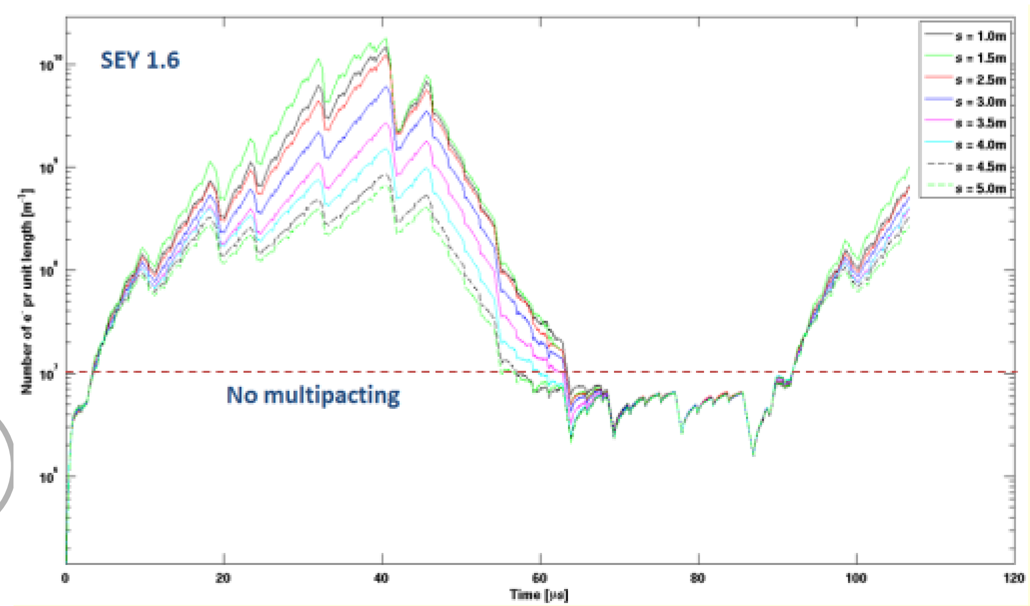
A Large Ion Collider Experiment

European Organisation for Nuclear Research

- Was not designed to operate with protons ….
  - Our friend beam induced multipacting explains why background was observed in ALICE with 50 ns bunch spaced protons beams



Very small electron cloud in the 800mm chamber

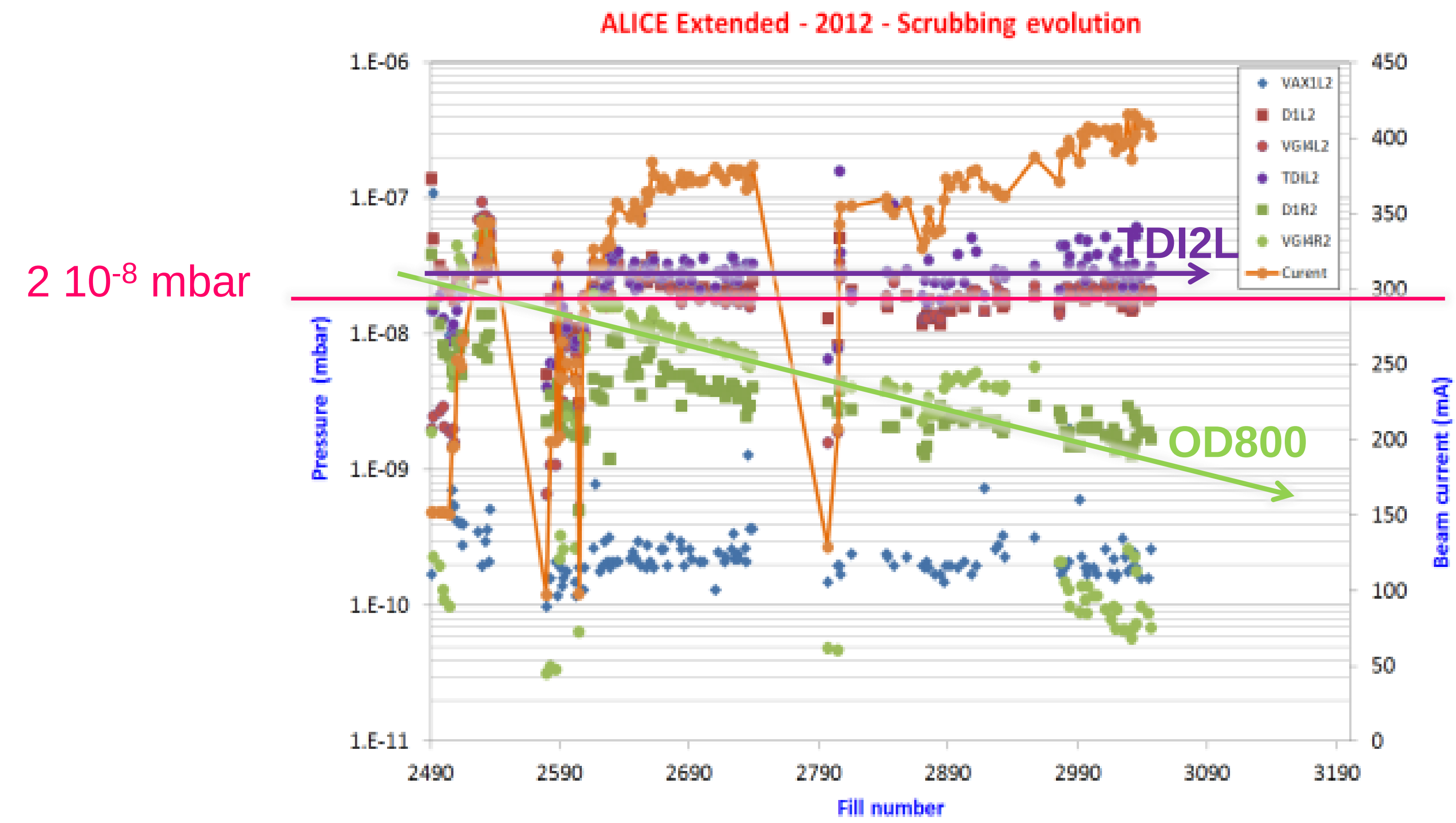


Due to counter rotating beams, several bunch spacing exist
In the OD800 chamber leading to multipacting even with 50 ns

