STRIPLINE KICKERS DESIGN

DAMPING RING DESIGN PROGRESS

09/05/2012

1) Introduction

2) Cross section design of the stripline extraction kicker for the the CLIC DR

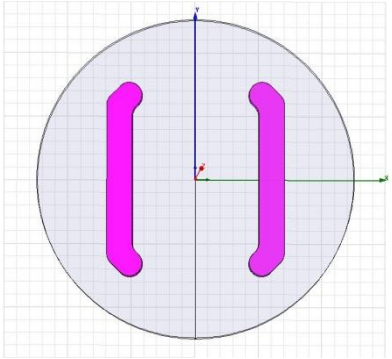
3) Design study of the tapers

4) Beam coupling impedance

5) Test campaign

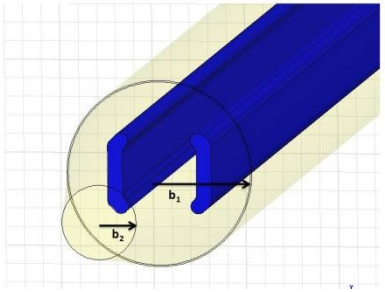
6) Conclusions

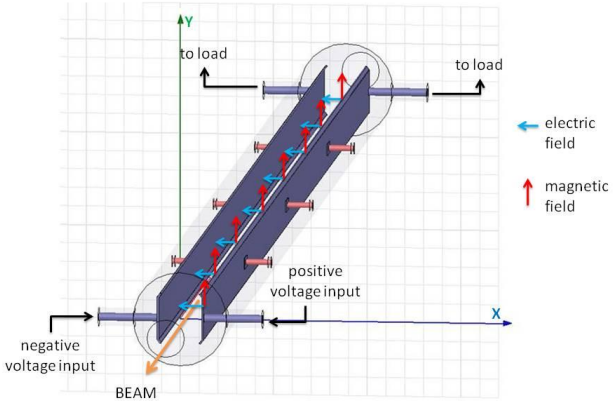
1) INTRODUCTION



The striplines design can be divided into two steps:

- Cross section design. The striplines cross section defines the characteristic impedance and field homogeneity of the striplines.
- Design of the transition between the stripline kicker and the beam pipe. A suitable tapering between the kicker and the beam pipe is needed to reduce the beam coupling impedance.



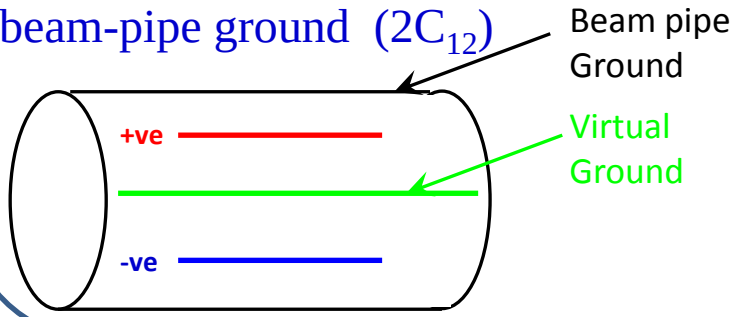


Once the design has finished, the stripline kicker will be built by Trinos Vacuum-Projects

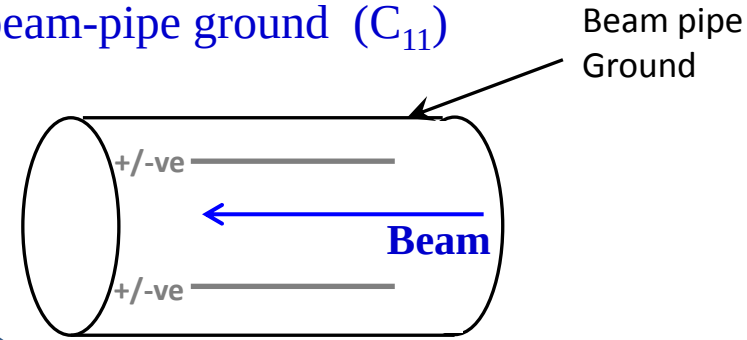
2) CROSS SECTION DESIGN OF THE STRIPLINE KICKER FOR CLIC DR

The cross section of the striplines must be matched to 50 Ω characteristic impedance

Striplines driven to same magnitude, but **opposite polarity**, voltage, to extract beam
⇨ **ODD mode characteristic impedance**.
Total capacitance (C) is given by:
- capacitance between a stripline and virtual ground (C_{11})
- capacitance between a stripline and beam-pipe ground ($2C_{12}$)



