Experience with first full year of LHC operation

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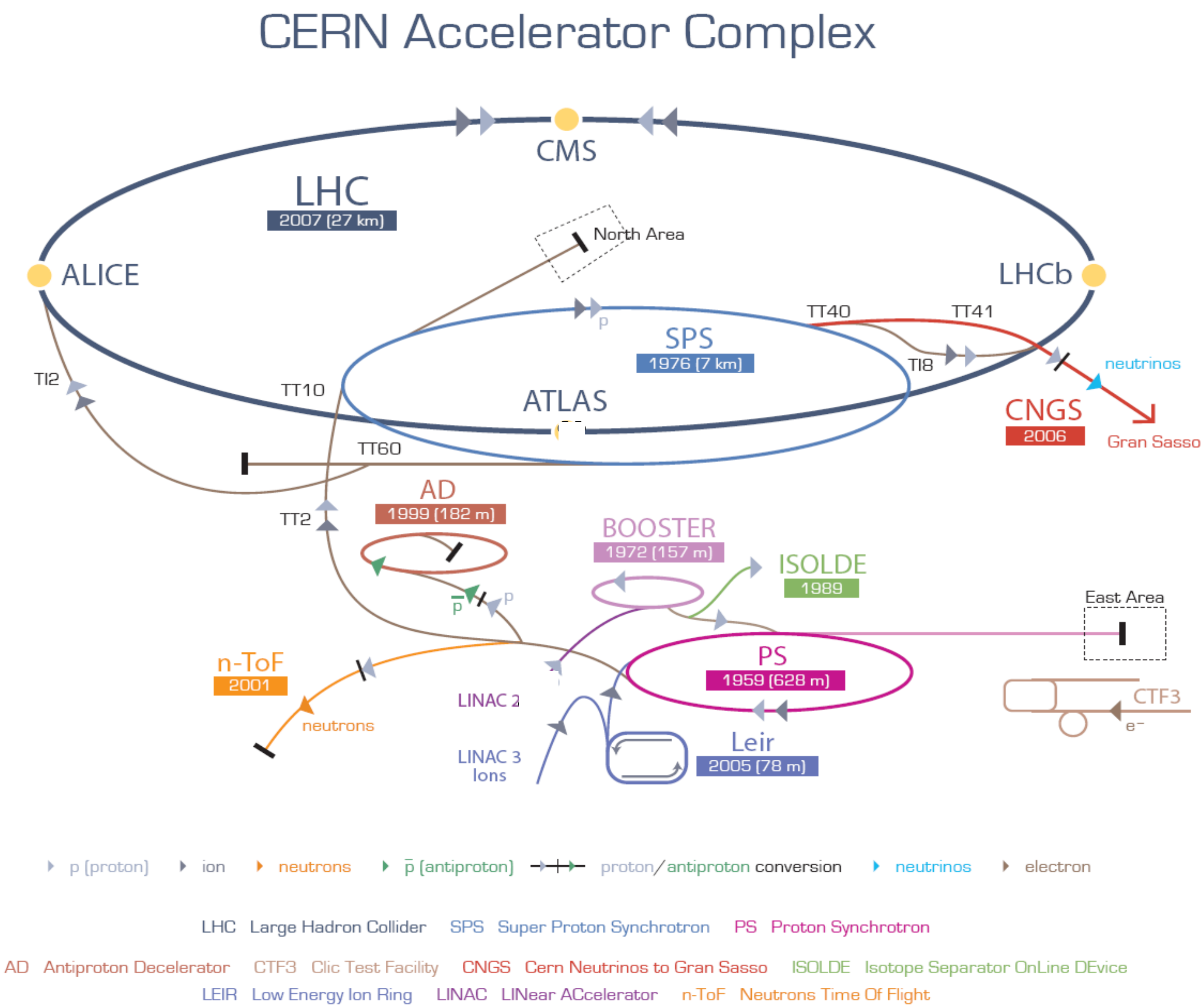
On behalf of
Vacuum, Surfaces and Coatings Group

Technology Department TE
Vacuum Surfaces.. Coatings

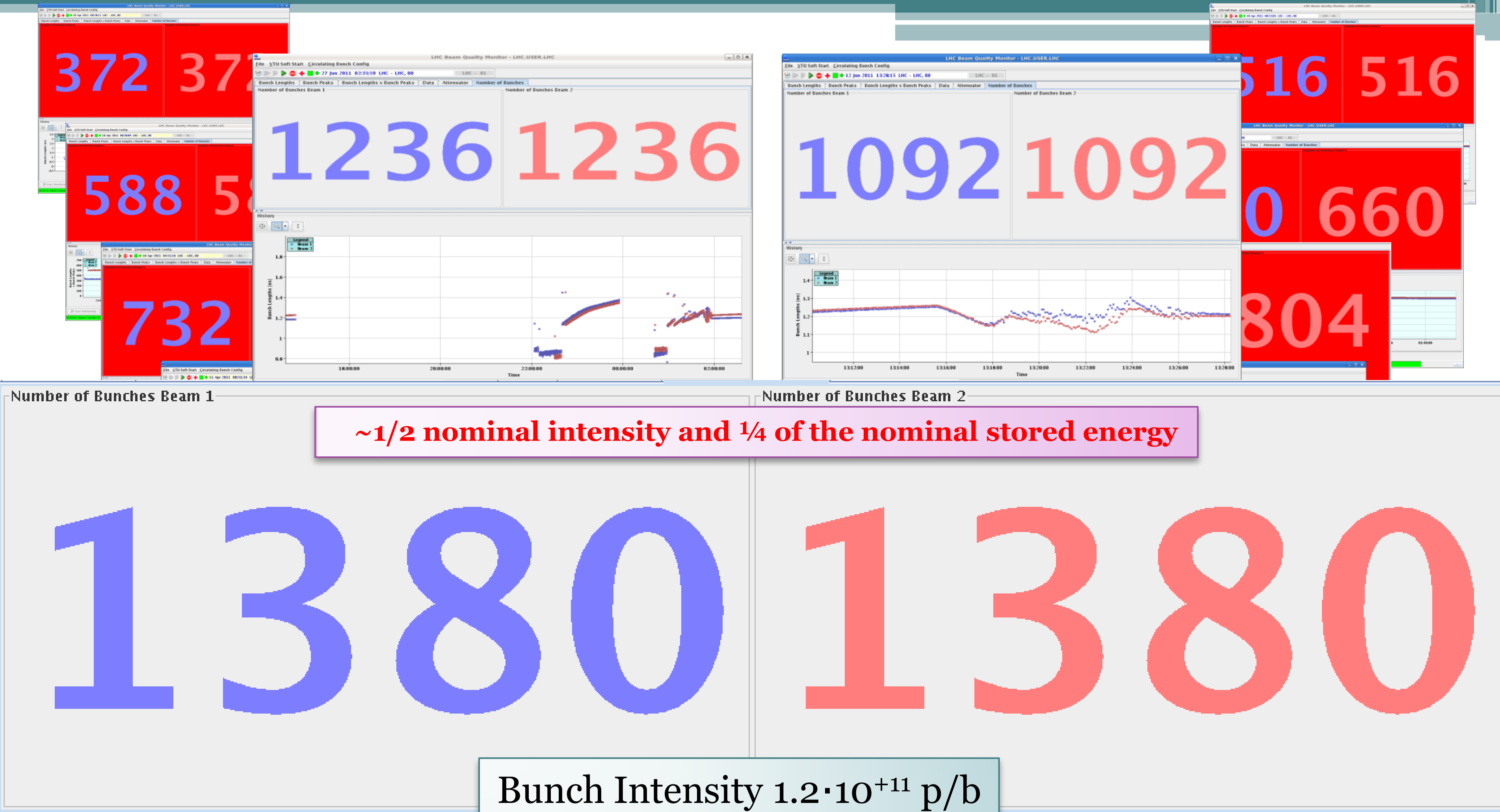
Outline

- First year of beam operation of the LHC
    - Luminosity & Efficiency.
- Vacuum System of the LHC: Operation with beam
    - Electron Cloud;
    - Synchrotron Radiation;
    - Cryogenic Transients.
- Vacuum System of the LHC: Operation without beam
    - Ultra Pure Neon Injection for fast equipments exchange;
    - Leak detection using total pressure gauge.
- Closing Remarks

The LHC


CERN Accelerator Complex
CMS
LHC
2007 (27 km)
North Area
ALICE
LHCb
TT40
TT41
SPS
1976 (7 km)
TI8
neutrinos
TI2
TT10
ATLAS
CNGS
2006
Gran Sasso
TT60
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
n-ToF
2001
PS
1959 (628 m)
CTF3
e⁻
LINAC 2
neutrons
LINAC 3
Ions
Leir
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
proton/antiproton conversion
neutrinos
electron
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

Bunches injected in 2011

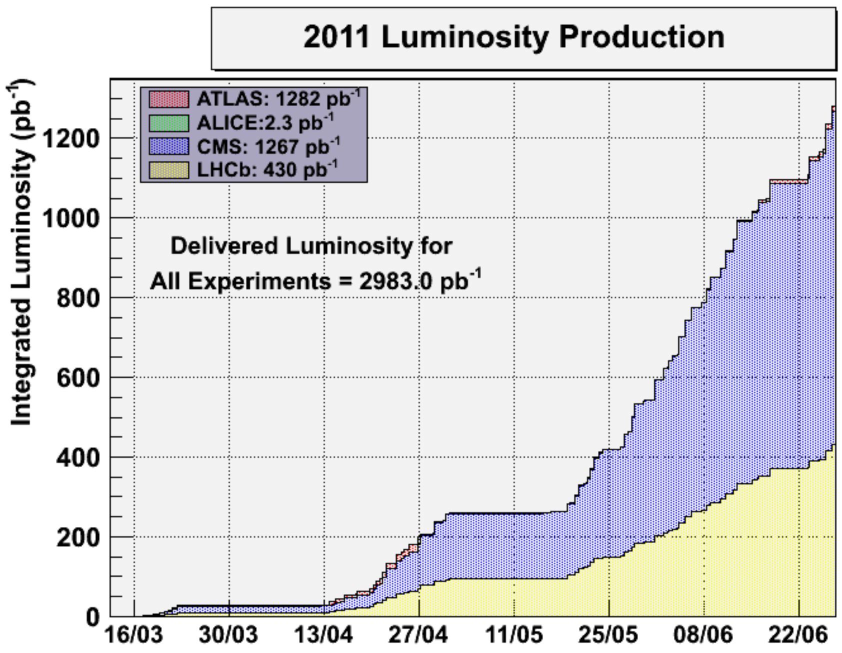


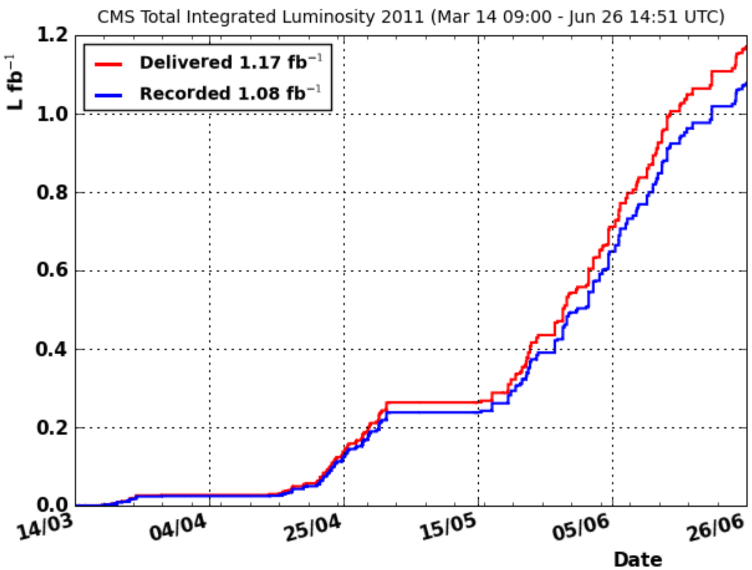
~1/2 nominal intensity and ¼ of the nominal stored energy

