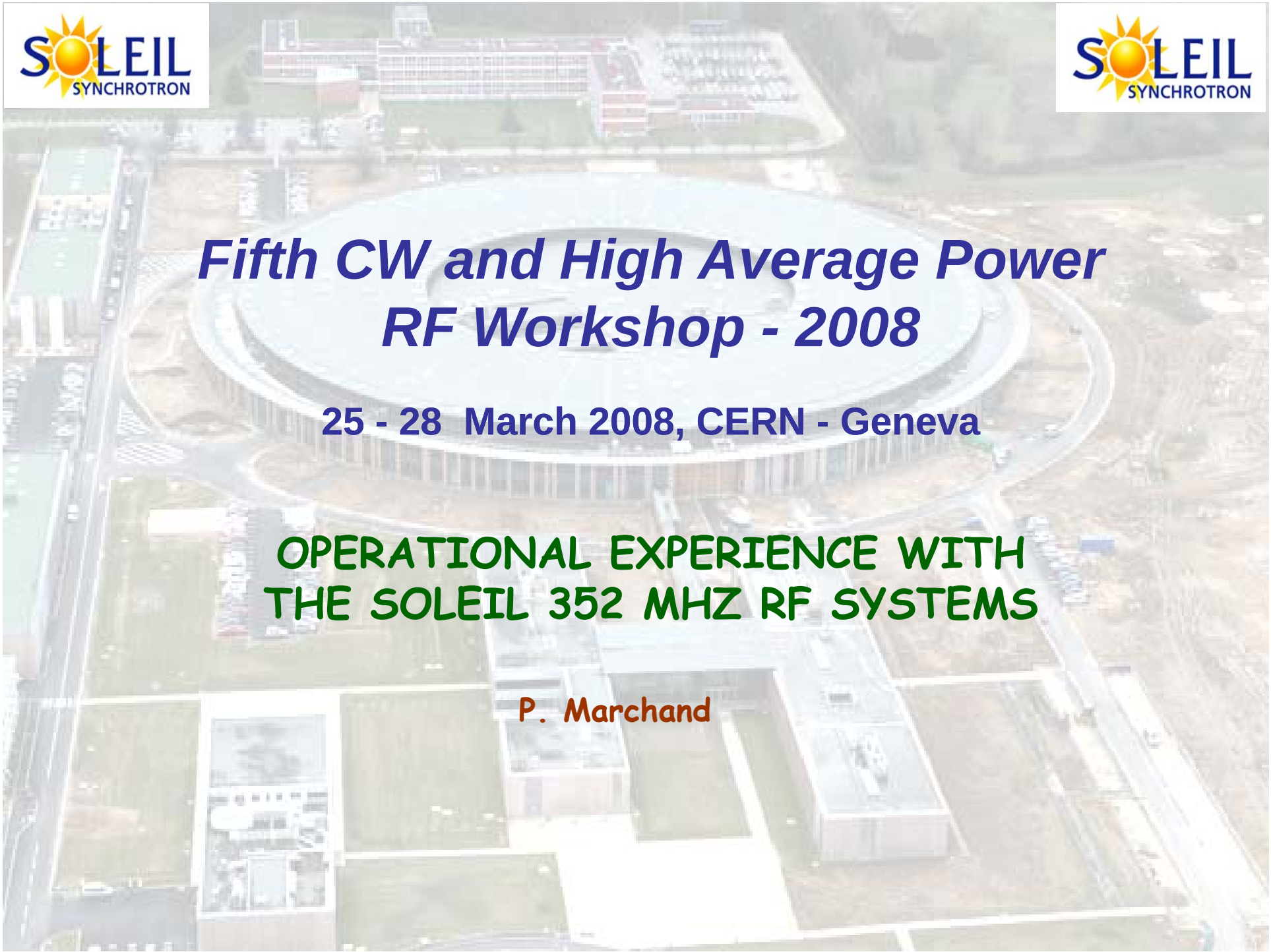


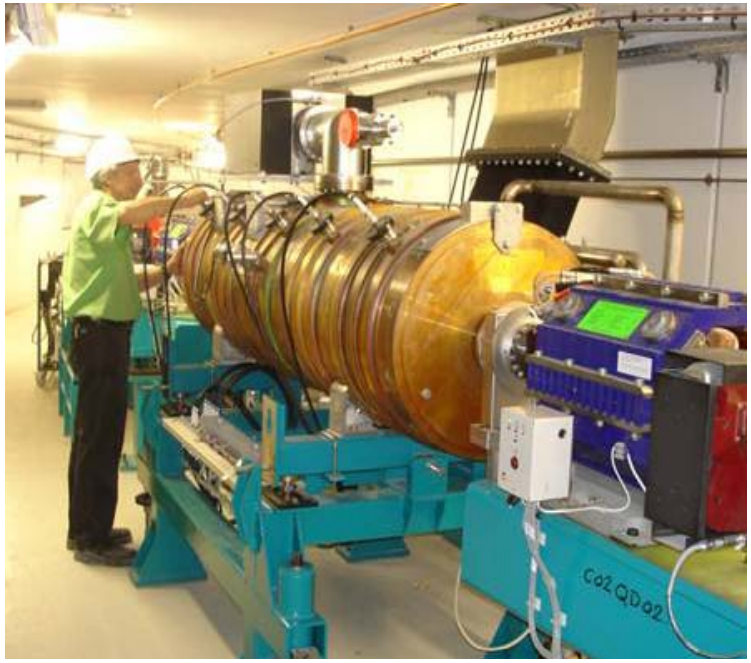
Fifth CW and High Average Power RF Workshop - 2008

25 - 28 March 2008, CERN - Geneva

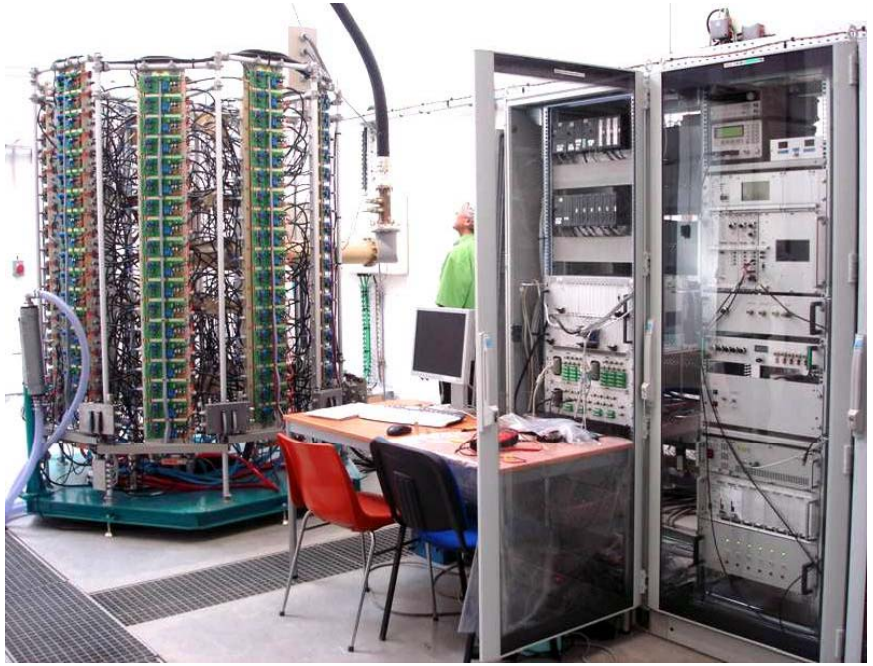
OPERATIONAL EXPERIENCE WITH THE SOLEIL 352 MHZ RF SYSTEMS

P. Marchand

Operational experience with the BO RF system



5-cell copper cavity of the LEP type in the SOLEIL Booster



35 kW solid state amplifier and LLRF system in the Booster RF room

The BO RF plant was commissioned mid 2005.