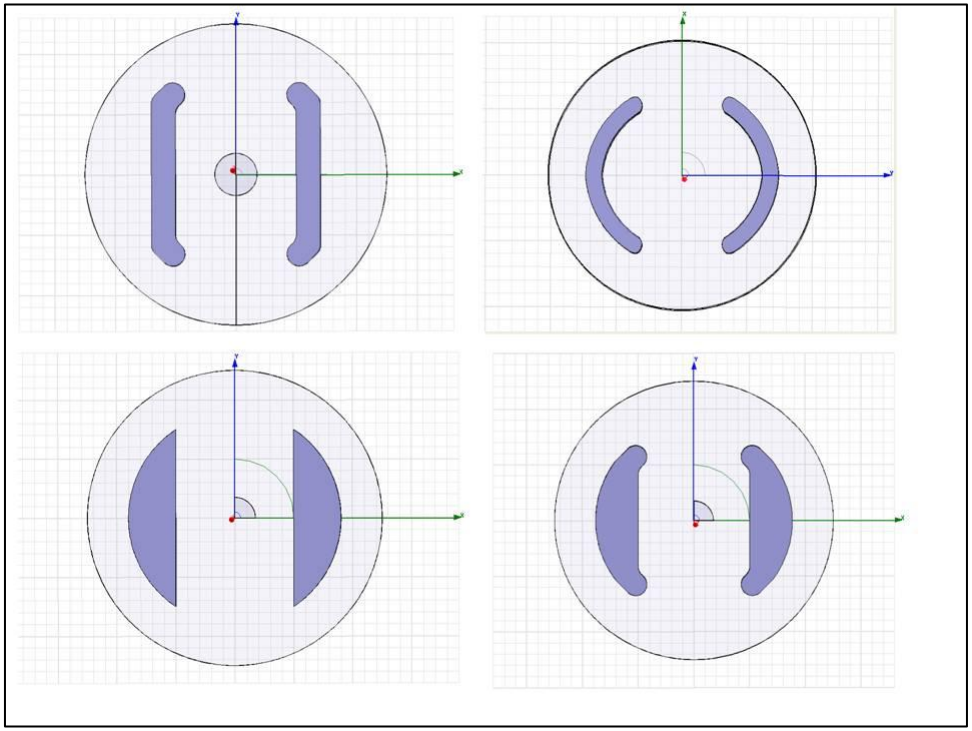
Same polarity and magnitude of current / voltage induced on both striplines by beam.
⇨ **EVEN mode characteristic impedance**
Capacitance (C) is given by:
- capacitance between a stripline and beam-pipe ground (C_{11})



Goal: achieve 50 Ω characteristic impedance in the even mode, while keeping the odd characteristic impedance as close as possible to 50 Ω. Furthermore, a field homogeneity of ± 0.01% at the center between the striplines is required.

2) CROSS SECTION DESIGN OF THE STRIPLINE KICKER FOR CLIC DR

Four possible cross sections have been considered to start the design of the striplines, all of them using cylindrical beam pipe, since it is the easiest shape for manufacturing from a commercial pipe.

