Key Luminosity Issues of the Ring to Main Linac

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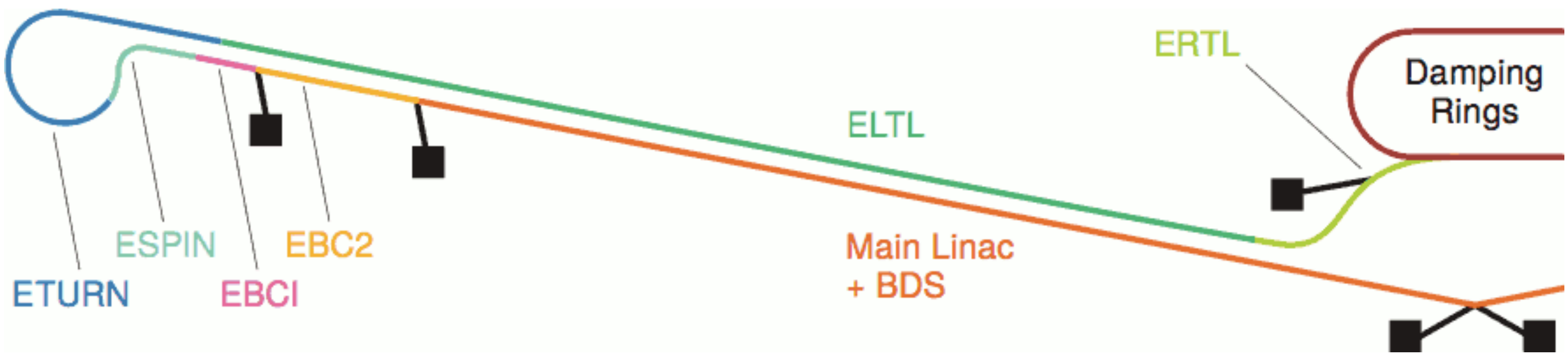
LCWS13 – Nov 11-15, 2013 – The University of Tokyo, Japan

ILC RTML Layout

TDR



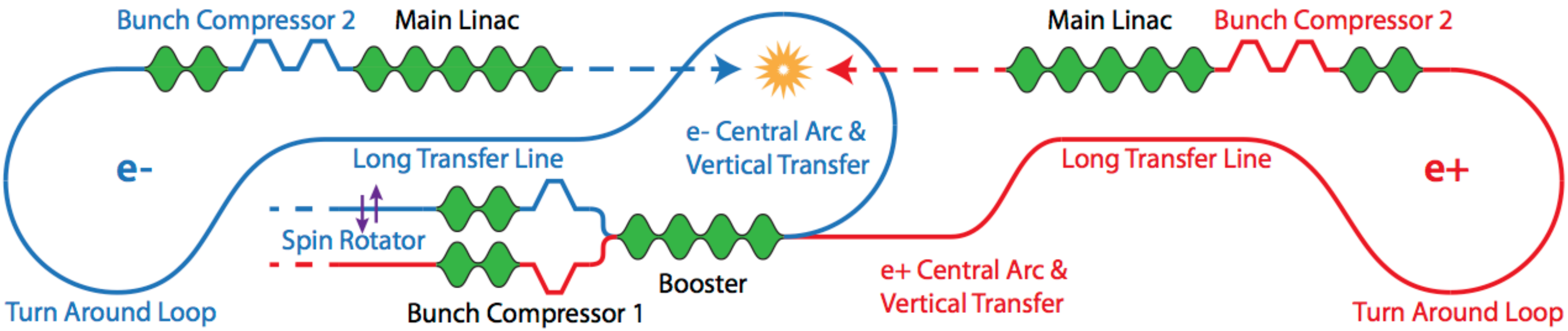
Entrance beam parameters

- Initial bunch length = 6/9 mm
- Final Bunch length = 1 mm
- Initial energy = 5 GeV
- Initial energy spread < 0.15%

Exit beam parameters

- Bunch length = 0.3/0.15 mm
- Energy = 15 GeV
- Energy spread = 1.07%

CLIC RTML



Particle energy	E_0	2.86	GeV
Bunch charge	Q_0	0.65	nC
RMS bunch length	σ_s	1600	µm
RMS energy spread	σ_E / E_0	0.13	%
uncorr. energy spread	σ_E / E_0	0.13	%
Energy chirp	u	0	1/m
Normalized emittance	$\varepsilon_{n,x}$	500	nm rad
	$\varepsilon_{n,y}$	5	nm rad
Polarization	P	?	%
Phase offset 2GHz	$\Delta\phi$	0	deg

@ exit of damping rings

Particle energy	E_0	9	GeV
Bunch charge	Q_0	> 0.6	nC
RMS bunch length	σ_s	44	µm
RMS energy spread	σ_E / E_0	< 1.7	%
uncorr. energy spread	σ_E / E_0	< 1.7	%
Energy chirp	u	0	1/m
Normalized emittance	$\varepsilon_{n,x}$	< 600	nm rad
	$\varepsilon_{n,y}$	< 10	nm rad
Polarization	P	?	%
Phase offset 12 GHz	$\Delta\phi$	0	deg

