One or Two Things That Can Go Wrong With Your Vacuum System: Examples of Vacuum Accidents at Accelerators

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Abstract:

- Vacuum systems of particle accelerators are often the "first line of defense" against damaging radiation and power deposition generated by sometimes very powerful beams
- A non exhaustive set of accident, from minor ones to major ones, involving the vacuum systems is discussed, and any lack of design or operational malfunction is highlighted
- General conclusions are drawn, and possible remedial/preventive actions are outlined;
- References to documents are given during presentation.

Introduction:

- **The vacuum system of a particle accelerator can often be the most stressed component of the machine, since it has to withstand…**
  - **Mechanical damage directly caused by high kinetic energy particles depositing all or part of their energy on it, e.g. beam loss, collision debris, e-cloud,…**
  - **Electromagnetic waves depositing copious amounts of energy, in a number of different ways, e.g. high-order modes, synchrotron radiation, and more…**
  - **High temperatures during bake-out sometimes followed by cool-down to cryogenic temperatures (LN_2 and/or LHe)**
  - **External atmospheric pressure and sometimes internal pressure applied to pneumatic components under vacuum**
  - **High electric and/or magnetic fields, either static or variable, e.g. stray fields from magnets, eddy currents,…**
  - **High levels of ambient humidity**
  - **Presence or contamination with chemical compounds**
  - **Mechanical stresses coming from a number of sources: pressurised water circuits, mechanical elongation during thermal cycling,…**

Introduction:

- **All this, and possibly other, environmental and operational circumstances are at the source of a number of accidents and incidents which have affected or will ultimately affect any accelerator, causing:**
    - **Loss of machine availability, or user-time availability**
    - **Increase of machine downtime**
    - **Permanent damage to components (not only vacuum components)**
    - **Increased radioactive activation of components**
    - **Increased dose-rate taken by personnel working around it**

- **We are going to see a set of photographs and diagrams of damaged vacuum components, and a short analysis of the causes, remedies, and lessons taken from this.**

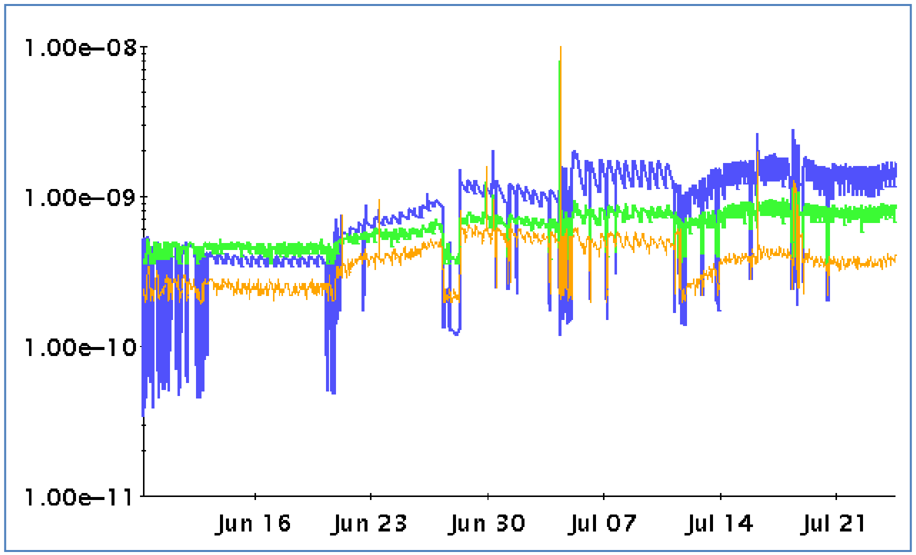
One or two things that can go wrong with your vacuum system: Examples of vacuum accidents

Problem 1:

- **Let's start softly: "*The fake problem*"… ☹**

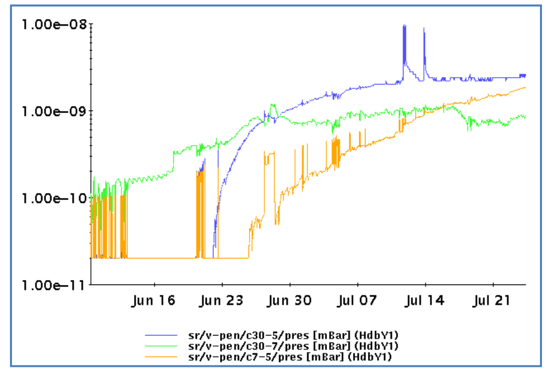
ESRF: CELL1 : CV11

The readout of several vacuum gauges shows, since a couple of weeks, a steady rising trend… **Question**: is there a vacuum leak?

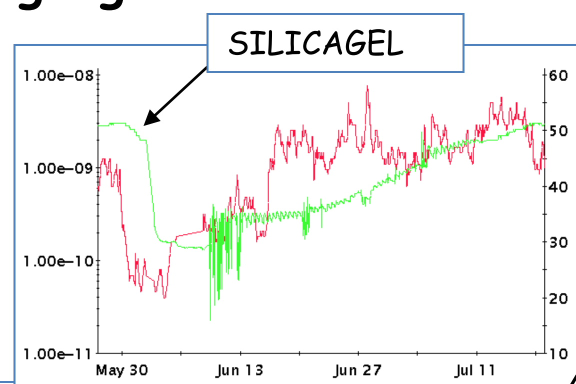


Consequences: headaches for operators and vacuum people; few tens Euros for the silical-gel bags;
As the problem reappeared later, ***some vacuum gauges had to be replaced*** (bad quality of the ceramic feedthrough)

Answer: No, what was actually happening was that the humidity level in the tunnel was going up (hotter summer days), and the cold-cathode gauges installed on the machine are sensitive to humidity.