Courtesy G. Iadarola BE/ABP

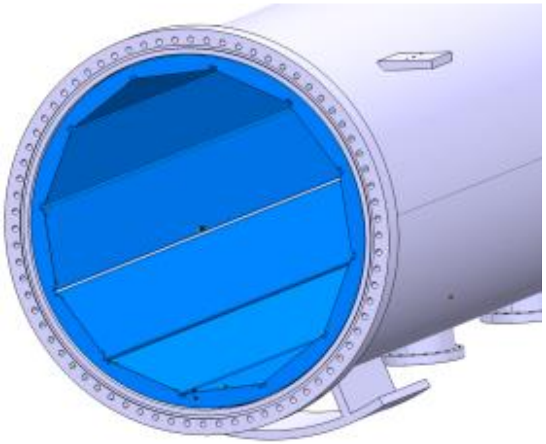
ALICE : The Struggle with Beam Scrubbing

- To properly operate with protons ALICE needs $P_{OD800} < 2\ 10^{-8}$ mbar
- Left side and right side of the IP behaves differently
- Right side scrubs as expected but the left side is dominated by TDI !



ALICE Extended : LS1 Consolidation

- ID 800 upgrade :
  - NEG coated liners along ID800



- TDI sectorisation:
  - allows exchange
  - allows long bakeout
- 2 000 l/s NEG cartridges

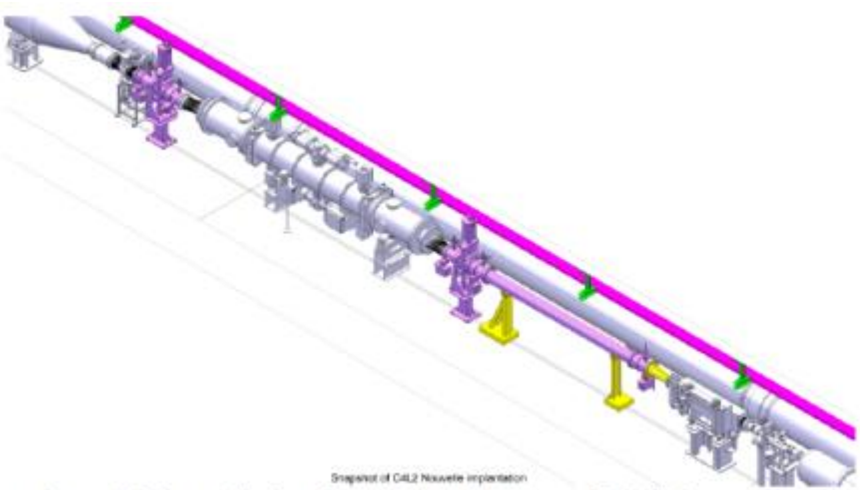


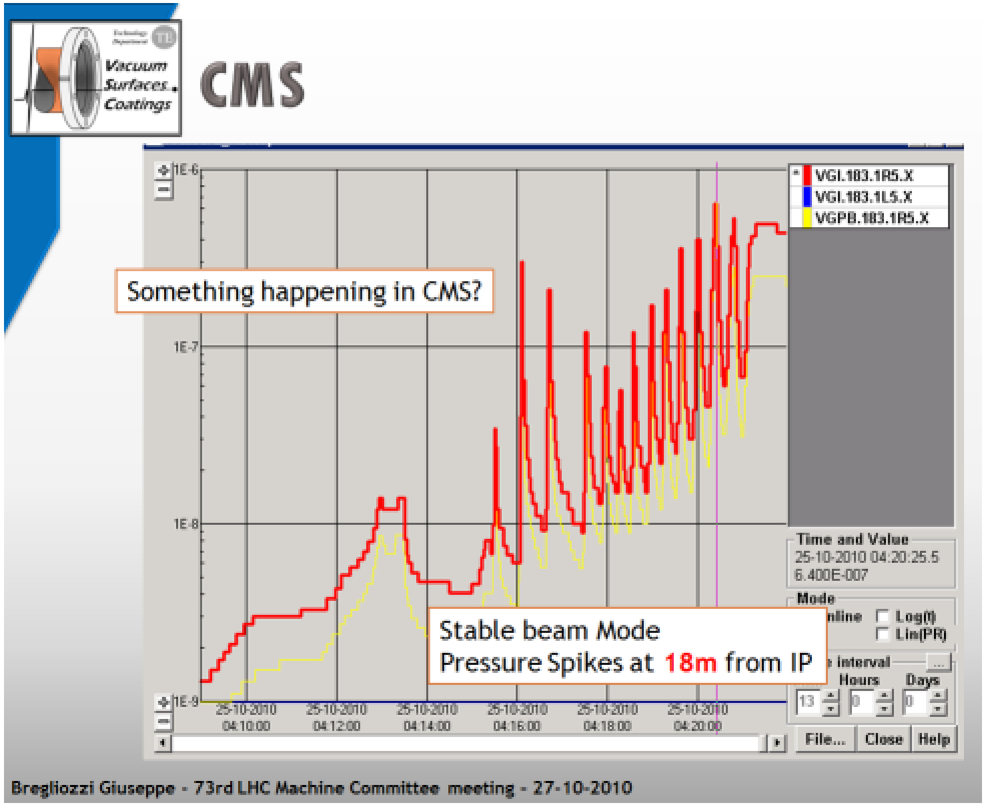
Figure 4: 3D isometric view of the LS1 layout (courtesy of B. Moles)

LESSON : Oblige your clients to write down their performance's objectives

4.5 Réparation de CMS sous atmosphère de néon

Document and Record of Informations

- During the show-up of electron cloud and scrubbing run, large pressure rise were observed in CMS till a few 10^{-7} mbar



- The issue was identified and associated (like many other phenomenon) to electron cloud but not followed closely afterward….

