Beam-based alignment performance in the main linac

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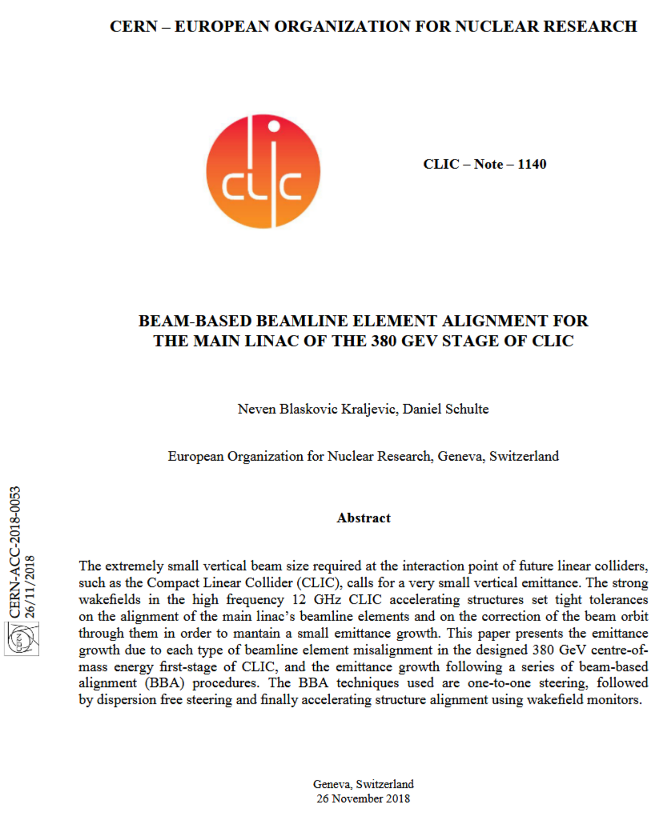
CLIC Note

- Presentation based on [CLIC Note 1140]
- Please refer to CLIC Note for PLACET commands



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CLIC – Note – 1140

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BEAM-BASED BEAMLINE ELEMENT ALIGNMENT FOR THE MAIN LINAC OF THE 380 GEV STAGE OF CLIC

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Abstract

The extremely small vertical beam size required at the interaction point of future linear colliders, such as the Compact Linear Collider (CLIC), calls for a very small vertical emittance. The strong wakefields in the high frequency 12 GHz CLIC accelerating structures set tight tolerances on the alignment of the main linac's beamline elements and on the correction of the beam orbit through them in order to mantain a small emittance growth. This paper presents the emittance growth due to each type of beamline element misalignment in the designed 380 GeV centre-of-mass energy first-stage of CLIC, and the emittance growth following a series of beam-based alignment (BBA) procedures. The BBA techniques used are one-to-one steering, followed by dispersion free steering and finally accelerating structure alignment using wakefield monitors.

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Linac imperfections

- Main linac imperfections assumed from CLIC CDR for 3 TeV design
- Tolerances could be relaxed at 380 GeV since main linac is shorter
- However, this would require upgrading the systems for better performance when the energy is upgraded
- Target: vertical emittance growth of <5 nm with a 90% likelihood

Linac imperfections

Imperfection	With respect to	Value
BPM offset	Wire reference	14 μm
Cavity tilt	Girder axis	141 μrad
BPM resolution		0.1 μm
Girder end point	Wire reference	12 μm
Girder end point	Articulation point	5 μm
Cavity offset	Girder axis	14 μm
Wake monitor	Structure centre	3.5 μm
Quadrupole roll	Longitudinal axis	100 μrad