@ entrance of main linac

Overview of the main issues

- Emittance preservation
- Transverse beam stability
- Magnetic stray fields
- Challenging instrumentation
- RF Phase / amplitude stability
- Slow and fast extraction lines

Low emittance transport

EMITTANCE BUDGETS	Initial emittance x/y	Design budget x/y	Static imp. budget x/y	Dynamic imp. budget x/y	Max emittance at exit
CLIC RTML	500 nm / 5 nm	60 nm / 1 nm	20 nm / 2 nm	20 nm / 2 nm	600 nm / 10 nm (*)
ILC RTML	8 μm / 20 nm	2 μm / 10 nm			10 μm / 30 nm (**)

(*) At RTML exit; (**) At LINAC exit

- Design emittance growth
  - ISR/CSR constraints, resistive wall wakes
  - this is addressed by design: both designs meet the nominal expected performances
- Static misalignments
  - Tight budgets in both systems
  - Performances aren't quite met: more efforts is needed
- Budgets not clearly defined for the ILC (static / dynamic)

Static misalignments

- Errors:
  - In ILC, agreed on "standard" errors (next page)
  - CLIC "reasonable" pre-alignment is assumed
  - Random Gaussian distributions are used for most studies
    - This model should be improved

- Beam-based alignment: several procedures have been envisaged
  - Magnetic shunting / Ballistic upstream the BC (BPM alignment)
  - DMS (Dispersion Matching Steering) / DFS correction
  - Dispersion bumps and cryomodule tilt adjustment will be necessary
  - For dispersion measurement, change beam energy in BC1/BC2 (phase/amplitude) –tricky
  - BPM scale error is important ← non-zero design dispersion

- Specific problems to ILC:
  - ILC: Couplers RF-Kicks and Wakes
  - Return line follows the earth curvature

ILC: Alignment and BPM requirements

"standard" alignment errors

Error	RTML/ML Cold	with respect to	RTML warm
Quad Offset	300 µm	cryo-module	150 µm (init)
Quad roll	300 µrad	design	300 µrad
RF Cavity Offset	300 µm	cryo-module	------
RF Cavity tilt	300 µrad	cryo-module	------
BPM Offset (initial)	300 µm	cryo-module	300 µm
Cryomodule Offset	200 µm	design	-----
Cryomodule Pitch	20 µrad	design	-----
Bend offset	-----		300 µm
Bend Roll	------		300 µrad

Strength Stability requirements

	cold	warm
Quad	1E-4	1E-5
Bend	---	1E-5
Corrector	1E-4	1E-3
Sext.	---	1E-5
Oct.	---	1E-5

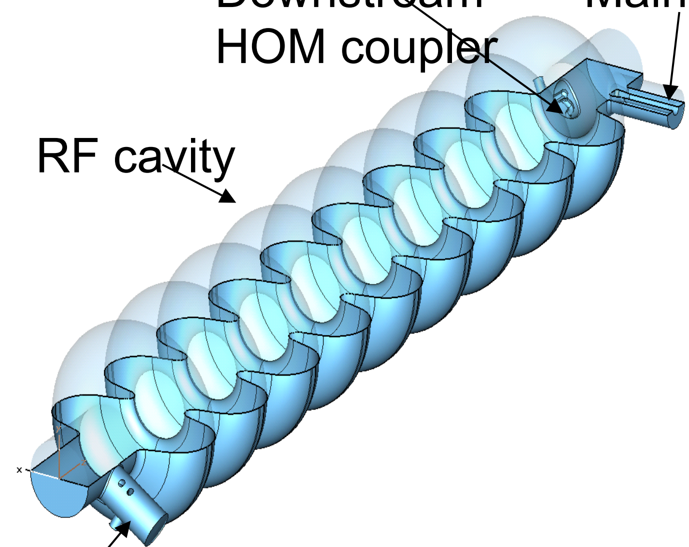
Independent Gaussian Random assumed in evaluation of all errors.
Not based on realistic survey/alignment models.
Distance range up to betatron period, ~400 m, is important.

Emittance Growth in ILC RTML

Region	Errors	Emittance Increase (nm)		Correction
		average	90% CL	
Escalator + Getaway + RL	X/Y Offsets	0.48	0.52	KM + knobs + CC
	+ Quad Strength	0.68	1.25	KM + knobs + CC
	+ Quad/Sbend Roll	1.87	3.23	KM + knobs + CC
Turnaround + Spin Rotator (OFF)	X/Y Offsets	2.26	5.33	KM + knobs
	+ Quad/Sbend Strength	3.69	8.12	KM + knobs
	+ Quad/Sbend Roll	6.11	12.73	KM + knobs
Turnaround + Spin Rotator (ON)	X/Y Offsets	2.14	4.83	KM + knobs
	+ Quad/Sbend Strength	4.63	9.42	KM + knobs
	+ Quad/Sbend Roll	6.86	13.66	KM + knobs
Entire "Front End"	X/Y Offsets	1.06	1.58	KM + knobs + CC
	+ Quad/Sbend Strength	2.01	3.51	KM + knobs + CC
	+ Quad/Sbend Roll	5.36	9.94	KM + knobs + CC