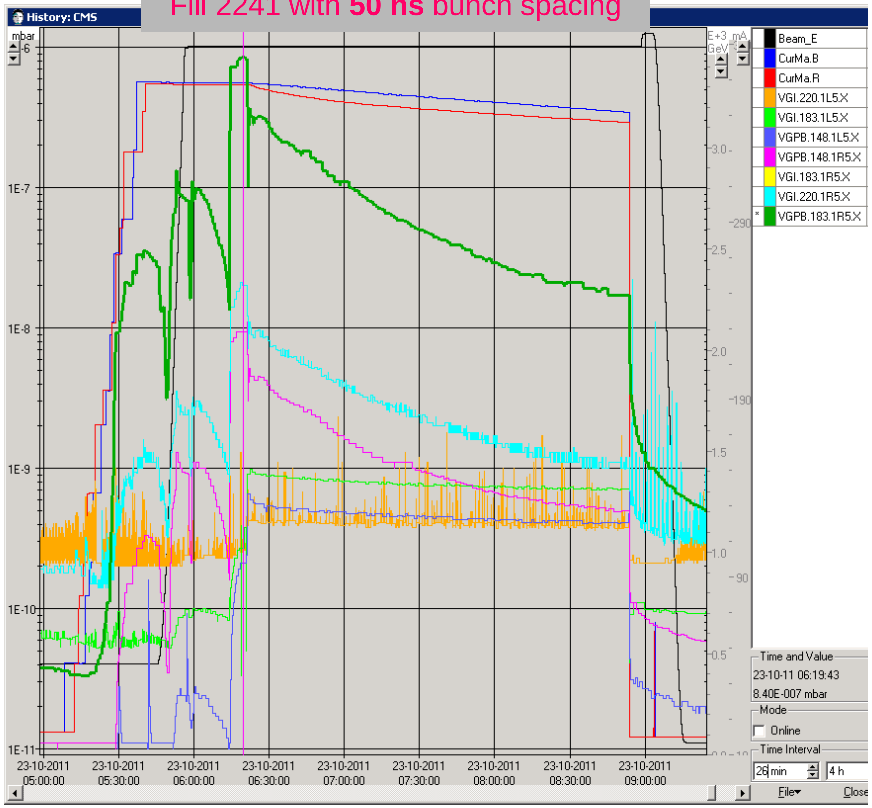
2011: Pressure spikes in right side of CMS

- In 2011, frequent pressure spikes, some up to 10^{-6} mbar, were observed at CMS, 18 m, right side.

- When the local pressure was above 10^{-8} mbar, CMS background was larger than 100 % thereby reducing the detector capability

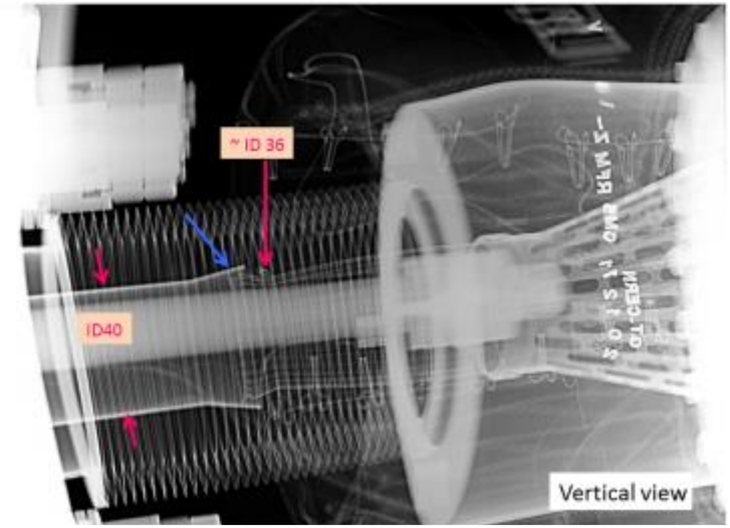
Typical Observation

Fill 2241 with **50 ns** bunch spacing



Pressure spikes: CMS

- During the winter technical stop 2011-2012, a non-conform vacuum module was identified by X-ray

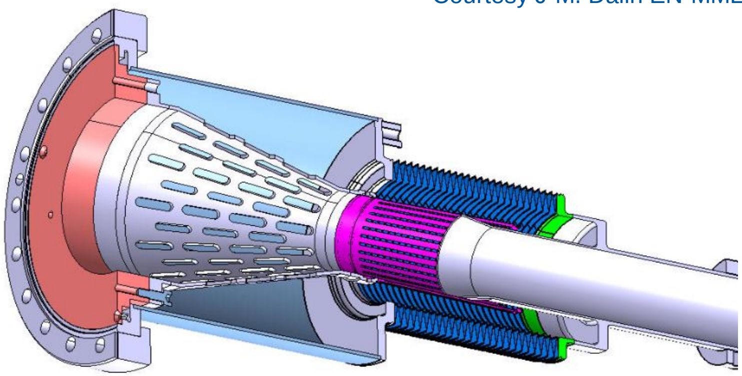


- The origin of this NC is due to a mis-positionning of the TAS-56 vacuum chamber

- To avoid the risk of further aperture reduction, a repair under Ne atmosphere was done

- This method avoided the full bake out of the CMS vacuum sector which would have meant dismounting the central detector !

