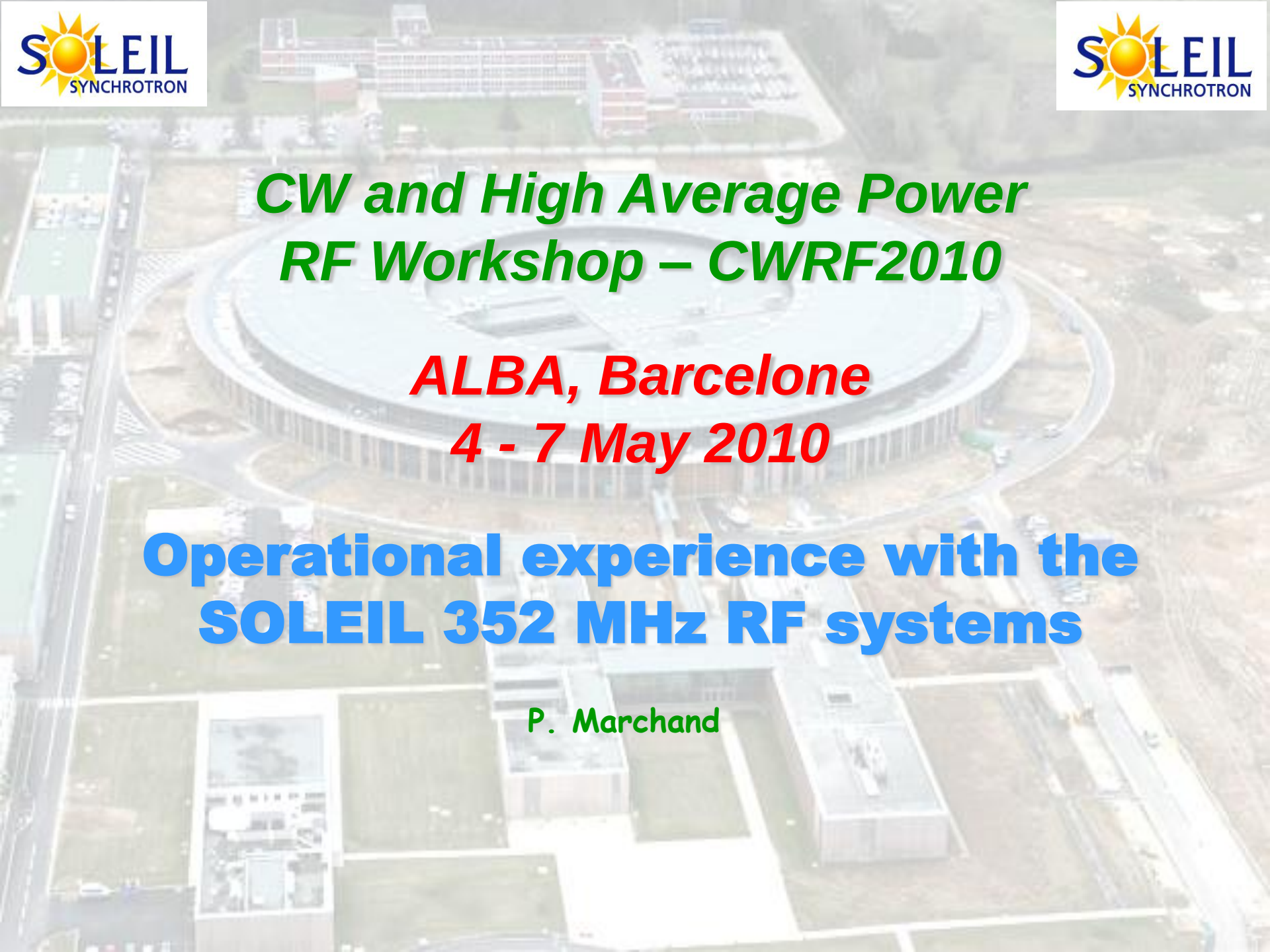


CW and High Average Power RF Workshop – CWRF2010

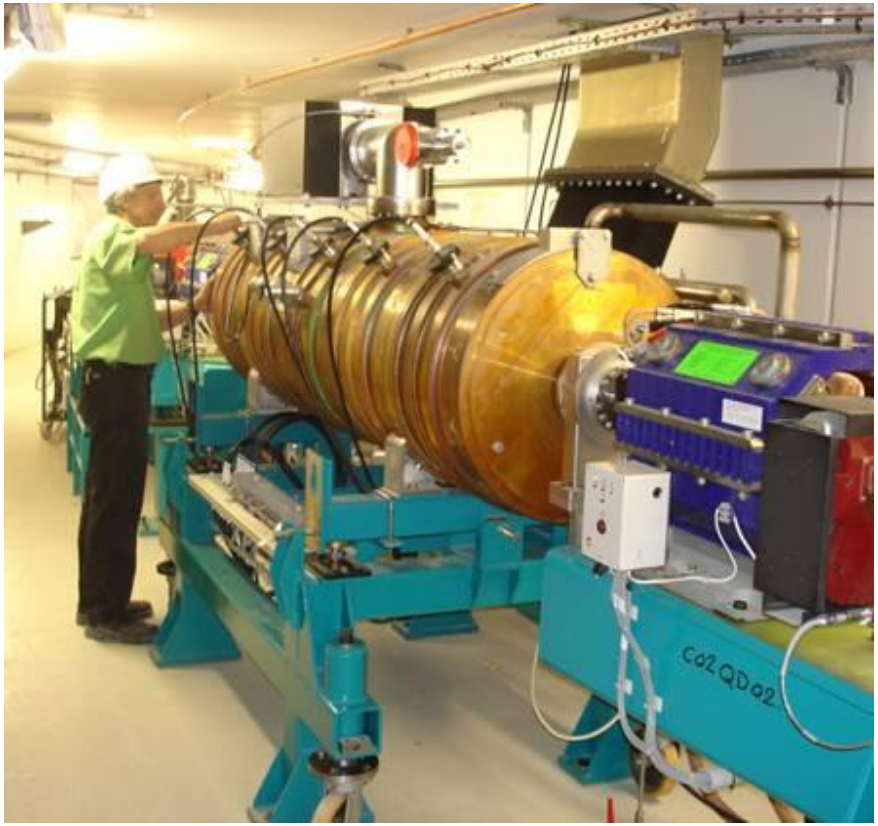
ALBA, Barcelone
4 - 7 May 2010

Operational experience with the SOLEIL 352 MHz RF systems

