LHC Crab Cavity Engineering Meeting, FNAL

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BE-RF-PM

13-14 December 2012

RF Power Amplifiers (PA)
&
Fundamental Power Couplers (FPC)

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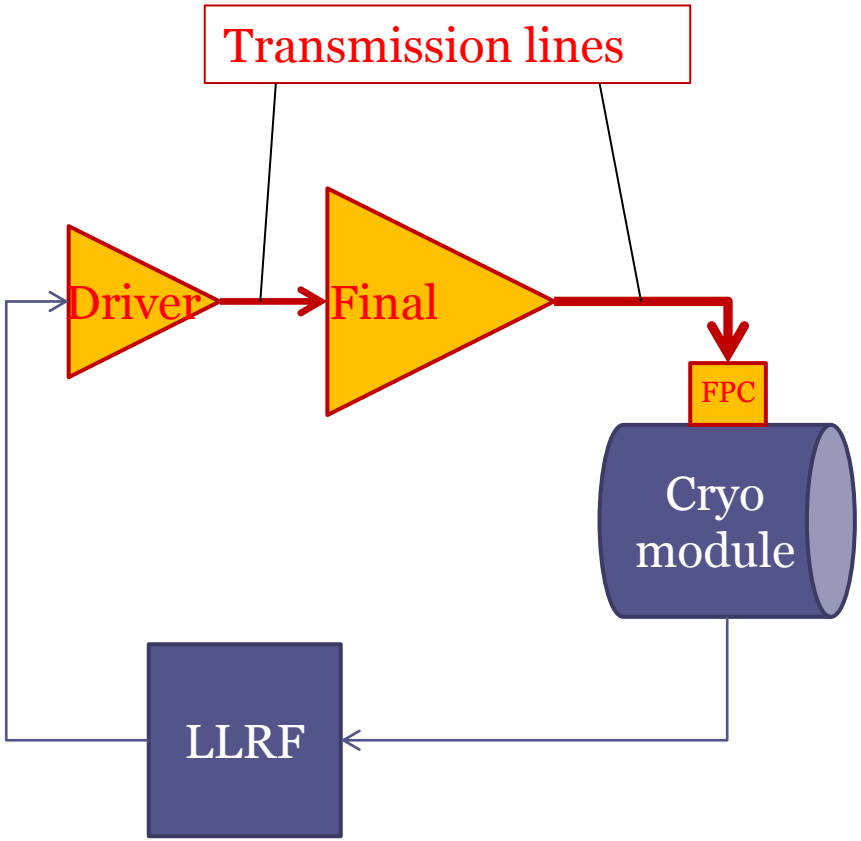
SPS Power system overview



- For the tests in the SPS we will have one RF power system per one new crab cavity :
  - Driver
  - Final
  - Transmission lines
  - Fundamental Power Coupler (FPC)

- Two power systems are to be built :

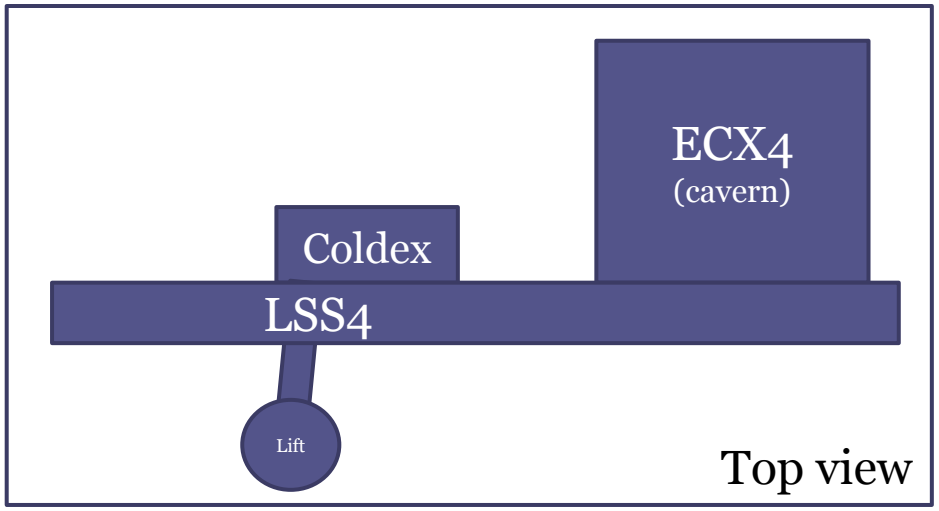
Parameters	
Fc	400 MHz
Pmax	60 kW cw
BW	1 MHz

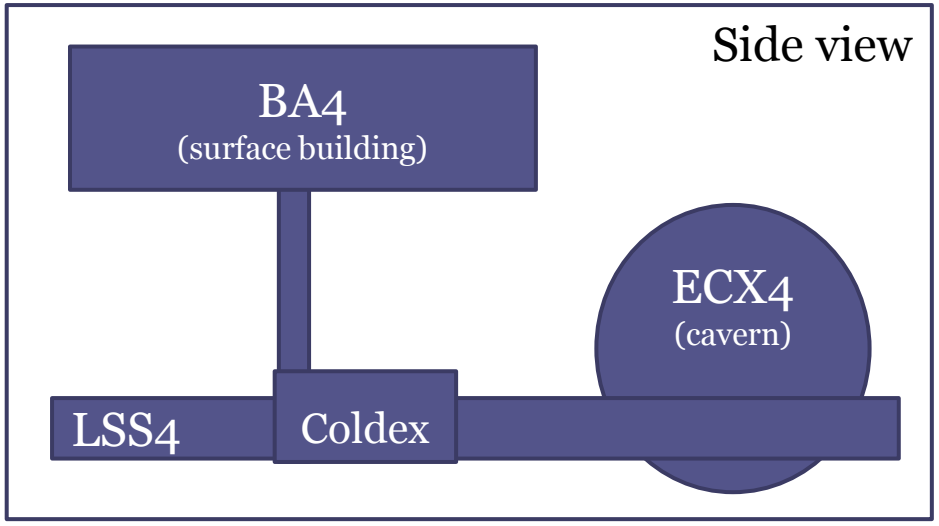
Finals

- During LEP time (1995-2000), four 352 MHz SC Cavities were in operation in the SPS
- Specially designed tetrode amplifiers were developed at CERN to feed these cavities
- In 1998, a prototype 400 MHz cavity has been tested in the SPS
- It was powered with a 352 MHz amplifier modified to operate at 400 MHz
- Maximum output power was 40 kW cw
- The main idea is to re-use this amplifier and to modify three 352 MHz
- The goal is to obtain 50 kW cw (instead 60 kW cw specified)

