Workshop on
Low Emittance Rings 2010

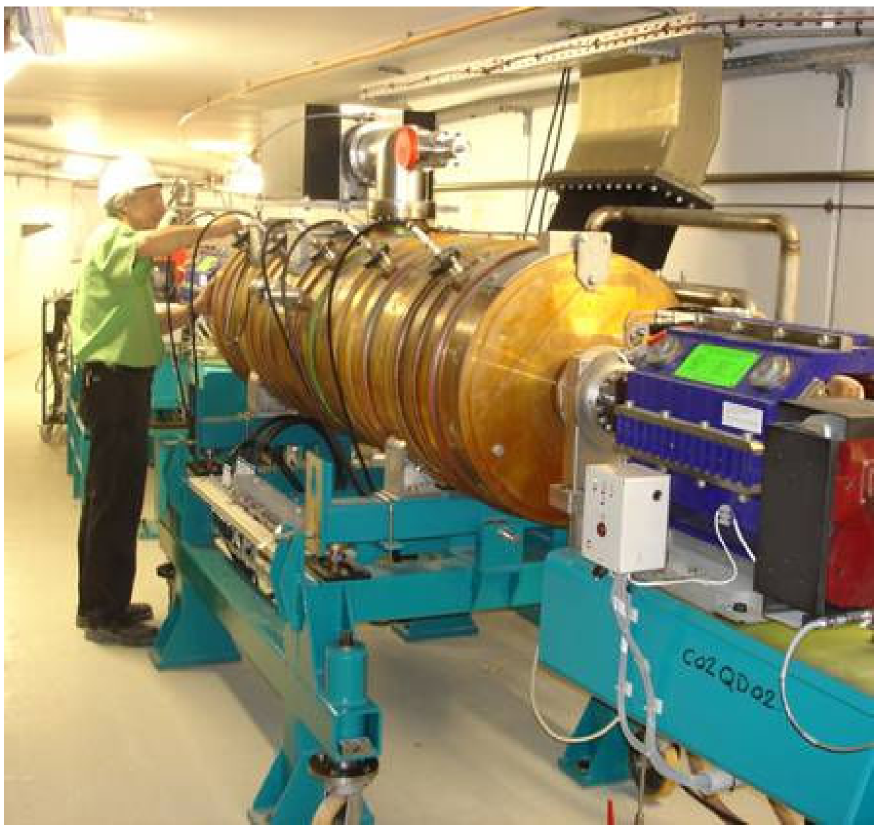
CERN, 12-15 January 2010

EXPERIENCE WITH THE SOLEIL 352 MHZ RF SYSTEMS

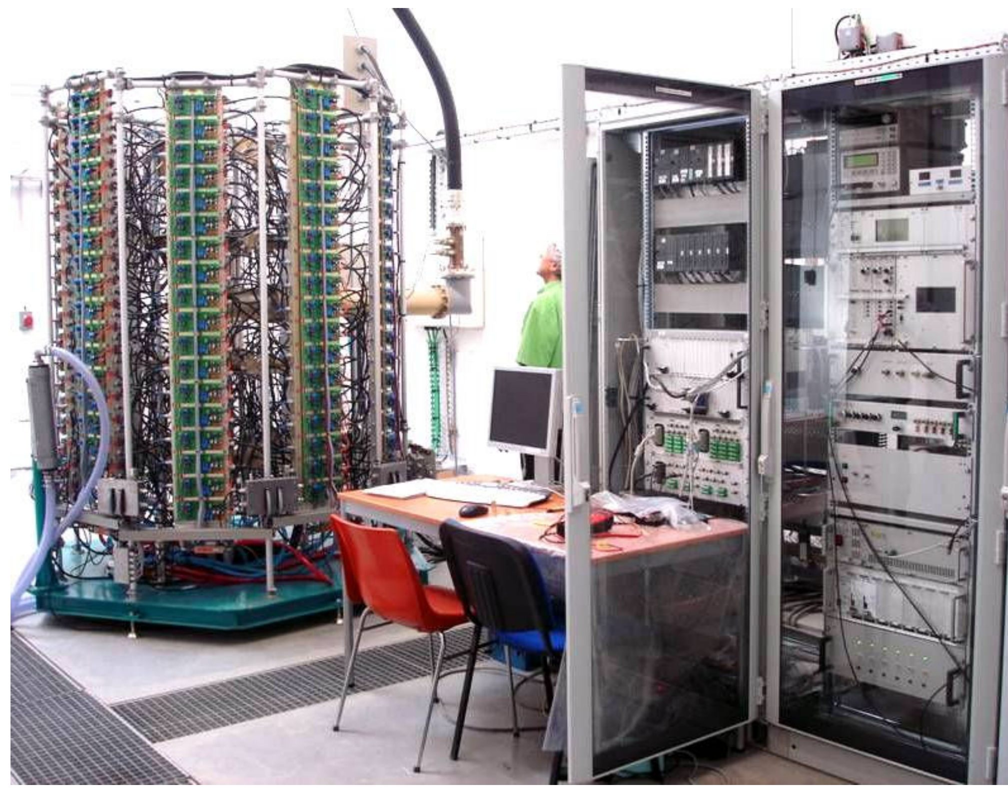
P. Marchand

Booster RF system

- E_n : 100 MeV → 2.75 GeV (rep. 3 Hz) ; V_{cav} : 100 → 900 kV @ 352 MHz
- 1 x 5-cell Cu cavity (CERN LEP) → P_{tot} : 20 kW (P_{dis} : 15 kW, P_{beam} : 5 kW)
- 1 x solid state amplifier → 35 kW CW @ 352 MHz (developed in house)



Cavity in the BO ring

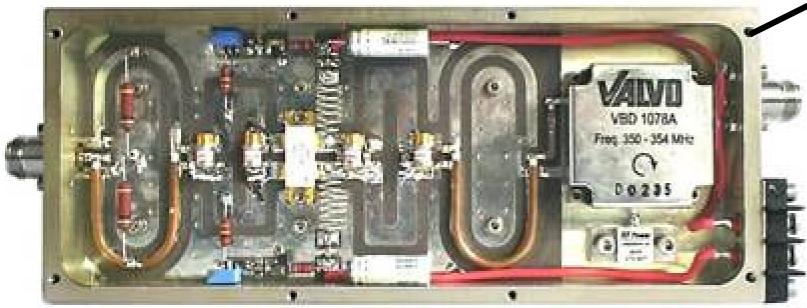


BO RF room (amplifier & LLRF)

