9th European Light Source Radio-Frequency Meeting

21-22 September 2005
University of Aahrus, Denmark

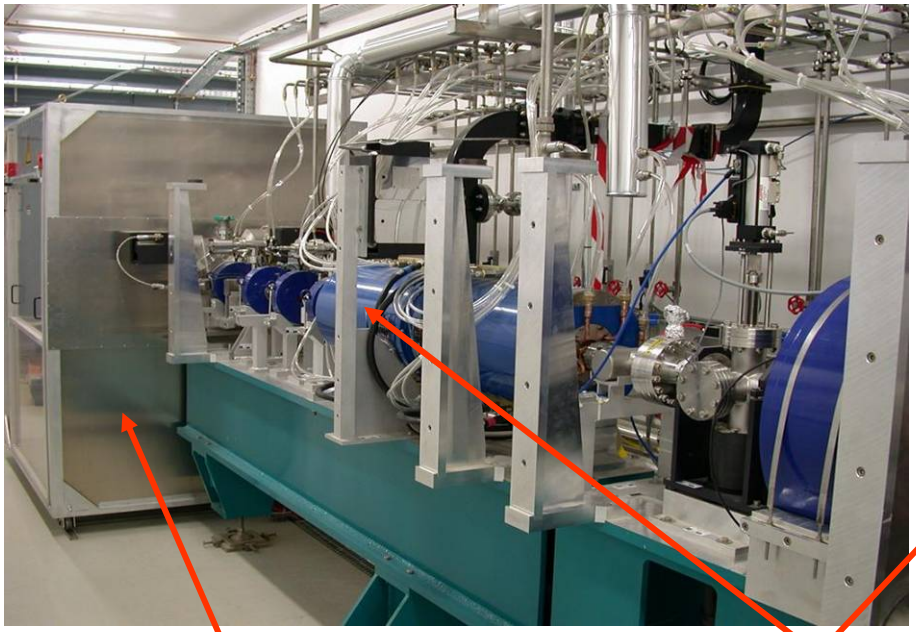
SOLEIL 352 MHZ RF SYSTEMS

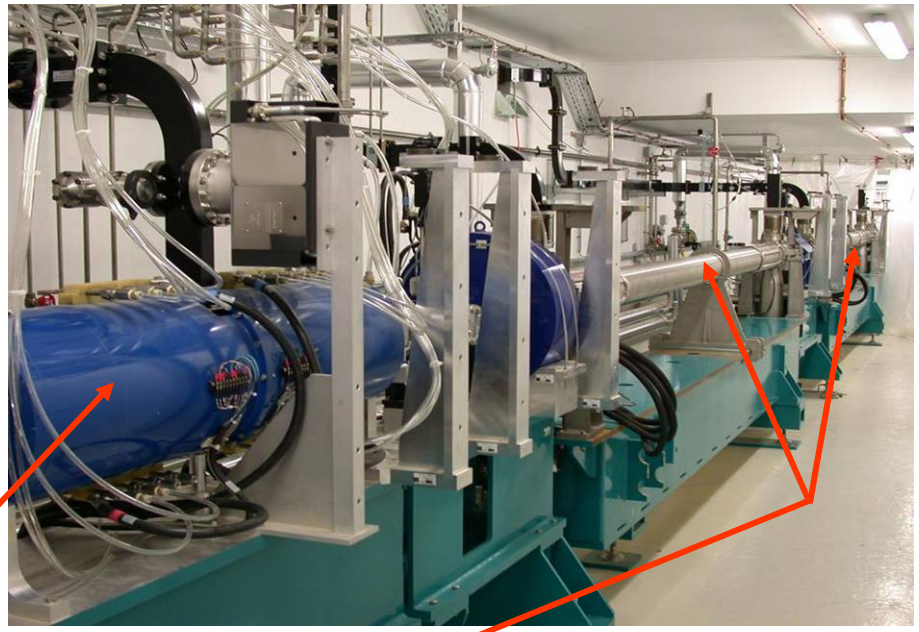
- ✓ SOLEIL general status
- ✓ BO RF system status
- ✓ SR RF Cryomodule tests at CERN
- ✓ SR RF Cryogenic source installation
- ✓ SR RF amplifier power tests

P. Marchand

SOLEIL site (June 2005)

SOLEIL 100 MeV LINAC





DC gun (352 MHz modulated) + 3 GHz bunching section + 2 accel. structures (CERN-LIL)
3 GHz RF power from 2 units of klystron & PFN modulator
Supplied "turnkey" by THALES

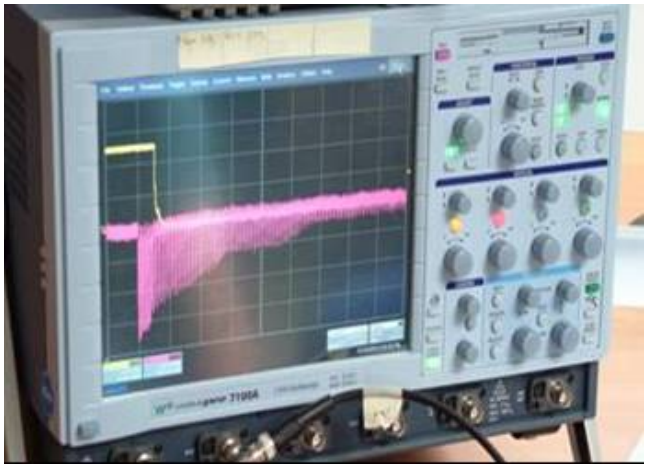
Commissioning started end June 05

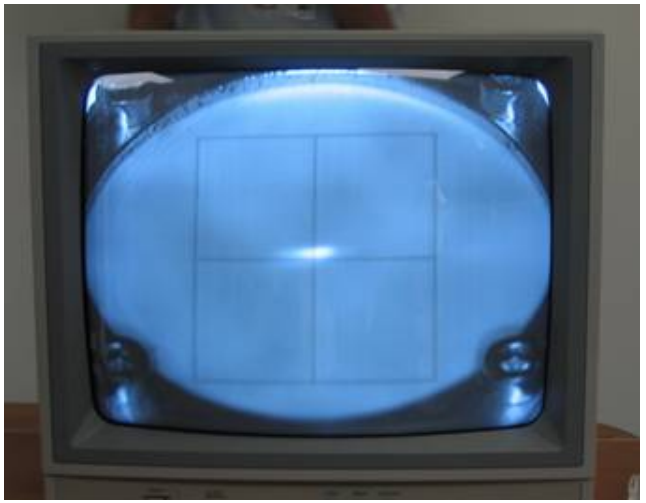
Now operational in multibunch mode
(single bunch mode to be tested)

First 100 MeV
e^- beam produced
on July 2nd 05

SOLEIL Booster

Single day of commissioning on 23 rd of July 2005
→ ~ 1 - 2 millions of turns at 100 MeV
Restart by the end of September





SOLEIL Storage Ring

Under installation

7 cells already equipped

Commissioning scheduled for Spring 2006

Booster main parameters

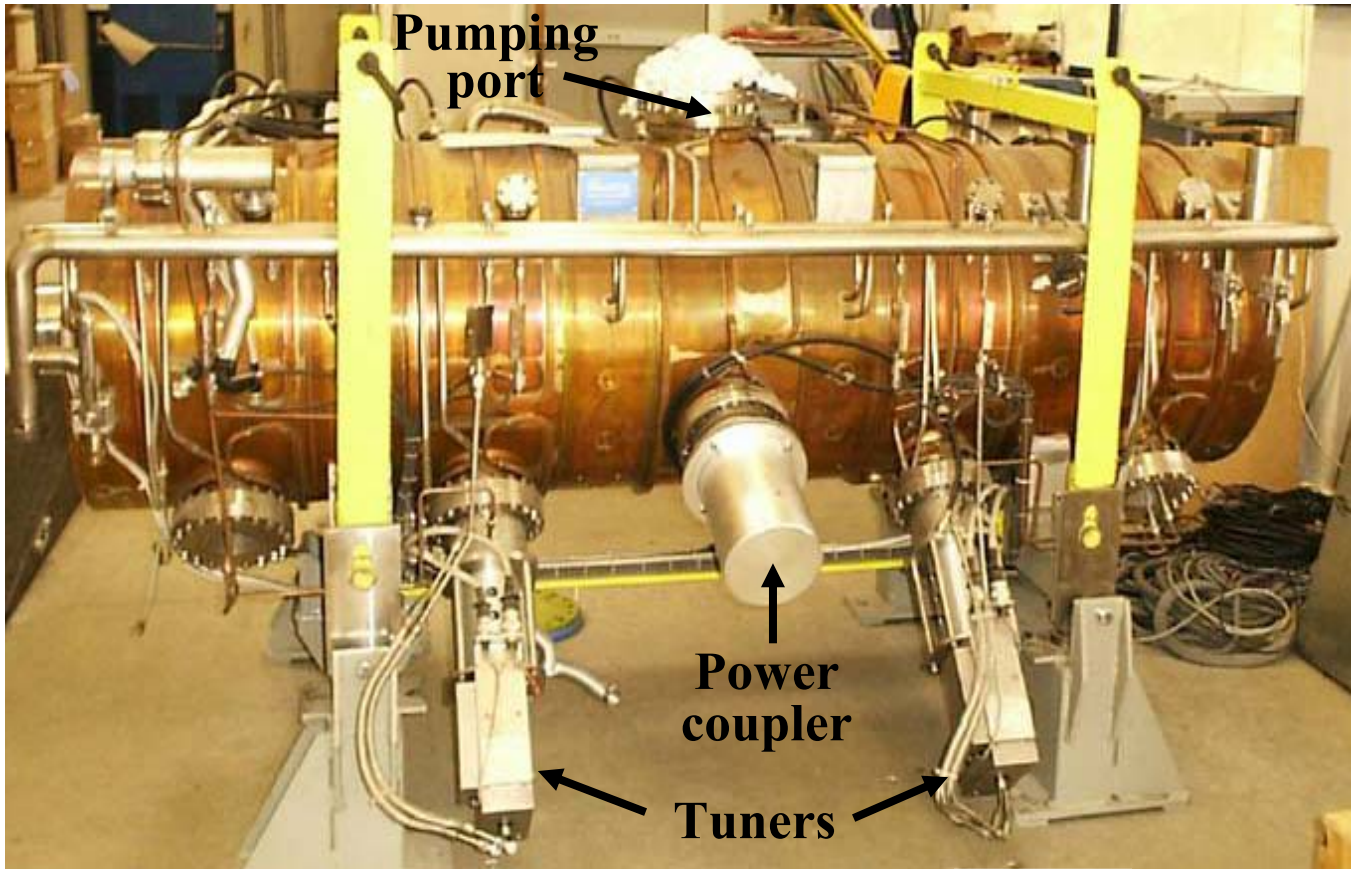
Circumference	156.6 m
Revolution frequency	1.91 MHz
Repetition rate	3 Hz
Injection energy , E_i	100 MeV
Final energy , E_f	2.75 GeV
Energy loss / turn @ E_f	410 keV
Beam current (max)	12 mA
RF acceptance @ E_f @ E_i with V_{RF} = 200 kV	± 0.35 % ± 1.5 %
Harmonic number	184
RF frequency	352.2 MHz
RF voltage @ E_f	0.85 MV
Beam power @ E_f	5 kW