SPS 400 MHz Tetrode Amplifier

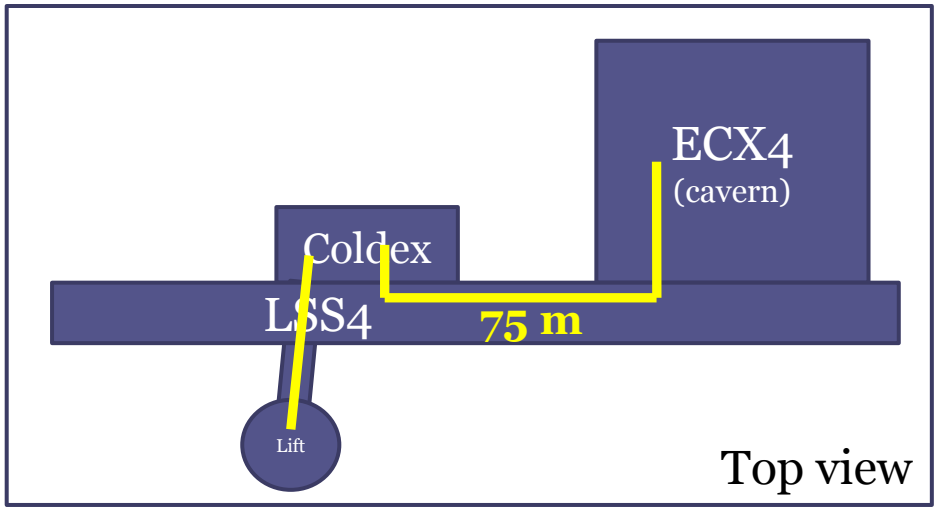
SPS available areas for PA

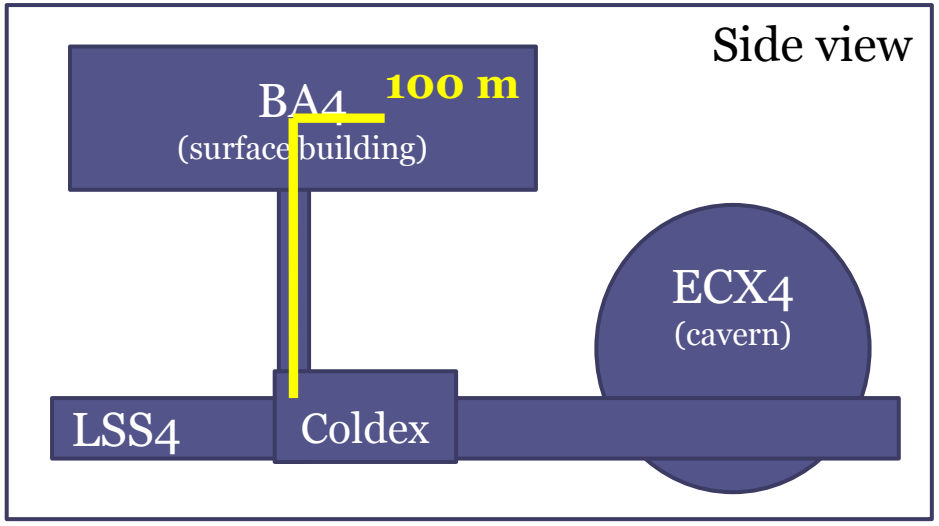




- Only available area for cavities is 'Coldex' alcove
- Possible locations for Finals are :
  - Coldex
  - ECX4 cavern
  - BA4 surface building
- Possible locations for Drivers & LLRF are, because of radiations:
  - ECX4 cavern
  - BA4 surface building

SPS available areas for PA





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  - BA4 surface building
- Possible locations for Drivers & LLRF are, because of radiations:
  - ECX4 cavern
  - BA4 surface building
- Distances :
  - ECX4 to Coldex = 75 m
  - BA4 to Coldex = 100 m

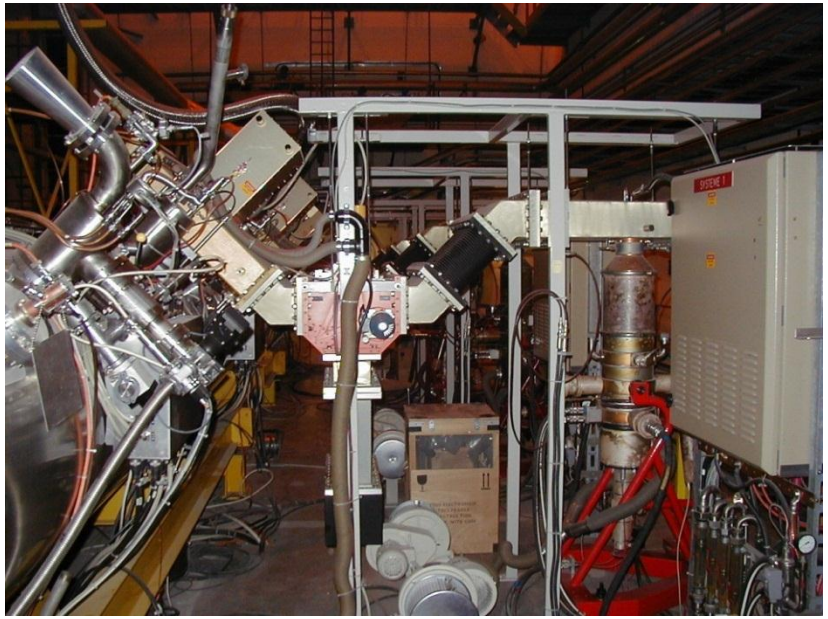
Transmission lines

- For 50 kW cw at 400 MHz, Waveguides (WG) would be WR2300 half-height
- WG cannot be installed between :
  - ECX4 and Coldex (ex-SWC100) as there is not enough space around
  - BA4 and Coldex as there is not enough space in the access gallery
- Another option would be the use of a low loss 6-1/8" flexwell coaxial cable :
  - Att @ 400 MHz = 0.4 dB / 100 m
  - Insertion losses connectors = 2 x 0.1 dB
  - Amplifier output adaptor = 0.2 dB
  - ~ + 0.75 dB : 50 kW -> 60 kW
  - Minimum Bending Radius = 1 meter

Tunnel between
Coldex (left) and ECX4 (right)
(ex-SWC100)

Transmission lines

- Having the Finals close to the cavities is therefore the best option
- Full power will be delivered to cavity through Waveguide as it was done with 352 MHz cavities
- Would then have low loss 1-5/8" flexwell coaxial cable :
  - Att @ 400 MHz = 1.3 dB / 100 m
  - Insertion loss of connectors = 2 x 0.1 dB
  - ~ 1.5 dB losses
  - Final gain = 14 dB
  - Drivers : 2.8 kW
  - Minimum Bending Radius = 0.2 meter

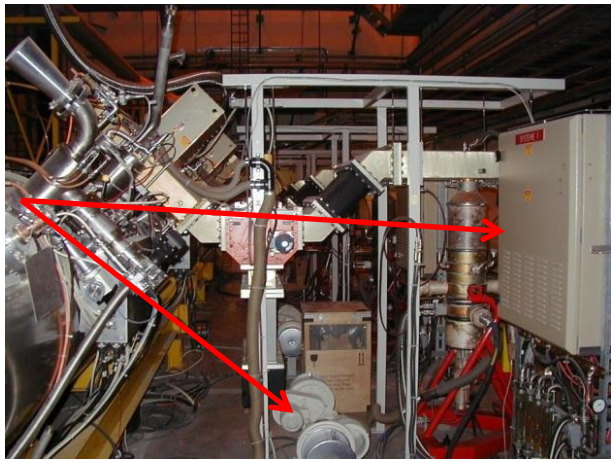


SPS 352 MHz SCC during the 90's

Power supplies and peripherals

- Anode HV power supplies, other power supplies, controls, LLRF cannot sit in the same tunnel area, not enough space, radiation concerns
- Two options are looked at :
  - BA4 surface building
  - ECX4 underground cavern
- Choice will mainly be driven by free cable trays and infrastructure availability
- Other peripherals will have to be close to the Finals :
  - Air blower
  - De-ionized water should also be available
  - HV Filtering Box (due to the distance between Finals and their HVPS)