Bunch Intensity $1.2 \cdot 10^{+11}$ p/b
Bunch Spacing: 50 ns
Energy of 3.5 TeV

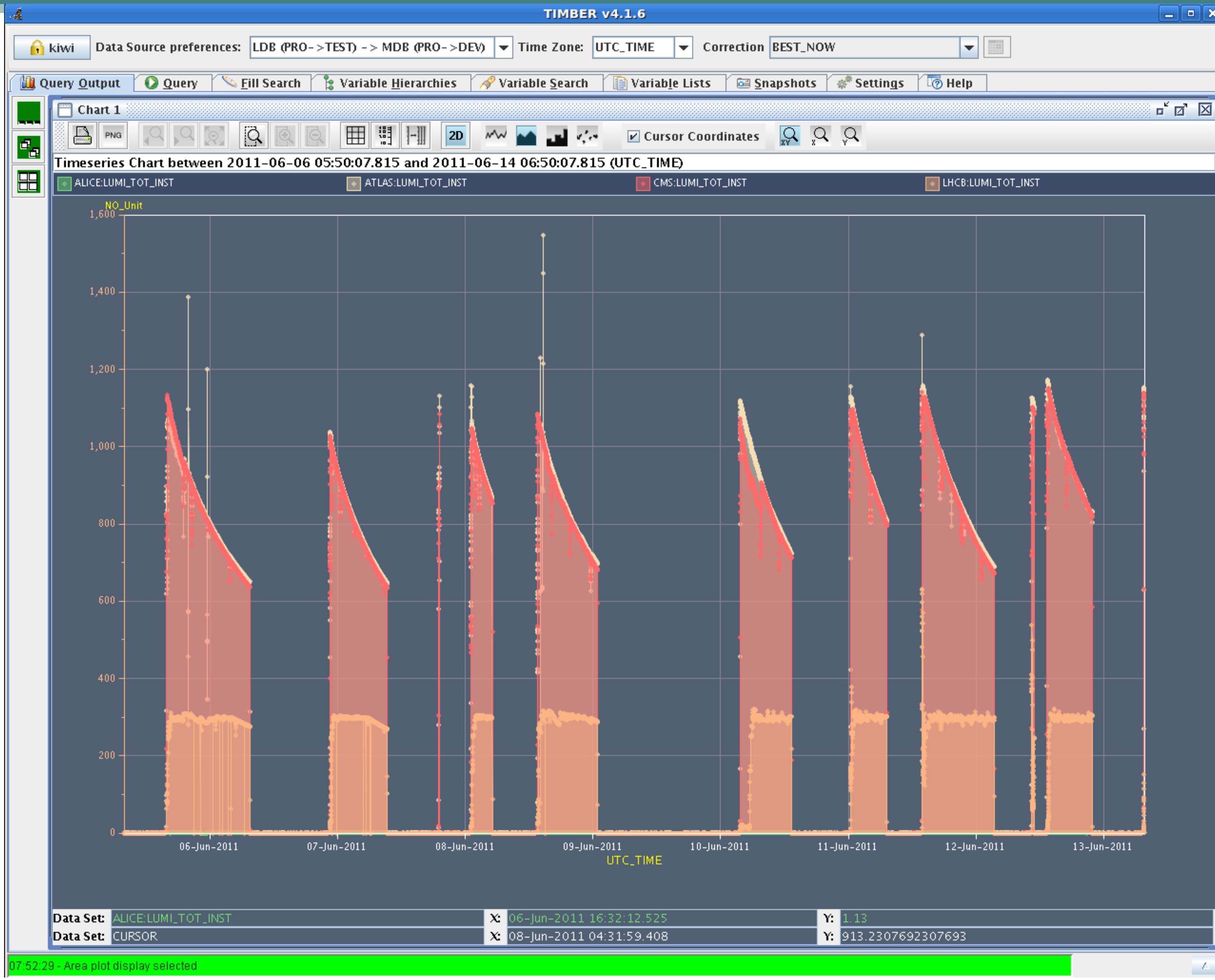
Record Obtained for 28th of June

- 1380 bunches colliding at 3.5 TeV
- Stored energy : 88 MJ
- Longest fill 1883 @ 1092b : 18 h
- Most productive fill 1883 : 47.5 pb-1
- Record luminosity : 1.26 x 10^{33} $cm^{-2}s^{-1}$



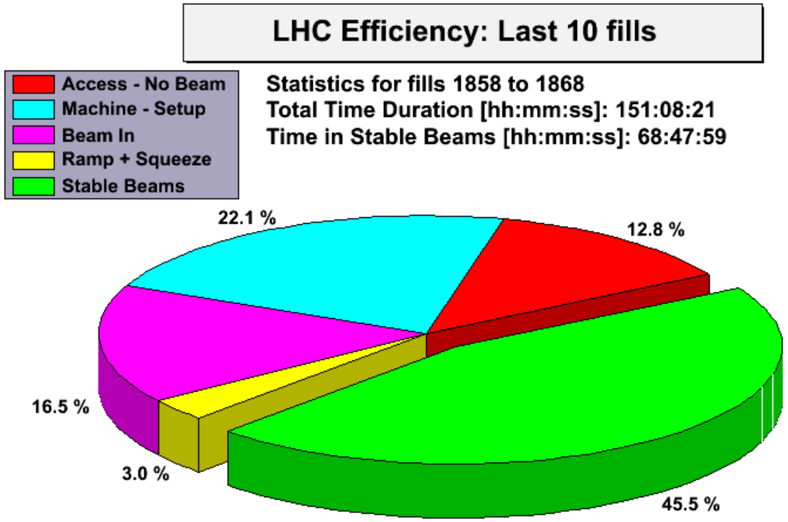


LHC Luminosity Production

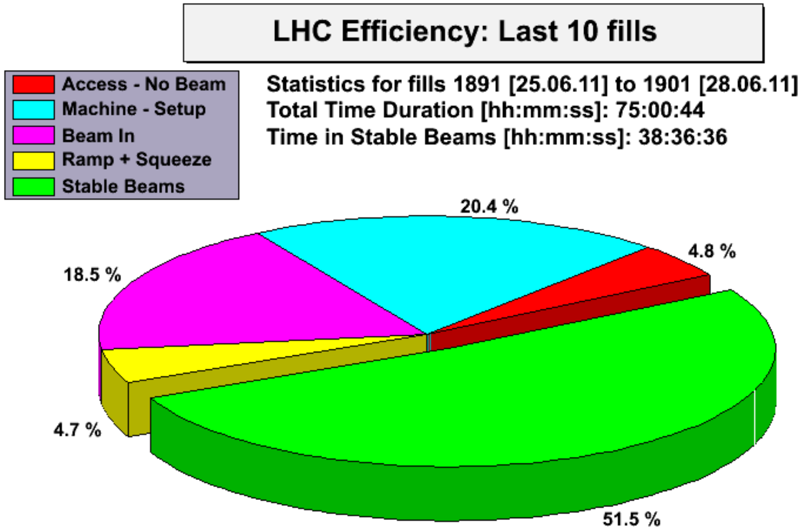


From Stephen Myers, LHC Performance, 15th June 2011

LHC Efficiency



From fill 1858 - 1868



From fill 1891 - 1901

From Stephen Myers, LHC Performance, 15th June 2011

It is not always easy! A day in June.

Cryo S56

Injection preparation for 144b

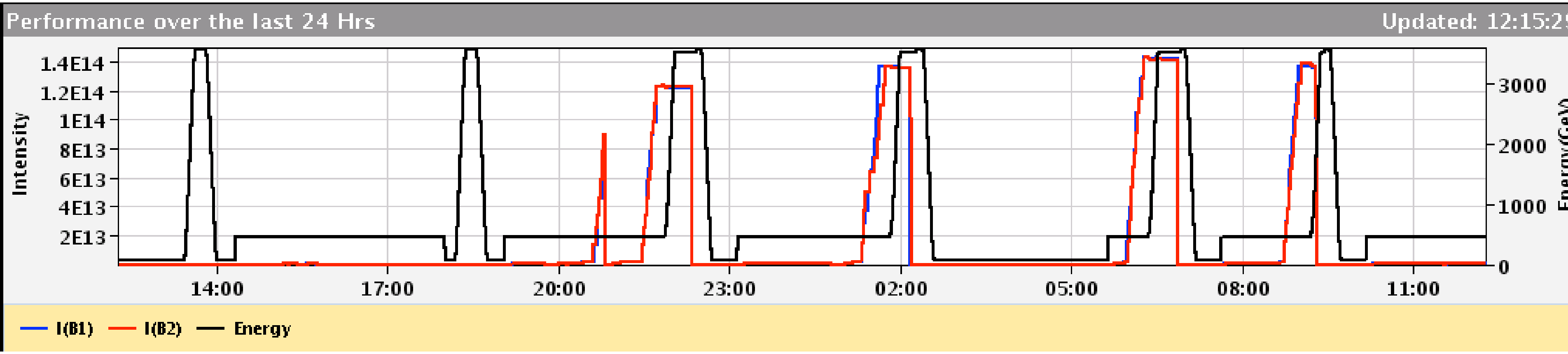
Cryo S34

UFO IR2

QPS noise → quench

RF arc

Collimator temperature



Vacuum System of the LHC: Operation with beam

- Losses at the Injections
- Synchrotron Radiation
- Electron Cloud
- Cryogenic Transients

Vacuum System of the LHC: Operation with beam

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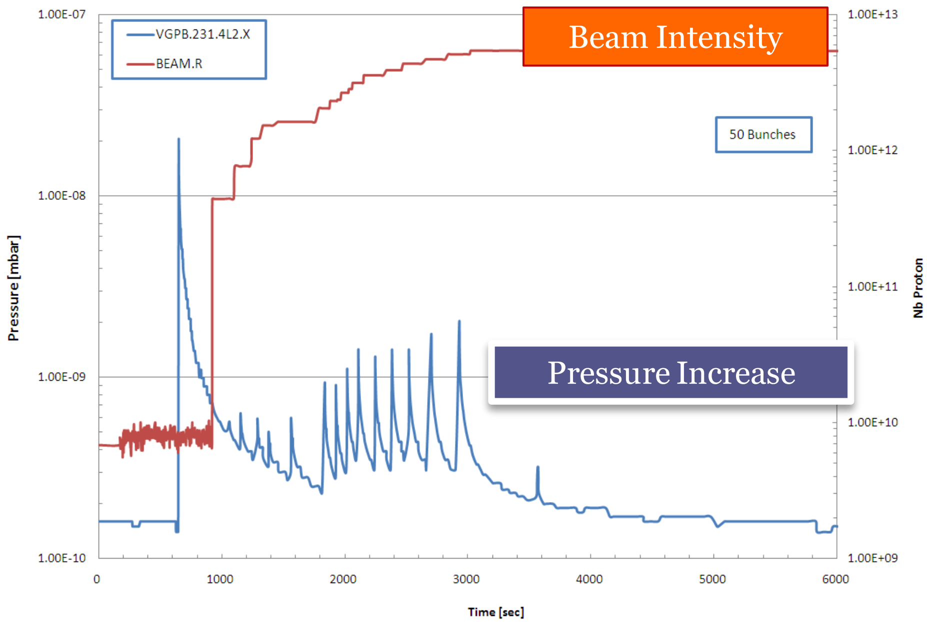
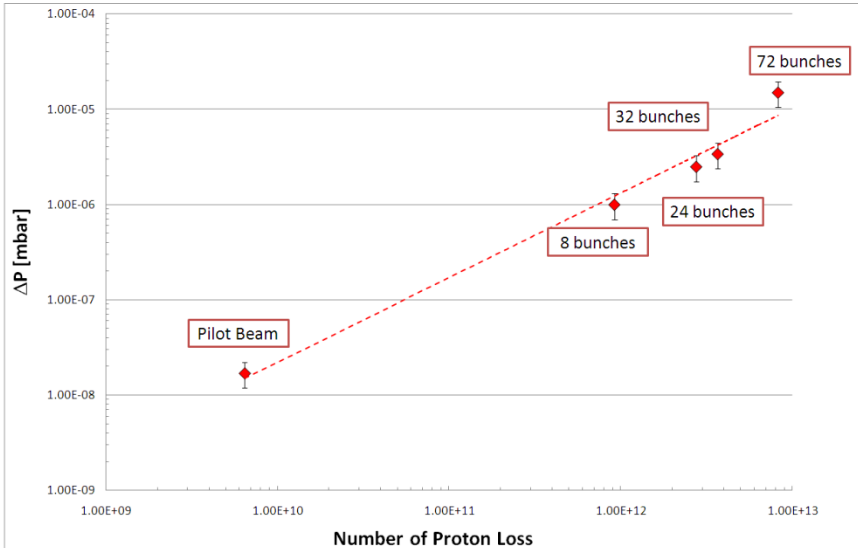
Protons Loss Losses at Beam Injection



