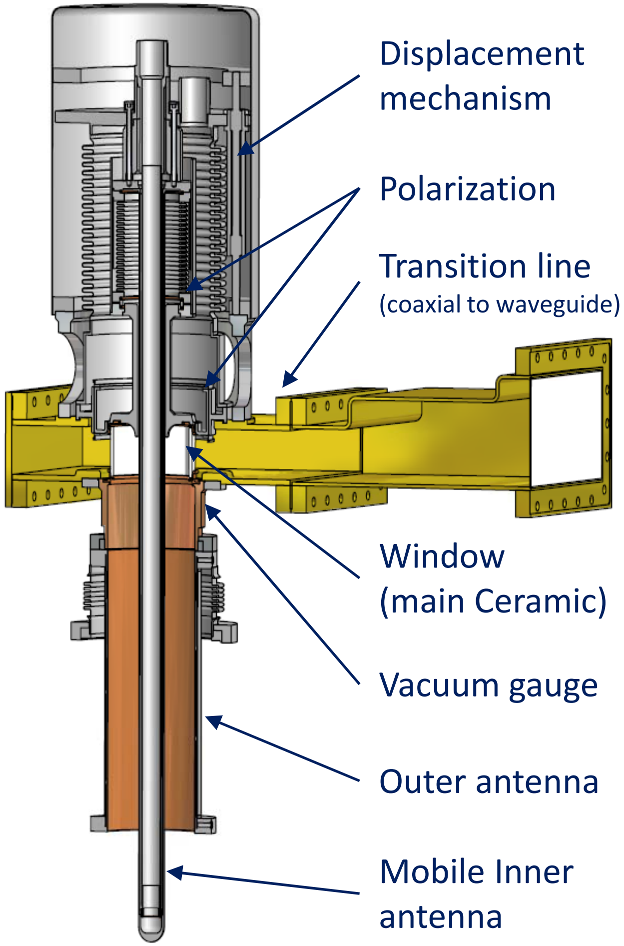
First SPL collaboration meeting

Experience with the

LHC Main power Coupler

over the last years

LHC Main power Coupler (1/2)



Project started in 1996

400 MHz

Mobile coupler

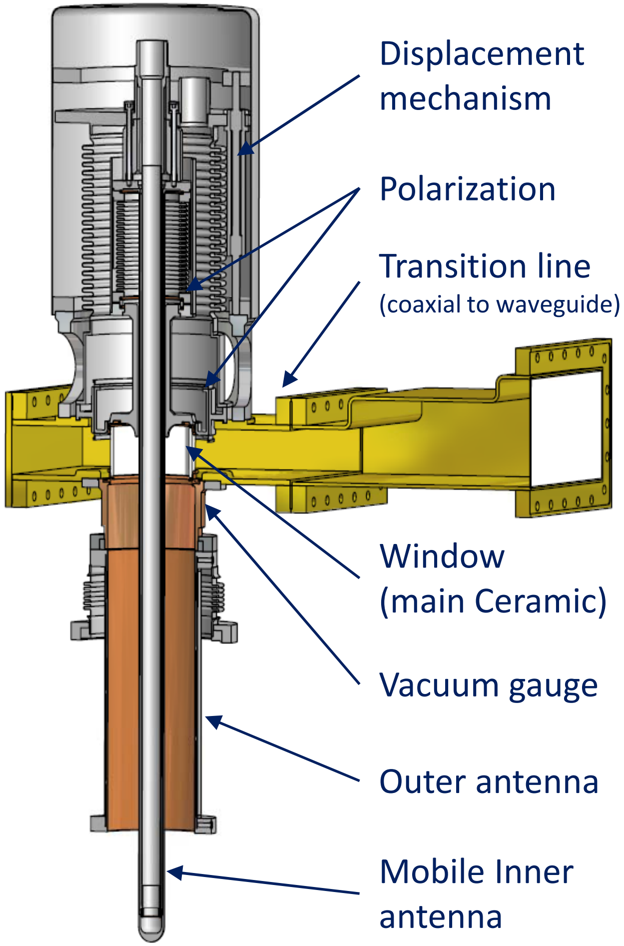
The Antenna has a 60 mm stroke without sliding contacts using bellows λ/4 long. Cavity Q_{ext} varies by factor 20