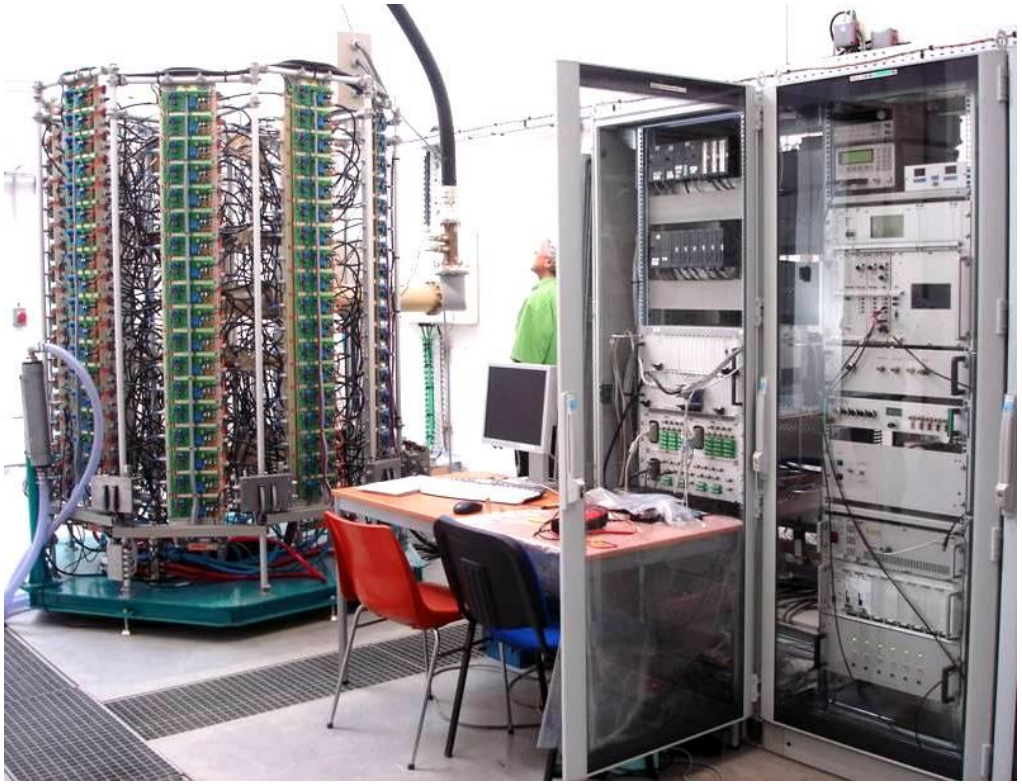
P. Marchand

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

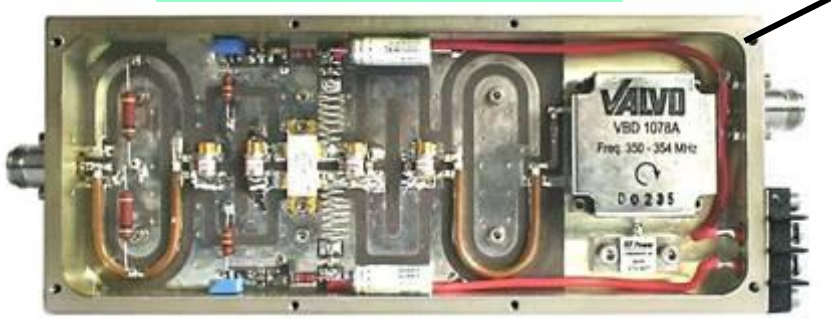


BO RF room (amplifier & LLRF)