- Pressure rise induced during injection with train of 48b @ 450 GeV
- Pressure increase due to proton loss on the Target Dump Injection (TDI)



- Due to miss kick of the Magnet Kicker Injection (MKI) protons were lost @ 450 GeV
- Pressure up to 10^{-5} mbar range was achieved when 72 bunches where lost

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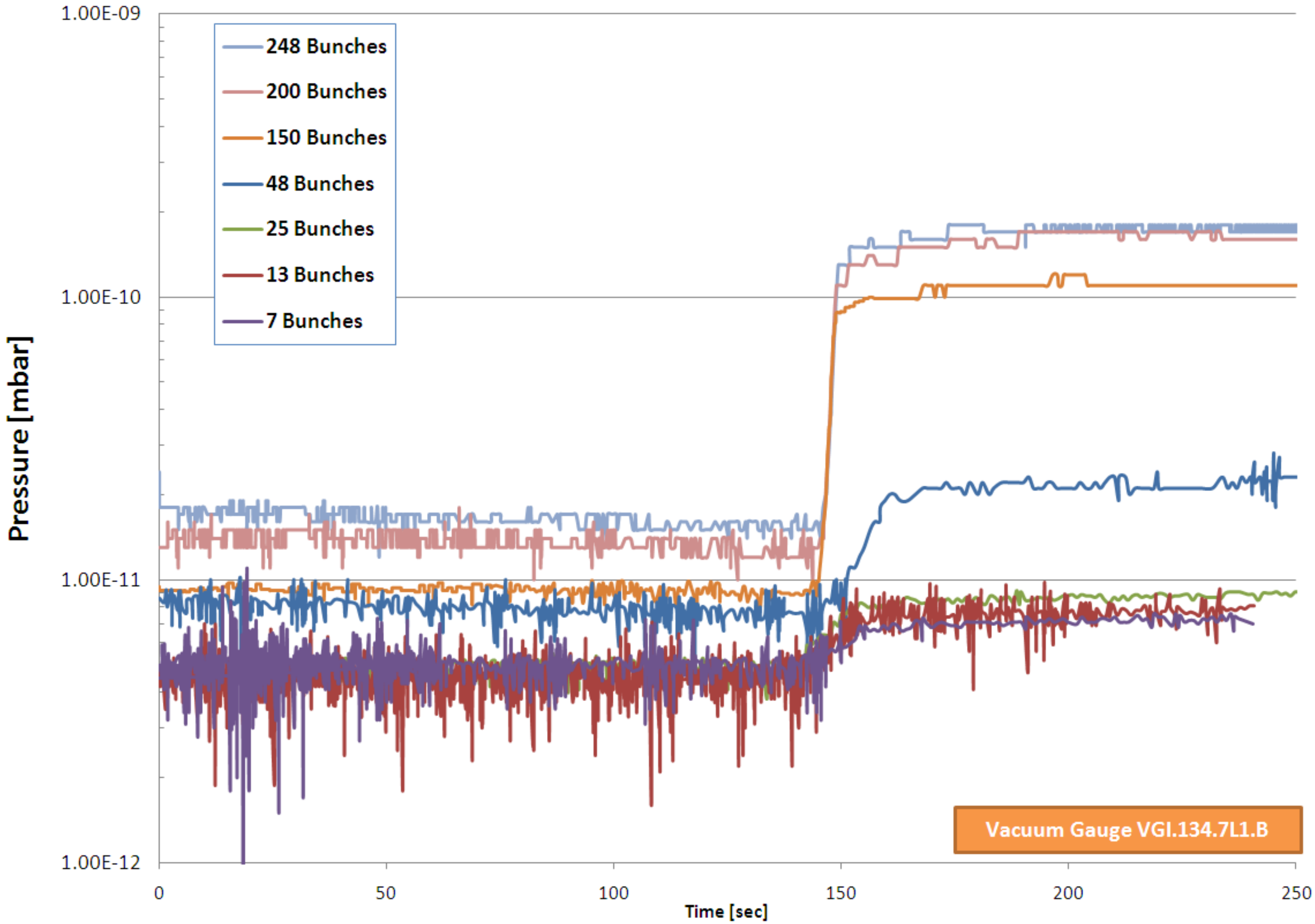
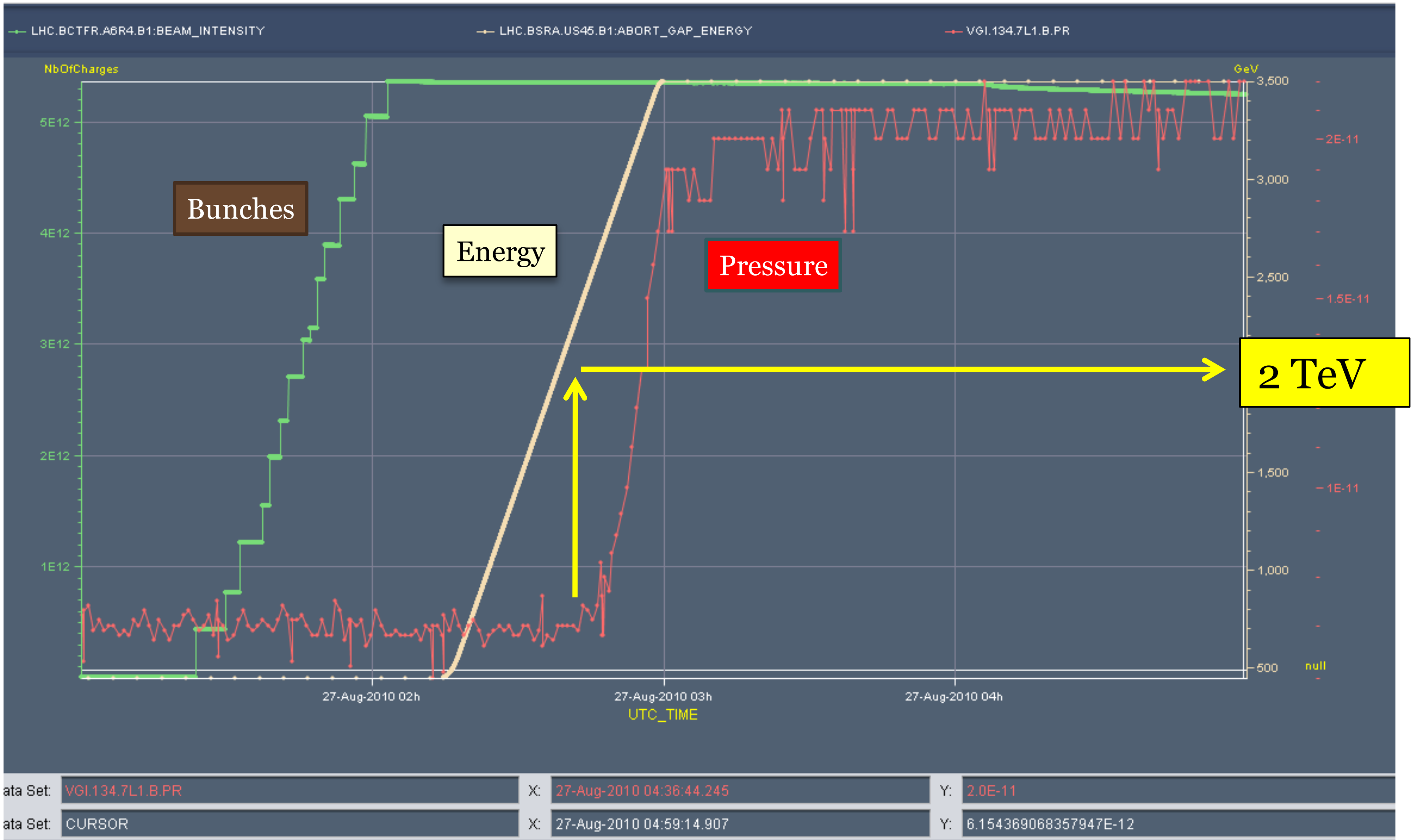
Synchrotron Radiation Effects in 2010

