10th European Synchrotron Light Source Radio-Frequency Meeting

27-28 September 2005
DELTA - Dortmund, Germany

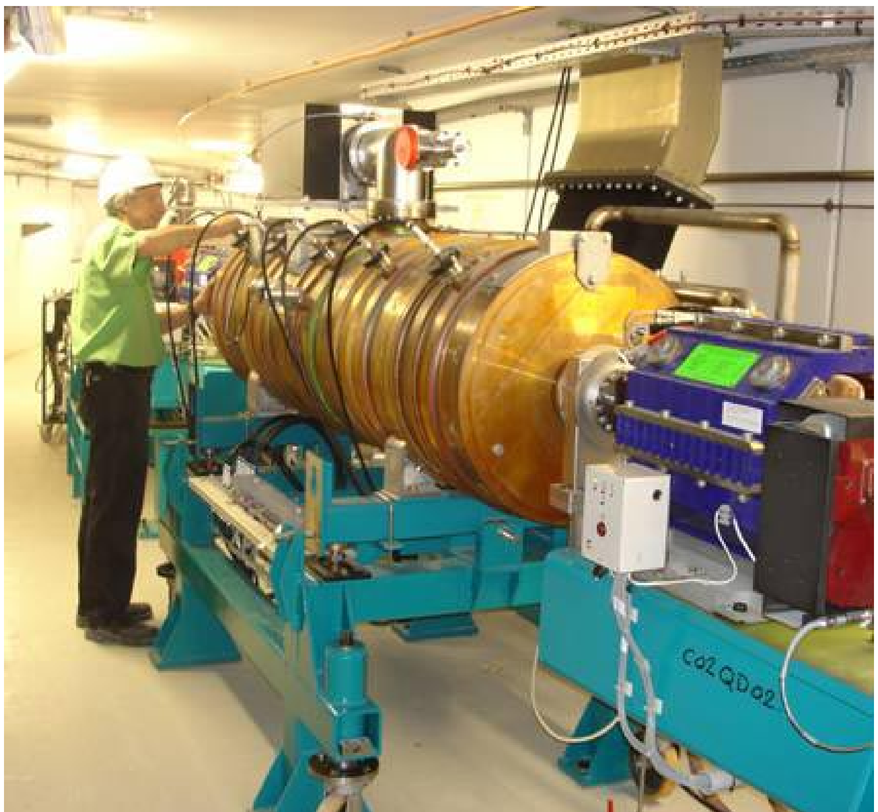
COMMISSIONING OF THE SOLEIL 352 MHZ RF SYSTEM

- BO RF operation
- Commissioning of the 1st SR RF plant
  - Cryogenic source
  - Amplifier power tests
  - CM1 cavity conditioning
- CM2 fabrication
- Cavity tuning → injection schemes
- 1st results of operation with beam & status of machine commissioning

P. Marchand

Booster RF system

- **1 CERN-LEP 5-cell Cu cavity , V_{cav} = 900 kV @ 352 MHz**
  → P_{dis} : 15 kW, P_{beam} : 5 kW, P_{tot} : 20 kW
- **1 solid state amplifier (147 modules) → 35 kW**



Cavity in the BO ring

BO RF room

Booster RF system

The complete BO RF plant was installed on site in spring 2005 and commissioned in July.
Up to date it has run for ~ 3000 hours without any problem (not the least interruption due to the RF !).
In particular the 35 kW solid state amplifier, which is the most innovative part of the system, proved to be quite reliable as well as very easy and flexible in operation.
Only a single module (out of 147) has failed; it has not yet been replaced since that does not affect at all the amplifier performance.

Storage ring RF system

- Required RF voltage of 4.4 MV and power of 580 kW (at 352 MHz)
  → 2 cryomodules, each containing a pair of single-cell superconducting cavities → 1.1 MV and 145 kW per cavity

- Both CM are supplied in LHe (4.5 K) from a single cryo-plant, HELIAL 2000 from AIR LIQUIDE, operated in mixed refrigerator/liquefier mode

- Each cavity is powered with a 180 kW solid state amplifier, based on the same principle as the BO one, extended to four towers of 45 kW

- 1st year of operation with limited number of ID's and I_{beam} below 300 mA
  → only a single CM and 2 amplifiers

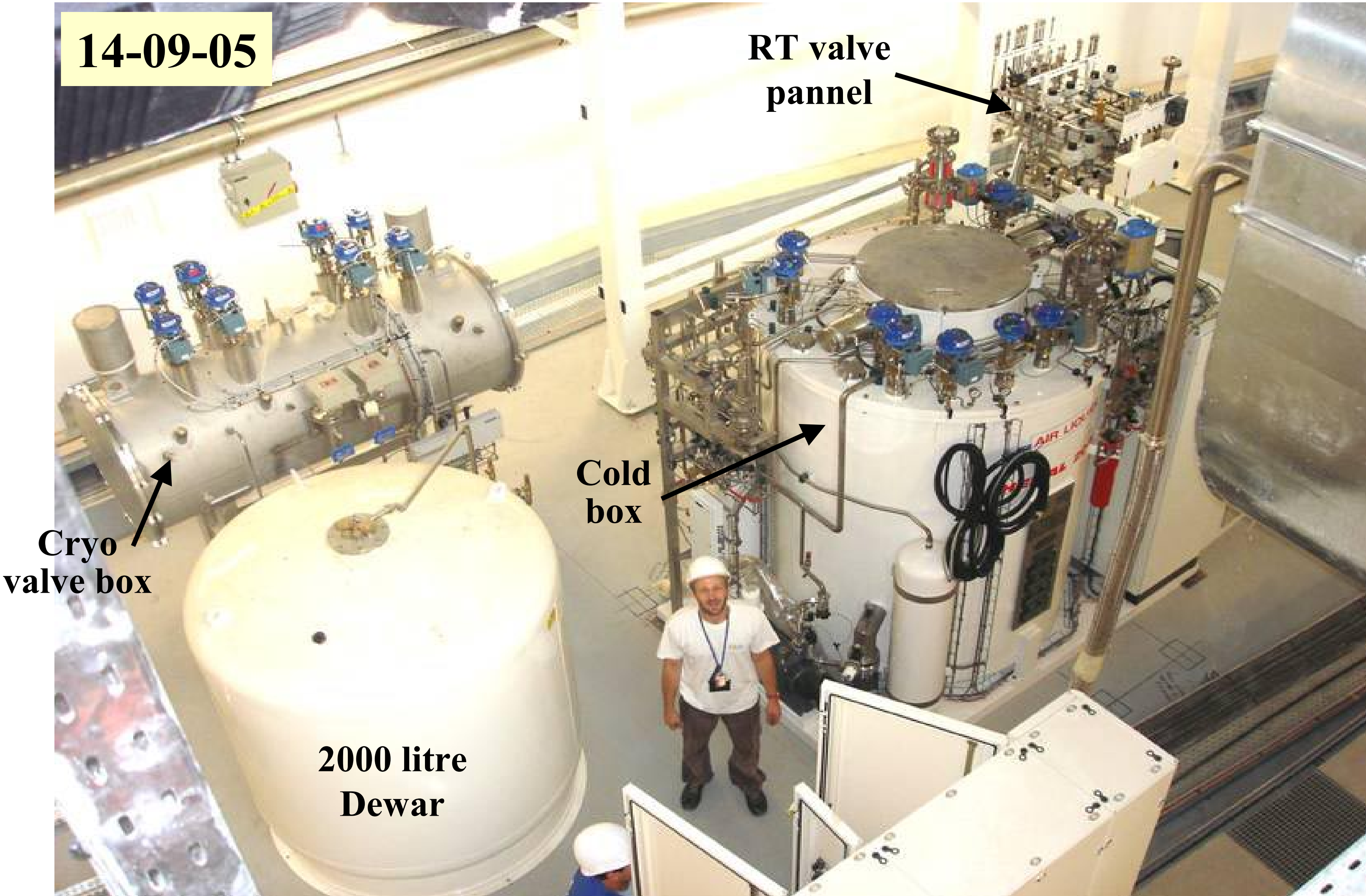
- The 2nd half of the system, presently under fabrication, should be implemented mid of 2007 → full performance (4.4 MV, 500 mA, all ID's)
  + new digital LLRF under development (→ R. Sreedharan)

Cryomodule N° 1 (CM1)