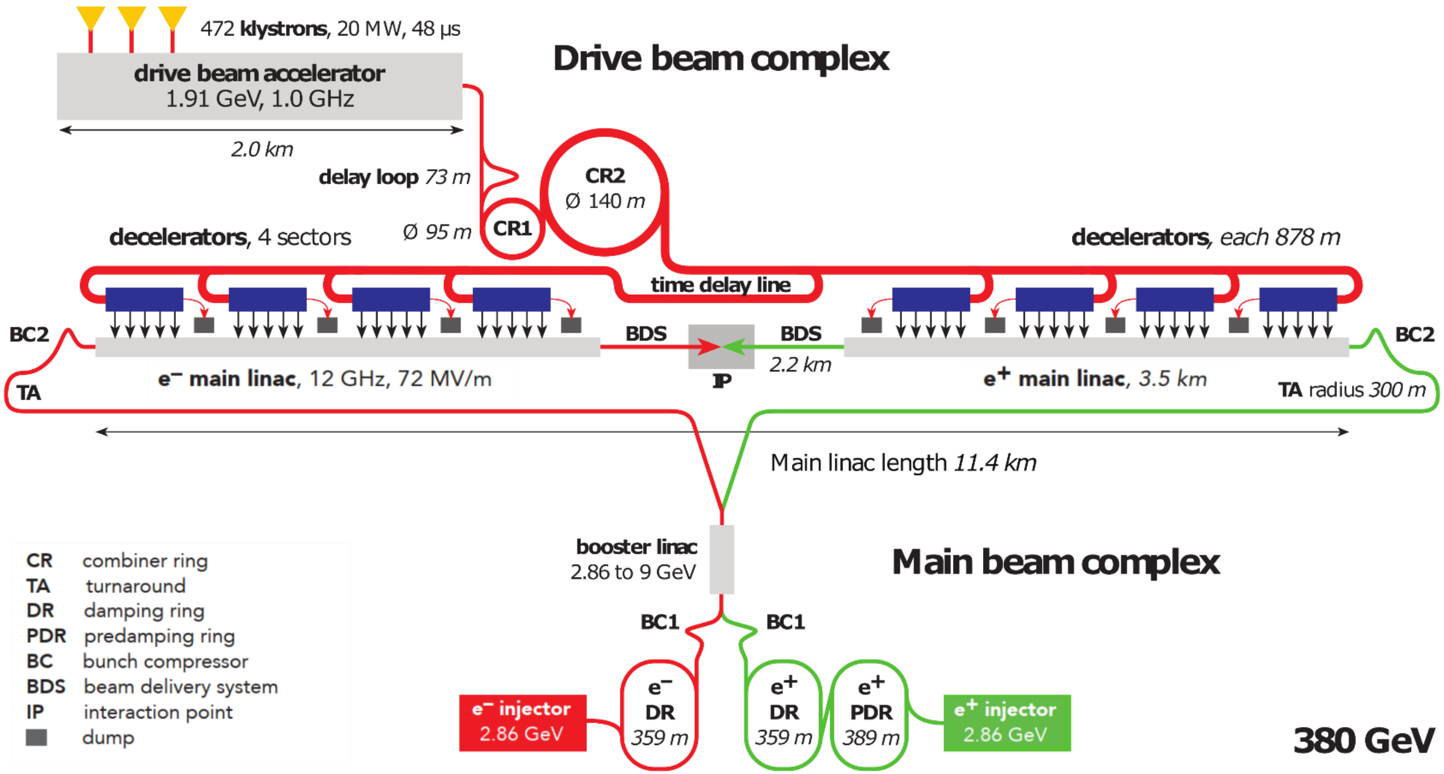
Beam-based alignment

- One-to-one steering (1-2-1):
  – Move quad to centre beam in next BPM
- Dispersion free steering (DFS):
  – Use 2 beams of different energies
  – Move quads to centre beam in BPMs & minimise orbit difference between 2 beams
- RF realignment (RF):
  – Move girders to minimise readings in accelerating structures' wakefield monitors

Main linac emittance growth

- Assume at the start of the main linac:
  - Vertical emittance: 10 nm
  - RMS fractional energy spread: 1.6%
- Compute emittance growth in the main linac for each imperfection (averaged over 1000 machines), after successive BBA techniques
- Consider first the drive-beam-based 380 GeV design for CLIC

