Comparison of RF Distribution Systems for SPL

E. Ciapala

O. Brunner, Jean-Paul Burnet, Carlos De Almeida Martins, G. McMonagle, Eric Montesinos, Daniel Valuch, Sylvain Weisz.

CERN

Amos Dexter, Jonathan Smith,

Cockroft Institute

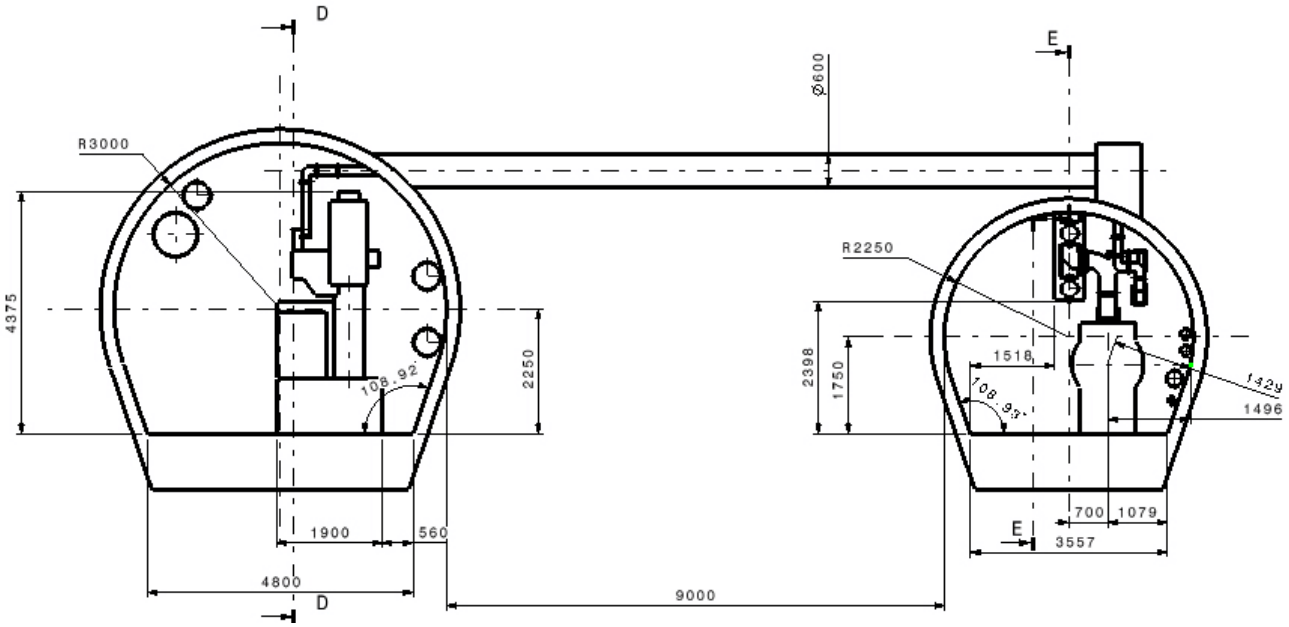
Comparison of RF Distribution Systems

Content

- LP SPL and HP SPL parameters and power requirements.
- Tunnel Layout (integration)
- Powering Options : four, two and single cavity per klystron.

  (LP SPL and HP SPL)
- Critical components
  - Power Sources – Klystrons vs. IOTs (and magnetrons..)
  - Vector Modulators
  - Klystron Modulators – “Integration” Issues
- Costing and overall comparison of options
- Conclusions & Outlook

Tunnel Layout



Schematic only!

6m klystron tunnel, 4m machine tunnel, separated 9m. All 20m below surface.
Surface buildings, above klystron tunnel

- Minimum equipment in cavity tunnel - Radiation, accessibility, maintenance
- Minimum number of passageways - one waveguide per cavity, passed in groups (CE preference...)