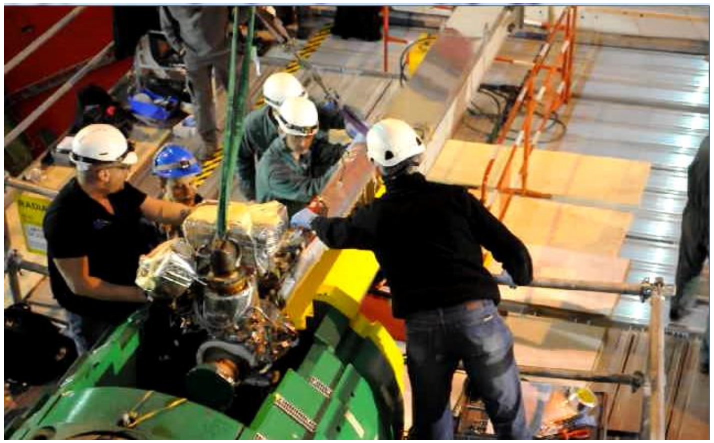
Courtesy J-M. Dalin EN-MME



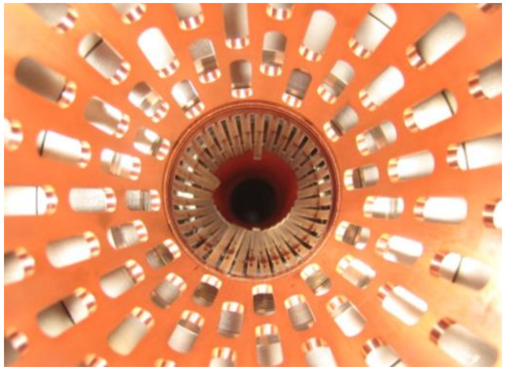
- A new RF insert, with an additional 20 mm thick copper ring was made to compensate the mis-positionning

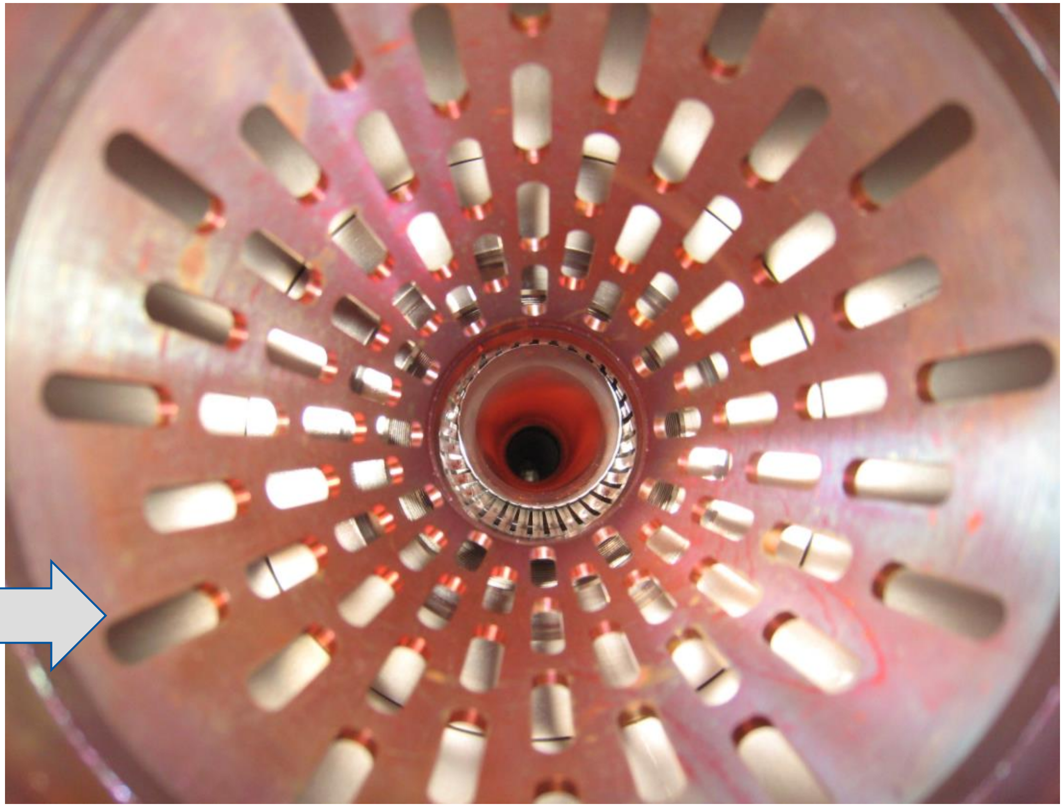
CMS: Repair under Ne

- The vacuum system was over pressurised to + 200 mbar to minimised air backstreaming into the NEG chambers
- The CMS forward vacuum chamber was opened and moved away for inspection