Remedy: install silica-gel bags around the gauge connector

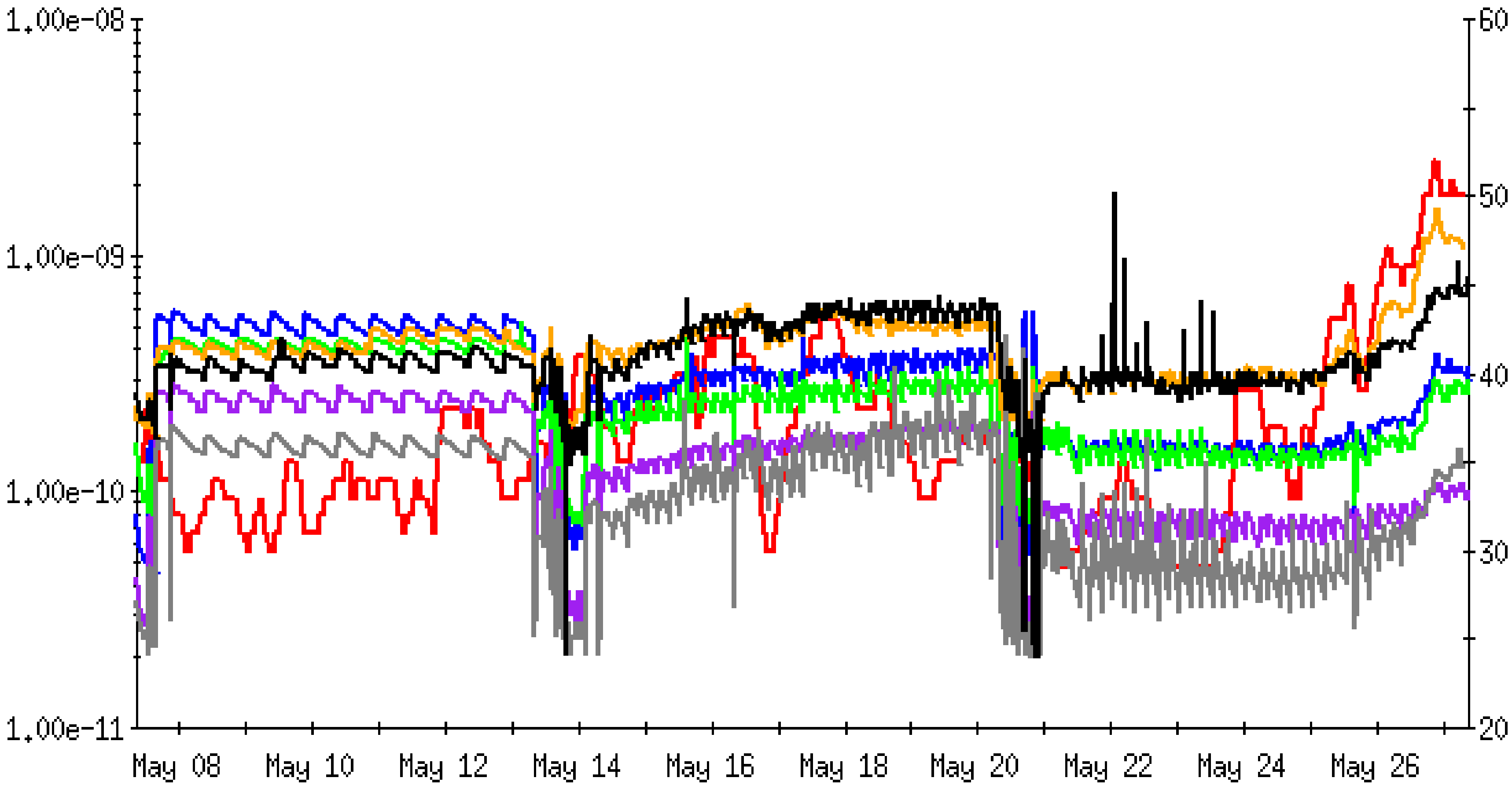


Problem 1bis:

- **More cases of the fake vacuum problem: again humidity on ceramic gauge feedthroughs…**

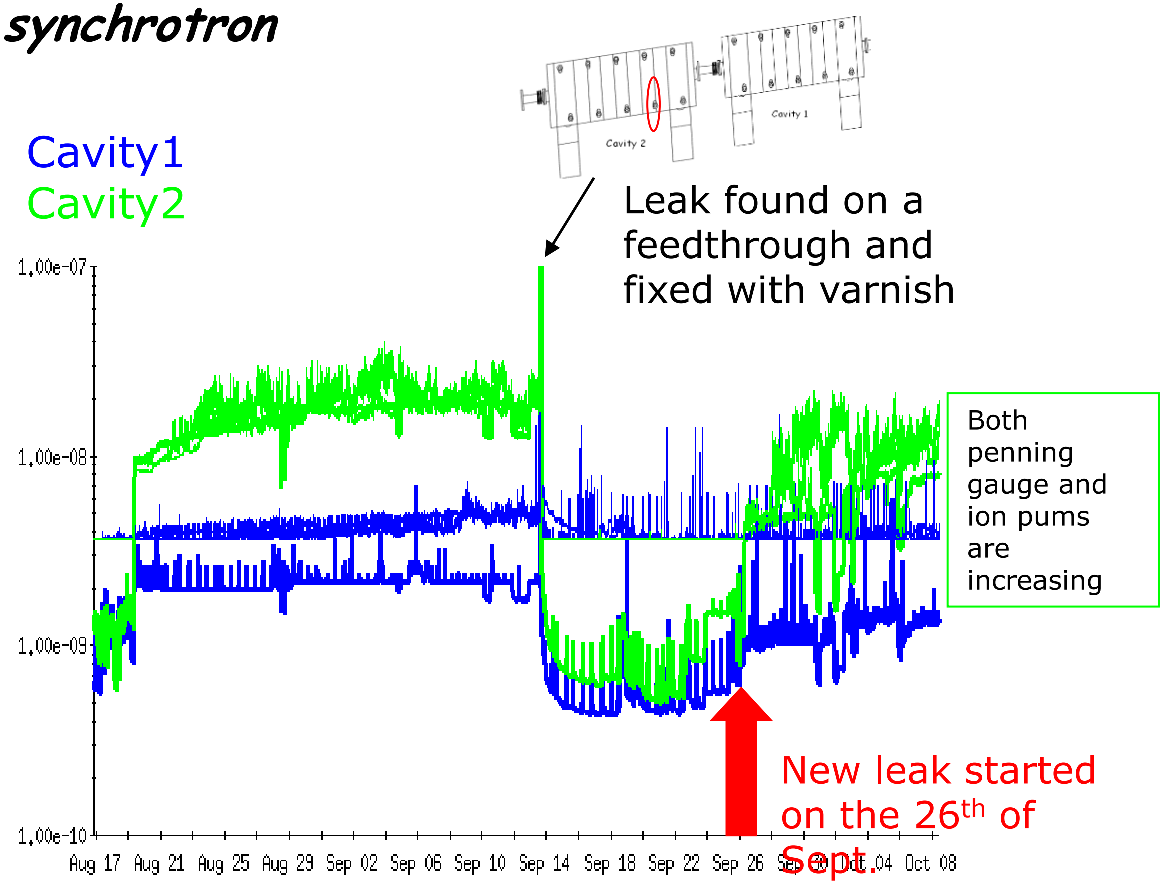
PRESSURE

HUMIDITY



Problem 2:

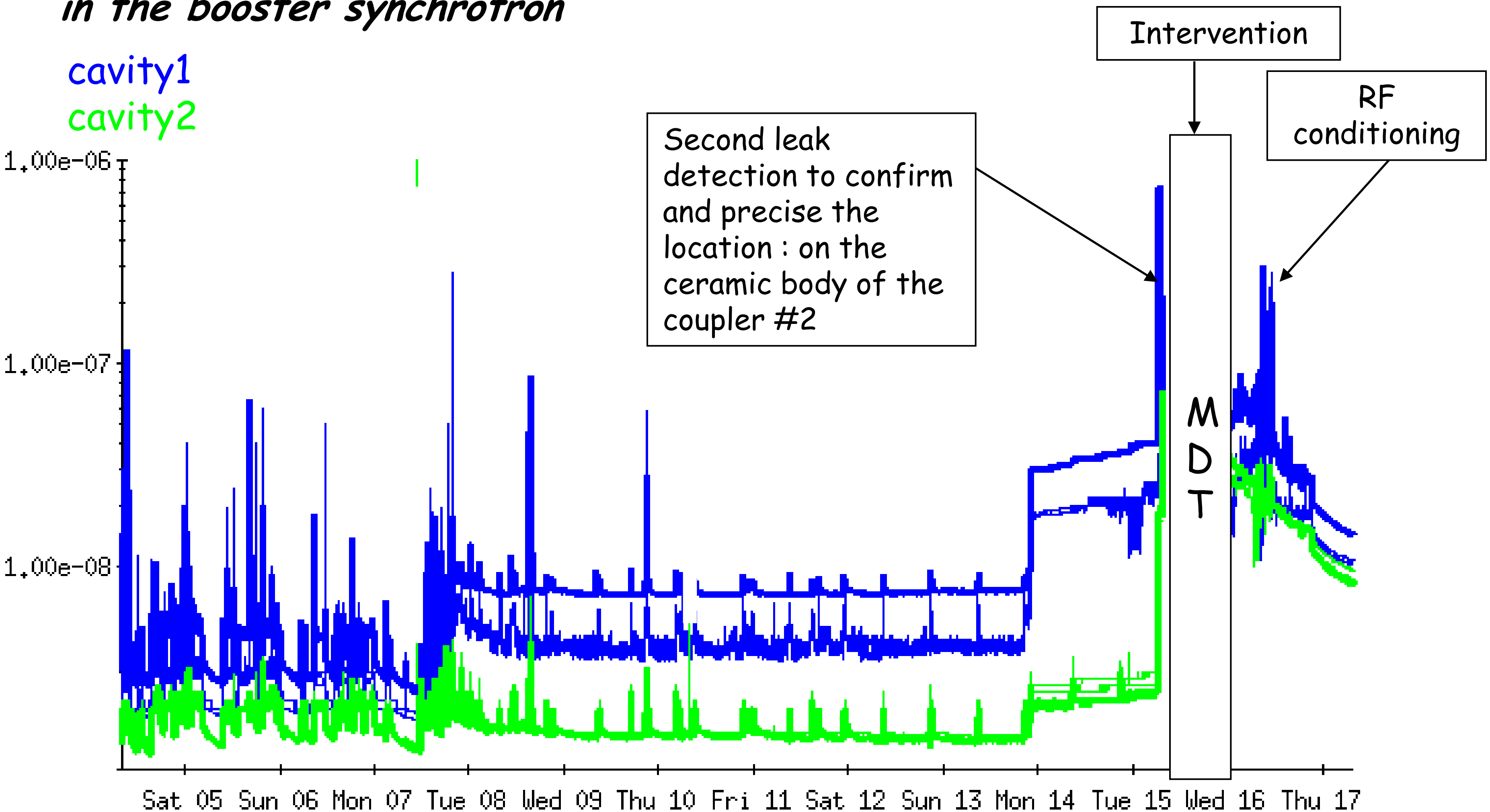
- **A more serious case:** ***ESRF, leak on an RF cavity in the booster synchrotron***



