Status of RF System

(Working Group 1)

E. Ciapala

RF Power (WG1) Contents

- Conclusions & follow-up from the Third Meeting at CERN
- Reminder on power requirements
- Layout considerations

  (Initial cost, reliability, operational issues, running costs, other overheads)
- Power sources
- Power couplers
- Scope of upcoming work

Conclusions of Third Collaboration Meeting (1)

- Baseline layout for Low/High B sections proposed:
  * 1.5 MW klystron for 2 cavities in **High B LPSPL**
  * Single lower power source (IOT?) in **Low B section**
  * Individual klystron per cavity in HPSPL High B (Integration must allow this..)
- No difficulties with long WR1150 waveguides (80m)
- Studies nevertheless need to continue on stability/repeatability attainable in presence of microphonics, Lorenz detuning, detuned cavities, reflections due to RF distribution component imperfections etc. (W.H. Saclay et al.)

Conclusions of Third Collaboration Meeting (2)

- Power coupler experience from CEA, LAL & CERN is very valuable, synergy & common experience.

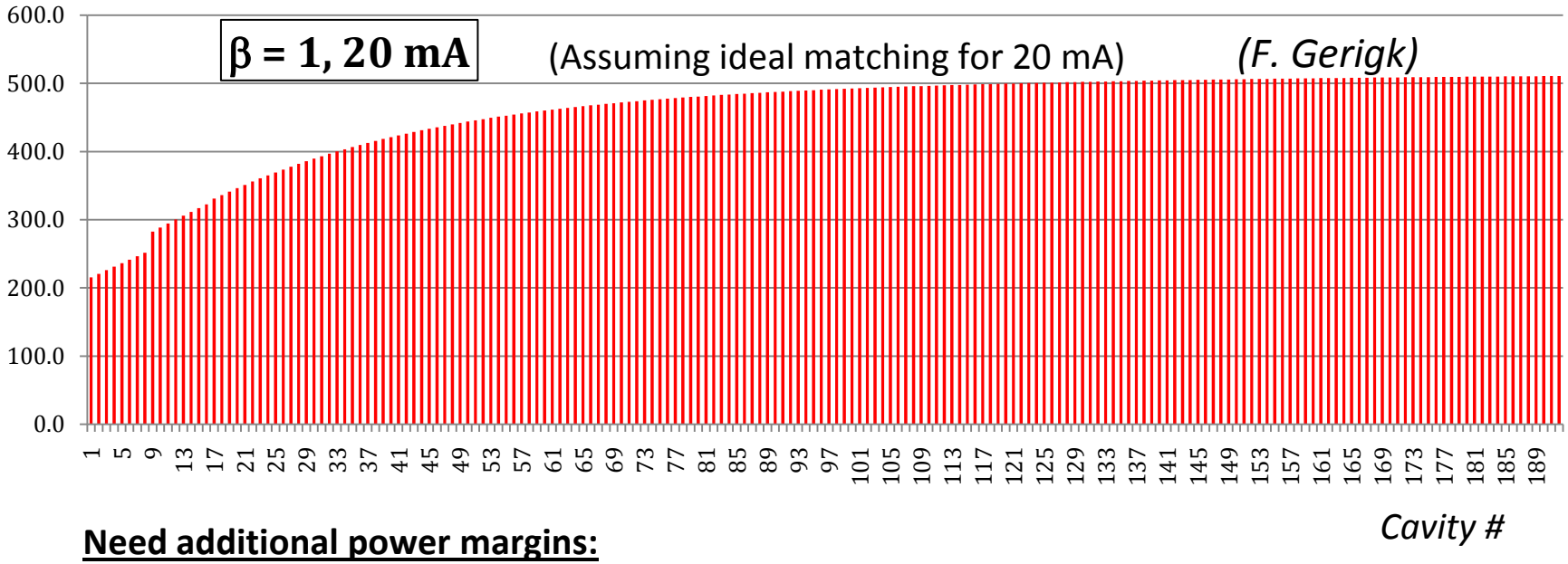
  => Final designs studied at March 2010 Workshop
- Magnetron development work to be followed up (A.D. CI, R.R. JLAB)
- Construction of test area in SM18 for RF power and cavity work (O.B. et al)

  (Details to be elaborated shortly after the workshop - January 2010 meeting)

Other issues raised in third collaboration meeting

1. Need for adjustable coupler ?	**No**
2. Use of 3 stub tuner in waveguide to compensate Qext differences in multi cavity / klystron configurations ?	**Yes**
3. Positioning of coupler (Top / Bottom) ?	**Bottom**
4. Can we get a 'compact' modulator for HPSPL ?	**Under study (Jema, Scandinova)**
5. Baseline power configuration – detailed work	**Ongoing**

RF Power Requirements along the LPSPL



Need additional power margins:

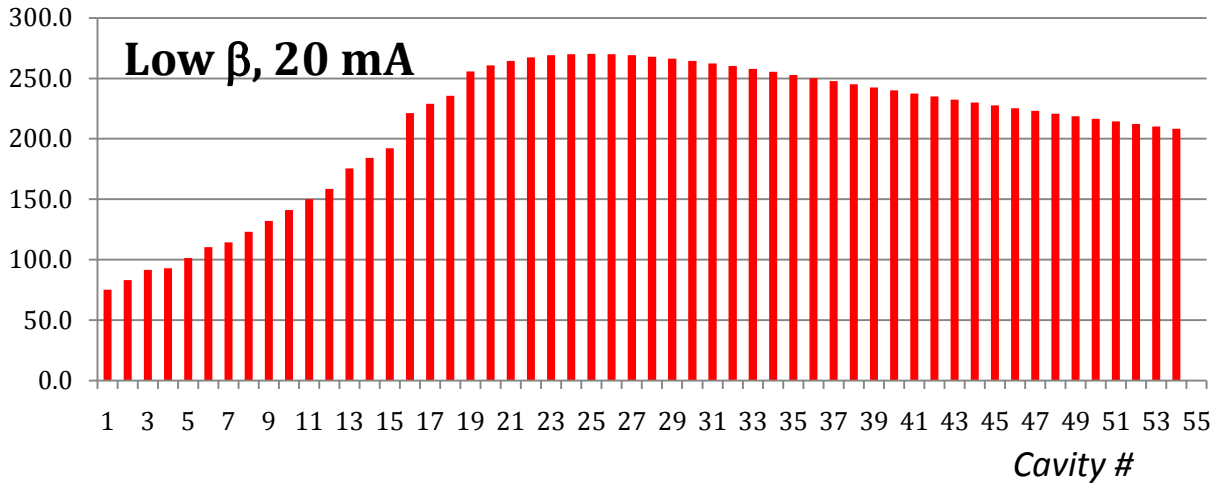
- 11% for 40 mA coupling settings, 10-15 % for RF feedbacks **(TBC),** 7% waveguide losses , Modulator droop, (?), coupling variations => (30-40% overhead)
- **500 kW** nominal on cavity => **< 700 kW from klystron/cavity for 20 mA**

Powering options:

- **For 40 mA in β = 1 section use 1.5 MW klystron per cavity**
- **For 20 mA could use one 1.5 MW klystron for two cavities**
- **(For 40 mA one 3 MW klystron for two cavities ?)**

RF Power Requirements along the LPSPL

Low Beta section, assuming ideal matching for 20 mA



Maximum power ~ 250 kW:

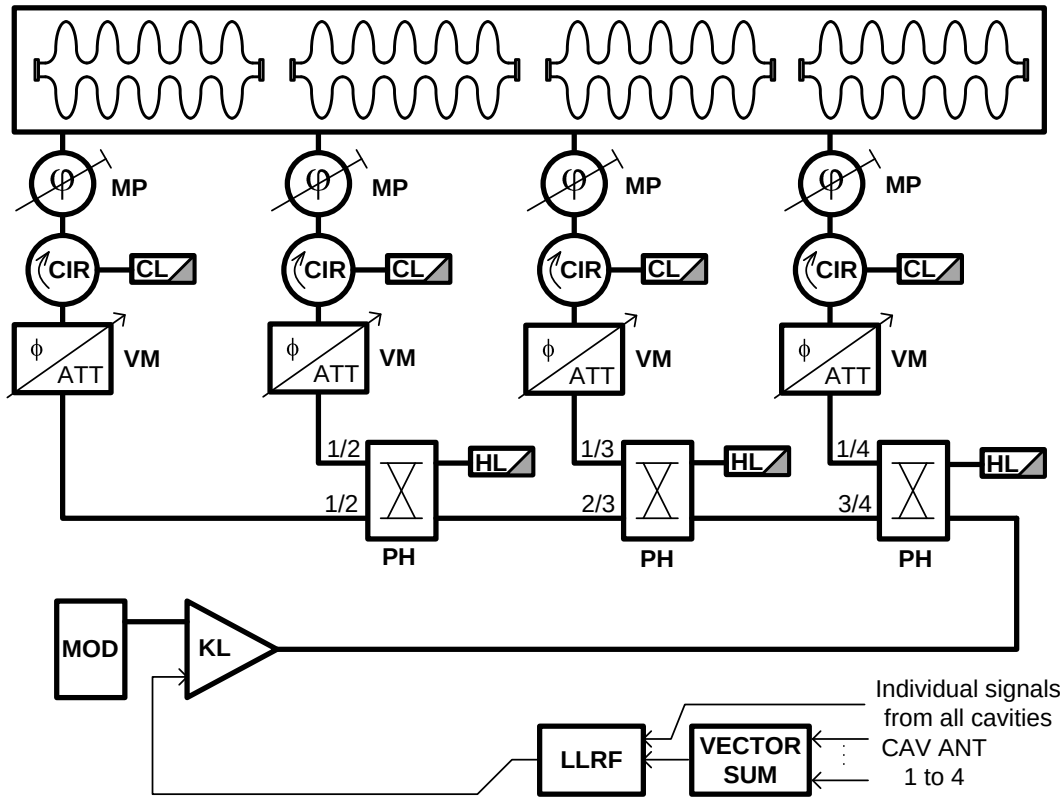
Again 40 % overhead

- **<350 kW nominal klystron power per cavity in β = 0.65 section**
- **<700kW klystron power per cavity for 40 mA in β = 0.65 section**
- **1.5 MW klystron for two cavities in higher energy part**
- **IOTs or solid state for low energy part**
- **NOTE precise phase & amplitude control most critical in lowest energy part of the linac**

