Specific requirements for CLIC RF structures

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CERN-UK Kick-off meeting

13 April 2011

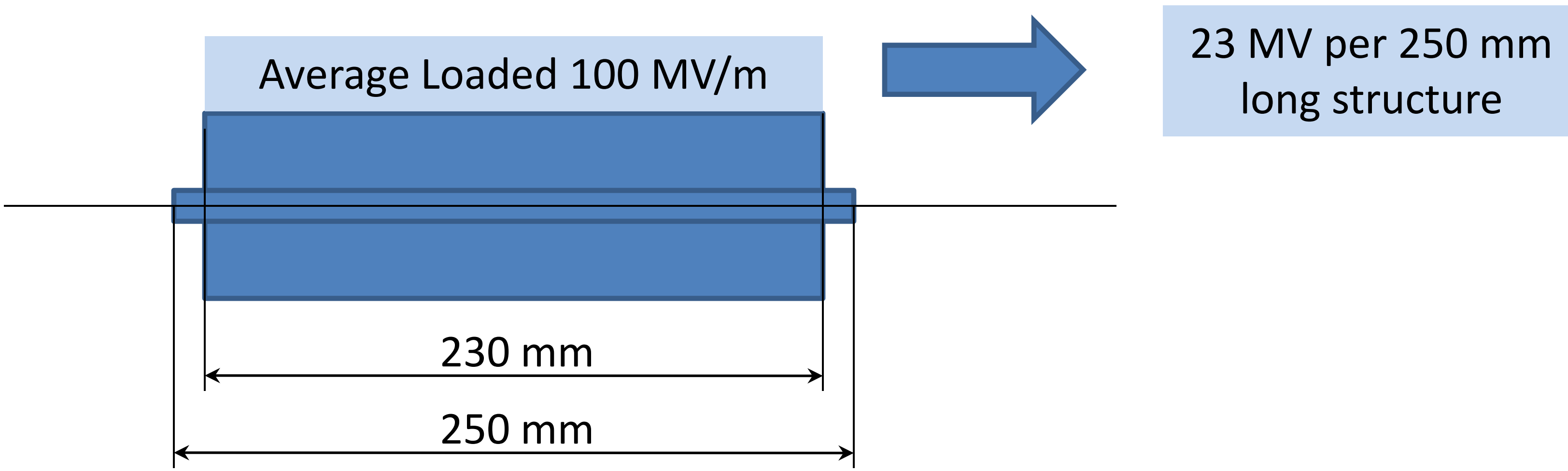
Outline

- CLIC main linac accelerating structure (AS)
- CLIC crab-cavity (CC)

N.B. Most of the information is already well known to our UK collaborators. Even more, for the crab-cavity, most of it came form them ! Nevertheless, it is an attempt to summarize it and to get common understanding of the problems.

Acknowledgements to D. Schulte and R. Thomas for useful discussions

CLIC AS layout and space constraints



C L I C

Optimization constraints for CLIC_G

Beam dynamics (BD) constraints based on the simulation of the main linac, BDS and beam-beam collision at the IP:

- N – bunch population depends on $\langle a \rangle/\lambda$, $\Delta a/\langle a \rangle$, f and $\langle E_a \rangle$ because of short-range wakes
- N_s – bunch separation depends on the long-range dipole wake and is determined by the condition:

$$W_{t,2} \cdot N / E_a = 10 \text{ V/pC/mm/m} \cdot 4\text{x}10^9 / 150 \text{ MV/m}$$

RF breakdown and pulsed surface heating (rf) constraints:

- $\Delta T^{max}(H_{surf}^{max}, t_p) < 56$ K
- $E_{surf}^{max} < 250$ MV/m
- $P_{in}/C_{in} \cdot (t_p^{P})^{1/3} < 18$ $\text{MW/mm}\cdot\text{ns}^{1/3}$

These constraints have been used in 2008 in the design of the CLIC baseline structure: CLIC_G.