High power requirements

- Continuous : 250 kW

- Pulsed : 300 kW fwd + 670 kW rev,
  i.e. 1.85 MW local peak power

LHC Main power Coupler (2/2)



Cylindrical ceramic window with solid copper rings brazed

Antenna inner conductor is a copper tube cooled by forced air

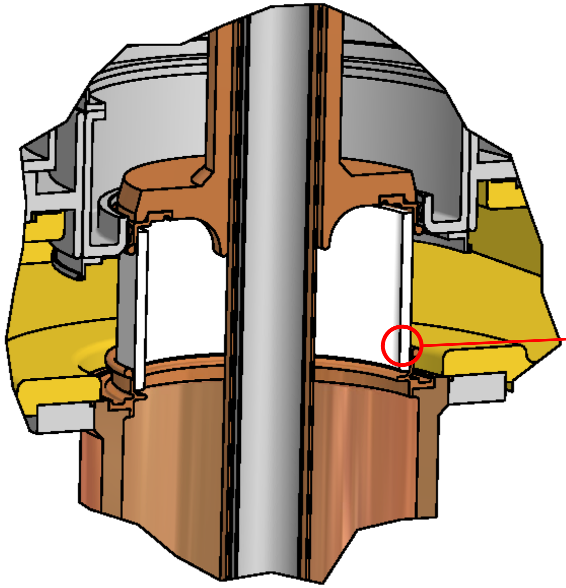
Antenna outer conductor is a copper-plated stainless-steel double-walled tube, cooled with 4.5 K helium gas

A Reduced height waveguide directly provides matching to the coaxial line, avoiding the usual “doorknob”

To suppress multipactor during operation two DC bias levels are applied.

A Vacuum gauge is located close to the window and is used for coupler conditioning and interlock

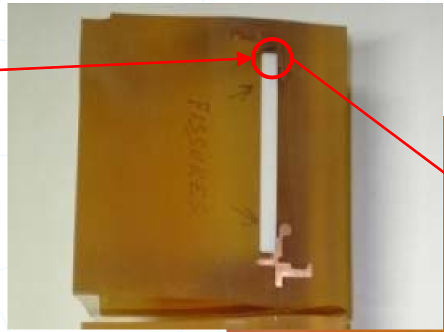
Design difficulties

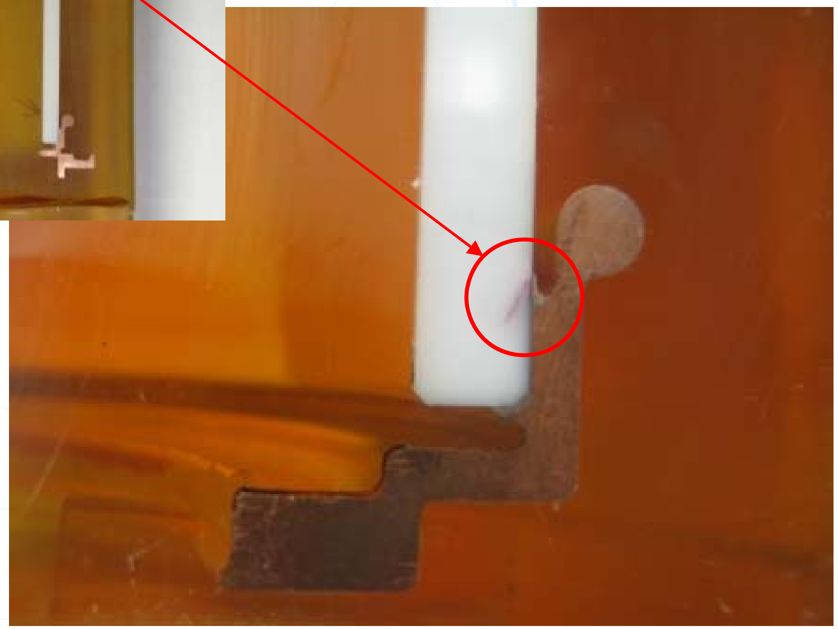


Main ceramic

The design appeared to be correct, but :

major problems with semi-cracks developing with time





To find a developing crack masked by a copper ring in a ceramic :

- clean the ceramic, paint it with colorized leak detection ultra fluid, mould it, cut it
- ***Coloured cracks*** are those ***originally present***, ***un-coloured cracks*** are those induced by ***cutting process***.