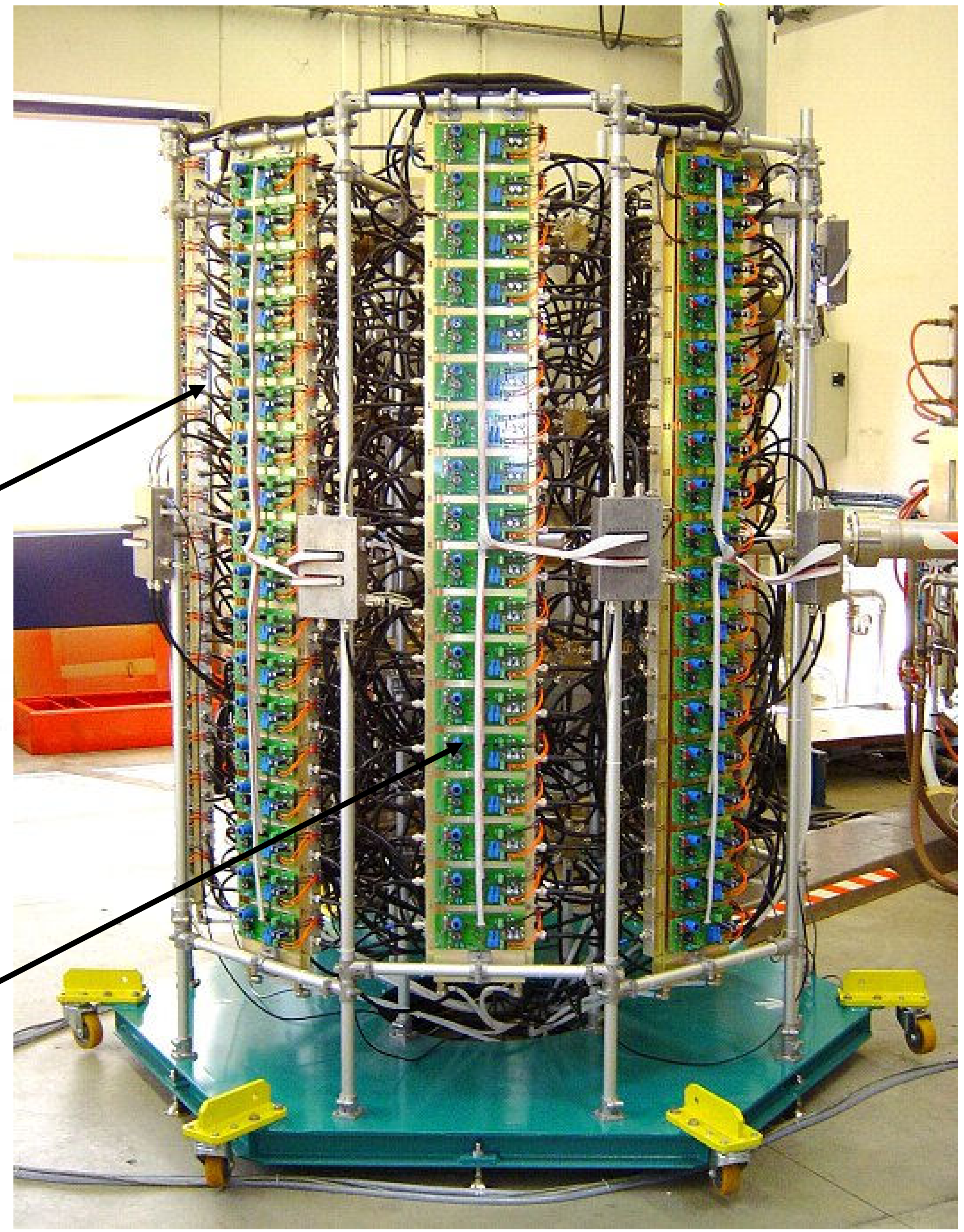
Booster
35 kW amplifier

147 amplifier modules and power supplies on 8 water-cooled dissipaters

330 W amplifier module

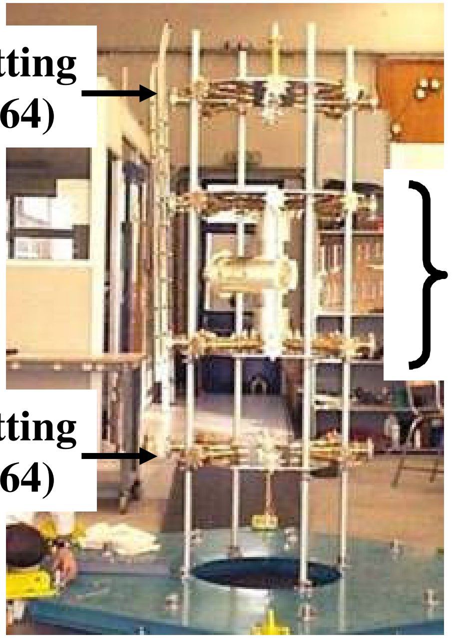


600 W, 300 Vdc / 30 Vdc converter



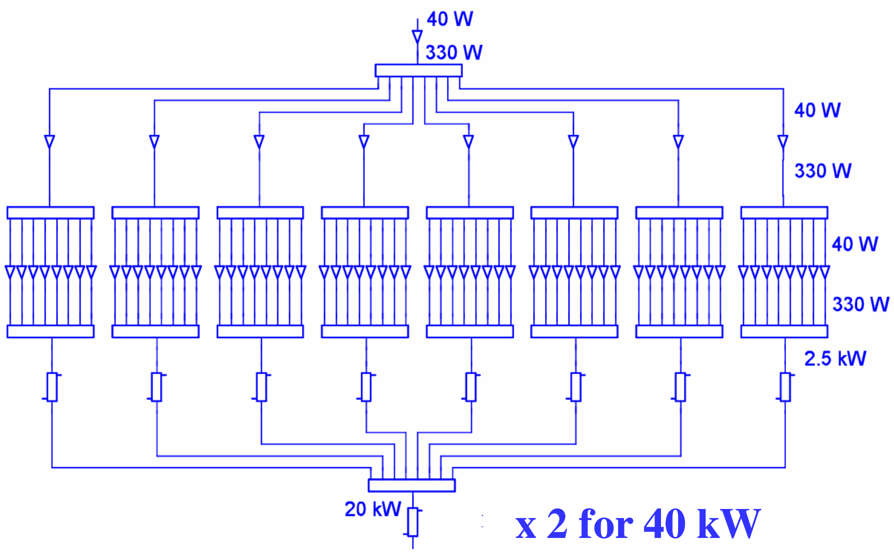
Booster amplifier power combination

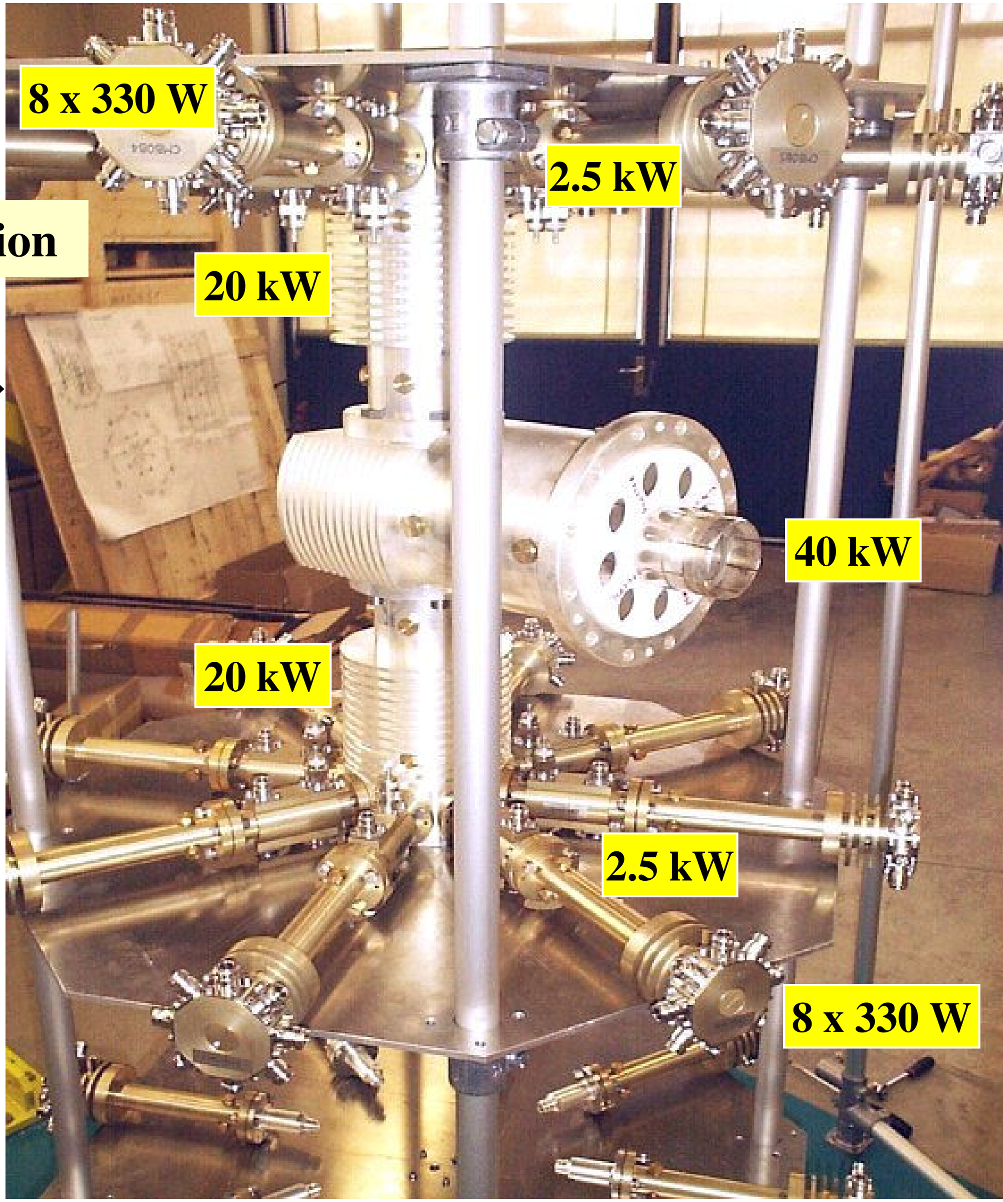
Splitting (1/64)



Splitting (1/64)