50 K

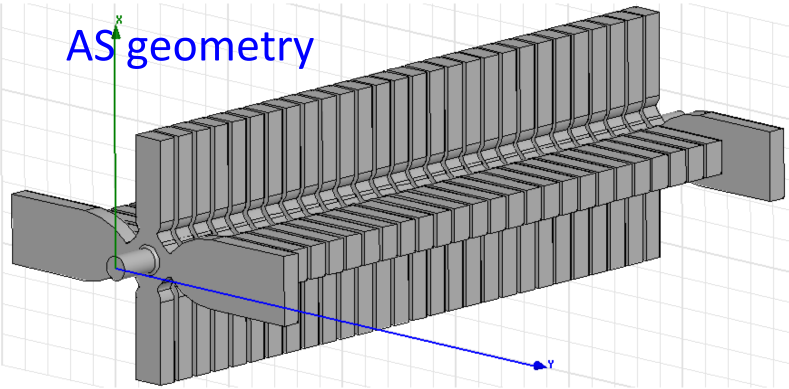
220 – 250 MV/m

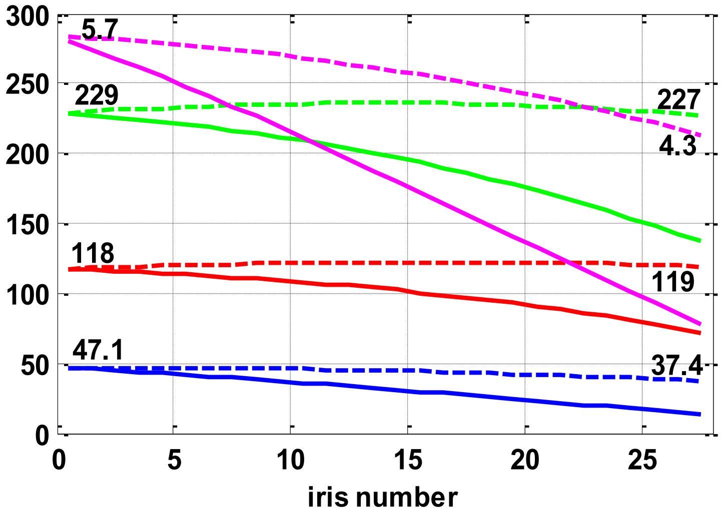
15 – 17 $\text{MW/mm}\cdot\text{ns}^{1/3}$

Sc < 4 – 4.5 MW/mm^2

These are the values which correspond to the current (2011) understanding of the RF breakdown constraints

CLIC baseline AS for the CDR





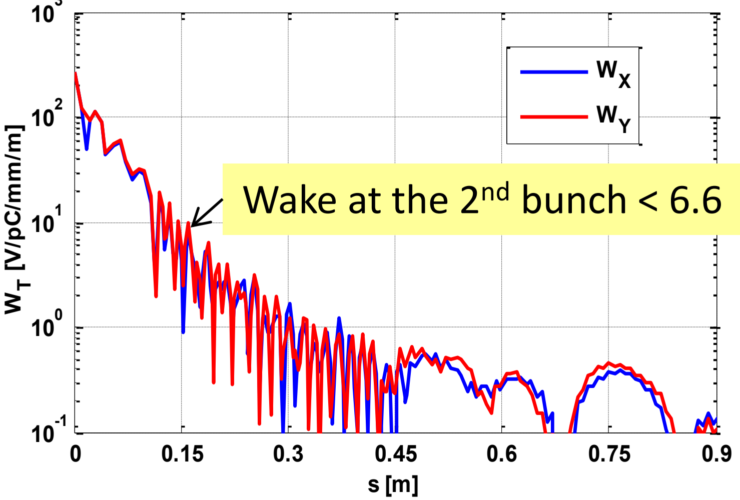
$P/C*tp^{1/3}$ = **17** $MW/mm*ns^{1/3}$

The fundamental mode properties are shown.
The traces from top to bottom are:
S_c·40 [W/µm^2](pink),
Surface electric field [MV/m](green),
Accelerating gradient [MV/m](red),
Pulse surface temperature rise [K](blue).
Dashed traces are unloaded and solid are beam loaded conditions