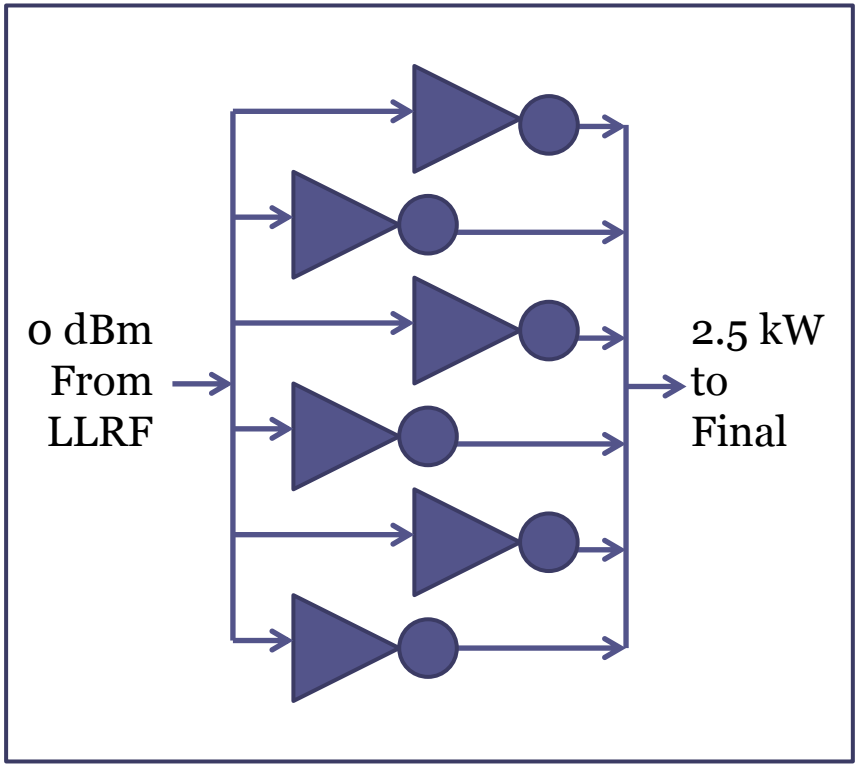
Air blower and HV filtering box close to the tetrode amplifier



Four HVPS for SPS 352 MHz tetrode amplifiers

Drivers

- 2.8 kW will be needed
- With some margin :
  6 x 500 W or 8 x 400 W
- Off the shelf modules from several vendors (500 W : 6 k€ to 35 k€)
- Combining system will be built by CERN (λ/4, n to 1)
- There will be an individual circulator per module
- These will be located ECA4 or BA4 close to LLRF system

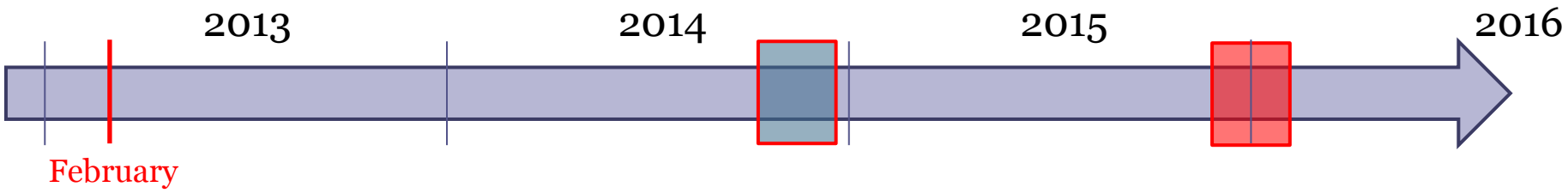


Drivers option with 6 x 500 W SSA

Fundamental Power Coupler

- SUMMARY OF THE 4TH “LHC-CC10” CRAB CAVITY WORKSHOP, EXECUTIVE SUMMARY :
- …
- Also power couplers should be tested
- Each cavity needed a special power coupler, but a common platform for power coupler development is highly desirable to focus the R&D
- …

Schedule



- Cavities to be installed in SPS in December 2015
- Cryostat fully tested Q3-2015
- Cryostat fully dressed Q2-015
- Couplers available for cryostat Q1-2015
- Couplers RF processed 50 kW SW cw all phases Q4-2014
- Couplers assembled in clean room Q2-2014 onto test box
- Special processes FPC + Test Box (Cleaning, Brazing, EB welding, Gold plating, Ti coating) completed Q1-2014
- All couplers + Test Box parts machined Q4-2013
- All raw material delivered Q2-2013
- All raw material ordered Q1-2013
- (common) Coupler design completed February 2013 **(+ Test Box !)**

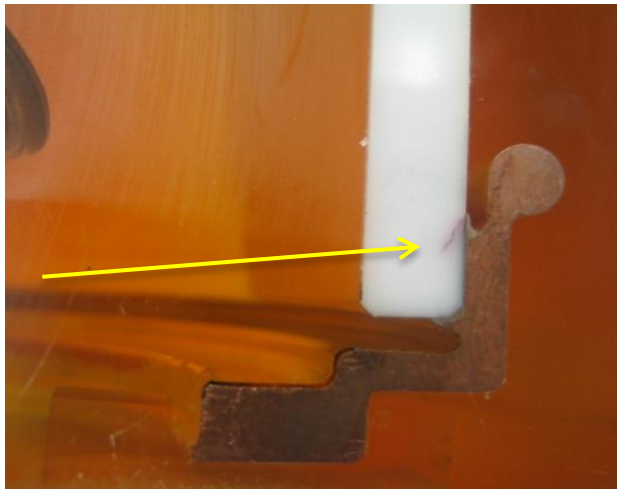
Air cooled Coupler

- Very tight schedule
- No time for a ‘from the scratch’ design
- CERN’s rule :
  - No jointing with direct contact between water and vacuum to allow vacuum leak detection in case of failure
  - ➢ If water cooled, Body and Antenna will be machined from single massive copper block without Brazing neither Welding or they will have to be air cooled

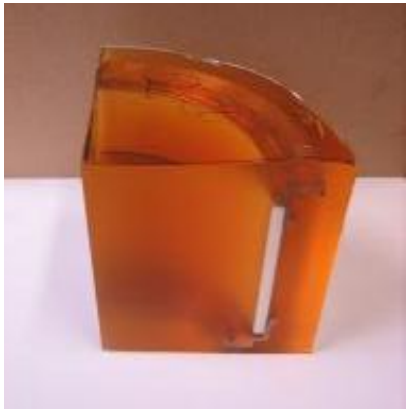
LHC window

- Design of the window has taken 7 years, from 1996 to 2002
- Very powerful window :
  - 575 kW full reflection @ 400 MHz with LHC couplers
  - 1 MW TW and 575 kW SW all phases @ 704 MHz with SPL prototype couplers