Re-combination

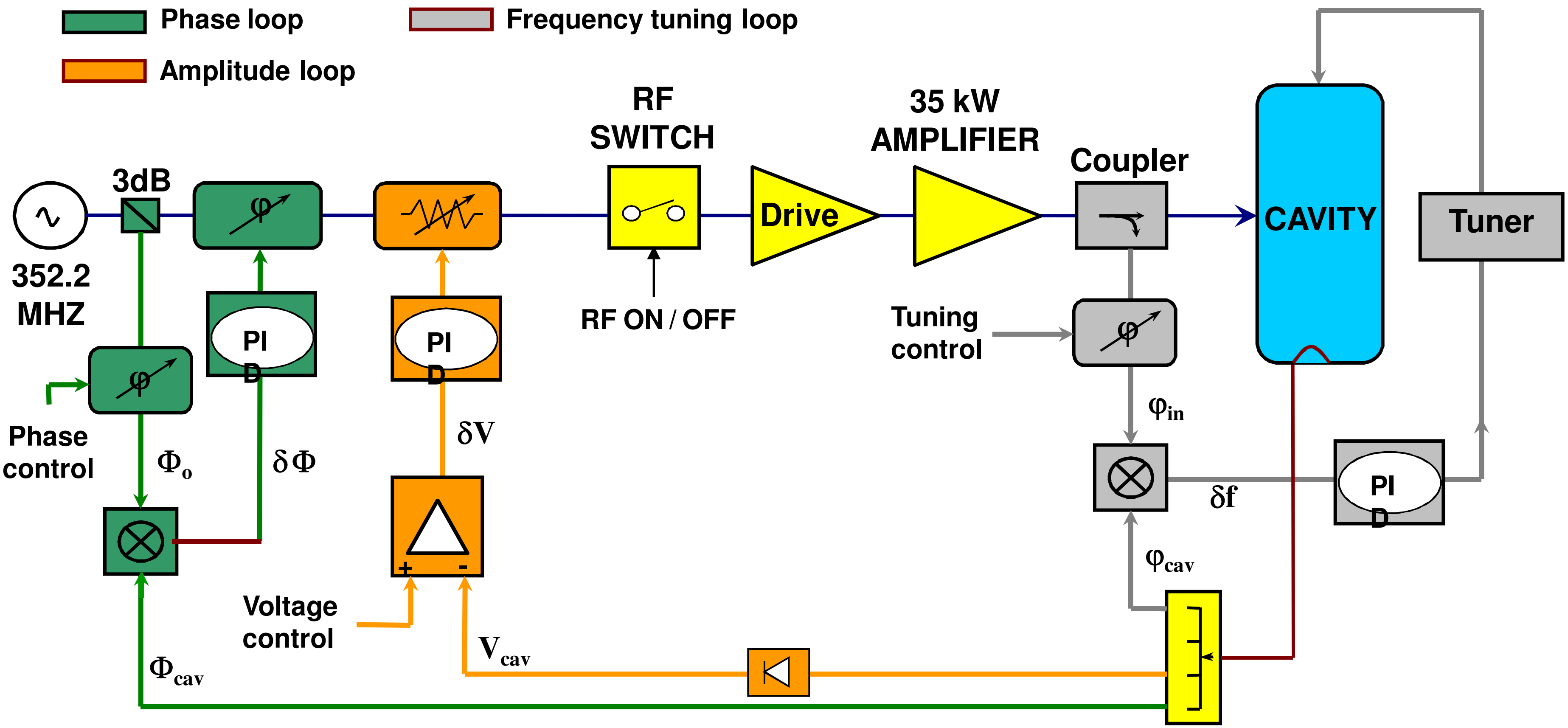




Booster Low Level RF Electronics

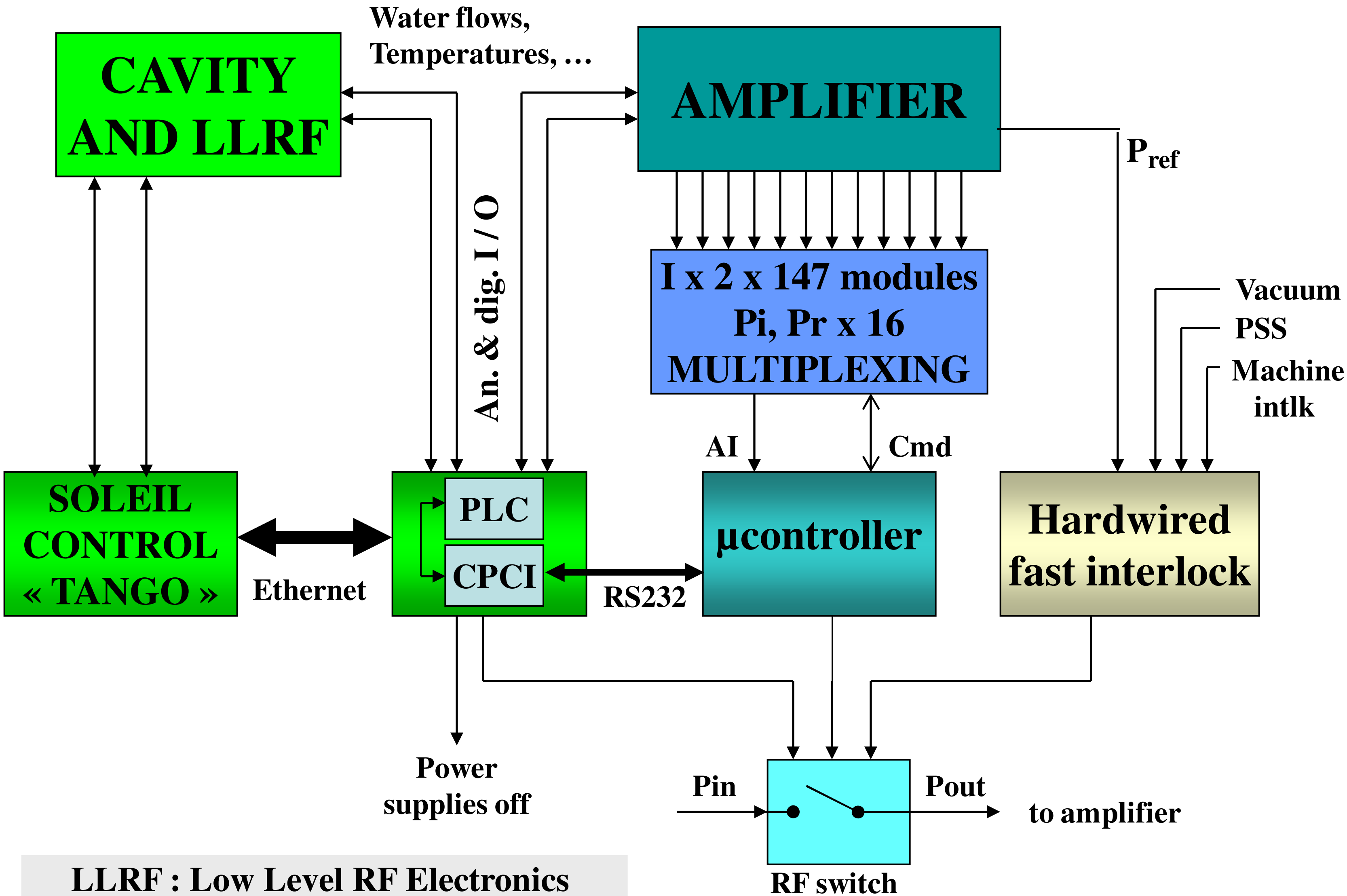
SOLEIL SYNCHROTRON

3 « slow » control loops for the frequency, amplitude & phase



→ Stability of ± 0.25 % in amplitude and ± 0.2 ° in phase with bandwidth > 1 kHz

Diagram of the Booster RF control system



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

Operational experience with the Booster RF system

The Booster RF plant is in operation since mid 2005.

Up to date, after ~ 20 000 running hours,

only a single trip in operation, due to a human mistake (2006)

→ Never play with the equipment during the operation !

***The 35 kW solid state amplifier* has proved to be very reliable.**

Only 5 (out of 150) modules had minor problems

which did not affect at all the operating conditions,

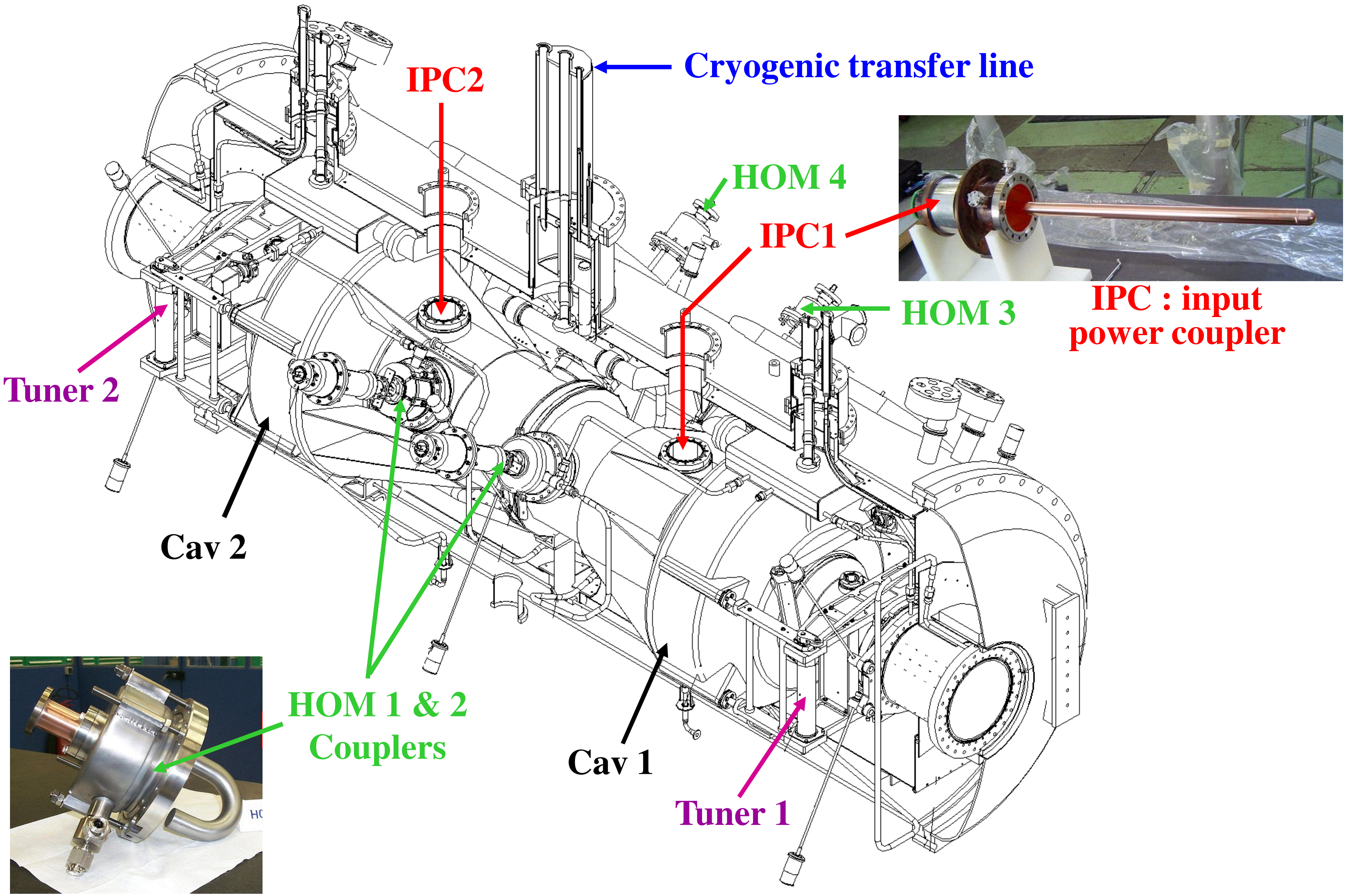
and could be quickly repaired during scheduled machine shutdowns.

→ Advantage of the high modularity and redundancy

Storage Ring (SR) RF system

- $E = 2.75$ GeV, $\Delta E = 1.2$ MeV, $I_b = 500$ mA
  → $P_{RF} = 600$ kW & $V_{RF} = 4$ MV @ 352 MHz
- 2 cryomodules (CM), each containing a pair of single-cell s.c. cavities
- Each cavity powered with a 180 kW solid state amplifier
- Both CM supplied with LHe (4.5 K) from a single cryo-plant

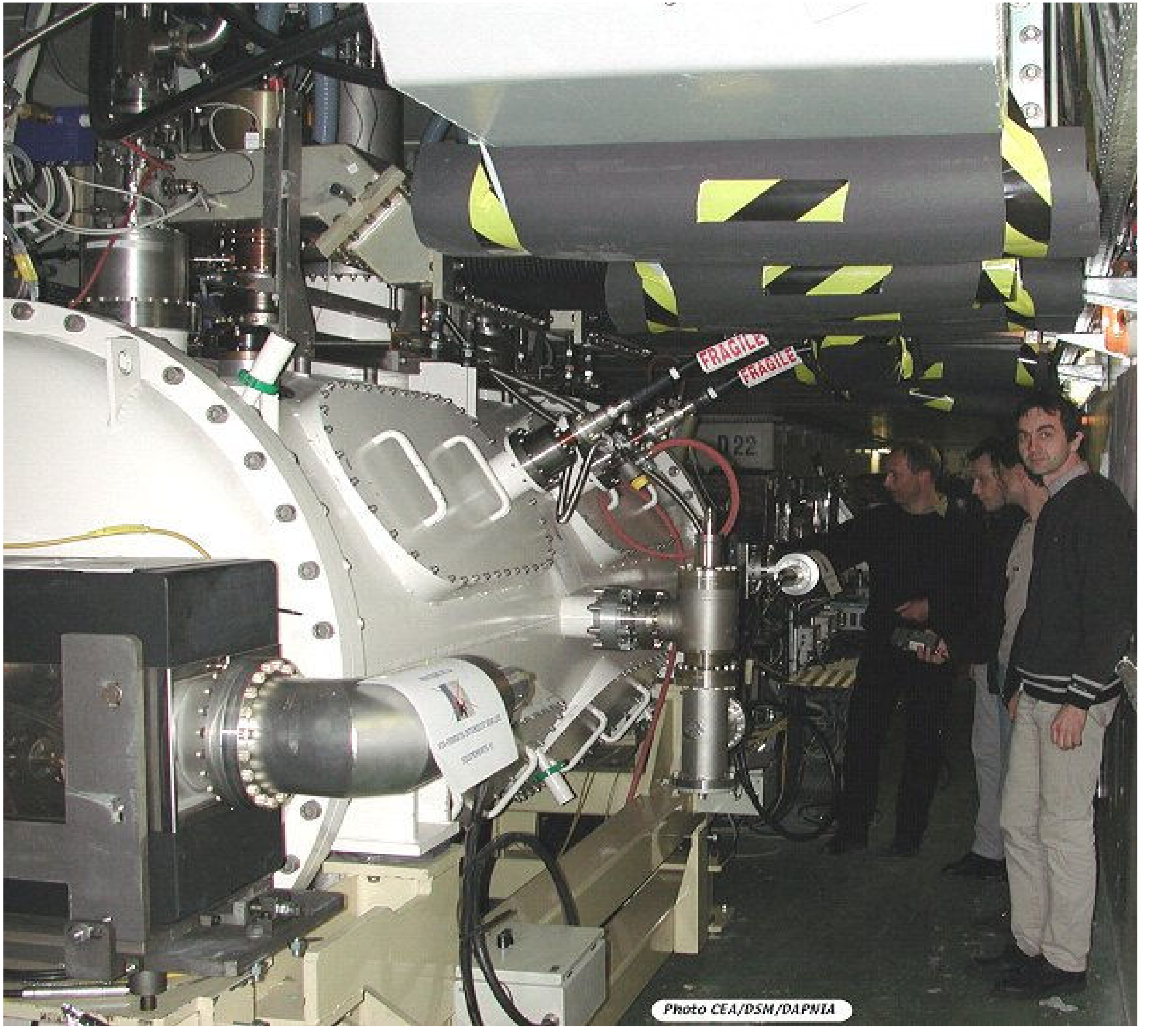
SOLEIL cryomodule design



Cryomodule (CM) history

- *SOLEIL studies (1996)* → launch the development of a CM prototype
  → realized in the frame work of a CEA/CERN collaboration
- After a *campaign of tests on the ESRF SR (2001 - 2002),* the CM prototype was fully disassembled, significantly modified and then re-assembled and tested at CERN, in order to be used as the 1^{st} CM of SOLEIL (CM1)