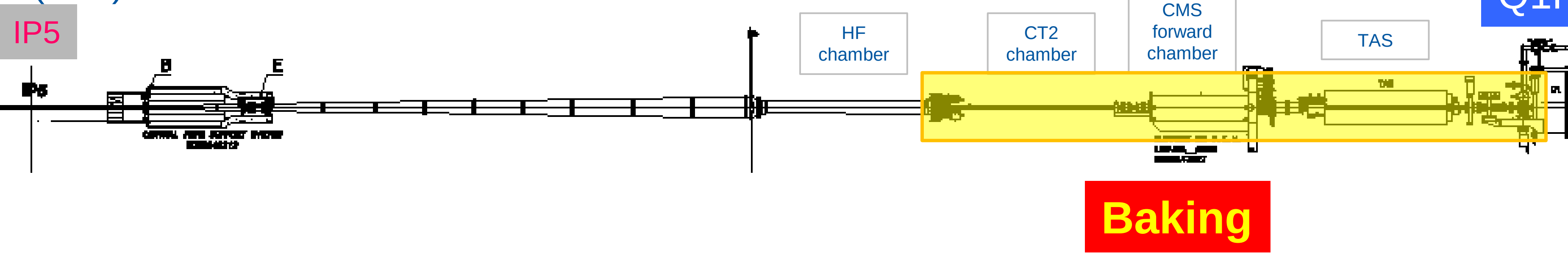
- And the RF insert exchanged





CMS: Ne pump down and NEG activation

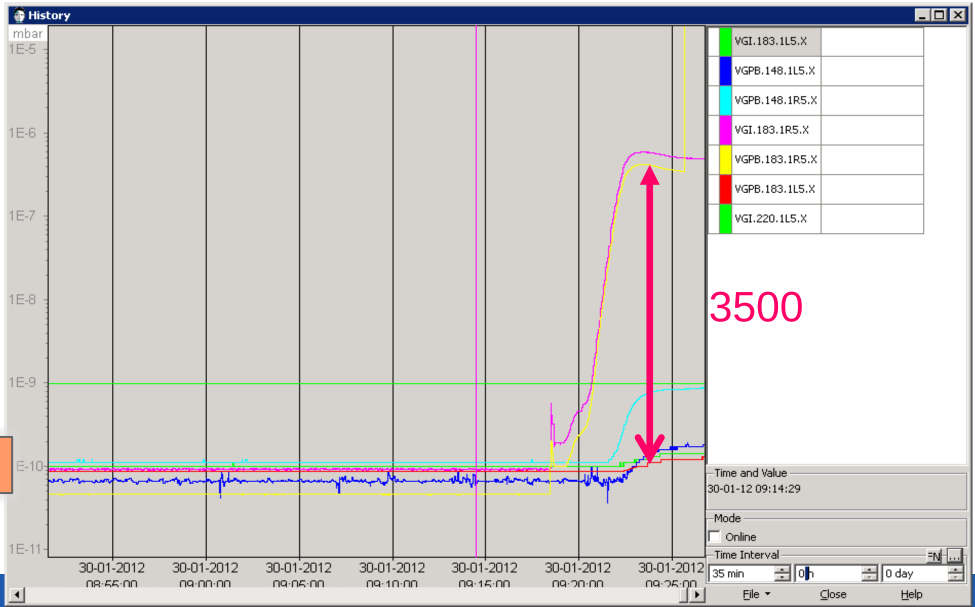
- Once the flanges closed, Ne was evacuated by a mobile pumping group located at Q1R5
- 10^{-9} mbar was reached after 2 days indicating that NEG chamber located at the IP were still pumping
- CMS forward chamber and vacuum chambers located upstream (CT2) and downstream (TAS) were re-activated



- Achieved pressure are < 1 10^{-10} mbar
- Transmission from – 18 till + 18 m equals 3500

→ The CMS IP chambers are still activated
The vacuum performance are restored

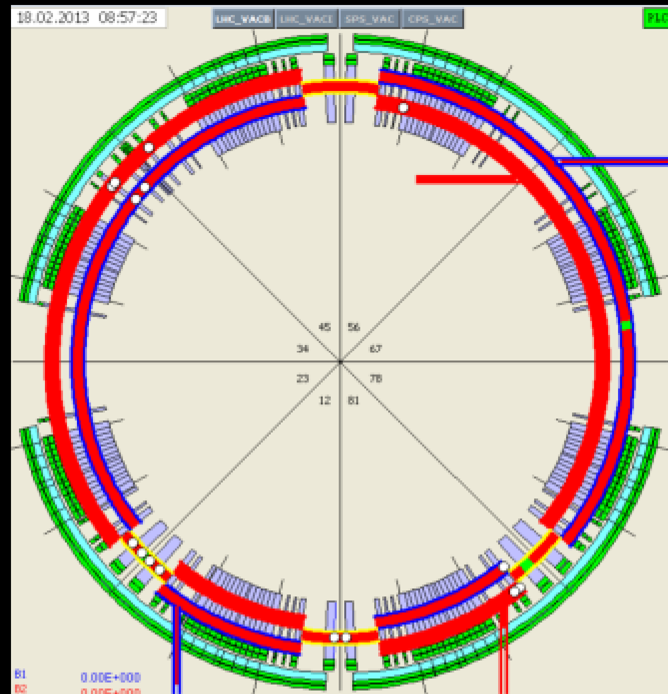
10^{-10}



5. Consolidations et améliorations

LHC Page1 | Fill: 3575 | E: 0 GeV | 18-02-13 08:54:13

SHUTDOWN: NO BEAM



Comments (16-Feb-2013 08:25:13)

*** END OF RUN 1 ***

No beam for a while. Access required
time estimate: ~2 years

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	false	false
Setup Beam	true	true
Beam Presence	false	false
Moveable Devices Allowed In	false	false
Stable Beams	false	false