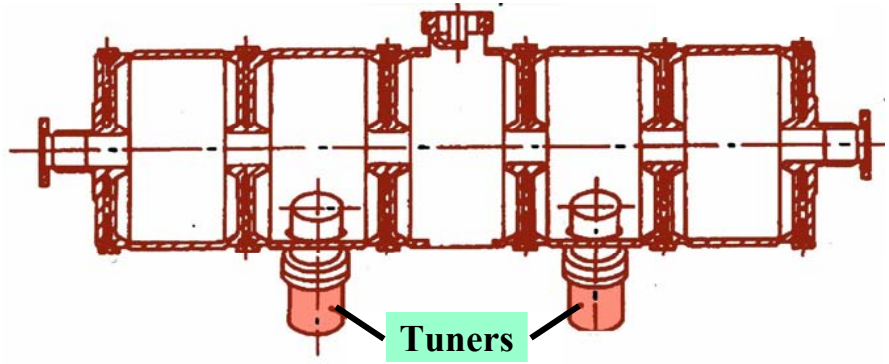
RF SYSTEM

→ 1 CERN-LEP 5-cell Cu cavity, R_s = 26 MΩ
P_{dis} : 15 kW, P_{beam} : 5 kW, P_{tot} : 20 kW

→ 1 solid state amplifier, $P_{available}$: 35 kW

BO 5-cell Cu cavity (CERN-LEP type)