2002, the CM prototype under tests on the ESRF SR



2003, back to CERN for disassembling; at the entrance of the clean room

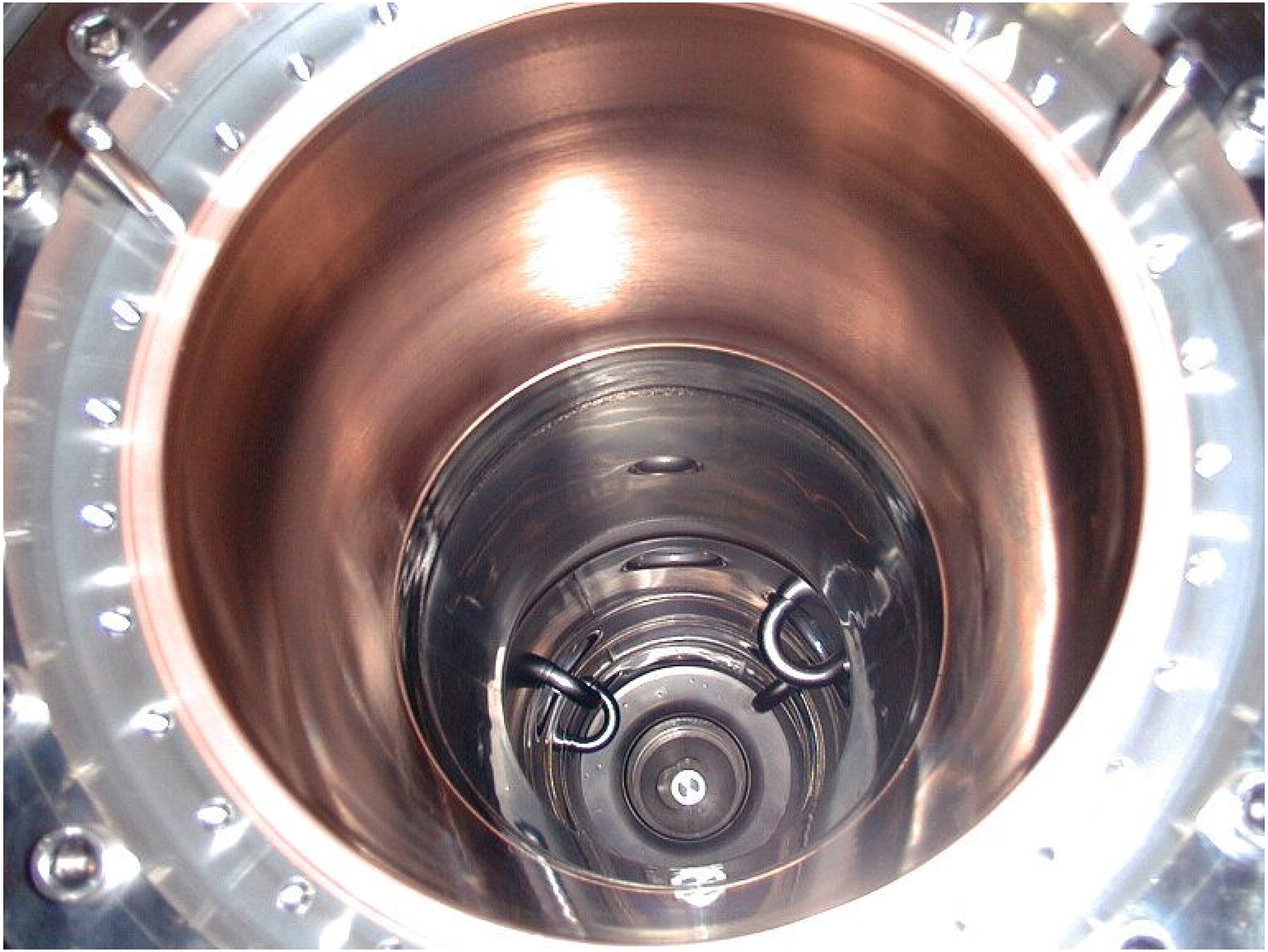
Feb. 2004, inside the clean room, removal of the power couplers

1

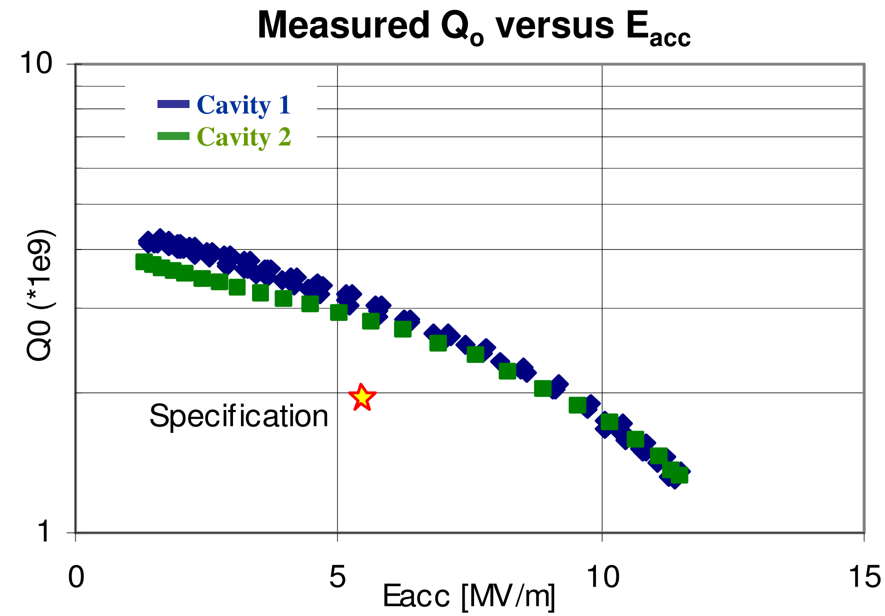
2

3

What the electrons can see when entering the CM

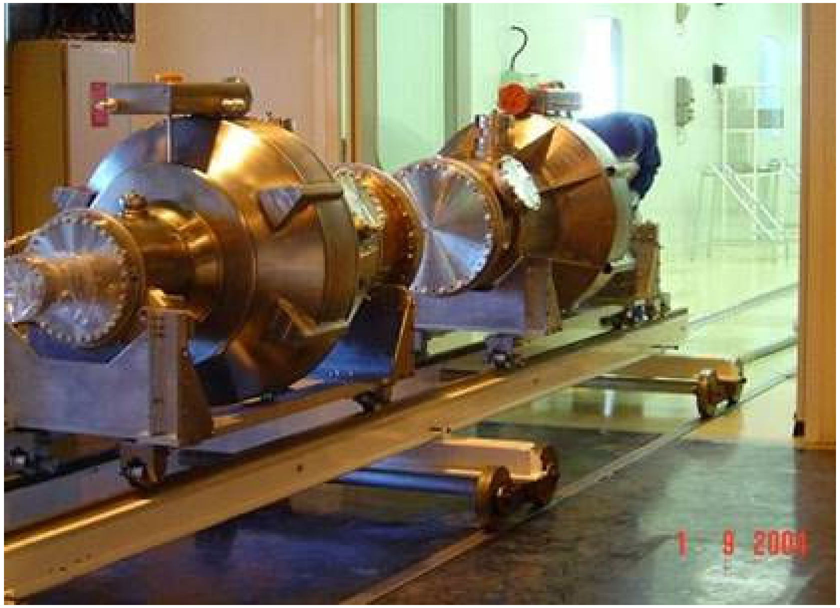


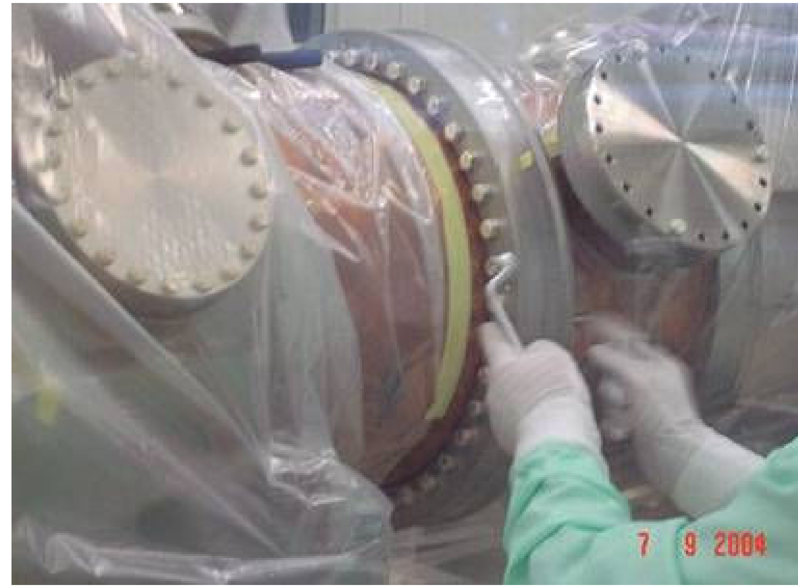
Tests of the single cavities in vertical cryostat



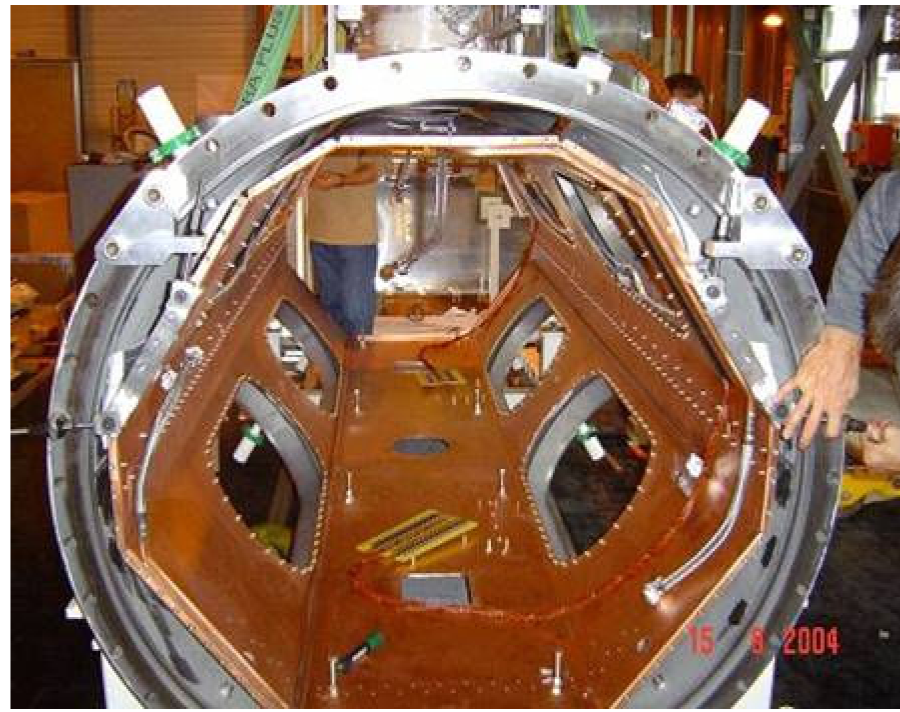
For each cavity, Qo larger than the specified value of 2 10^9 at E_{acc} of 6 MV/m