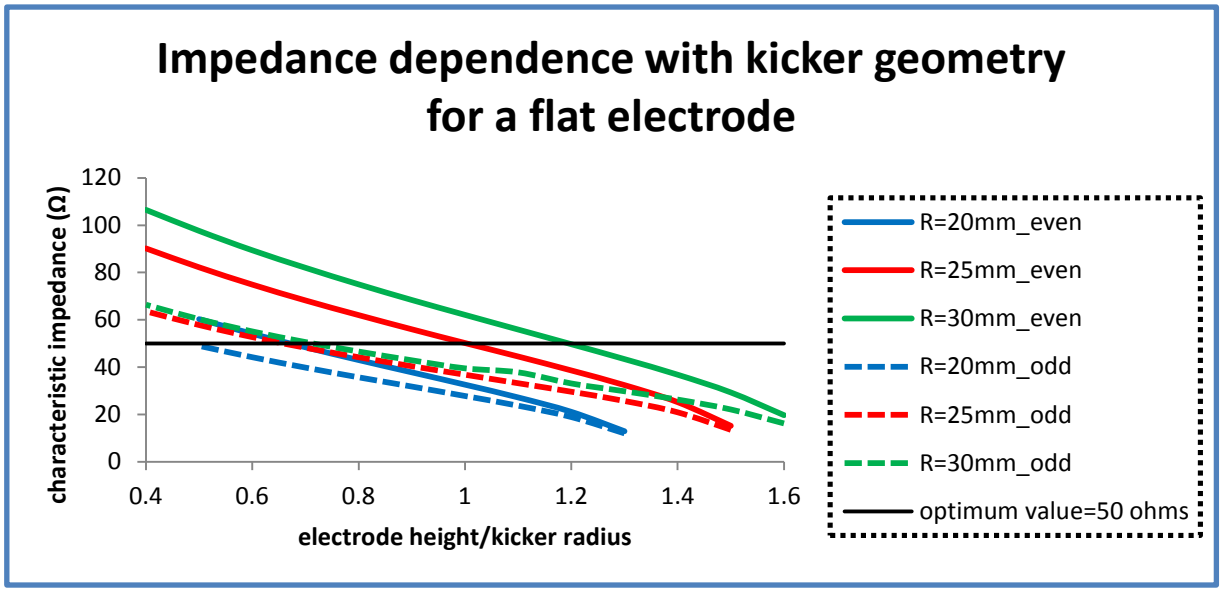


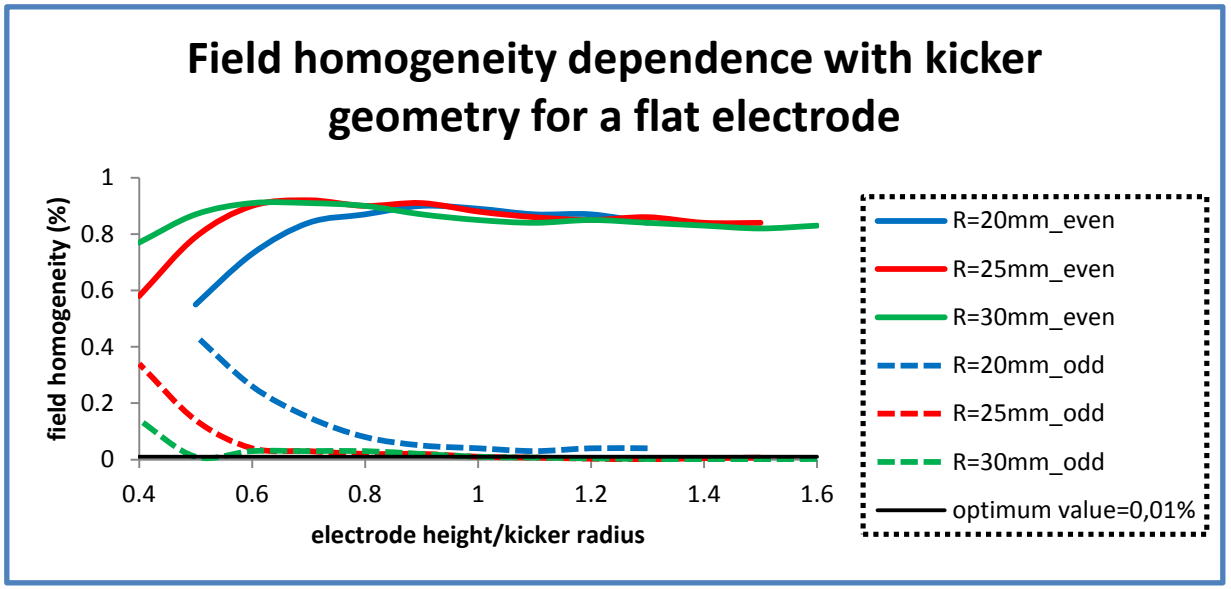
The challenging value required for the field homogeneity at the center of the kicker is achieved with minimum kicker radius in the case of flat shape electrodes

Parameter	Optimum value
Kicker radius	24.625 mm
Aperture	20 mm
Electrode height	24.2 mm
Electrode thickness	4 mm
Electrode edge length	4.9 mm
Electrode edge angle	45°

Odd characteristic impedance = 37.3 Ω
Even characteristic impedance = 50.4 Ω

2) CROSS SECTION DESIGN OF THE STRIPLINE KICKER FOR CLIC DR





Aperture = 20 mm
Electrode thickness = 4mm
Electrode edge length = 5 mm
Electrode edge angle = 45°