RF distribution schemes

Option 1) 1 klystron/4 cavities Initially Preferred Layout – **klystron economy**

- Linear distribution, using less space consuming "planar" hybrids with individually adjusted coupling.
- Vector modulators for fast phase/amplitude field control
- Mech. phase shifters for cavity phasing or isolation



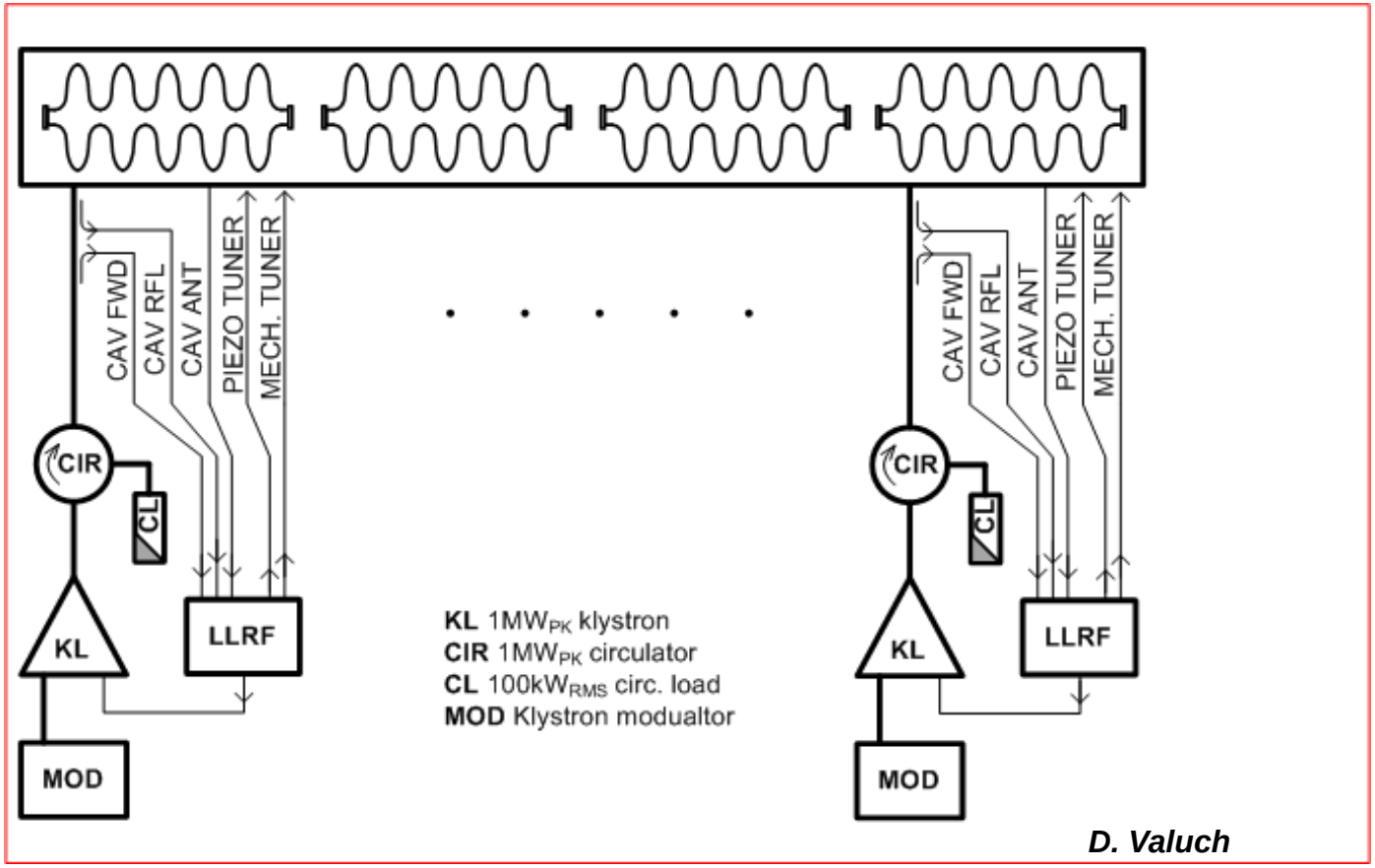
D. Valuch

KL 5MW$_{PK}$ klystron
CIR 1MW$_{PK}$ circulator
CL 100kW$_{RMS}$ circ. Load
PH hybrid (e.g. planar 90°)
HL hybrid load
VM 1MW$_{PK}$ vector modulator
MP Mech. phase-shifter/switch
MOD Klystron modualtor