CERN, Sept. 2004 : re-assembling

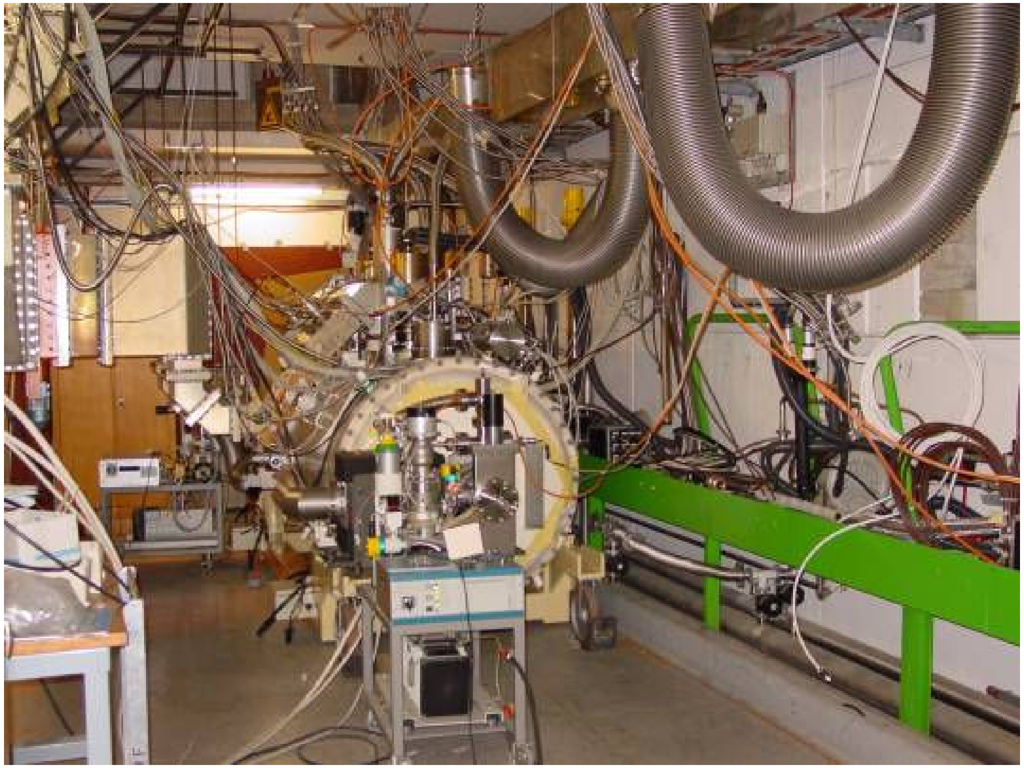




CEA, Sept. 2004, insertion of the LN2 - cooled Cu thermal shield



Dec. 2004, inside the CERN “bunker” for cryogenic & RF power tests

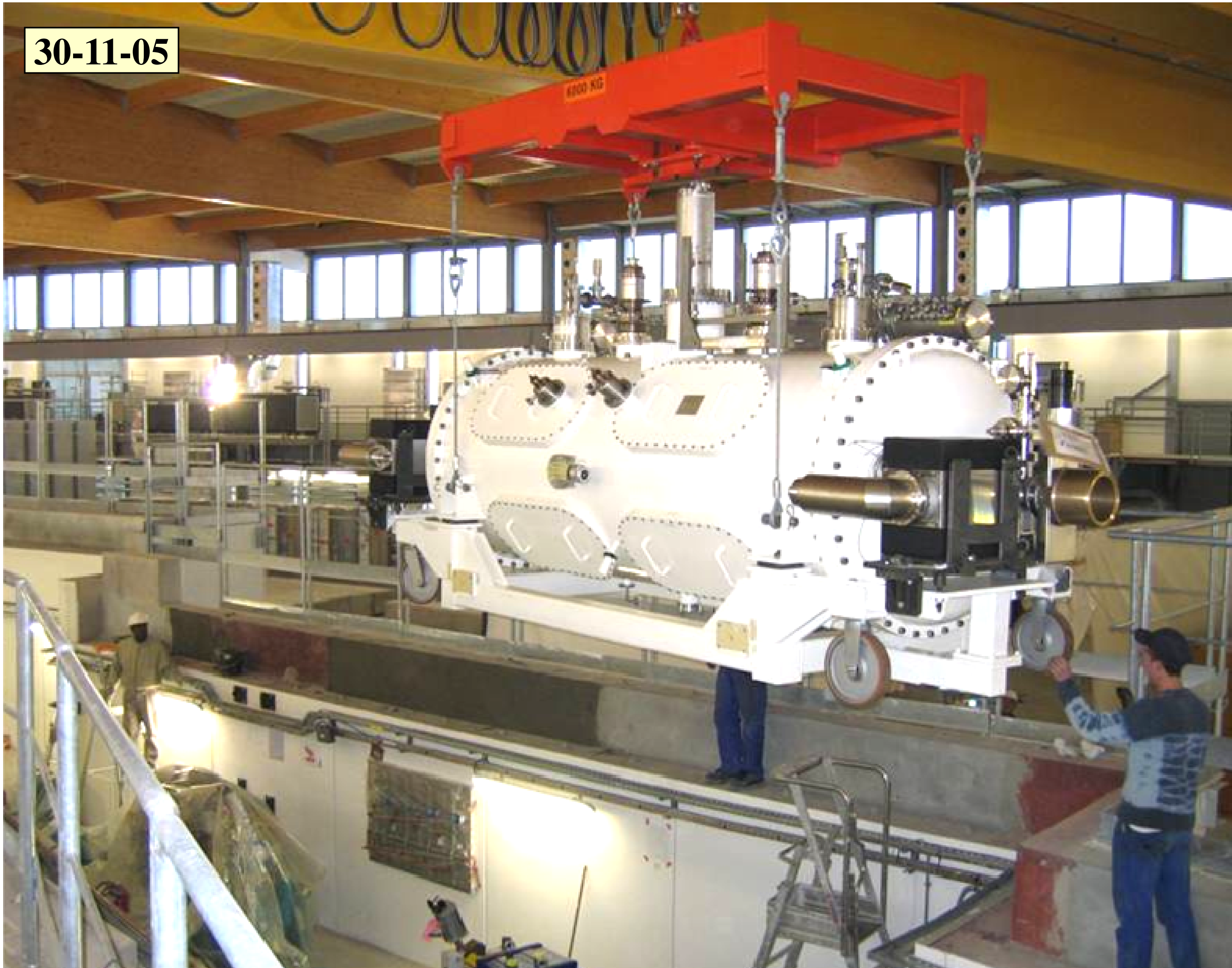


→ ***In Feb. 2005,*** **the tests of CM1 were successfully completed :**

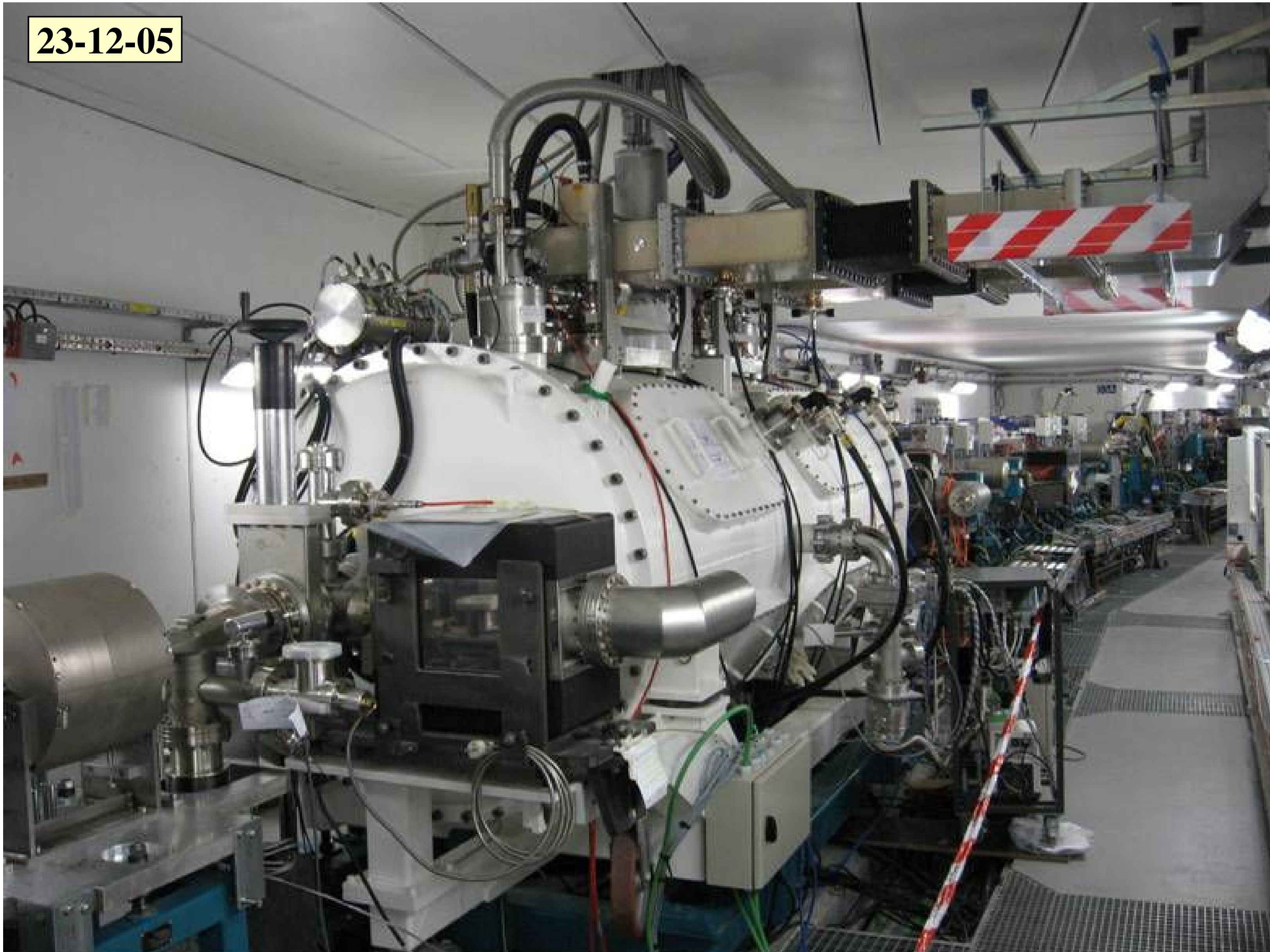
- 2.5 MV / cavity

- 200 kW / coupler (full reflection)