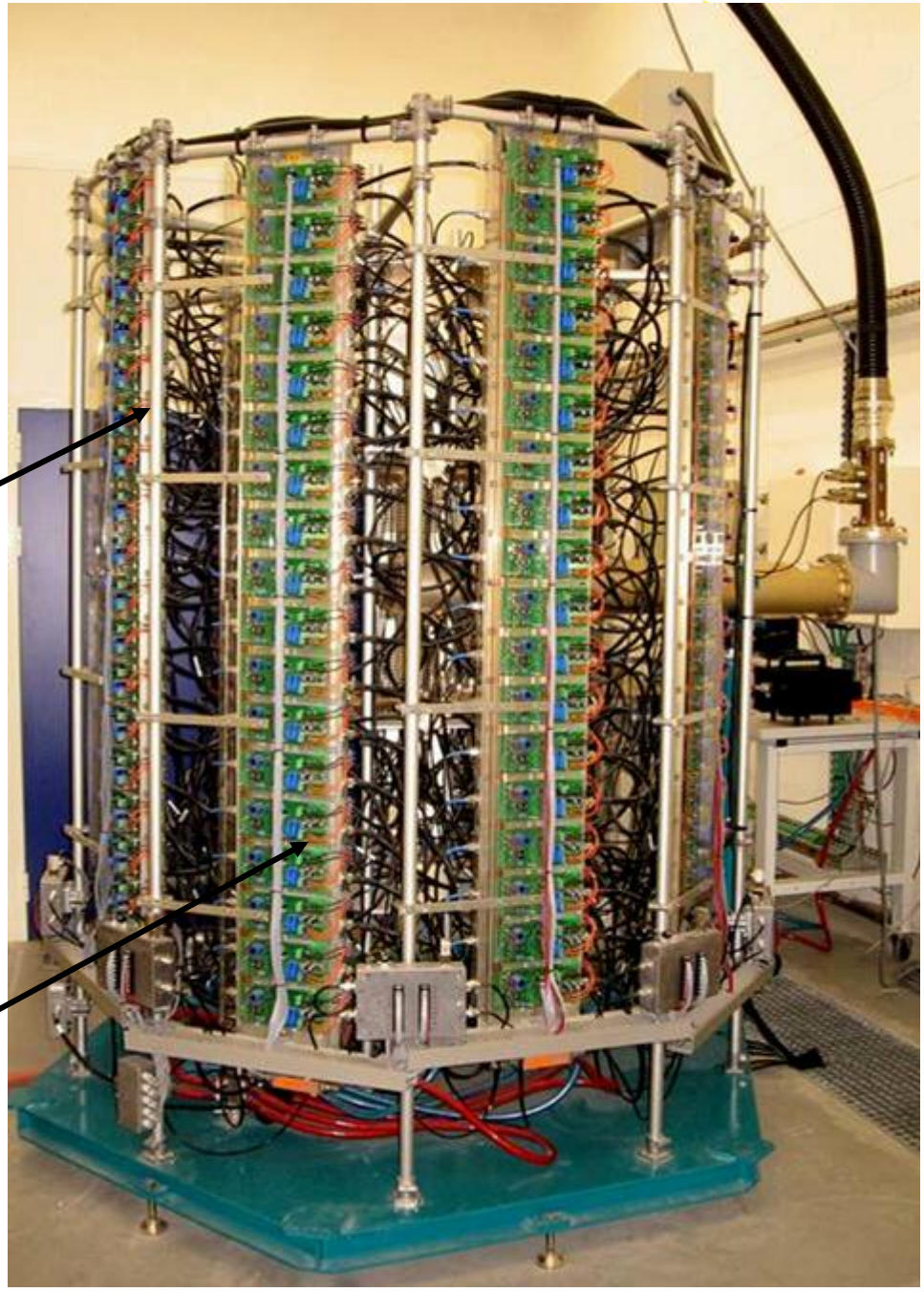
Booster
35 kW amplifier

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