RF distribution schemes

Option 2) 1 klystron/cavity

- No hybrids, no Vector Modulators, no mech. phase shifters
- **But a total of 240 klystrons…**

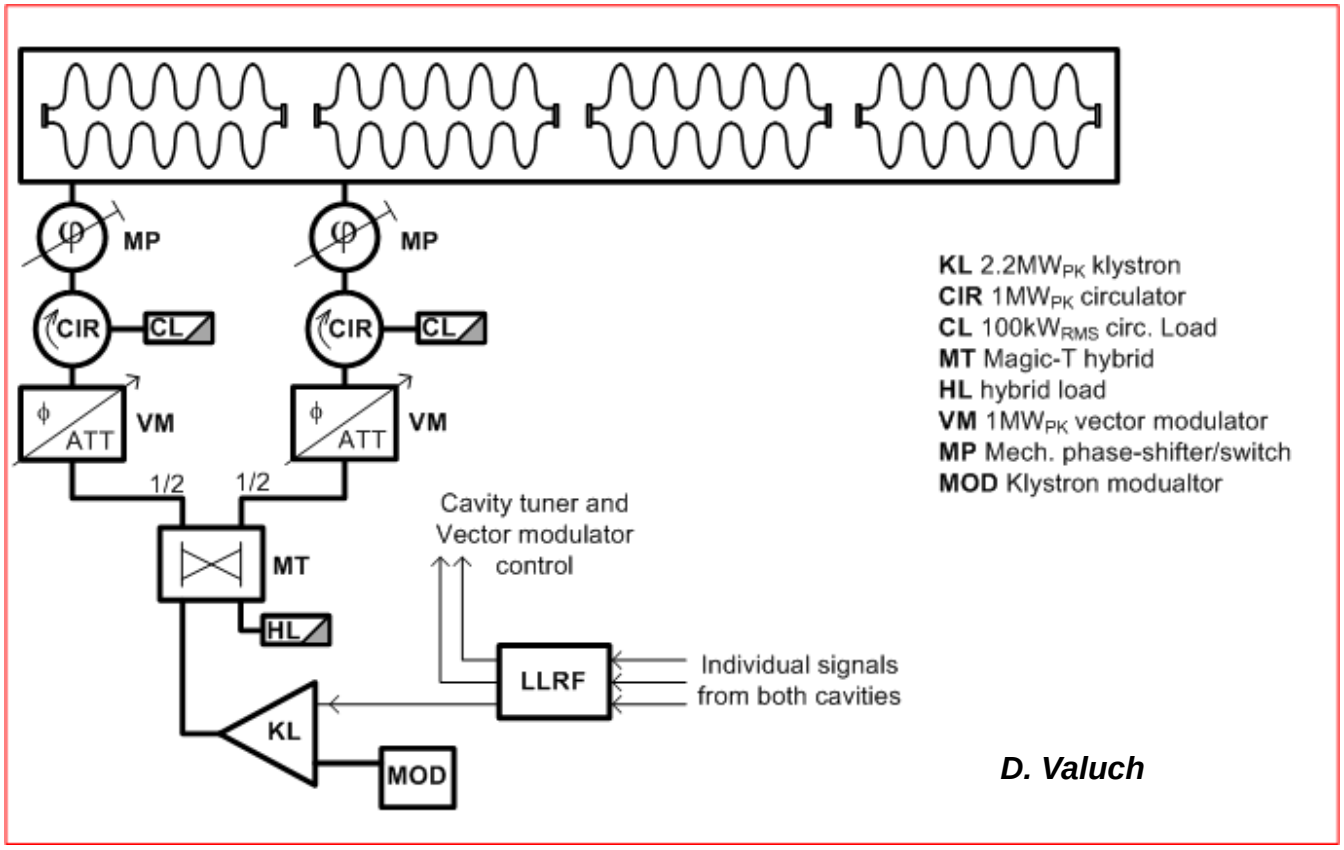


RF distribution schemes

Option 3) 1 klystron/2 cavities

- Hybrids, Vector modulators, mech. phase shifters
- All as option 1, saving is 2 klystrons per unit, unless we can suppress VMs
- => **suppress VMs, use 3-stub waveguide tuners**

(Option 3a)



SPL RF Power Distribution – Costing

Costing of Major Components

Item	Cost/item kCHF
6 MW Klystron	700
3 MW Klystron	600
1.5 MW Klystron	500
700 kW Klystron	400
1MW Circulator	50
500kW Circulator	35
Circulator load 100kW	40
Circulator load 50kW	25
Hybrid	20
Hybrid load 100kW	40
Hybrid load 50kW	25
Waveguides - per cavity 30m	60
Phase shifter (mechanical)	30
Vector Modulator 1MWp	75
Klystron Modulator 6 MW pk	600
Klystron Modulator 3 MW pk	300
Klystron Modulator 1.5 MW pk	175

Item	Cost/item kCHF
IOT 700 kW	400
IOT 350 kW	250
Local Water Distribution - Klystrons & modulator	30
Driver for klystron	20
Driver for IOT	60
LLRF for 1 klystron, VME, incl. signal treatments	45
LLRF per cavity, incl. signal distribution & treatment	30
Controls - per klystron	20
Controls - per cavity	20
Cabling - Klystron HV, RF, Controls - per klystron	70
Cabling - Cavity RF, HV, Controls - per cavity	70
Installation - per klystron	60
Installation - per cavity	60

See previous meetings for comparison of configuration options….