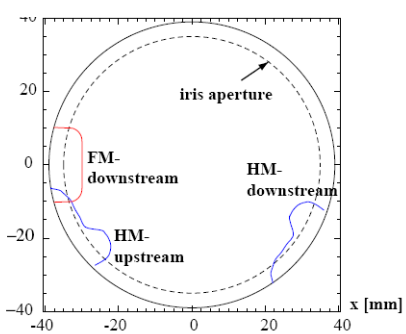
- Dynamic effects are not included
- Emittance growth is large (pre-RDR budget 4nm, might be ≤10nm)
- Need further studies to reach goal for emittance growth
- Cross-checking with different codes (important)

Simulations of Coupler Kick and Wakes



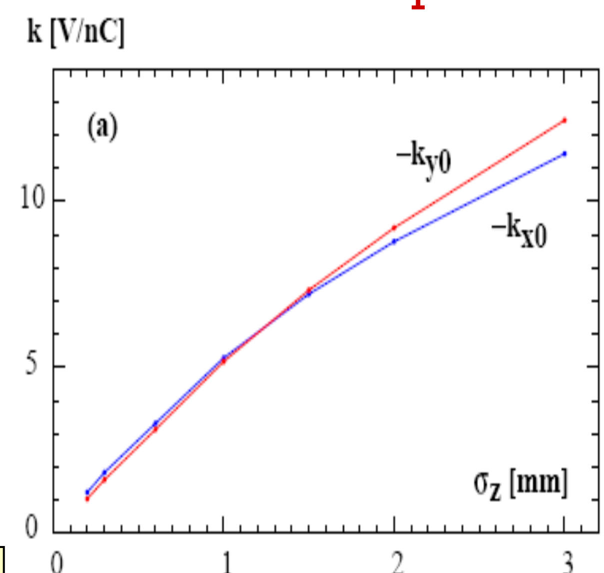
The couplers break the RF field symmetry and cause transverse RF kick and Wakes DESY,2007. Simulations DESY/FNAL/SLAC

Total RF KICK	FNAL $Q=3.5\times10^6$ HFSS	DESY $Q=2.5\times10^6$ MAFIA	SLAC $Q=3.5\times10^6$ OMEGA3P
$10^6 \cdot (V_x/V_z)$	-105.3+69.8i	-82.1+58.1i	-88.3-60.2i*
$10^6 \cdot (V_y/V_z)$	-7.3+11.1i	-9.2+1.8i	-4.6+5.6i

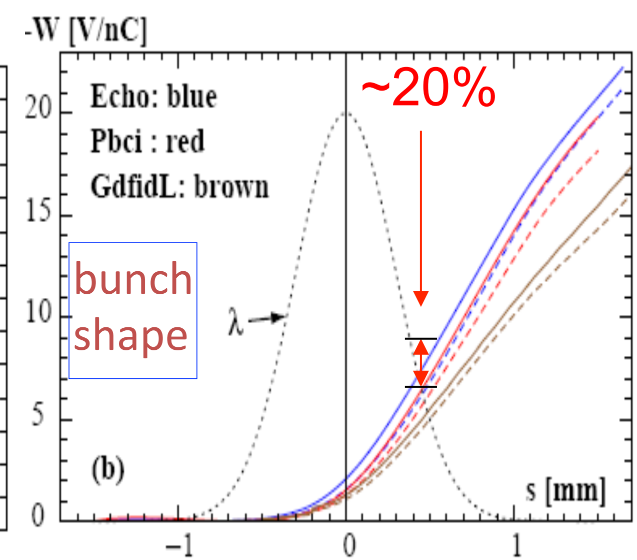


The profiles of the 3 couplers, as seen from the downstream end.