Nov. 2005, CM1 transfer to SOLEIL SR



End 2005, CM1 in SOLEIL SR



Cryomodule (CM) history

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- *CERN (Feb. 2005)*, tests of CM1 successfully completed
  → 2.5 MV / cavity & 200 kW / coupler (full reflection)
- *End of 2005 :* Delivery and installation of CM1 in the SOLEIL SR
- *May 2006 :* CM1 cooldown & RF conditioning; *Sept. 2006 :* 300 mA stored I_b
- *Opération using 1 CM & I_b < 300 mA, for ~ 2 years (as scheduled in phase 1)*

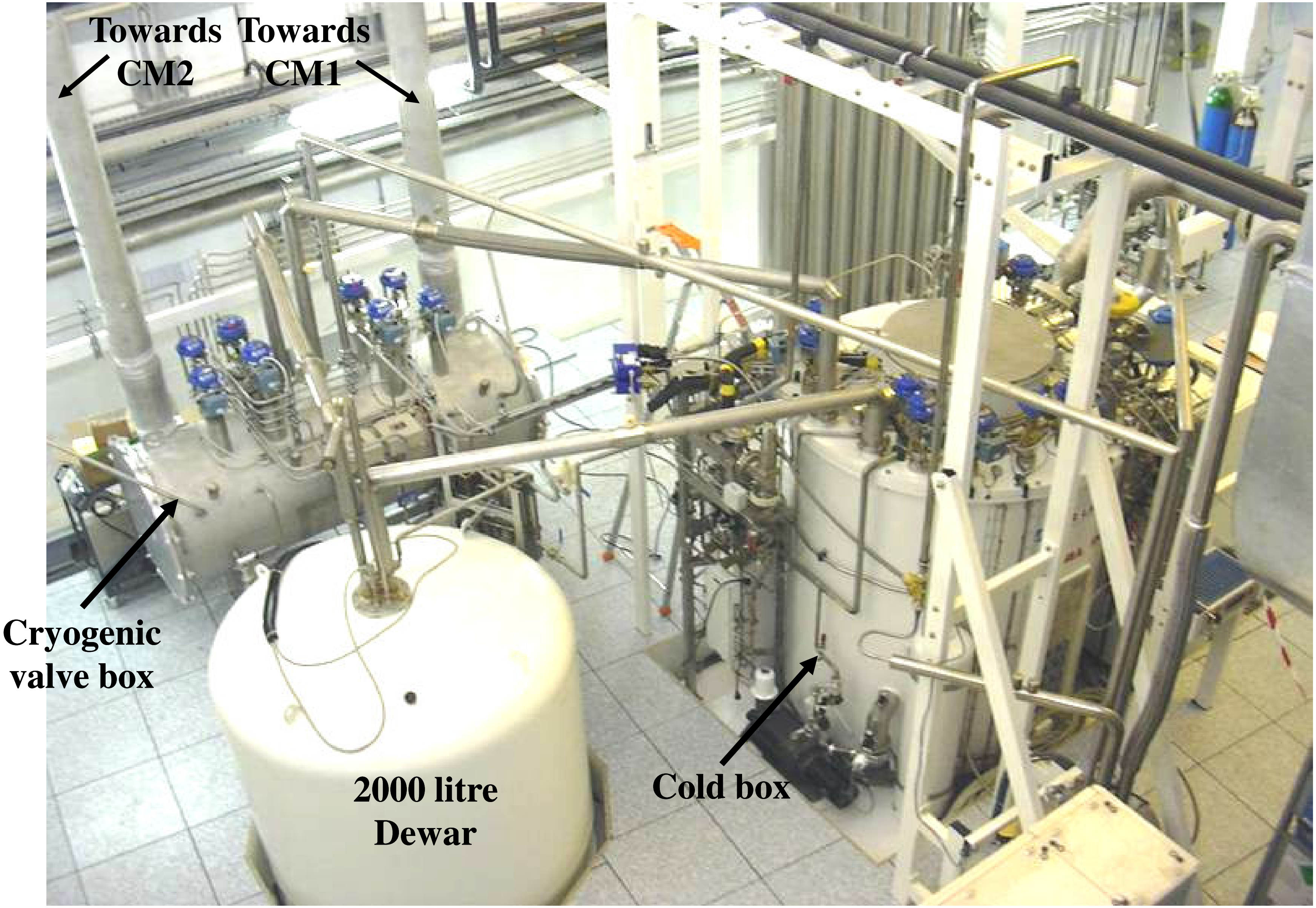
CM2

- Decision to build CM2 in the industry → *Sept. 2005*, order to ACCEL
- *May 2008 :* Delivery of CM2 → *Nov. 2008 :* 455 mA stored beam (2 CMs)
- *In 2009 :* 500 mA stored beam (machine R&D); 400 mA in top-up for users

RF cryogenic system

**Both CM are supplied with LHe (4.5 K)
from a single cryo-plant,
a HELIAL-2000 device from AIR LIQUIDE,
operated in mixed refrigerator/liquefier mode;
it can provide up to 400 W of refrigeration
and 60 l / h of liquefaction, simultaneously.**

RF cryogenic area in the technical gallery

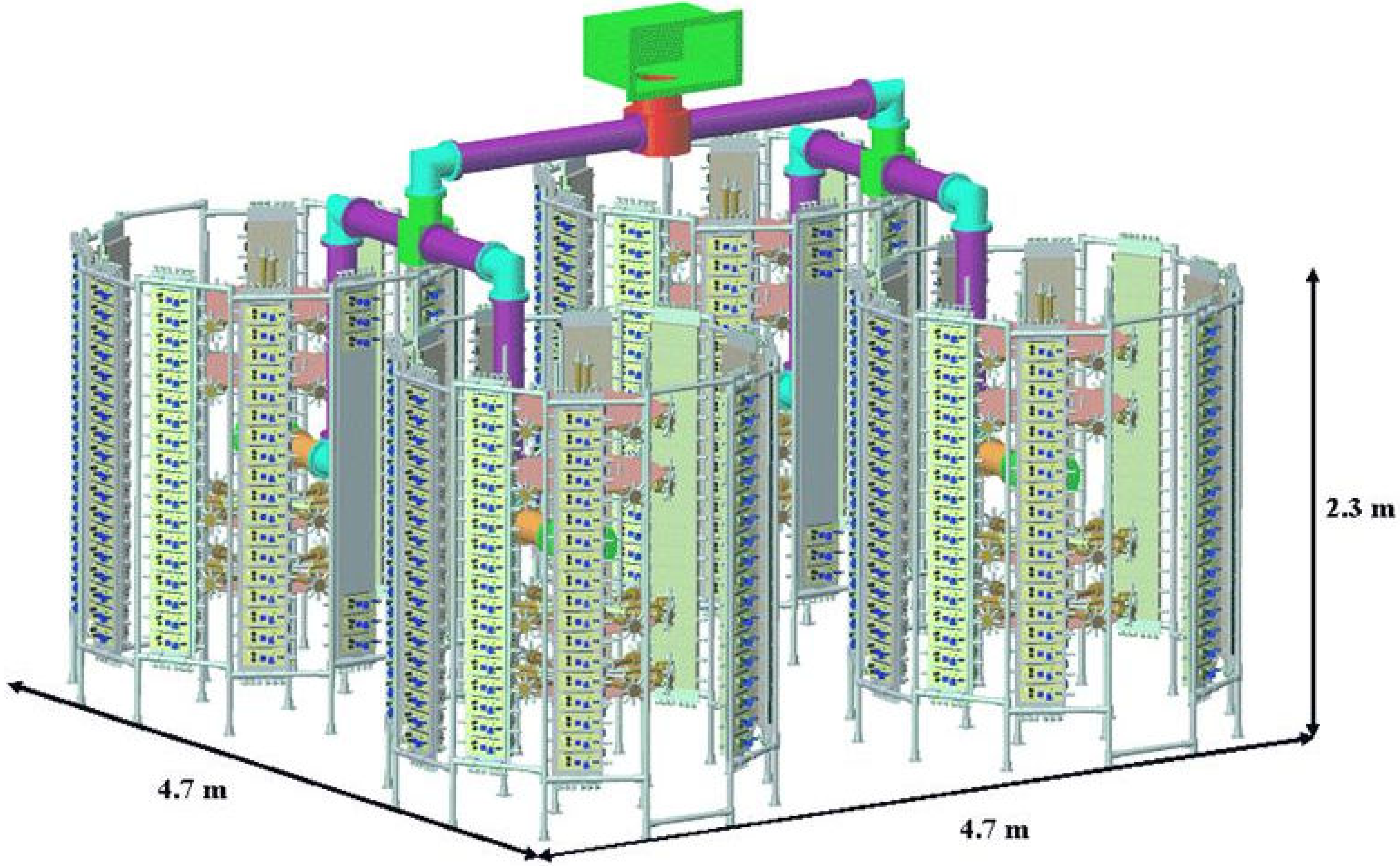


Helium compressor station

Helium gas buffers (2 x 50 m^3)