Important CE cost issue: size of tunnels

LP SPL and HP SPL power requirements

Operating parameters 704 MHz, Φs=15 deg.

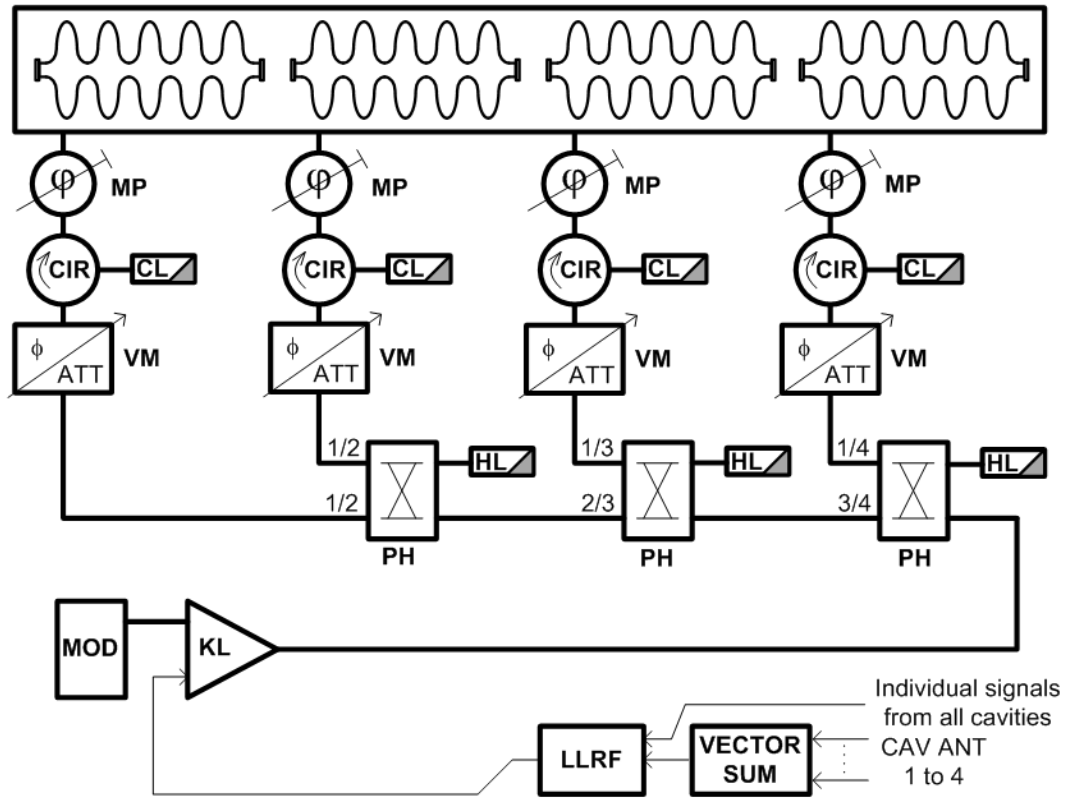
High energy section: **200 cavities** β=0.92, R/Q = 285Ω, 24MVm
Low energy section: **42 cavities** β=0.65, R/Q = 145Ω, 19MV/m

	Application	Duty Cycle [%]	P pk [kW]		P av [kW]	
Cavity Beta			0.65	0.92	0.65	0.92
LP-SPL	LHC Injector "neutrino operation (0.4ms)"	0.39	270	475	1	1.8
HP-SPL		3.92	540	950	21	37
HP-SPL	"high-power EURISOL (1.2ms)"	7.92	540	**950**	42	**75**
LP-SPL; HP coupled	LHC injector - upgradable	0.39	304	**534**	1	**2**