AFS: Single_36b_4_16_16_4bpi9inj | PM Status B1: ENABLED | PM Status B2: ENABLED

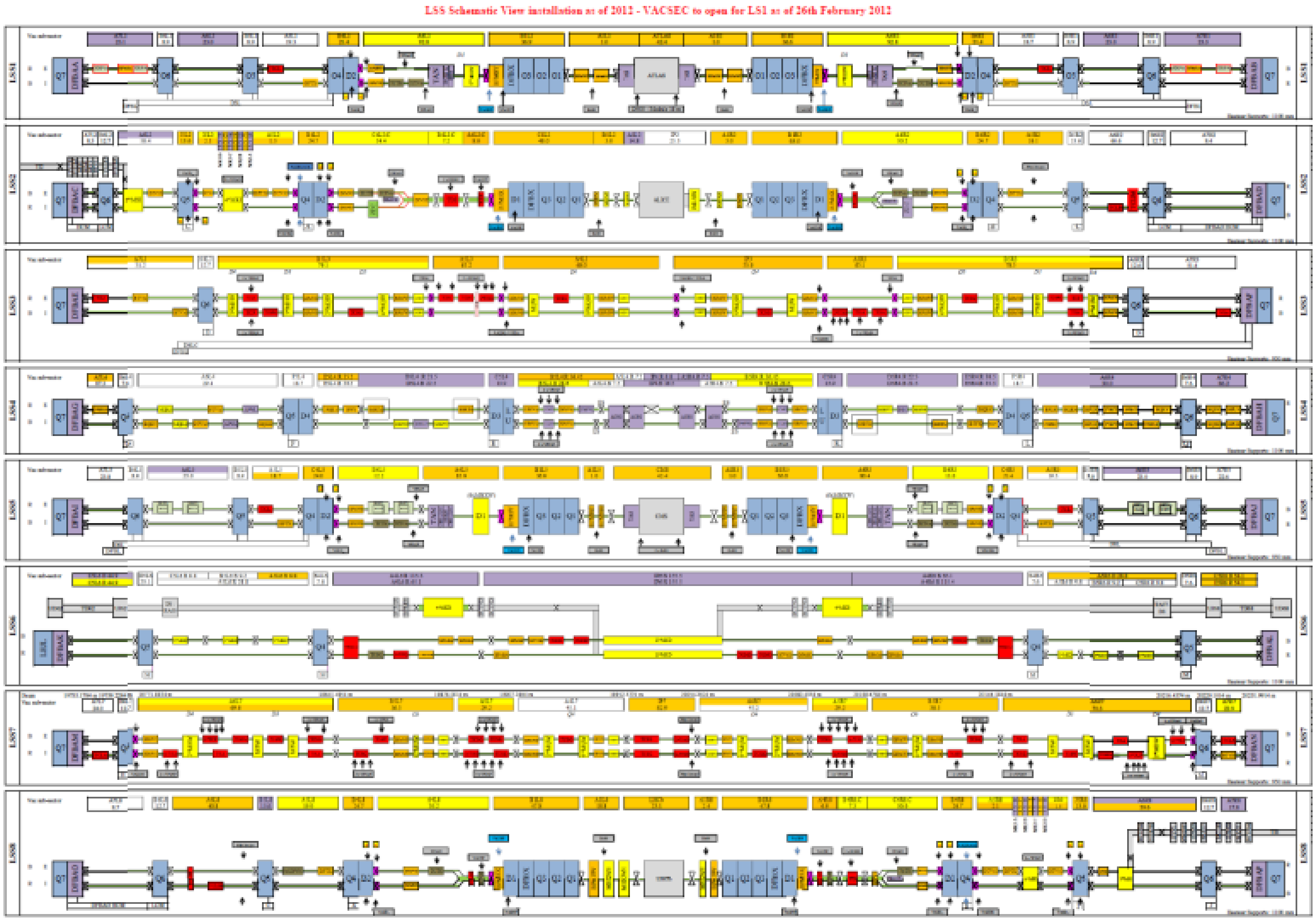
Long Shutdown 1 (LS1)

- Main aim : consolidate the splice interconnection between superconducting magnets to allow operation at 7 TeV/beam