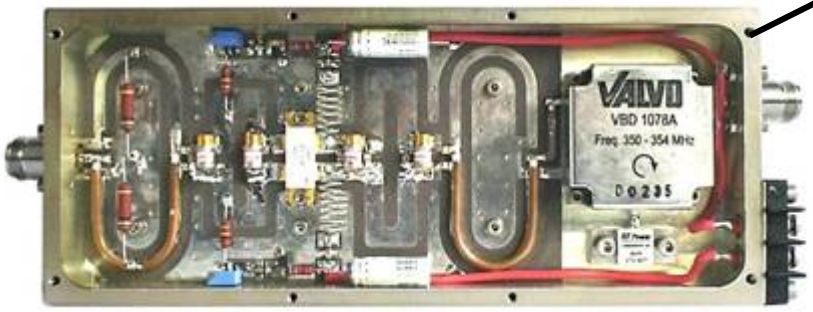


Power coupler

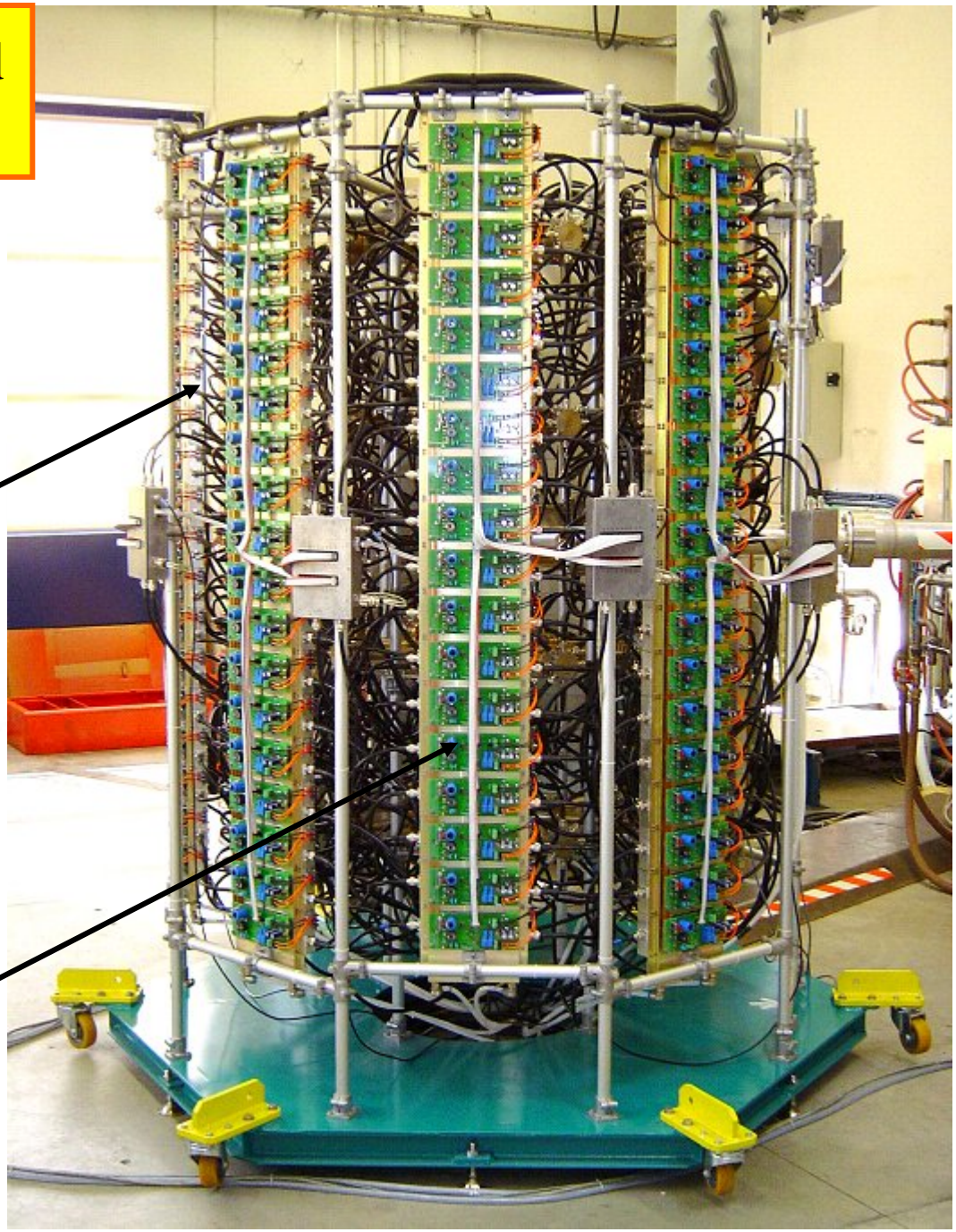
BO 35 kW solid state amplifier

147 amplifier modules
& DC/DC converters
on 8 water-cooled dissipaters

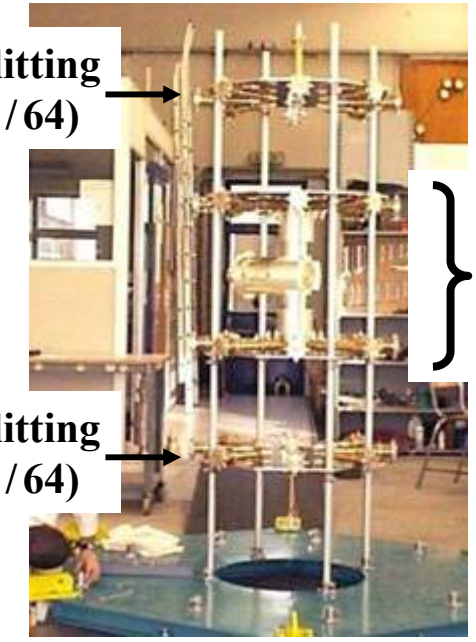
330 W amplifier module



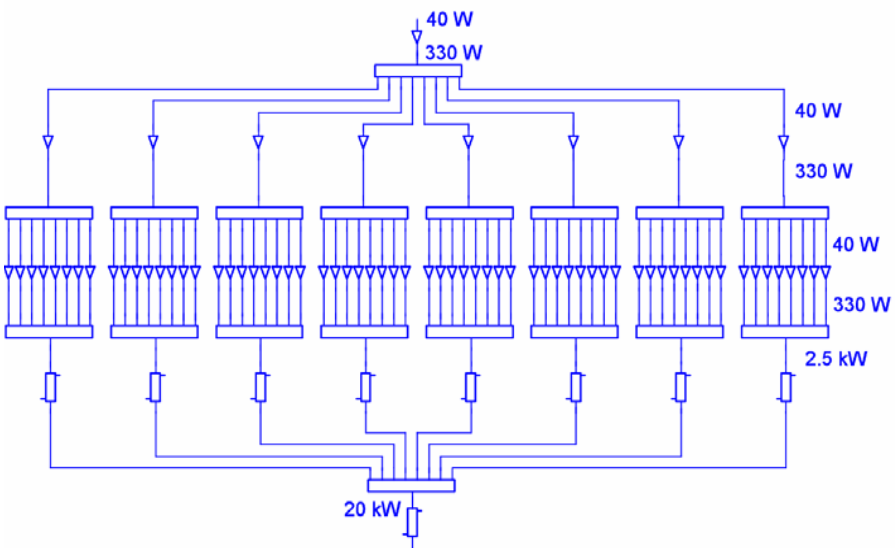
600 W, 300 Vdc / 30 Vdc converter



BO amplifier power combination



Re-combination



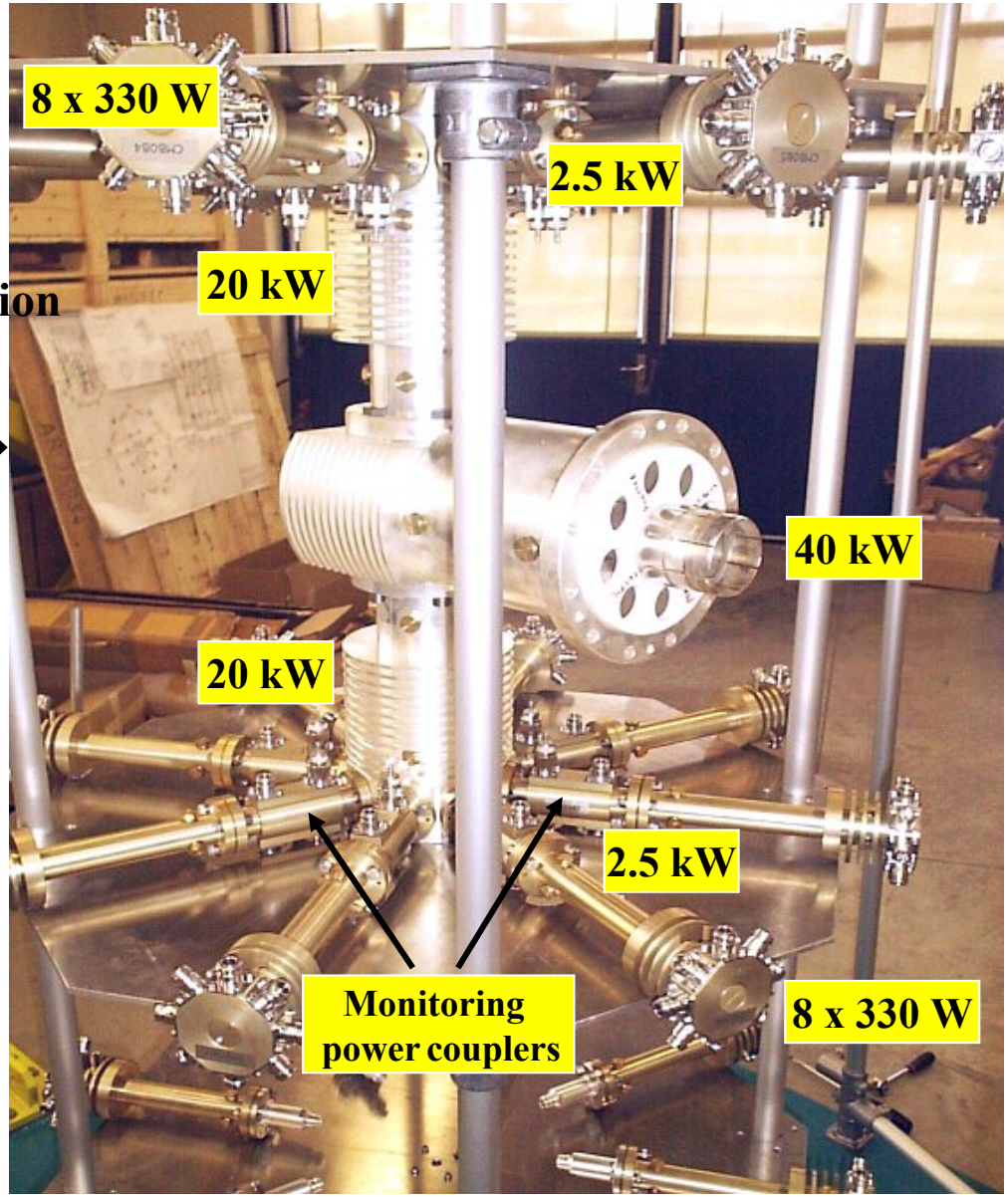
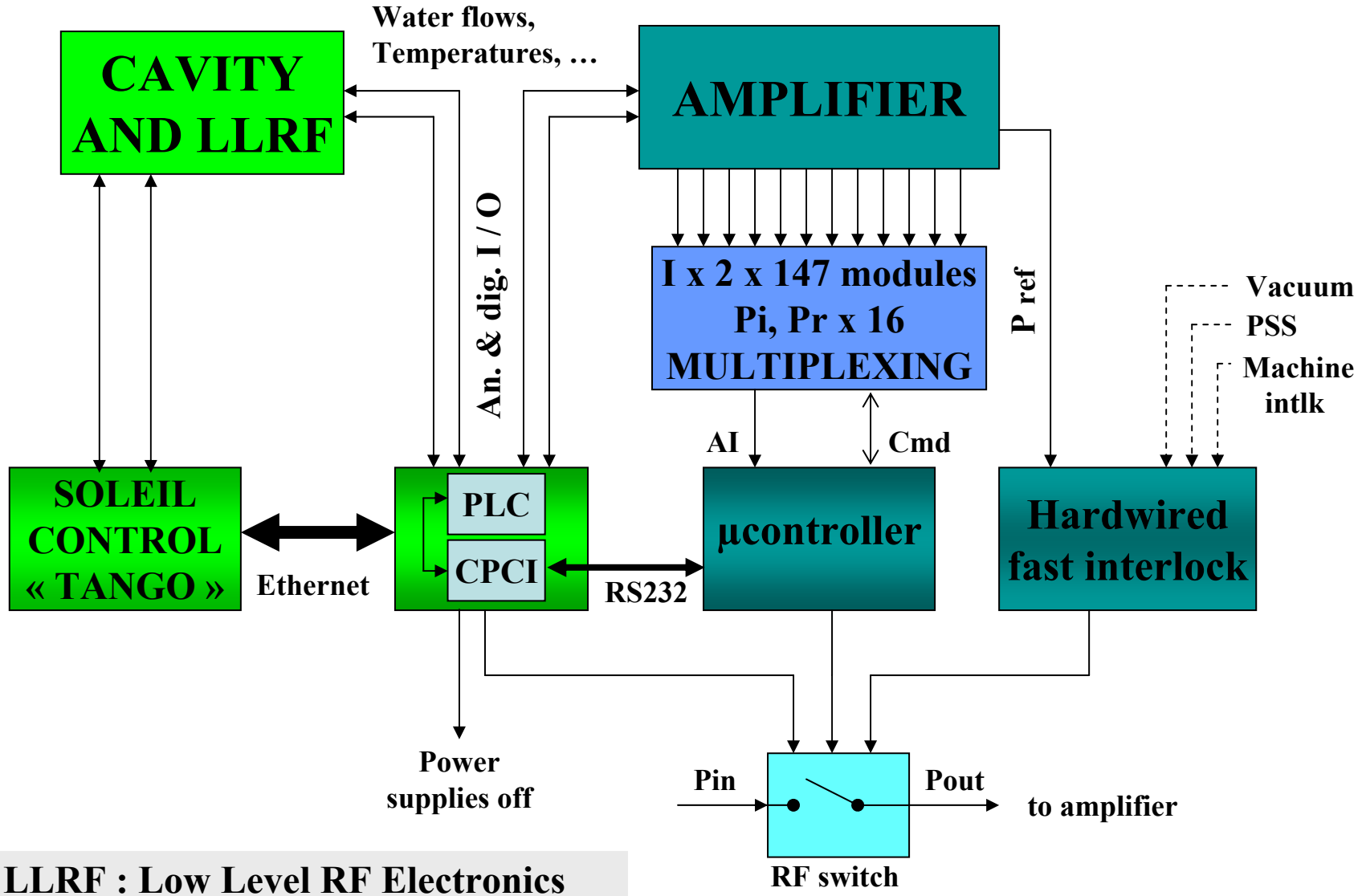


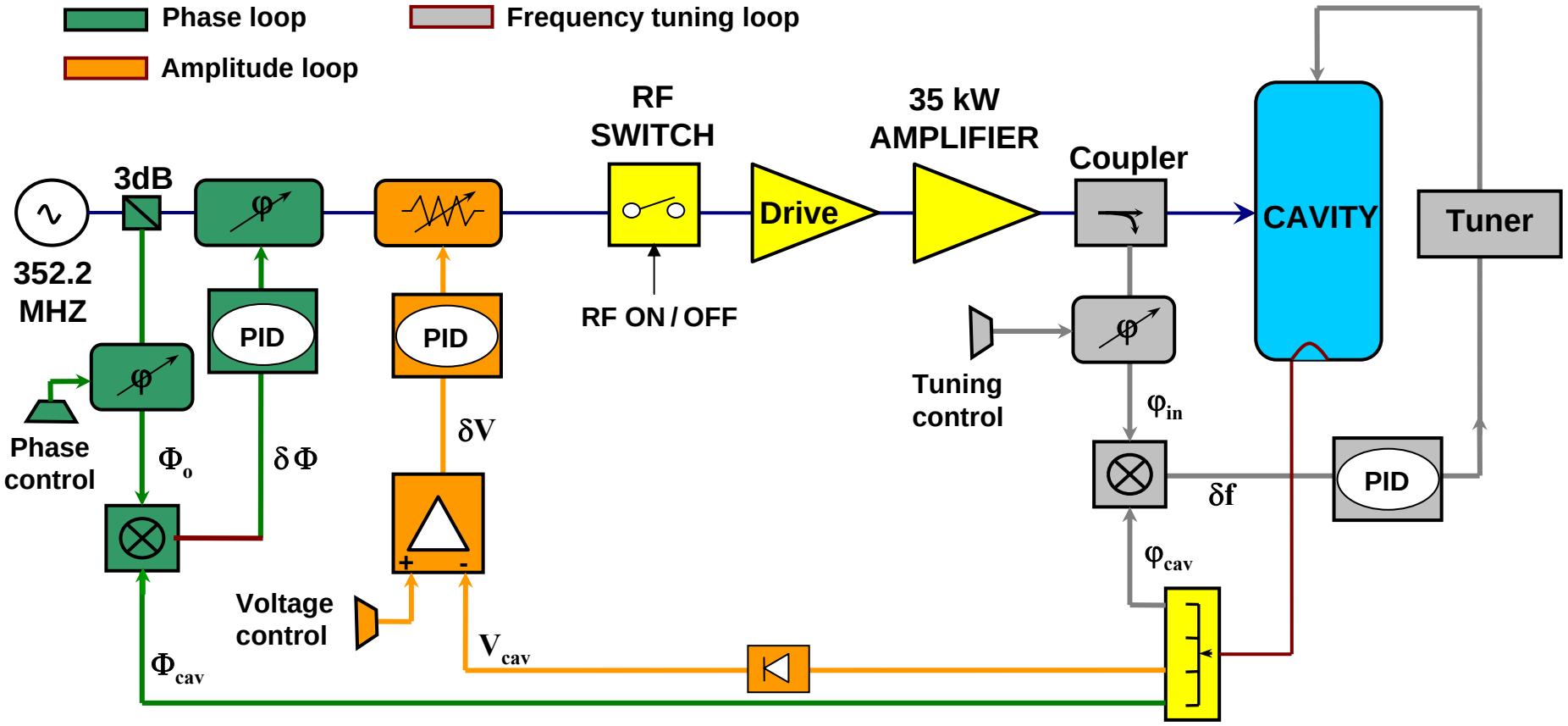
Diagram of the BO RF control system



LLRF : Low Level RF Electronics (amplitude, phase & frequency loops)

BO Low Level RF Electronics

3 conventional « slow » control loops for the frequency, amplitude & phase remake of a LURE design adapted to the SOLEIL needs



	Amplitude	Phase	Frequency
Accuracy	± 0.25 %	± 0.4°	± 30 Hz
3 dB BW	12 kHz	7 kHz	5 Hz

Booster RF power plant : review of test results and status

- ***Spring 2004*** **: 1st day of operation, amplifier tested up to 35 kW CW on dummy load and then 30 kW CW for ~ 600 hours without any interruption**

- ***June 2004 :*** **cavity RF conditioning up to 30 kW CW (1.5 x V_{max} , 3 x <P>)**
  Several "full reflection" events occurred during the conditioning process
  → normal switch-off without trouble for the amplifier

- ***Summer 2004 :*** **implementation of the control (µcontroller + PLC) and LLRF (drive chain, amplitude, phase and tuning loops)**

- ***Autumn 2004 :*** **tests of the complete BO RF plant (cavity, amplifier, control & LLRF) at 30 kW CW for more than 1500 h without major trouble nor performance degradation; only a few minor faults due to cabling mistakes that could be quickly repaired (→ ESLS RF 2004)**
  → the fault events did not stop neither perturb the amplifier operation