LHC window with beginning of crack



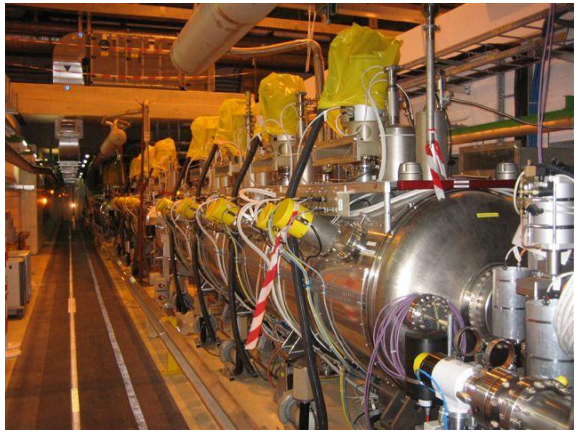
¼ LHC window



LHC window

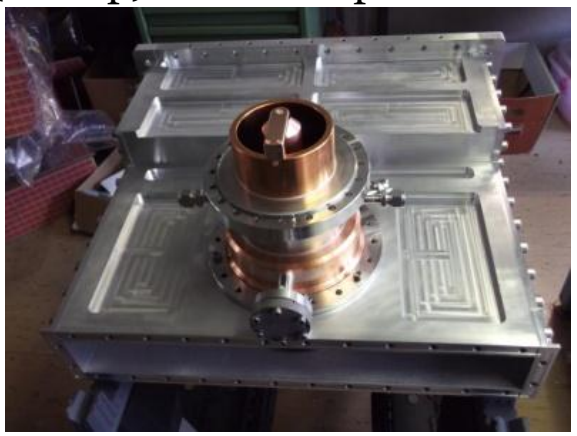
LHC window

- In operation with 16 cavities in LHC
- Following ESRF-LEP window defects (5), has also been integrated in new ESRF & new APS coupler designs
- Has been tested @ 352 MHz up to 300kW cw at ESRF and 100 kW cw at APS (still on-going)
- Both ESRF and APS designs with H loop
- A third new redesign based on this ceramic is also on-going with E antenna for SOLEIL



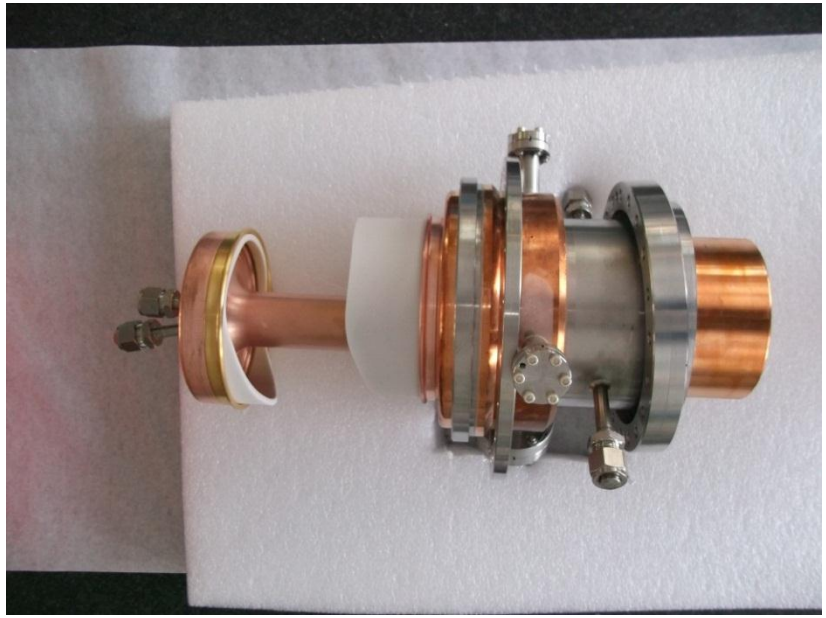
LHC Power couplers

ESRF (H loop) Power coupler



LHC window crack at APS

- H loop : the only ceramic breakage due to stress into the ceramic
- Mechanical stress while connecting WG to the coupler or thermal stress during bake out at APS premises ?

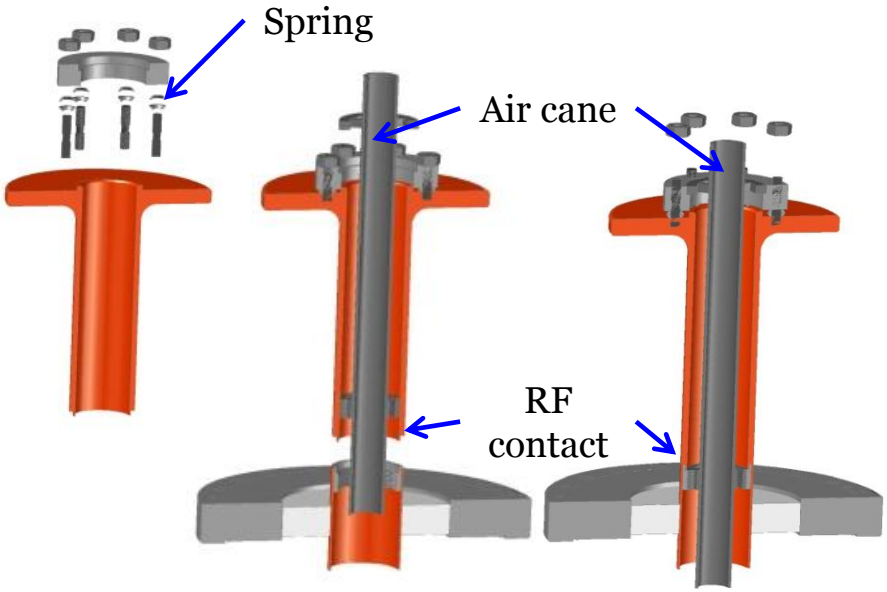


APS (H loop) Broken ceramic

Disk Window

- Design of the window for SPS power load, but designed as a coupler window :
  - Titanium Flange outer line
  - Metalized on its edge disk Ceramic
  - Copper tube inner line
- Very powerful window :
  - 500 kW TW @ 200 MHz with SPS loads
  - 1 MW TW and 1 MW SW all phases @ 704 MHz with SPL prototype couplers

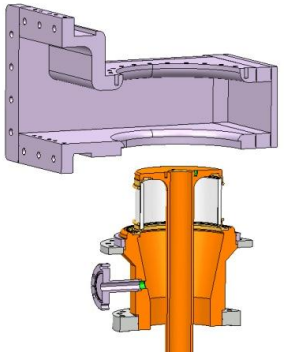
SPS Window: very simple brazing process



Crab Cavity FPC window

- We do not need these power levels
  (Crab Cavities 50 kW cw TW + 50 kW cw SW all phases)
- Nevertheless, these two ceramics designs have proven to be powerful and reliable (SPS & LHC)
- CERN very well masters both brazing processes
- Few LHC ceramics are already available
- Pretty quick to have disk ceramic available if within the same range of dimensions (100 mm external diameter or smaller)

Mono bloc ‘plug and play’ waveguide



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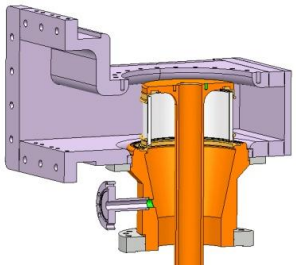