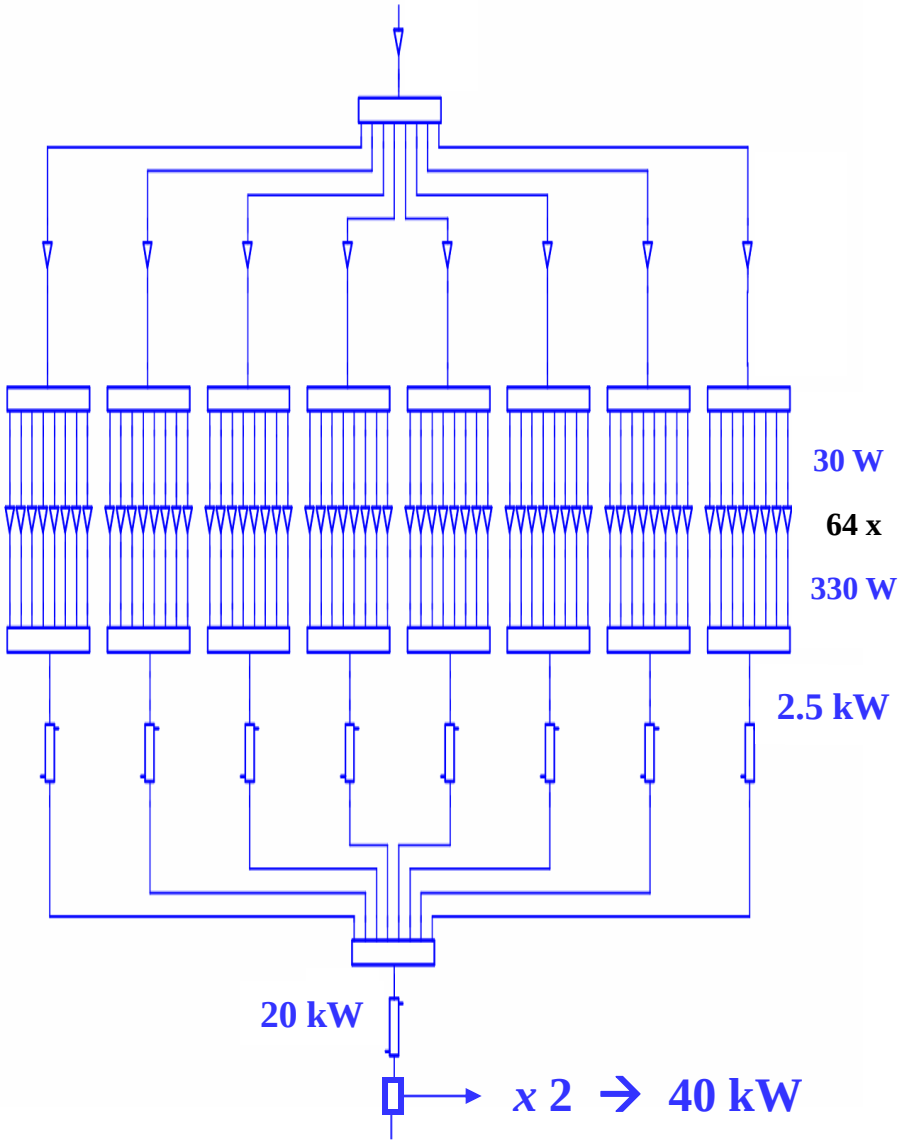
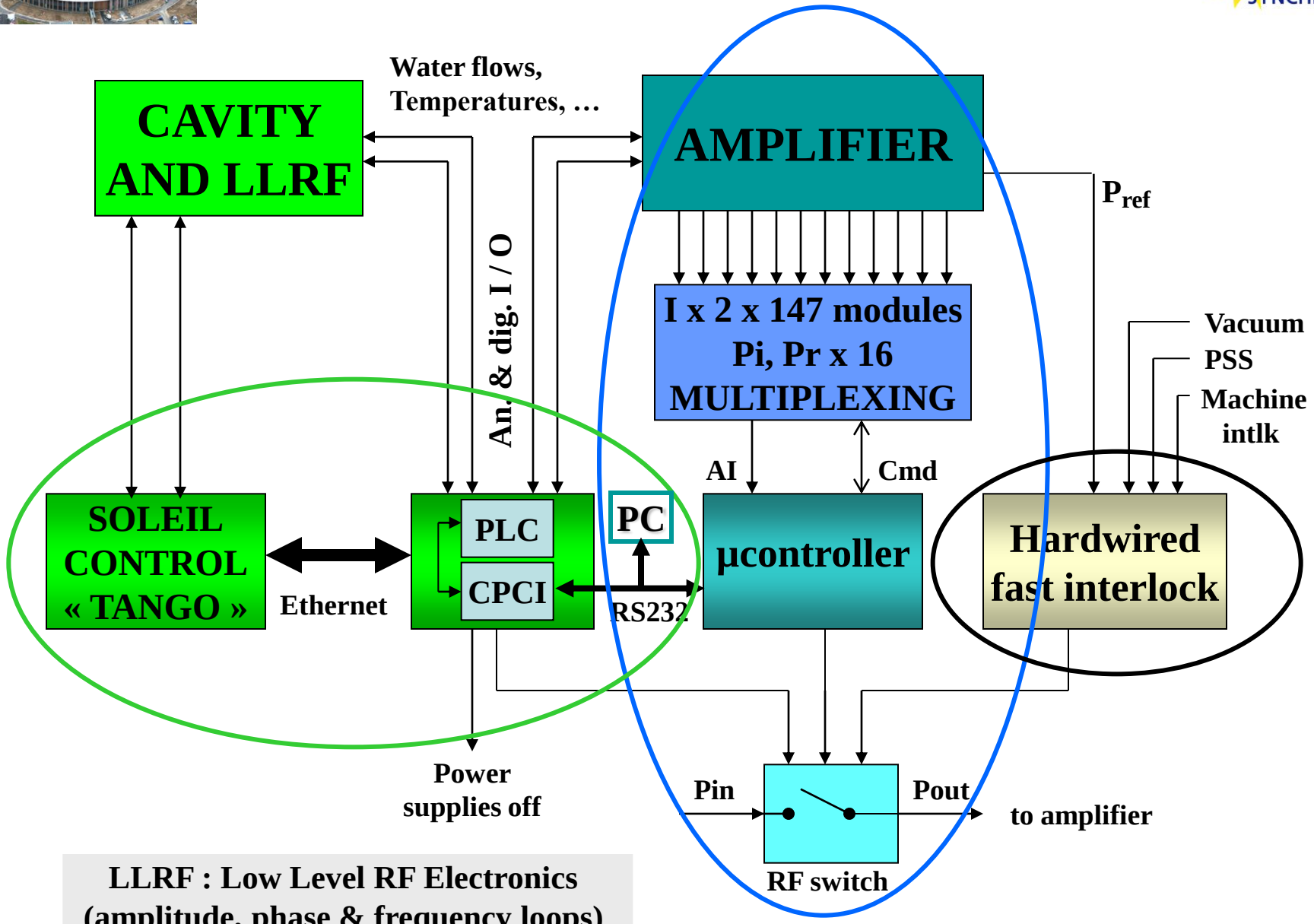