Coupler Transverse Wakefield



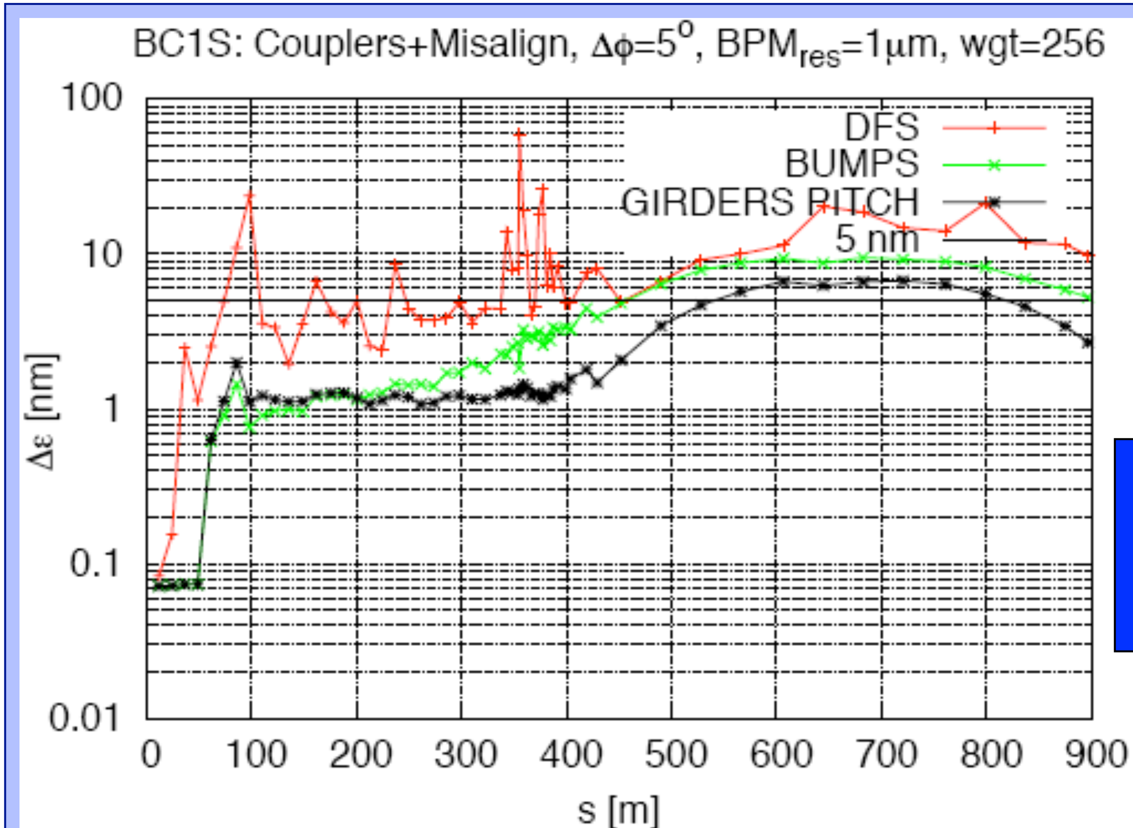
On-axis kick factor vs. σ_z



$W_x(s)$-solid,, $W_y(s)$-dashed for σ_z = 300 μm.

Effect of couplers on emittance growth see in V.Yakovlev talk

Coupler and Misalignments in BC1S



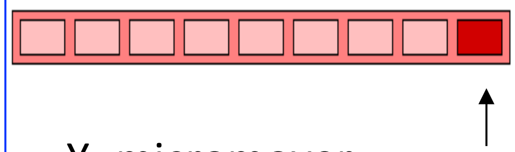
- Emittance Growth along the beamline, 1 machine

10 nm
5 nm
2.6 nm

2.2 nm from coupler only

New proposal !!!

Girder Pitch



Y- micromover:
- Range 300 um
- Step size 10 um

#N of adjustable CM's

- RF section of BC1S - 1 every 2 (total 3)
- Pre-linac: 1 every 12 CM's (total 3)

- BC1S (incl. diagnistics+matching+Pre-linac (5➔15 GeV))
- Standard misalignments (300 um/300urad); ISR +coupler RF kick/wake
- 1-to-1, DFS and bumps, girder optimization