Consequences: none, operation carried out during downtime;
As the problem reappeared later, ***some feedtroughs had to be replaced*** (bad quality of the ceramic).
Lost some machine time…

Problem 3:

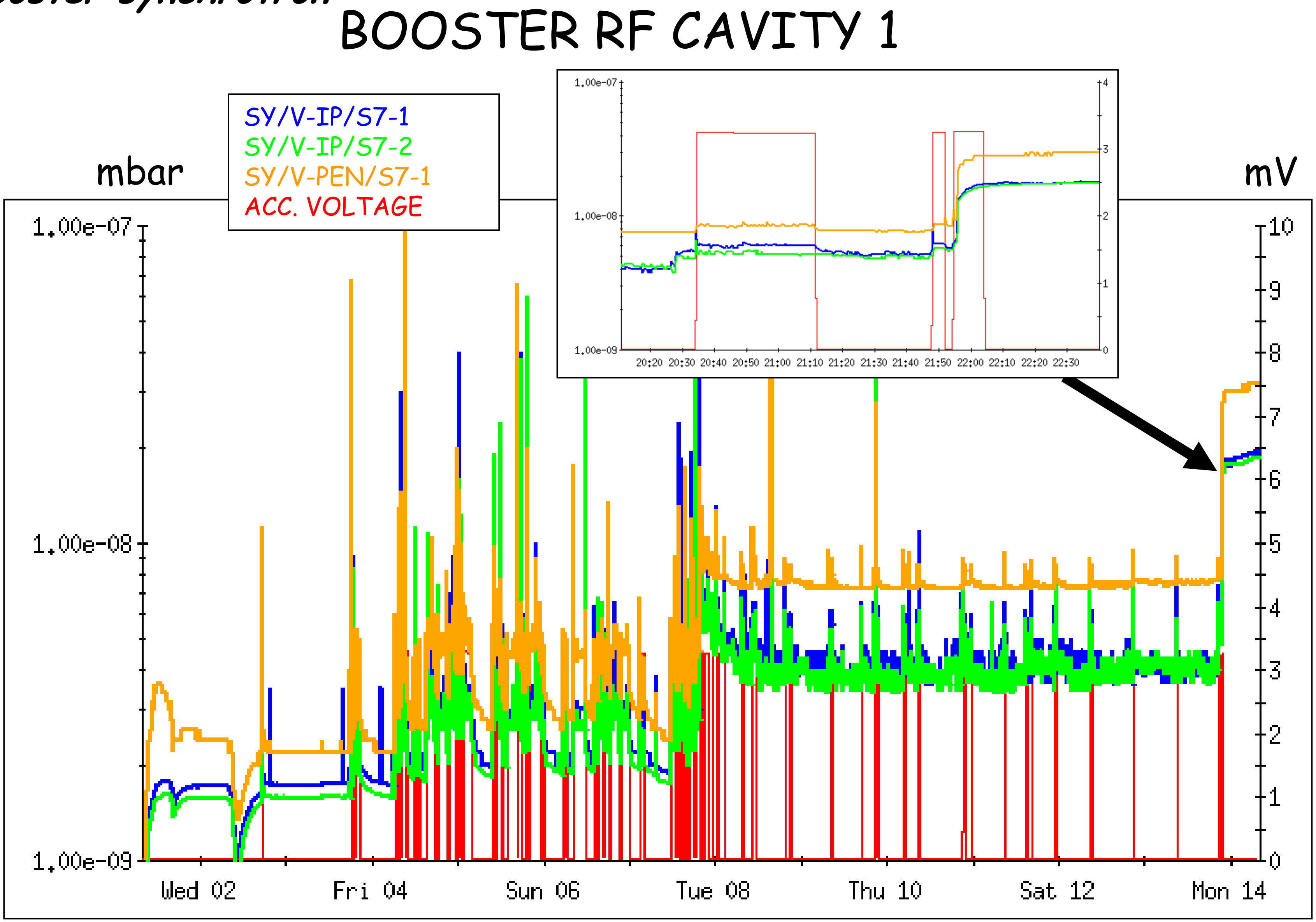
- **A more serious case: *ESRF, leak on an RF ceramic coupler of one cavity in the booster synchrotron***



Consequences: none, operation carried out during Machine Dedicated Time (lost);
As the problem reappeared later (see next slide), ***some couplers had to be ordered to industry. Long lead time.***

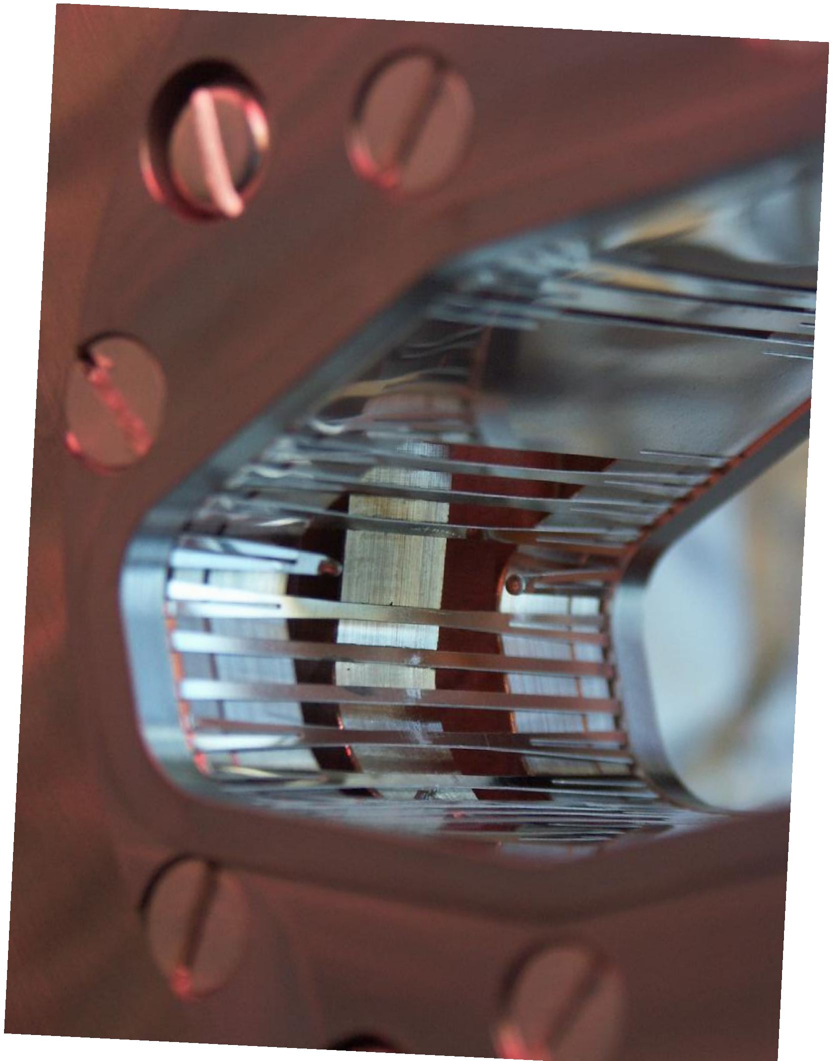
Problem 3, part 2:

- ***ESRF: Another leak on an RF ceramic coupler of one cavity in the booster synchrotron***



Problem 4:

- **Increasing seriousness:** ***ESRF, damaged RF contact fingers inside an all-metal gate valve, with loss of tightness***