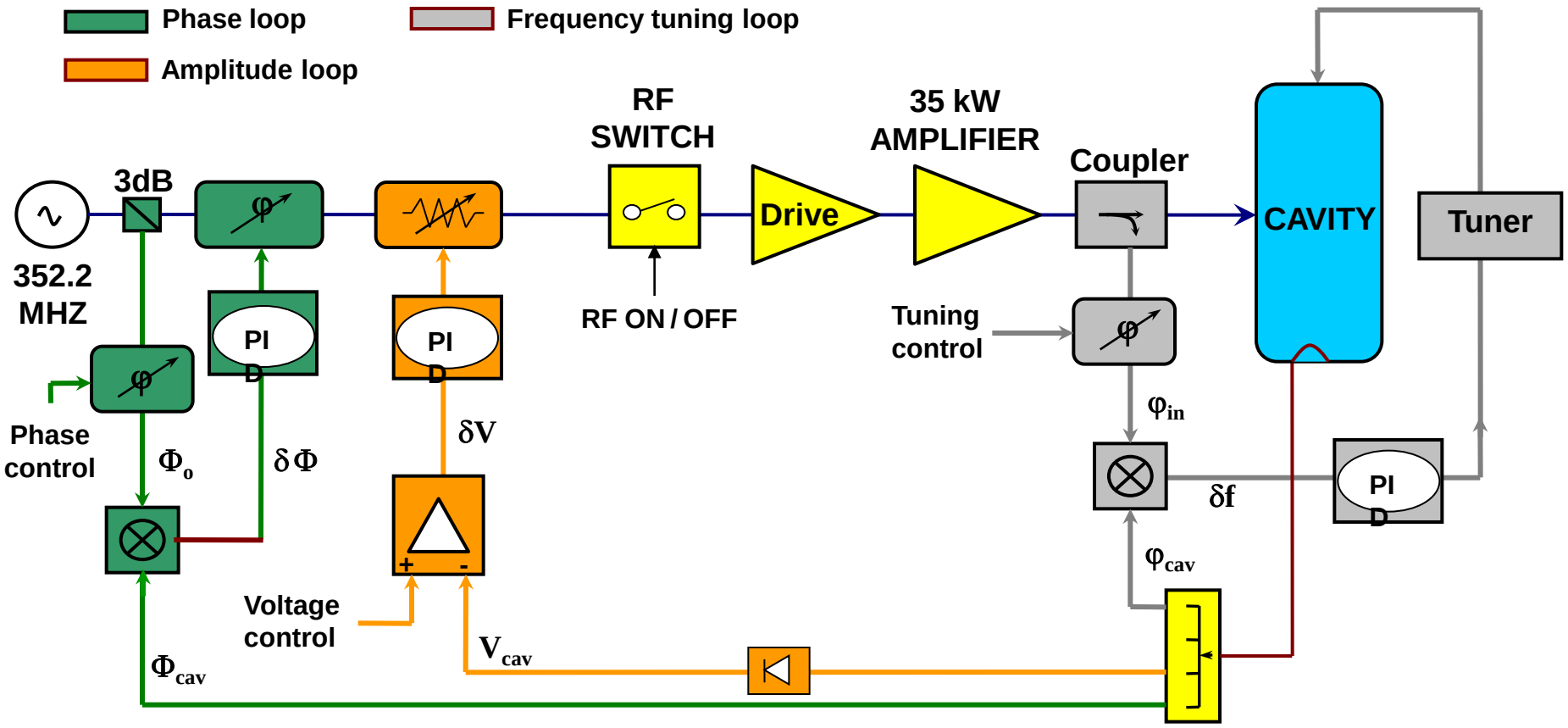
Diagram of the Booster RF control system



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

Booster Low Level RF Electronics

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



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

Operational experience with the Booster RF system

SOLEIL SYNCHROTRON

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, ΔE = 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 is powered with a 180 kW solid state amplifier**
- **Both CM supplied with LHe (4.2 K) from a single cryo-plant**

SOLEIL cryomodule design

SOLEIL SYNCHROTRON

IPC2

Cryogenic transfer line (LHe & LN2)

HOM 4

IPC1

IPC : input power coupler

HOM 3

Tuner 2

Cav 2 vessel

HOM 1 & 2 Couplers

Cav 1 vessel

Tuner 1

Cryomodule (CM) history

- ***SOLEIL studies (1996)*** → launch the development of a CM prototype
  → realised 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 1st CM of SOLEIL (CM1)
- ***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
- ***Operation 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 :*** With 2 CMs, 455 mA stored beam
- ***In 2009 :*** 500 mA stored beam during machine R&D
- ***Beg. 2010 :*** 500 mA validated; in routine for users, 400 mA in top-up

Cryomodule in SR

SOLEIL SYNCHROTRON

RF cryogenic system

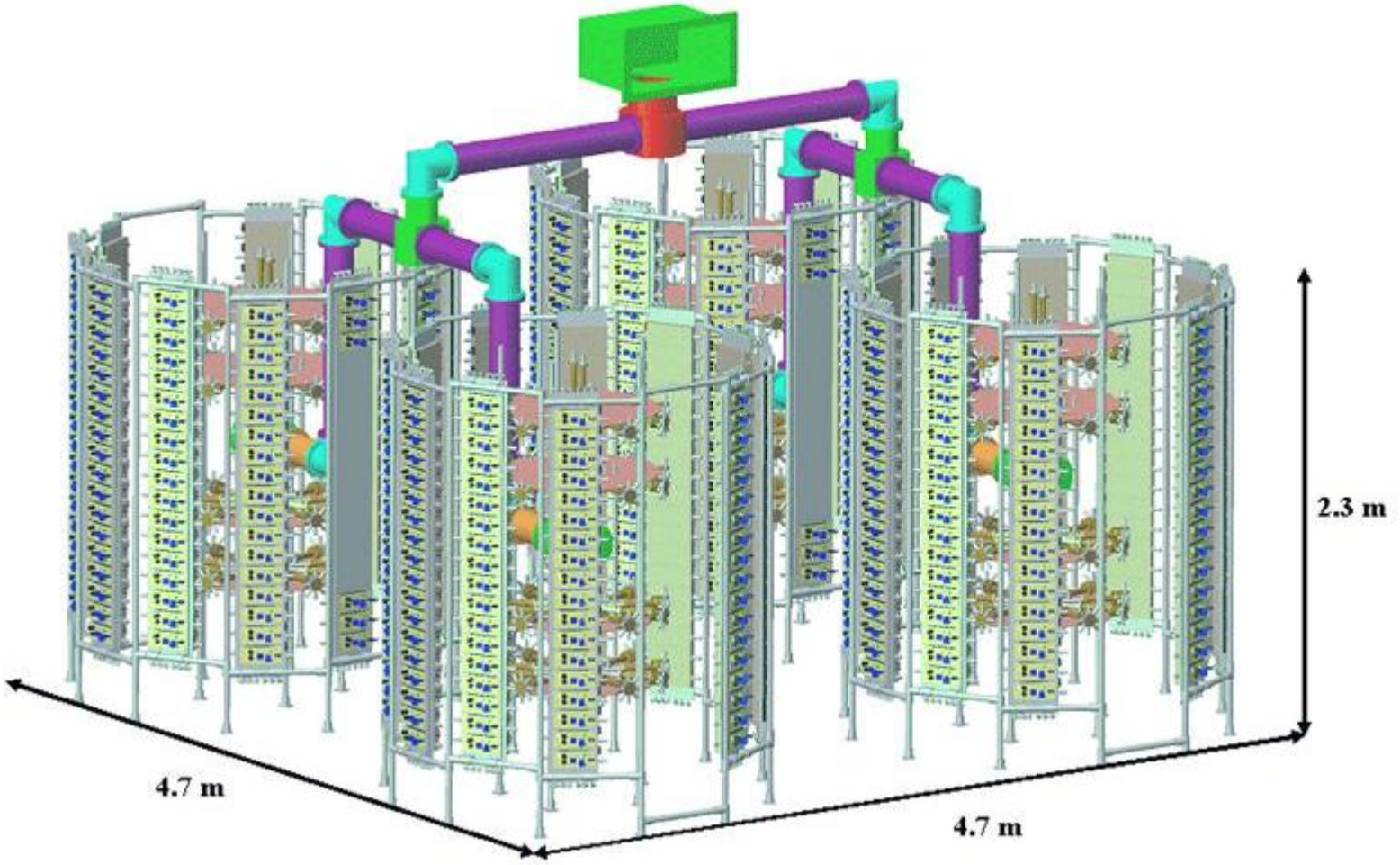
Both CM are supplied with LHe (4.2 K)
from a single cryo-plant,
a HELIAL-2000 device from AIR LIQUIDE,
operated in mixed refrigerator/liquefier mode;
it can provide up to 400 W of refrigeration
and 60 l / h of liquefaction, simultaneously.