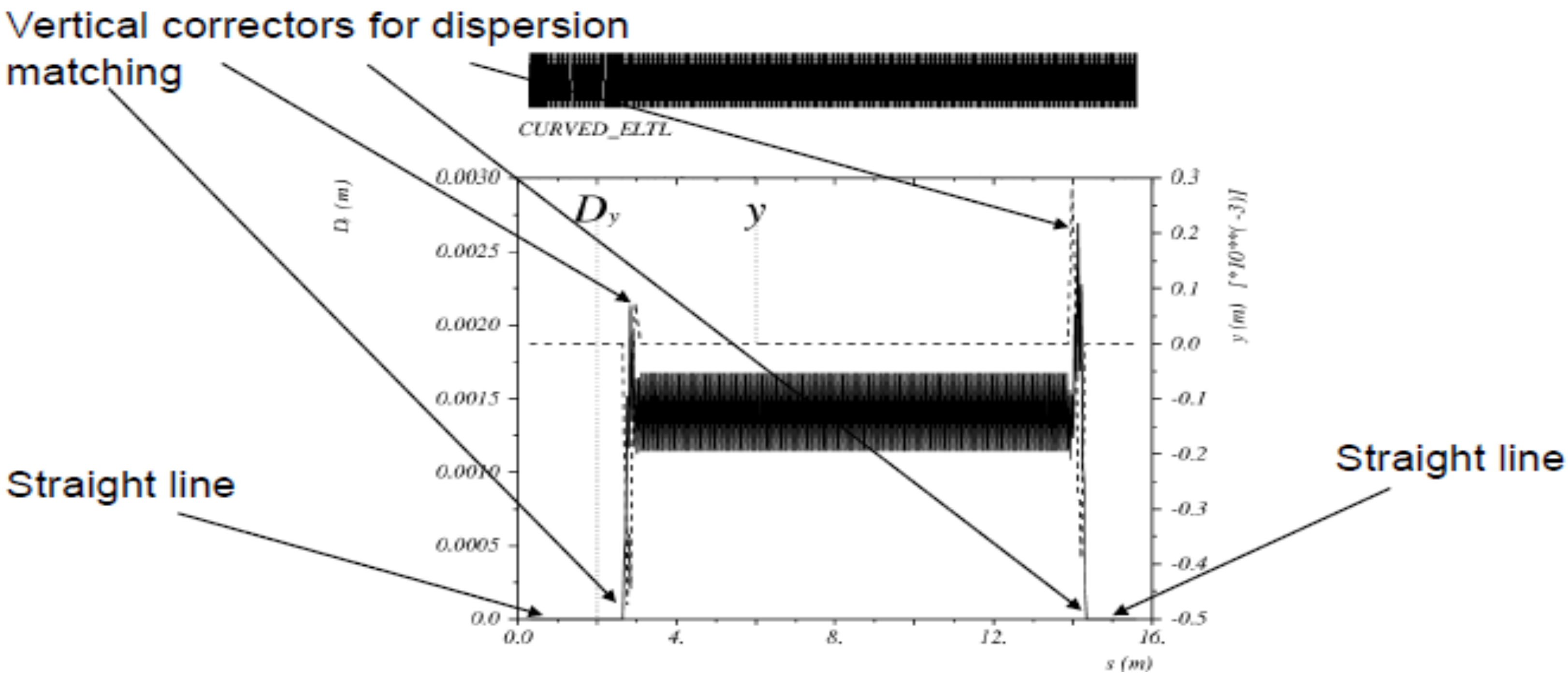
Emittance growth summary in BCs

Region	Errors	Emittance Increase (nm)		Correction
		average	90% CL	
BC1+BC2	X/Y/X'/Y' Offsets	0.98	1.6	DFS + knobs + Girders
	+ Quad Strength	-	-	DFS + knobs + Girders
BC1+BC2 w/Couplers	X/Y/X'/Y' Offsets	1.09	1.48	DFS + knobs + Girders
	+ Quad Strength	-	-	DFS + knobs + Girders
BC1S w/Couplers	X/Y/X'/Y' Offsets	2.3	-	DFS + knobs + Girders
	+ Quad Strength	-	-	DFS + knobs + Girders

- **Emittance growth due to misalignments and couplers seems to compensated both for BS1S and BC1+BC2**
- **Girder pitch optimization is very effective to counteract coupler kicks, both for BS1S and BC1+BC2**
- **In BC1S, Crab Cavity seems to be similar effective, but it would require a new hardware and slight redesign of the cryomoodule**

Return line following the earth's curvature

Vertical offset and dispersion of beams in curved ELTL/PLTL



Diffilult to measure nonzero dispersion accurately → BPM Scale should be calibrated.

See S. Seletskiy's talk on Thursday morning (Overview of BC design issues)

CLIC: static alignment tolerances

- Acceptable static misalignments after beam-based alignment (BBA) to produce 1 nm emittance growth
- 1 um BPM resolution
- In progress work: fine tuning of the parameters will lead to improvement (*)

Subsystem	Tol. after 1:1 - [μm]	Tol. after DFS - [μm]†
BC1	17 (11)	55 (24)
BOO	29 (19)	45 (23)
CA	7 (5)	14 (7)
LTL	153 (88)	280 (150)
TAL	6 (4)	9 (5)
BC2	1.4 (0.8)	3.5 (2)

$\dagger$ *Average tolerance and percentile 90 in brackets.*

- In SR and LTL tols. seem slack $\lesssim 200\mu m$
- In BC1 and Booster, tols. seem moderate $\lesssim 50\mu m$
- In CA (VT), TAL and BC2, tols. seem tight $\lesssim 15\mu m$

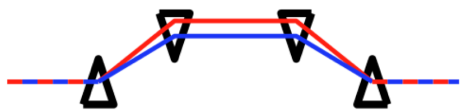
(*) with 0.1 um resolution BPMs the tighter tolerances are relaxed by a factor ≈1.3.

Emittance preservation - conclusions

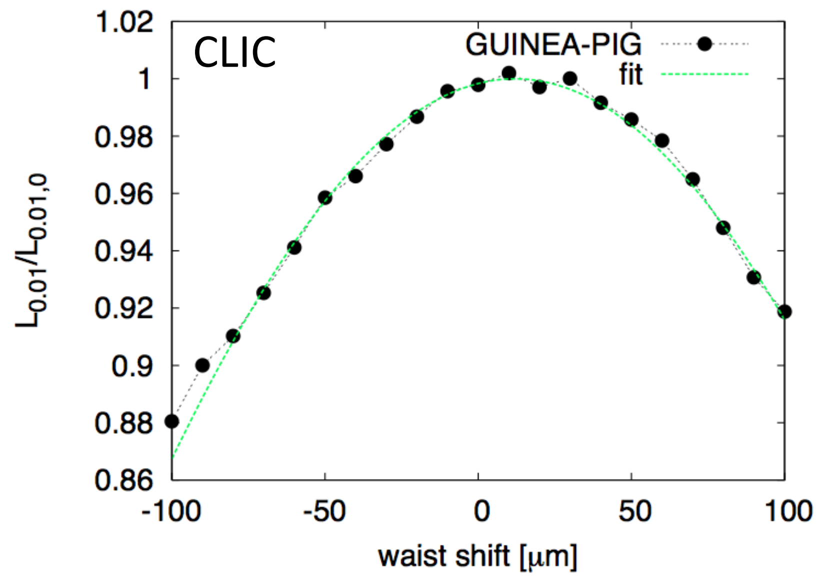
- **Performances aren't quite met yet**
  - Not badly, but vertical emittance growth in both machine is somewhat high
  - ILC goal 4nm with 90% (RDR), achieved 9nm with 90% and 5nm average
  - CLIC goal 2nm with 90% likelihood but 2.7nm average emittance growth, but only DFS used so far
- **To do list**
  - Studies should be completed with **better pre-alignment models**
  - **Integrated start-to-end simulations** must be performed
- **More effort needed**
  - Need for more simulation / theoretical work of BBA
  - Experimental tests of BBA are on-going, but we still need to test dispersion / emittance tuning bumps
  - Experimental tests of Girder Pitch Optimization?