Up to date, after ~ 9 500 running hours, only a single trip in operation, due to a human mistake → **Don't play with the equipment during the operation !**

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

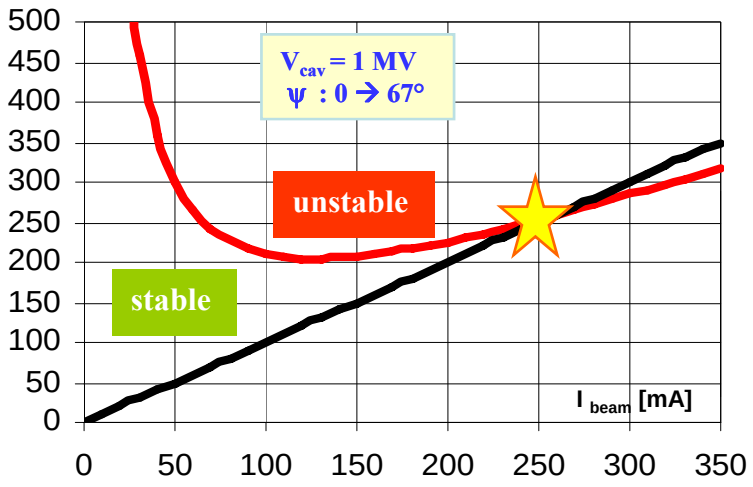
- 4 (out of 147) modules had a failing → bad soldering (3) + 1 filter **(0 transistor failure !)**
- In any case, that did not affect at all the operating conditions and could be quickly repaired during scheduled machine shutdowns.