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



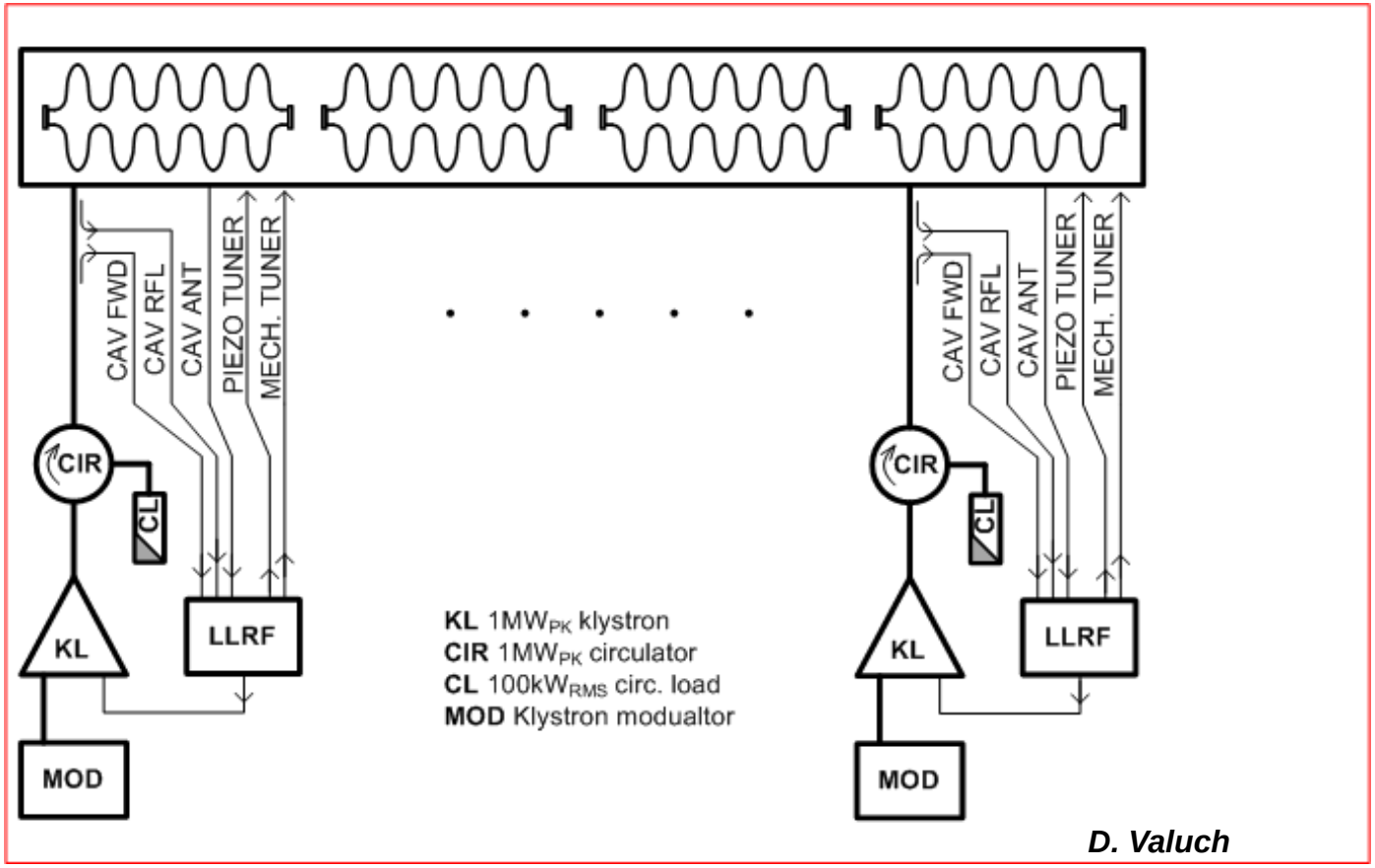
D. Valuch

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…