RF cryogenic area in the technical gallery

Helium compressor station

SOLEIL SYNCHROTRON

SR 180 kW RF amplifier



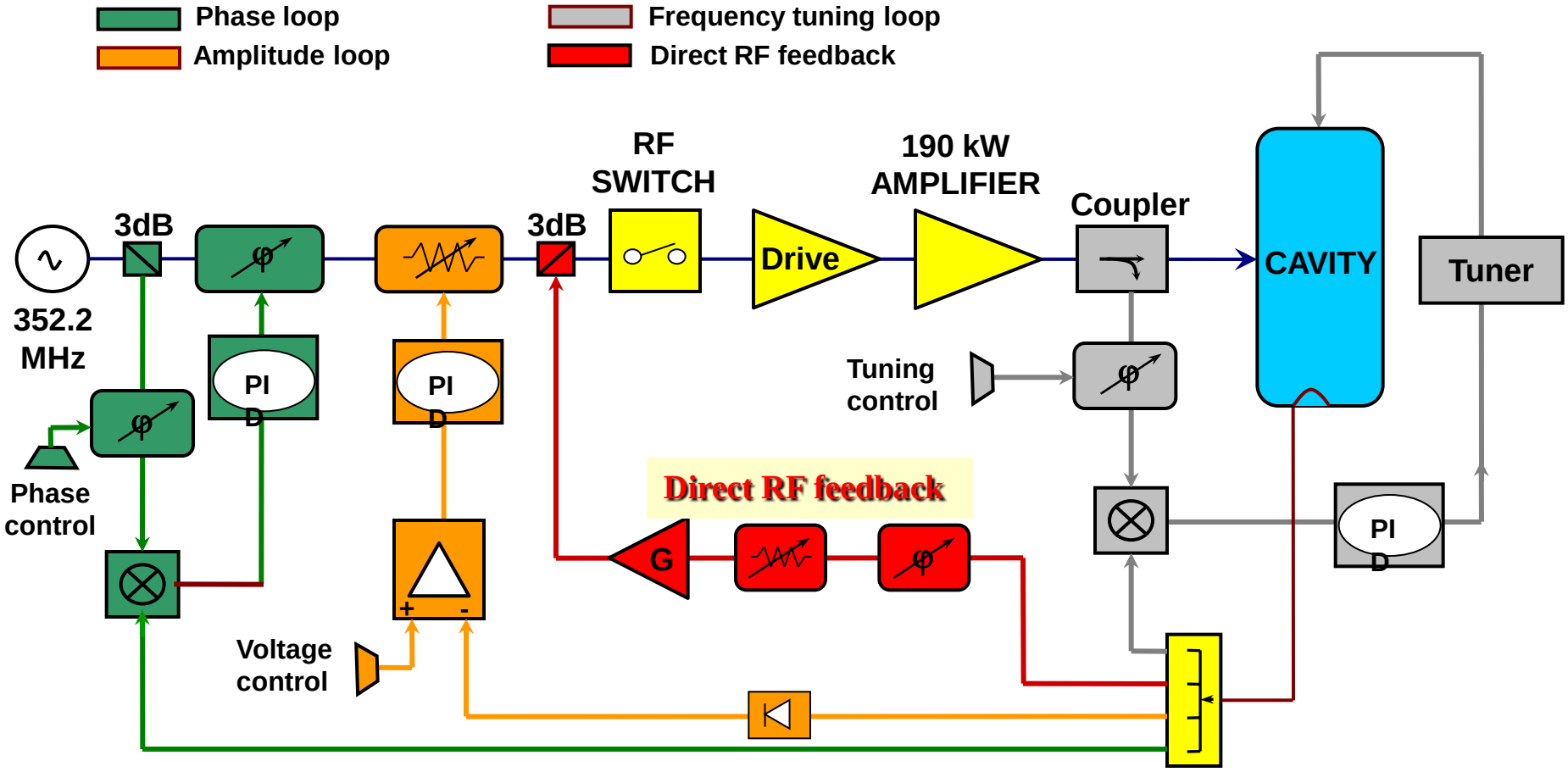
Same principle as for the BO one, extended to 4 towers of 45 kW
→ 726 modules / amplifier *x* 4 cavities → 16 towers & ~ 3000 modules