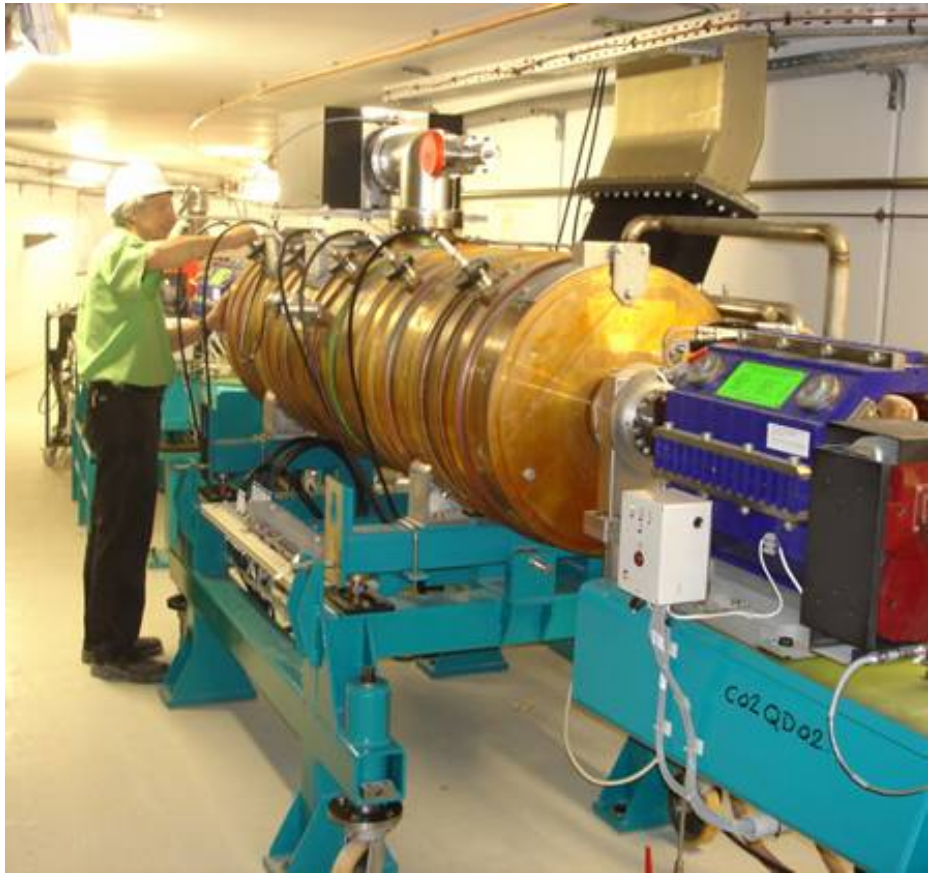
- ***December 2004 :*** **tests with 33 % $P_{reflected}$ (10 over 30 kW) in CW for a few days**

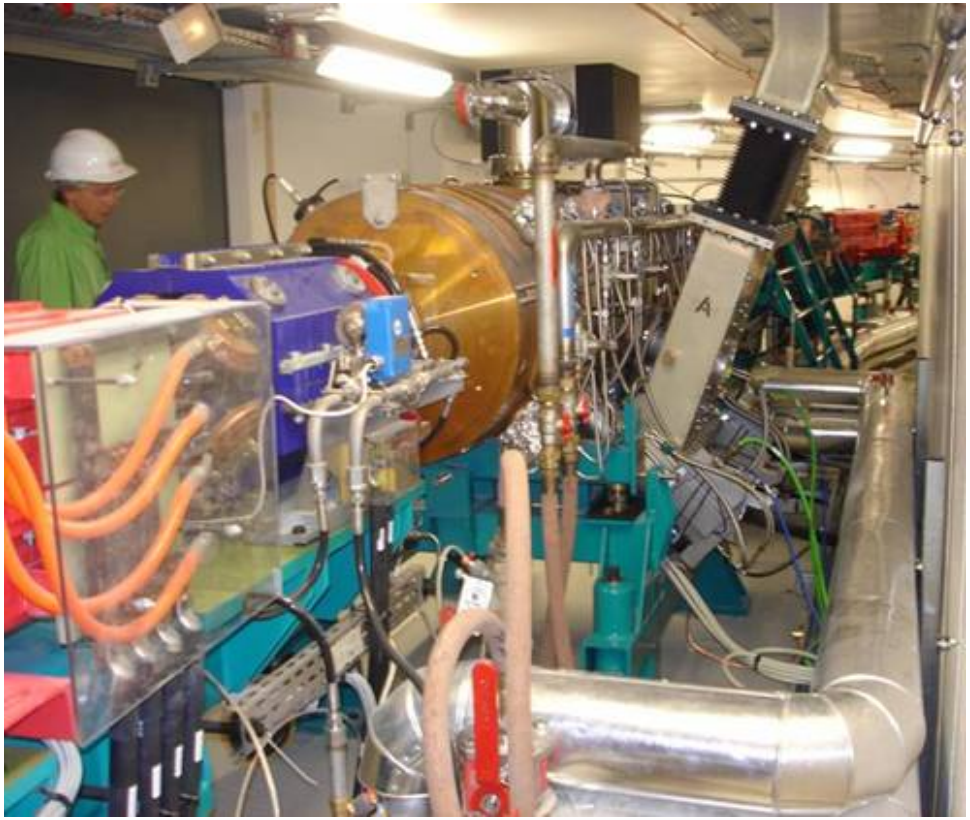
- ***July 2005 :*** **complete BO RF plant installed, tested and operational on site**

BO amplifier and cavity inside the test area at LURE

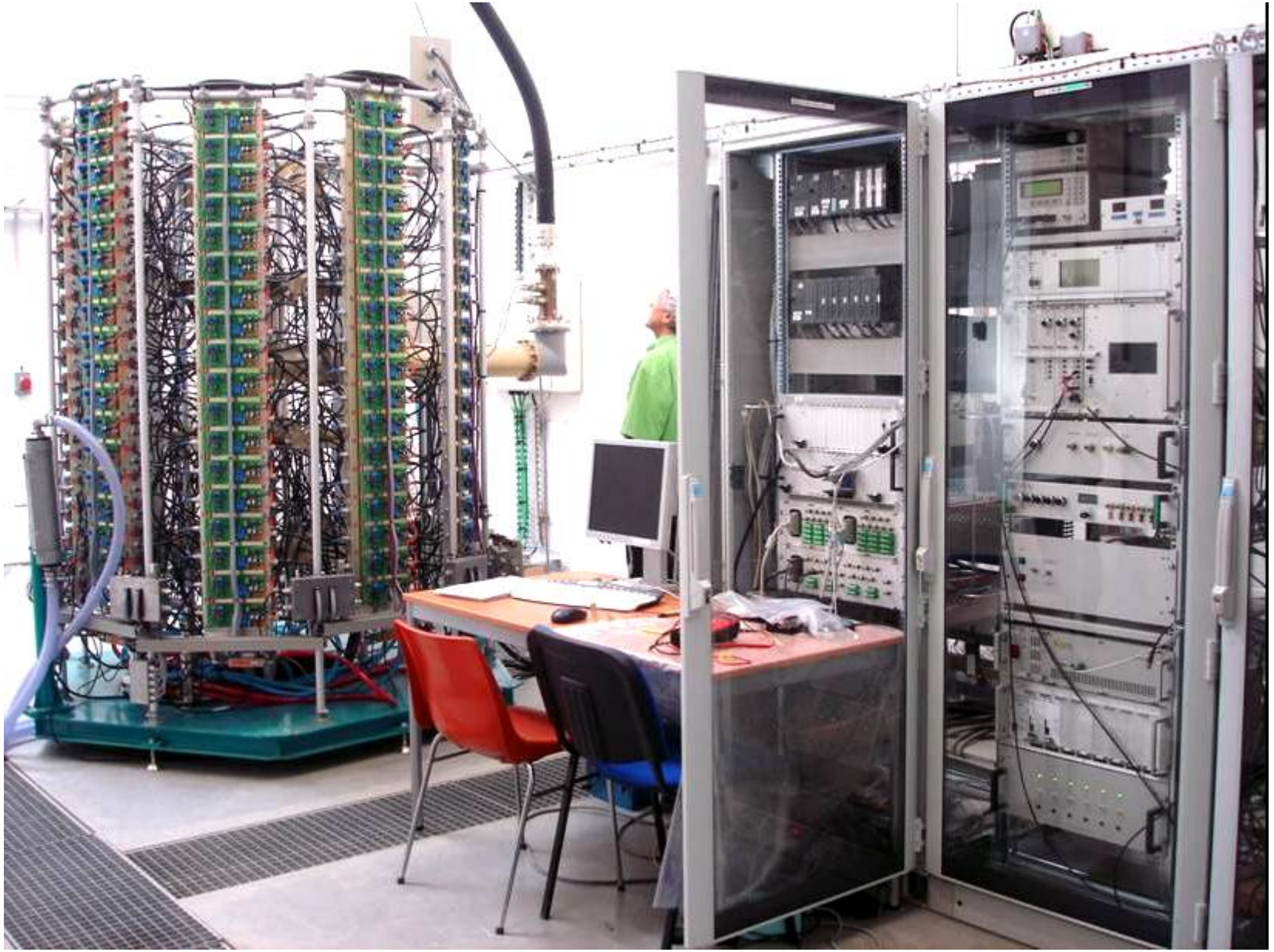
Cavity transfer towards the BO ring

Cavity accommodated in the BO ring





Booster RF room



Storage ring main parameters

Circumference	354 m
Revolution frequency	0.85 MHz
Energy	2.75 GeV
Energy loss / turn	1.15 MeV
Beam current	500 mA
Momentum compaction	4.4 E-4
Momentum spread	0.1 %
RF acceptance	± 6.15 %
Bunch length	4.2 mm
Synchrotron frequency	5.9 kHz
Harmonic number	416
RF frequency	352.2 MHz
RF voltage	4.8 MV
Beam power	575 kW