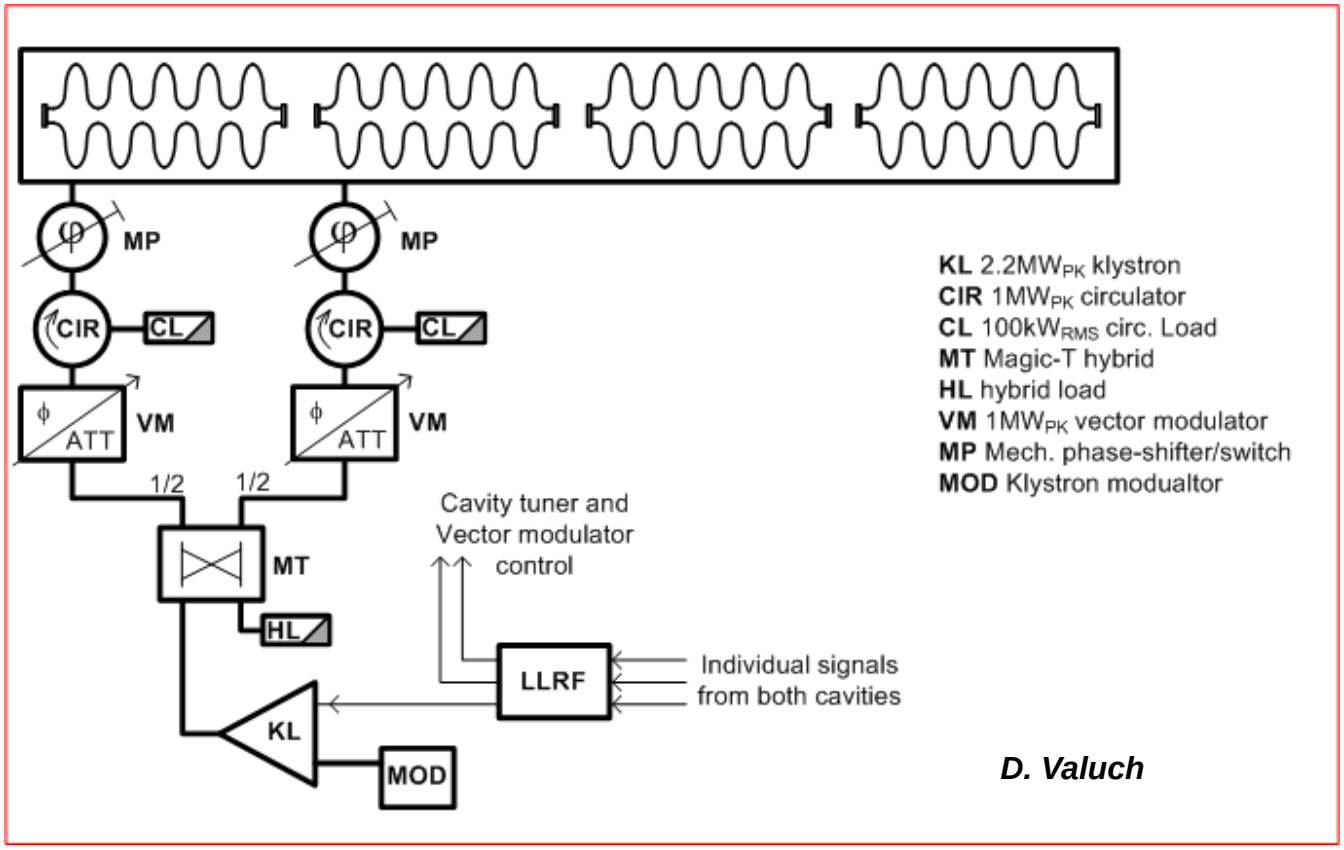


RF distribution schemes

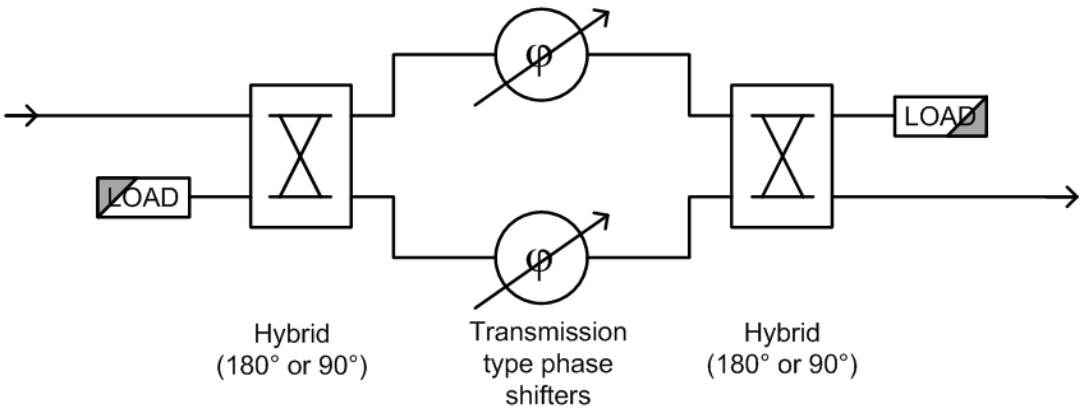
Option 3) 1 klystron/2 cavities

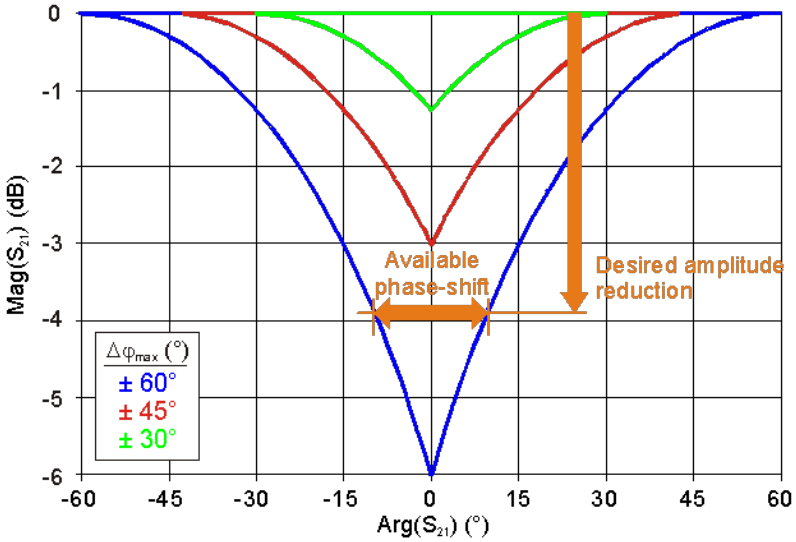
- Hybrids, Vector modulators, mech. phase shifters
- All as option 1, only saving is 2 klystrons per unit, unless we can suppress VMs

(Option 3a)