Drive-beam-based design



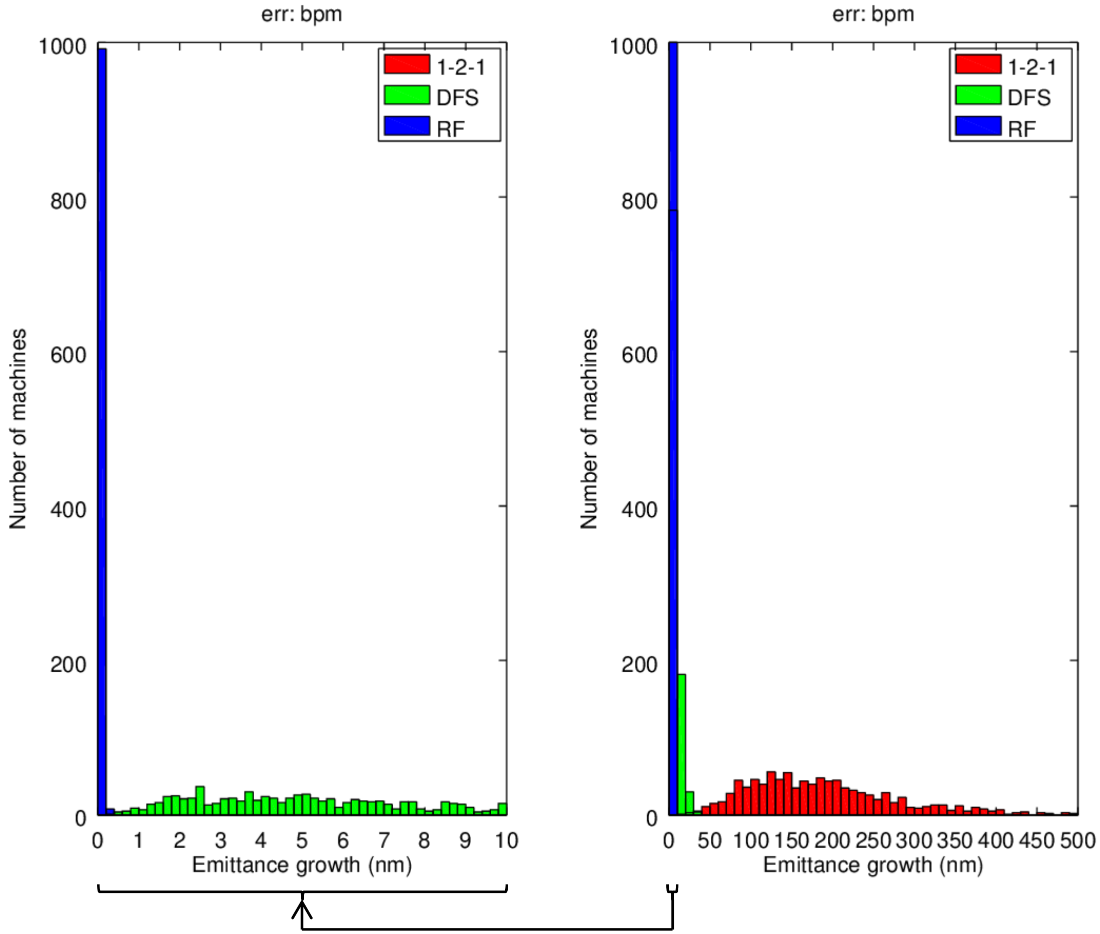
from the CLIC Project Implementation Plan (2018)

Drive-beam-based design

			$\Delta\epsilon_y$ [nm]		
Imperfection	With respect to	Value	1-2-1	DFS	RF
BPM offset	Wire reference	14 μm	188.99	7.12	0.06

- DFS mitigates effect of BPM offsets as they are common to both energy beams
- RF realignment uses wakefield monitors, not BPM readings

BPM offset



err: bpm
1-2-1
DFS
RF
Number of machines
Emittance growth (nm)
0
200
400
600
800
1000
0 1 2 3 4 5 6 7 8 9 10
err: bpm
1-2-1
DFS
RF
Number of machines
Emittance growth (nm)
0
200
400
600
800
1000
0 50 100 150 200 250 300 350 400 450 500

Drive-beam-based design

			$\Delta\epsilon_y$ [nm]		
Imperfection	With respect to	Value	1-2-1	DFS	RF
BPM offset	Wire reference	14 μm	188.99	7.12	0.06
Cavity tilt	Girder axis	141 μrad	0.12	0.40	0.27
BPM resolution		0.1 μm	0.01	0.76	0.03

- Cavity tilts lead to beam kicks, different for 2 beams of different energies
- DFS is sensitive to BPM resolution as it finds difference in position of 2 beams