Production of the series (1/2)

We needed 16 couplers plus spares, 24 (+8) total

It starts by machining all individual pieces : more than 250 different components of varying complexity

Up to 9 months are needed to obtain special components, such as the brazed main window.

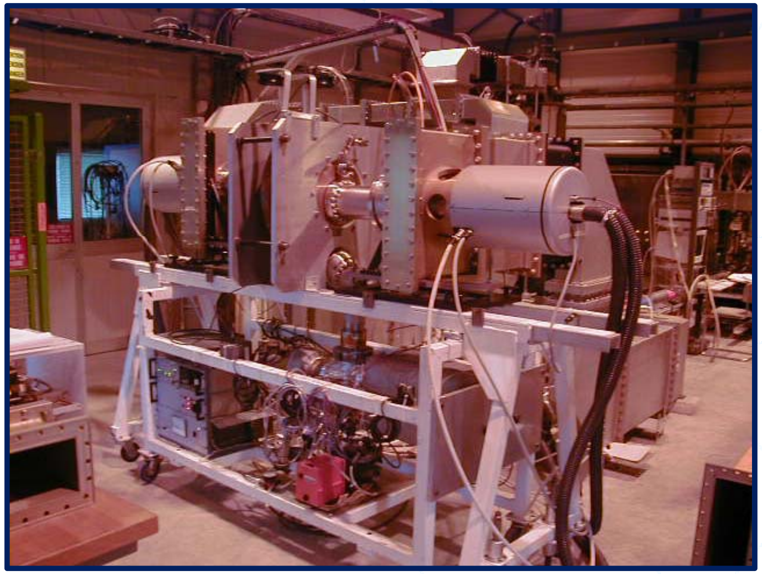
When all components are built, a first pre-assembly is done to check the whole ensemble

To avoid any contamination, all components are carefully cleaned then assembled in a class 100 clean room

After 15 months we have a bare coupler !

And it is not finished...

Production of the series (2/2)



We then bake out each coupler at 250 ˚C to help conditioning and disclose weaknesses

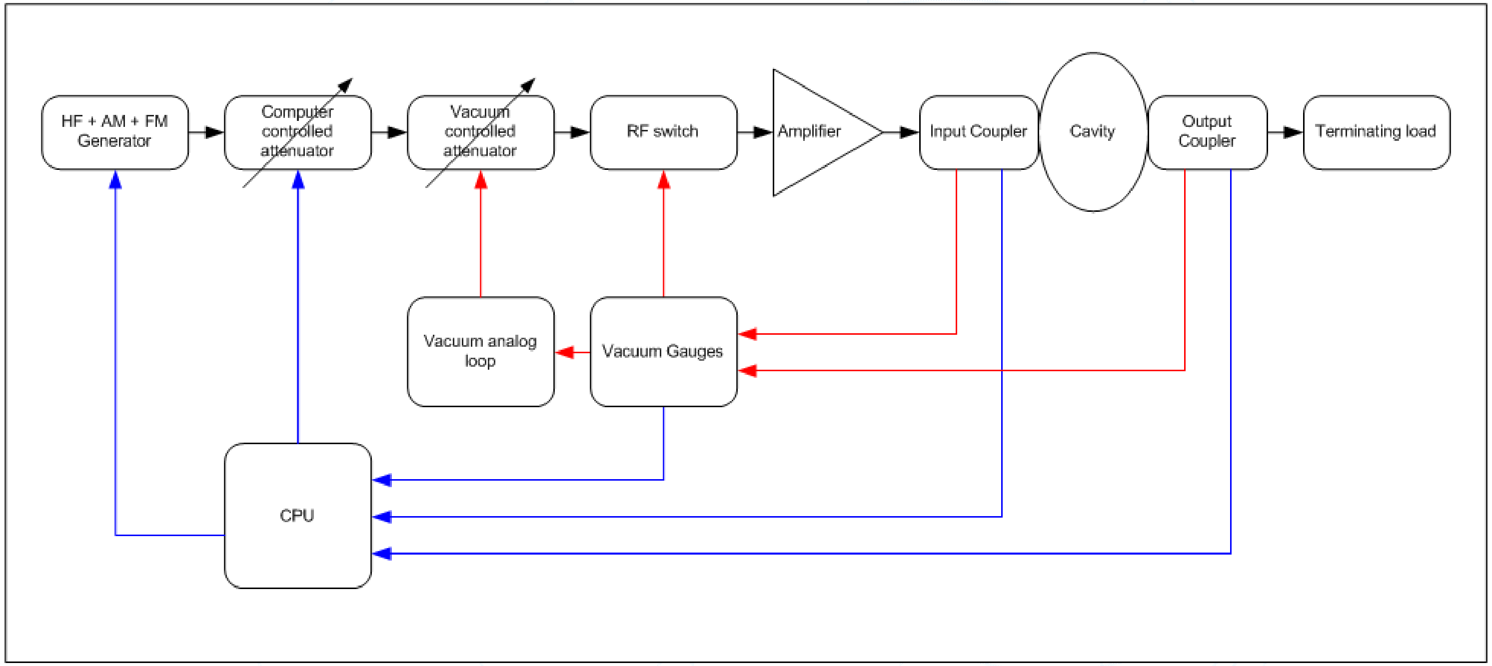
After bake out, the coupler’s RF life starts