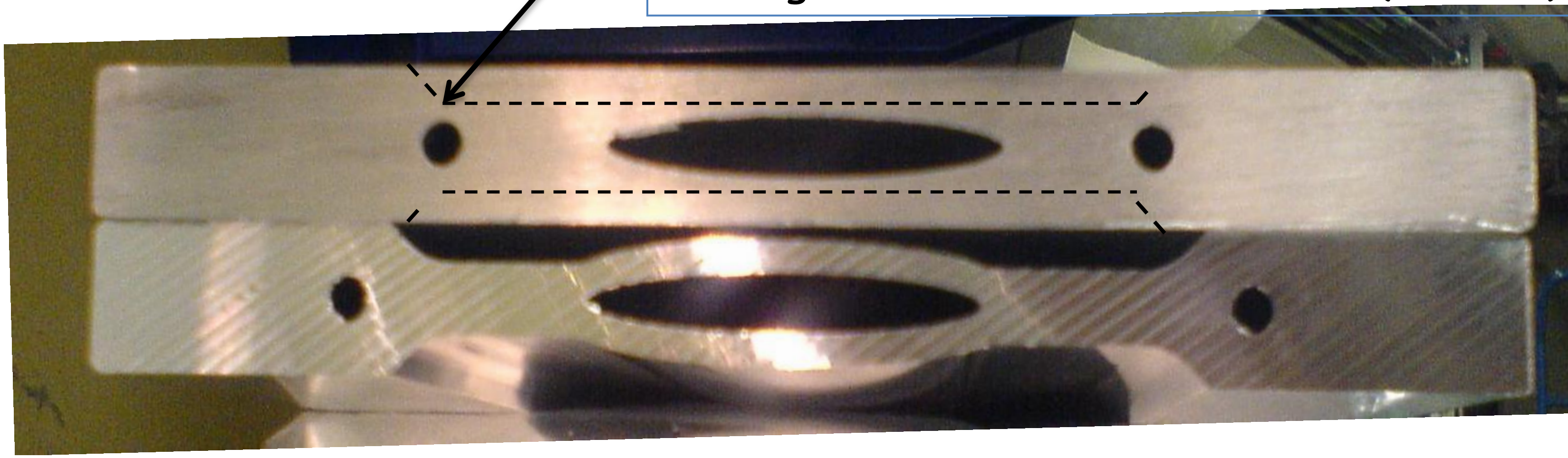


Consequences: valve had to be replaced, leading to venting of *additional* cell
Cost: all-metal GVs are expensive! ☹

Problem 5:

- **Increasing seriousness:** ***ESRF, corrosion leak at NEG-coated "10-mm ID" aluminum chamber***

Top: Sharp corner machine here (45 deg) generates stress which leads to water leaking **out** of the cooling tube
Solution: new extrusion with distanced cooling holes and rounded corner (**bottom**)



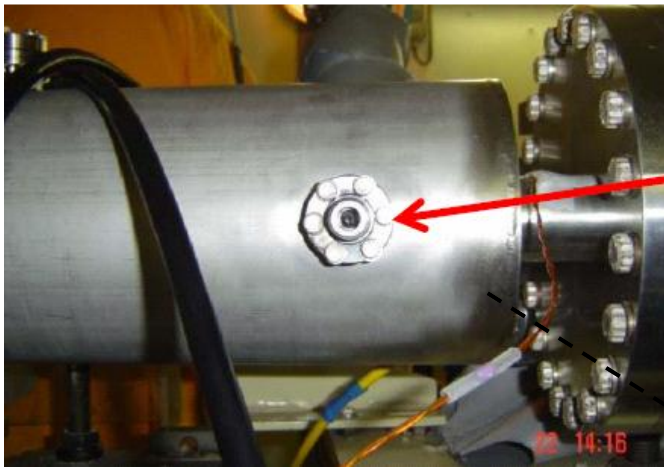
Consequences: "Water leak alarms" in the tunnel. Lost machine and user time; extrusion dye had to be modified; new extrusions made; new NEG-coating made (can be a *long* process);

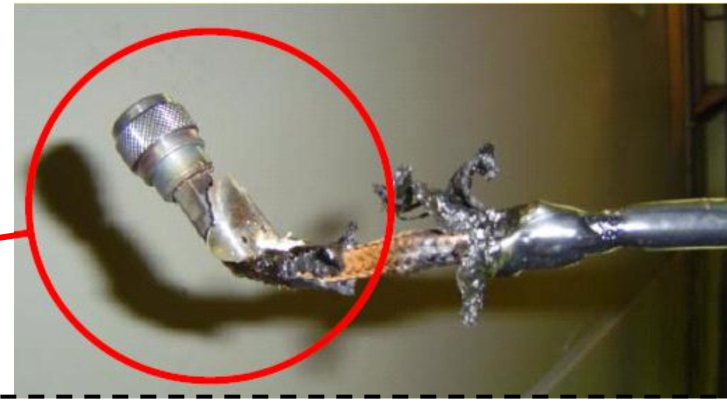
Cost: difficult to quantify, but substantial, especially in terms of manpower and resources

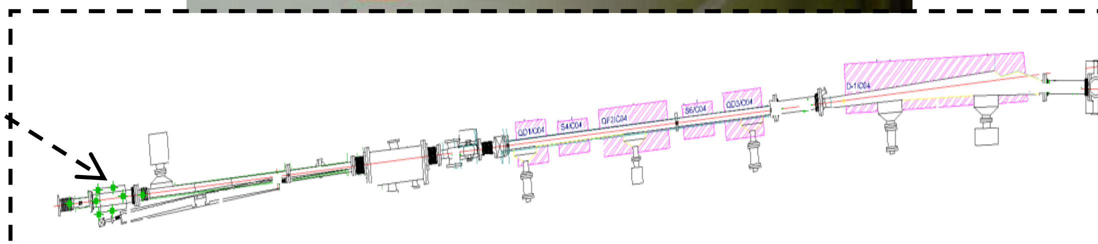
Problem 5:

- **Dangerously serious:** ***ESRF, failure of a stripline kicker***

Reason: high peak power induced by 4 x 10 mA and 16-bunch filling modes operation and ***faulty design*** of HV feed-through







Consequences: *Fire alarm* and broken feed through on the horizontal strip line in cell4 (injection straight); Two cells vented; injection straight vented; 1 NEG-coated aluminum ID chamber vented; Leak repaired, but *end of the run cancelled*, *75 hours lost* (no time to re-bake the cells and IDs before scheduled end-of-run)

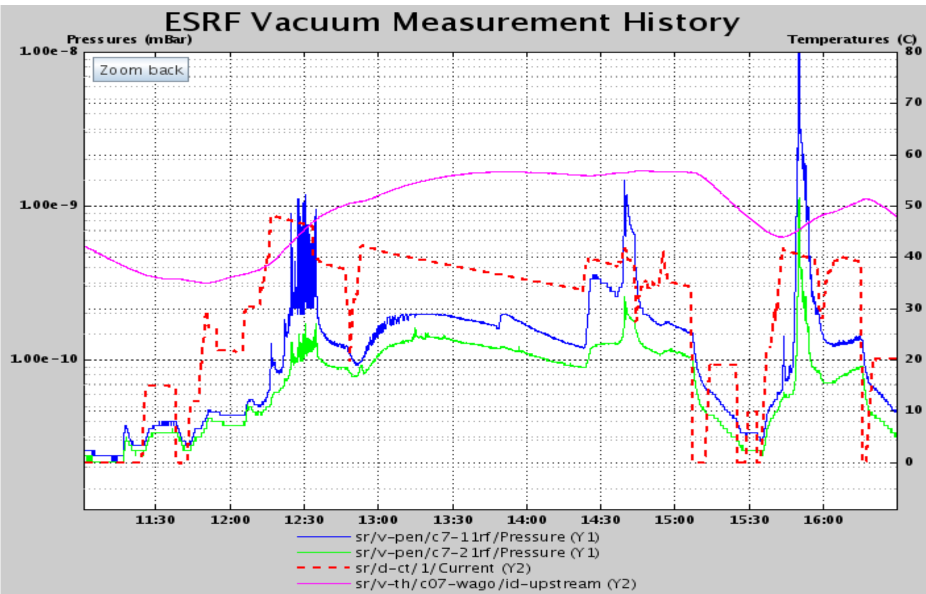
Cost: custom-made kicker to be re-designed and procured. Not for free.