R = 20 mm → h/R = 0,68
$(Z_0)_e$ = 49,5 Ω
$(Z_0)_o$ = 40,7 Ω $(FH)_o$ = 0,16%

R = 25 mm → h/R = 1
$(Z_0)_e$ = 50,2 Ω
$(Z_0)_o$ = 36,8 Ω $(FH)_o$ = 0,01%

R = 30 mm → h/R = 1,18
$(Z_0)_e$ = 50,9 Ω
$(Z_0)_o$ = 33,7 Ω
$(FH)_o$ = 0,005%

3) DESIGN STUDY OF TAPERS

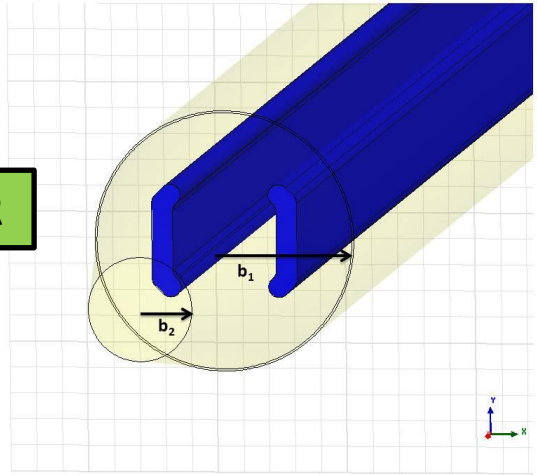
- An abrupt change in the cross section of a beam pipe will produce scattered fields when the beam passes through the kicker.
- By using long gradual tapers the total energy loss may be drastically reduced.
- Approximate criteria to choose a reasonable taper length, valid for short bunches:

MINIMUM TAPER LENGTH

$$\frac{l\sigma}{(b_1 - b_2)^2} > 1$$

***l* > 12.5 – 14 cm for CLIC DR**

- l = electrode length
- b_1 = stripline kicker tube radius
- b_2 = beam pipe radius
- σ = bunch length



Connical transitions will be used to connect the 25 mm stripline kicker tube, with the 10 mm beam pipe of CLIC DR.

4) BEAM COUPLING IMPEDANCE

PERMISSIBLE BEAM COUPLING IMPEDANCE PER KICKER SYSTEM

- Longitudinal beam coupling impedance: $Z_{\parallel}\left(\frac{f}{f_0}\right) = \frac{Z_{\parallel}}{n} = 0.05\ \Omega$
- Transverse beam coupling impedance: $Z_{\perp} = 200\ k\Omega/m$

ANALYTICAL EQUATIONS FOR UNTAPERED STRIPLINES BPMs

LONGITUDINAL BEAM COUPLING IMPEDANCE

$$Z_{//} = 2Z_c\left(\frac{\phi_0}{2\pi}\right)^2\left[2\sin^2\left(\frac{\omega L}{c}\right) - i\sin\left(\frac{2\omega L}{c}\right)\right]$$

TRANSVERSE BEAM COUPLING IMPEDANCE

$$Z_{\perp} = \left[\frac{Z_{//}}{\omega}\right]_{pair}\left[\frac{c}{b^2}\right]\left[\frac{4}{\phi_0}\right]^2\left[\sin^2\left(\frac{\phi_0}{2}\right)\right]$$

ANALYTICAL EQUATIONS FOR TAPERED STRIPLINES BPMs

TAPERING FACTOR (S. Smith, SLAC)

$$f_{taper} = \frac{\sin^2\left(\frac{\omega l}{c}\right)}{\left(\frac{\omega l}{c}\right)^2}$$

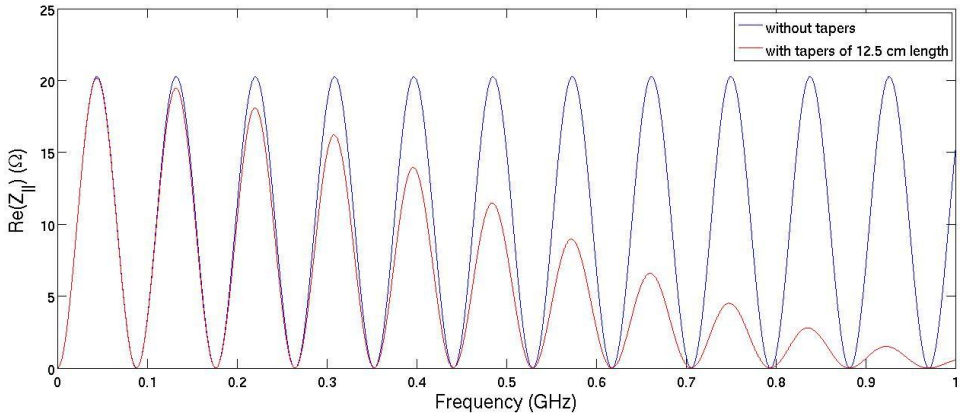
$$Z_{\parallel tapered} = f_{taper}\, Z_{\parallel}$$