Commissioning of the SR RF

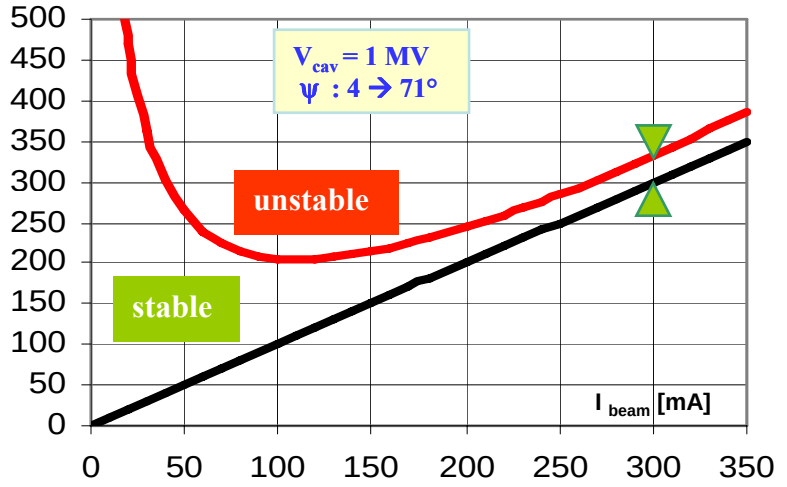
As scheduled for SOLEIL - phase 1, with $I_{beam} < 300$ mA and a reduced number of insertion devices, one half of the SR RF system was installed and commissioned, during summer 2006 (CM1, cryogenic plant, 2 amplifiers, control and LLRF systems).

The goal of storing up to 300 mA of stable beam, using a single CM, was quickly achieved.

At first, without the RF feedback, the cavity was slightly detuned in order to cope with the **Robinson instability**, at the expense of ~ 10 kW extra reflected power.



$\psi = \psi_{opt}$ (P_r min) → beam lost at 230 mA



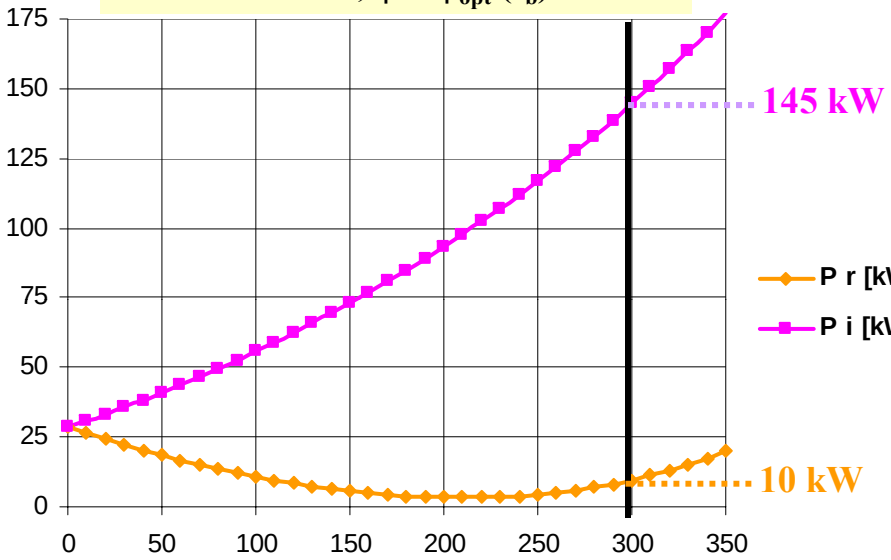
$\psi = \psi_{opt} + 4°$ → stable up to 300 mA

Later on, we have commissioned the RF feedback, which enabled to store up to 300 mA stable beam without any tuning offset, hence saving ~ 10 kW of reflected power.