Running costs - one / two cavities per klystron

Take HP-SPL with 40mA beam ***(Rough exercise also done for ESS by R. Ruber)***

a) One 1.5 MW klystron per cavity, or: b) One 3.0 MW klyst per two cavities.

Determining factors:

- Klystron lifetime, cost of two 1.5 MW klystrons compared to one 3 MW klystron , duty factor, Electricity cost (0.1 CHF/kW hr)
- RF Margin LLRF 15%, waveguide losses, Efficiency wall plug to RF,
- Addit. overhead in two cavity config. (VMs, coupling diffs, tuners, etc.) **8%**

For a) vs. b) does not quite compensate the increased klystron cost/cavity

However Klystron costs may come down, energy costs will only rise.

Other issues – operability, reliability, flexibility need to be counted!

Need inexpensive, efficient klystrons with long lifetimes !

Klystrons & IOTs

- Power: IOTs reaching klystron levels - 600kW feasible**..(TBC)**
- Efficiency: IOTs 75%, Klystron 55-60% (70% limit)
- HV requirements: IOTs lower ~ 40kV (may not need HV oil)
- Size: IOTs shorter
- Cost: IOTs lower (30% ?)
- Lifetime: IOT - Not known for high power, low power as klystrons
- Drive Requirements: Klystron gain 35db, IOT 20dB – needs more RF drive
- Characteristic Klystron gain reduces at high drive, IOT saturates

Possibility of 1MW+ IOT for HPSPL ?

Magnetrons

- Efficiency high, but can we get the power we need?
- Phase locking needed, in development by CI
- Response in a feedback loop? Bandwidth, group delay..
- Cost, HV requirements, size ?
- *Being studied, CI /JLAB have had success with PL magnetron driving an 2.45 GHz SC cavity*

Solid State

- ***More suited to pulsed applications***
- ***Power handling increasing rapidly***
- ***Cost decreasing rapidly***

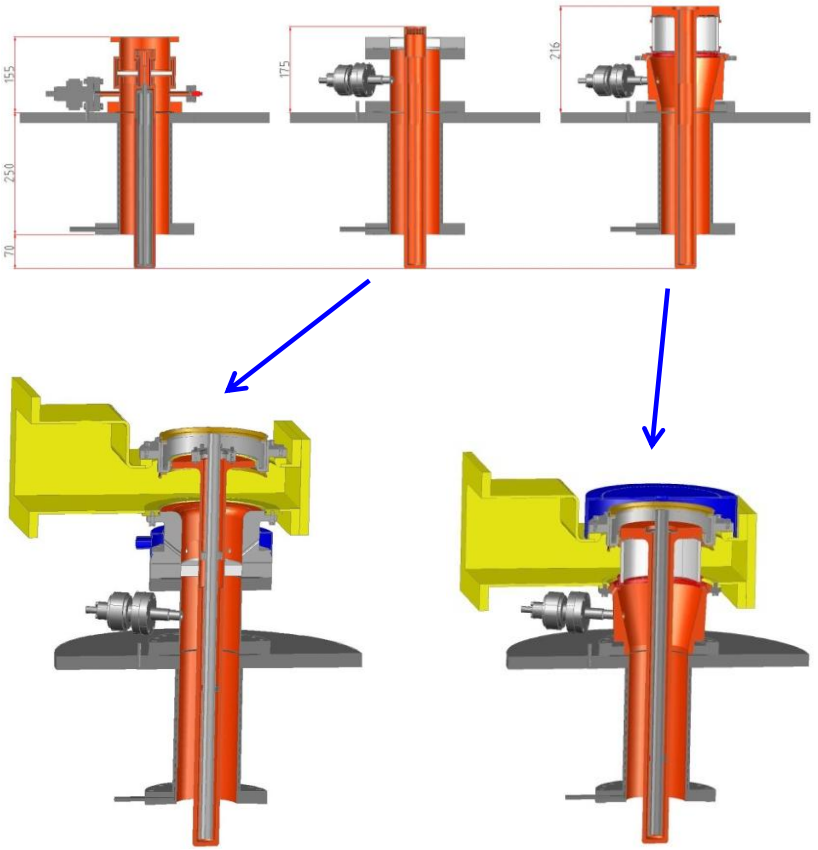
March 2010 Review: Power coupler specification