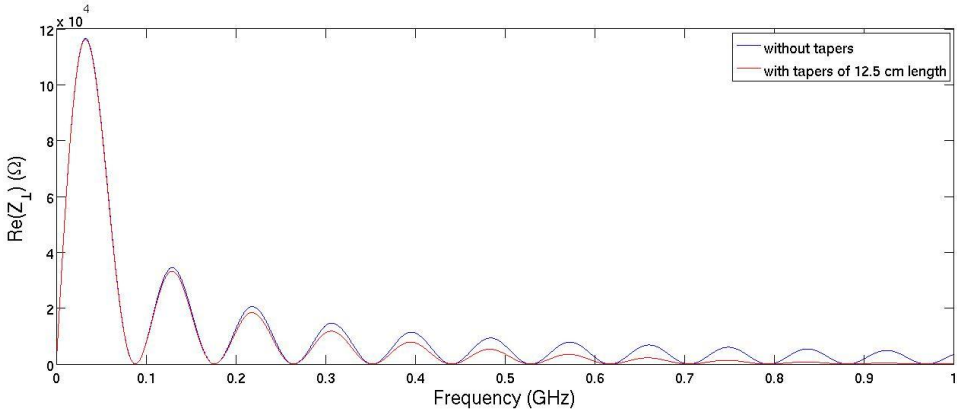
$$Z_{\perp tapered} = f_{taper}\, Z_{\perp}$$

- Z_c is the even characteristic impedance
- Φ_0 is the coverage angle
- L is the electrode length
- c is the speed of light
- b is the kicker radius
- l is the taper length