Amplifiers 1 & 2 → 2 cavities of CM1

SOLEIL SYNCHROTRON

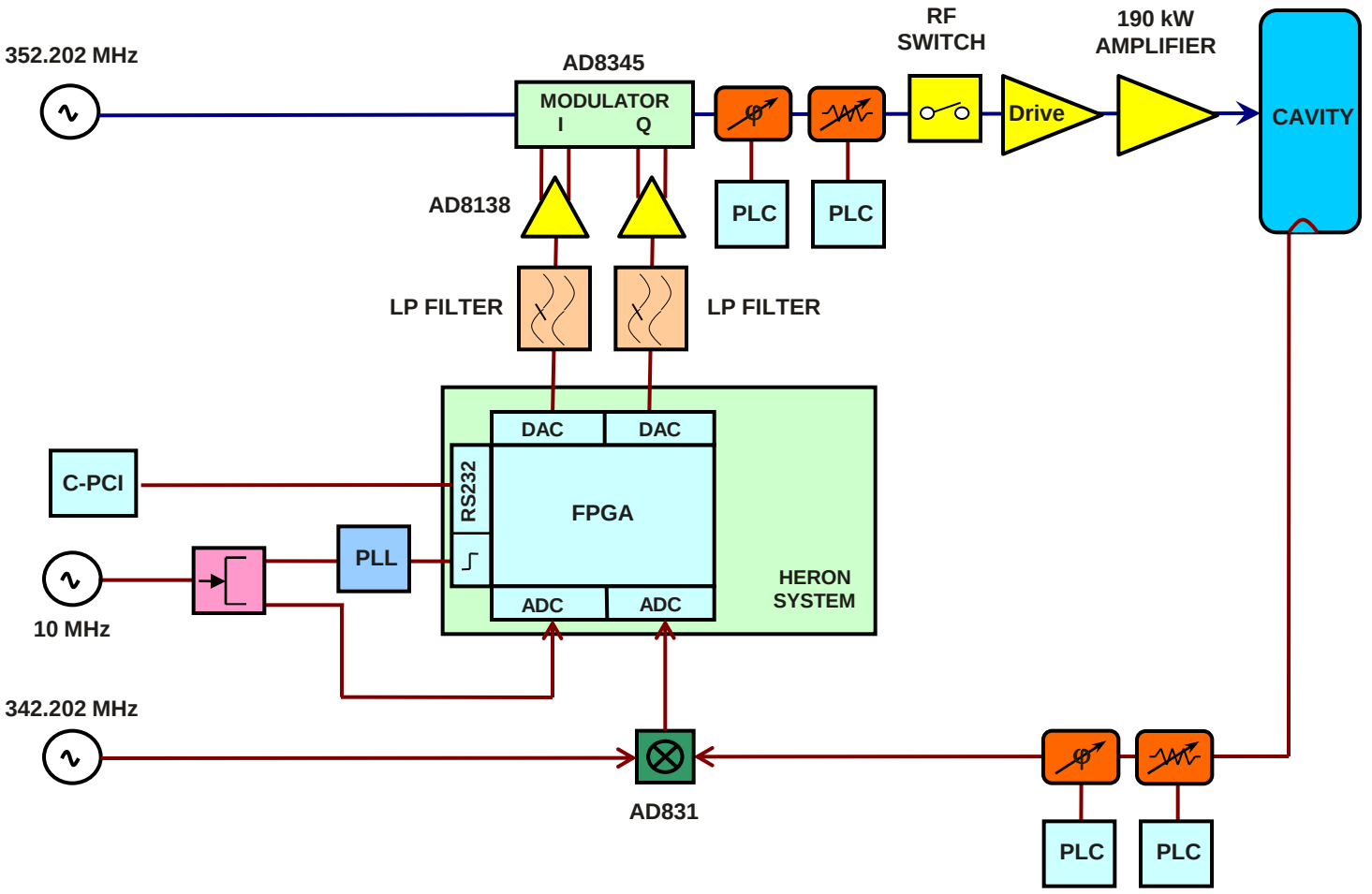
SR Low Level RF Electronic system

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



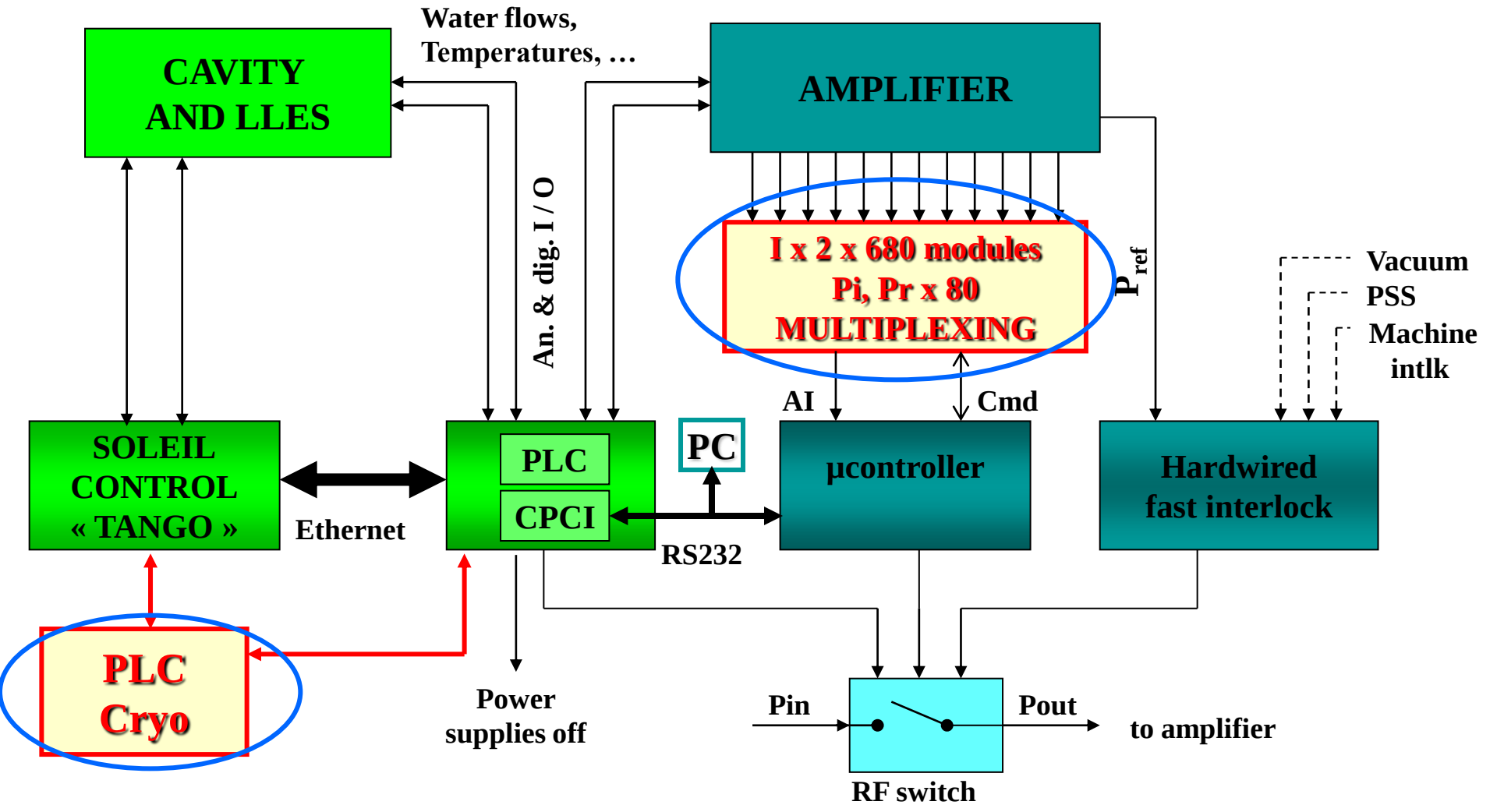
→ Stability of ± 0.1 % in amplitude and ± 0.05 ° in phase with a BW of ~ 50 kHz

Fast digital Low Level RF 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 mechanisms (→ sticking)

- 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 ⟺ + 30 years of SOLEIL operation
    - New version implemented in Aug. 2009 on CM2 & Jan. 2010, on CM1
- In spite of repetitive pbs with the tuners, relatively weak impact on the operation, 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 ~ once a week, which disappeared after operating with 2 CM (< 400 mA) → Discharges on coupler window → (500 mA with 2 CM) ?

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

→ 500 mA with 1 CM (redundancy)

↳ E. Montesinos

SR operational experience

Cryogenic system

- ~ 100 % operational availability, but for a while, difficulties in maintaining the LHe level in the CM → transfer line too deeply pushed into the Dewar
- Losses of utilities (electricity & water) → long restarts (few hours)
  → Spare compressor station with separate utilities is being implemented
  → Redundancy in operation and easier maintenance

RF power amplifiers

- Proved to be very reliable : after > 20 000 running hours over ~ 4 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. change
  → Yearly repair cost of ~ 5 k€ (for the four 200 kW amplifiers)