- Started Feb 2013, Physics will resume April 2015

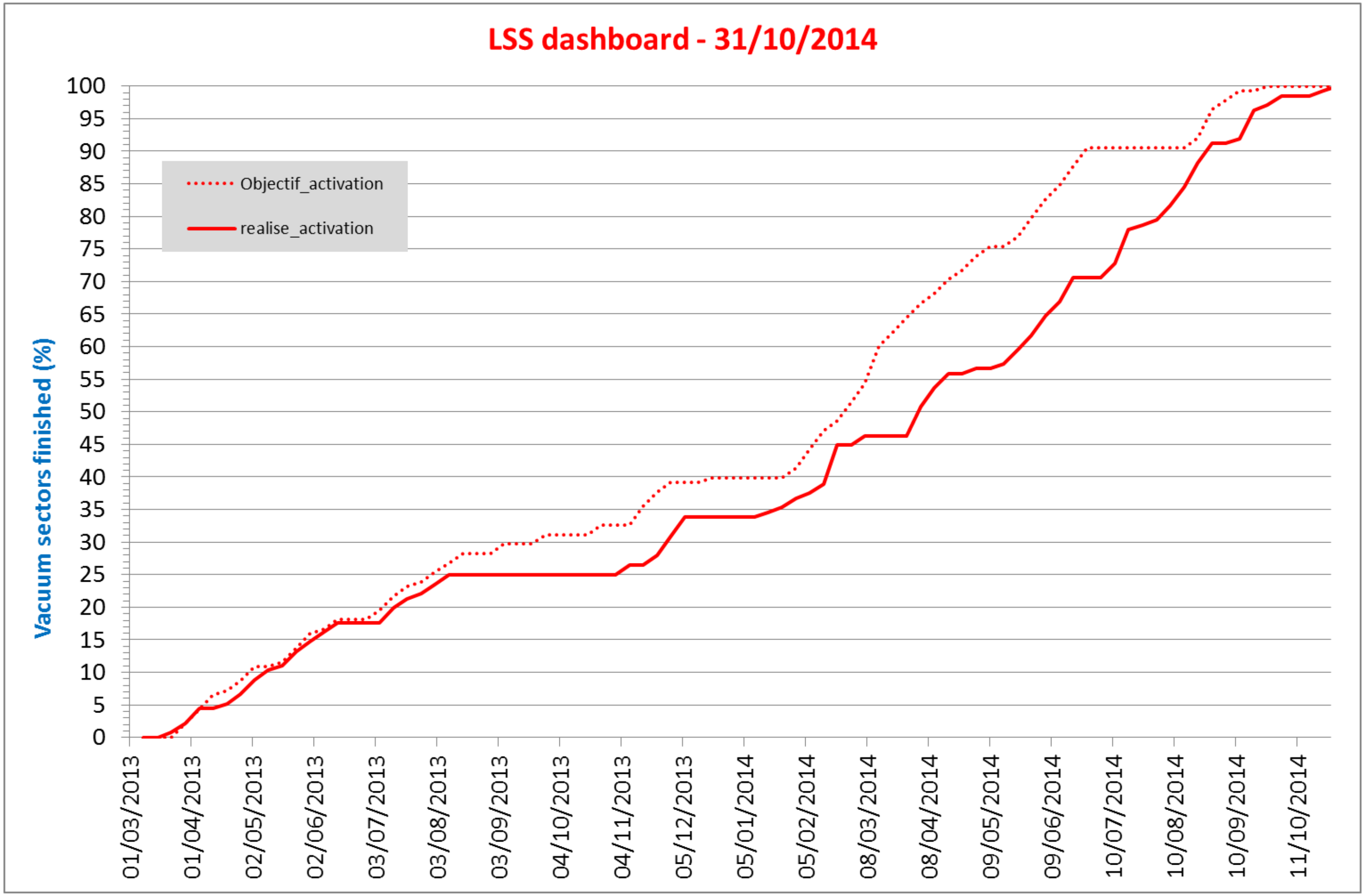
Overview of LSS Beam Vacuum Activities

- 148 vacuum sector to re-commission *i.e.* 5.1 km of vacuum system (80 % of the LSS)



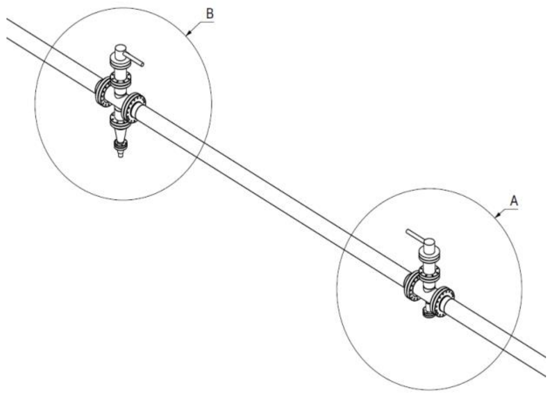
Completed !

- Only 6 weeks delay as compared to base line
- Only 11 vacuum sectors re openned for 2nd repair



Consolidations

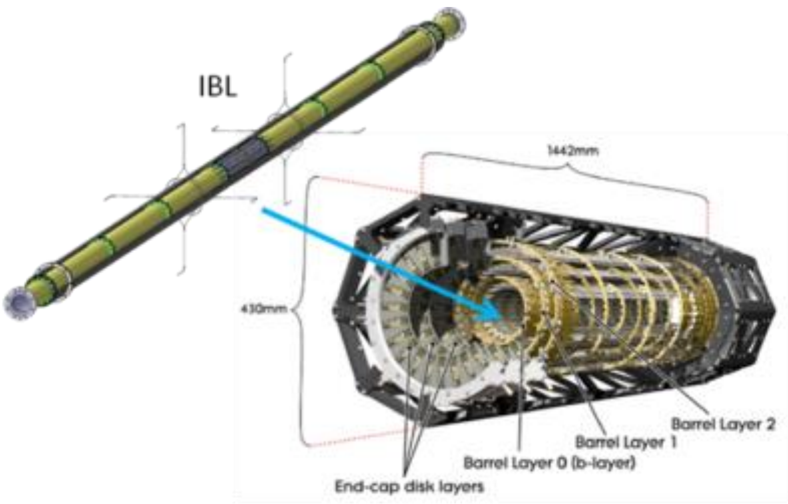
- Consolidation of pumping scheme, main activities :
  - reduce background to the experiments:
    - NEG coating of RF bridges inserts located inside and in the vicinity of the LHC experiments
    - 180 inserts to replace
  - minimise impact of radiation onto the personnel:
    - installation of remotely powered NEG cartridge as complementary lumped pumping system in collimators areas
    - 190 D400 NEG cartridges to install
- Consolidation of diagnostic scheme, main activities :
  - Installation of electron cloud pilot sector
  - Installation of NEG pilot sector :
    - Characterisation of NEG by H2 transmission