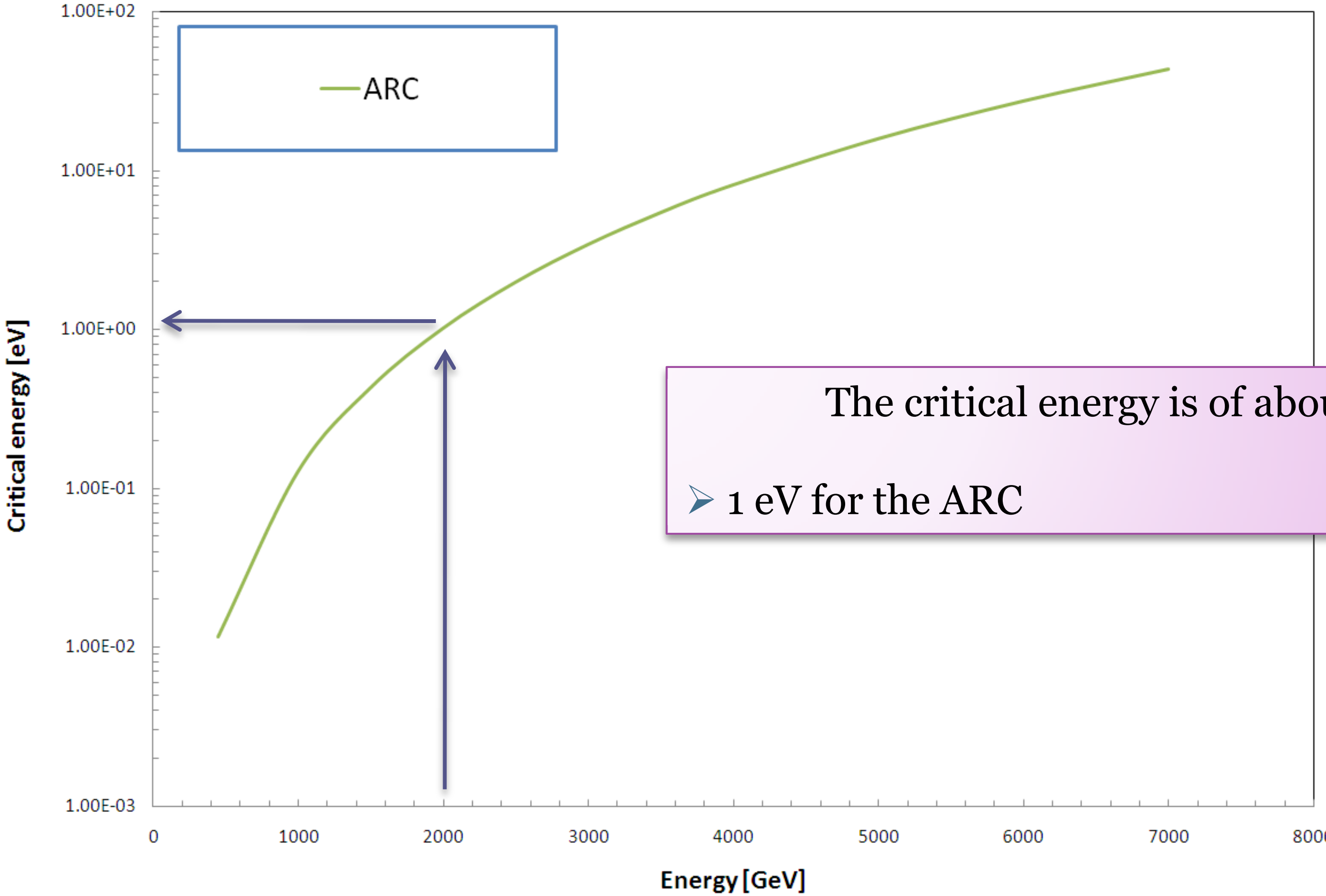


Synchrotron Radiation: Threshold Critical Current



27 August 2010 – 48 Bunch – 3.5TeV

Critical Energy



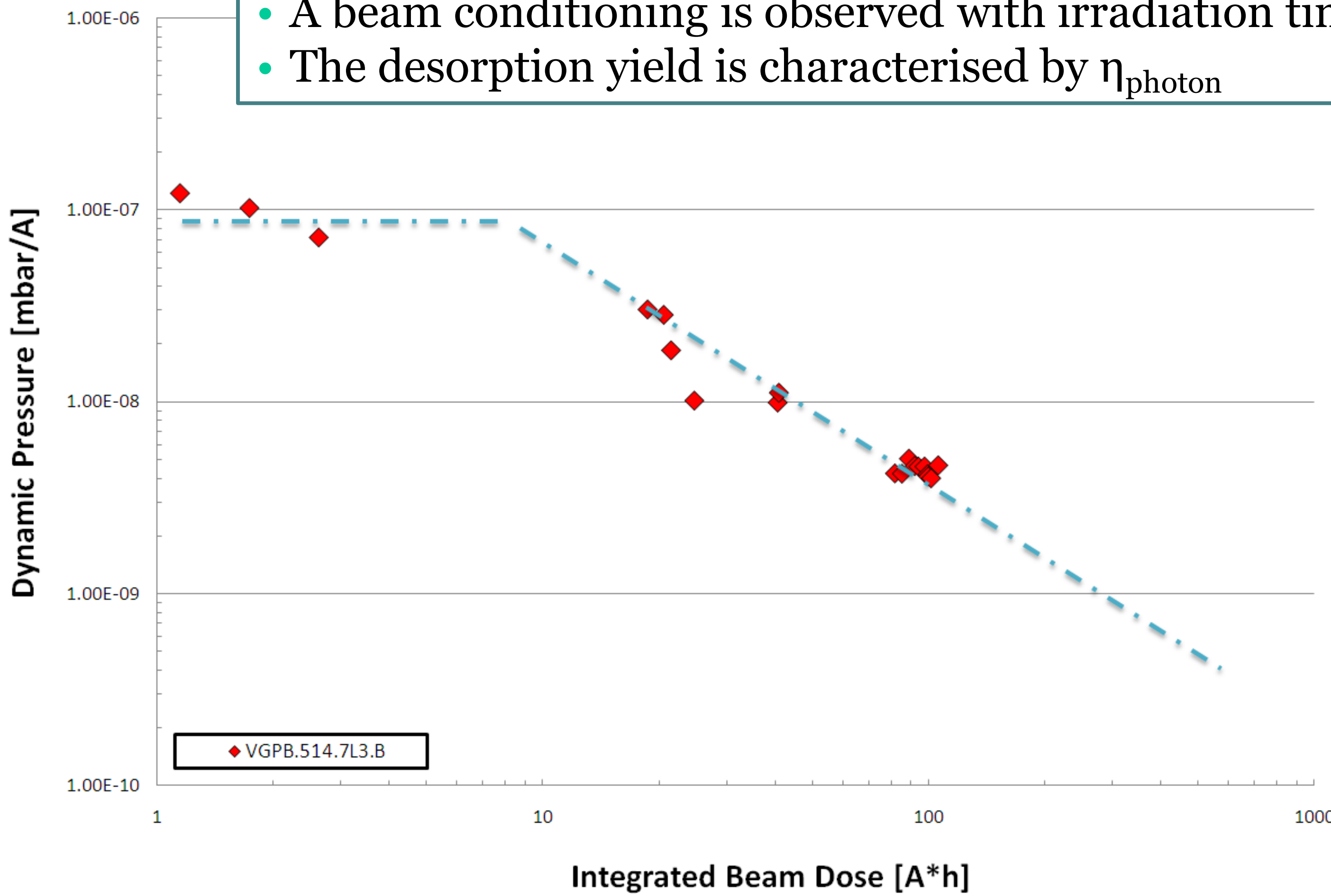
The critical energy is of about

- 1 eV for the ARC

$$\text{Protons}: \varepsilon_c[\text{eV}] = 3.5835\,10^{-7}\,\frac{\text{E}[\text{GeV}]^3}{\rho[\text{m}]}$$

Conditioning under photon irradiation

- A pressure increase is observed due to SR irradiation
- The pressure increase can be up to several orders of magnitude !
- A beam conditioning is observed with irradiation time
- The desorption yield is characterised by η_{photon}



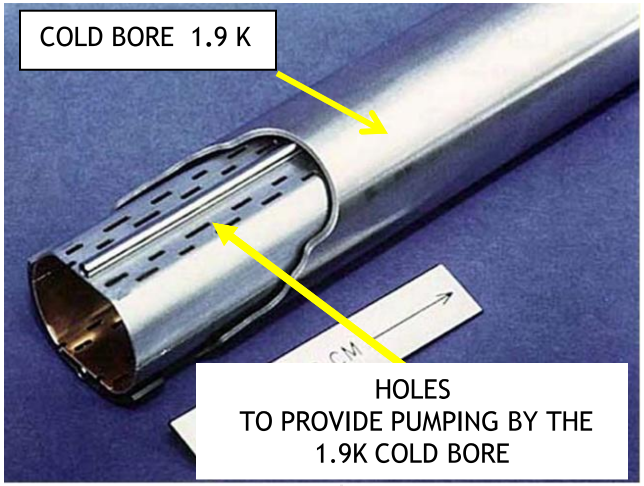
Preliminary Results

Cold Beam Vacuum: How to deal with Synchrotron Radiation?

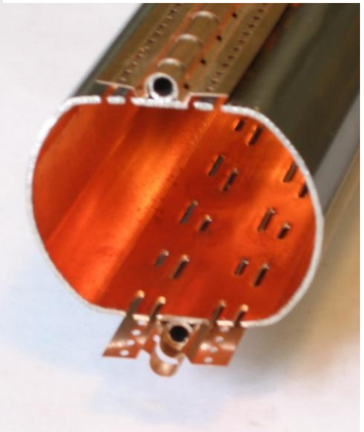
Innovating conceptual design with a "beam screen"

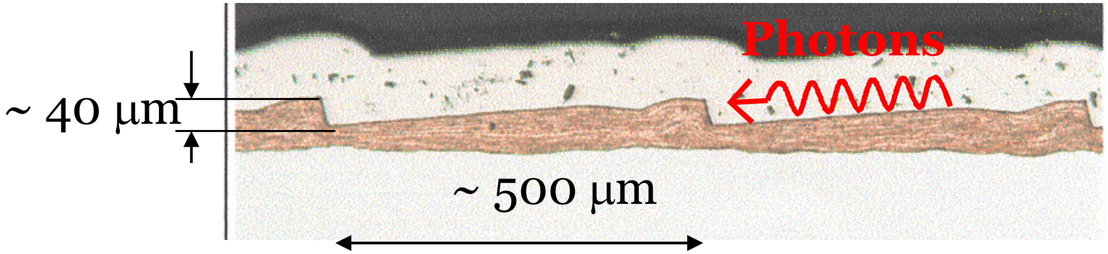
Beam screen inserted inside cryomagnet cold bore

- **Intercept the heat loads**
  - Synchrotron light,
  - Energy loss by nuclear scattering,
  - Image currents,
  - Electron clouds.
- **Provide vacuum pumping**
- **Low photo-electron reflection**
- **Optimize the beam aperture**



BEAM SCREEN AT 5→20 K





Vacuum System of the LHC: Operation with beam

- Losses at the Injections
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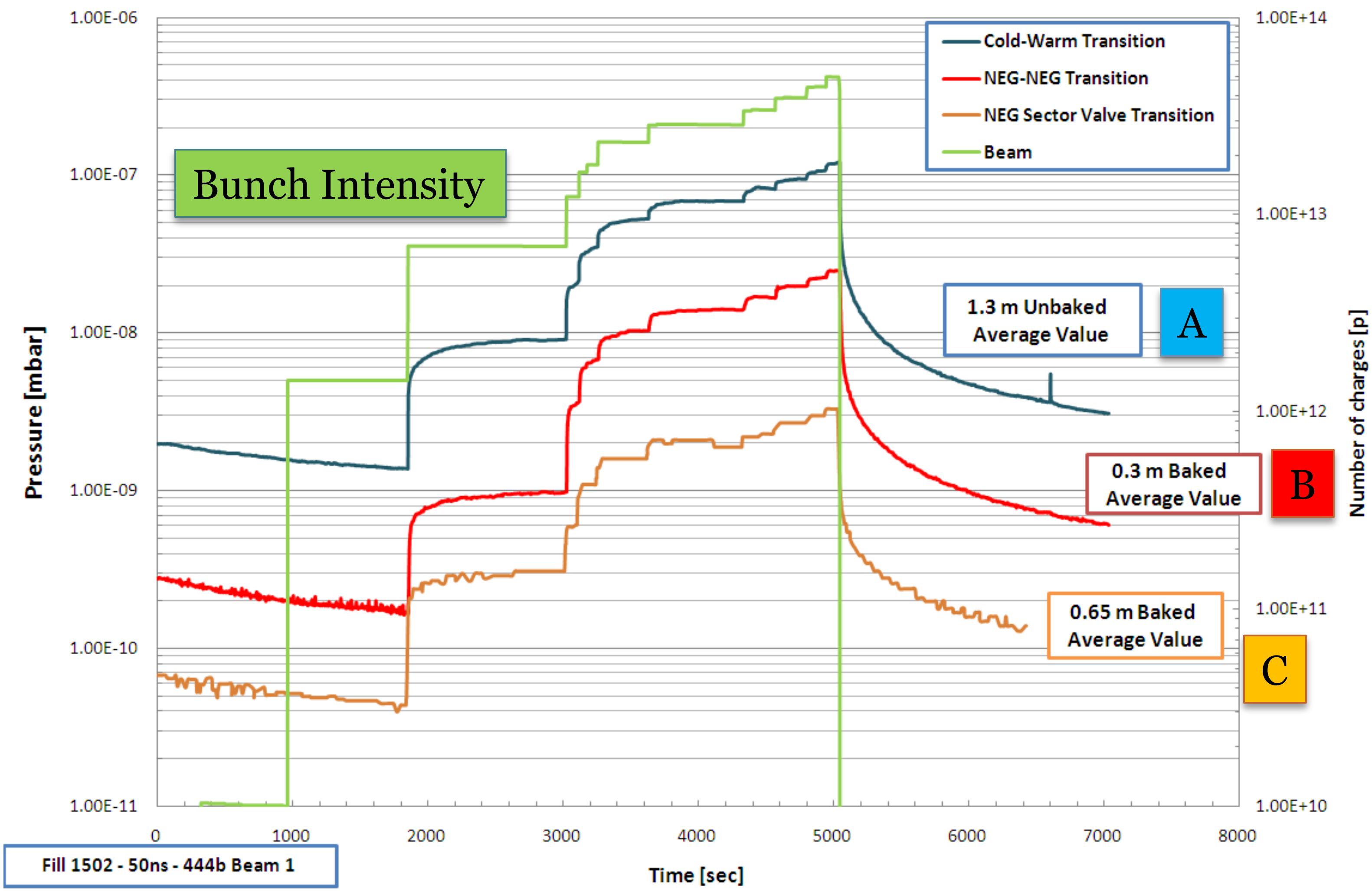
- **Electron Cloud**
- Cryogenic Transients

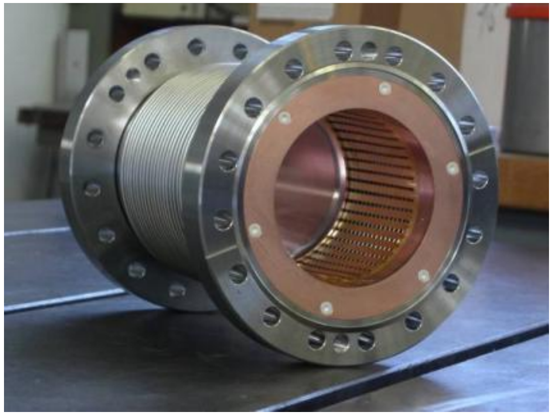
Electron Cloud Build-Up

- The electron cloud build-up:
  - Is a threshold phenomenon → bunch population; → number of bunches in the train → Linear build-up
  - Depends highly on the Secondary Electron Yield (SEY) δ
    - Is enhanced by the low energy electrons surviving the gaps between bunch trains (reflectivity of low-energy electrons)
  - Is attenuated by the spacing between bunches and bunch trains
  - Is affected by many other parameters like:
    - Size of the beam vacuum pipe
    - Magnetic field
    - Temperature of the beam pipe walls