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

R&D with solid state amplifiers

SOLEIL SYNCHROTRON

6th 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 (G > 20 dB, η > 70 %)
& thermal stress strongly reduced (T_{max} : 130 °C → ~ 70 °C) → longer lifetime

→ Similar performance @ 500 MHz

→ 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 (Brazilian LS) : 2 x 45 kW @ 476 MHz under commissioning
- SESAME (LS in Jordan) : 4 x 150 kW @ 500 MHz

R&D at other frequencies

- FM band (88 – 108 MHz) → 1 kW module with G > 25 dB and η ~ 80 %
- L band (1.3 & 1.5 GHz) for 4th generation LS → P_{mod} > 400 W

→ Talks by T. Ruan (SOLEIL), J-P. Abadie (ELTA), J-M. Mercier (ESRF)

Summary & conclusions

After ~ 4 years of operation, result globally satisfying :

- For the BO RF, no pb at all
- In the SR, over 4 years, beam time availability : 95 → 98 %
  - The first 2 years, using a single CM, 5 % of the dead time due to the RF
  - The third year, with the commissioning of CM2, it has nearly tripled
  - Last 12 months → ~ 2 %
- Improvements expected from the corrective actions :
  - → Upgrade of the CM frequency tuners
  - → Implementation 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

R&D with solid state amplifiers

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

Acknowledgements

SOLEIL RF and LINAC group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Massamba DIOP


Rajesh SREEDHARAN


Marc LOUVET


Nicolas GUILLOTIN


Jean-Pierre BAETE


Julien SALVIA


Helder A. DIAS


Jocelyn LABELLE


Moussa EL AJJOURI


Cyril MONNOT

+ SOLEIL, CERN, CEA