Components - Vector Modulators





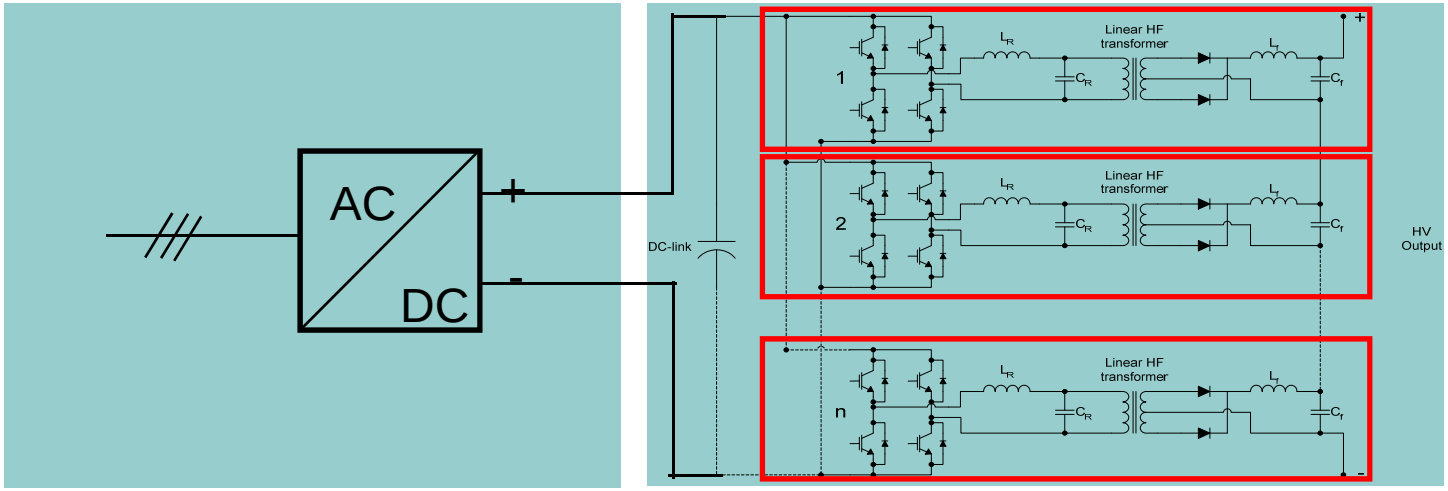
- Bulky systems
- 6 components
- Need power supplies, RF loops
- Range and frequency response may not be adequate.
- R&D program needed, especially for HPSPL

Components - Klystron Modulators

- **LPSPL** – Use CERN Linac 4 as basis for the estimations – cw power scaling
- **HPSPL - 110 kV, 91A, 2.3ms, 50** Hz (10 MW pk, 1.15 MWav)
- Proposed topology for the HP-SPL - Carlos DE ALMEIDA MARTINS, First SPL collaboration meeting:

Capacitor charger: In surface building

Pulse former: In the tunnel



HPSPL Design still to be elaborated, cost, size,

- layouts & space requirements in surface building & tunnel need to be identified. ***Our biggest challenge..***

Components – RF Power Sources

Klystrons & IOTs

- Power: IOTs reaching klystron levels - 600kW feasible..
- 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 – need more pwerful driver
- Characteristic Klystron gain reduces at high drive, IOT saturates

Possibility of 1MW+ IOT for HPSPL ?

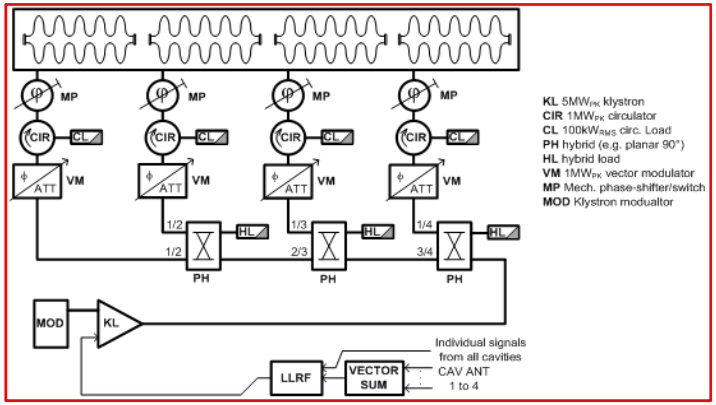
Magnetrons

- 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 ? ***To be studied, CI are looking***

RF distribution schemes - Costing

Option 1) Four cavities per klystron

Equipment	Qty	Cost/item. k Euro	Total kEuro
Klystron 5MW	1	600	600
1 MWp Circulator	4	100	400
Circulator load 100kW	4	20	80
Hybrid	4	20	80
Hybrid load 100kW	4	20	80
Phase shifter (mechanical)	4	20	80
Vector Modulator 1MWp	4	100	400
Klystron Modulator 6 MW pk	1	700	700
Total (per 4 cavity unit)			**2420**



***LPSPL**, but take HPSPL specs for all components incl. klystron, but not klystron modulator*

Advantages:

- Reduced number of klystrons
- Full RF control of each cavity, due to VMs

Disadvantages:

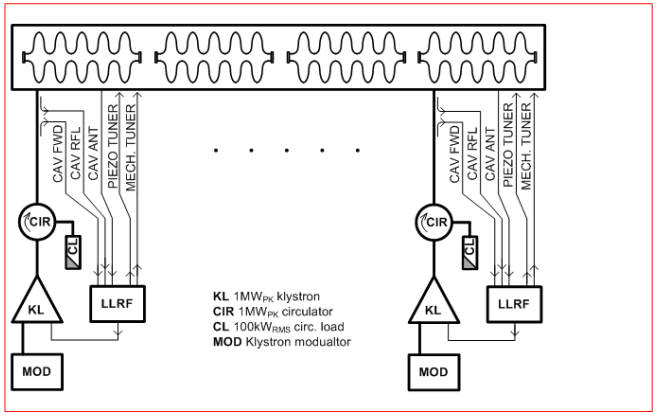
- Complexity, many different components
- Power overhead in hybrids & VMs

  ⇒Higher RF power spec- 5MW klystron at least, extra cooling (Probably need klystron **> 6 MW** with LLRF control margin)
- Space consuming

RF distribution schemes - Costing

Option 2) 1 klystron/cavity

Equipment	Qty	Cost/item. k Euro	Total kEuro
Klystron 1MW	4	400	1600
1 MWp Circulator	4	100	400
Circulator load 100kW	4	20	80
Hybrid	0	20	0
Hybrid load 100kW	0	20	0
Phase shifter (mechanical)	0	20	0
Vector Modulator 1MWp	0	100	0
Klystron Modulator 1.5 MW pk	4	200	800
Total (per 4 cavity unit)			**2880**



All components, except modulator, compatible HPSPL

Advantages:

- Simplest RF hardware set
- Full Direct RF control of each cavity. Simple non-interdependent RF loop controls
- No additional power overhead or extra cooling
- Good operability, best fault tolerance
- Easy upgrade LPSPL to HPSPL

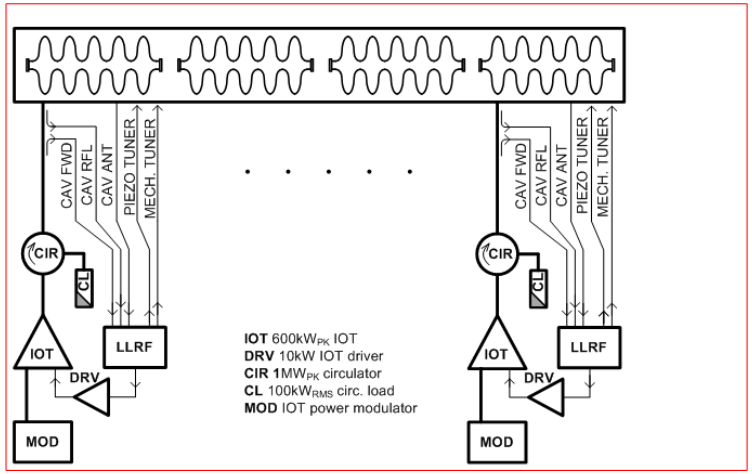
Disadvantages:

- 240 power sources…
- ?

RF distribution schemes - Costing

Option 2a) 1 IOT/cavity

Equipment	Qty	Cost/item. k Euro	Total kEuro
IOT 600kW	4	300	1200
Increased cost of IOT 10kW driver	4	30	120
1 MWp Circulator	4	100	400
Circulator load 100kW	4	20	80
Hybrid	0	20	0
Hybrid load 100kW	0	20	0
Phase shifter (mechanical)	0	20	0
Vector Modulator 1MWp	0	100	0
Klystron Modulator 1 MW pk	4	180	720
Total (per 4 cavity unit)			**2520**



