RF for CLIC DR
A very first look

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Outline

- CLIC DR energy acceptance
- Scaling NLC DR RF system to CLIC *
- Traveling versus Standing wave system
- RF source issue
- Conclusions

** Parameters of NLC DR RF are taken from "Collective effects in the NLC damping ring design" T. Raubenheimer ,et. al., PAC95*

Energy acceptance

$$\Delta E = \Delta E_0 \sqrt{\cos\phi_s + (\phi_s - \pi/2)\sin\phi_s}$$

$$\Delta E_0 = \sqrt{\frac{2e\hat{V}_{rf}\beta^2 E}{\pi h|\eta|}} \approx \Big|_{\beta\approx 1} \sqrt{\frac{2e\hat{V}_{rf} E}{\pi h|\alpha_p|}}$$

$$\sin\phi_s = \frac{U_0}{\hat{V}_{rf}}$$

CLIC DR parameters*	
Circumference: C [m]	365.2
Energy : E [GeV]	2.42
Momentum compaction: α_p	0.8×10^{-4}
Energy loss per turn: U_0 [MeV]	3.9
Maximum RF voltage: V_{rf} [MV]	4.115
RF frequency: f_{rf} [GHz]	2.0

Energy acceptance versus rf voltage	
V_{rf} [MV]	ΔE/E [%]
4.115	±0.8
4.5	±1.7
5	±2.6

* From Yannis CLIC pars WG, 2/10/07

Scaling of NLC DR RF cavity

NLC DR RF cavity parameters	
Frequency: f[GHz]	0.714
Shunt impedance: R [MΩ]	3
Unloaded Q-factor: Q_0	25500
Aperture radius: r [mm]	31
Max. Gap voltage: V_g [kV]	500

Scaled RF cavity parameters	
Frequency: f[GHz]	2
Shunt impedance: R [MΩ]	1.8
Unloaded Q-factor: Q_0	15400
Aperture radius: r [mm]	11
Max. Gap voltage: V_g [kV]	180

Calculated RF cavity parameters	
Number of cavities: N	$V_{rf}/V_g \sim 23$
Total wall losses: P_{Ohm} [MW]	$V_{rf}^2/2NR \sim 0.2$
Peak beam current: I_b [A]	$Q_b*f \sim 1.3$
Peak beam power: P_b [MW]	$U_0*I_b \sim 5$
Loaded Q-factor: Q_{ext}	$Q_0*P_{Ohm}/P_b \sim 620$
Filling time: T_f [ns]	$Q_{ext}/f \sim 310$

Five 1 MW CW klystrons feeding 5 SW 5-cells accelerating structures would do it.