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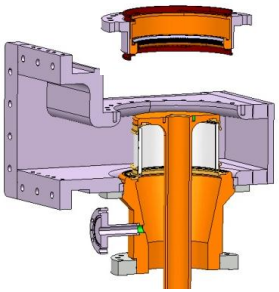
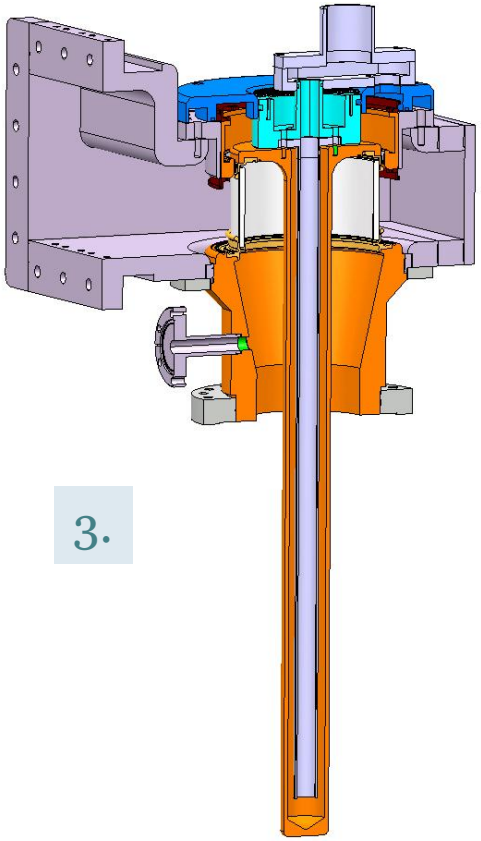


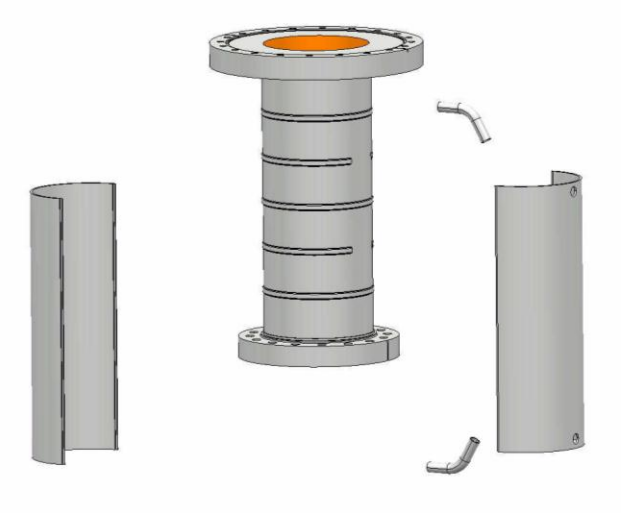


3.

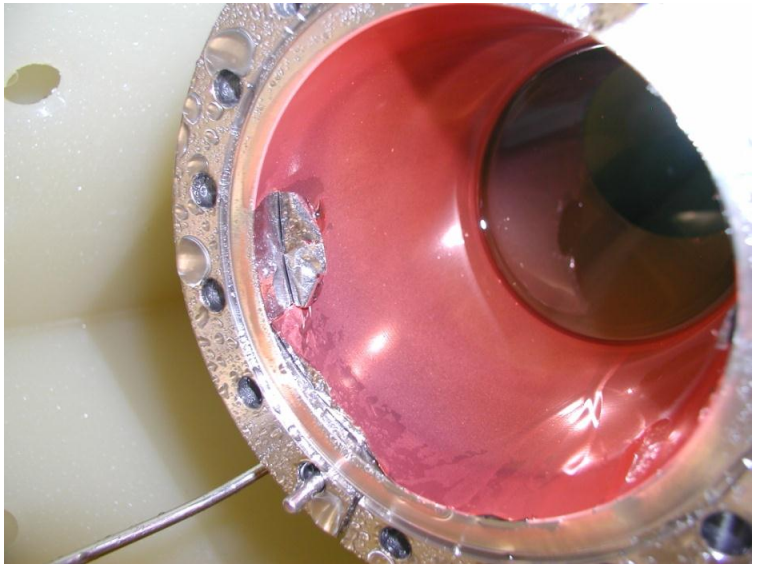
- ‘Plug and Play’ waveguide with matching step and DC capacitor included :
  1. Connect the waveguide to the body line
  2. Insert the contacts ring (DC biasing capacitor)
  3. Final assembly of air cooling system (or water cooling)
- No doorknob, reduced height, with no mechanical stress to the ceramic
- Successfully tested with ESRF, APS and SPL couplers

Double walled Tube (DT)

- As 50 kW cw are requested, we plan to have a DT to connect FPC to cavity
- DT are copper plated, and it is never a simple process, copper peeling -> 1 year delay in SPL coupler production
- Regarding schedule, we would prefer to design only one common DT
- This means a common outer transmission line for all FPC
- Preferably a very simple straight tube



SPL Double walled Tube (copper peeling)

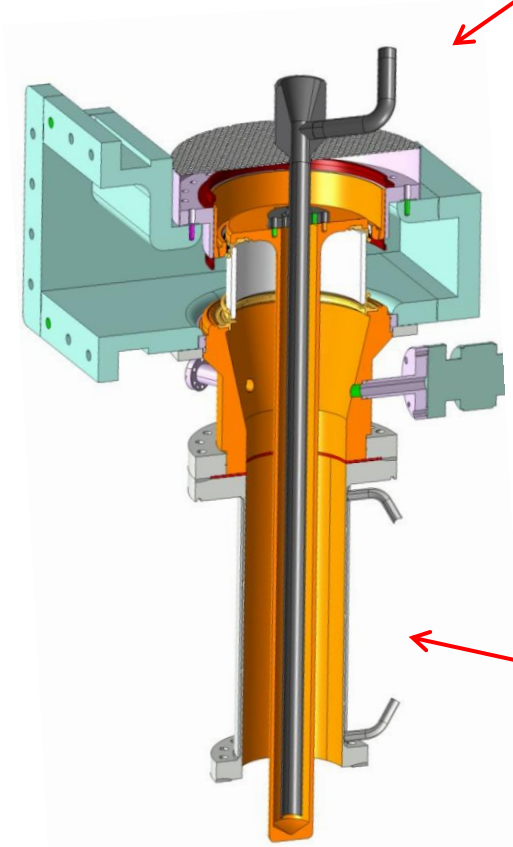


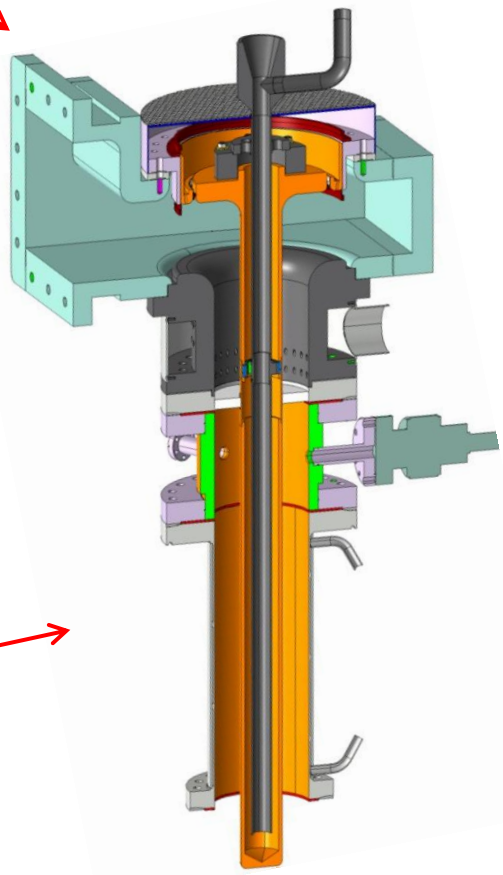
Common FPC Platform : SPL example

Cylindrical
ceramic window

Same Waveguide with
integrated matching step
(instead of a doorknob)
And same DC capacitor