Drive-beam-based design

Imperfection	With respect to	Value	$\Delta\epsilon_y$ [nm]		
			1-2-1	DFS	RF
BPM offset	Wire reference	14 μm	188.99	7.12	0.06
Cavity tilt	Girder axis	141 μrad	0.12	0.40	0.27
BPM resolution		0.1 μm	0.01	0.76	0.03
Girder end point	Wire reference	12 μm	12.91	12.81	0.07
Girder end point	Articulation point	5 μm	1.31	1.30	0.02
Cavity offset	Girder axis	14 μm	5.39	5.35	0.03

- RF realignment uses wakefield monitors mounted on cavities, so excellent to correct cavity offsets and girder offsets (as cavities are on girders)

Drive-beam-based design

			$\Delta\epsilon_y$ [nm]		
Imperfection	With respect to	Value	1-2-1	DFS	RF
BPM offset	Wire reference	14 μm	188.99	7.12	0.06
Cavity tilt	Girder axis	141 μrad	0.12	0.40	0.27
BPM resolution		0.1 μm	0.01	0.76	0.03
Girder end point	Wire reference	12 μm	12.91	12.81	0.07
Girder end point	Articulation point	5 μm	1.31	1.30	0.02
Cavity offset	Girder axis	14 μm	5.39	5.35	0.03
Wake monitor	Structure centre	3.5 μm	0.01	0.01	0.35

- RF realignment using wakefield monitors is sensitive to wake monitor alignment relative to cavity

Drive-beam-based design

Imperfection	With respect to	Value	$\Delta\epsilon_y$ [nm]		
			1-2-1	DFS	RF
BPM offset	Wire reference	14 μm	188.99	7.12	0.06
Cavity tilt	Girder axis	141 μrad	0.12	0.40	0.27
BPM resolution		0.1 μm	0.01	0.76	0.03
Girder end point	Wire reference	12 μm	12.91	12.81	0.07
Girder end point	Articulation point	5 μm	1.31	1.30	0.02
Cavity offset	Girder axis	14 μm	5.39	5.35	0.03
Wake monitor	Structure centre	3.5 μm	0.01	0.01	0.35
Quadrupole roll	Longitudinal axis	100 μrad	0.05	0.05	0.05

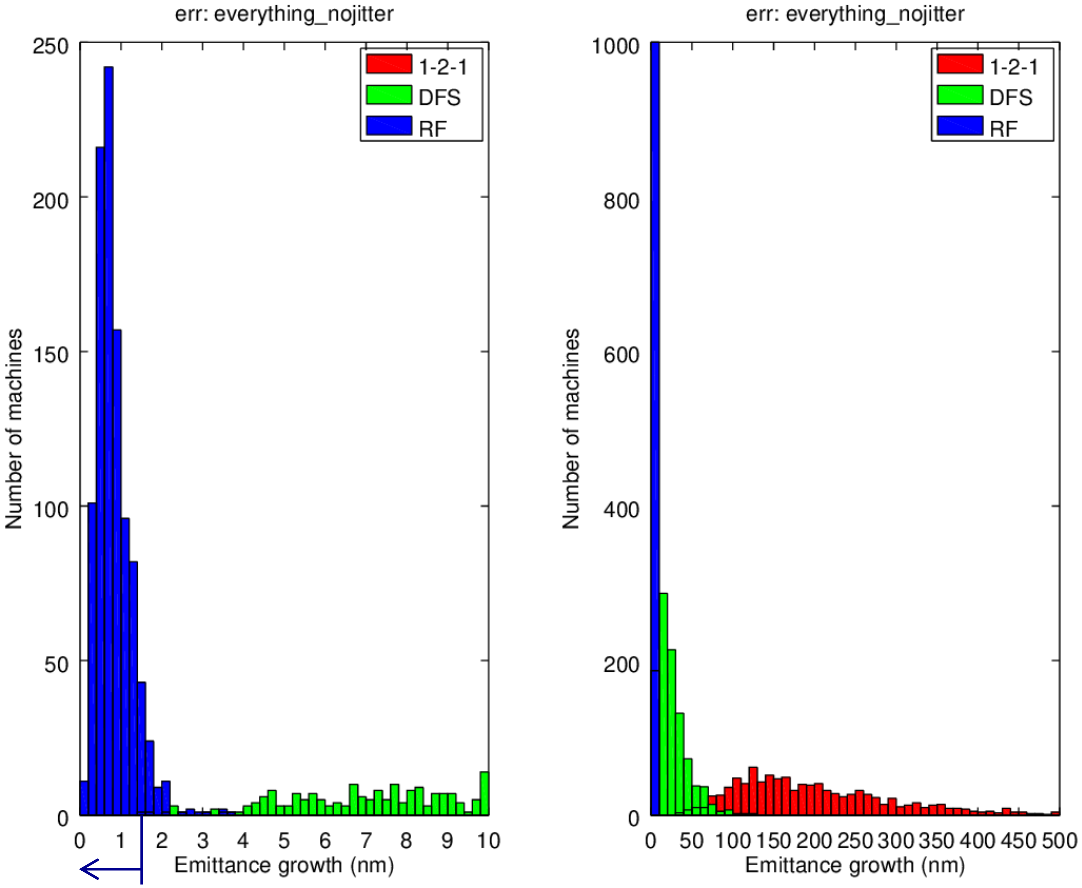
- x–y coupling is not targeted by these BBA techniques, as only vertical BBA is done