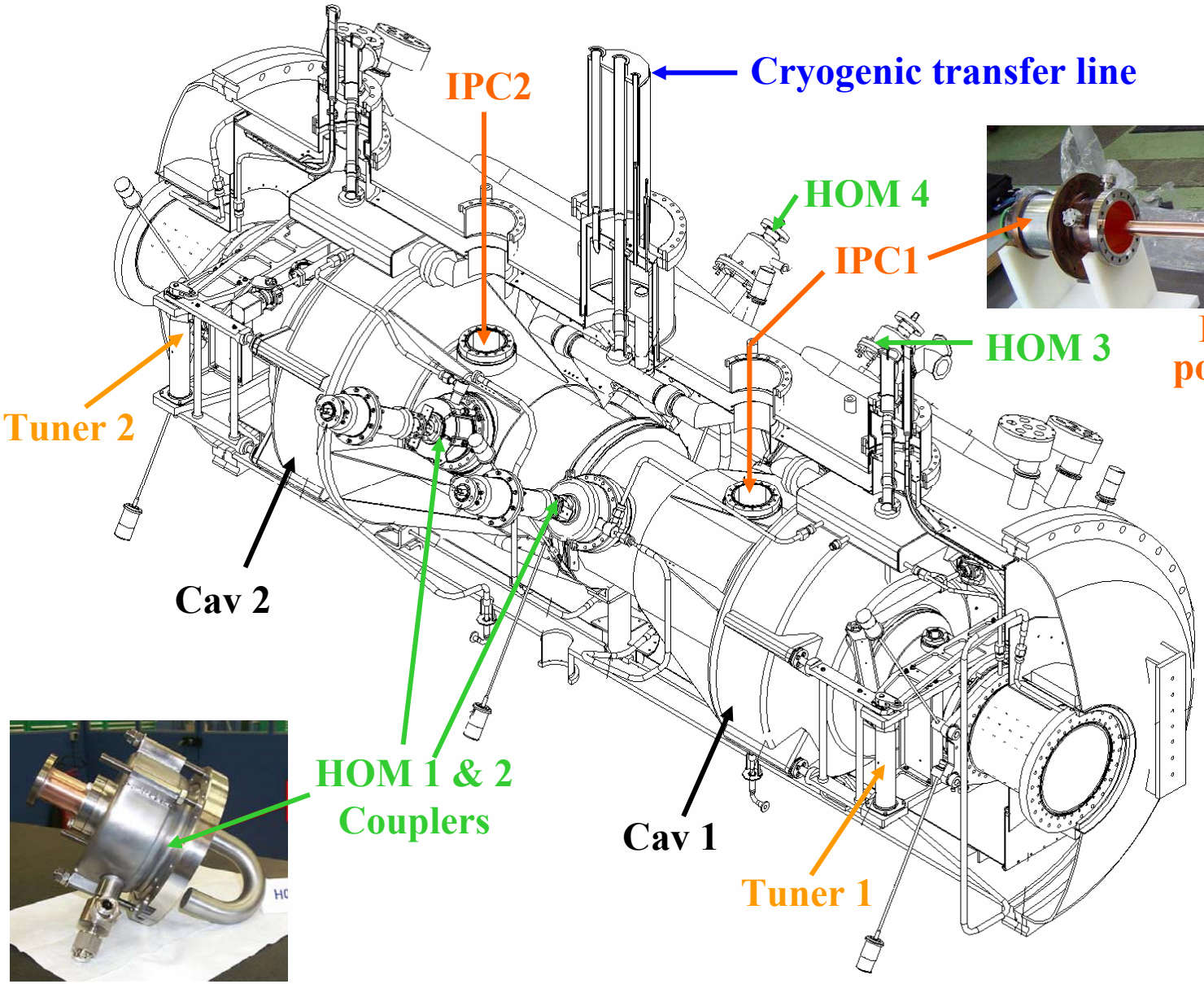
RF SYSTEM

→ 4 superconducting cavities (inside 2 cryomodules)

V_{cav} = 1.2 MV ; P_{cav} = 145 kW

→ 4 solid state amplifiers : 4 x 190 kW

SOLEIL cryomodule design



IPC : input power coupler

CM1 : brief history

1996, SOLEIL studies → prototype development (CEA-CERN collaboration)

End of 1999, first tests (without beam) at CERN

2001, SOLEIL approval → performance validation in ESRF e^- beam

End of 2001, installation in the ESRF storage ring

2002, test of the prototype in the ESRF e^- beam, using LHe from Dewar
→ 1.5 MV/cav , 190 kW/coup @ 200 mA (ok for phase 1 of SOLEIL)

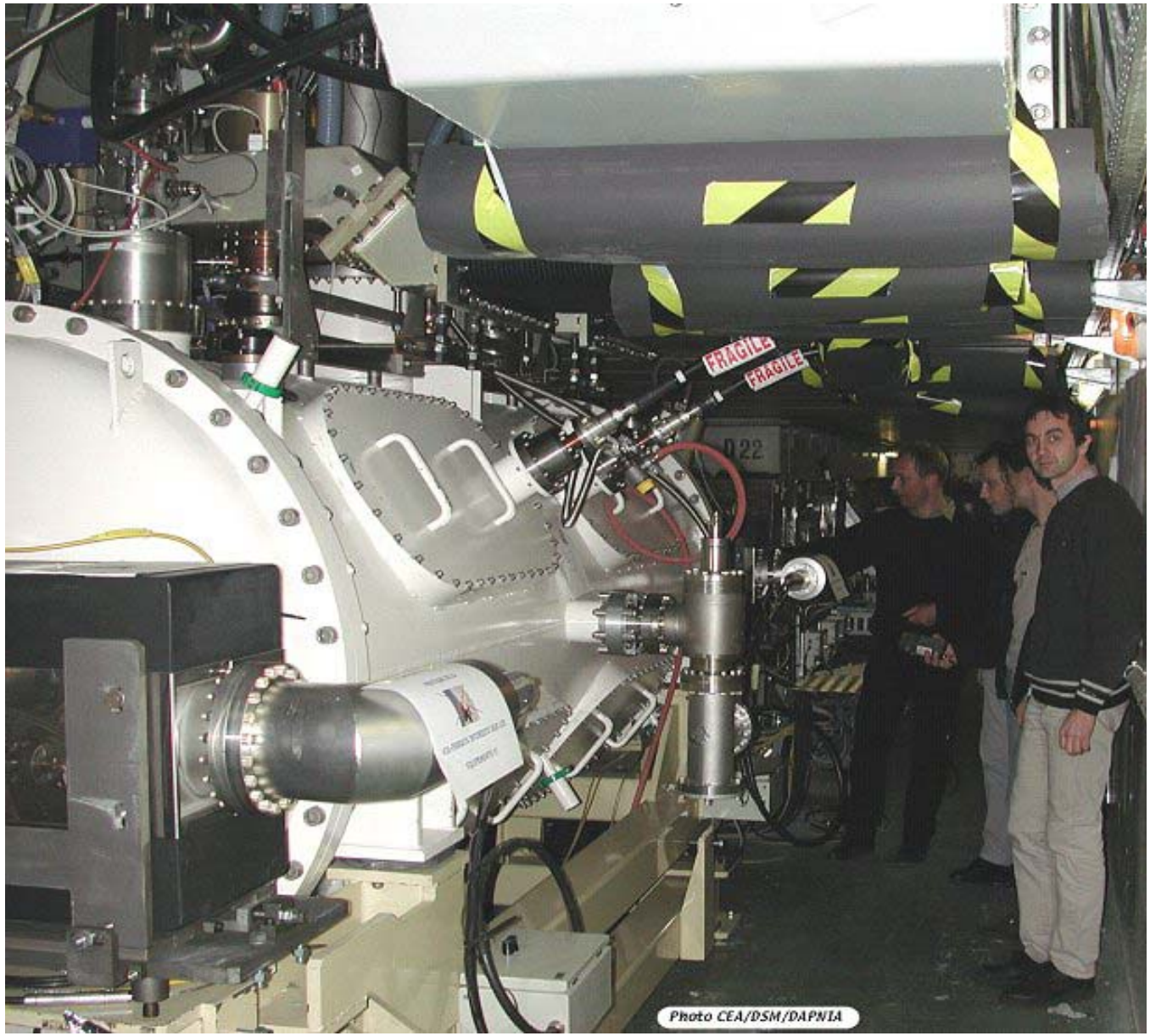
<u>End of 2002, it is decided</u> :

1) The prototype will become the 1st cryomodule of SOLEIL (CM1)
2) "Refurbishment" before the installation in SOLEIL (HOM & input power couplers, thermal screen, cryogenic circuitry & instrumentation)
3) Order of a 2nd cryomodule (CM2 ≈ CM1) in the industry

2003-2004, disassembling, modifications & re-assembling of CM1 at CERN

2004-2005, cryogenic & RF power tests of CM1 at CERN

2002 , the cryomodule prototype in the ESRF storage ring



End of 2003, at the entrance of the CERN clean room

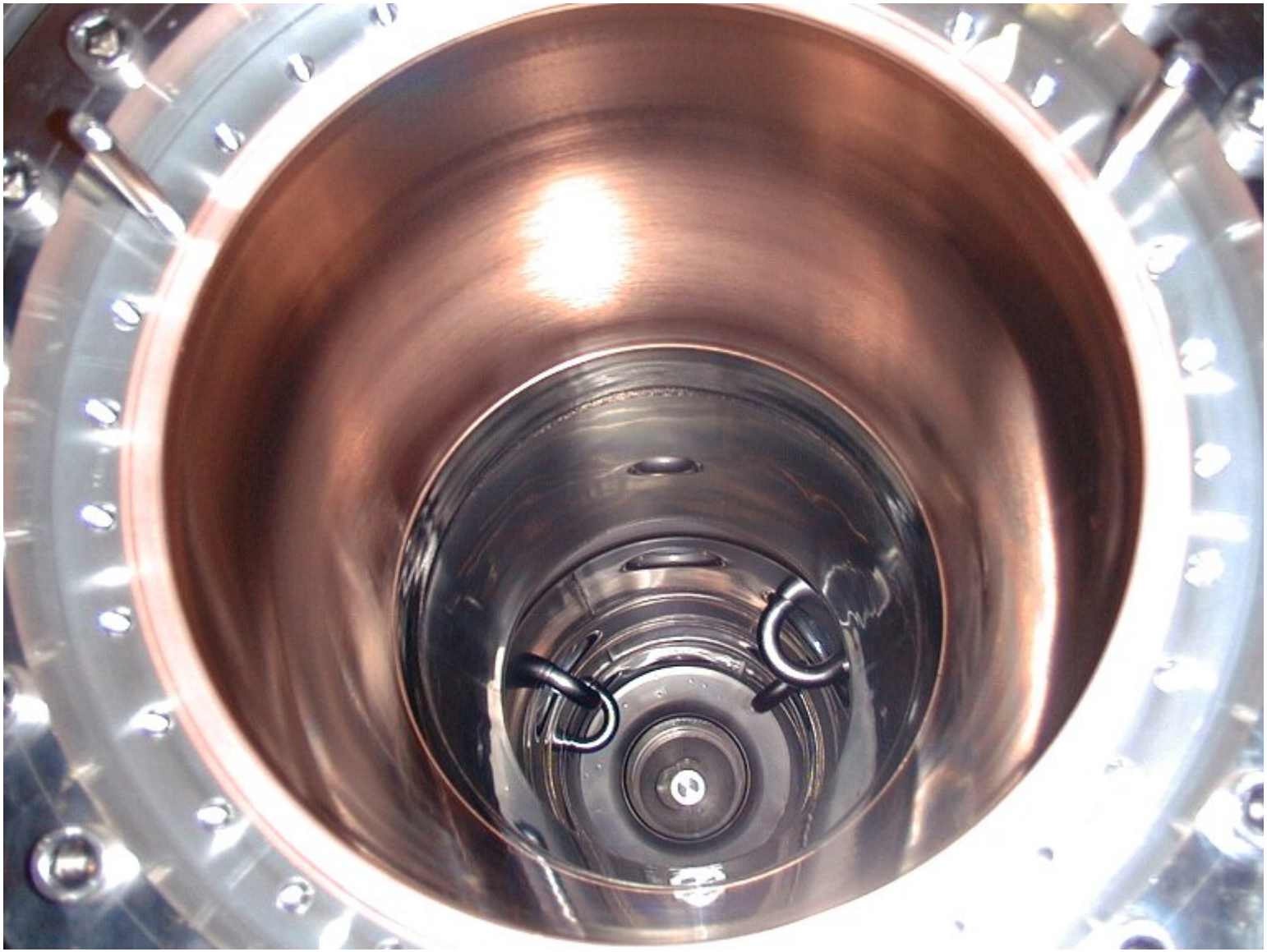
Feb. 04, inside the CERN clean room : removal of the input power couplers