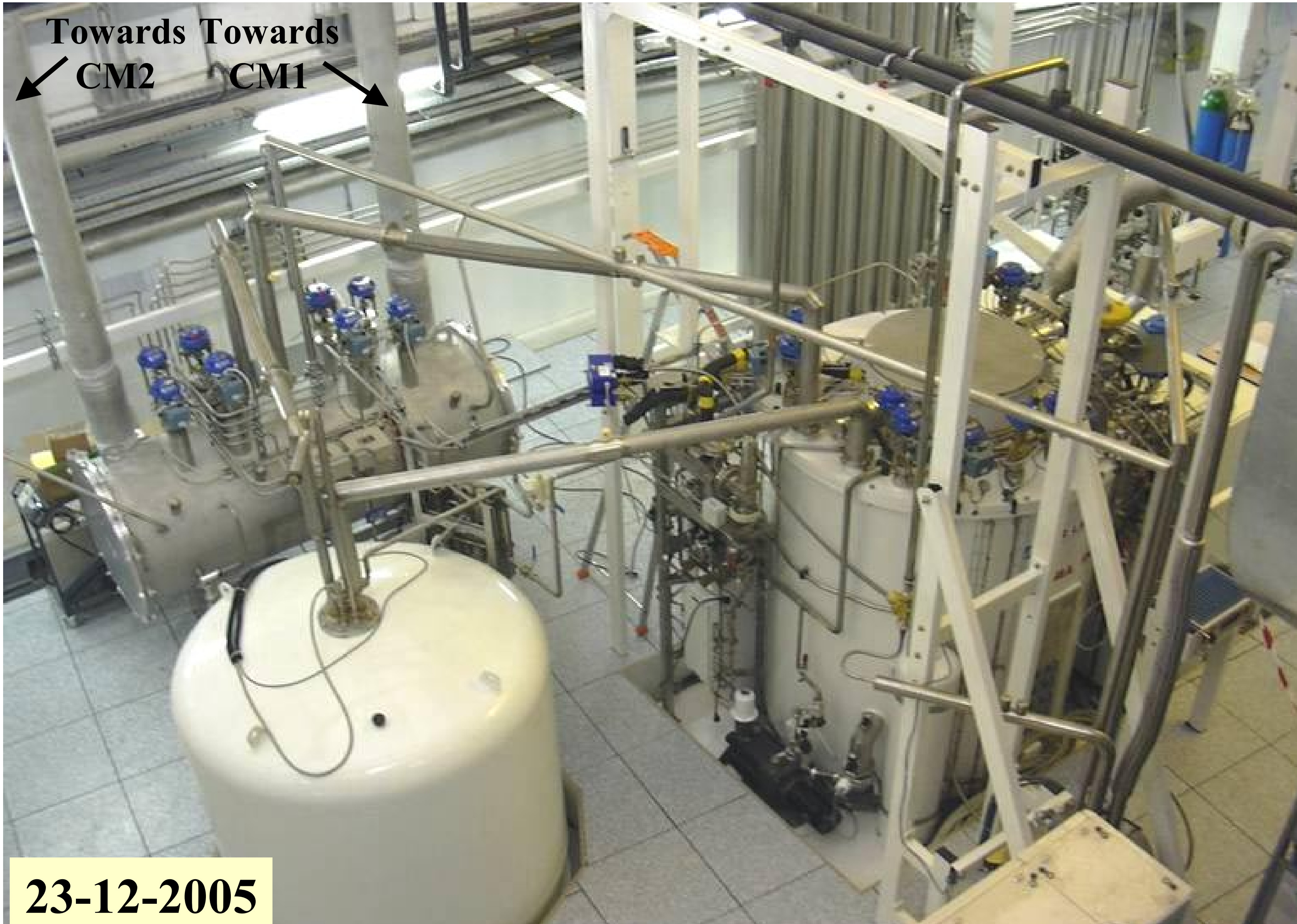
After a campaign of tests on the ESRF SR (2001), the CM prototype was fully disassembled, significantly modified and then re-assembled & tested at CERN, in order to be used as the first cryomodule of SOLEIL.

CM1 installation at SOLEIL

RF cryogenic area in the technical gallery

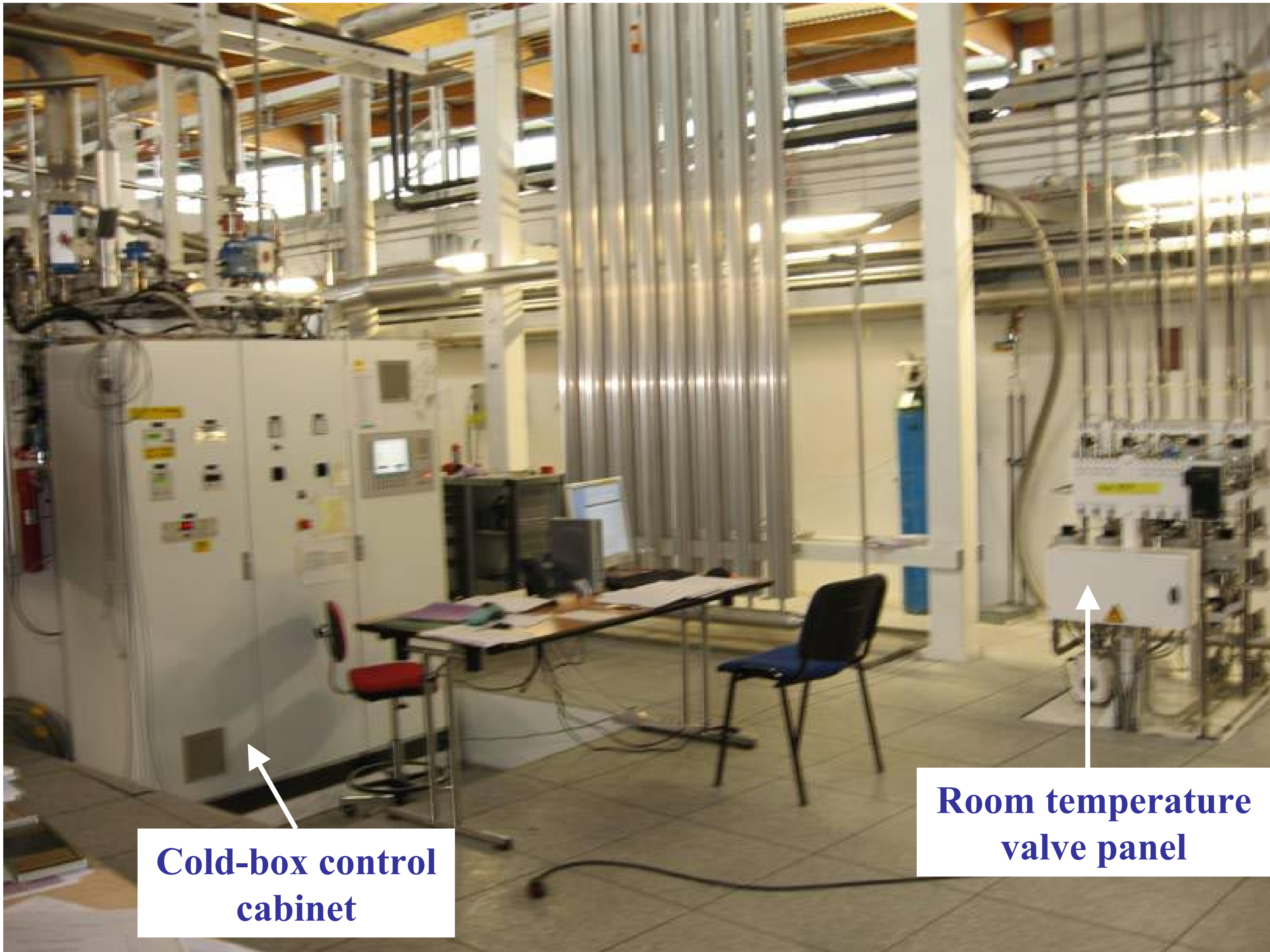


RF cryogenic area in the technical gallery



RF cryogenic area in the technical gallery : cold-box control cabinet & RT valve panel

SOLEIL SYNCHROTRON



Compressor plant

He gas buffers (2 x 50 m^3)

Cryo-source installation & commissioning

Jan. 06 : installation of the cryo plant completed

End Jan. : conditioning of the GHe circuit → 2 leaks due to bad welding
→ radiography of other welds : many are unacceptable
→ rebuild the whole GHe circuitry (HP & LP) from compressor to cold box (~ 200 m) & to GHe buffers

Beg. Apr. : start commissioning of the cryogenic plant with AL **(~ 3 month delay)**

End Apr. : production of LHe into the Dewar → tests with internal heater :
50 l/h liquefaction + 400 W refrigeration at 4.5 K, simultaneously, which is significantly more than specified

May 9th : connection to the CM → 15 hours* for cooling down to stable temperature
** Restart after the summer shutdown, from a fully warm system :*
12 hours → Dewar full of LHe + 10 hours → cold CM

May 15th : optimisation for stable CM LHe vessel pressure → **start CM RF conditioning**

STARTING PROBLEMS & CURES

- Few shut-downs & "painful" restarts → ok after elimination of bugs in the process
- Difficulties in achieving accurate control of the pressure in the cavity LHe vessel
→ better after modifications on the cryo valve box (during summer shut down)

RF power amplifiers

End of Feb. 06 : **8 towers assembled and tested up to ~ 50 kW**

May - Dec. 05 : T1 - T6 in the LURE test area

End of 2005 : move from LURE to SOLEIL (material & personal)

Jan. - Feb. 06 : T7 & T8, using the SOLEIL BO RF utilities

T1 (180 modules) : 5 transistor failures after 1000 hours of operation
T2-T8* (1250 mod.) : total 13 transistor failures (runs from few hours to few days)

*** 50 modules damaged, all at once, on T4, due to a mistake (switch-on with the direct RF feedback at maximum gain !)**

Insertion of additional protections

End of March : **SR RF room utilities (electrical power & cooling water) available**
→ assembling of 2 amplifiers (2 x 4 towers) & connection of utilities

Apr. 7th : **2 amplifiers successfully tested up to 180 kW into a dummy load**

4 weeks of tests on dummy load → 6 failures of transistors (out of 1400)

May 9th : **2 amplifiers connected to the cryomodule for the RF conditioning**

Dec 2005 : transfer from LURE to SOLEIL

SOLEIL SYNCHROTRON

Storage at SOLEIL

2 towers inside the RF room (well protected !)

Mounting of waveguides inside the RF room

SOLEIL SYNCHROTRON

Wave guides through the technical gallery

Waveguides & cryo transfer lines on tunnel roof

Cryomodule n°1 in the SR

April 2006, assembling of the amplifiers inside the RF room

April 2006, assembling of the amplifiers inside the RF room

Dummy load mounted on amplifier n°1 ready for power tests !