Coaxial disk
ceramic window

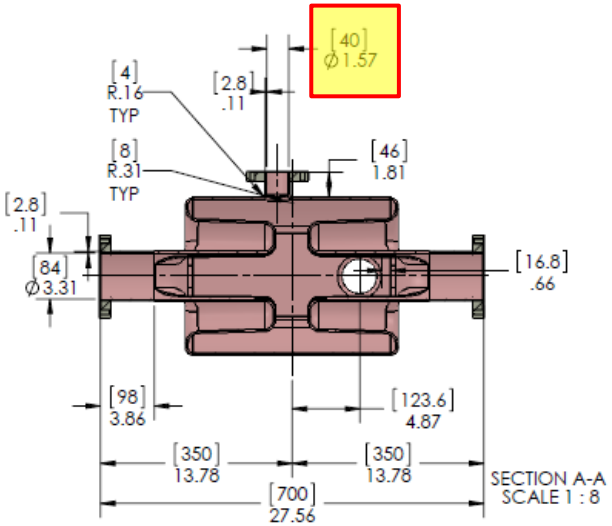


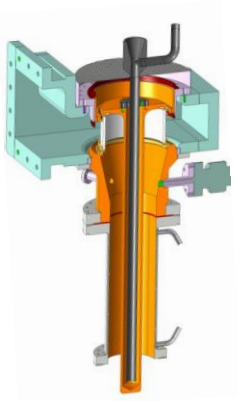


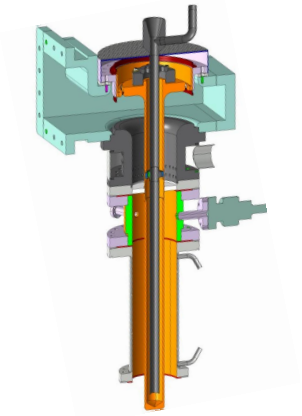
Same Double Walled Tube
(Outer line of a coaxial
transmission Line)
With same interface flange
To cavity and cryomodule

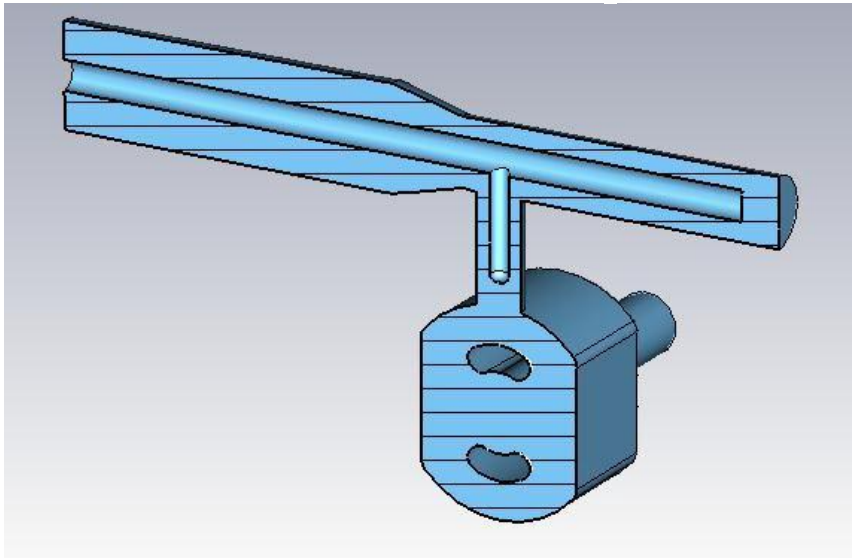
4rod FPC

- Both FPC proposals seem quite easy to be integrated with respect to the cryomodule
- Be on top of the cavity
- Input coupler port 40 mm