$\eta_{rf\text{-}to\text{-}beam}$ < 30%

Total length ≥ 2m

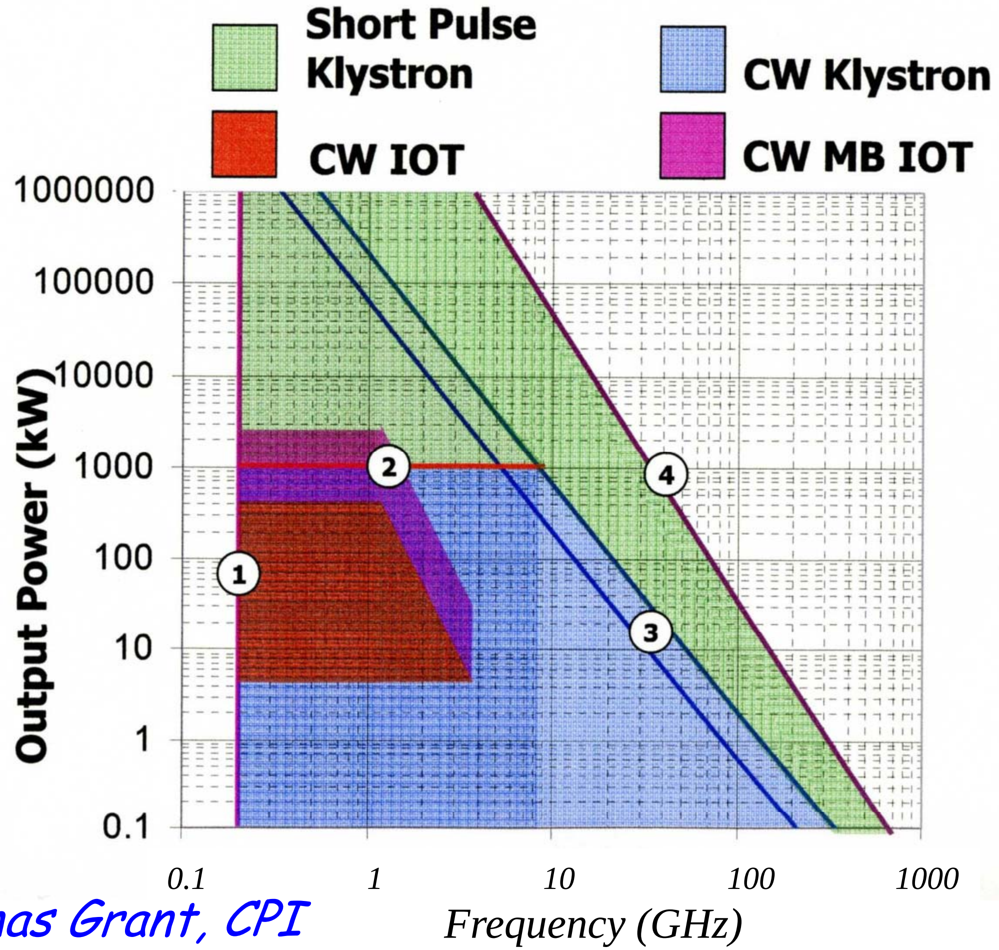
TW versus SW acc. structure

- Several fully beam loaded travelling wave accelerating structures with shorter filling time ~20ns could increase efficiency significantly but only at fixed (nominal) current and voltage.
- SW structure would require tunable coupler in order to change the loaded Q-factor and maintain efficiency when changing beam current
- In summary, both systems are possible

RF power source

- In case of a klystron,
  - It must be pulsed with DR revolution frequency of ~1 MHz repetition rate in order to maintain efficiency OR
  - a better option would be to do pulse compression on each turn, this will also reduce peak power requirements on klystrons at the expenses of pulse compression efficiency (~70%) though
- And it must have certain bandwidth in order to be able to shorten the filling time to increase efficiency (more of an issue in TWS).
  - T_f~50ns => df~20MHz => df/f~1%
- IOTs are better choice from the point of view efficiency and bandwidth (-> efficiency). But they have less power per tube and lower gain (two stages will be required). An R&D item at 2 GHz.
- Solid state rf power amplifier showed 50% efficiency from the plug at 500 MHz (SOLEIL). BUT Efficiency and power at 2 GHz -?

Considerable part of former klystron domain claimed by IOTs



Why?

Wakefields of the rf system

- Loss/kick factors of NLC DR rf cavity for bunch length of 3.3 mm and aperture radius of 31 mm from the reference:
  - Total loss factor: k_l = 1.7 V/pC
  - Transverse kick factor: k_t = 39.4 V/pC/m
- Scaling to CLIC DR rf cavity for bunch length of 3.3 mm and aperture radius of 11 mm:
  - Total loss factor: ~1/d: k_l ~ 4.8 V/pC per cell
  - Transverse kick factor: ~$1/d^3$: k_t ~ 873 V/pC/m per cell
- Number of cavities (cells) is also higher for CLIC: ~23
- In summary: it is ~10 times higher for longitudinal wake and ~100 times higher for transverse wake for the whole rf system
- One good thing is that at 2 GHz HOM damping is more compact and could be done more efficient. Q-factor of HOM could of the order of few tens or so.

CLIC DR RF system issues

- Frequency: 2 GHz
- Highest peak power
- High average power
- Very strong beam loading transient effects:
  - Peak beam power of ~5 MW during 156 ns
  - No beam power during the other 1060 ns
  - Small stored energy at 2 GHz
- High energy loss per turn at relatively low voltage results in big sin φ_s = 0.95 (any examples of operation ?)
- Wakefields
- Pulsed heating related problem (fatigue, …)

Recommendations

- Reduce energy loss per turn
  - This will help anyway
- Consider frequency reduction down to 1 GHz
  - It makes rf system a conventional high power rf system (other DRs, B-factories, etc.)
  - One can take advantage of a superconducting RF system
  - Reduce beam peak power by 2, so the SR peak power, less pulsed heating, less rf peak power, etc.
  - It makes life easier for positron capture

  BUT

  - Recombination of bunches is necessary at extraction or in a separate delay loop. Potential impact on the beam emittance must be addressed.