***Worst of all*: 3 days of experiments cancelled... ☹**

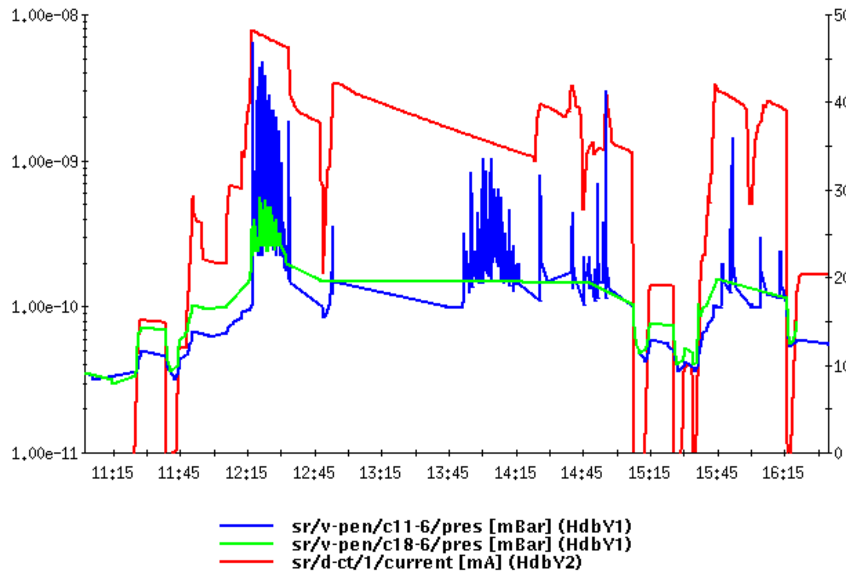
Problem 6:

- **ESRF:** ***Damaged/Broken RF contact fingers inside bellows***

SR cavity3 : RF fingers on the upstream bellow



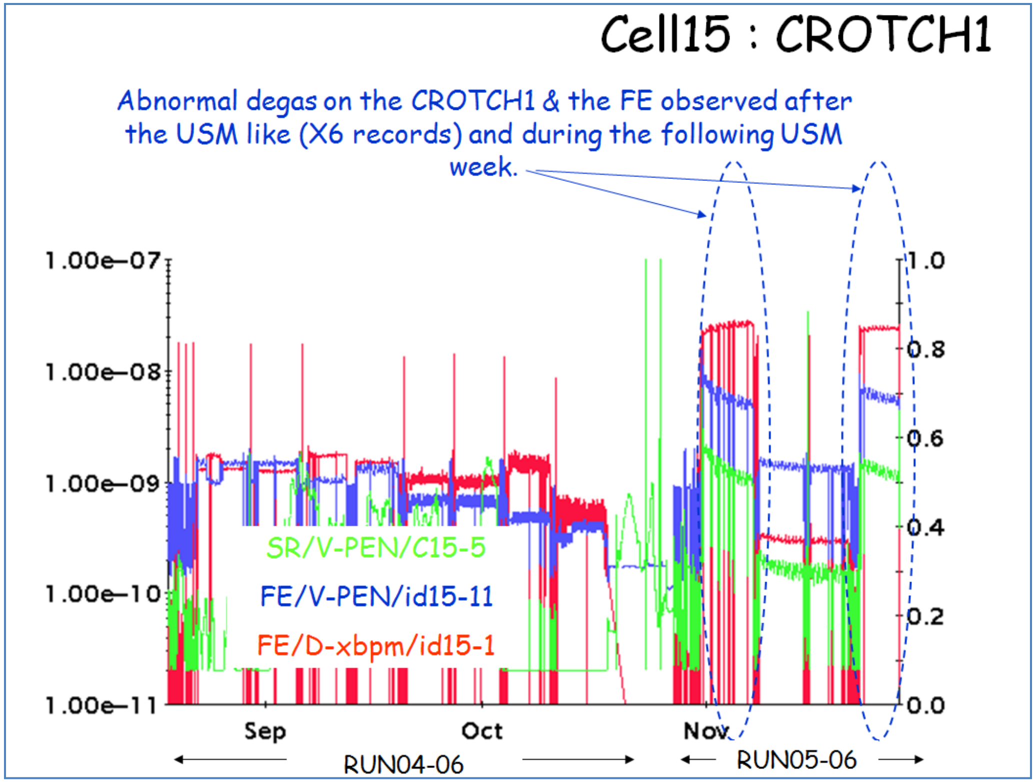
RF fingers problems on CV11 in (4x 10mA)

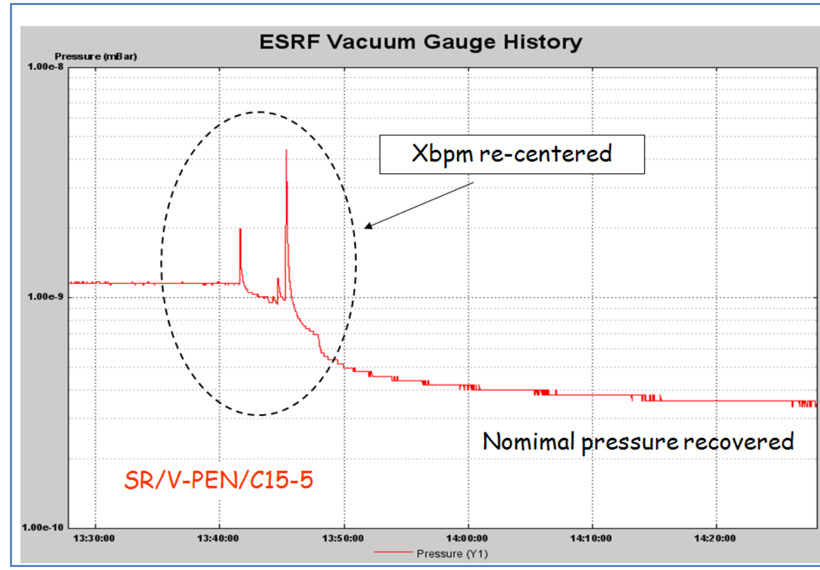


Consequences: pressure spikes affecting the beam lifetime, increasing the bremsstrahlung dose to beamlines (important safety aspect), potentially preventing operation (fingers can melt and go in the way of the beam)
Cost: Ag-coated, Be-Cu fingers are not made overnight. New/improved design had to be studied. Long procurement time.

Problem 7:

- ***Could be dangerous: ESRF, misalingment of X-BPM***



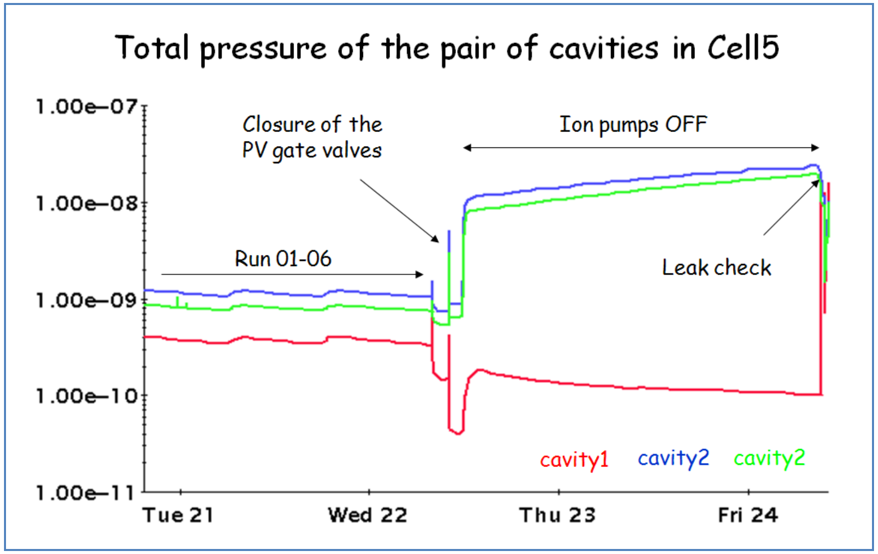


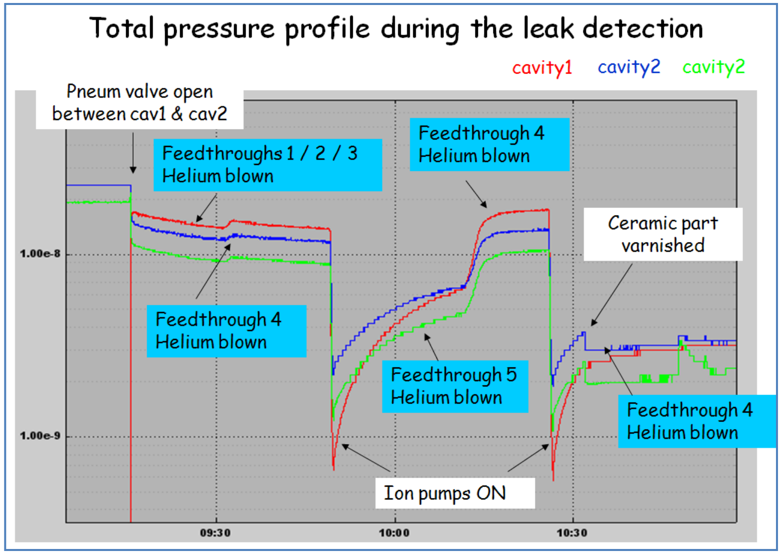
Consequences: pressure spikes affecting the beam lifetime, increasing the bremsstrahlung dose to beamlines (important safety aspect), could lead to triggering of valve closure and lost beam/experimental time.