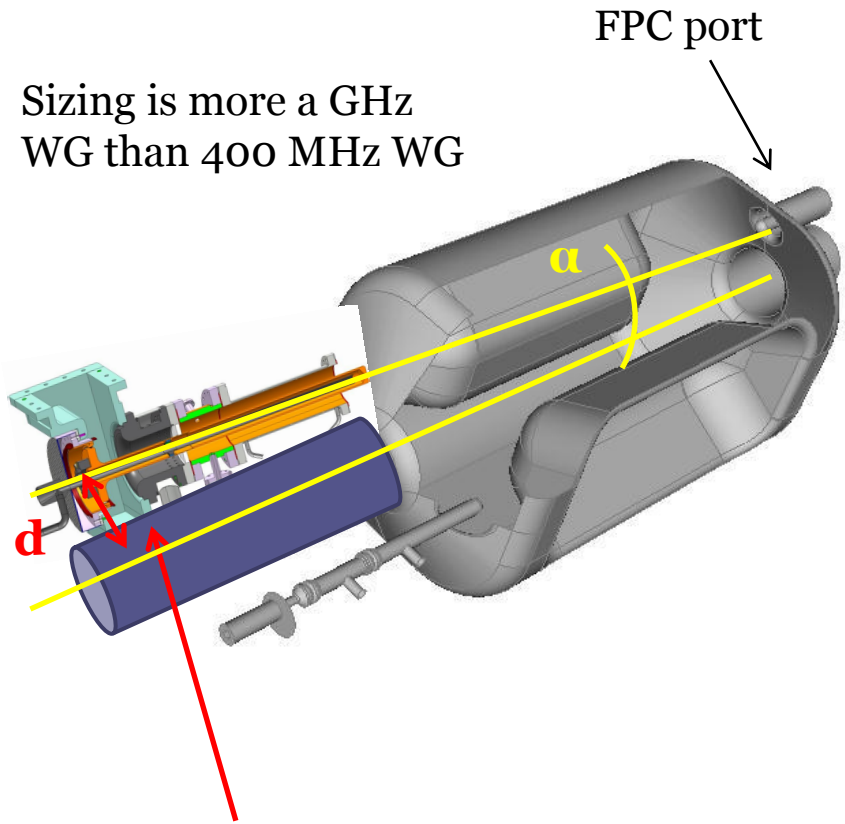






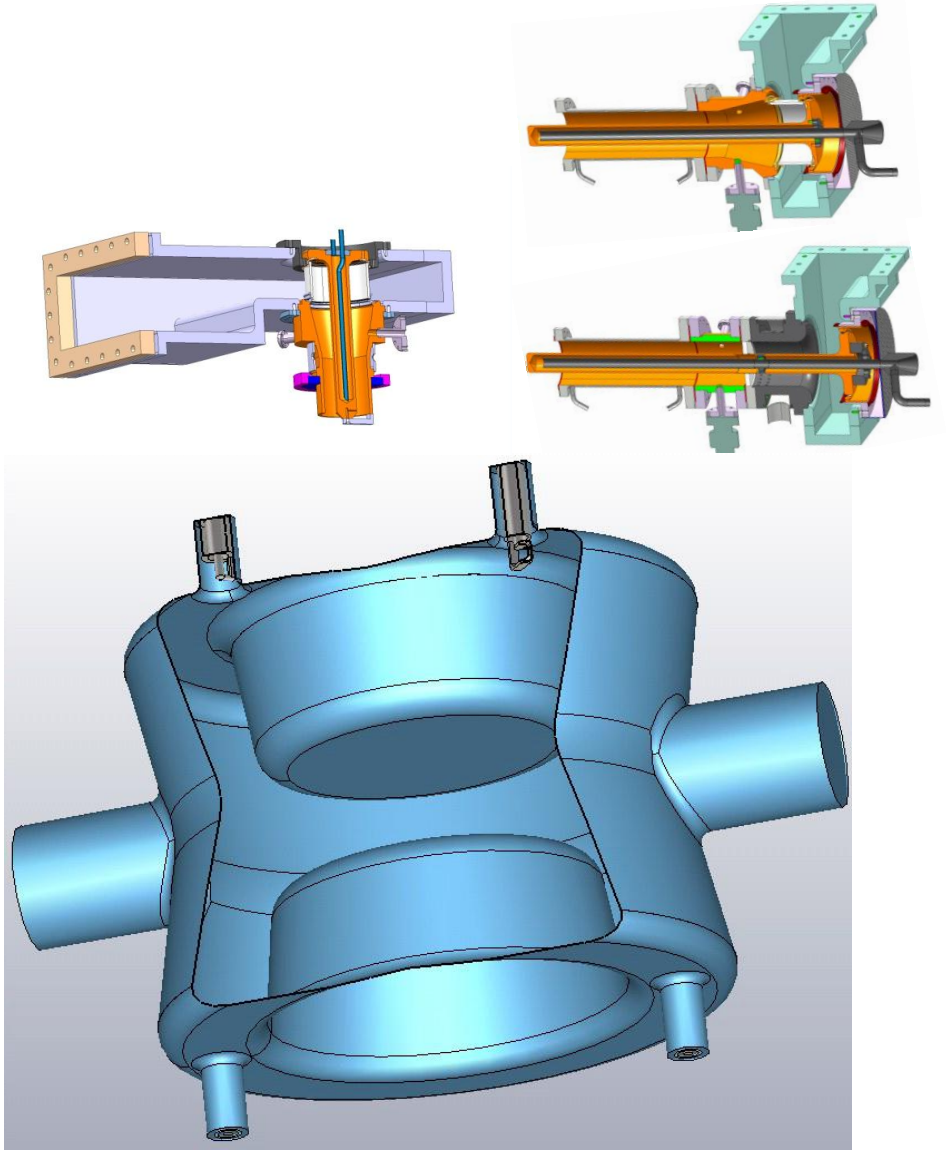
Double Ridge FPC

- A bit more complex with respect to the proposed angle regarding beam pipe
- Can this angle be increased ?
- Need an antenna to short circuit minimal distance (d) and with some free space room regarding beam pipe
- Input coupler port 36 mm
- What about cryomodule DT integration at the end side ?



Quarter Wave FPC

- H loop as with ESRF & APS is possible (nevertheless, remind that the only ceramic breakage was with that configuration)
- Input coupler 40 mm with a 'Triaxial' line
- E antenna preferable as no stress given to the ceramic, but in that case what about E coupling axis and again beam pipe vs antenna axis compatibility ?



Common Crab Cavity FPC Platform

- We propose to stick to these design parameters :
  - LHC window or Disk window
  - Waveguide line to coaxial antenna
  - Plug and play waveguide
  - DC biasing (if E antenna)
  - Preferably E antenna (no stress to the ceramic)
  - Same simple straight pipe DT
  - If possible 50 Ω antenna (easier for mock-up measurements)

- Specifications from Rama :
  - cavity FPC port diameter : 40 mm / 36 mm / 40 mm
  - DT : 40 mm
  - Inner line : 17 mm
    (two tubes, cooling inlet (4/6) + cooling outlet (13/17))

- Can we increase the DT diameter ?
  - Incompatibility between the sizes and power level requested
  - Should be the main topic at the FPC dinner table tonight

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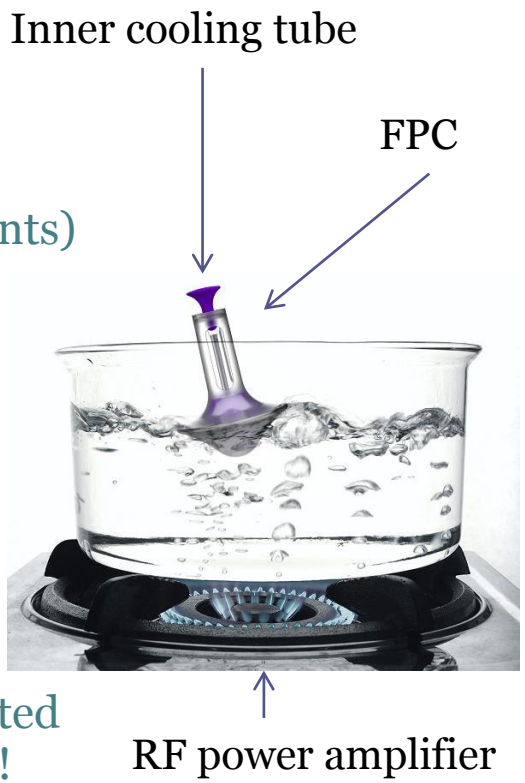
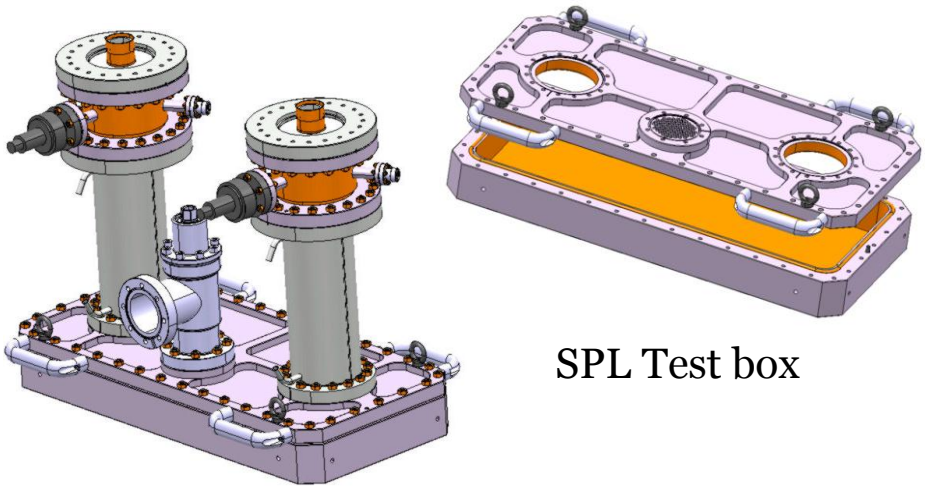