1

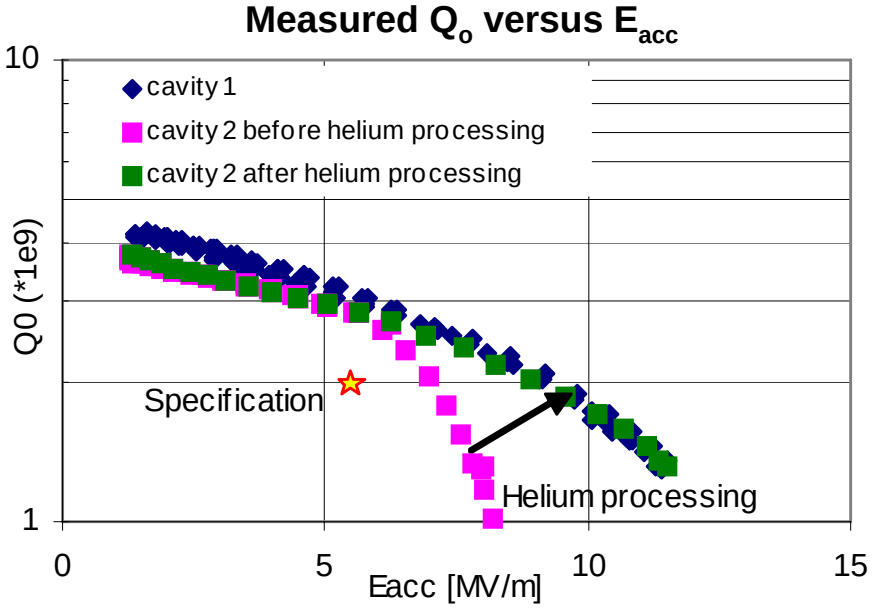
2

3

What the electrons can see when entering the cryomodule

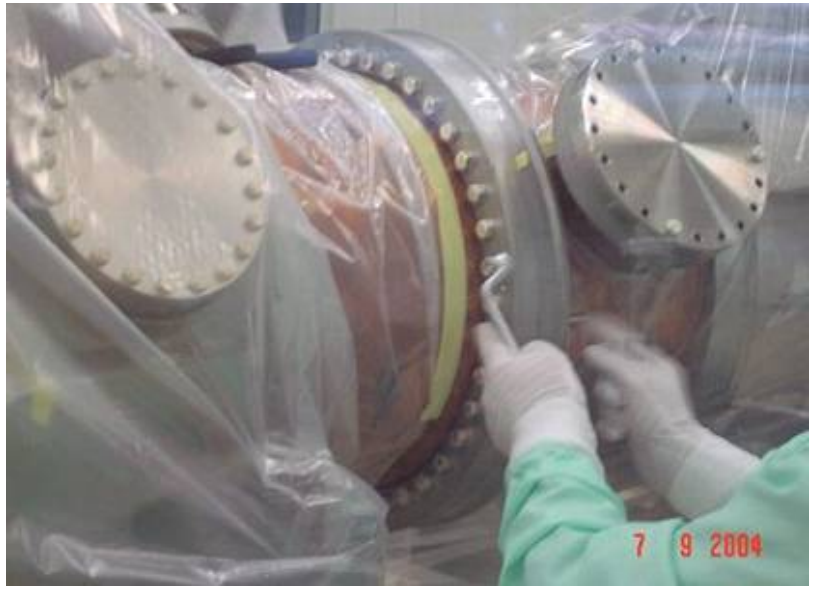


After disassembling of the cryomodule, cleaning and then tests of the single cavities in vertical cryostat (CERN, June 2004)

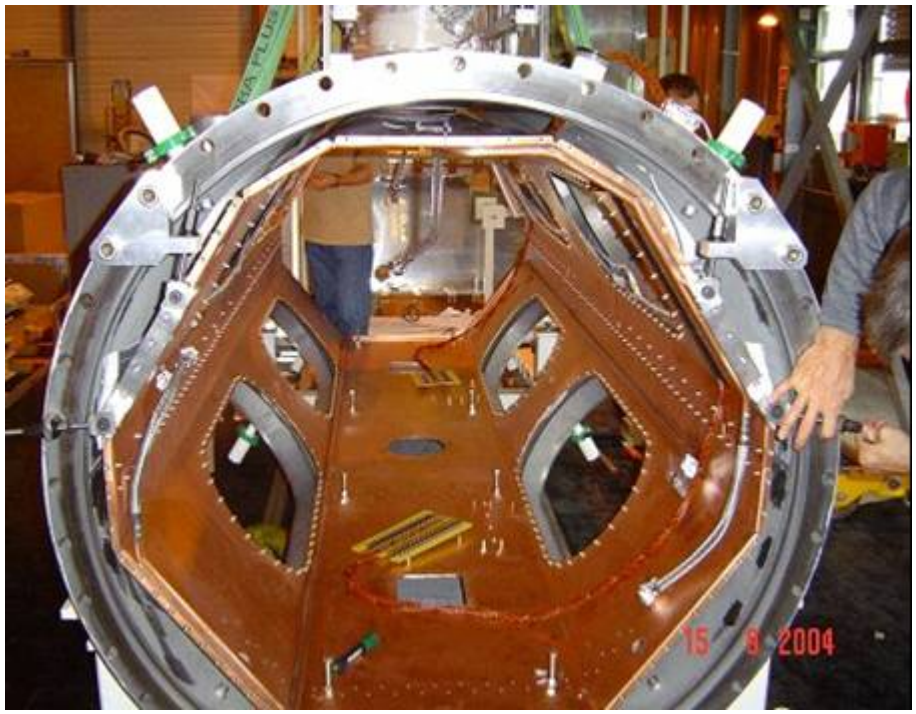


For each cavity, Qo larger than the specified value of 2 10^9 at E_{acc} of 6 MV/m

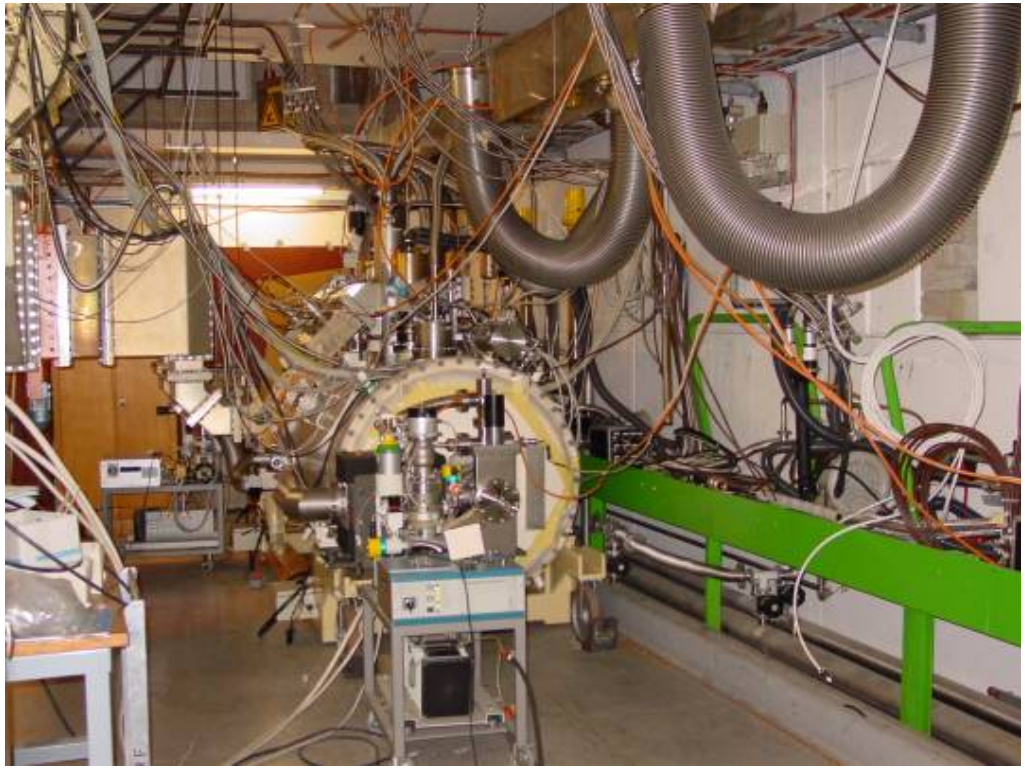
CERN, Sept. 2004 : re-assembling



CEA, Sept. 04 : mounting of the Cu thermal shield (LN2 cooled)



Dec. 04 : installation inside the CERN « bunker » for cryogenic and RF power tests



- LHe supplied from a CERN 18 kW liquefier through a buffer Dewar
- RF power from a LEP type klystron

Successful results of the cryogenic and RF power tests at CERN

- Tests in 2 steps : Dec. 04, without the T-type HOM couplers (not yet available); they were implemented in Jan. 05 and the tests completed in Feb. 05
- Each IPC was conditioned up to 200 kW CW with full reflection and $V_{cav} > 2.5$ MV in each cavity (SOLEIL normal operation : $P_{coupler} \sim 150$ kW and $V_{cav} \sim 1.5$ MV)
- Lengthening of the IPC antennas → $Q_{ext} = (1 \pm 0.1)\ 10^5$, as expected
- Cooling improvements (cryogenic circuits, thermal shield + thermalisation straps, …)
  - → ½ cryogenic losses
  - → He collector 50% filled → He is liquid at the inlet of the HOM couplers
- After a proper redesign of the single wave bellow of the T-HOM couplers, their filter proved to be easily tunable → rejection of 34 dB instead of 19 dB, previously
- Check of the tuning system functionality with the standard SOLEIL driving unit

Cryomodules status & schedule

- ✓ CM1 stored at CERN, ready for use → installation on site, by the end of 2005
- ✓ CM2 ordered at ACCEL in August 05 → implementation in SR, by May 2007