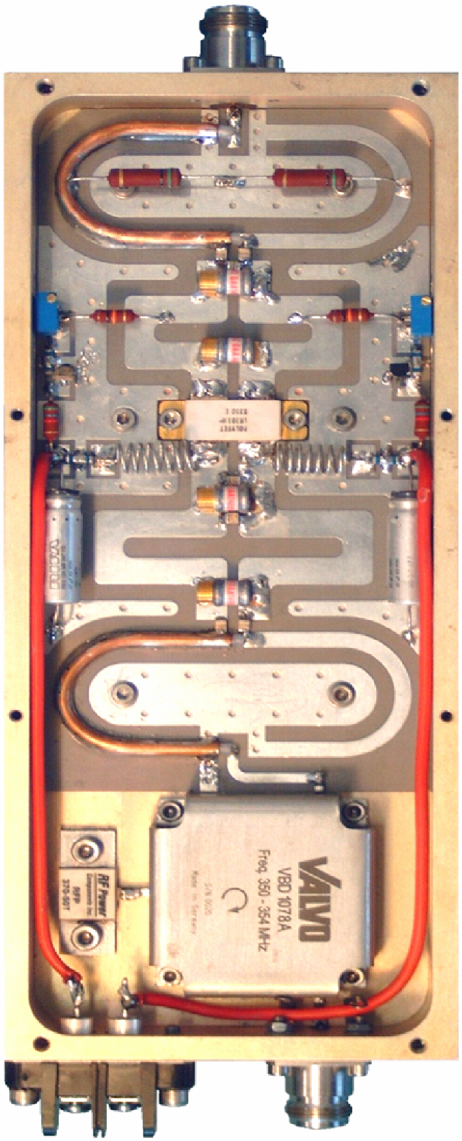
SOLEIL SYNCHROTRON

SR 180 kW RF amplifier

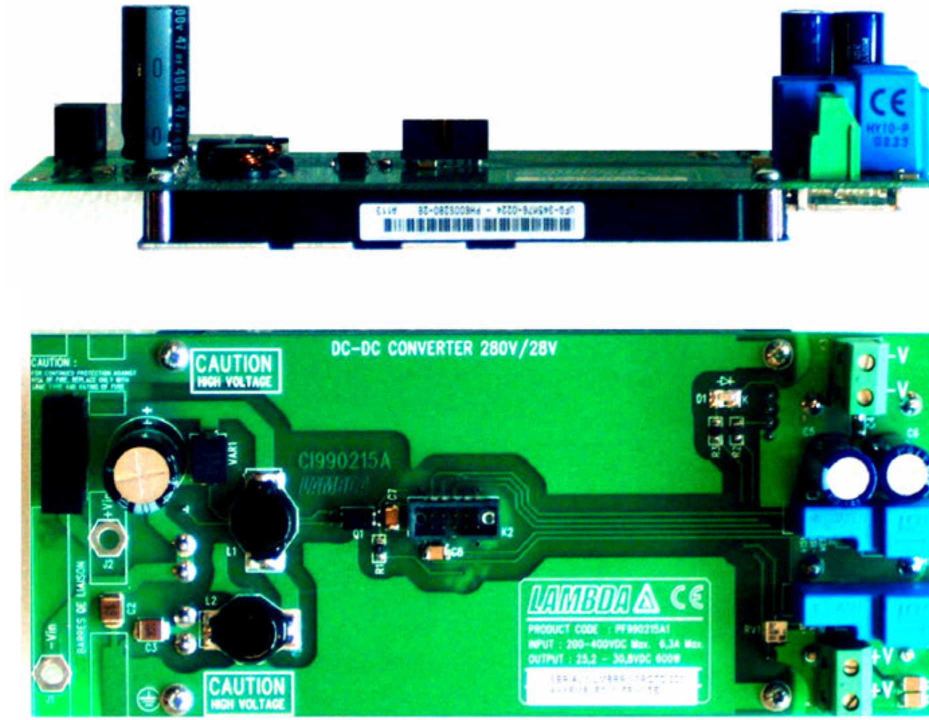


Same principle as for the BO one, extended to 4 towers of 45 kW
→ 724 modules / amplifier x 4 cavities → 16 towers & ~ 3000 modules

Components of the SR amplifier



352 MHz - 315 W
amplifier module

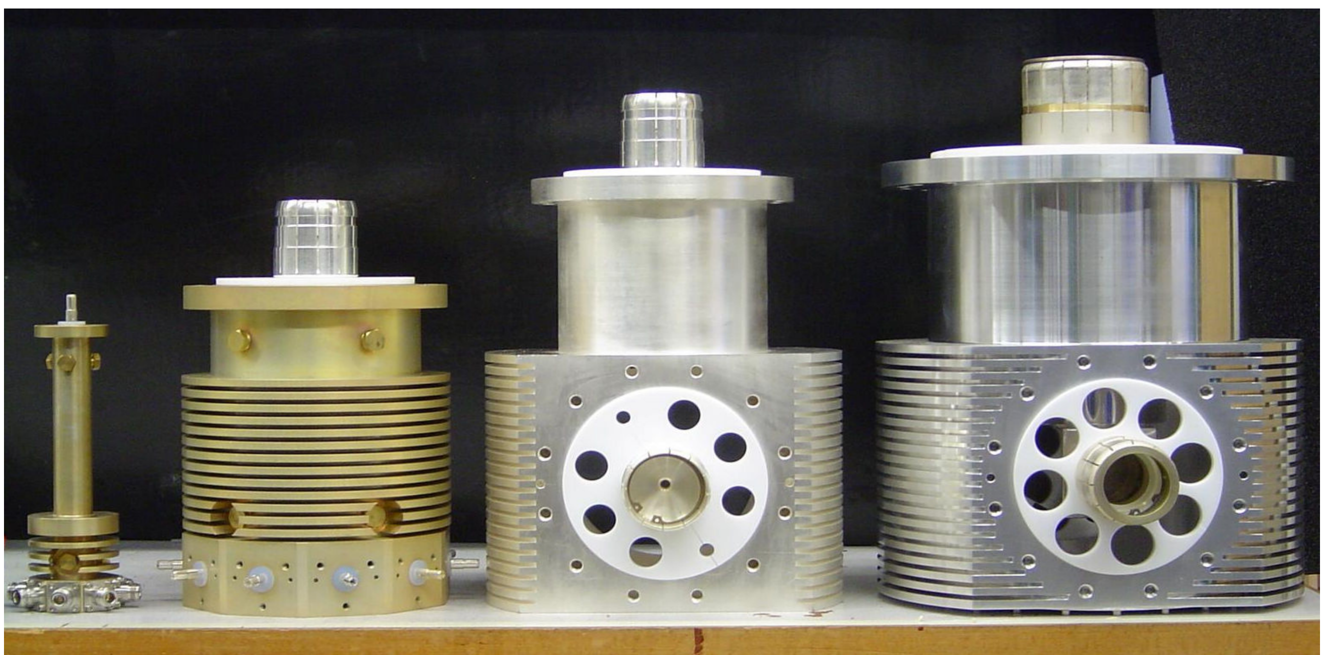


600 W – 280 Vdc / 28Vdc converter

Components of the SR amplifier

SOLEIL SYNCHROTRON

Power splitters
2 , 8 and 10 ways
(90, 350 & 20 pcs,
respectively



Power combiners
2.5, 25, 100, 200 kW;
320, 34, 26 & 6 pcs,
respectively
(S11 < - 30 dB)

March 2006, assembling of the amplifiers inside the RF room

March 2006, assembling of the amplifiers inside the RF room

SOLEIL SYNCHROTRON

Amplifiers 1 and 2 (CM1), ready for power tests on dummy load

April 6th 2006 : 180 kW on amplifier 1

April 7th 2006 : same result with amplifier 2

R&D with solid state amplifiers

6^{th} generation transistors (V_{dc} = 50 V) + SOLEIL expertise → fast progress

→ P_{mod} ~ 700 W, G ~ 20 dB, η > 70% @ 352 MHz

[Current module (V_{dc} = 28 V) : P = 315 W, G = 13 dB, η = 62 % @ 352 MHz]

→ Huge improvement : P_{mod} x 2.2 & better performance

& thermal stress strongly reduced (T_{max} : 130 °C → ~ 70 °C) → longer lifetime

→ Beg. 2009, transfer of technology agreement concluded with ELTA-AREVA

→ ESRF contract for 7 SOLEIL type amplifiers of 150 kW (14 x 75 kW towers)

Collaboration agreements

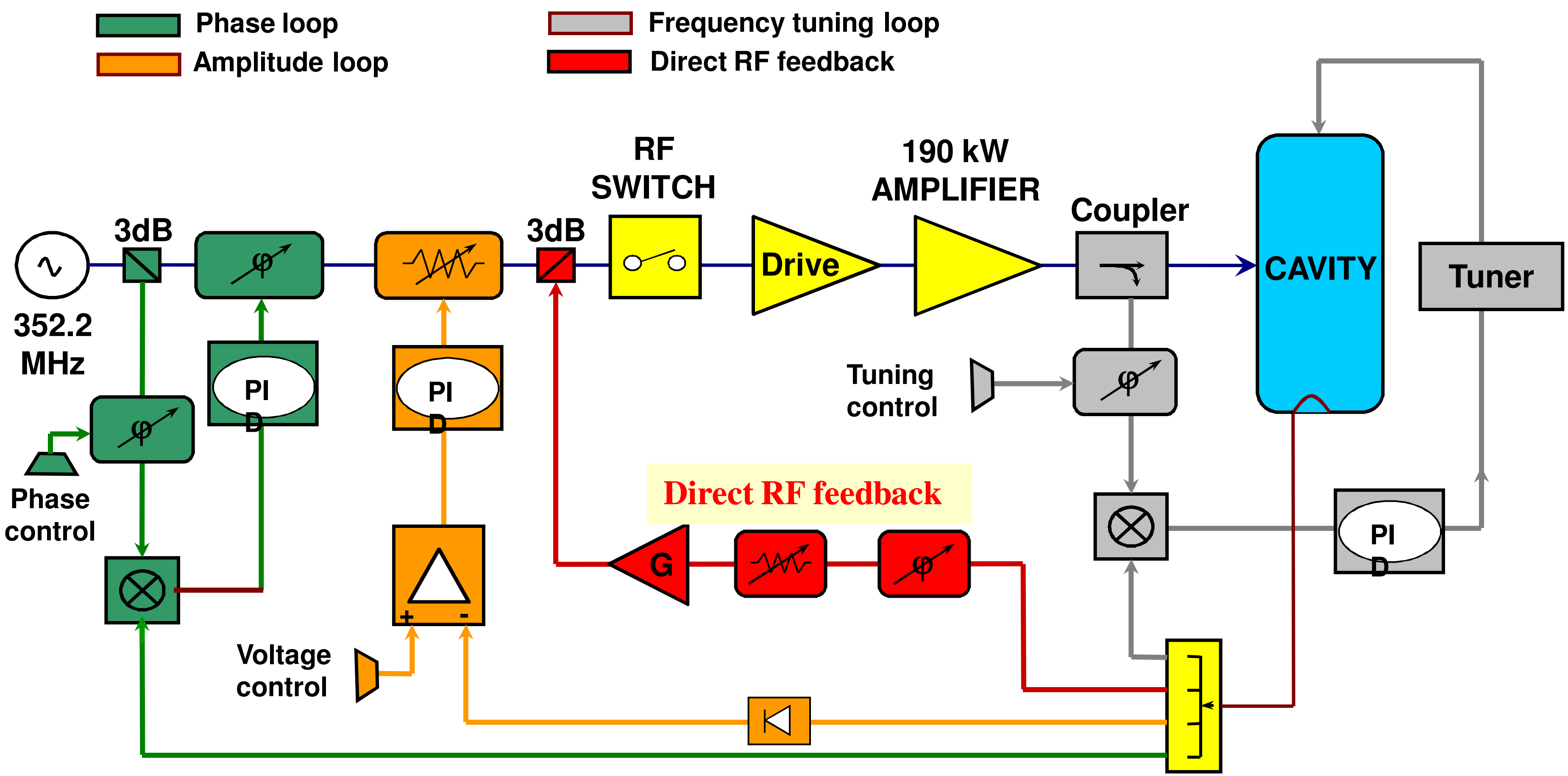
- **LNLS (Brésilian LS) : 2 x 40 kW @ 476 MHz (tests beg. 2010)**
- **SESAME (LS in Jordan) : 4 x 150 kW @ 500 MHz**

R&D at other frequencies

- **L band (1.3 & 1.5 GHz) for 4^{th} generation LS**
- **88 MHz (SPIRAL2 – GANIL)**