Courtesy E. Montesinos

- The SPL coupler will be :
  - A single window coupler
  - A fixed coupler ($Q_{ext} = 1.25 \times 10^6$)
  - With a Double Walled outer line (Tube)
  - Mounted in clean room with its double walled tube in a single operation
  - With its final position vertically below the cavity (opposite HOMC, cryomodule integration, pollution, etc…)
  - With a HV DC biasing capacitor
  - Air cooled

March 2010 SPL Coupler Review: Launch Coaxial and Cylindrical air cooled couplers

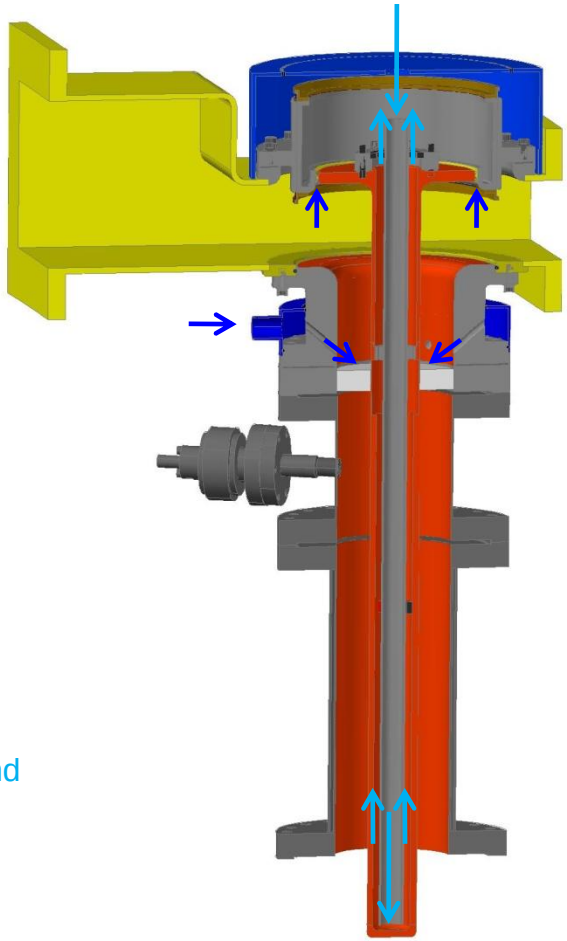
- Keep open the three possible designs:
  - SPL-CEA HIPPI coaxial disk water cooled window (if necessary, to be modified with an air cooled window)
  - SPL-SPS coaxial disk air cooled window
  - SPL-LHC cylindrical air cooled window
- All use the same double walled tube
- All use the same vacuum gauge, electron monitor and arc detector
- All designed to be compatible without modifying the cryomodule



SPL coupler with SPS Window

SPL coupler with LHC Window

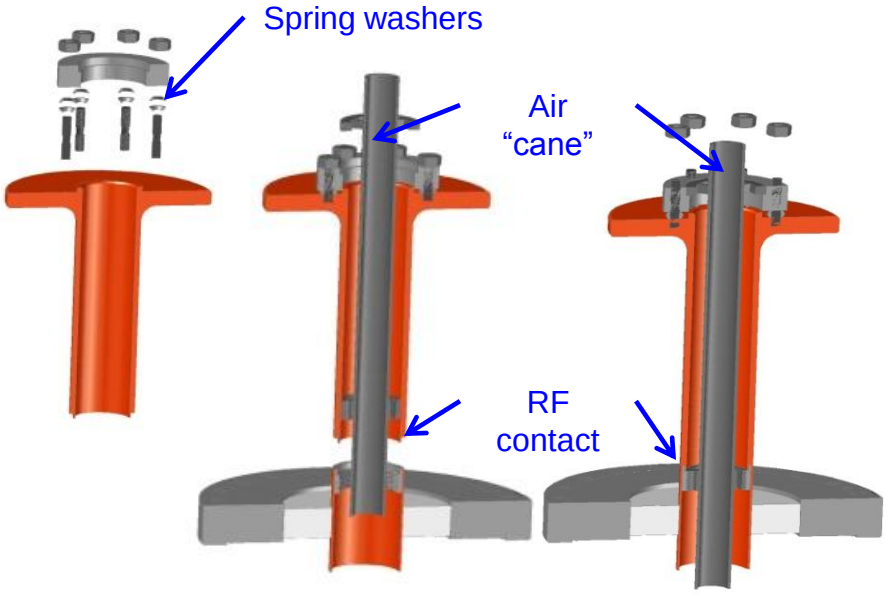
Coaxial disk air cooled window (SPS window)