April 6^{th}, 2006 : 180 kW on amplifier n°1

SOLEIL SYNCHROTRON

April 7^{th} : same result with amplifier n°2

Amplifier control display (for each tower : transistor currents, P_i & P_r)

SOLEIL SYNCHROTRON

D0		D1		D2		D3		D4		D5		D6		D7		D8		D9		D10		
		6.8	6.7	0.0	0.0	6.9	6.8	0.0	0.0	7.0	6.9	0.0	0.0	7.0	6.8	0.0	0.1	6.8	6.8	0.1	0.1	0
0.0	0.0	9.2	9.2	9.2	9.3	9.0	9.2	8.9	9.0	9.0	9.3	9.3	9.3	9.2	9.3	8.9	9.0	8.9	9.2	9.2	9.1	1
0.0	0.0	9.4	9.3	9.1	9.4	8.8	9.1	8.9	9.3	9.4	9.4	9.0	9.3	9.1	9.2	9.2	9.3	9.2	9.2	8.9	9.0	2
0.0	0.0	9.0	9.0	9.2	9.4	9.0	9.1	8.9	8.9	9.1	9.2	9.1	9.1	9.0	9.3	9.1	9.1	9.3	9.5	9.0	9.0	3
0.0	0.0	9.1	9.1	9.0	9.3	8.9	9.1	8.9	8.9	9.2	9.2	9.2	9.4	9.1	9.3	9.1	9.3	9.3	9.3	9.1	9.2	4
0.0	0.0	9.0	9.2	9.1	9.2	9.2	9.1	9.0	9.1	9.1	9.2	9.0	9.2	8.9	9.3	9.1	9.3	9.1	9.4	9.1	9.2	5
4.2	4.0	9.1	9.3	9.0	9.2	8.8	9.3	8.9	9.2	9.1	9.2	9.1	9.3	9.1	9.3	9.0	9.1	9.3	9.3	9.3	9.1	6
		8.8	9.2	9.1	9.0	9.0	9.3	9.1	9.3	8.8	9.0	9.0	9.2	9.1	9.1	9.1	9.3	9.1	9.3	9.0	9.2	7
		9.2	9.3	9.1	9.1	9.2	9.3	8.8	8.9	8.9	9.0	9.3	9.1	9.1	9.4	9.0	9.3	9.0	9.0	8.9	9.2	8
		2.3	0.0	2.6	0.0	2.2	0.0	2.6	0.0	2.4	0.0	2.4	0.0	2.6	0.0	2.2	0.0	2.4	0.0	2.3	0.0	Pi/Pr
		2.5	0.0	2.4	0.0	2.6	0.0	2.5	0.0	2.4	0.0	2.4	0.0	2.4	0.0	2.4	0.0	2.2	0.0	2.2	0.0	Pi/Pr
		8.9	9.1	9.2	9.2	9.4	9.5	9.0	9.2	9.4	9.4	9.1	9.4	8.9	9.1	9.3	9.5	9.4	9.6	9.2	9.5	8
		9.1	9.1	9.2	9.3	9.0	9.3	9.0	9.1	9.2	9.2	9.2	9.3	9.3	9.5	9.2	9.4	9.0	9.2	9.2	9.3	7
		8.7	9.0	9.3	9.1	8.9	9.2	9.3	9.1	9.5	9.4	9.1	9.4	9.0	9.1	9.4	9.5	9.1	9.1	9.2	9.2	6
		9.1	9.1	9.2	9.3	9.2	9.2	9.2	9.1	8.9	8.9	9.2	9.2	9.2	9.1	9.2	9.3	9.1	9.2	9.5	9.6	5
		9.0	9.3	8.9	9.0	9.0	9.2	9.1	9.3	8.9	9.2	9.0	9.1	9.1	9.3	9.3	9.4	9.1	9.4	8.9	9.2	4
		8.9	8.9	9.2	9.3	9.0	9.1	9.1	9.1	9.1	9.0	9.2	9.3	8.9	9.2	9.3	9.3	9.1	9.2	9.3	9.3	3
		8.9	9.1	8.8	9.3	9.2	9.1	9.2	9.2	9.2	9.3	9.1	9.2	8.9	9.2	9.6	9.5	9.0	9.3	9.0	9.0	2
		9.0	9.1	9.2	9.4	9.4	9.3	9.2	9.3	9.2	9.4	9.0	9.0	9.1	9.1	9.2	9.3	9.1	9.4	9.2	9.3	1
		7.2	7.1	0.0	0.1	6.9	7.1	0.1	0.0	7.3	7.3	0.0	0.0	7.2	7.3	0.0	0.0	7.6	7.7	0.0	0.0	0