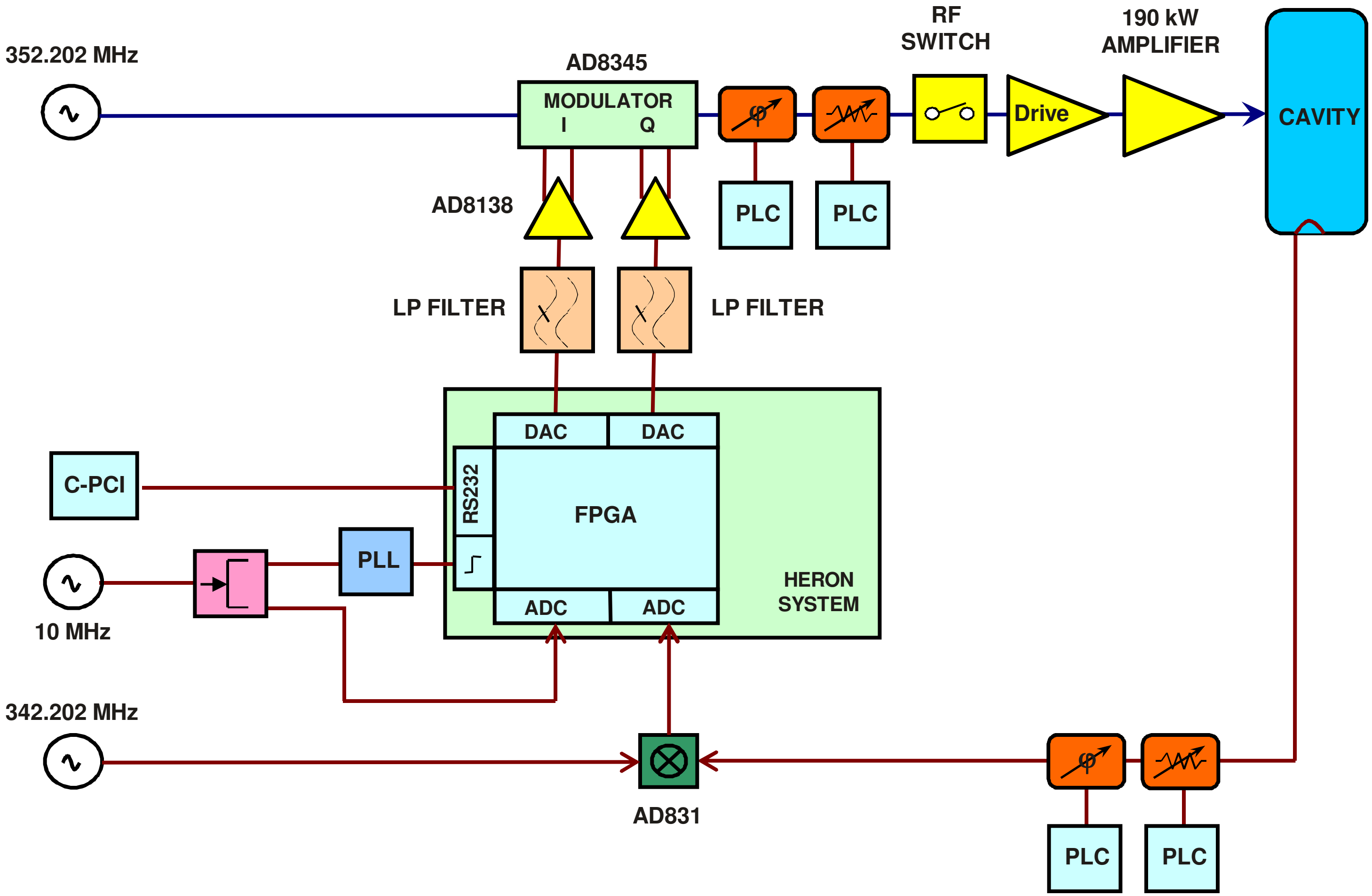
SR Low Level RF Electronic system

SR LLRF = BO LLRF + direct RF feedback (figure below)



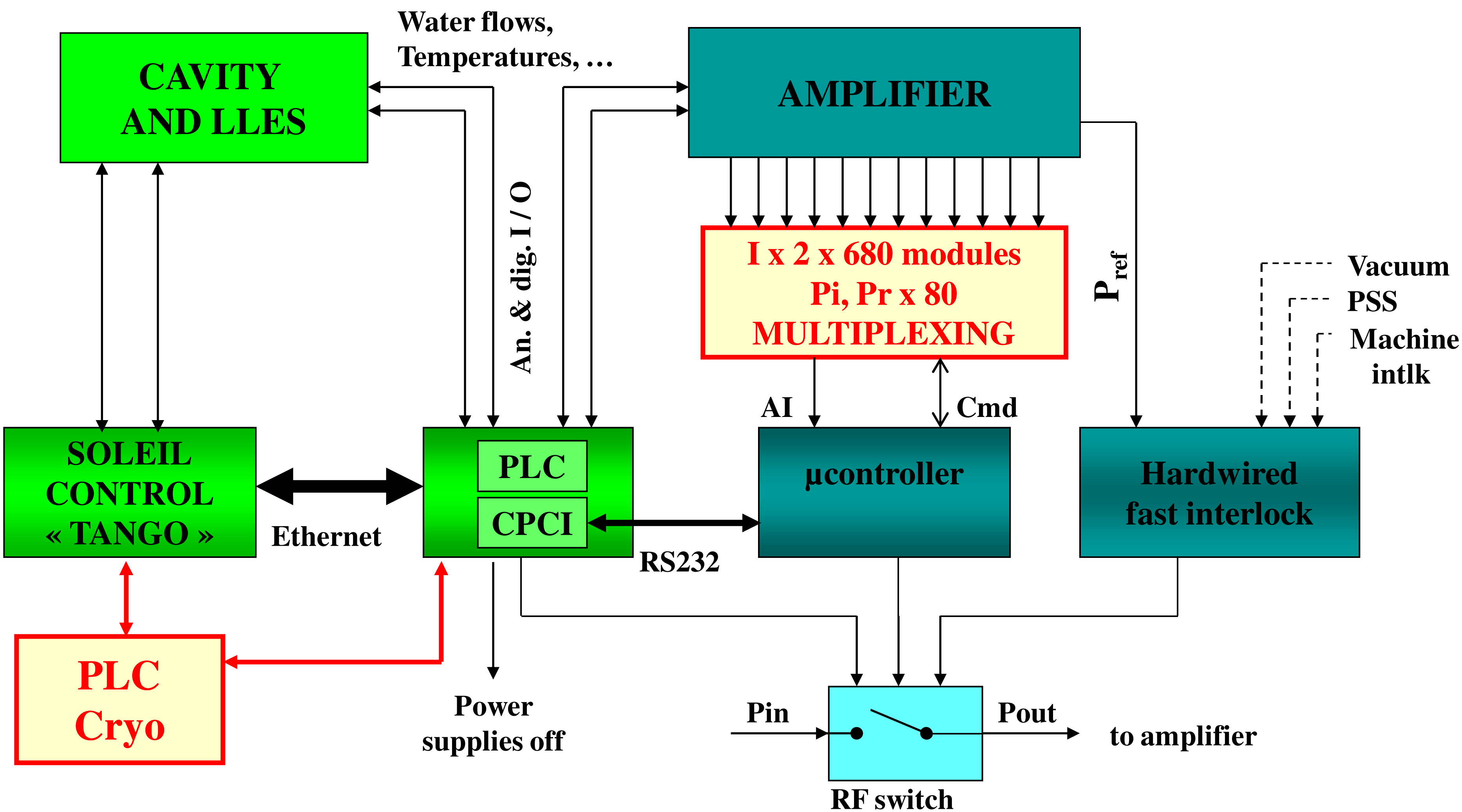
→ Stability of ± 0.1 % in amplitude and ± 0.05 ° in phase with a BW of ~ 50 kHz

Digital FPGA based LLRF system



→ Stability of 0.1 % in amplitude and 0.1° in phase

Diagram of the SR RF control system



SR operational experience

Repetitive pbs with the CM frequency tuning mechanism

- Complete tuner assembly (step-motor, gear-box, driving screw, lever system) inside the CM, under vacuum and cryogenic environment
- Pbs on SUP3HC cavity at ELETTRA with a similar design
  - Sparing use → back-up mode at fixed tuning (I_b^{max}) → V_{cav} (I_b) & ϕ (V_{cav})
  - Development of a new design
    - March 2009, prototype successfully tested on a test bench @ cold in CryHolab at CEA ⟺ + 20 years of SOLEIL operation
    - New version implemented in Aug. 2009 on CM2 & Jan. 2010, on CM1

→ In spite of repetitive pbs with the tuners, the impact on the operation was relatively weak, thanks to our *back-up mode at fixed tuning*

Trips « Excess of P_{ref} », which occurred @ 250 mA with 1 CM

Erratic events at a mean rate of ~ 1 / week, which disappeared after operating with 2 CM (< 400 mA) → Discharges on coupler window → (500 mA with 2 CM) ?

→ New coupler design (P > 300 kW), developed in collab. CERN/ESRF/SOLEIL

→ 500 mA with 1 CM (redundancy)

SR operational experience

Cryogenic system

- ~ 100 % operational availability, but for a while, difficulties in maintaining the CM LHe level → transfer line too deeply pushed into the Dewar !

- Losses of utilities (electr., water) → long restarts (few hours)
  → Spare He compressor station with separate utilities (install., beg. 2010)
  → Redundancy in operation and easier maintenance

RF power amplifiers

- Proved to be very reliable : after ~ 18 000 running hours, over + 3 years, only 3 short beam dead times → ~ 100 % operational availability

- Module failure rate of ~ 3.5 % per year → ~ no impact on the operation
  → Matter of maintenance : 1 hour @ each shutdown for ~ 10 mod. repair

Significant improvement expected from the new generation modules with more robust transistors and less thermal stress

Summary & conclusions

SOLEIL SYNCHROTRON

After ~ 3.5 years of operation, result globally satisfying :

- **For the BO RF, no pb at all**
- **In SR, for the first 2 years, using a single CM, only 5 % of dead time due to RF**
- **The third year, with the commissioning of CM2, it has nearly tripled**
- **Last 8 months → 4 %**
- **Significant improvements expected from the corrective actions :**
  - **→ Upgrade of the CM frequency tuners**
  - **→ Installation of a spare He compressor station**
- **Longer term → Upgrade of the power couplers (collab. with CERN & ESRF)**
  → Replace the actual amplifier modules by the 700 W generation

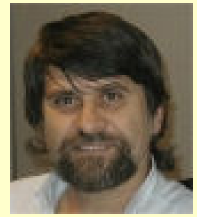
<u>R&D with solid state amplifiers</u> :

- **ESRF contract with ELTA → 352 MHz**
- **Collaborations (LNLS, SESAME) → ~ 500 MHz**
- **L and VHF bands**

Acknowledgements

SOLEIL RF and LINAC group

Fernand RIBEIRO



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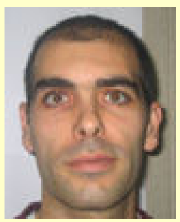

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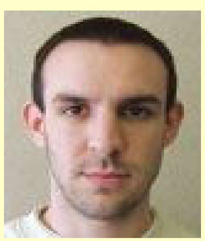

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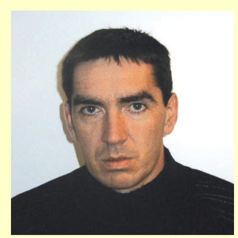

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