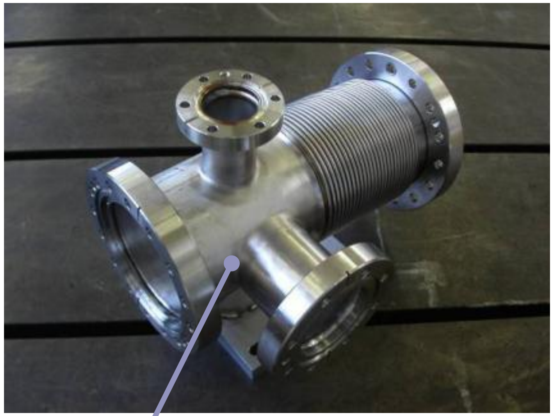
Pressure rise @ different locations: 50 ns bunch spacing



Bellows Modules: Source of Electron Cloud

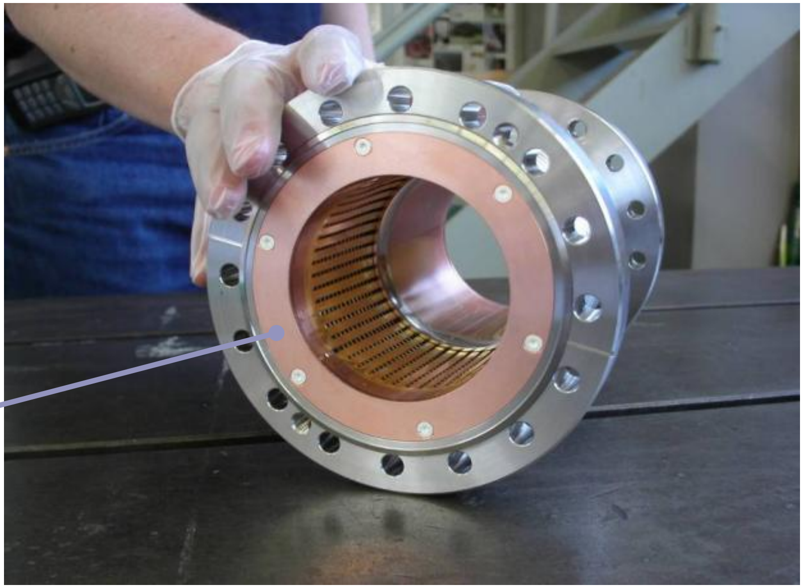


Short module 200 mm



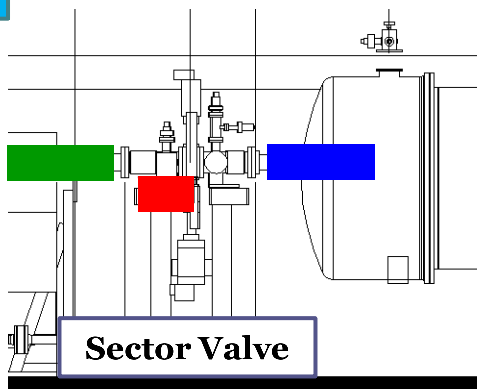
Long modules 300 mm

- Short: no pumping
- Long: pumping & support option
- Cross-sectional transitions with inserts



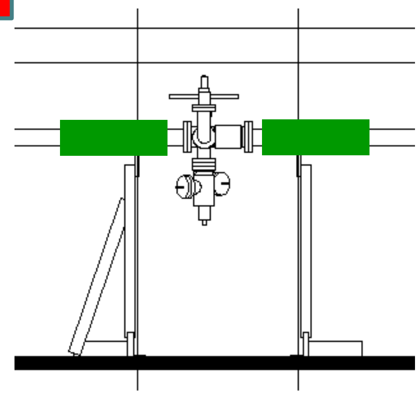
Pressure rise @ different locations: Gas composition

A Cold-Warm transitions



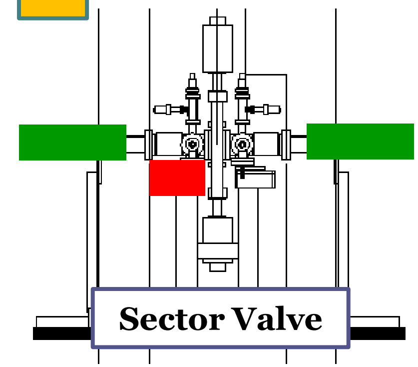
- Unbaked: SEY ~2.3.
- Length 1.3 m
- Pumping speed from NEG, Cryo and Ion pumps

B NEG / NEG transition



- Baked but uncoated: SEY ~1.6-1.9.
- Length 0.3 m
- Pumping speed from NEG and maximum for $CH_4 \approx 10$ L/s

C NEG / Sector Valve

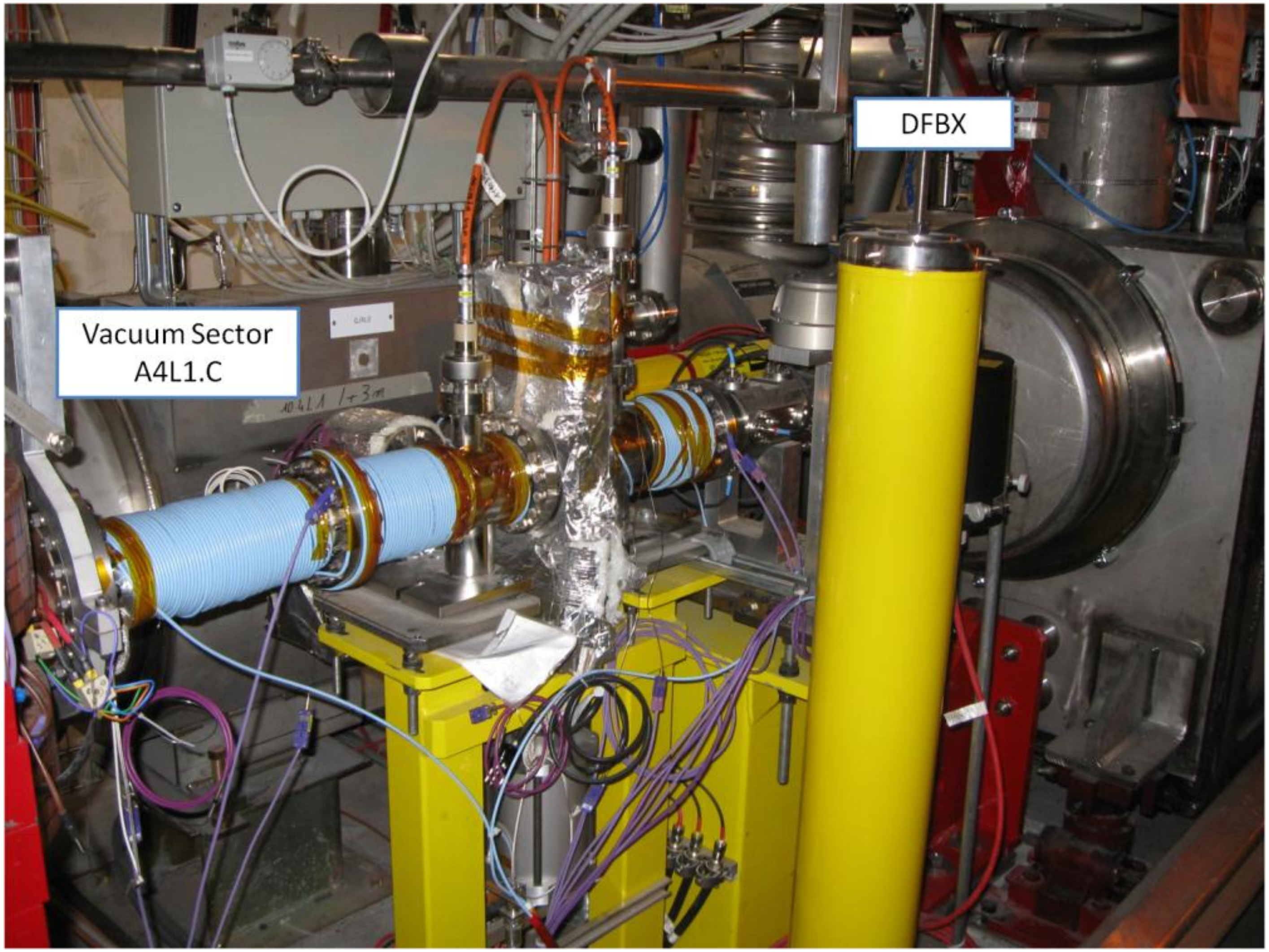


- Baked but uncoated: SEY ~1.6-1.9.
- Length 0.6 m
- Pumping speed from NEG and ion pumps