Dissipater n°

$I_{1,2}$ for the 9 upper modules

Pi, Pr @ 2.5 kW

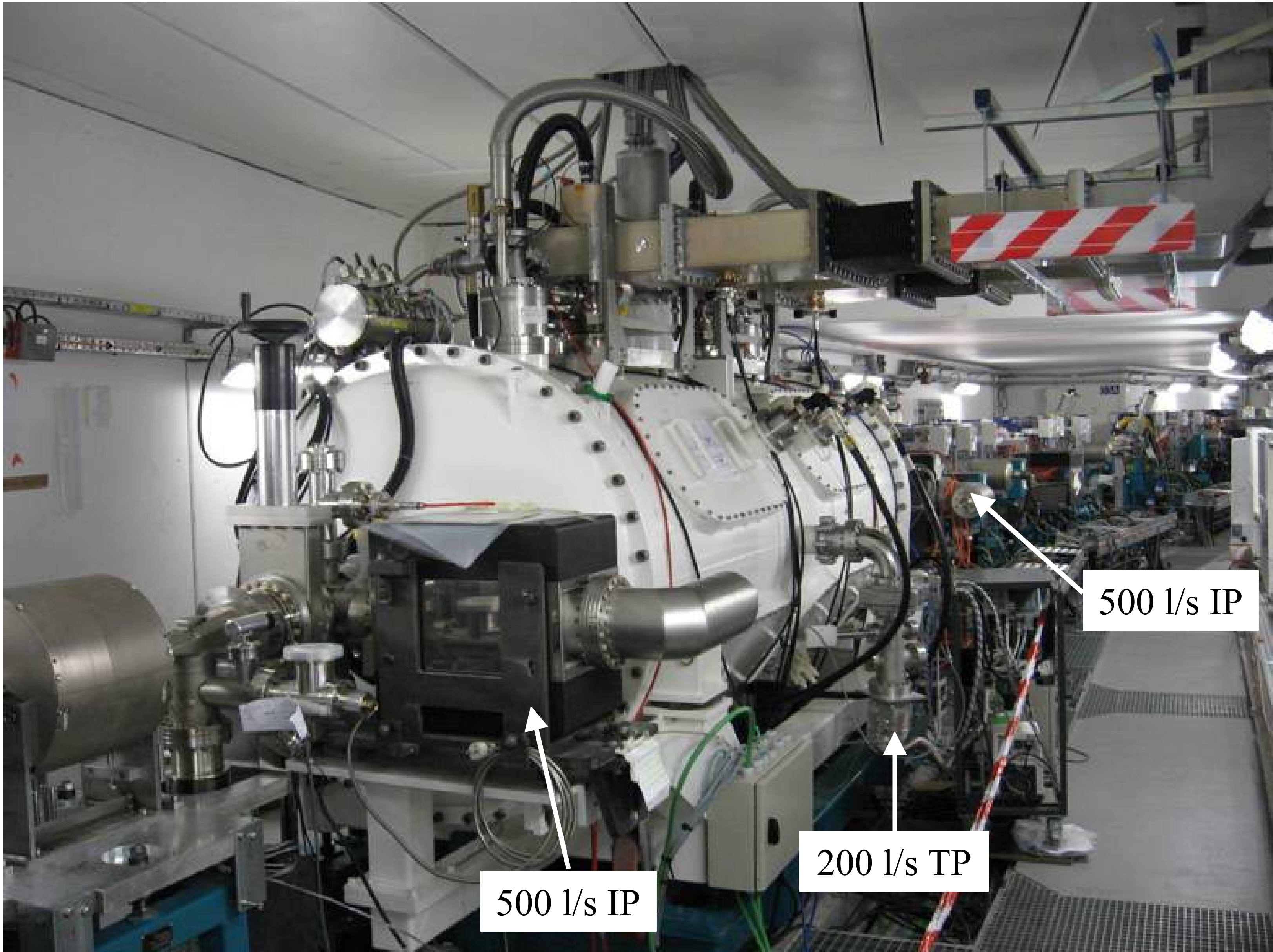
$I_{1,2}$ for the 9 lower modules

1st stage or stand-by

May 9th, amplifiers 1 & 2 connected to the CM1 cavities

SOLEIL SYNCHROTRON

Cryomodule n°1 ready for RF conditioning



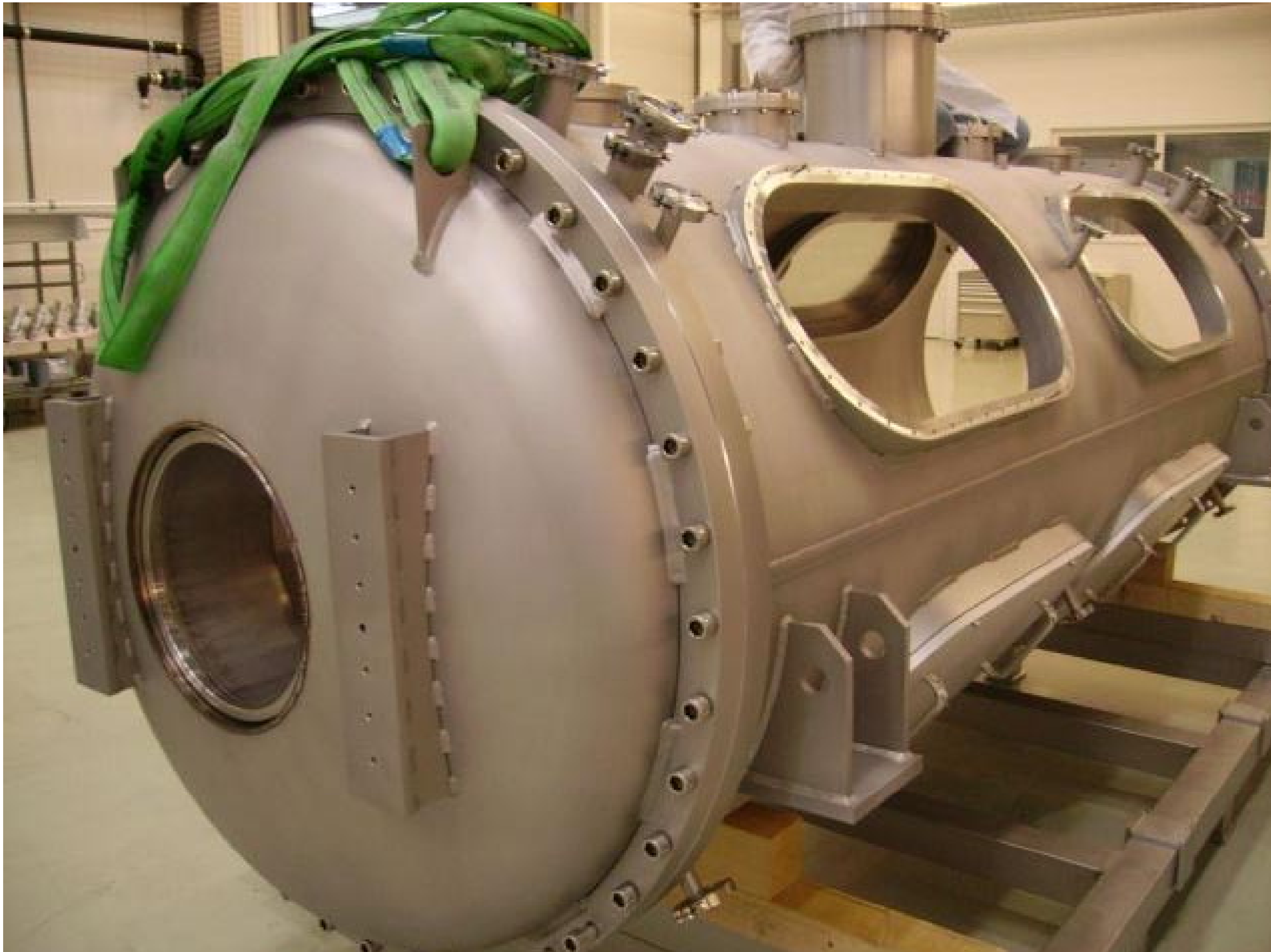
RF conditioning of the CM1 cavities

- ***May 15th 2006 :*** CM1 cold → start of RF conditioning
- For the RF conditioning without beam (full reflection), we limited ourselves at 80 kW per cavity in order to avoid too high reflected power in CW towards the amplifiers (with 80 kW one can store up to 200 mA)
- ***Vacuum conditions :***
  - cryostat vac : ~ 10^{-7} mbar ← 1 turbo pump 200 l/s
  - cavity vac : ~ 10^{-11} mbar ← 1 ionic pump (500 l/s) at each CM extremity
  - coupler vac : 10^{-11} mbar range (gauge close to the ceramic window)
  - for RF conditioning, coupler vac < 5 10^{-8} mbar & interlock at 5 10^{-7} mbar
- For each cavity, about 50 hours of conditioning, up to 80 kW CW (fully reflected) with FM of ± 10 kHz @ 0.1 Hz → V_{cav} = 1.7 MV at resonance
- ***Remind :*** at CERN, each coupler conditioned up to 200 kW CW (fully reflected), but without FM ; then transfer of the CM to SOLEIL with the cavities under vacuum and the cryostat under N2
- During the 2 weeks of conditioning with high reflected power, 8 modules (out of 1400) were damaged by burning out the load of the circulator