Two couplers are installed face to face on a test cavity. Assembly is done in a clean enclosed area with laminar air flow

The whole system is vacuum leak tested

Then, after 18 months of construction,
RF tests on the couplers can finally start.

Conditioning (1/3)

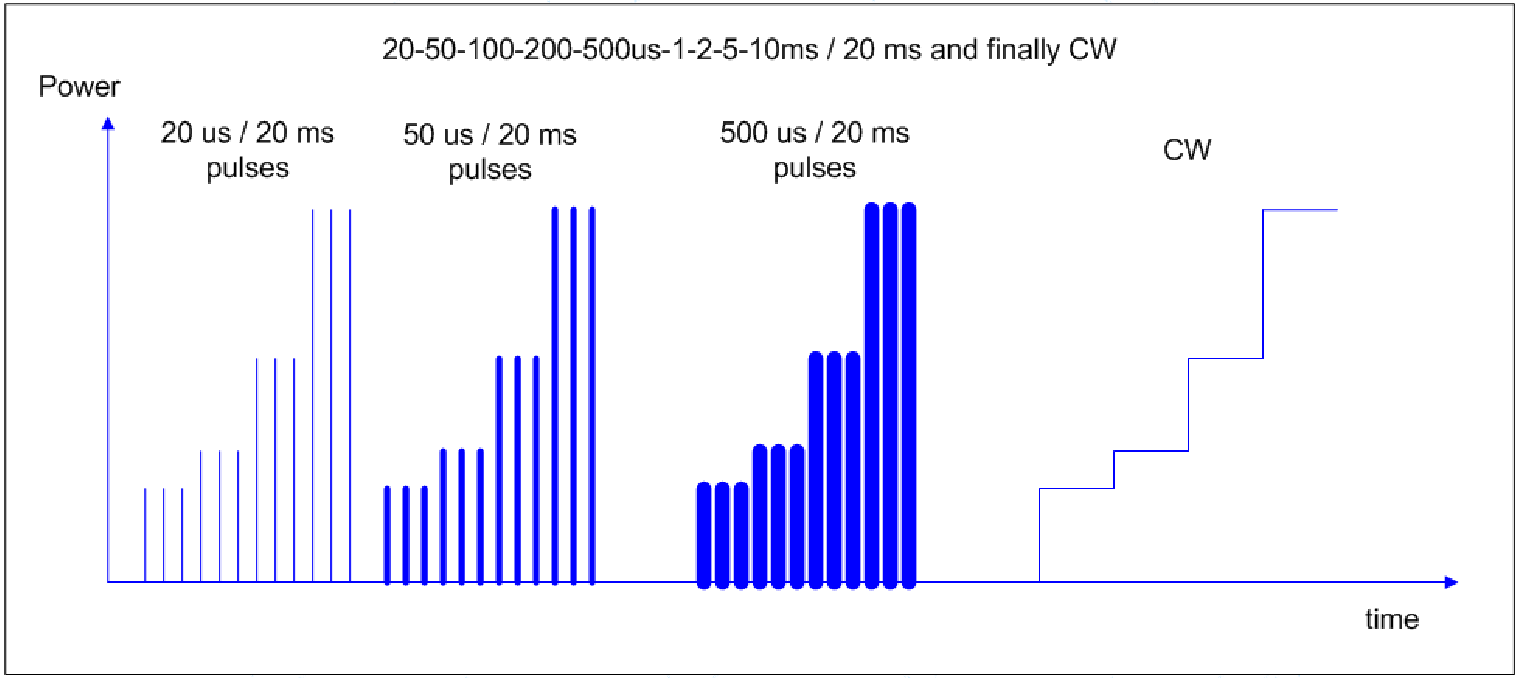


With the two couplers mounted face to face on the test cavity:

- A first vacuum direct loop (red) ensures RF is never applied if pressure exceeds 2.5 x10^{-7} mbar

- A second vacuum loop (blue), cpu controlled, applies the automated process

Conditioning (2/3)



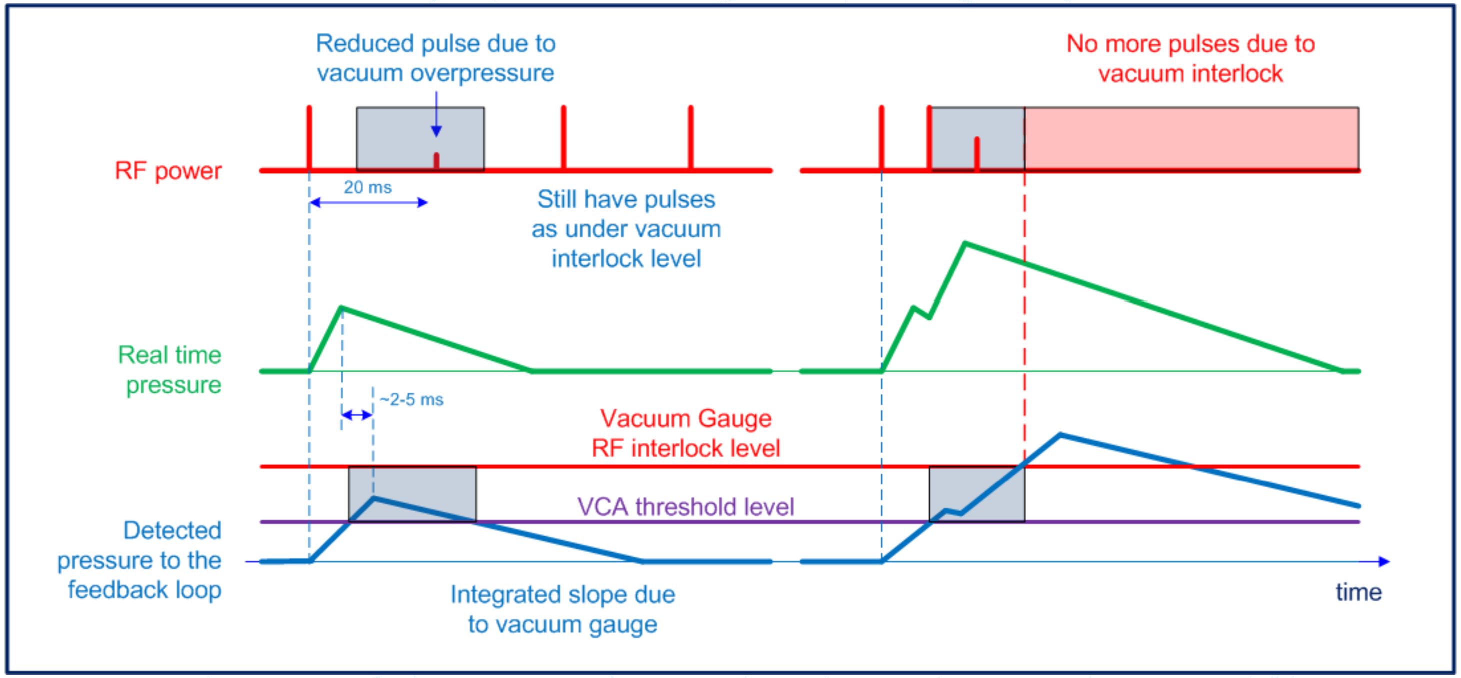
Automated process always starts, under vacuum control, with very short pulses, 20 µs every 20 ms

Power level is increased with short pulses up to full power, passing slowly through all power levels

A short circuit moves by λ/2 to ensure that all phases have been conditioned

Same procedure applied from short pulses to cw

Conditioning (3/3)



Why 20 ms repetition rate ?

repetition rate must be higher then vacuum gauge integration time (2-5 ms with our gauges)

The conditioning electronic will react only after the vacuum gauge integration time

If repetition rate slow enough, with correct settings, can avoid vacuum interlock

If repetition rate is too high, could have a vacuum interlock, no more RF until reset, time consuming

Not need the HV polarisation anymore...