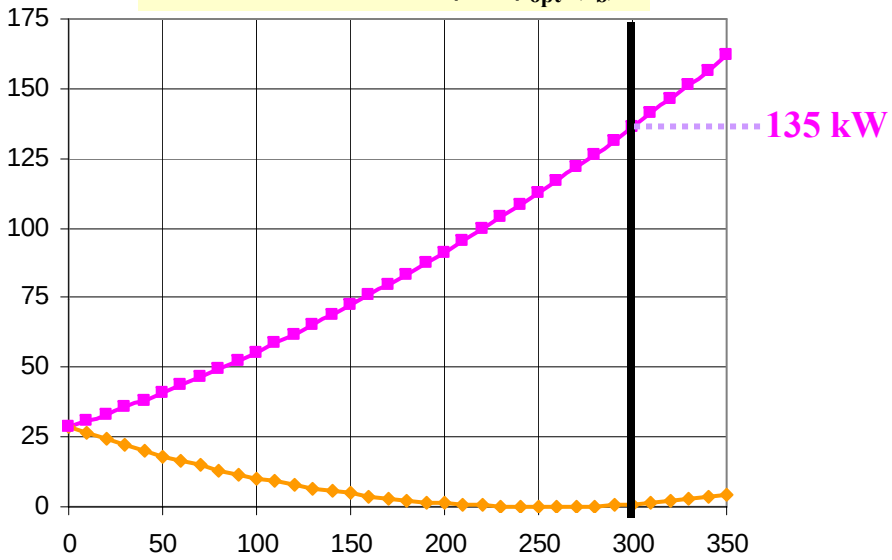
Commissioning of the SR RF

RF power required per cavity (Pi, Pr) vs I_{beam} at cst voltage of 1 MV / cav

No RF feedback, $\psi = \psi_{opt}(I_b) + 4°$

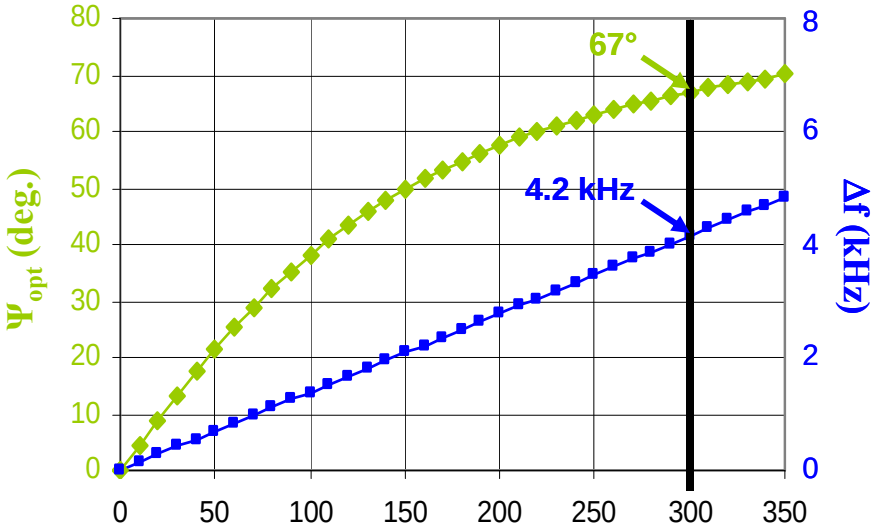


With RF feedback, $\psi = \psi_{opt}(I_b)$



Under these conditions, at cst V_{cav} = 1 MV, the tuning loop is continually active, compensating for the reactive beam loading either partially (no RF feed-back) or fully (with RF feed-back)

→ **Frequency changes of ~ 4 kHz, about 10 000 motor steps, required at each injection.**