Since no other failure of loads

CM2 cryostat at ACCEL premises

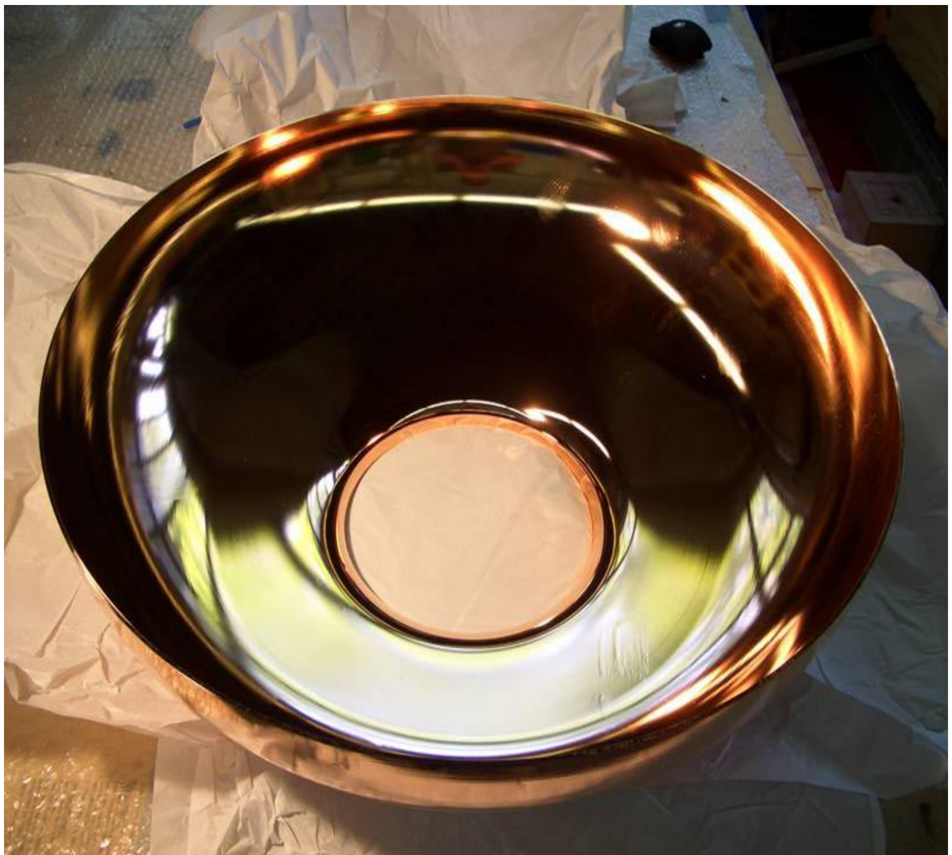
SOLEIL SYNCHROTRON



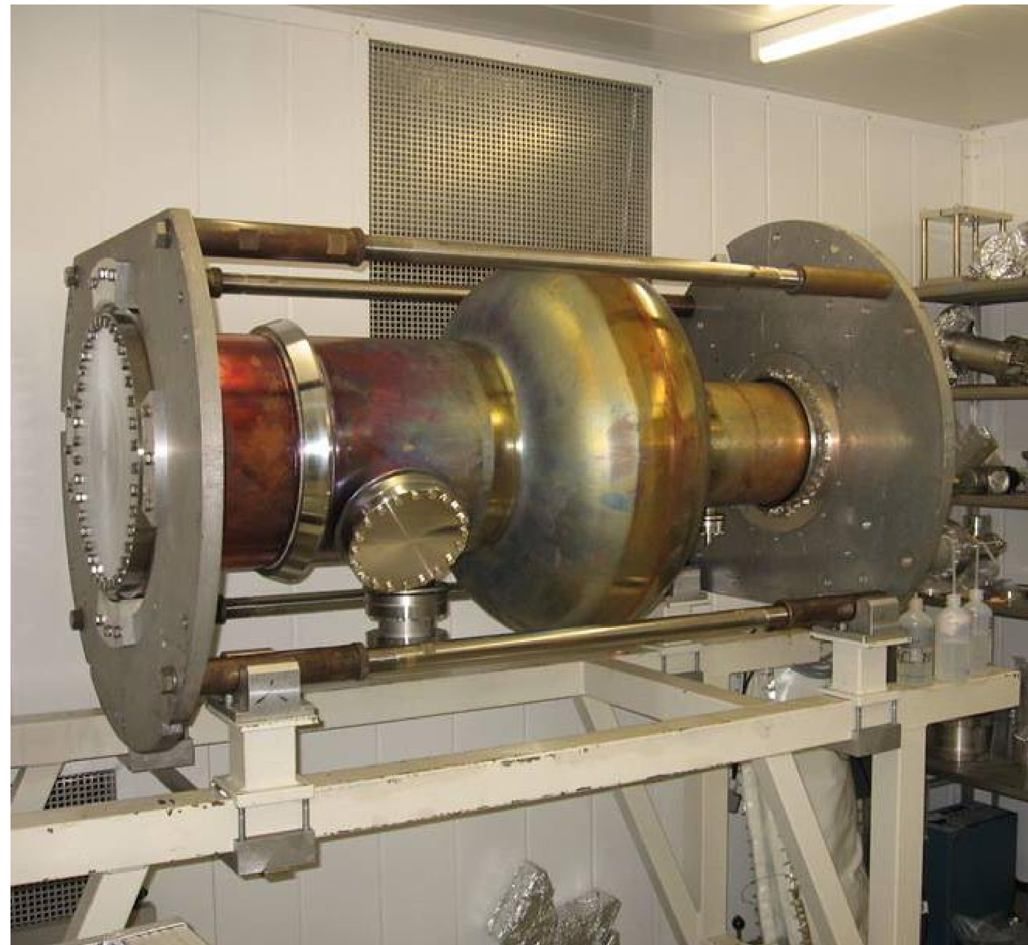
CM2 thermal shielding, from inside

SOLEIL SYNCHROTRON

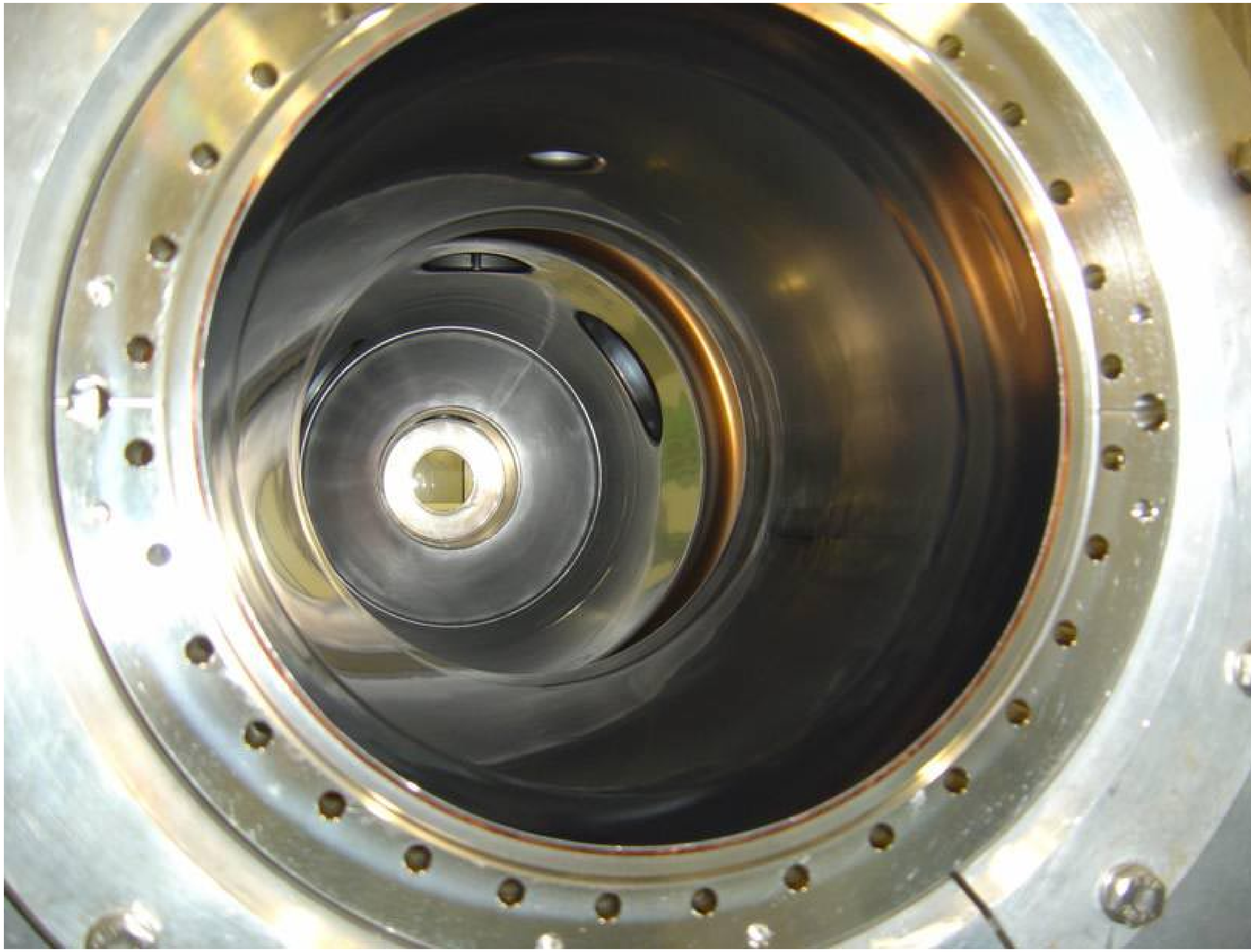
Two of the ½ cells for CM2 at ACCEL premises



CM2 cavities at ACCEL premises



Cavity inner part after Nb sputtering



Single cavity tests in vertical cryostat at CERN in October 2006
Delivery of the complete CM in May 2007

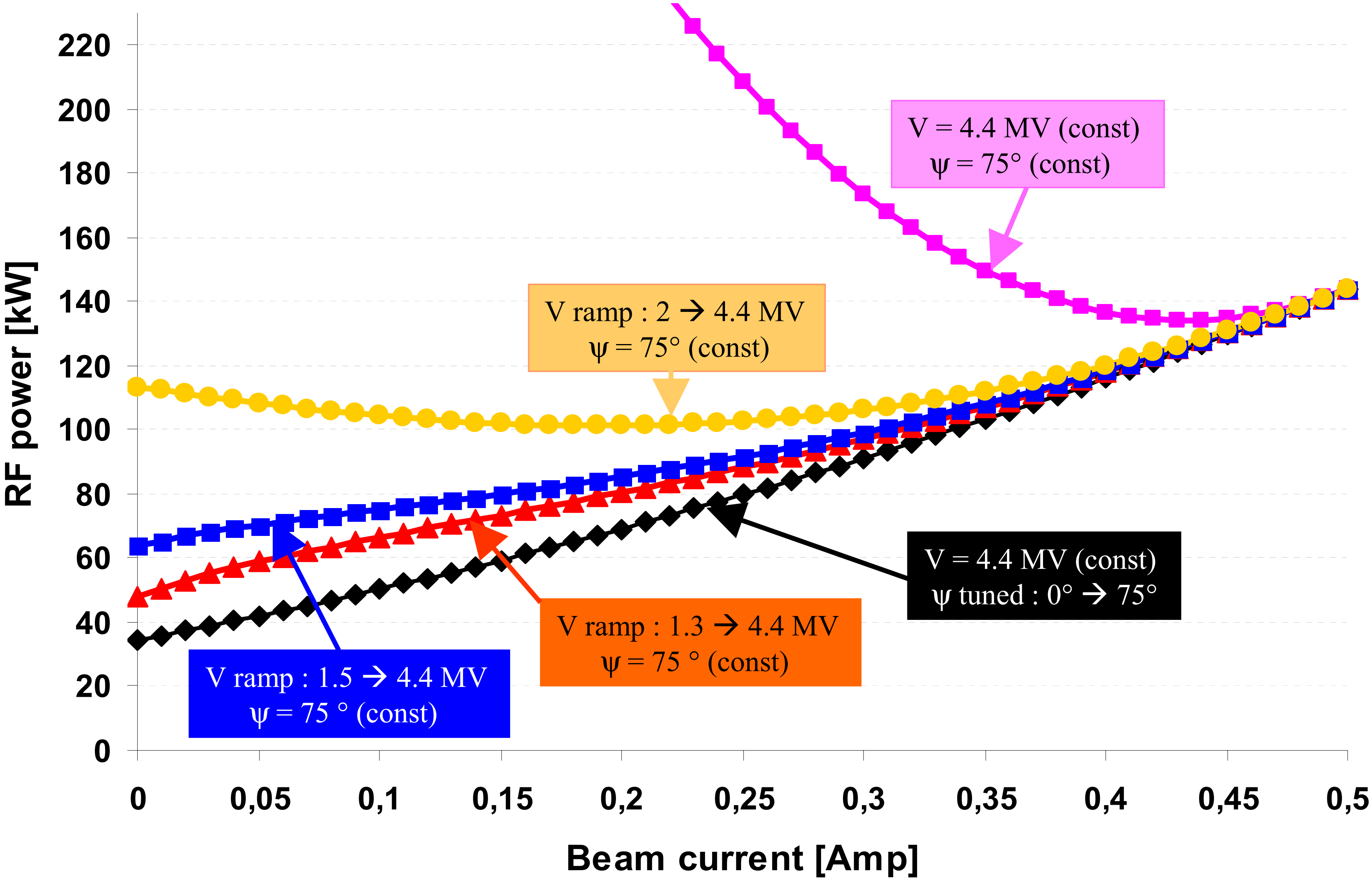
Cavity frequency tuning system

- Mechanism driven by a stepping motor, which changes the cavity length
- Located inside the cryomodule, under vacuum and cold environment
- Also used for TTF and for SUPER3HC at SLS & ELETTRA
  - At ELETTRA : stuck after ~ 50 10^6 motor steps (~ 1 op. year)
  - At TTF : "as new" after 51 10^6 motor steps
  - At SLS : no problem after 4 years operation, but rarely moving

Unsuitable setting of motor parameters at ELETTRA ?