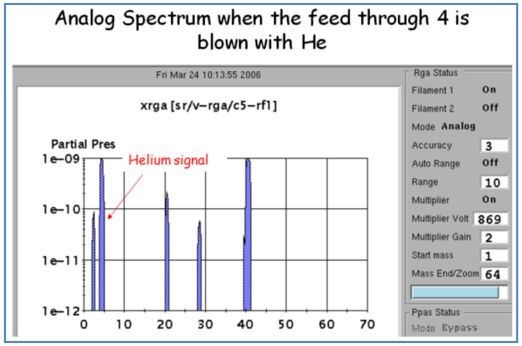
Remedy: remote re-alignment of the device. No costs involved.

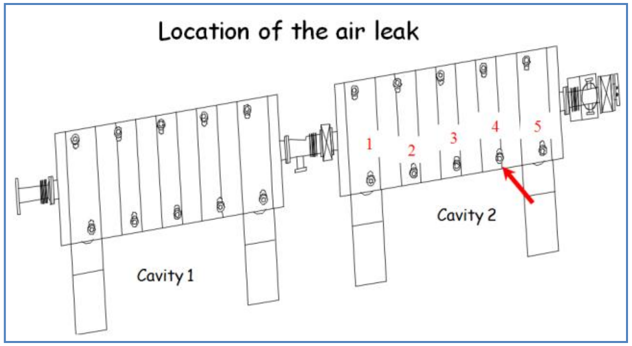
Problem 8:

- ***Time consuming: ESRF, leak on ceramic feedthrough of RF cavity in the storage ring***









Consequences: Lost machine and experimental time.

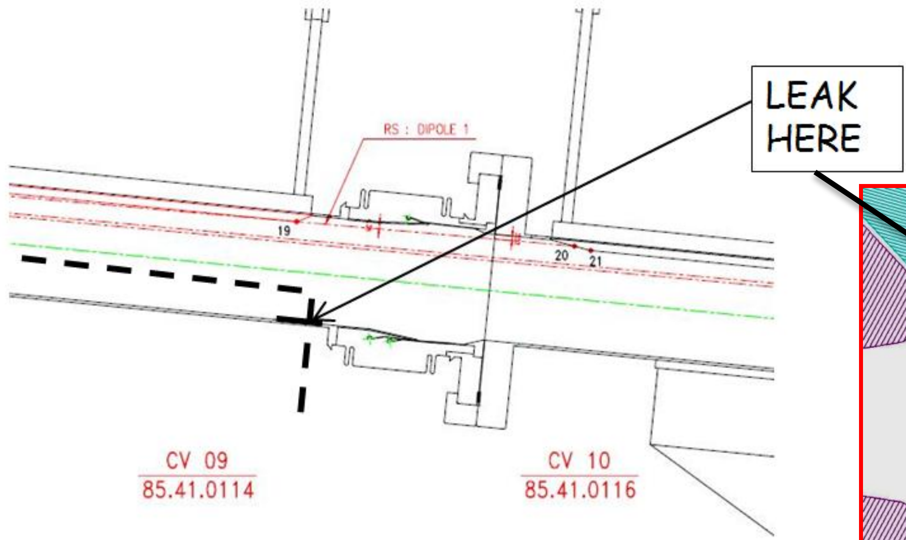
Remedy: Leak check; Vent cavity; replace feedthrough; pump-down and bake the cavity;

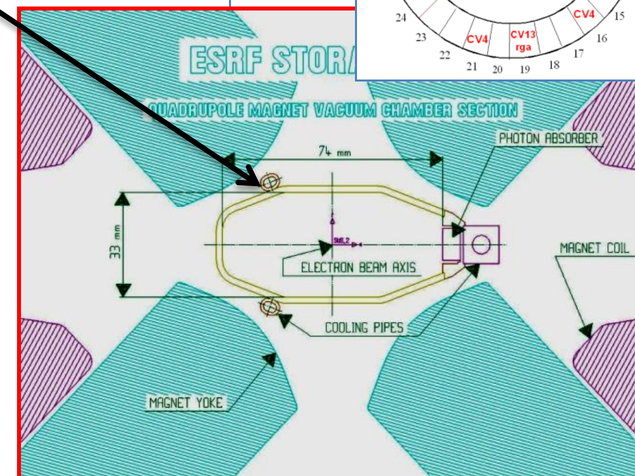
Costs: Several days lost; ☹

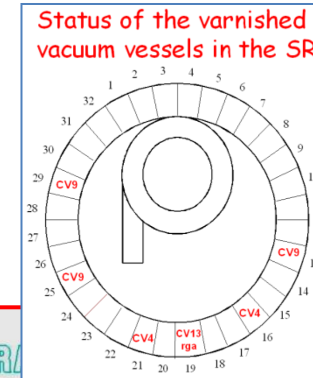
Problem 9:

- ***Annoying: ESRF, evanescent leak, coming and going.*** **Cause: corrosion after contamination with clorine on metallic support of cooling tubes**

• The leak had first appeared at the end of January 2005, and fixed on 1 Feb. It was located on the upper cooling tube support, downstream end of the CV9







•It has come back again on Sun Dec 3rd

•It has been sprayed with varnish during the MDT intervention time of Tue 6 Dec

Consequences: Several interventions (leak check, varnish spray);
Remedy: Fix temporarily with varnish until incoming shutdown; new chamber had to be fabricated.
Costs: recurring problem, tens of chambers with corrosion issues, capital costs are relevant (multi-year contract for spares)

One or two things that can go wrong with your vacuum system: Examples of vacuum accidents

Problem 10:

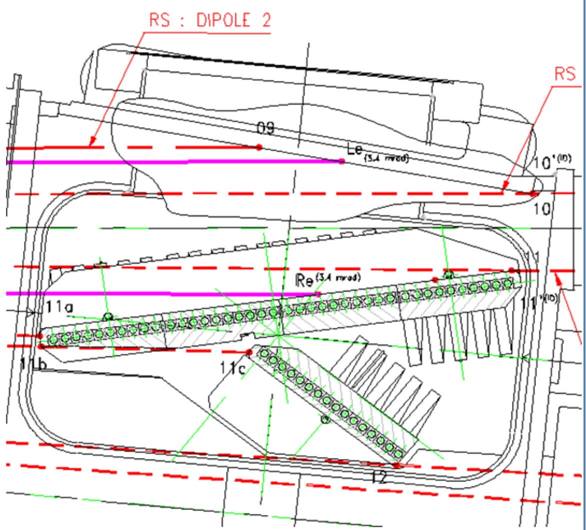
- ***This looks really bad!: ESRF, water leak on high-power crotch absorber***

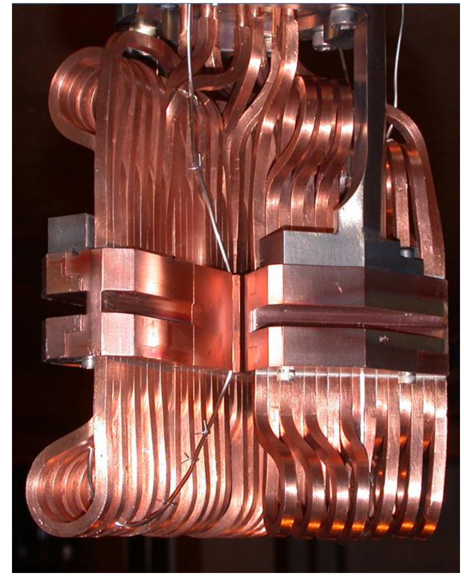
(preceding straight section: 5T SC wavelength shifter → 3T permanent-magnet wiggler)
(preceded by 1.8T AMPW on same straight section)

SR POWER (@200mA):