$$P \approx \frac{\eta_{Electrons} \cdot \dot{\Gamma}_{Electrons}}{S}$$

Cold
NEG
Ion Pump

Solenoids: Multipacting Suppressors



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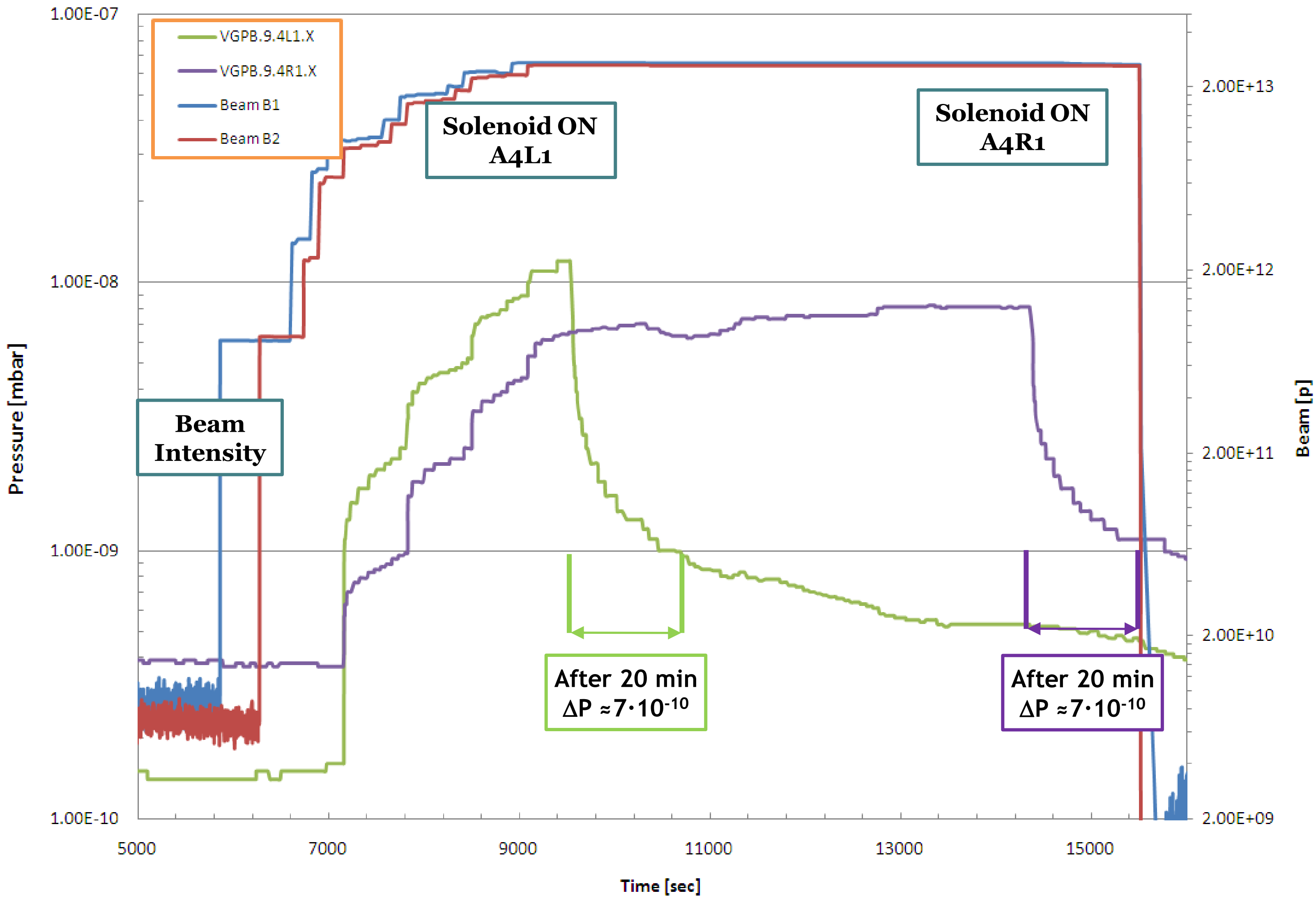
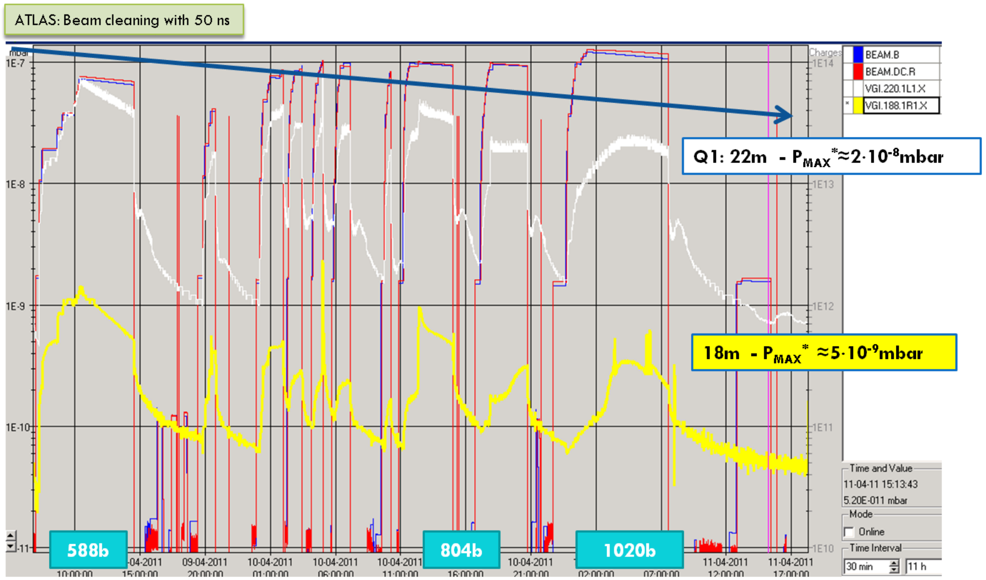
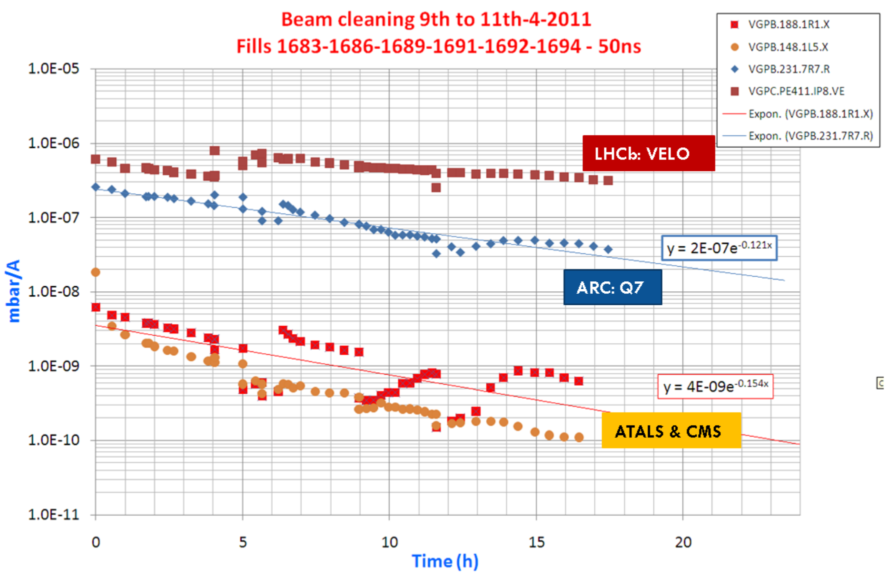


Remedies: Vacuum Scrubbing





Scrubbing run:
Increase beam current
Pressure decrease due to vacuum cleaning & scrubbing

For ATLAS and CMS reduction of one decade in about 17h (periods with constant number of bunches)

All the desorbed molecules are chemisorbed on NEG and physisorbed on the beam screen

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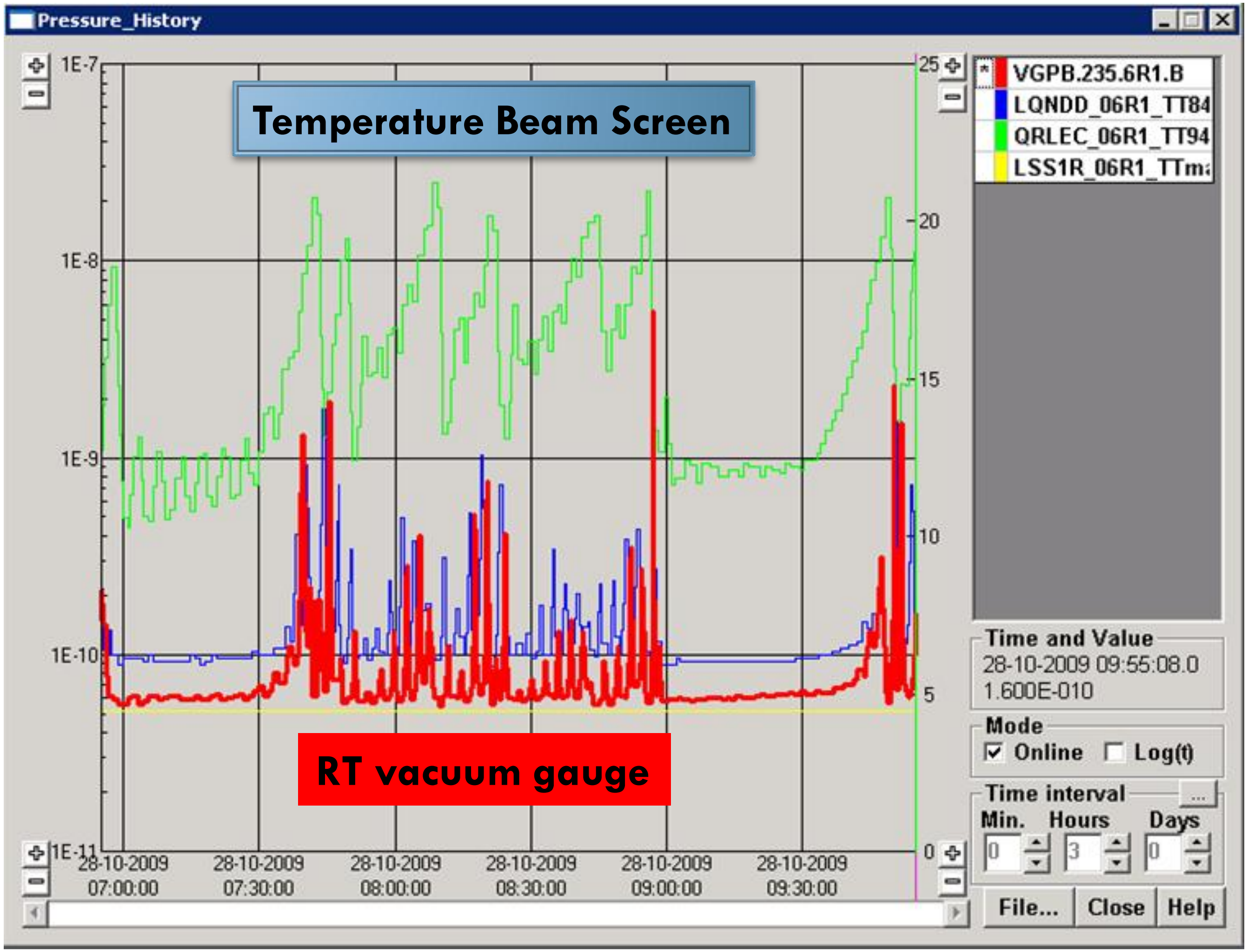
“Coupling” the cold and RT beam vacuum

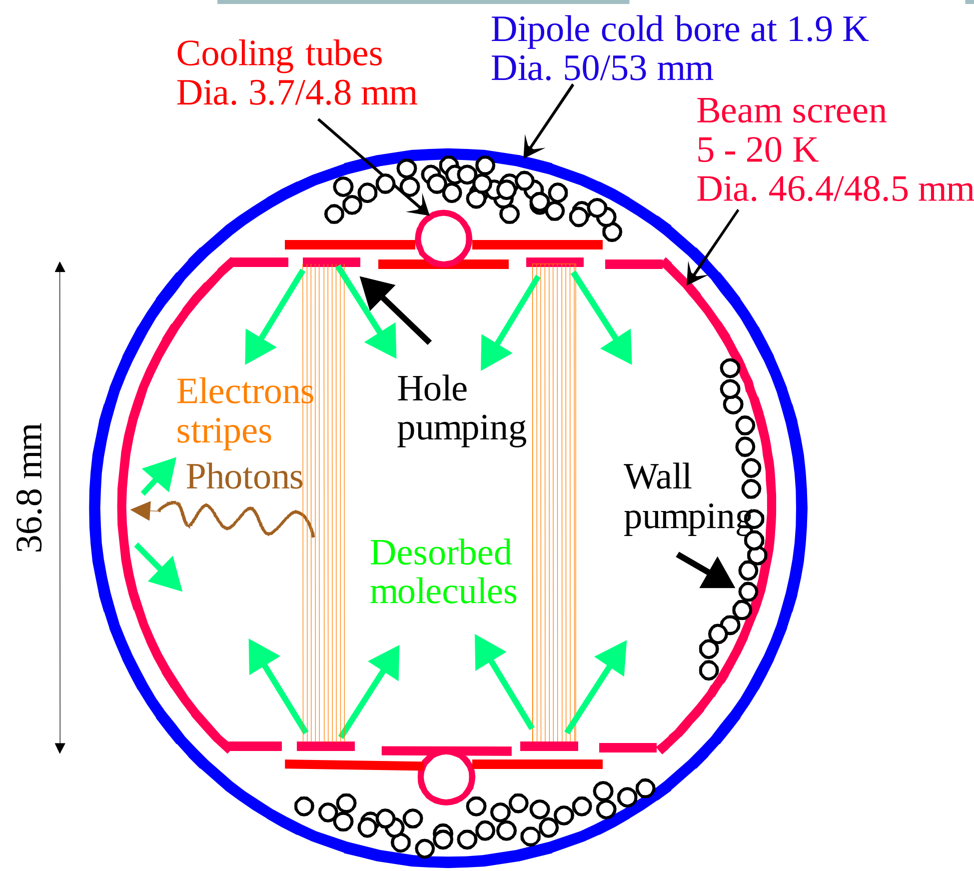


Temperature instabilities around 20K on the beam screen lead pressure oscillations on both “RT” and “Cold” vacuum gauges