(but keep it for security)

Results

Finally, powers up to ***575 kW cw full reflection* were achieved *for some hours***

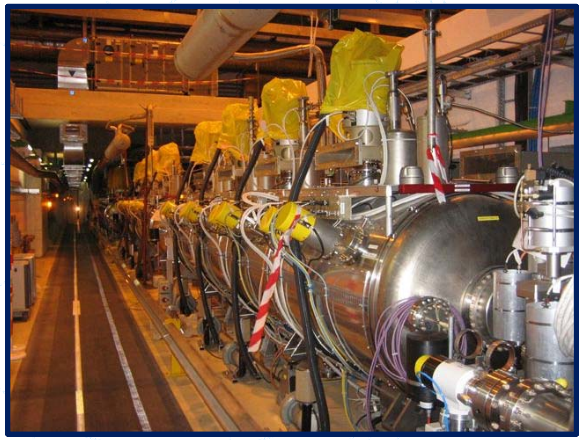
These values largely exceed the operational LHC requirements of 250 kW average

All our test area was at its limits, the waveguides were ***heated up to 70 ˚C***, but the couplers worked perfectly

These very high power tests validated the LHC couplers to the maximum power available.

They were successfully repeated with a second set of couplers

The first module of four cavities fully fulfilled all requirements in November 2004



Four modules with 16 couplers were installed in the LHC in December 2006 and have seen the first beams in September 2008

Conclusion (1/3)

Design Very important to reduce difficulties
Design simulation - HFSS, Microwave Studio - ceramic choice, collars, brazing - antenna, inner and outer - transition line
Multipactor simulation - modify geometry to reduce multipactor - Secondary Emission Coefficient measurements - need of a HV DC polarization - magnetic surface “roughness”,…
Thermal simulation - inner antenna with forced air cooled or water cooled - outer antenna helium cooled
Mechanical simulation - mechanical constraints

Window assembly Critical component
Ceramic choice : - cylindrical, planar disk, plain waveguide - one or two ceramics - cold and/or warm ceramic
Ceramic metallization for collars brazing
Coating (Ti, …)
Collars : - design (plain massive copper collars for higher power with LHC couplers and only air cooling) - machining - brazing
Vacuum gauge near the ceramic (for conditioning)
Bake out
Cutting process for prototype validation

Conclusion (2/3)

Inner antenna

No bellows, easier for higher power levels

Fixed antenna without bellows
Variable antenna with bellows

Plain copper to minimize vacuum leaks (long term)

Vertical position easily allows plain copper

Inner cooling with water or air forced

Electropolishing

Outer antenna (double tube)

Bottom side is the fixed point of the coupler :
- mechanically strong
- Stainless steel

Copper sputtering

Double tube for warm to cold side, helium cooled

No bellows for higher power levels

Main Line assembly

Cleaning (High pressure pure demineralized water)

Assembly under clean room

Bake out

Transition line

Machining with specific shapes

Surface treatment

DC polarization capacitor (if needed)

Machining with specific shapes

To avoid multipactor, to be used after a careful conditioning

Conclusion (3/3)

Test stand

Test cavity or coupling box :
- two independent cavities
- frequency tunable
- warm temperature

Instrumentation :
- Monitoring (RF measurements, temperature,…)
- interlocks (arc detectors, vacuum,…)
- cooling (flow and thermal measurements)

Strong vacuum pumping capability
Dry pump

Test area devoted to coupler tests, for TW and SW mode, with :
- power source
- circulator
- waveguide switch
- power load
- variable short circuit

Test stand available 24/24h

Conditioning

Conditioning electronics:
- vacuum controlled direct loop
- cpu vacuum controlled loop

Conditioning software process :
- automated
- short pulses to long pulses process
- RF never applied if pressure exceeds 2.5 $\times 10^{-7}$ mbar

Tests

Tests:
- TW mode
- SW mode all phases

Thermal measurements

Optimization of conditioning time for large numbers of couplers

The end

Thanks

This slide only to not have 13 slides (couplers drove me superstitious)