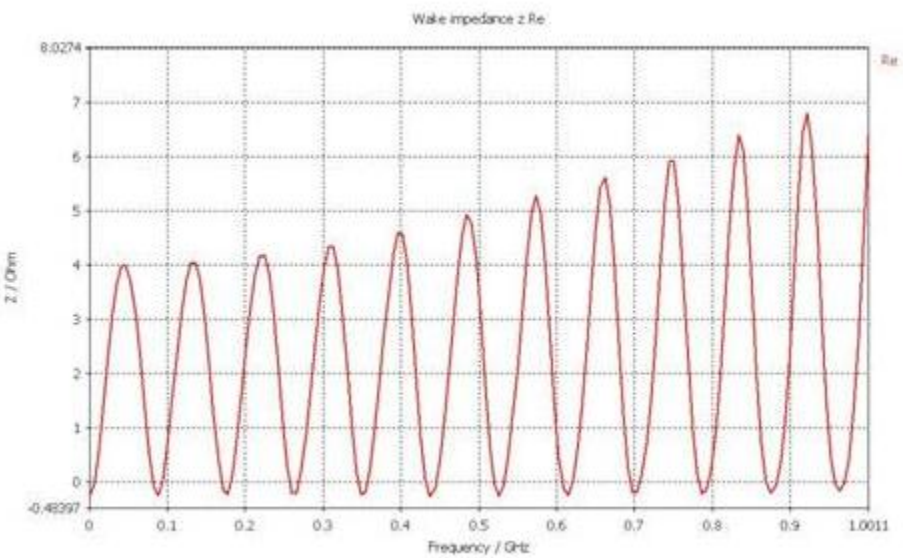
4) BEAM COUPLING IMPEDANCE

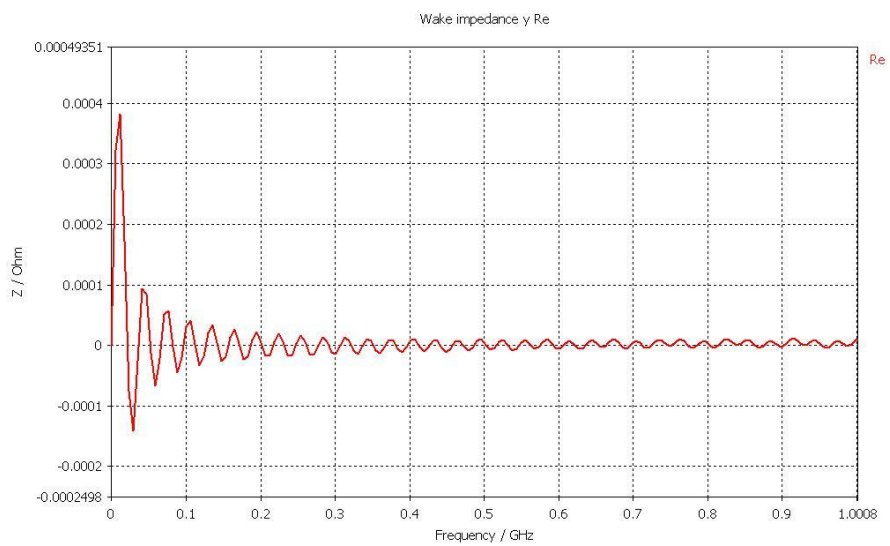
PREDICTIONS FROM ANALYTICAL EQUATIONS





SIMULATIONS FOR THE UNTAPERED KICKER





5) TEST CAMPAIGN

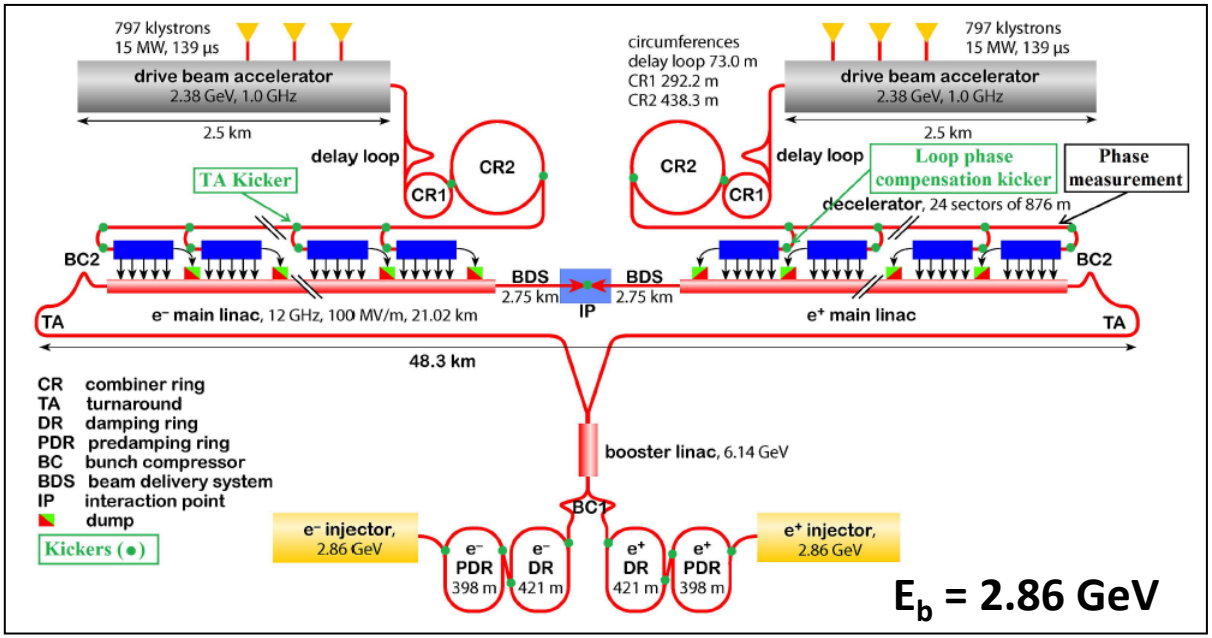
1) Laboratory test at CERN
   - Verification of dimensions, including tapering;
   - Vacuum compatibility;
   - Longitudinal and transverse beam coupling impedance measurements;
   - Field homogeneity
   - Others…
2) Test in ALBA, without inductive adder
   - Field homogeneity measurements with DC current supplies
   - Beam impedance measurements with circulating beam (transverse impedance measurements with DC supplies and a closed bump).
   - A proposal is being prepared for ALBA
3) Test in ATF2, with the inductive adder
   - Stripline kicker + inductive adder will be tested from the point of view of stability issues
   - The kicker will be installed in a straight section in the ATF2 FFS, which is provided with cavity BPMs.
   - Due to the fact that the kicker will not extract the beam in ATF2, we have the possibility to match as much as possible the parameters to the performances of CLIC DR ones.
   - A formal proposal will be presented in June 2012 in front of the ATF2 Technical Board.