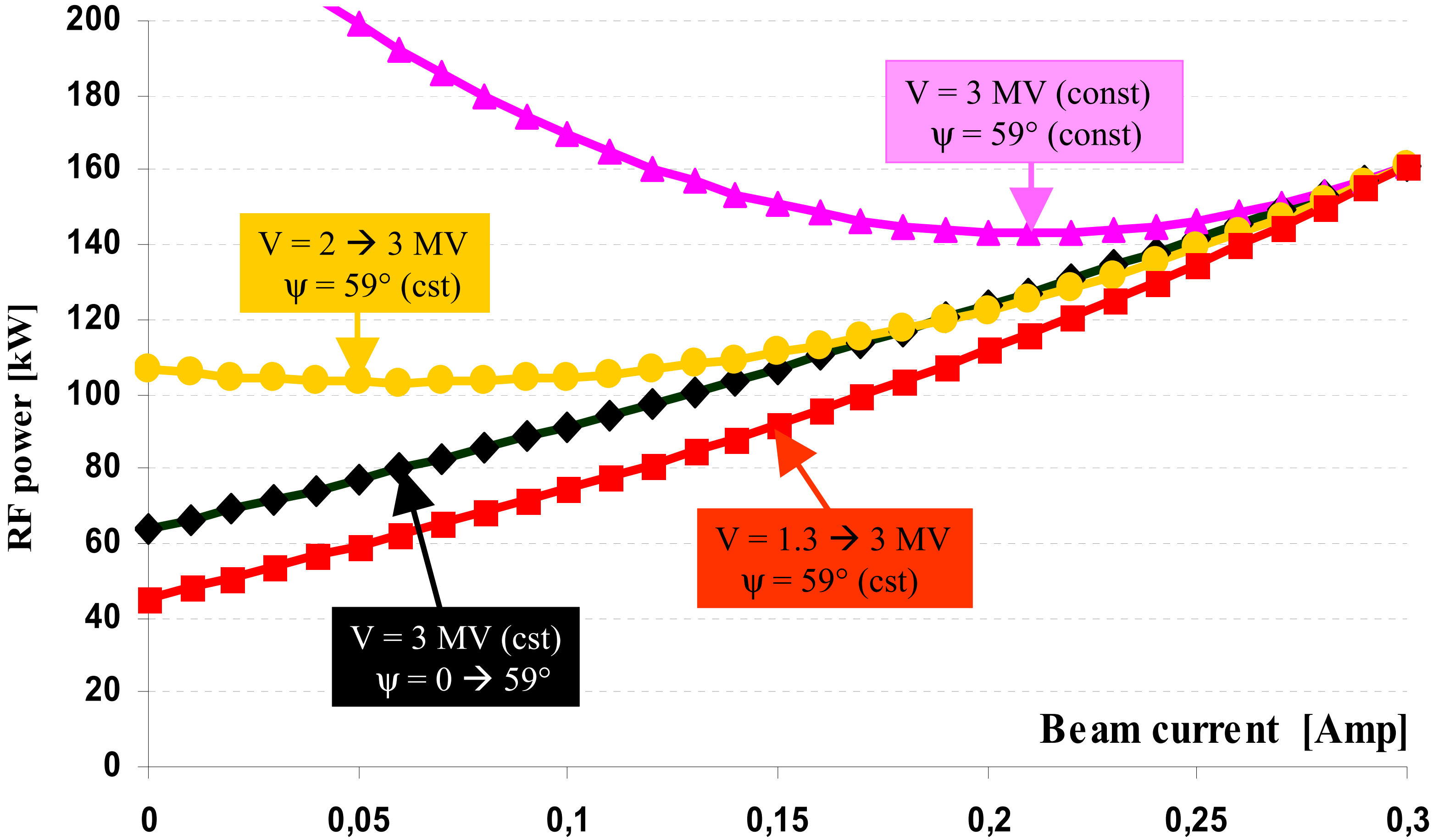
- SOLEIL nominal operation (500 mA) with reactive current compensation :
  - ~ 2.10^4 motor steps per injection → ~ 10 times less than ELETTRA
  - Top-up mode of injection → no pb
  - Encoder implementation → earlier detection of signs heralding a failure
  - Fixed tuner position during injection → Ramping of V_{RF}

RF power (1 cav) vs stored beam current
(2 CM, ΔU = 1.15 MeV, I_{max} = 500 mA, V_{max} = 4.4 MV)



RF power (1 cav) vs stored beam current

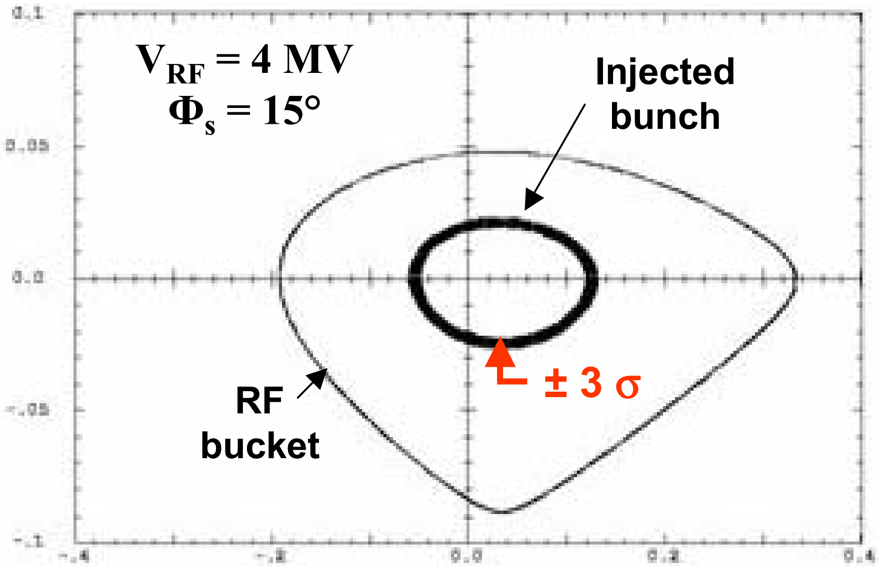
(*Phase 1* : 1 CM, ΔU = 1 MeV, I_{max} = 300 mA, V_{max} = 3 MV)

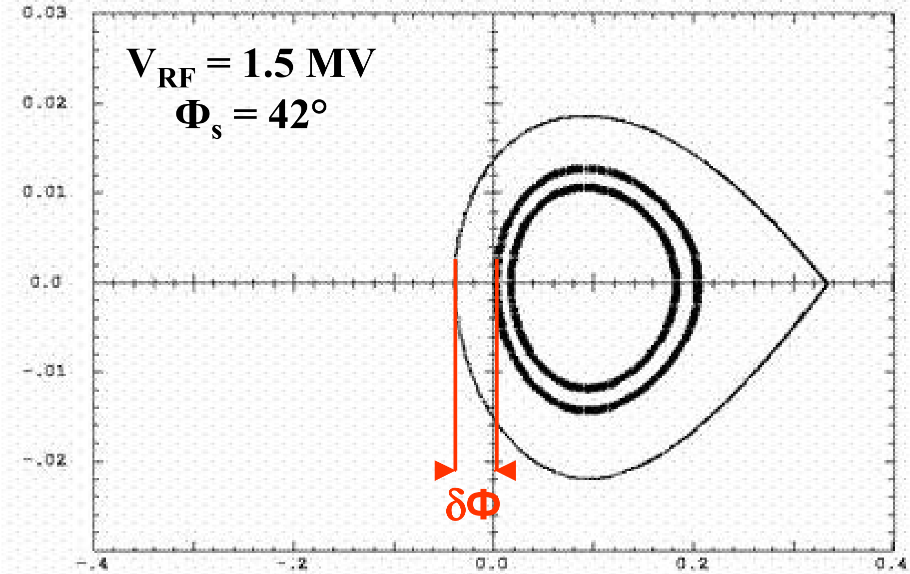


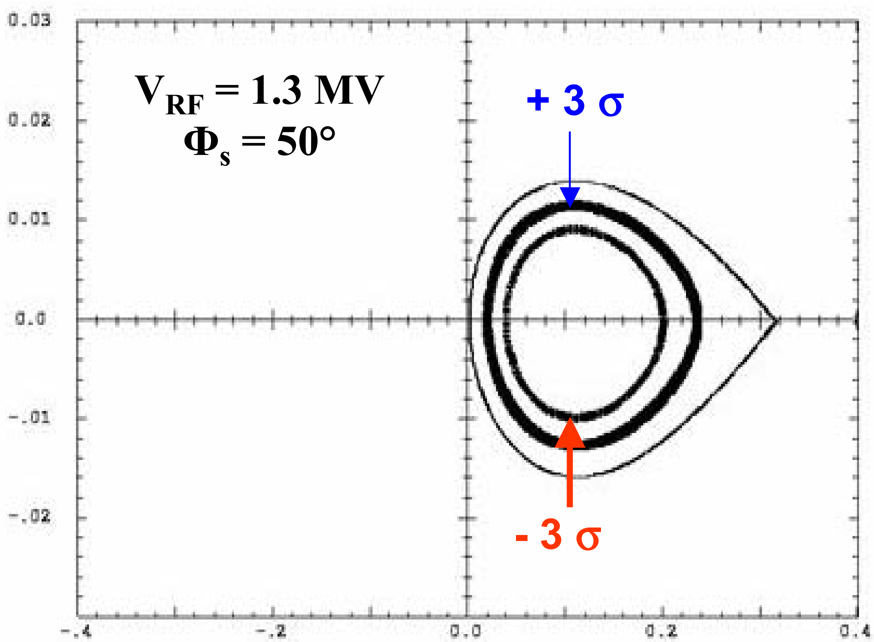
Conclusion : for both phases, injection at fixed tuning possible, while maintaining P_{ref} at reasonable level (< 60 kW), provided that V_{RF} is ramped, starting below 1.5 MV.