Ceramic and waveguide air cooling

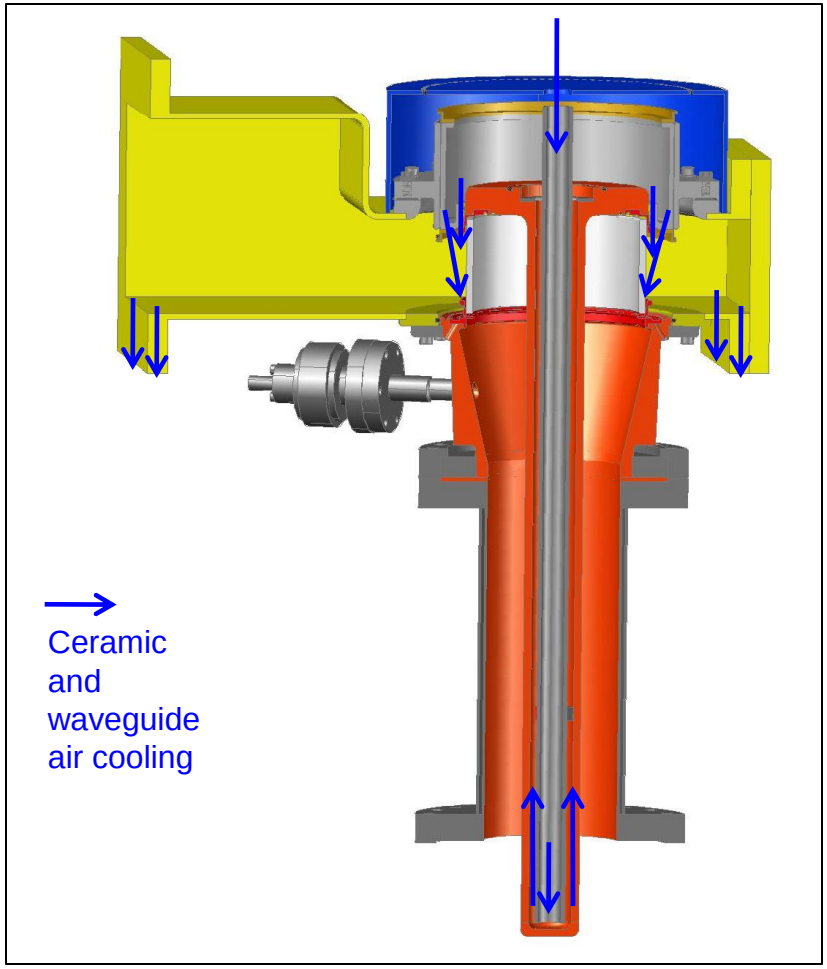
Antenna and outer ceramic air cooling

SPS Window: very simple brazing process

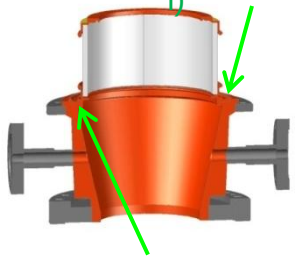


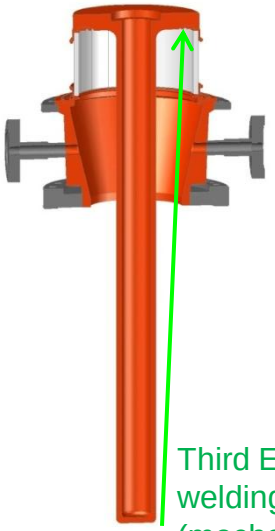
RF contact without stress to the ceramic
by compression of the outer line through the air "cane"

Cylindrical air cooled window (LHC window)



LHC window:
Two solid copper collars brazed to the ceramic





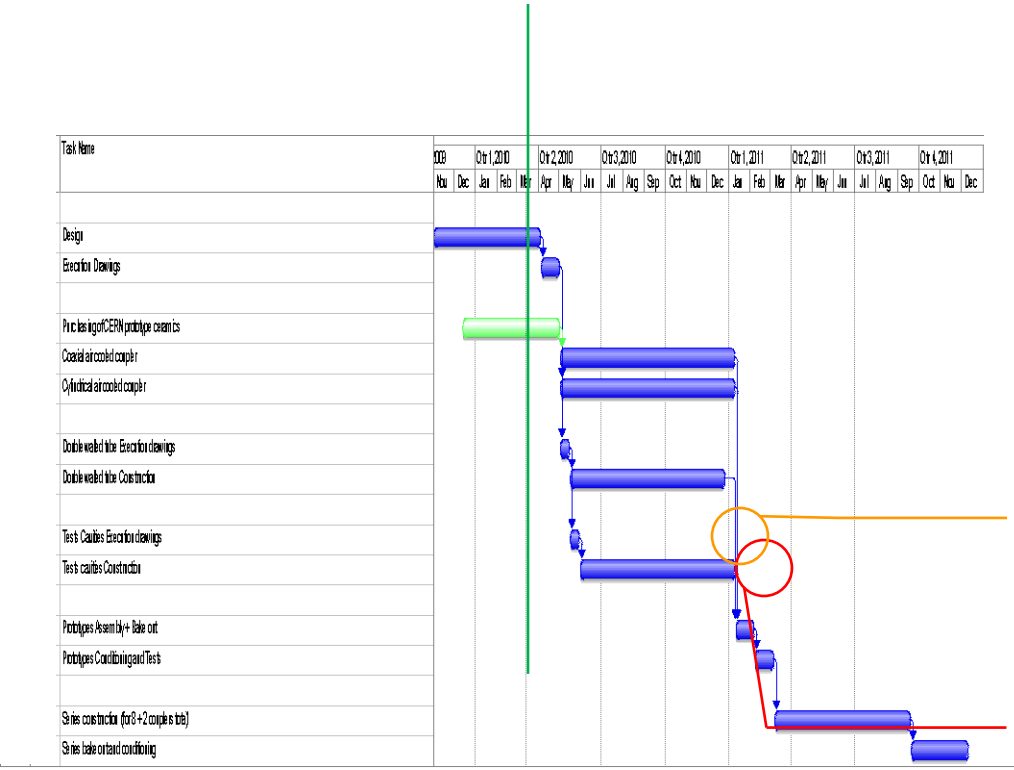
Power Coupler – pre-series/series production