RF Phase and Amplitude Jitter

RF errors in the bunch compressors (and the CLIC Booster linac) cause luminosity loss through waist shift at the IP



$$\delta z = R_{56} \Delta E / E$$



RMS tolerances require to limit the integrated luminosity loss to 2%, and to limit growth in IP energy spread to 10 % of the nominal energy spread.

ILC	Tolerance BC1 / BC2
Relative phase on the two sides	0.24° / 0.16° (ext. ref.)
Amplitude stability tolerance	0.5% / 0.35% rms

CLIC Main Beam	MB ref.	Ext. ref.
Phase error of BC1 RF @ 2GHz	0.08°	0.14°
Gradient error booster linac	1×10^{-3}	1×10^{-3}
Phase error of BC2 RF @ 12GHz	0.2°	0.2°

CLIC Drive Beam Requirements

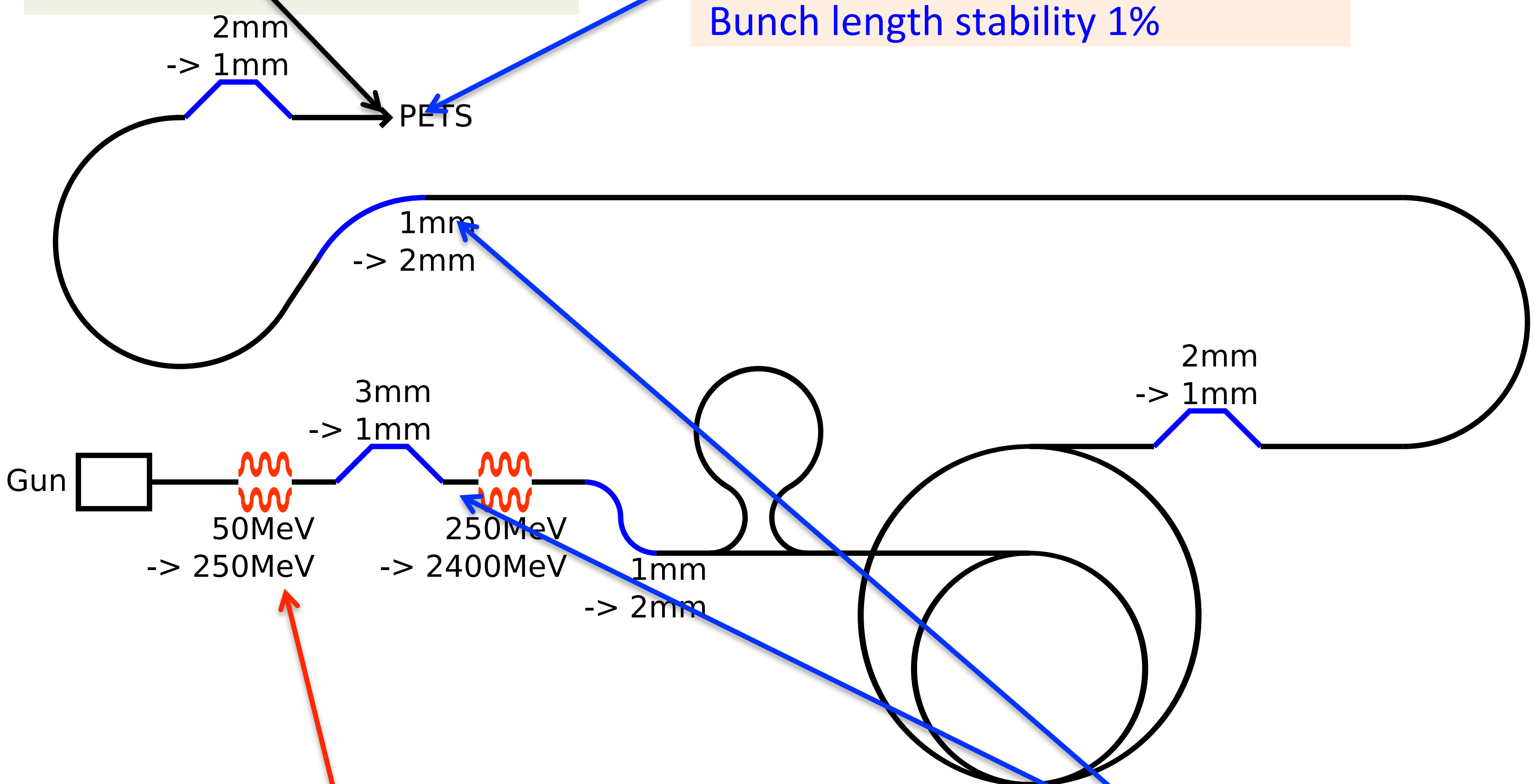
Emittance $\varepsilon_{x,y} \leq 150\mu m$