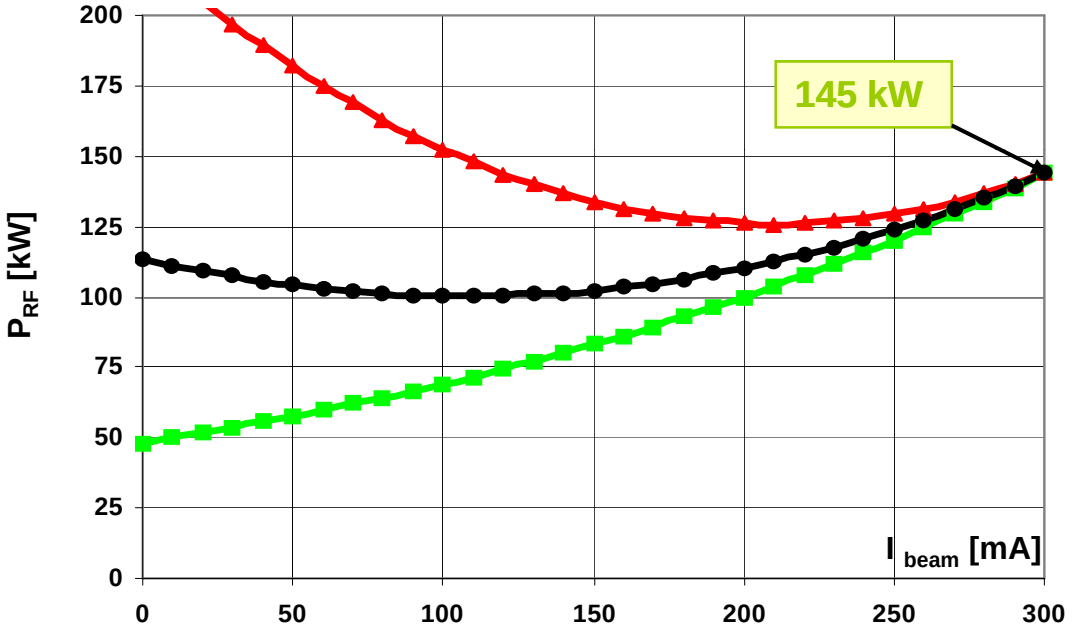


Commissioning of the SR RF

Injection at constant tuning

Considering the difficulties encountered on Super-3HC at ELETTRA with a similar tuning system, which happened to get stuck after ~ 50 millions of motor steps, it was proposed to **operate at constant tuning during the injection**, in order to use the tuners more sparingly.

Injecting at constant tuning requires a ramping of V_{cav}; otherwise too large P_r at low current (red plot).



V_{cav} : 1.4 MV cst, $\psi = 60°$

V_{cav} : 1 → 1.4 MV, $\psi = 60°$

V_{cav} : 0.65 → 1.4 MV, $\psi = 60°$

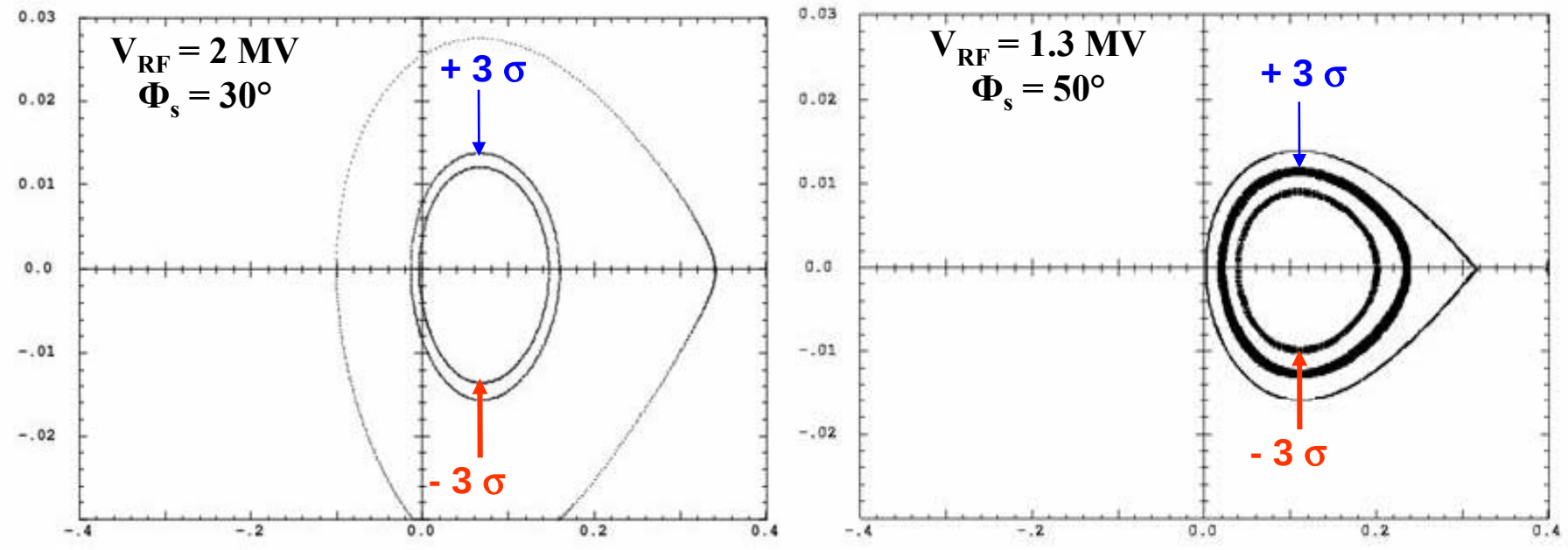
Ramping V_{cav} from 650 kV at 0-current, up to 1.4 MV at 300 mA, with fixed tuning angle, $\psi = 60°$, allows to maintain $P_r < 50$ kW and Pi ~ 145 kW (green plot).

Energy and phase acceptance at low RF voltage ?