Test box

- Almost the same amount of work as to design a coupler
- As well as coupler, must be prepared in clean room
- Not yet simulated, but probably based on the SPL principle :
  - Two covers
  - All vacuum flanges machined all-in-one
  - Self supporting
  - Easier for copper coating

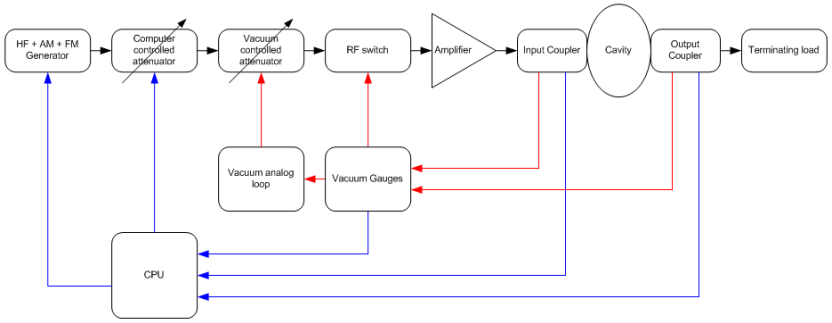


SPL Test box

SPL Test box assembly in DESY clean room

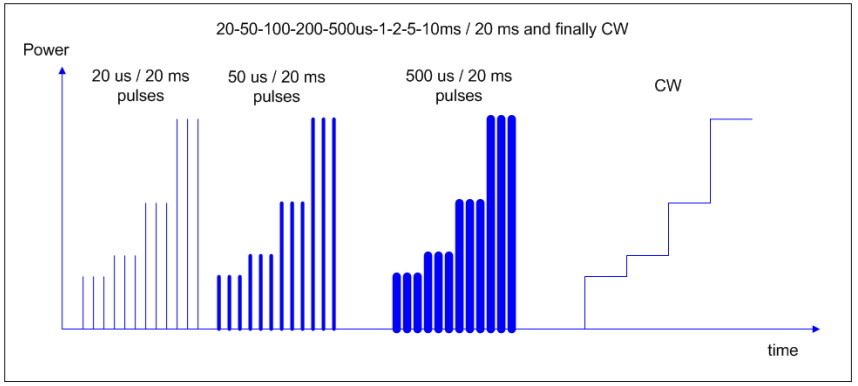
Test area(s)

- We are refurbishing our test area to be able to test all amplifier chain as well as to perform coupler processing on test box (TW & SW all phases)
- Goal is to be ready by end 2014 with tested couplers !
- Then once couplers will be delivered for clean room mounting, all these will be moved to SM18 for fully dressed cavity test at high power prior to installation in the SPS



FPC conditioning process :

- Vacuum controlled power generator
- Starts with very short pulses
- Long repetition time
- Ramp from low power to full power



Conclusion : Power Amplifiers

- Tight schedule, but for SPS, Power system seems not to be a trouble maker
- Power system will be very similar to the one we already operated at this exact location 15 years ago
- SSA Drivers are available from vendors
- Cable work will be prepared during LS1 (not installed as incompatible with Coldex)
- As we will need amplifiers for FPC tests on test box & on cavity, sooner than we need them in the SPS, we will be ready on time

Conclusion : FPC

- Common platform has to be understood as a quite 'large' proposal range :
  - LHC ceramic
  - Disk ceramic, various sizes
  - H loop possible
  - E antenna preferred
- However, with respect to the so tight schedule, parameters must be decided and frozen very quickly (tonight ? coming weeks the latest)
- As design will not be from the scratch, we should be able to have the design ready soon after parameters have been defined
- We will then be able to launch raw material purchasing needed for couplers, as well as material needed for test box

Thank you very much for your attention

- APS
  - Ali Nassiri, Doug Horan, Gian Tenko, Dave Brubenker, and team
- CEA :
  - Stephane Chel, Guillaume Devanz, Michel Desmond, and team
- DESY :
  - Wolf-dietrich Moeller, Axel Matthaisen, Birte Van der Horst, and team
- ESRF :
  - Jorn Jacob, Vincent Serriere, Jean-Maurice Mercier, and team
- SRF 2003 DESY, Brian Rusnak : http://srf2003.desy.de/fap/paper/TuT02.pdf
- CAS 2010, Wolf-Dietrich Möller : http://cas.web.cern.ch/cas/Denmark-2010/Lectures/Moeller.pdf
- CERN
- Mechanical & Material Engineering group :
  - Francesco Bertinelli, Serge Mathot, Agostino Vacca, Thierry Tardy, Thierry Calamand, Thierry Renaglia, Ofelia Capatina, Marc Polini, Laurent Deparis, Philippe Frichot, Jean-Marie Geisser, Jean-Marc Malzacker, Pierre Moyret, Alain Stadler, and team
- Vacuum, Surface & Coating group :
  - Miguel Jimenez, Sergio Calatroni, Wilhelmus Vollenberg, Marina Malabaila, Nicolas Zelko, and team
- Magnets, Superconductors & Cryostats group :
  - Vittorio Parma, Arnaud Van de Craene, Rossana Bonomi, and team
- RF group :
  - Sebastien Calvo, Antoine Boucherie, all FSU-AB03 members

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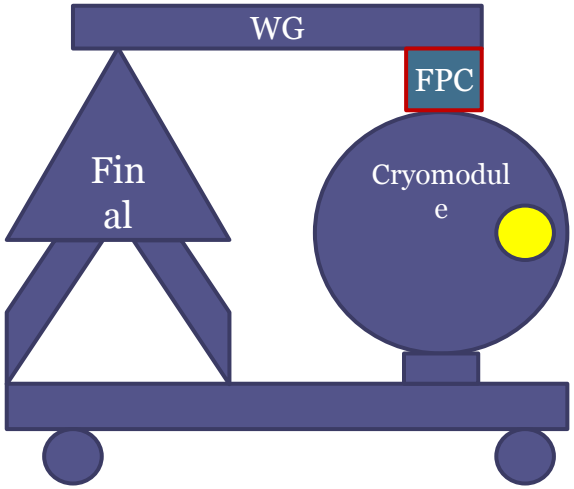
‘Moveable’ cavities

- In addition, cavities must be able to mechanically be removed from beam pipes



- An additional reason for having the amplifiers close to the cavity

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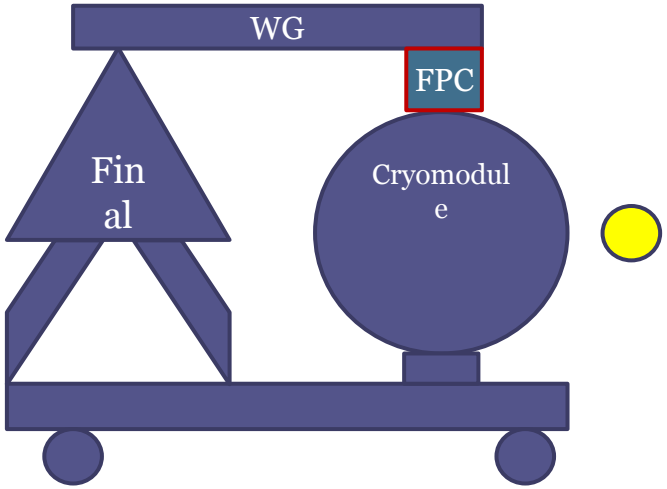

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