Transverse jitter $\leq 0.3\sigma$

Current stability $0.75 \cdot 10^{-3}$

Phase stability 0.2° @ 12GHz

Bunch length stability 1%



RF power stability 0.2%

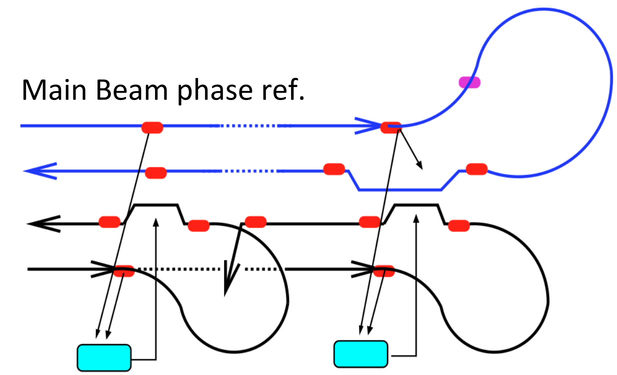
RF phase stability 0.05°

Phase stability 2.5° @ 12GHz

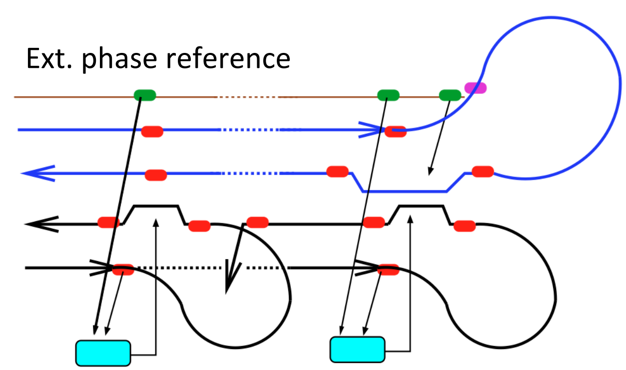
0.2° @ 1GHz

Addressing the problem

- Minimise beam phase jitter sources
  - Drive beam RF stability
    - Stable design
  - Lattice design
    - Reduced sensitivity to errors



- Develop beam-based correction feedbacks
  - RF feedback loop based on beam
  - Beam phase feedforward/feedback



- Require relevant components
  - Reference timing system
  - Instrumentation
  - LL RF (also in the DB, for CLIC)
  - kickers and amplifiers

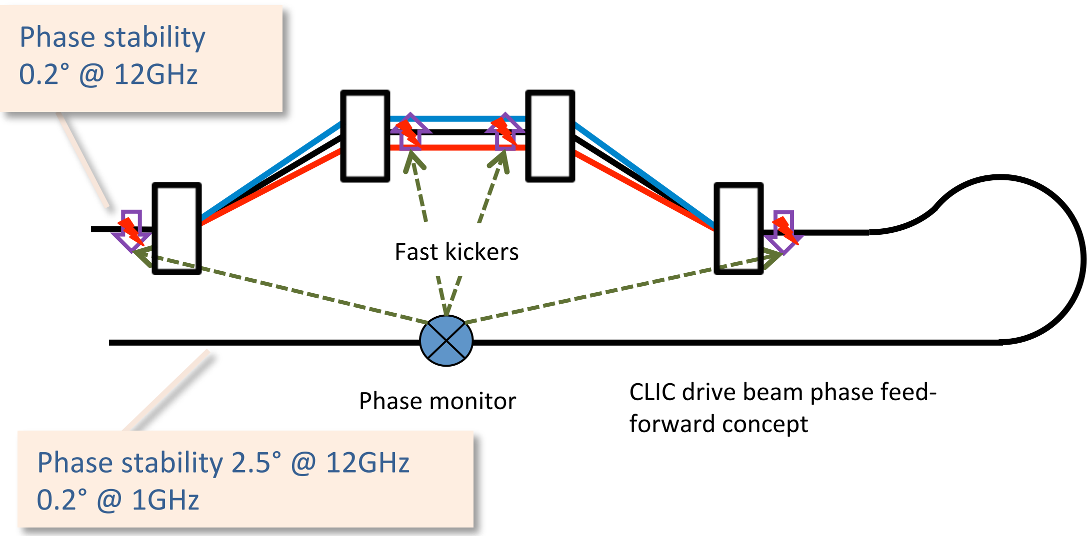
- Experimental determination of noise and test of correction schemes