Commissioning of the SR RF

Injection at constant tuning

At V_{RF} as low as 1.3 MV (650 kV / cav), E & Φ acceptance strongly reduced



The experience demonstrated that it remains tolerable : injection efficiency nearly unaffected while keeping V sin Φ cst : $V(I_b)$ and Φ(V), numerically controlled via the PLC

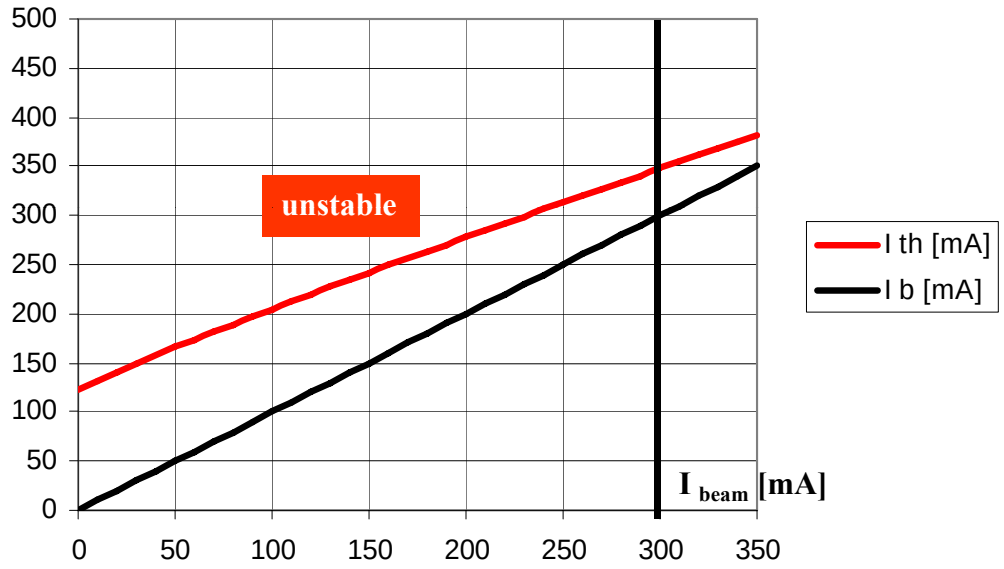
Precise control of Φ(V) required for operating with the multibunch transverse feedback

Constant tuning mode routinely used in operation ; easy switching from constant to variable tuning mode (for run dedicated to machine R&D → free control of V_{RF})

Commissioning of the SR RF

Injection at constant tuning – Robinson stability

V_{cav} : 0.65 → 1.4 MV, ψ = 60°



Large stability margin even without RF feedback

Operational experience with the cryomodule (CM1)

CM1 had been RF conditioned with full reflection (I_{beam}= 0) up to 200 kW per coupler, at CERN and then up to 80 kW, once installed in the SOLEIL SR (always kept under UHV).

Re-conditioning with beam went quite smoothly : a few coupler vacuum trips, at first when reaching P > 160 kW ; further conditioning likely would be required for operating at such power level ; however, with proper settings, P < 145 kW @ 300 mA with a single CM, which is more demanding than 500 mA with 2 CMs.

Not the least trip under nominal operating conditions

No evidence of HOM excitation : up to 300 mA, power dissipation in the HOM loads always negligible & residual beam phase oscillations < 0.1°

Taking care of using the cavity tuners sparingly → cst tuning operation as much as possible + additional diagnostic → rev counter for early detection of signs heralding a sticking

R&D for improved design { **- gear box** / **- transmission screw** } → **Test bench**

Operational experience with the cryogenic plant

At the beginning of the commissioning, difficulties were encountered with LHe feeding and pressure instabilities inside the cavity He tank, due to an unexpected thermal load on the cryogenic valve box.

This was solved after bringing in slight modifications on the cryogenic valve box

→ Pressure variations below ± 2 mbar, namely ± 0.1° in phase.

→ **Not the least trip in operation.**

A few shutdowns caused by utility losses (water / electrical) → fast restart

<u>Forthcoming upgrades</u> → improve the autonomy

- **Process modification → take profit of the autonomy provided by the Dewar**
- **UPS extension to all the Cold-box components**
- **Cold-box dedicated water-cooling**