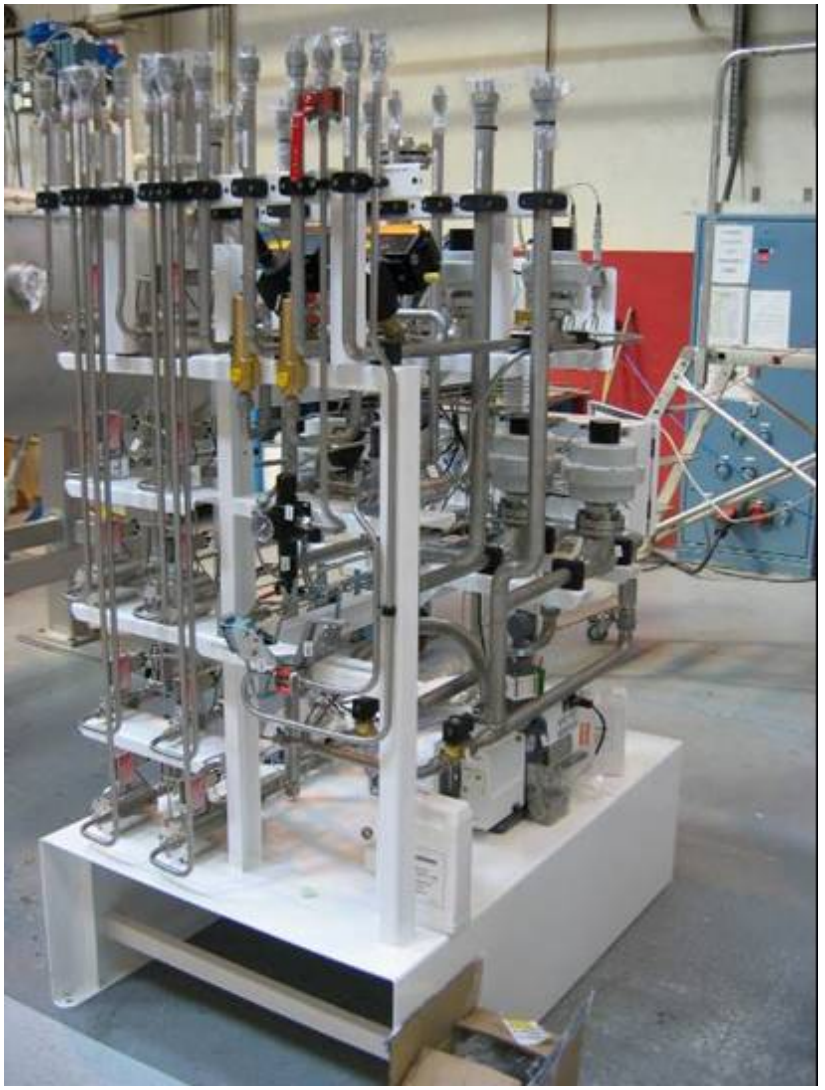
Cryogenic source (LHe @ 4.5 K)

HELIAL 2000 liquefier (Air Liquide), specified for 40 l/h of LHe & 350 W @ 4.5K
Delivery is completed; installation on going → commissioning before the end of 2005

Cold-box

Cryogenic source (LHe @ 4.5 K)

Cryogenic valve box



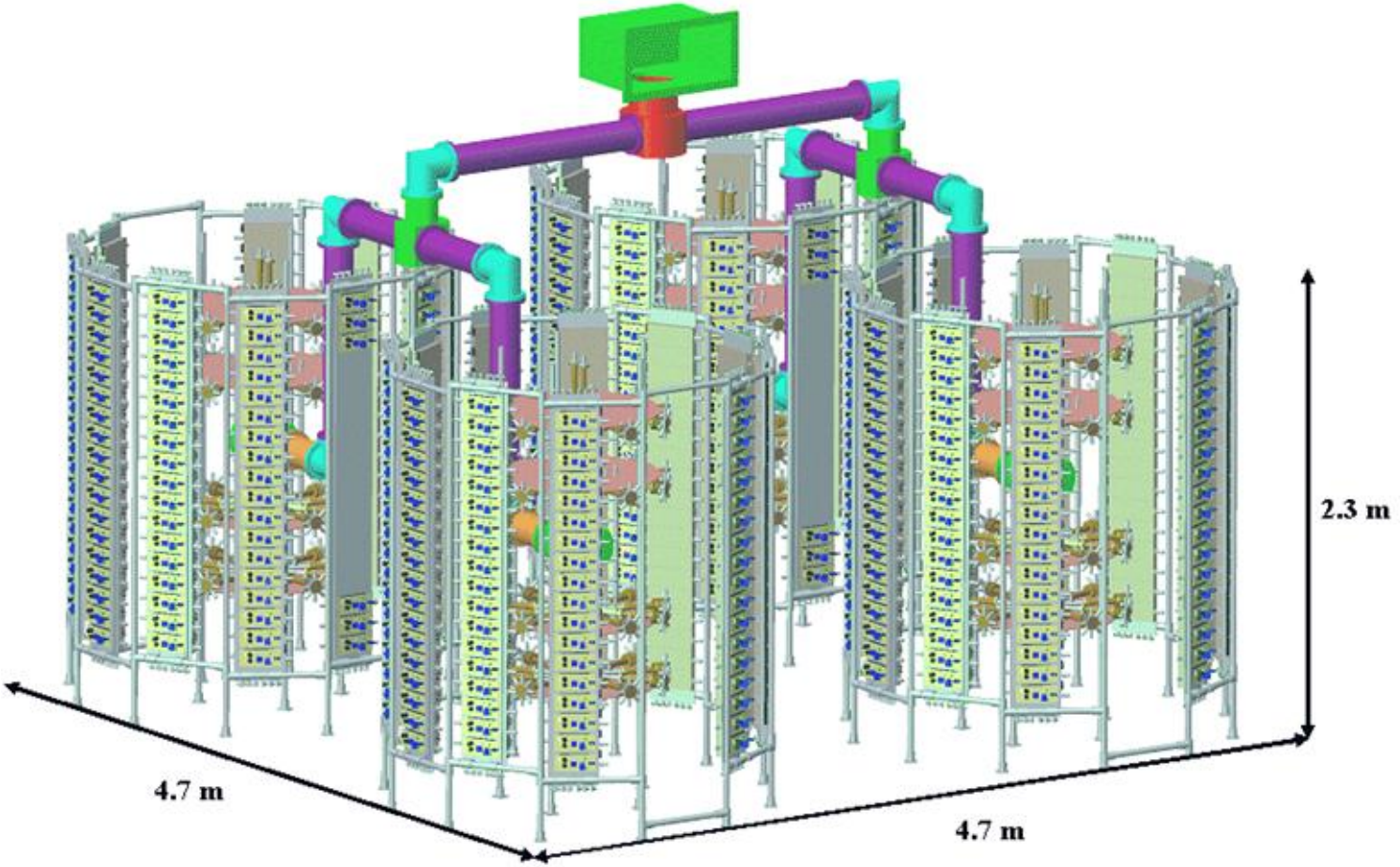
Room temperature valve panel

RF cryogenics area

RF cryogenics compressor room

SR 190 kW amplifier

Each of the 4 cavities powered with a 190 kW solid state amplifier
Same principle as for the BO one, extended to 4 x 50 kW
(→ 724 modules of which 42 in « stand-by »),
but other type of transistors



SR LDMOS amplifier : history & test results

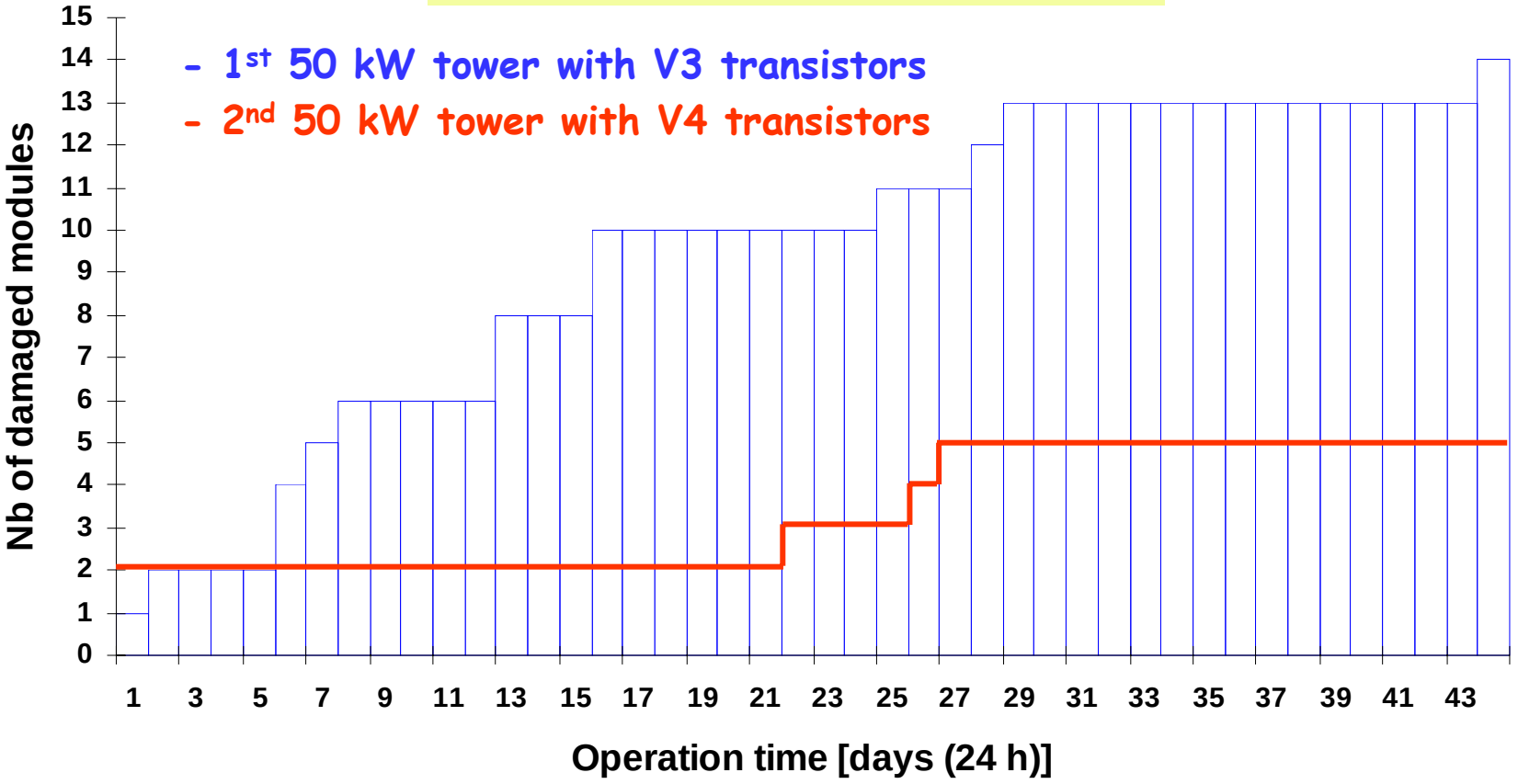
- **BO : only one transistor supplier, SEMELAB (VDMOS - D1029UK05)**
- **SR : SOLEIL-POLYFET development of LDMOS (several iterations)**
  → LR301-V3 : tests on a few samples ok
- **Contract with BBEF for 3000 modules with validation on a pre-series of 10 pcs**
- **June 04 : a 2.5 kW unit, made of 8 pre-series modules, successfully run for ~ 4 weeks**
  → production of 180 modules for one "50 kW tower" (1/4 amplifier)
- **Dec. 23rd 04 : the first "tower" delivered 48 kW CW for ~ 2 hours**
- **Feb. 05 : long duration tests → after ~ 1000 hours of operation, 14 over 180 modules had failures (high gate leakage current at one side of the push pull pair)***