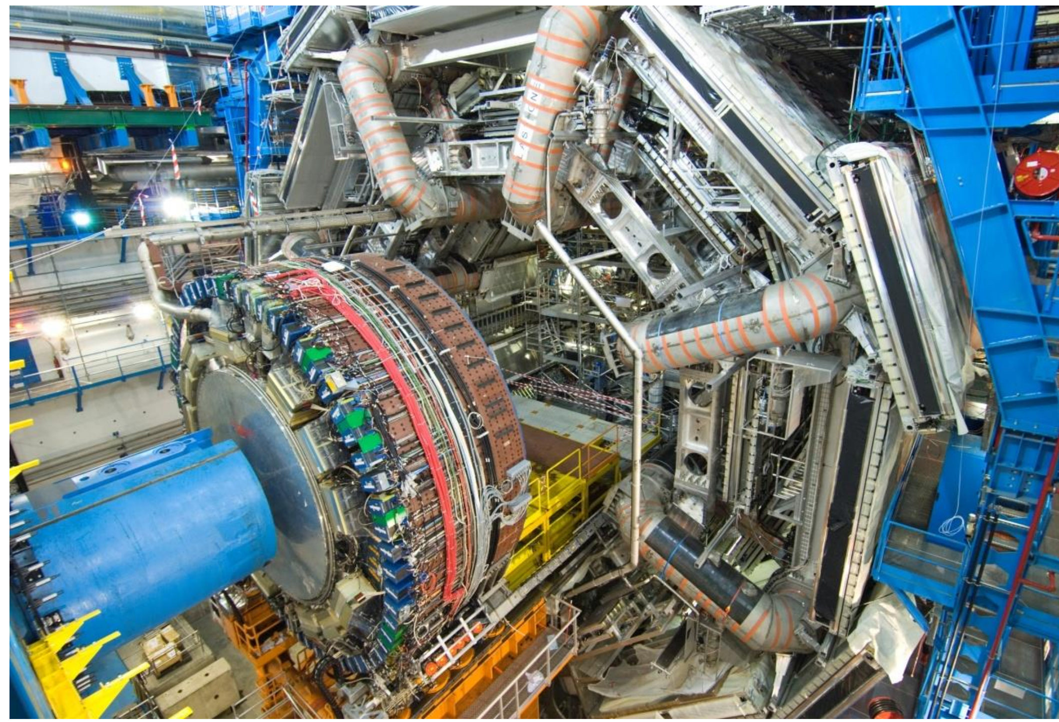


Courtesy G. Bregliozzi

Upgrade of Experiments

- Aperture reduction of experimental beam pipes at ALTAS and CMS interaction points:
  - Diameter reduction from 58 to 47 mm
  - install detectors closer to the vertex point
  - Full opening of the detectors to exchange the chambers





6. Résumé

Summary

- The LHC vacuum system is made of :
  - cryogenic systems (1,9 K – 5 to 20 K)
  - baked systems
  - NEG coating

- The LHC vacuum system has been designed to deal with:
  - static sources of gases (metallic and graphitic surfaces)
  - dynamic sources of gases (ions, photons and electrons loads)

- The LHC vacuum system is presently operating as expected

- Some QAP issues but no design issue

- During installation and commissioning phases, innovative solutions have been developed:
  - RF ball
  - Ne venting

- Activities are conducted during 2013-2014 long shutdown to:
  - repair, consolidate and upgrade

2015

- First beams:
  - March, April
- 50 ns beams:
  - scrubbing run mid May
  - Intensity ramp up in June
- 25 ns beams:
  - scrubbing run end June
  - Intensity ramp up in July-August
- Physics with nominal beams:
  - from September

Acknowledgments

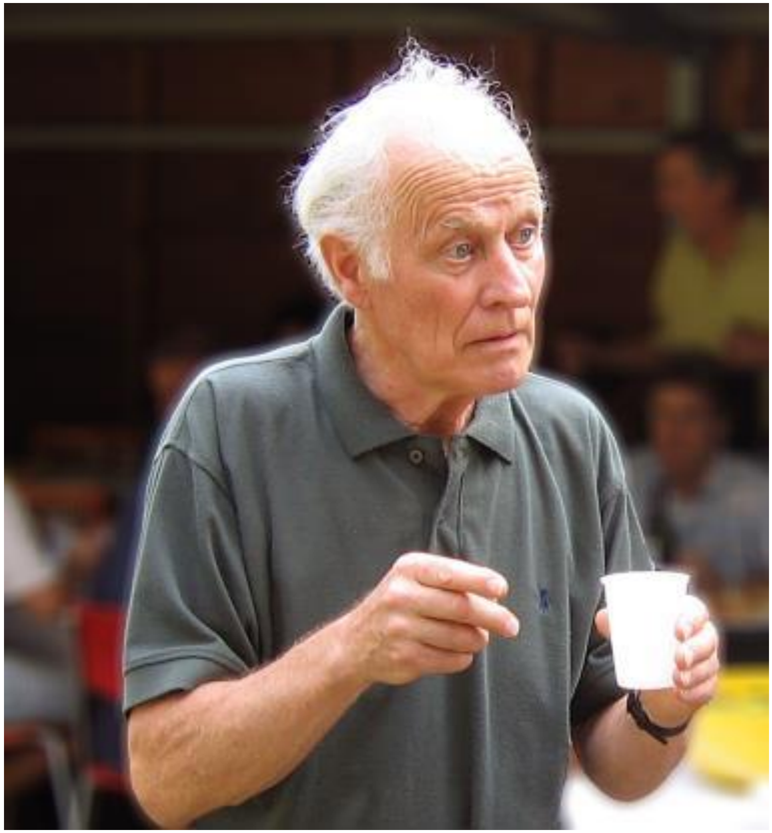
- Many thanks to the CERN and external collaborators who participated to the design and installation of the LHC vacuum system under the successive directions of A.G. Mathewson, O. Gröbner and P. Strubin

- Warm thanks also to J M. Jimenez for the constant support and to the TE-VSC-LBV team for its investment and constant commitment during commissioning of the LHC.

In memory of Roger Calder

1934 – 22 Feb 2014

- Who, among other important contributions such as vacuum firing and glow-discharge for the ISR, invented the 'perforated beam screen' in the LHC



Thank you for your attention !!!

CERN

YEARS / ANS CERN