A Hitch-Hiker’s Guide to the LEP3 RF System

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Thanks to E. Ciapala, O. Brunner, E. Jensen, J. Tuckmantel

Outline

Results of very preliminary brainstorming!

- Introduction & scope
- Overall dimensions
- RF power components
- Cryogenic load
- Low Level RF
- Conclusions

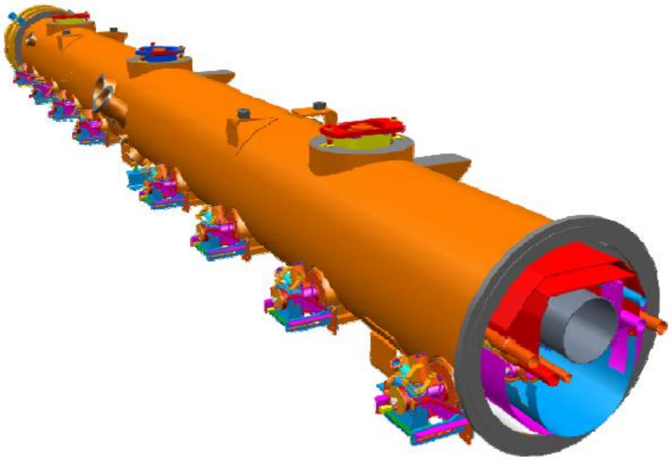
Introduction and scope

beam energy E_b [GeV]	120
circumference [km]	26.7
beam current [mA]	7.2
#bunches/beam	4
#e_/beam [10^{12}]	4
bending radius [km]	2.6
damping partition number J_ε	1.5
momentum compaction α_c [10^{-5}]	8.1
SR power/beam [MW]	50
E_{SR} loss/turn [GeV]	6.99
$V_{RF,tot}$ [GV]	12
δ_{max},RF [%]	4.2
f_s [kHz]	3.91
E_{acc} [MV/m]	20
effective RF length [m]	606
f_{RF} [MHz]	1300
$\delta_{SR,rms}$ [%]	0.23
$\sigma_{SRz,rms}$ [cm]	0.23

- Assume 1.3 GHz ILC-type cavities
  - but 700 MHz SPL/ESS/LHeC type also possible (and might be preferable)
- Have initially considered only the collider ring
  - Suggestion to share RF sections with accelerator ring?
- No comments on the feasibility of co-existence with LHC or LHeC !

Overall dimensions

- 12 GV @ 20 MV/m → 606 m effective RF length
  - 580 TESLA cavities @ 1.038 m per cavity
- 73 cryomodules with 8 cavities/module (XFEL type)
  - even number easier for RF distribution
  - total length 818 m
- cf. LEP2: 864 m



RF sections at the 4 even points as in LEP2?

RF Power

- 200 MW total wall-plug power
- 100 MW total beam power @ 7.2 mA/beam
- 580 cavities

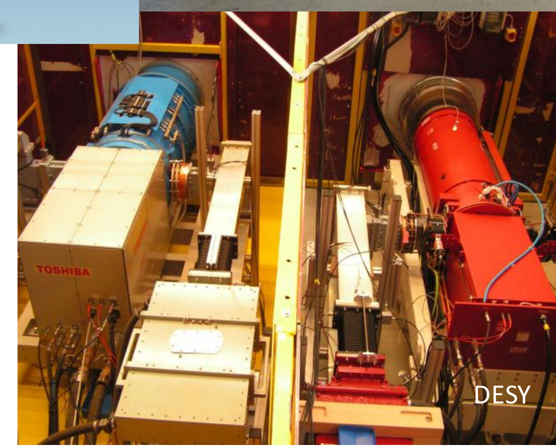
→ 172 kW/cavity at maximum beam current

What power source?
How many cavities per source?

Available 1.3 GHz klystrons

- 1.3GHz ILC – FNAL-KEK (TH2104)
  - U_{cat}/I_{cat} : 128kV/88A
  - duty cycle: 2ms / 10Hz
  - gain / η: 50dB / 45%
  - av. Power ≤ 200 kW
  - Cost estimate: 240kEuros/tube