Drive-beam-based design

Imperfection	With respect to	Value	$\Delta\epsilon_y$ [nm] 1-2-1	DFS	RF
BPM offset	Wire reference	14 μm	188.99	7.12	0.06
Cavity tilt	Girder axis	141 μrad	0.12	0.40	0.27
BPM resolution		0.1 μm	0.01	0.76	0.03
Girder end point	Wire reference	12 μm	12.91	12.81	0.07
Girder end point	Articulation point	5 μm	1.31	1.30	0.02
Cavity offset	Girder axis	14 μm	5.39	5.35	0.03
Wake monitor	Structure centre	3.5 μm	0.01	0.01	0.35
Quadrupole roll	Longitudinal axis	100 μrad	0.05	0.05	0.05
All			204.53	25.88	0.83

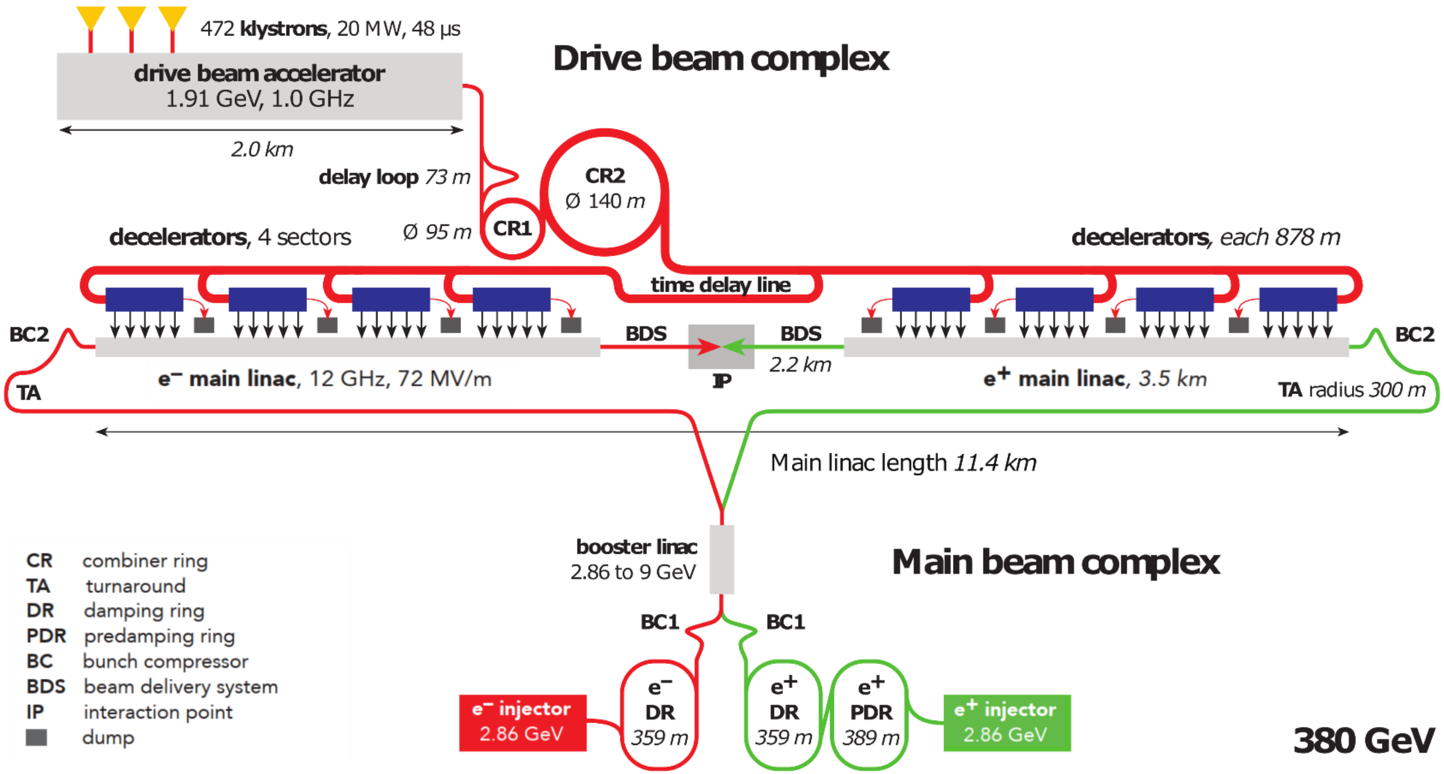
- Average overall emittance growth: < 1 nm