Average loaded accelerating gradient	100 MV/m
Frequency	12 GHz
RF phase advance per cell	2π/3 rad.
Average iris radius to wavelength ratio	0.11
Input, Output iris radii	3.15, 2.35 mm
Input, Output iris thickness	1.67, 1.00 mm
Input, Output group velocity	1.65, 0.83 % of *c*
First and last cell *Q*-factor (Cu)	5536, 5738
First and last cell shunt impedance	81, 103 MΩ/m
Number of regular cells	26
Structure length including couplers	230 mm (active)
Bunch spacing	**0.5 ns**
Bunch population	**3.7×10^9**
Number of bunches in the train	312
Filling time, rise time	66.7 ns, 21 ns
Total pulse length	243.7 ns
Peak input power	**61.3 MW**
RF-to-beam efficiency	27.7 %
Maximum surface electric field	**230 MV/m**
Maximum pulsed surface heating temperature rise	**47 K**

CLIC baseline AS for the CDR

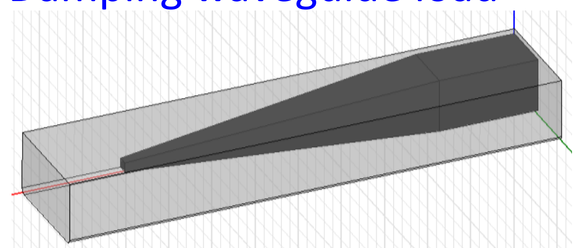
The envelope of the transverse wakefields for both planes is shown. The CLIC bunch spacing is 0.15 m.

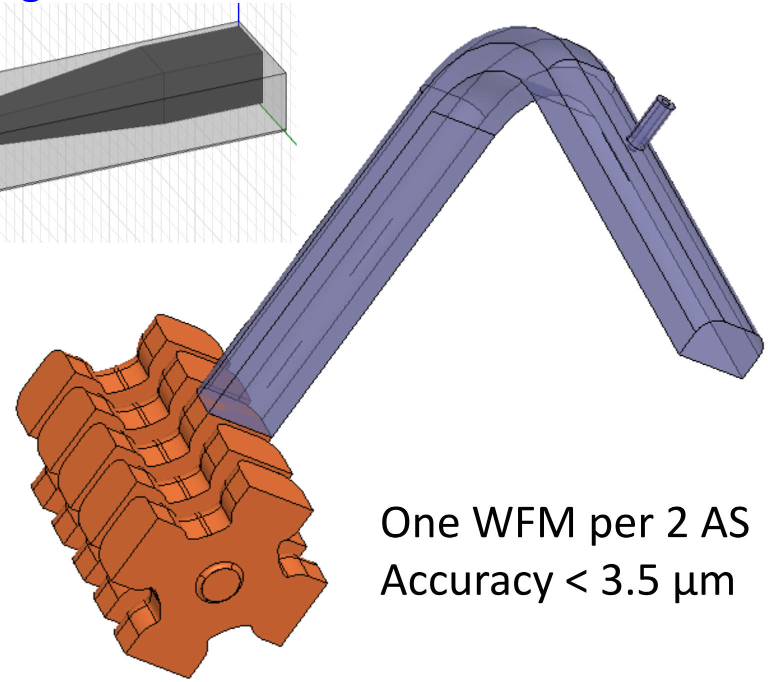


Parameters of the lowest dipole-band modes

Cell	First	Middle	Last
Q-factor	11.1	8.7	7.1
Amplitude [V/pC/mm/m]	125	156	182
Frequency [GHz]	16.91	17.35	17.80