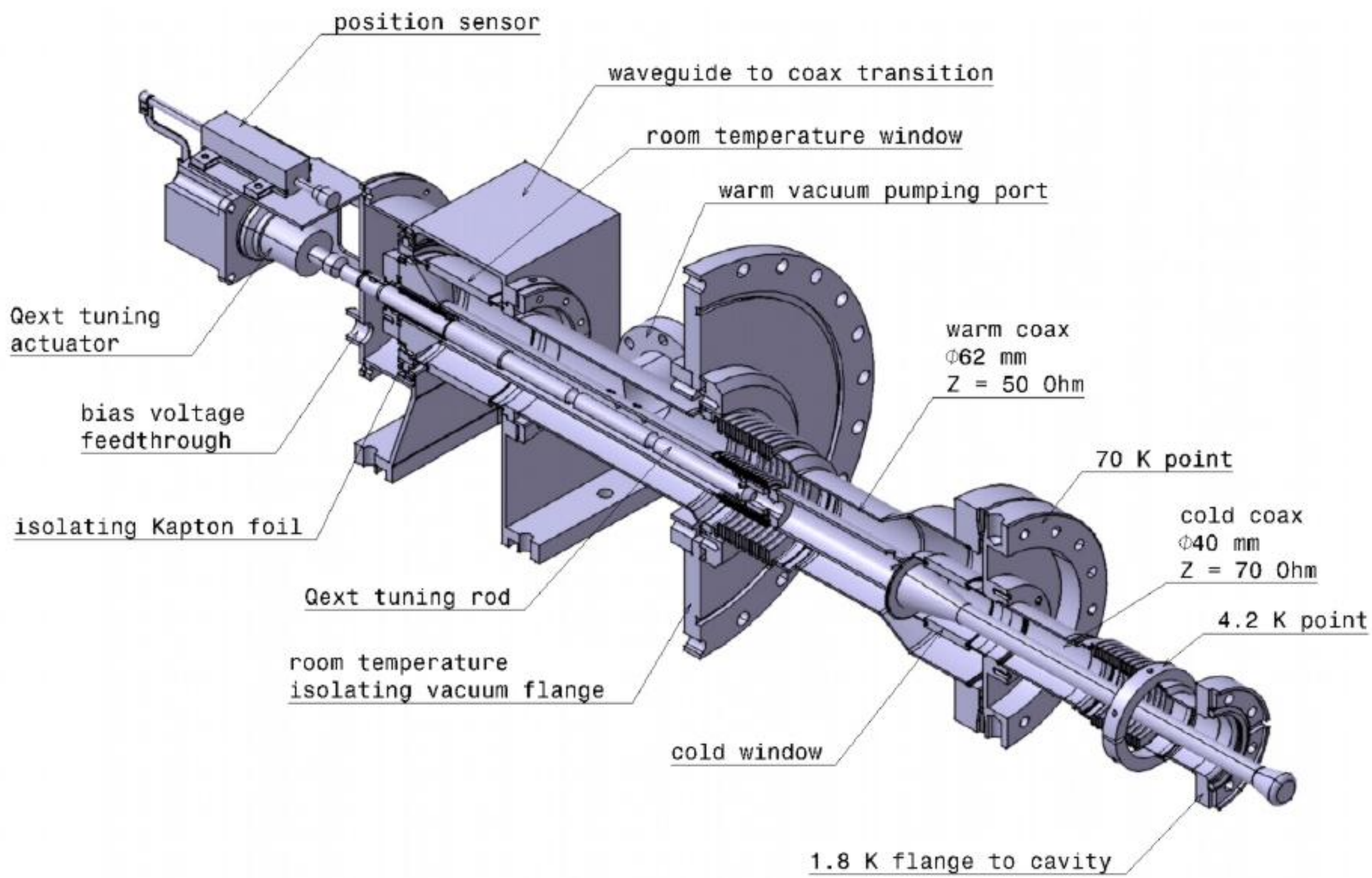
- 10MW 1.3GHz MBK – FLASH/XFEL
  - U_{cat}/I_{cat} : 140kV/155A
  - duty cycle: 1.5ms / 10Hz
  - gain / η: 50dB / 50%
  - av. Power ≤ 150 kW
  - Cost estimate: 400kEuros/tube



Need to develop a klystron for CW operation
P_{CW} ~450kW feasible? → 2 cavities/klystron

Power couplers

- XFEL dual window design, limited in power
  - ~280kW, pulsed 1.4 ms @ 10Hz, 2.5 kW average

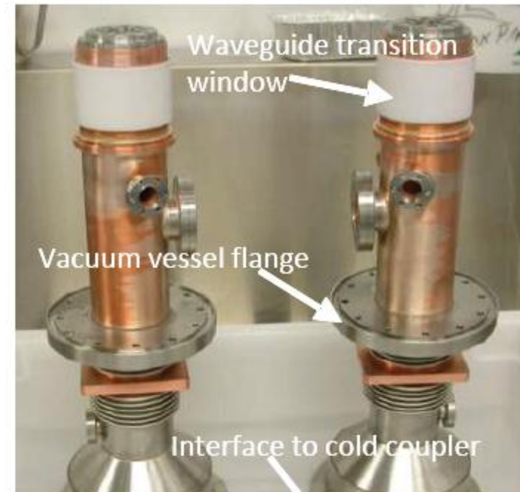


Power couplers

Cornell design for ERL:

- tested up to 60kW CW
- 2 couplers/cavity

Cold coupler part



Warm coupler part

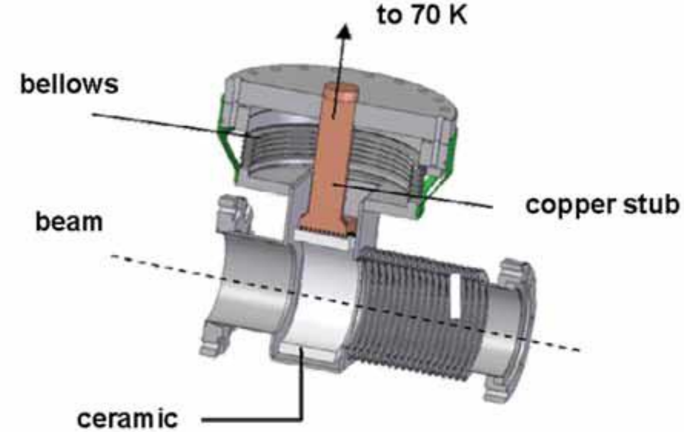
Cannot use ILC/XFEL cryomodule "as-is"

- main power coupler development necessary
- high power difficult at 1.3 GHz due to small physical size
- dual coupler c.f. Cornell ERL, XFEL higher-harmonic cavities?

Higher order modes

- Short bunches, high beam power
- IKC/XFEL cryomodules:
  - HOM couplers
    - modes below beam pipe cut-off
  - Beam pipe absorbers (XFEL)
    - modes above beam pipe cut-off
    - designed for 100 W CW
- LEP3 vs XFEL:
  - 250 x CW beam current
  - 10 x bunch length

ILC HOM coupler

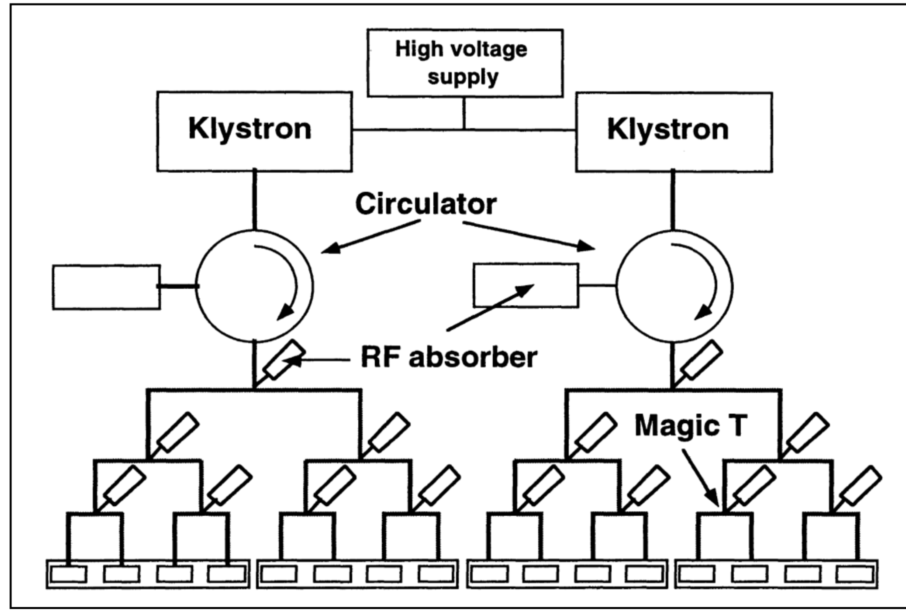


beam pipe absorber XFEL

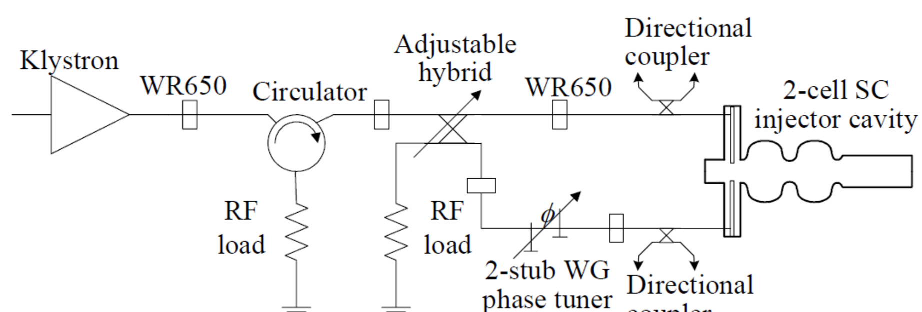
Study of HOM requirements needed

RF distribution

- LEP2:
  - 1 klystron (1.3 MW)
  - feeding 8 cavities via waveguides
  - tree-like distribution
  - circulators to protect klystron from reflected power
- LEP3:
  - 1 klystron for 2 cavities ?
  - load & circulator power rating
  - 170 kW CW circulator (Cornell)
  - a twin coupler scheme would introduce complicated power splitting