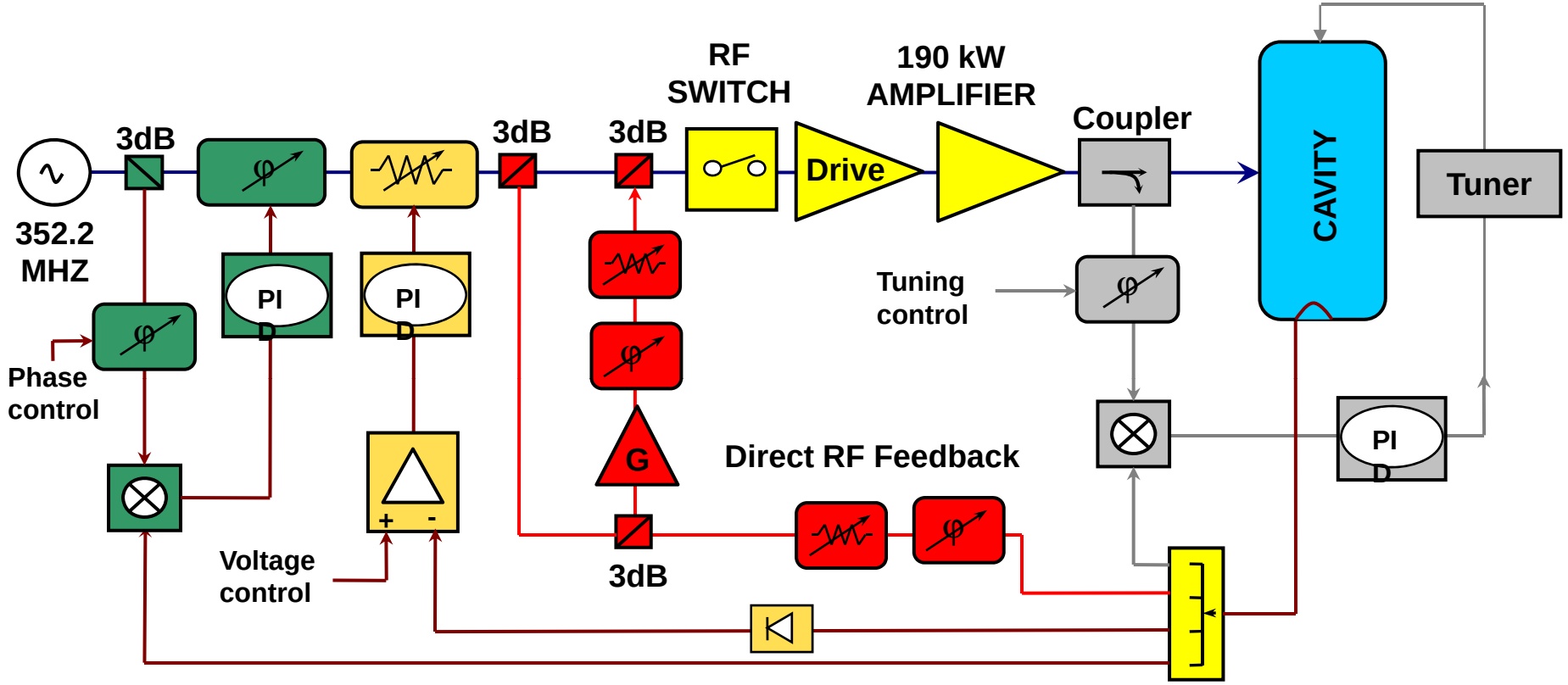
Operational experience with the RF power amplifiers

- The two 180 kW solid state amplifiers for CM1 have demonstrated good reliability in operation.
  After ~ 7 500 running hours, only 4 trips :
  - **3 due to human mistakes (a fault in the interlock logic, a wrong manipulation, a cable pull out by accident)**
  - **1 due to a failure on preamplifier module**
- Although not perturbing for the operation,
  56 (out of 1400) modules have suffered from transistor failures in operation;
  for 10 of them it was the result of a circulator load failing → solved by adding thermal grease

- **Failure rate < 3.5 % / year → pessimistic, as it includes part of the infant mortality, lack of grease, damages by accident on amplifier 1 → expected failure rate ~ 1%**
  → longer running periods are required to find out the *actual MTBF*
- **100 available spare modules → turn over : 50 usable in house while 50 under repair**

R&D
- **Upgrading of the 350 MHz design (investigation of other suitable transistors)**
  → Collaboration with ESRF (~ 50 towers of 50 kW)
- **Other freq. : 300 W module @ 500 MHz → 476 MHz (2 x 40 kW for LNLS)**
  90 x 15 kW @ 1.3 GHz → 4th generation LS (ARC-EN-CIEL)