Damping waveguide load



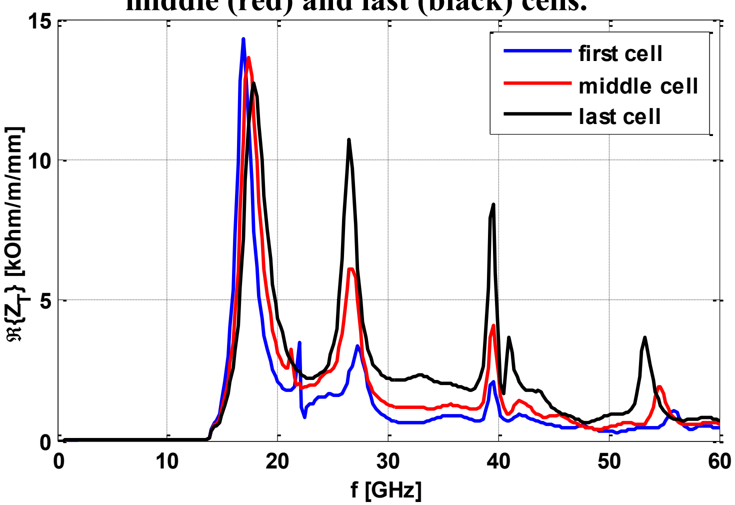


One WFM per 2 AS

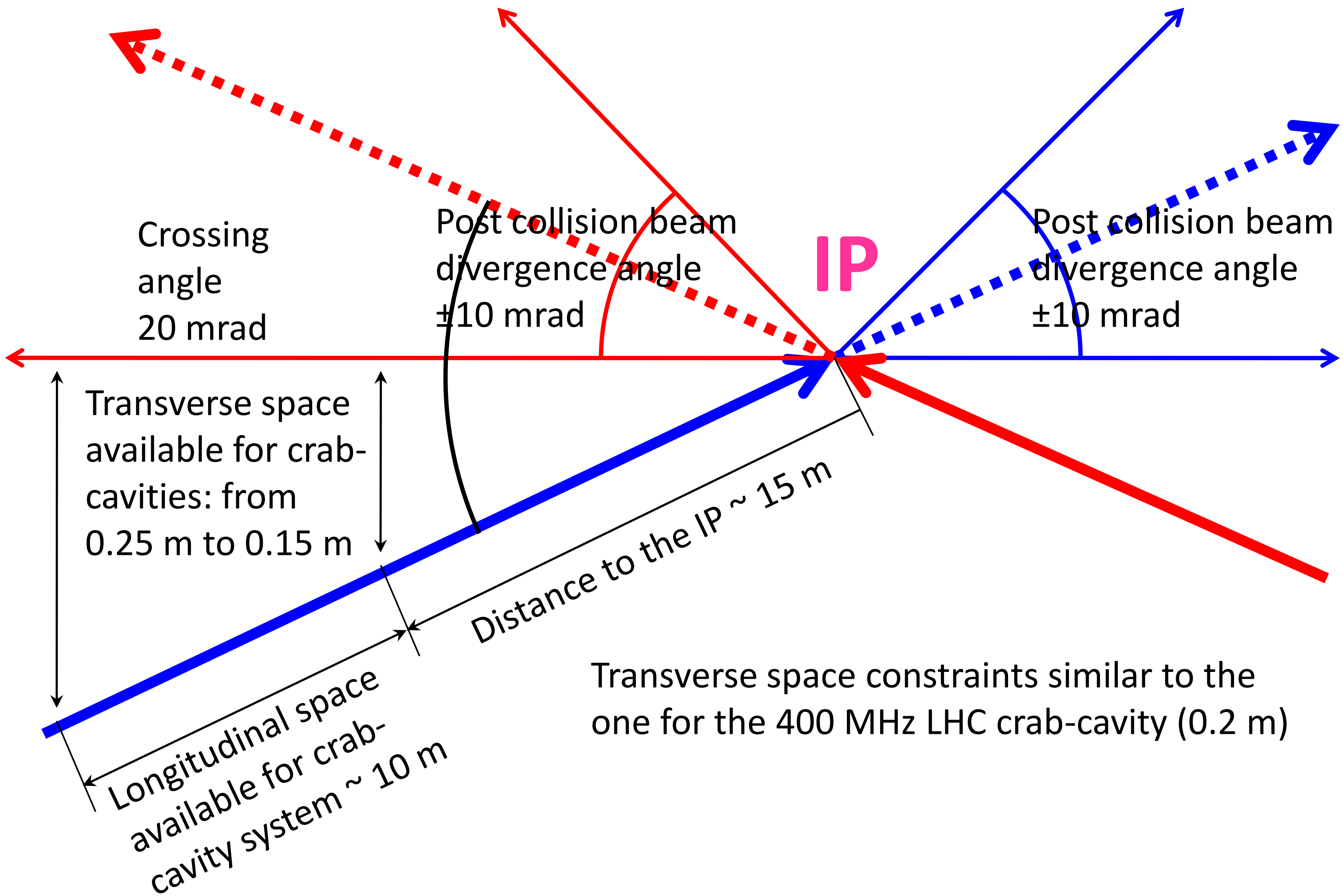
Accuracy < 3.5 µm

Geometry of one of the four arms of the wakefield monitor. (Courtesy of F. Peauger, CEA, France).