Advantages – as opt 2a):

- Simplest RF hardware set
- Full RF control of each cavity. Simple non-interdependent RF loop controls
- No additional power overhead or extra cooling
- Good operability, best fault tolerance
- Easy upgrade LPSPL to HPSPL – More powerful (preferred) or double up on IOTs

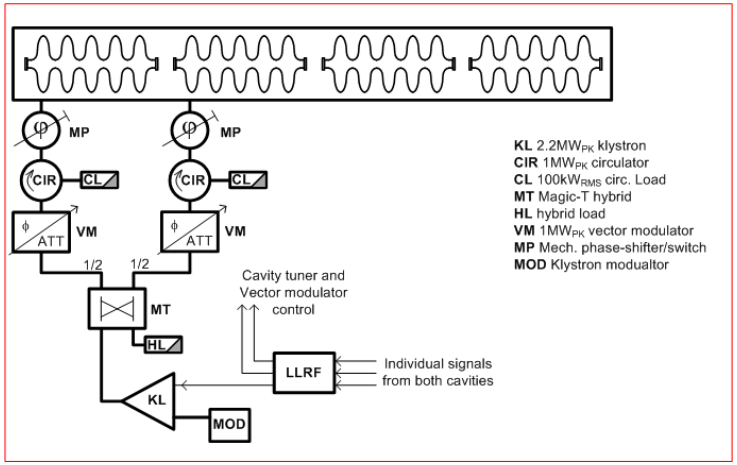
Disadvantages: - as opt 2a)

- 240 power sources…
- But IOTs appear less expensive

RF distribution schemes - Costing

Option 3) 1 klystron/2 cavities

Equipment	Qty	Cost/item. k Euro	Total kEuro
Klystron 2.2MW	2	500	1000
1 MWp Circulator	4	100	400
Circulator load 100kW	4	20	80
Hybrid	2	20	40
Hybrid load 100kW	2	20	40
Phase shifter (mechanical)	2	20	40
Vector Modulator 1MWp	2	100	200
Klystron Modulator 3 MW pk	2	360	720
Total (per 4 cavity unit)			**2520**



Advantages:

- 120 power sources instead of 240

Disadvantages:

- Still need the full hardware set, with associated cost, development effort…
- Still have additional power overhead with its extra cooling requirement

Option 3a) , *without VMs, relying on phase shifters (saving 150k)* *Cost 2370*

RF Power Schemes Costing - Summary

Configuration	Cost for 4 cavity 'unit' (Eu)	For	Against
Option 1) Four cavities per Klystron	2420	Fewest power sources	Complexity, bulk, power overhead, fault tolerence
Option 2) One Klystron per Cavity	2880	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 IOT per cavity	2520	As above, perhaps cheaper & more compact	HPSPL would need doubling of IOTs, or larger rating IOTs
Option 3) Two cavities per Klystron	2520	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	2370	Half the number of klystrons, more economical than Option 3	Risk for higher intensity?

=> Options 2 & 2a are the most attractive

Tunnel integration

- Preference is to situate maximum equipment in klystron tunnel
- Very preliminary studies show that the 6m klystron tunnel can accommodate all options, including the one source per cavity options
- Detailed layouts need to be done
- The situation for the HPSPL modulator needs to be studied urgently

Summary & Outlook

- Single power source is the preferred option.
  - Reduces R&D work on waveguide components, VMs etc
  - Rather put effort into finding best & most economical power source
    - IOT, Klystron, or Magnetron (CI collaboration).
- Collaborate with other projects, institutes & industry on IOTs.

  There is general interest for many applications at CERN
- Upgrade LP to HPSPL not a concern for the RF power systems proper,

  BUT
- Klystron Modulator – HPSPL 50 Hz is a new & very different device – needs complete upgrade in going LP to HP SPL . (ESS Bilbao collaboration)
- Modulator size & footprints in klystron tunnel & surface buildings need to determined urgently.