  *** That did not stop the amplifier, which was still delivering its power**

  Fabrication by POLYFET of a new version (V4), designed to be tougher, at the expense of a gain reduction of about 1 dB
- **May-June 05 : a 2.5 kW unit (8 modules - V4) has run for ~ 1000 h without trouble**
  Tower with V4 completed and tested up to 50 kW CW
  2 transistor failures in the first few hours,
  total of 5 failures after 1000 hours of operation

50 kW towers : transistor failure rate

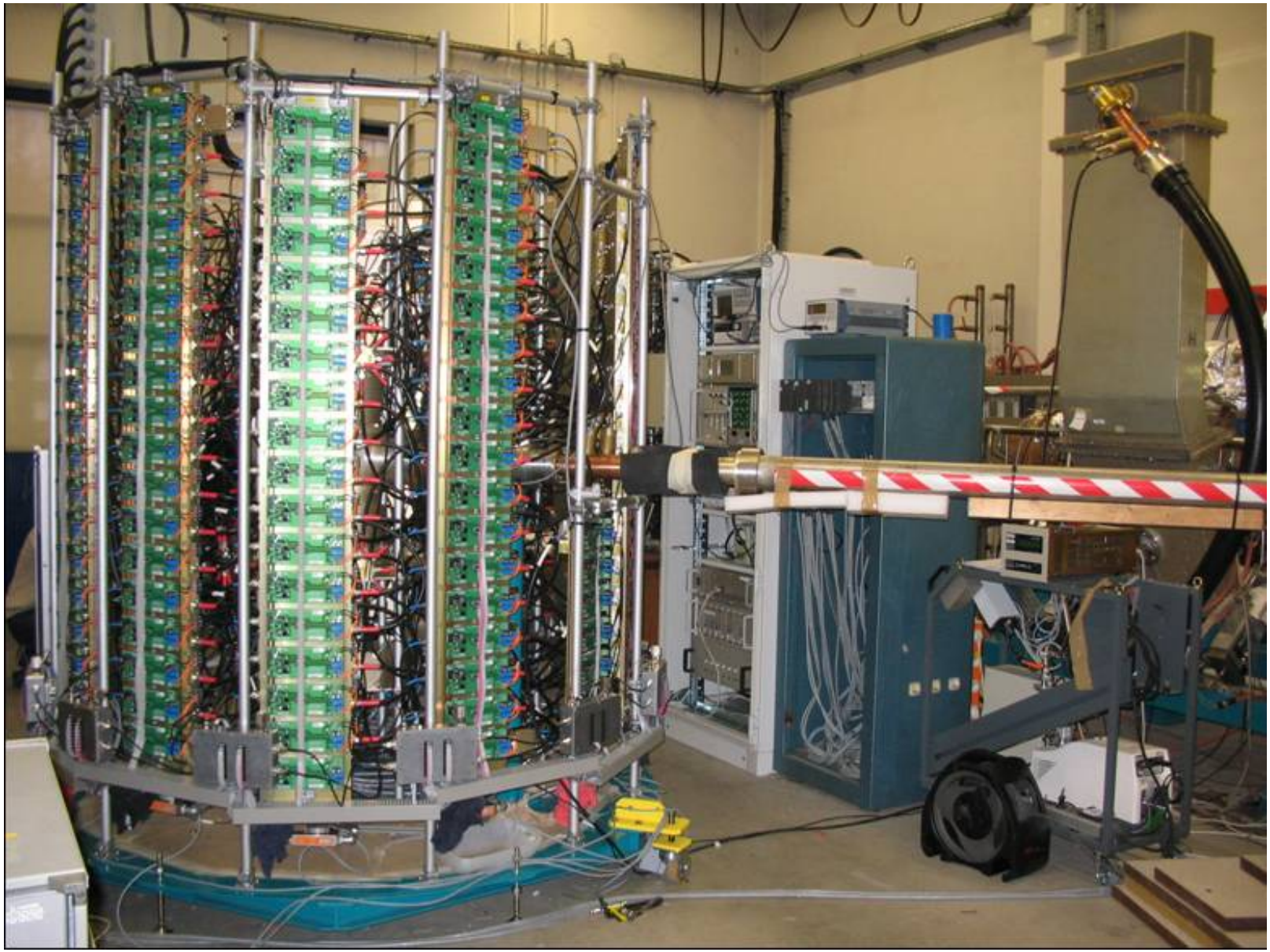
Histogram of transistor failures



Damaged transistors after ~ 1000 hours of operation randomly distributed on the amplifier

- **14 of V3**
- **5 of V4**

Dec. 2004, 1st "50 kW tower" under test



"50 kW tower" control display (transistor currents, Pi & Pr)

Dissipater n°

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

Pi, Pr @ 2.5 kW

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

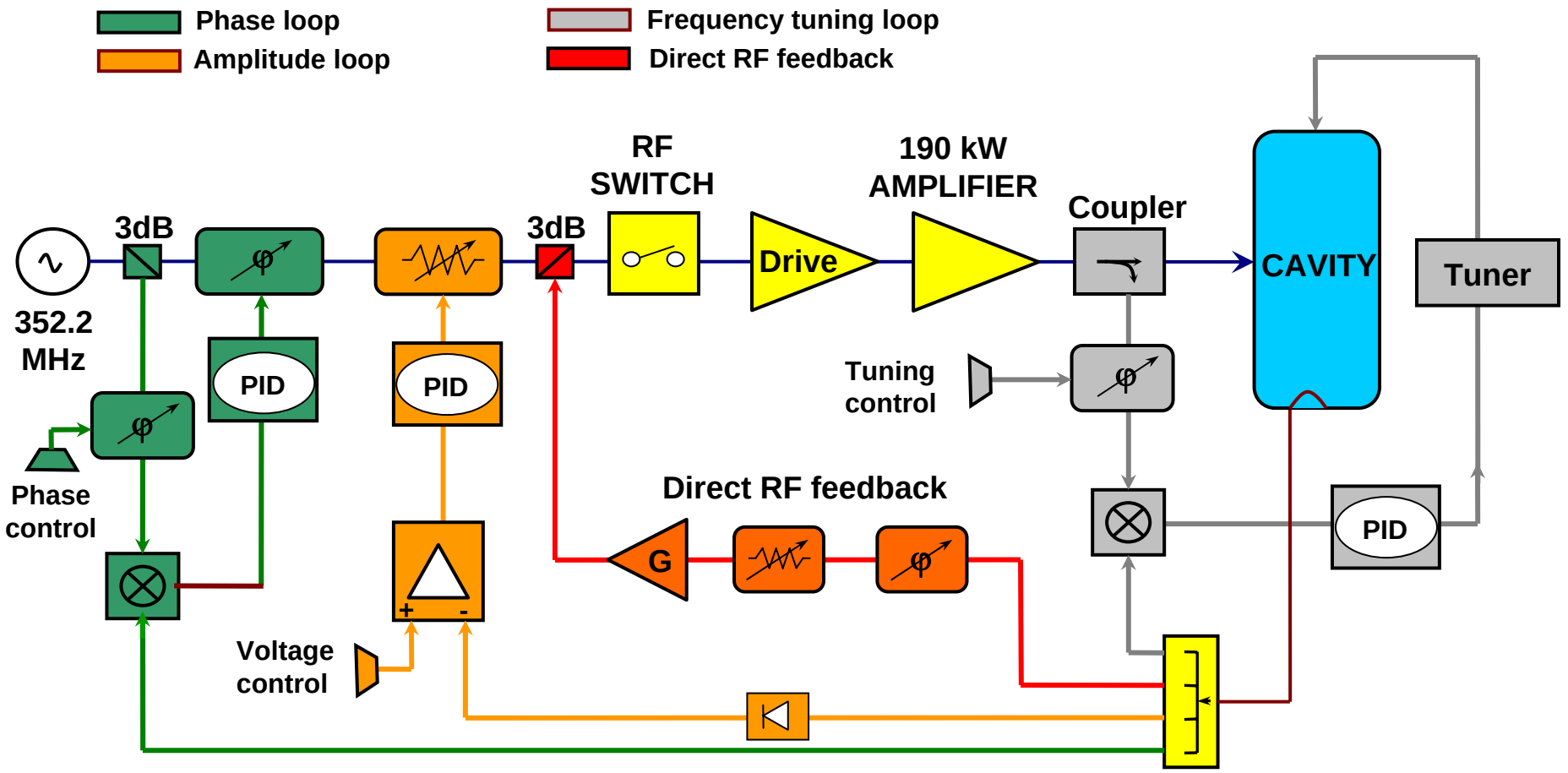
1st stage or stand-by

Destruction of a 2.5 kW combiner by arcing due to a bad contact

SR Low Level RF Electronics

Phase 1 : SR LLRF = BO LLRF + direct RF feedback (figure below ▬)

Phase 2 : fast digital (FPGA based) phase and amplitude loops, under development in collaboration with CEA



SOLEIL RF system
Summary of status and objectives

- **BO RF plant operational; BO commissioning is on going**

SR RF system

- **CM1 tested beyond the required performance ; on site installation → end of 2005**
- **Cryogenics : all components available ; installation on going ; tests → end of 2005**
- **Amplifiers : - four 50kW-towers completed**
  - one tower per month (fixed by transistor production rate)
  → Two 190 kW-amplifiers for CM1 operational by March 2006

SR commissioning (April 06) with CM1 → phase 1 (3 MV, 300 mA)

- **CM2 (built by ACCEL) & 2 other amplifiers → implementation by May 2007**

phase 2 (May 07): operation with 2 CMs (4.8 MV, 500 mA)

Upgrading projects

- ✓ **FPGA-based LLRF; transverse multi-bunch feedback**
- ✓ **Crab cavities for "slicing" (sub-ps X-rays), harmonic cavity for bunch lengthening (?)**

Rem **: several labs expressed their intention of using the solid state technology "à la SOLEIL"**
→ projects of collaboration for transfer of technology

Acknowledgement

SOLEIL RF GOUP


Jean POLIAN


Fernand RIBEIRO

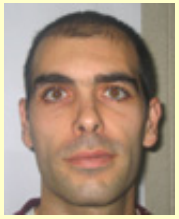

Patrick MARCHAND


Massamba DIOP


Rajesh SREEDHARAN


Catherine THOMAS-MADEC


Ti RUAN


Robert LOPES


Helder Antonio DIAS


Jocelyn LABELLE


Cyril MONNOT


Moussa EL AJJOURI


Marc LOUVET

SOLEIL, CEA, CERN, ESRF, LURE