All imperfections



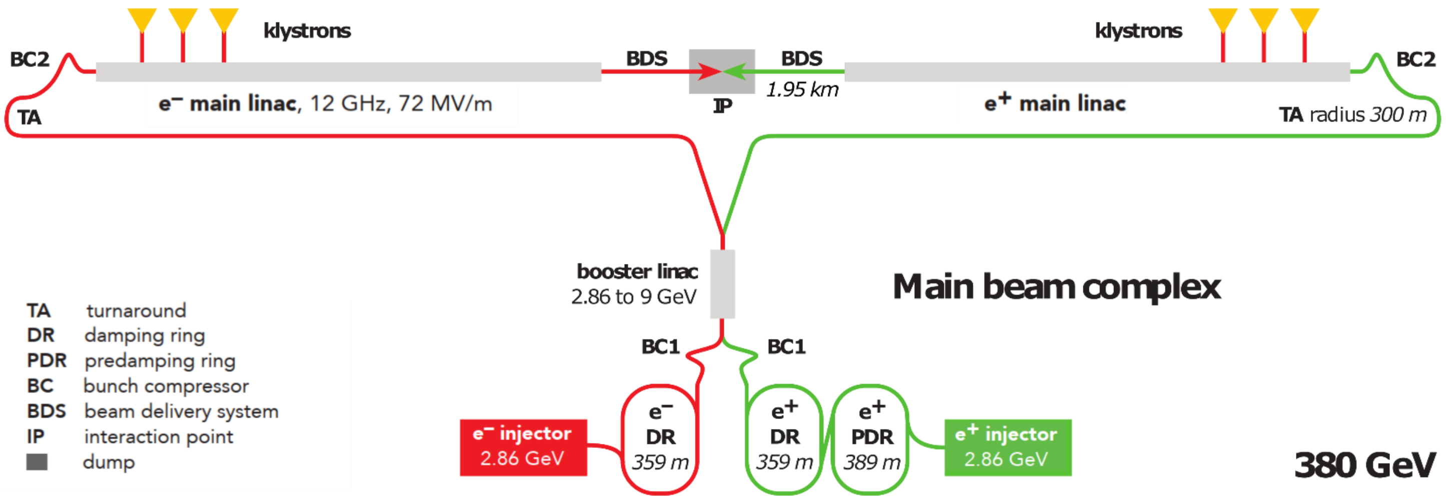
90% machines: <1.5 nm

Drive-beam-based design



from the CLIC Project Implementation Plan (2018)

Klystron-based design



adapted from the CLIC Project Implementation Plan (2018)

Klystron-based design

- Klystron-driven accelerating structures have smaller aperture, so larger wakefield

Parameter	Symbol	Drive Beam	Klystron
First iris radius / RF wavelength	a_1/λ	0.1625	0.145
Last iris radius / RF wavelength	a_2/λ	0.104	0.09