Cold Vacuum Principle

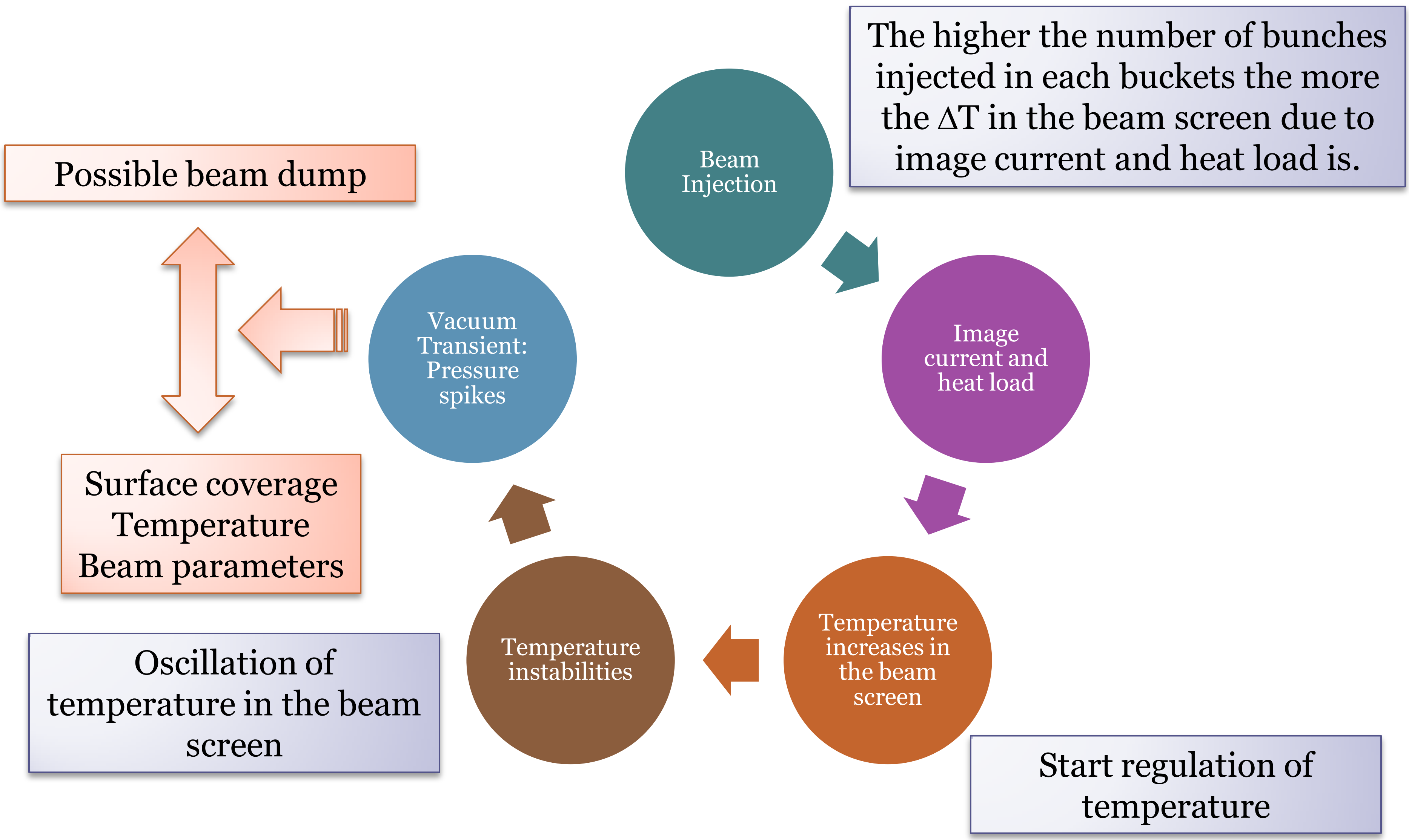
In cryogenic elements

- Molecular physisorption onto cryogenic surfaces (weak binding energy)
- For CH_4, H_2O, CO, CO_2 (molecules with a low recycling yield):
  1. First physisorbed onto the beam screen
  2. Then onto the cold bore
- H_2 is physisorbed onto the cold bore



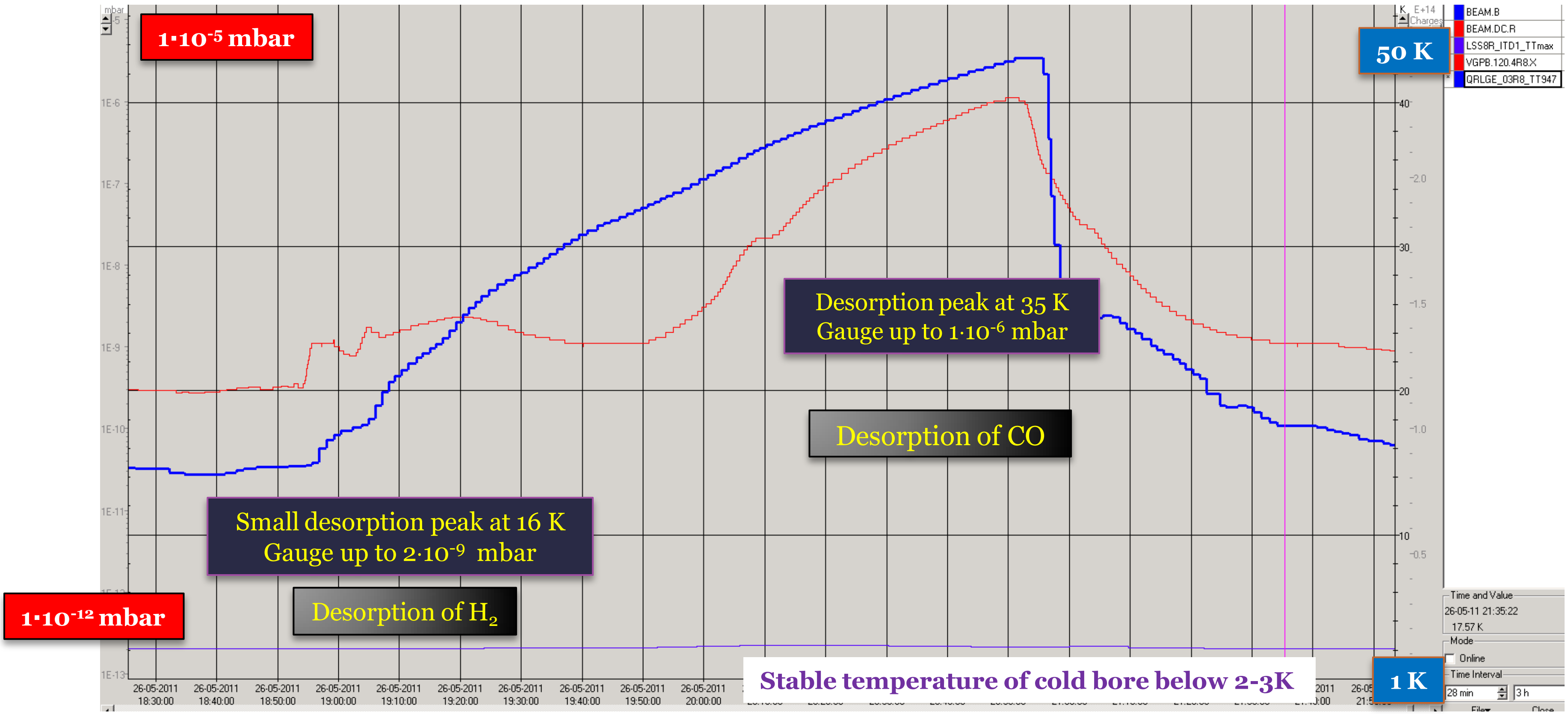
A wrong temperature could accumulate gas molecules in the beam screen surface

What can happen?



Remedies: Warming up the Beam Screen

Remove the excess gas on the beam screen inner surface onto the cold bore to avoid pressure transient

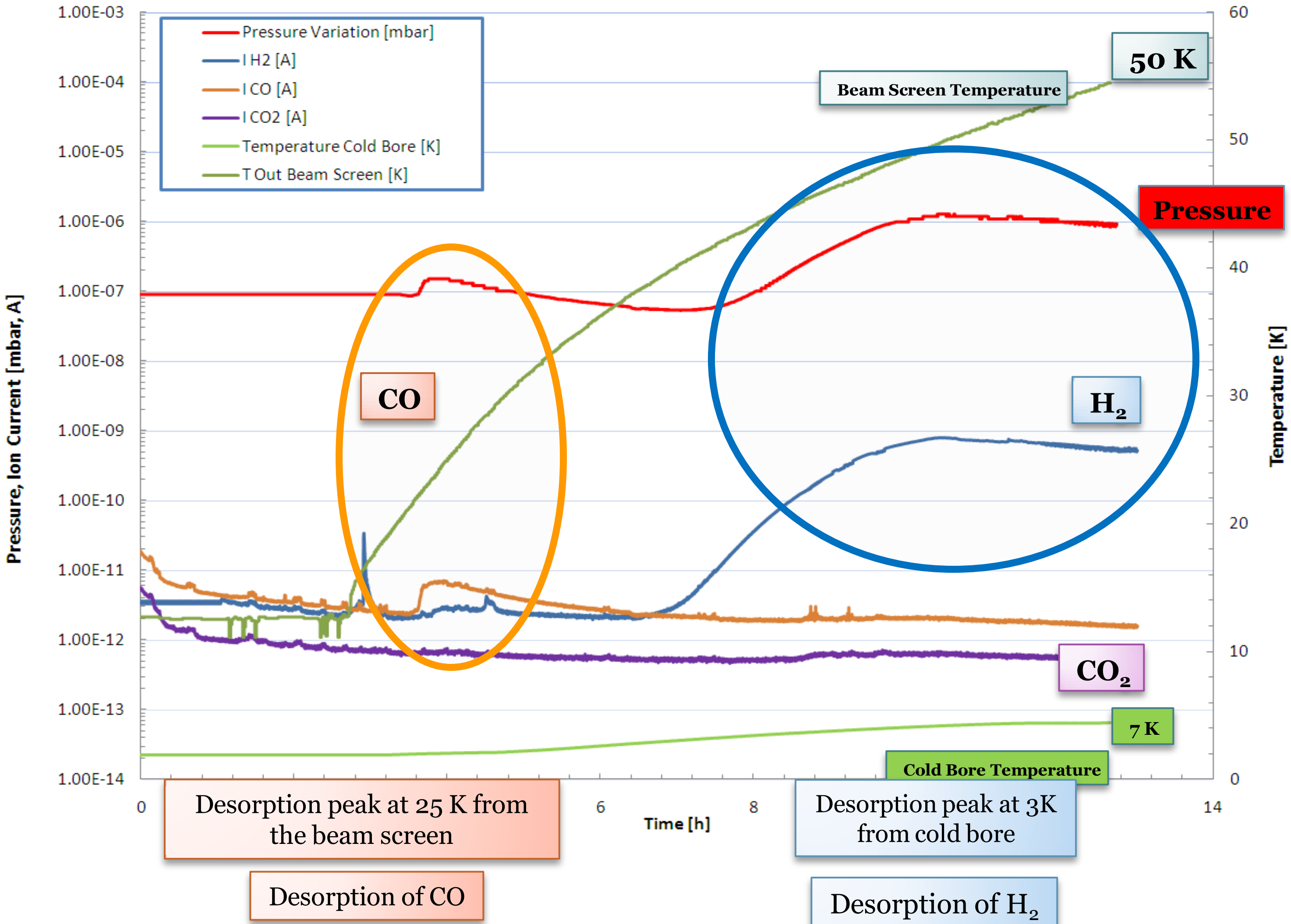


The CO desorbed is pumped by the cold bore

Test performed the 26/05/2011 at 19:00

Remedies: Pumping adsorbed gas

Warming up beam screen and cold bore while pumping



G. Bregliozzi, OLAV III , Oak Ridge, Tennessee, USA July 11-14, 2011

Vacuum System of the LHC: Operation without beam

- **Ultra Pure Neon Injection for fast equipments exchange;**
- **Leak detection using total pressure gauge.**

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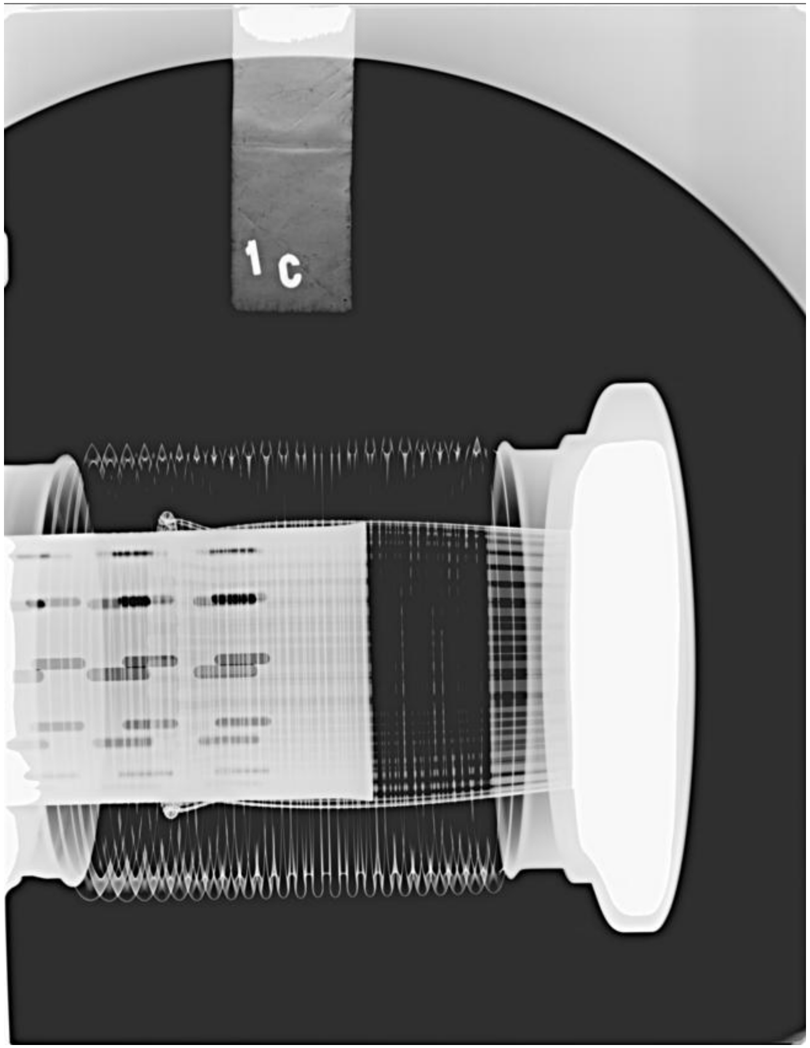
X-Ray of Interconnecting Modules: Non Conformity