Transverse impedances of the first (blue), middle (red) and last (black) cells.



Crab-cavity system layout and space constraints



Transverse space constraints similar to the one for the 400 MHz LHC crab-cavity (0.2 m)

CLIC parameters and specifications for the CC system

Relevant CLIC parameters:

- Beam energy at the IP: $E0 = 1.5$ TeV
- Crossing angle: $\theta\_c = 20$ mrad
- Beam normalized emittance: $\varepsilon\_x = 660$ nm, $\varepsilon\_y = 20$ nm
- Beta-function at the position of CC system: $\beta\_CC \approx 100$ km
- => Beam spot size at the position of the CC: $\sigma\_x \approx 150$ µm, $\sigma\_y \approx 25$ µm

Specifications for CC system:

- Frequency: $f = n \cdot 2$ GHz, n = 1,2,3,4,5,6 , ...
- Kick strength versus frequency:

  $Vt * f = \theta\_c \cdot E0 \cdot c/2\pi R12 \approx$ **2.5 MV * 12 GHz** = **7.5 MV * 4 GHz**
- Maximum beam offset horizontal: $dx \approx$ **4**$\sigma\_x \approx 0.6$ mm
- Maximum beam loading: $Vl = dx * \theta\_c \cdot E0/R12 \approx 370$ kV

  => peak: $Pb = Ib * Vl \approx$ **0.4 MW**

  => average: <Pb> = Pb * 50Hz*156ns ≈ **3 W**

Can be relaxed to ½ if it is critical

- Kick amplitude and time stability: ~2% and ~**5 fs** for ~2 % Luminosity reduction (CLIC CDR, Crab-cavity system)
- **RF constraint for AS design can be applied here to be verified with high power test**

Wakefields in the CC system

- No detailed beam dynamics (BD) simulations have been done at CERN on the acceptable level of the wakefields from the CC system
- It is very desirable (In my opinion, absolutely necessary) to do the BD study in order to get the acceptable level of the wakefields in the CC system.
- Below, an attempt to estimate the threshold level for the long-range wakefields (probably the most critical ones) is presented.

Multi-banch wake field effect is proportional to $W_t N e^2 \int \frac{\beta(s)\,ds}{2E(s)}$; D. Schulte, PAC09

For the main linac: <β(s)> ~sqrt(E(s)); E goes linear from 9 to 1500 GeV

=> integral ≈ 380 m^2/GeV (D. Schulte)

W_t@2^{nd} bunch < 6.6 kV/pCm^2 , and "no" wake for the others

For the CC system: <β> = 100 km; E = 1500 GeV

=> integral ≈ L_CC*33 m^2/GeV; about 10 times smaller for 1 m long CC

If **undamped**: L_{CC}*W_t= L_{CC}*W_{t0} = 1m* 66 kV/pCm^2 / (312/2) bunches ≈ 1m * **0.4 kV/pCm^2**

12 GHz CC: Typical level of W_{t0} ≈ 50 kV/pCm^2; L_{CC} ≈ 1/4m; **strong damping is needed**

4 GHz CC: Typical level of W_{t0} ≈ 2 kV/pCm^2; L_{CC} ≈ 10m; some damping is needed (?)

2 GHz CC: Typical level of W_{t0} ≈ 1/4 kV/pCm^2; **L_{CC} ≈ 20m**; no damping is needed (?)

Conclusion

❑ Requirements for the main linac accelerating structure are well known both from the point of view of beam dynamics and high power RF.
❑ Requirements for crab-cavity system are also well known, maybe with one exception. Namely, the acceptable level of the wakefields in the crab-cavity is still to be obtained from the beam dynamics simulations both for horizontal and vertical planes together with required alignment tolerances.
❑ Collaborators are welcome to present this work if it is already done. This is critical for the damped crab-cavity design. Build-in wakefield monitor for crab-cavity alignment may be considered.
❑ Collaborators are also welcome to present considerations on the frequency choice between 12 GHz pulse system (CDR baseline) and 4 (or 2) GHz CW system (possible alternative).