Parameter	CLIC DR	CLIC PDR	ATF2 (draft)
Beam energy (GeV)	2.86	2.86	1.30
Total kick deflection angle (mrad)	1.5	2.0	1.5
Deflection	horizontal	horizontal	horizontal
Aperture (mm)	20	40	20
Beam pipe range (mm)	20 - 30	40 - 50	20 - 30
Effective length (m)	1.7	3.4	1.7
Field rise/fall time (ns)	560/1000	428/1000	560/1000
Pulse flat top duration (ns)	900/160	900/160	900/160
Repetition rate (Hz)	50	50	1.56
Vacuum (mbar)	10^{-10}	10^{-10}	10^{-10}
Pulse voltage per stripline (kV)	± 12.5	± 17	± 5.5
Stripline pulse current [50 Ω load] (A)	± 250	± 335	± 115
Longitudinal beam coupling impedance (Ω)	< 0.05 · n	< 0.05 · n	< 0.05 · n
Transverse beam coupling impedance (kΩ/m)	< 200	< 200	< 200
Peak beam current (A)	110/120	70/50	60/20/30
Minimum bunch spacing (ns)	1/0.5	1/0.5	2.8/140
Bunch length (ps)	6/5.3	10/14	16.7

6) CONCLUSIONS

- The design of the stripline kicker for CLIC Damping Ring is almost done: 50 Ω even mode impedance and ± 0.01% field homogeneity over a cercle of 1 mm radius between the striplines have been achieved by using flat electrodes and cylindrical beam pipe. For the optimum geometry, the odd characteristic impedance is 37 Ω, and this will traduce in power reflections.
  - Further research is being carried out to diminish the power lost due to the impedance mismatching.
- The effect of the tapers is presently being investigated: tapers of at least 12-14 cm are needed between the stripline kicker tube and the beam pipe to damp beam coupling impedance at high frequencies. With this taper length, both longitudinal and transverse coupling impedance are almost zero above 1 GHz of frequency.
- Investigations are ongoing to understand differences between predictions and analytical equations.
- Tests with/without beam and with/without the inducte adder are being planned for the two next years.

1) INTRODUCTION



The extraction kicker for the Damping Rings will deflect the e^-/e^+ beam 1.5 mrad in the horizontal plane.