→ Energy and phase acceptance ?

Energy & phase acceptance







V_{RF} [MV]	4.0	1.5	1.3
Φ_s [deg]	15	42	50
ε [%]	+ 3.8 / - 6.0	± 2	± 1.5
δΦ [deg]	40	20	10

Computations → V ramp from 1.3 MV ok

Experiment → { as standard mode or as back-up

RF commissioning summary

- ✓ ***BO RF operation :*** **“ no news = good news ”**
- ✓ ***2 cavities of CM1*** **conditioned up to V_{cav} = 1.7 MV → 80 kW fully reflected (I_b = 0)**
  In previous test at CERN, 200 kW per coupler fully reflected (cavity detuned)
- ✓ ***First experiments with beam***
  - **using a single cavity with 1.3 MV up to 20 mA → P_i = 60 kW and P_r = 40 kW**
  - **up to 300 mA with on each cavity : V = 1 MV, P_i = 150 kW, P_r = 15 kW (detuning)**
  - ***LLRF*** **active, but direct RF feedback disabled (not yet necessary)**
- ✓ ***Cryogenic system***
  - **reliable operation after the elimination of a few bugs in the process control**
  - **good pressure stability in the cavity LHe vessel after modifying the cryo valve box**
- ✓ ***Solid state amplifiers***
  - **did not yet cause any interruption**
  - **although not perturbing for the operation, still significant nb of module failures (40 in operation + 50 accidentally out of 1500) → MTBF over longer running time**
  - **100 spare modules contracted → turn over (50 usable while 50 in repair)**
  - **50 spare transistors → maintenance contract including transistor supply (BBEF ?)**
  - **looking for other transistor suppliers (BLF369 from Philips → sample tests)**
- ✓ ***CM2 :*** **cavities are manufactured → tests in vertical cryostat at CERN, beg. of Oct 06**

General SOLEIL status

***LINAC* :** **operational since July 2005 (no major problem)**

***BO* :** **- single day commissioning on July 25th, 2005 → 1-2 millions turns @ 110 MeV**

- restart beginning of October 2005 :

→ Oct. 13th, beam accelerated up to 2.75 GeV with few % injection efficiency

→ Oct. 20th , 75 % injection efficiency (finally, 95 %)

→ end of Oct. , stop BO operation → full resources to SR installation

- week-end of May 6-7th , 2006 → tests of the BO extraction

***SR* :** **- 1st week-end of commissioning, on May 13-14th, 2006 → a few turns (no RF)**

- interruption of 2 weeks for the RF cavity conditioning

- commissioning restart, on May 31st → first stored beam (0.3 mA), on June 3rd

- 3 weeks of commissioning (June - July 2006) → up to 120 mA stored,

limited by several combined effects :

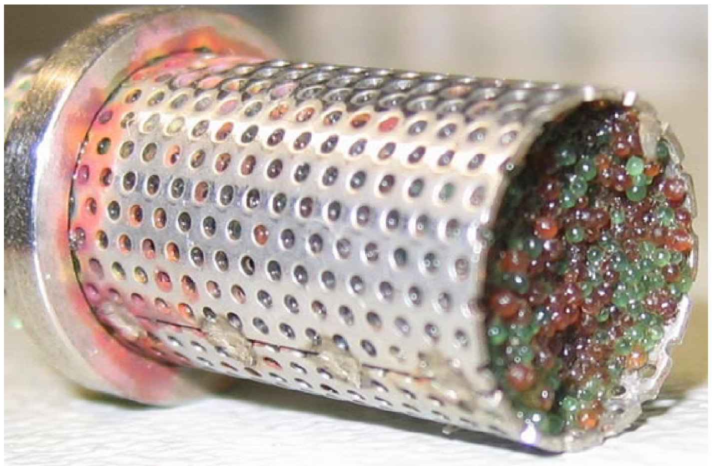
- ✓ **although vacuum processing in good progress, further conditioning required (only 5 A.h accumulated dose) → fast ion instability**
- ✓ **reduction of the beam stay clearance aperture by damaged bellows**

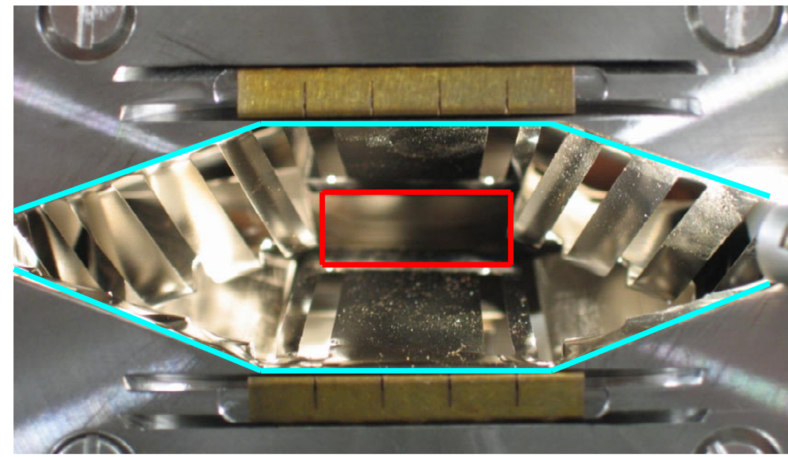
} **losses at ~ 100 mA**

- ✓ **contamination of water cooling circuits with resin (human mistake)**

→ reduction of the flow → overheating on crotches

Problems and cures





Water filter blocked by resin balls

→ during this summer shutdown, cleaning of the circuits and insertion of filters at the inlet of all the connected components.

Beam stay clearance aperture reduced by damaged bellows (bent fingers)

→ Check all of them (γ -graphy) : pb on 8 short section bellows ; 3 replaced this summer shutdown; other 5, later.

Commissioning restart in Sept 2006

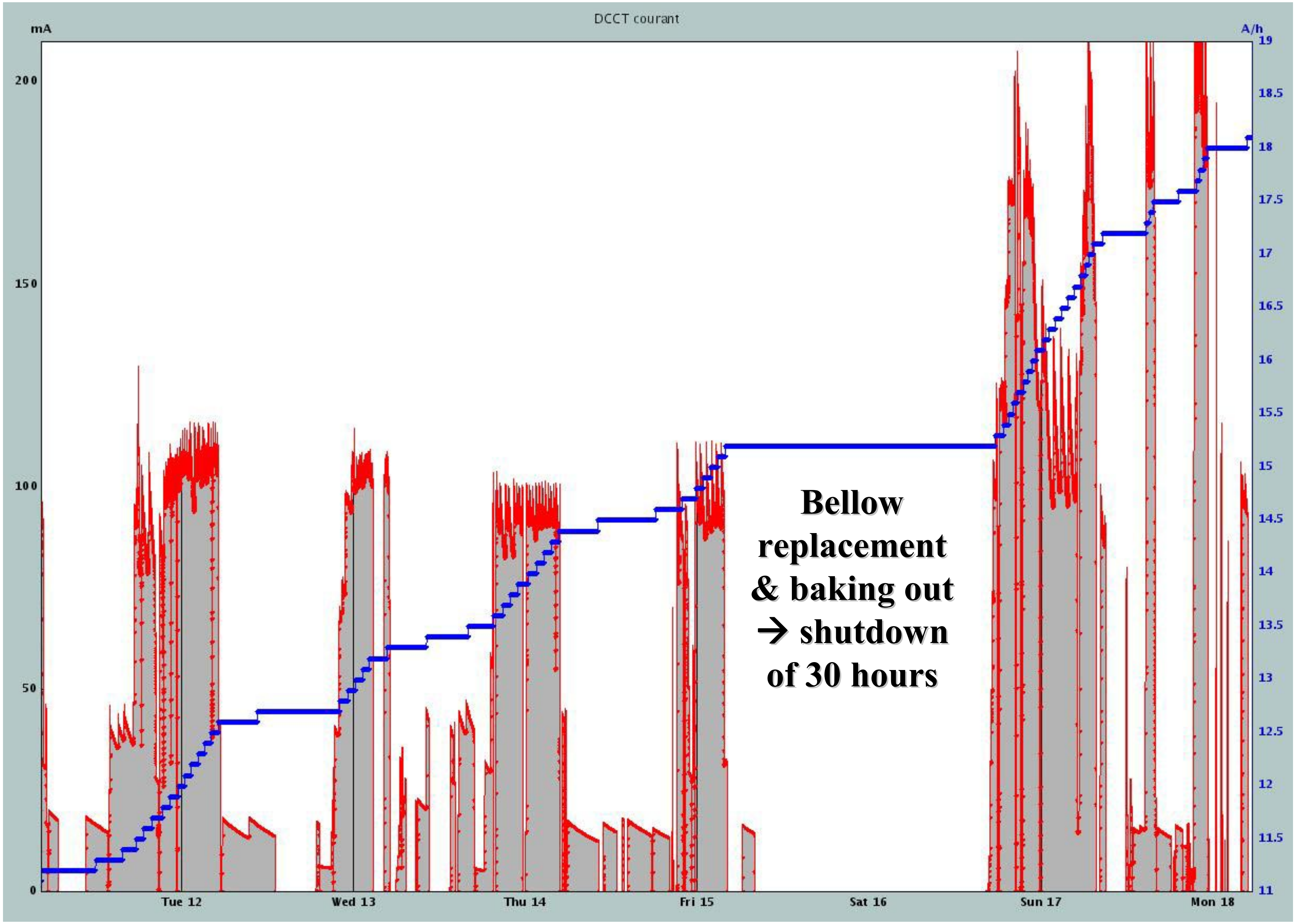
- After 1 week, 200 mA stored → heating of a bellow mounted without RF fingers
  → operation limited at 100 mA, usable by the beam lines
- Sept 6th, undulator HU 80 fully closed (15 mm) with 50 mA stored
  → did not affect neither the lifetime nor the dynamic aperture
- Sept 13th, first photons produced by beam line « Diff-Abs » with 100 mA stored
- Sept 15-16th, the faulty bellow is replaced → **Sept 20th, 300 mA stored**
  2.5 hour lifetime at 250 mA → further vacuum conditioning with beam
- Time sharing : machine physics, vacuum conditioning & user runs (< 100 mA)