- Bunch charge & length reduced to compensate emittance growth

	Drive-beam-based	Klystron-based
Bunch charge [10^9]	5.2	3.87
Bunch length [μm]	70	60

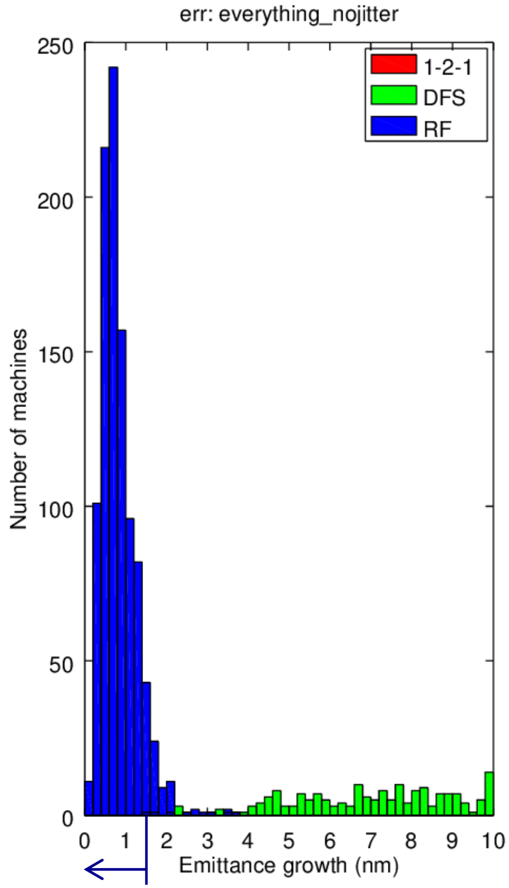
from the CLIC Project Implementation Plan (2018)

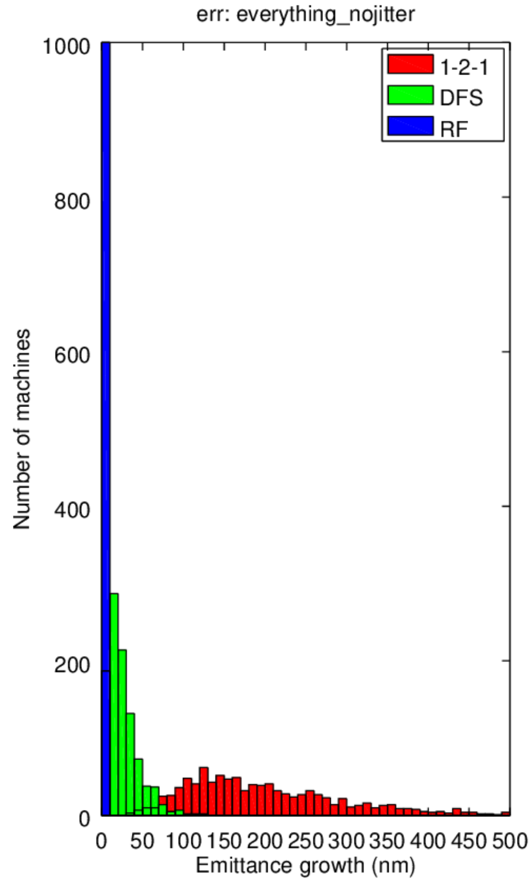
Klystron-based design

Imperfection	With respect to	Value	$\Delta\epsilon_y$ [nm] 1-2-1	DFS	RF
BPM offset	Wire reference	14 μm	154.54	14.01	0.10
Cavity tilt	Girder axis	141 μrad	0.10	0.47	0.25
BPM resolution		0.1 μm	0.01	1.03	0.02
Girder end point	Wire reference	12 μm	11.37	11.31	0.07
Girder end point	Articulation point	5 μm	1.45	1.45	0.02
Cavity offset	Girder axis	14 μm	5.51	5.50	0.04
Wake monitor	Structure centre	3.5 μm	0.01	0.01	0.40
Quadrupole roll	Longitudinal axis	100 μrad	0.04	0.04	0.04
All			176.68	32.72	0.84