P_{tot} = (3.1+5.3) kW
~ 83 (64) W/mm
(pt.11b(c))
~206 (149) W/mm² (")

Same design for "leading edge" as Standard Crotch-1 Absorber





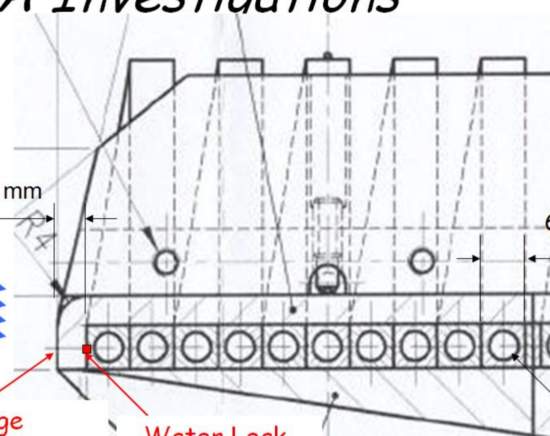
FEA Investigations

Bending Magnet Radiation

5 mm

6 mm

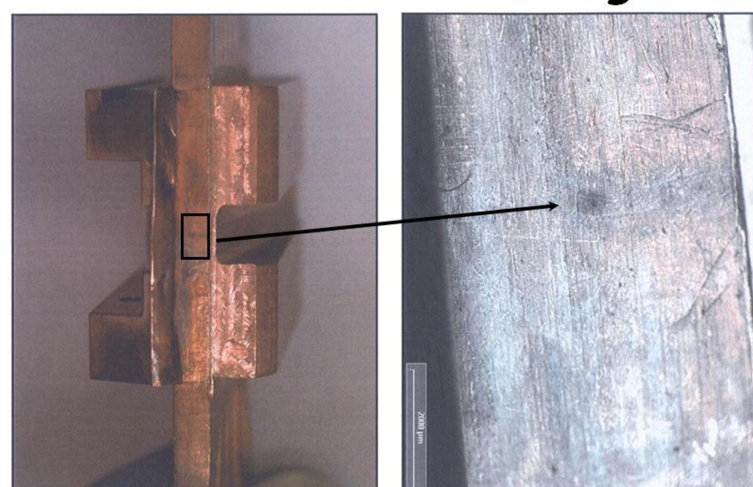
Diam 4 mm



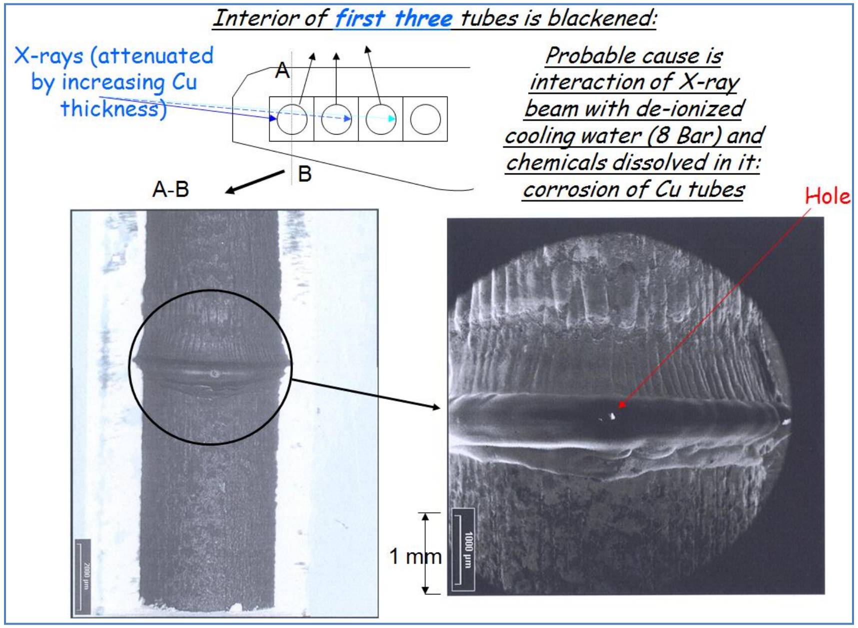
No Visible Damage
83 W/mm; 206 W/mm² @ 200 mA
T ~ 450 °C

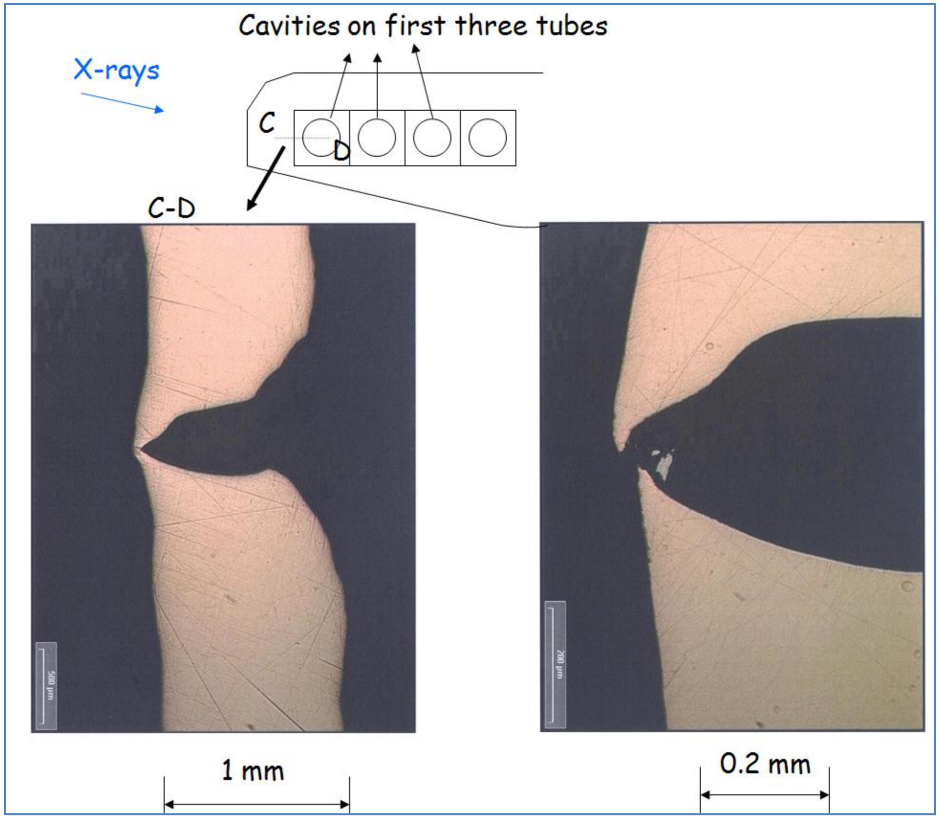
Water Leak
T ~ 80 deg C
Stress ~ 50 Mpa

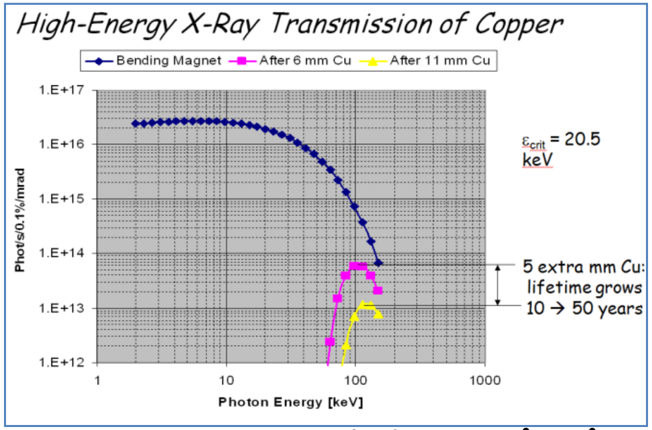
Hole in the first cooling tube



Problem 10, continued:







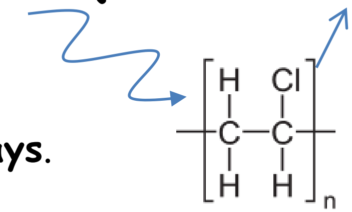
Consequences: Water leak inside the machine (one big ion-pump full!).

Remedy: careful analysis showed problem common to ALL 62 crotch absorbers; replace them all. Time to do it: couple of years. ☹

Costs: expensive, really expensive; ☹

And to conclude…. problem 11:

- ***A collection of failures with a common cause, water leaks (and all that goes with it): CERN, leaks in tunnels (several slides)***



PVC

Dehydrochlorination is the major mechanism of PVC degradation **by X and γ-rays**.