LEP2 RF distribution scheme



Cornell ERL power splitting scheme

Cryogenic load

- TESLA/ILC cavities:

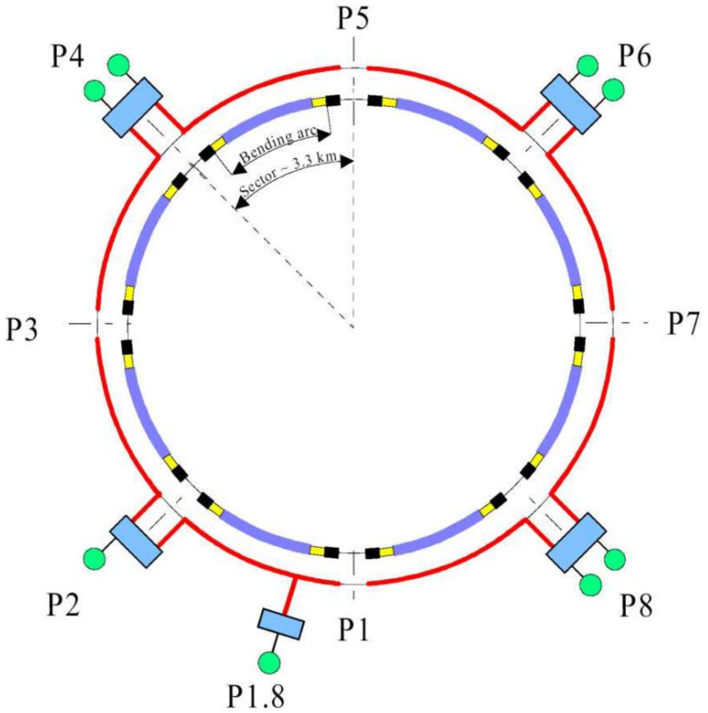
Q_0	$\geq 1 \times 10^{10}$
R/Q	1036 linac ohms
V_{cav}	20.7 MV

→ dyn. load: 41 W/cavity @ 2 K

→ total dyn. load: 24 kW @ 2 K

→3 kW/sector

c.f. LHC cryoplants 2.1 or 2.4 kW/sector @ 1.9 K



Existing LHC cryo capacity may not be sufficient

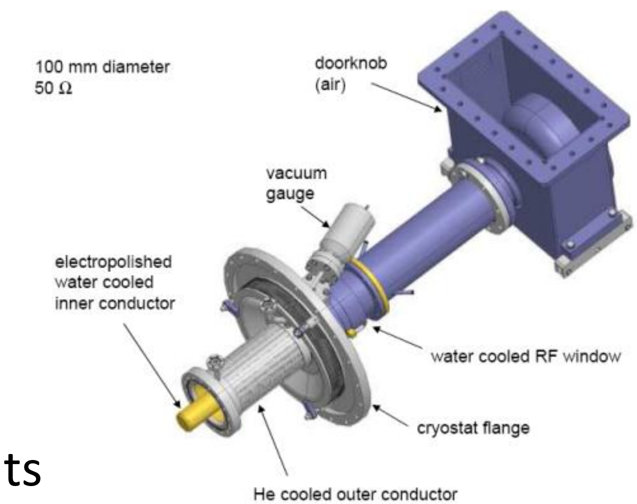
Low Level RF

- Low Level RF in LEP2:
  - continuous beam loading
    - high loaded Q → filling time >> f_{rev}
  - slow voltage control loop
  - static phase adjustment
  - fast RF feedback acting on 8-cavity vector sum was tried to stabilize cavity field against ponderomotive oscillations (Lorenz force detuning driving mechanical resonances)
    - not (very) successfully used operationally
    - can certainly do better with modern digital system

How about a lower frequency (700MHz)?

- Potentially higher klystron average power levels
  - 450 kW average power klystron already exists (SNS TH2168 @ 805 MHz)
  - Reduced number of power stations

- Power couplers:
  - Larger physical size → lower power density
  - e.g. HIPPI 1MW power coupler: 1MW peak, 10% duty cycle



- Average power availability of passive components
  - waveguides, loads

- More robust, less sensitive and less challenging

Conclusions

- Size of collider ring RF system similar to LEP2
- High-power RF components not available off the shelf:
  - klystrons
  - main power couplers
- HOM coupler requirements need to be studied
- Existing LHC cryogenic capacity at 2K may be insufficient
- Is 1.3 GHz the best frequency choice?
  - RF power considerations