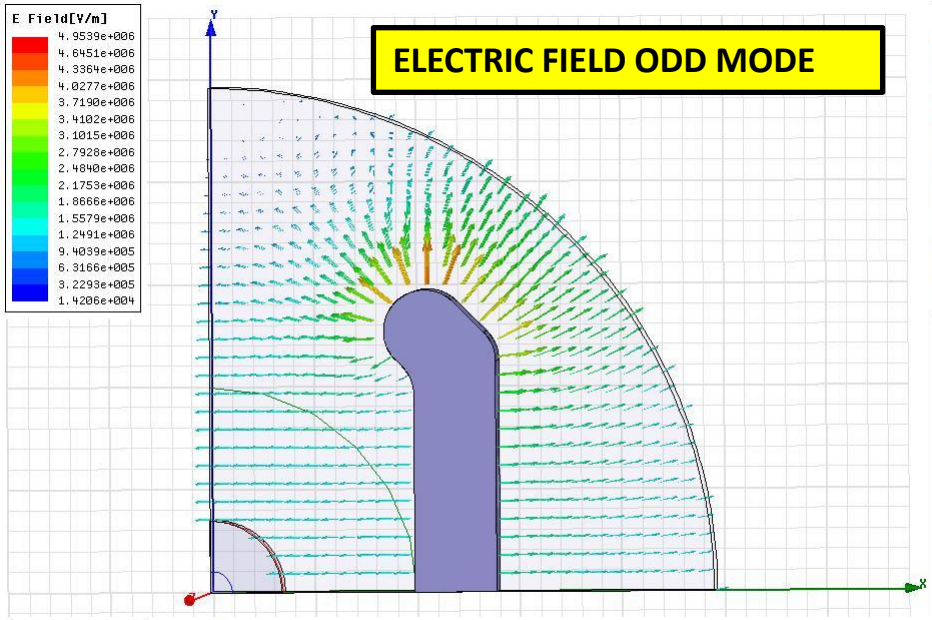
1 GHz baseline

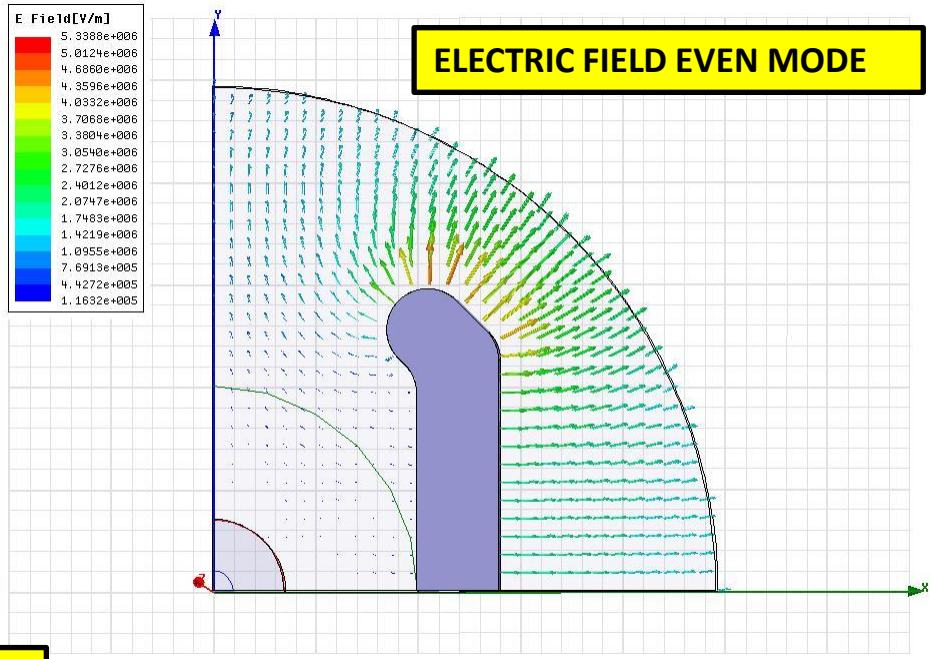
- Beam current = 110 A
- Bunch length = 6 ps
- Minimum spacing between bunches = 1 ns

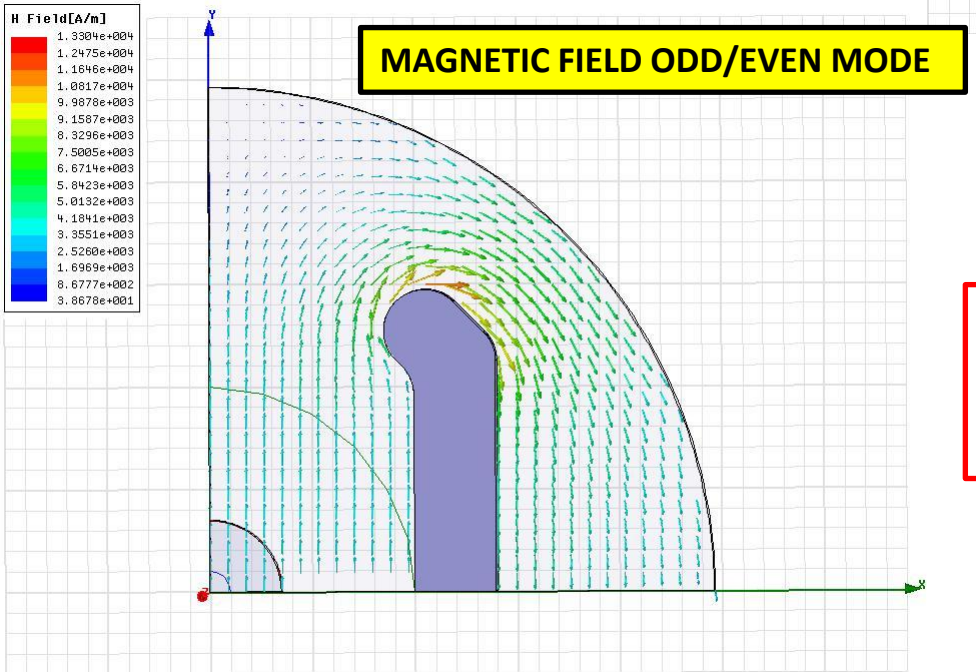
2 GHz baseline

- Beam current = 120 A
- Bunch length = 5.3 ps
- Minimum spacing between bunches = 0.5 ns

2) CROSS SECTION DESIGN OF THE STRIPLINE KICKER FOR CLIC DR







Plots normalized to a power input of 3.125 MW, which corresponds to a voltage input of 12.5 kV

- ❑ Maximum electric field expected at the kicker walls: 2 MV/m
- ❑ Kilpatrick limit: 2.35 MV/m

3) STRIPLINE KICKER EFFICIENCY

Transverse shunt impedance (R'_s or $R_\perp T^2$): figure of merit which relates the strength of the transverse voltage with the input power. Therefore, it is a measure of the efficiency of the kicker.

TRANSVERSE SHUNT IMPEDANCE FOR A STRIPLINE KICKER

$$R'_s = 2Z_0 \left(\frac{\tanh\left(\frac{\pi h}{a}\right)}{ka/2} \right)^2 \sin^2(kL)$$

- k = ω/c is the wave number
- h is the electrode height
- a is the striplines aperture
- Z_0 is the odd characteristic impedance.