	Coaxial water cooled *	Coaxial air cooled	Cylindrical Air cooled
Unit prototype price: Coupler	87 kCHF	27 kCHF	30 kCHF
Eight bare couplers	696 kCHF	216 kCHF	240 kCHF
Unit price: Double walled tube	15 kCHF	15 kCHF	15 kCHF
Unit price: Coupling box	25 kCHF	25 kCHF	25 kCHF
Unit price: Miscellaneous (clean room, leak detections, bake out, transports, …)	15 kCHF	15 kCHF	15 kCHF
Eight peripherals	340 kCHF	340 kCHF	340 kCHF
Eight couplers (+ 2 spare ceramics)	**1036 kCHF**	**550 kCHF**	**600 kCHF**
Coupler unit price (no quantity reduction, including double walled tube 15kCHF, and Misc. 10kCHF)	112 kCHF	52 kCHF	55 kCHF
275 couplers (no test cavities, no conditioning process)	**30'800 kCHF**	**14'500 kCHF**	**15'000 kCHF**

* prices based on Toshiba quotation date March 19, 2010

Proposed schedule

16-17 March: coupler review



- The double walled tube is under study
- A test cavity is needed, it will :
  - Connect two couplers in vertical position for conditioning
  - Also be a storage and transport chamber
  - Be from solid copper and EB soldered or assembled from two parts
- End 2010: two pairs of couplers will be assembled (CERN, DESY or Jefferson Lab, still under discussion)
- Beginning 2011: Two pairs of couplers will be ready for tests at CEA Saclay

RF Couplers - Status

- RF Simulations completed
- Under way :
  - Detailed verification of each component (few hundreds)
  - Mechanical assembling simulations
  - Study of double walled tube
  - Study of test cavity
  - Study of tooling
- Ceramics ordered
- First prototypes foreseen by end 2010 (optimistic planning without difficulties)
- First high power tests foreseen by mid 2011 (idem)

RF Power: Scope of upcoming work

- Completion of SPL Study:
  - Refined calculations on two cavity per klystron for high power proton driver using fixed coupler and waveguide tuner, performance, cost
  - High power (compact) klystron modulators
  - LLRF simulation and specs
- In context of focused R&D for neutrino physics,

  => R&D on high power proton sources:
  - Fabrication of 4 high gradient cavities
  - Power Coupler prototyping, pre-series preparation.
  - Test stand in SM18 for 4-cavity cryomodule
  - Procurement of klystron modulator
  - Procurement of RF power equipment

    Klystron, Circulator, Waveguides, basic controls & LLRF

See following presentations…

Thanks for your attention

Spare Slides

SPL RF Power Distribution – Costing

Comparison of RF Power schemes for LPSPL

Configuration	Revised Cost per Cavity (kCHF)	For	Against
Option 1) Four cavities per 3 MW Klystron	780	Fewest power sources	Complexity, bulk, power overhead, fault tolerance…
Option 2) One ~700 kW Klystron per Cavity	1150	Reduced hardware inventory, minimum R&D, fully independent control, minimum RF power overhead, best fault tolerance, easy upgrade to HPSPL	Number of power sources
Option 2a) One 700kW (?) IOT per cavity	1130	As above, perhaps cheaper & more compact	HPSPL would need doubling of IOTs, or larger rating IOTs
Option 2a LB0) One 300 kW IOT per cavity in LB section	712	Cheaper & more compact	300kW per IOT
Option 3) Two cavities per Klystron	935	Half the number of klystrons	Need full hardware set, associated R&D, Power overhead, Reduced flexibility wrt option 2
Option 3a) Two cavities per Klystron Without VMs	900	Half the number of klystrons, more economical than Option 3	Risk for higher intensity?

"Options 2 ,2a are the most attractive (single power source per cavity)" - for a LPSPL

But cost requires us to look closely at Options 3 & 4……

!! In particular Option 3 for HPSPL