PVC components were accidentally installed in TDC2: hoses, cables (fire alarm), mechanical protections for vacuum bellows (☹). The recent events suggest that PVC is still there…

Moisture

In the TDC2 there are several sources of **moisture**:

- Leaking magnet cooling circuits.
- Leaking water valves,
- Infiltration from the tunnel ceiling.

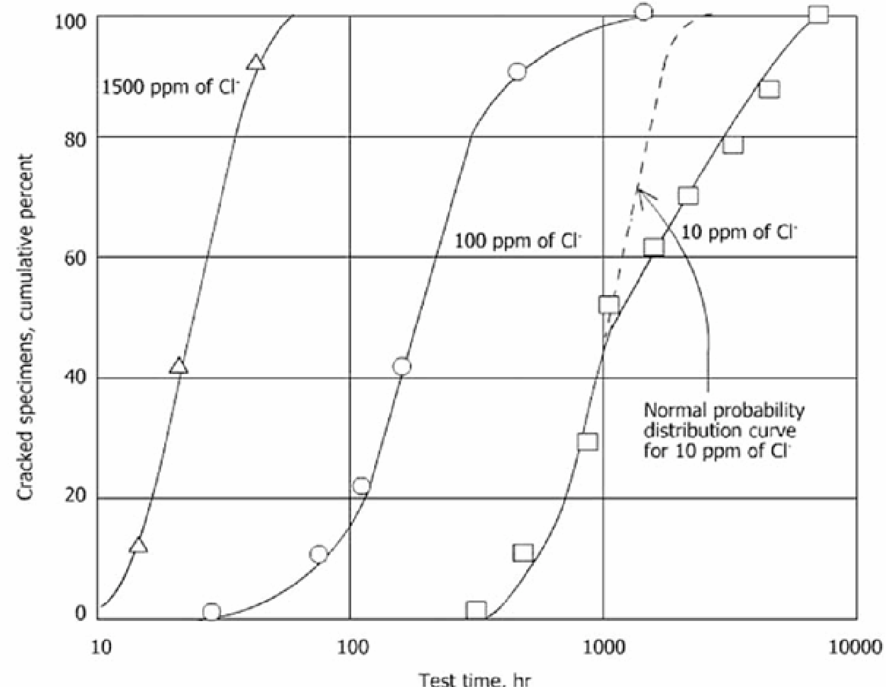
And to conclude…. problem 11:

- ***A collection of failures with a common cause, water leaks (and all that goes with it): CERN, leaks in tunnels (several slides)***

The last two leaks in sectors 2006 and 2007 appeared in 'protected' bellows.
Their Al protections was not damaged at the time of the last survey in January 2011.
Few droplets, maybe a single one, are enough to generate corrosion and failure in 'protected ' bellows.

Problem 11 continued:

A few ppm of Cl^- ions are enough to develop a crack in austenitic stainless steels.



Ahmad Zaki , Principles of Corrosion Engineering and Corrosion Control, Elsevier

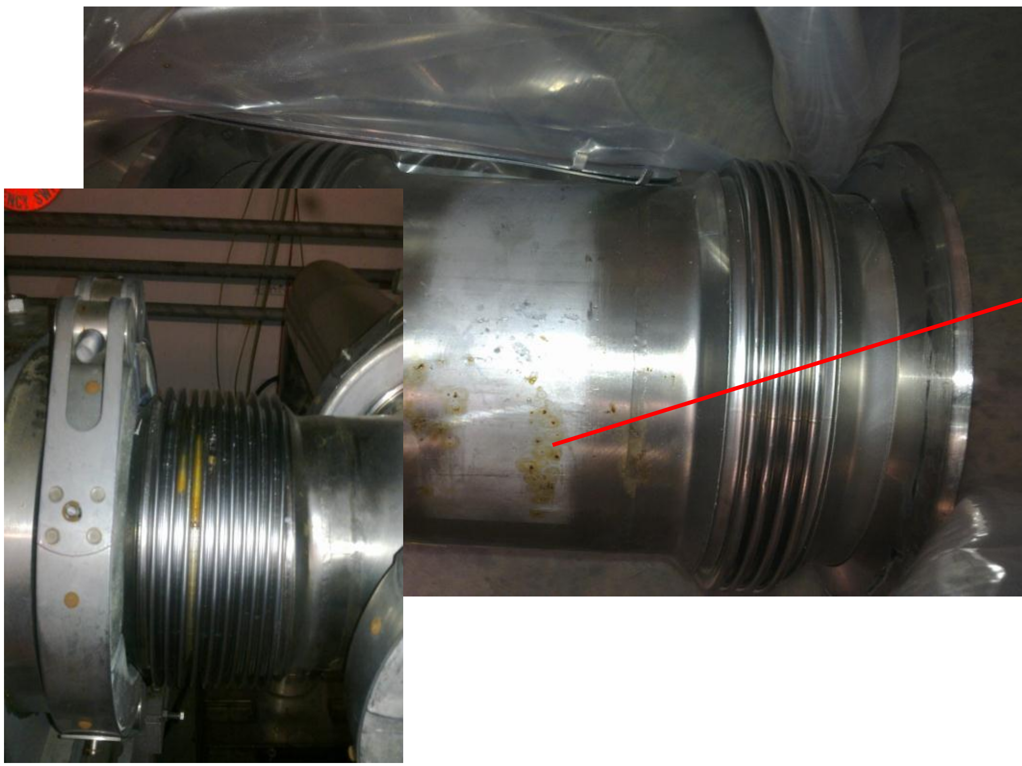
It is impossible to specify a Cl concentration threshold: even in small concentration (less than 10 ppm) Cl is concentrated to pitting site.

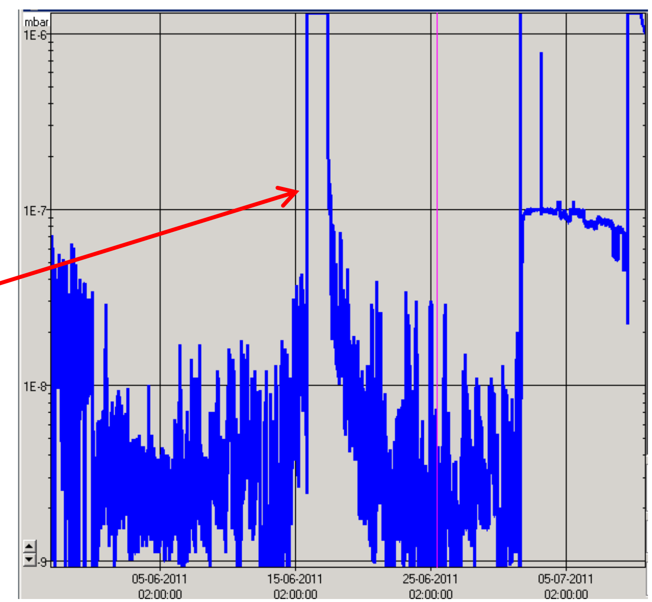
Vacuum leaks induced by stress corrosion cracking are characterised by a rapid, unexpected and huge pressure rise.

Problem 11, last:

- The leak in sect. 2006 developed first.
- The bellow replacement and the pressure recovery was fast because the sector is short.
- The collective dose was shared amongst 8 TE-VSC staff members.

- At the same time a corrosion attach was observed in the bellow of the nearby sector. However the sector was not leaking.
- The corroded part was painted with **VacSeal**, the whole beam pipe covered with a thick stainless steel **protection**, and the **production** of the special **vacuum chamber** started. Hoping to keep the sector 2007 operational until the next winter shutdown…





Conclusions:

- **During this short tutorial I have tried to give you a glimpse, by way of several examples, of a small fraction of the vacuum problems that affect almost daily the operation of particle accelerators.**
- **As we have seen, more often than not the failure is not originating in the vacuum component itself, it comes from other devices which happen to be "vacuum clients".**
- **A complete list just of those witnessed by the speaker would be very long (and often tedious), but taking care and documenting this type of problems is very important, as it helps avoid their repetition.**
- **A dedicated workshop series is devoted in part to this kind of problems, although not limited to accelerators: OLAV, "Operation of LArge Vacuum system".**

Thank you for your attention