Present goals

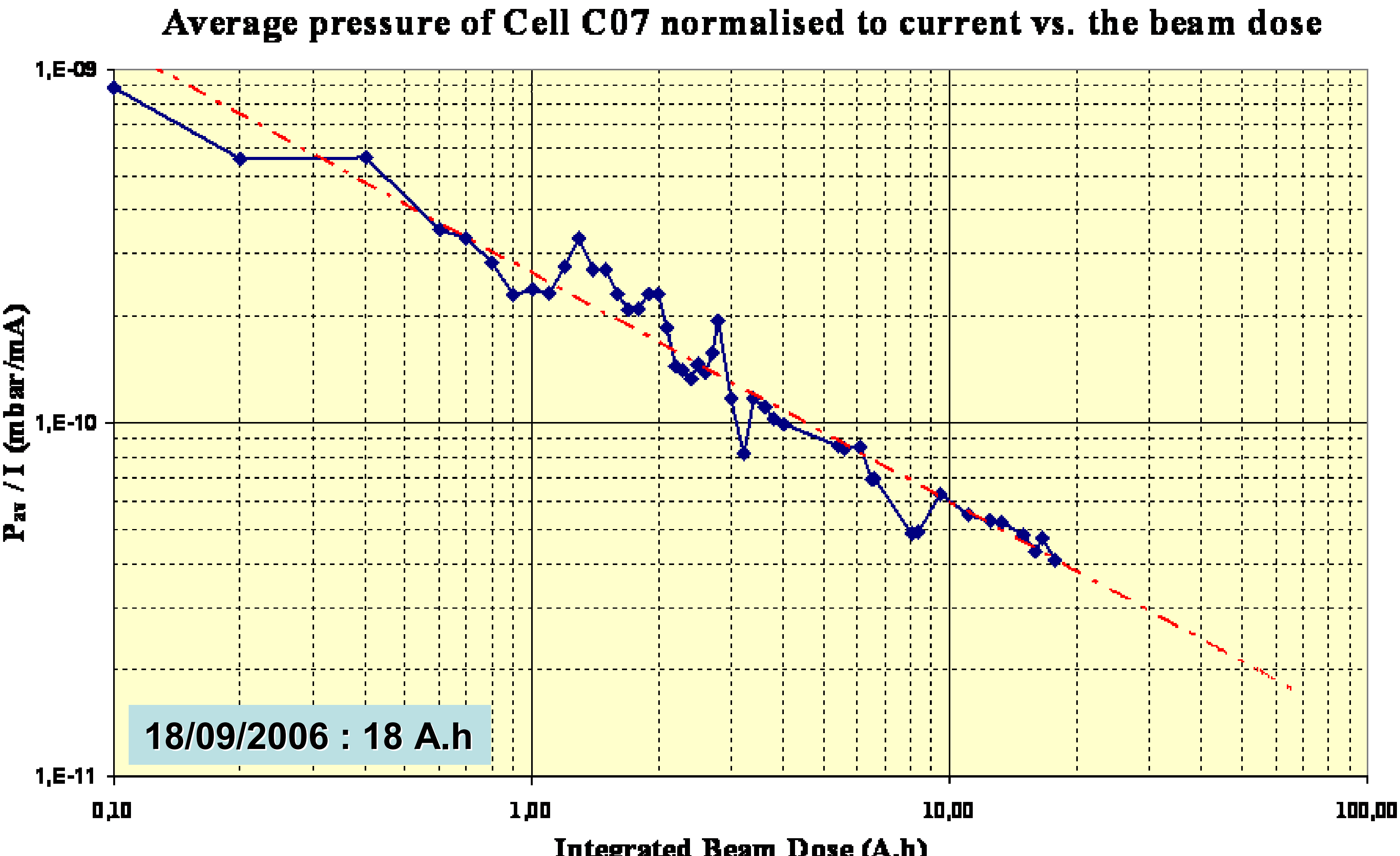
300 mA for users, beginning of 2007

CM2 → 500 mA for users, end of 2007

Beam current and integrated current week 37 : 11 -18 September

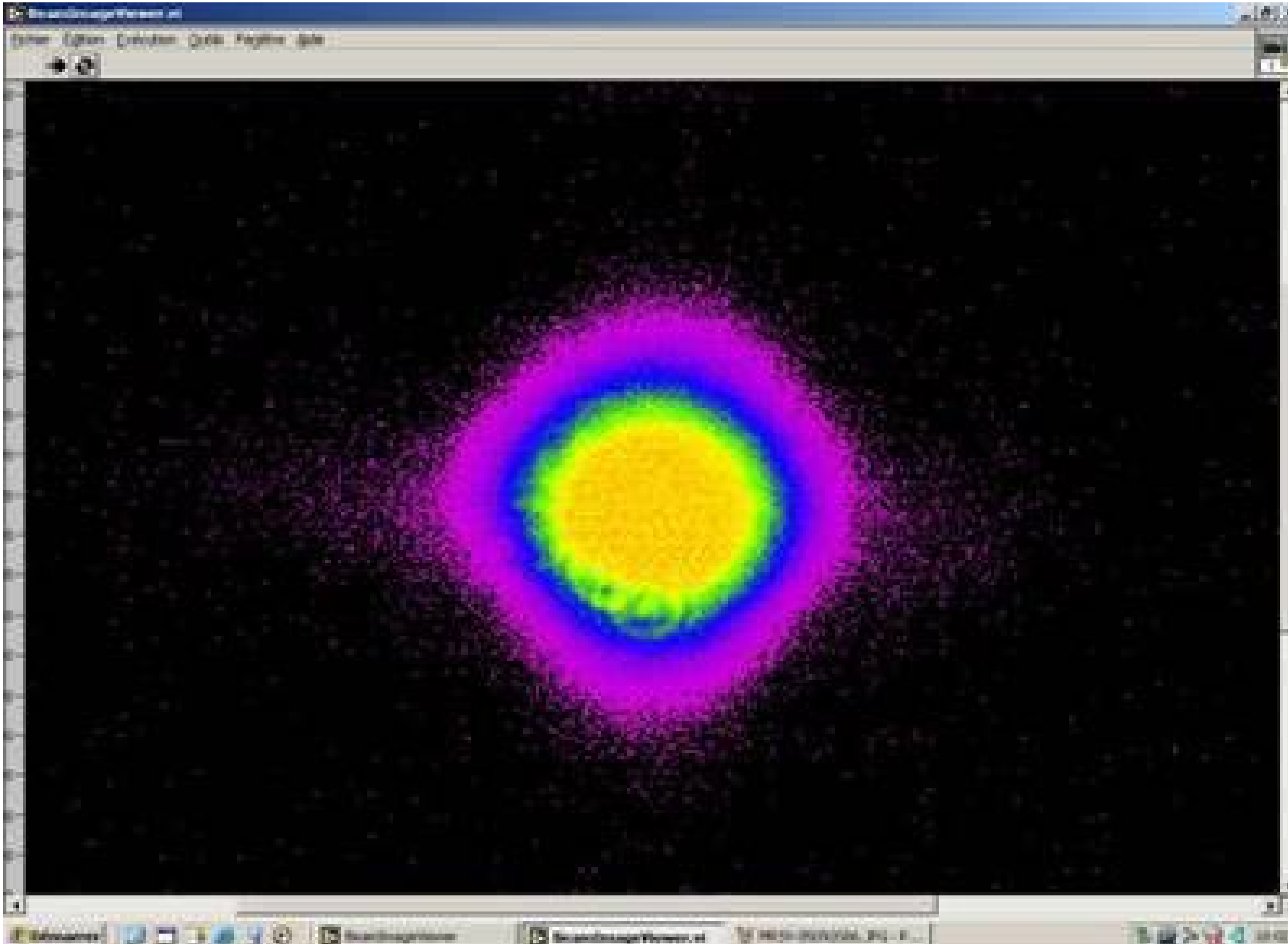


Vacuum conditioning



Beam spot image on the synchrotron radiation monitor (from a SR dipole)

SOLEIL SYNCHROTRON



Acknowledgement

SOLEIL RF GOUP

Retired since June 06

Jean POLIAN

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Catherine THOMAS-MADEC

Massamba DIOP

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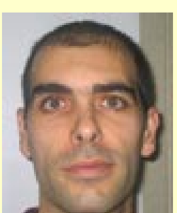
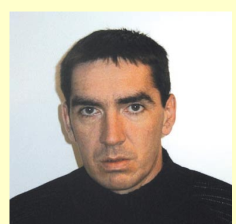
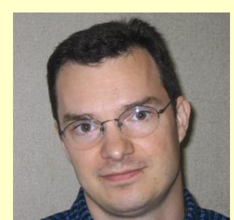


Robert LOPES

Helder Antonio DIAS



Jocelyn LABELLE



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SOLEIL, CEA, CERN, ESRF, LURE