Operational experience with the LLRF



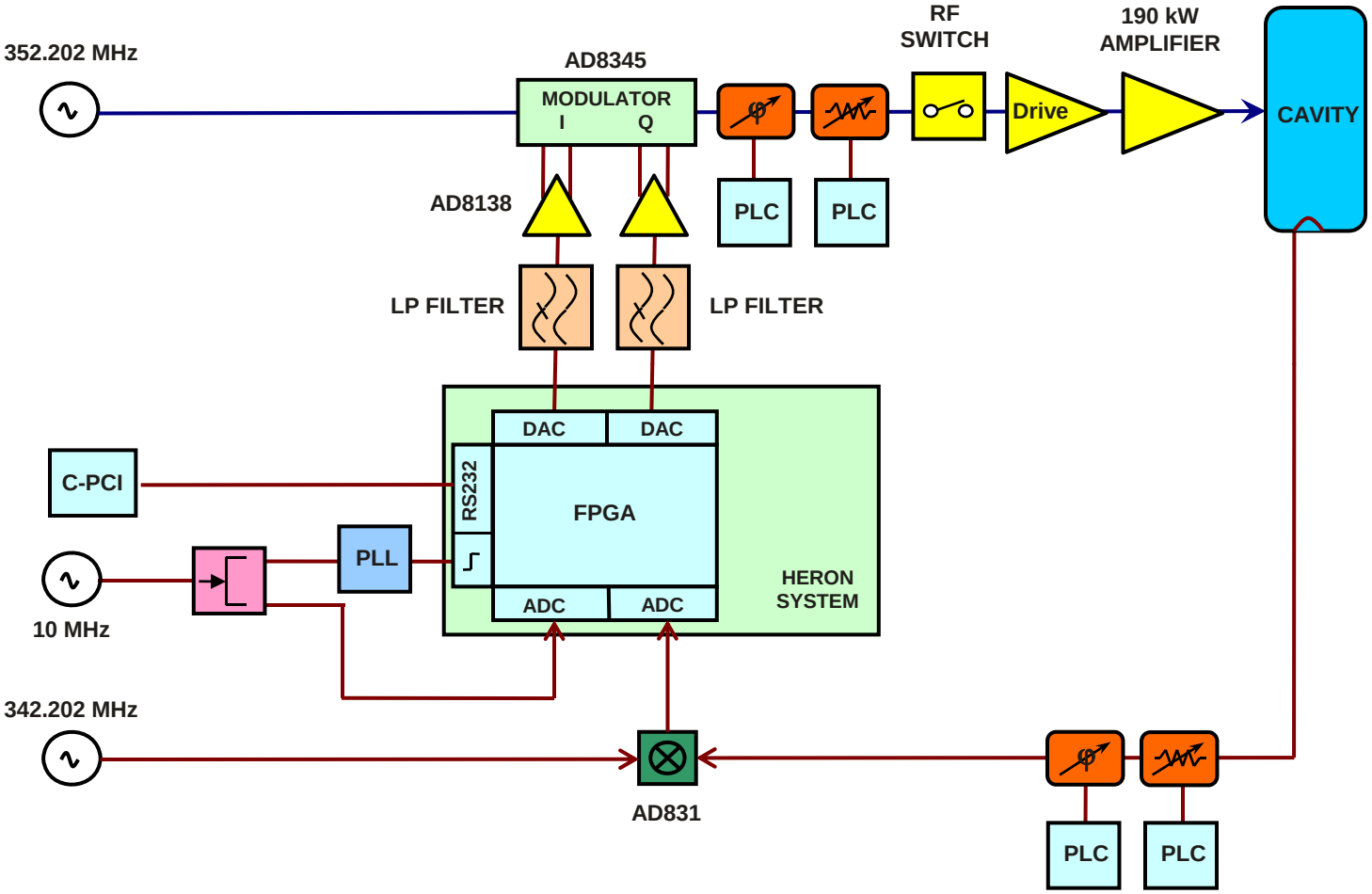
Without RF feedback : ± 0.5 % in amplitude and 0.15° in phase

With RF feedback : ± 0.1 % in amplitude and 0.05° in phase

Recently, a few trips due to wrong P_r interlocks on fast hardwired system

→ Solved by compromising speed & sensitivity to interference

Fast digital LLRF



First measured performance : 0.1 % in amplitude and 0.1° in phase
→ to be completed in forthcoming runs

Summary & conclusions

- Up to date, the BO and half of the SR RF systems have been commissioned
- The technological choices, sc cavities and high power solid state amplifiers, both designed in house, were quite challenging
- The first operational experience is fully satisfactory : after ~ 9 500 running hours in the BO and 7 500 in the SR, only a few trips in operation due to minor incidents
  - → CM : Improve the frequency tuning system
  - → Amplifiers : MTBF of transistors (?)
- Several laboratories are about to adopt the solid state technology "à la SOLEIL"
  - @ 352 MHz : CEA and ESRF
  - @ 500 MHz : LNL-Legnaro, LNLS-Brazil, SLS-PSI, NSLS II-Brookhaven (?)
    - → Collaborations under discussion
    - → R&D is going on at SOLEIL → L - Band
- The 2nd half of the SR RF system, which is under fabrication, should be implemented in May 2008 → nominal performance (4.4 MV and 500 mA)

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