Damaged RF-shielding fingers

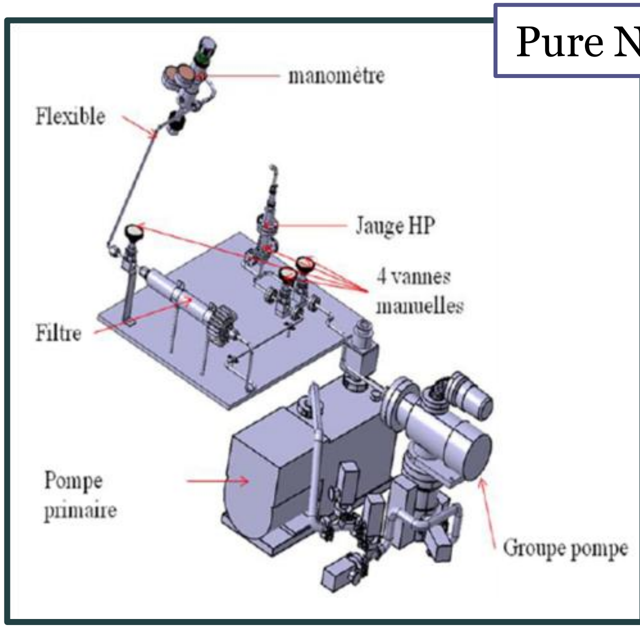


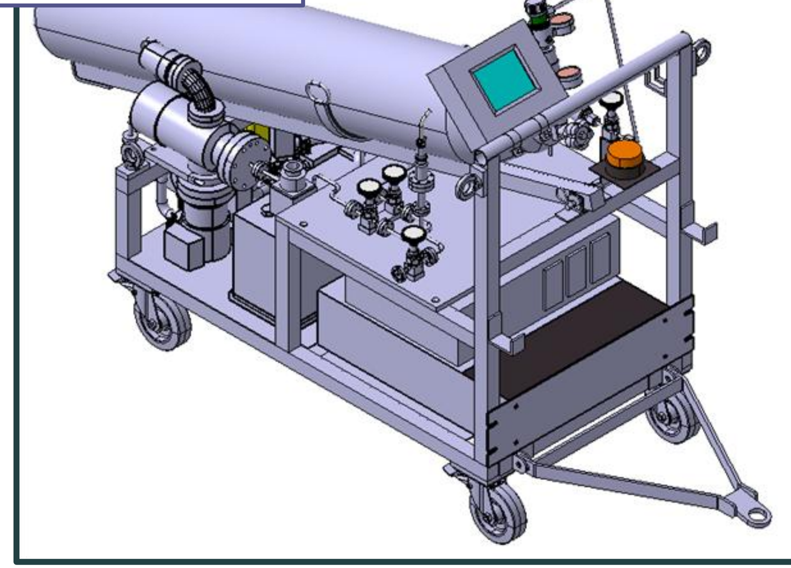
Fast exchange of equipments under vacuum by maintaining the NEG vacuum activation

240 modules inspected, 25 non-conform according to the acceptation criteria

Intervention on LSS with vacuum activated NEG

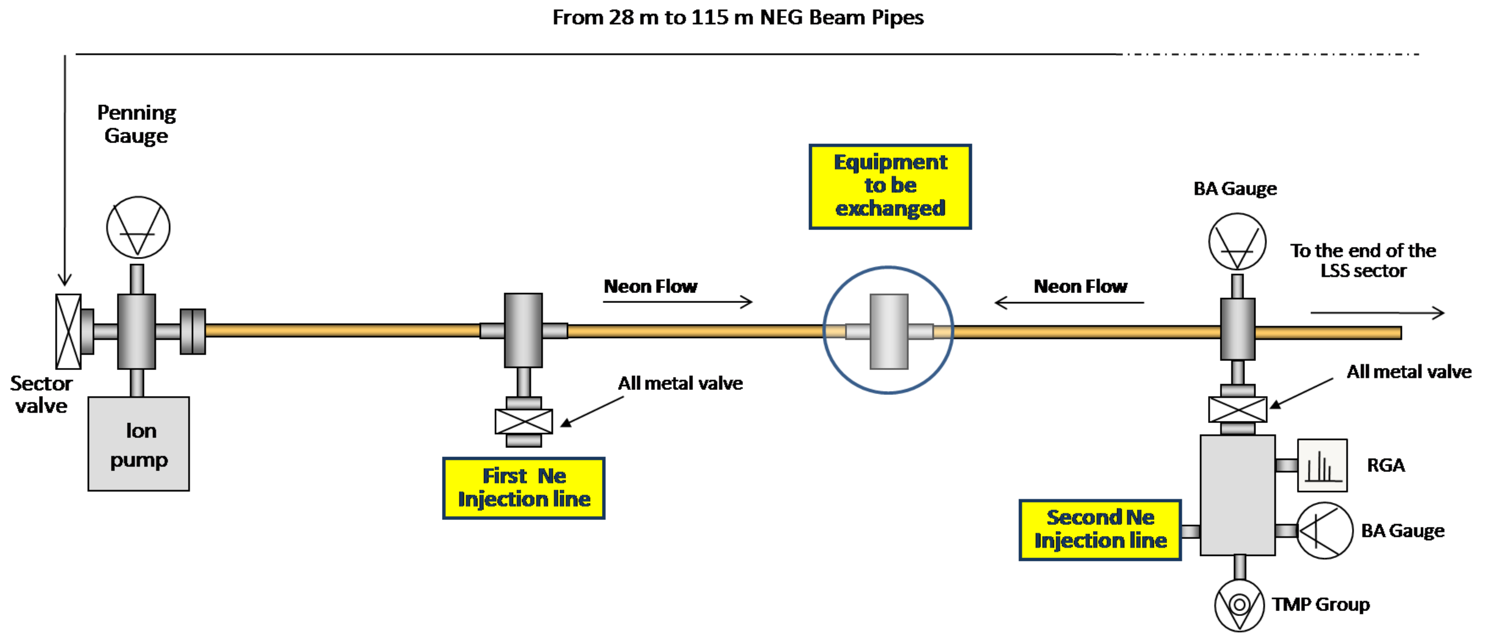
Pure Neon Injection System





- The principle:
  - ✓ Over-pressurize the vacuum sector;
  - ✓ Use an ultra pure gas that is not pumped by the NEG;
  - ✓ Exchange the faulty component while having a constant flux of pure gas;
  - ✓ Pump down the sector again.

Intervention on LSS with vacuum activated NEG



Typical configuration in the case an interconnecting module should be changed.

- The principle:
  - ✓ Over-pressurize the vacuum sector;
  - ✓ Use an ultra pure gas that is not pumped by the NEG;
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Vacuum System of the LHC: Operation without beam

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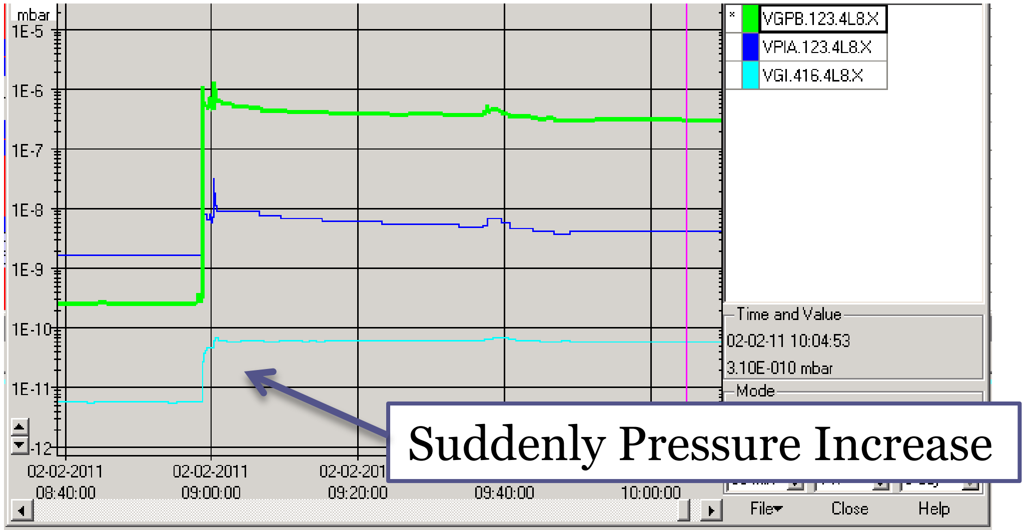
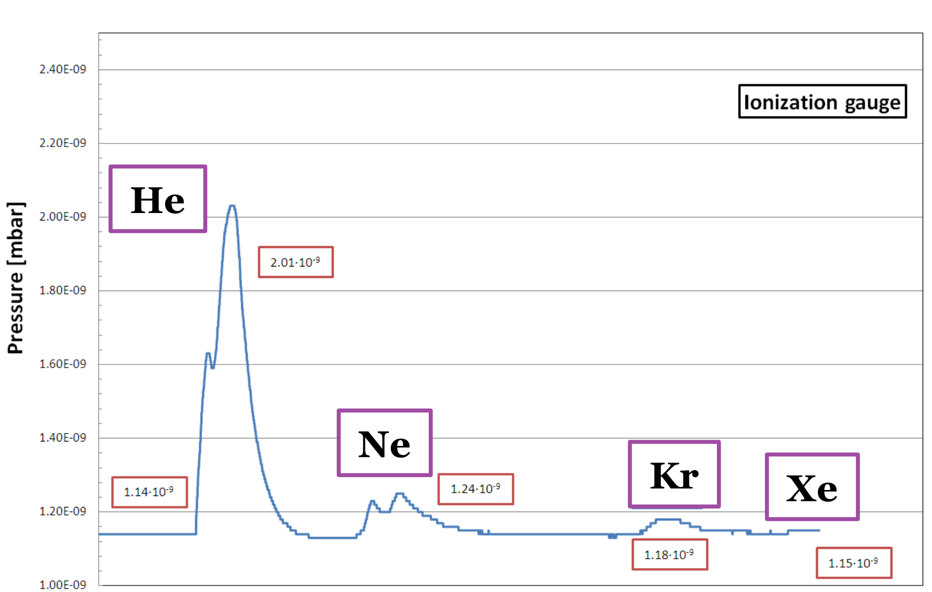
- Leak detection using total pressure gauge.

Leak detection using total pressure gauge reading





- During Christmas Break a pressure increase was recorded in a vacuum sector of 50 meter long with activated NEG;
- Leak detection could be done after the installation and the bake-out of a turbo molecular pump.
- The leak detection using total pressure gauge reading allow a fast detection of the possible leak;
- No installation of equipments;
- Use of noble gas because not pumped by the NEG;
- Pressure reading function of the conductance of the leak and the different sensitivity of the gauge to the gas.

Closing Remarks

The operation of the LHC is challenging due:

- The expected dynamic effects at high intensities:
    - Electron cloud;
    - Synchrotron Radiation;
- The presence of room temperature and cryogenic vacuum sections;
- The fast and reliable interventions requested;
- Future operation with:
    - 25 ns bunch spacing;
    - Higher bunch intensity.

Thank you for your attention

OLAV III
RGA-USer's-1

U.S. DEPARTMENT OF ENERGY

OAK RIDGE
National Laboratory

Technology Department TE
Vacuum Surfaces.. Coatings

CERN