- Average overall emittance growth: < 1 nm

All imperfections





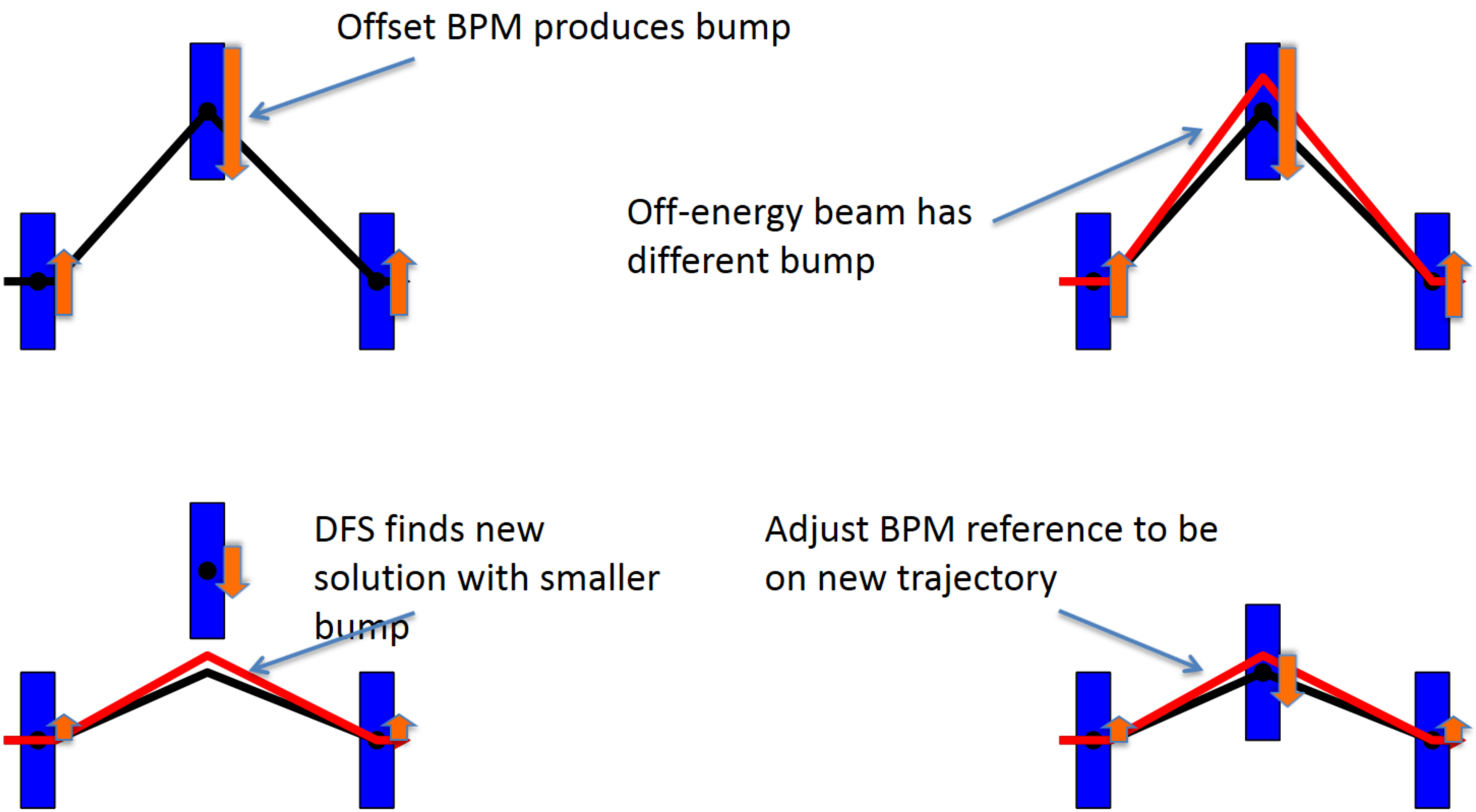
90% machines: <1.5 nm

Conclusions

- For both drive-beam-based & klystron-based CLIC 380 GeV designs, emittance growth in main linac with all imperfections:
  - Average over 1000 machines: <1 nm
  - 90% of machines: <1.5 nm
- Falls well within <5 nm budget for 90% machines

Thank you for your attention!

Dispersion Free Illustration



from Daniel Schulte at CERN Accelerator School (Zürich, 2018)