RF Phase and Amplitude Jitter in ILC

- Low-level RF system for ILC benefits from the progresses and tests made at **FLASH**
- All LLRF systems now compensate beam loading using bunch-to-bunch charge measurements
- The amplitude and phase of the RF systems upstream of the bunch compressors are dynamically regulated in order to stabilise the downstream bunch-to-bunch energy and compression angle. This compensates for arrival-time jitter at the start of the bunch-train and any slewing over the length of the train.
- Beam-based feedback

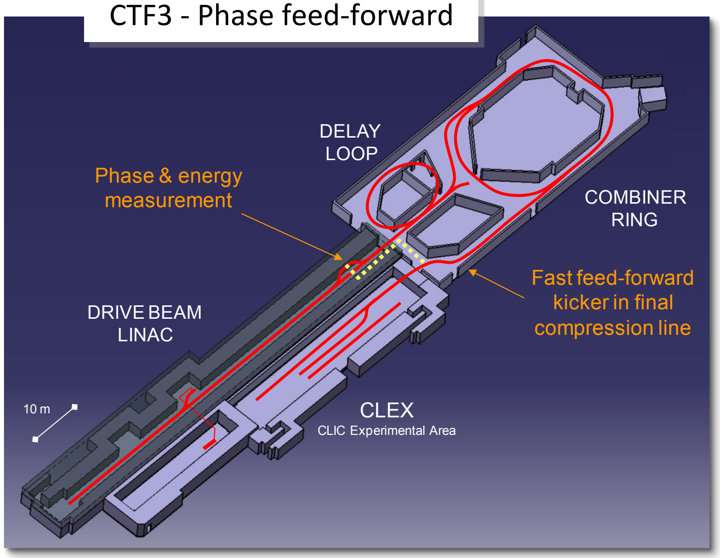
Drive Beam phase feed-forward experiment at CTF3

R. Corsini, P. Skowronski



CLIC drive beam phase feed-forward concept

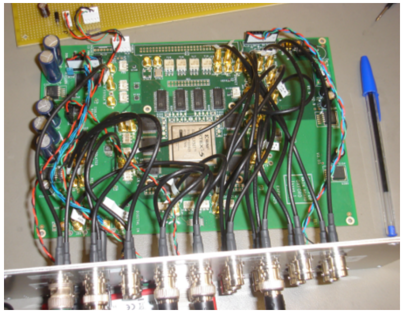
CTF3 - Phase feed-forward



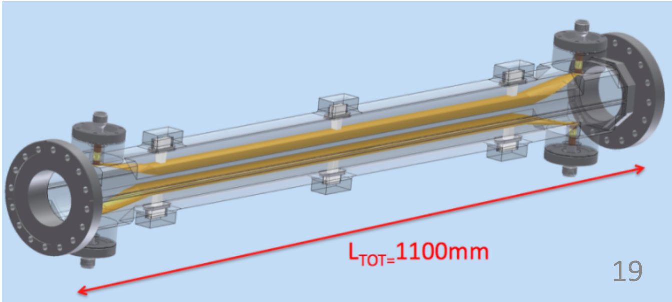
Series of related studies:

- Measure phase and energy jitter, identify sources, devise & implement cures, extrapolate to CLIC
- Show principle of CLIC fast feed-forward

FONT5 board (Oxford)



Stripline kicker (INFN-LNF)



Close link to collaborating partners:

- *INFN-LNF: Phase monitors, stripline kickers*
- *Oxford University/JAI: feedback electronics, amplifiers*

See R. Corsini's talk on CTF3 later.

RF Phase and Amplitude Jitter Summary

- **Addressed by**
  - Design
  - Beam-based feedback
  - Low-level RF
  - Timing system
- **Status:**
  - ILC made lot of progress with the developments for FLASH
  - CLIC in progress
- **Plan and resources available**
  - FLASH
  - Tests of phase feed-forward on-going at CTF3
  - More consistent efforts needed

Stray fields

	resonances	random fluctuations
Transfer line	0.1 nT*	10 nT/m*
Main linac	10 nT	50 nT/m
Main linac + BDS	1 nT	10 nT/m

- Tolerances:
  - CLIC: less then 1 nT few Hz
  - ILC: less 2nT @ f >1 Hz
- Addressed by:
  - Measurement / modeling / simulations
  - Theoretical study / hardware development
- Status:
  - Activities need to be pushed
- Resources:
  - So far nearly zero
  - Need one person doing interdisciplinary work (1 PhD?)

Other issues

- Pre-linac beam collimation
- Transverse beam stability (see talk by R. Apsimon on Thursday morning)
- Beam-ion instability
  - Good vacuum needed ($2x10^{-8}$hPa in ILC, $0.1x10^{-9}$hPa in CLIC)
- Halo formation
  - Small, use of pre-linac collimation
- Space charge tune shift
  - 0.15 in ILC, needs to be studied for both designs

Hardware components tests should be envisaged

- beam collimation system
- high resolution BPM's
- correctors and skew correctors
- dedicated emittance diagnostics
- fast and slow extraction lines
- fast feed-forward system (to reduce jitter coming before turnaround), stable power supplies in turnaround and other lines.

Conclusions, and review of test facilities

- Long list of potential issues, but none seems critical
- More theoretical studies are needed
  - Pre-alignment models, Start-to-end beam-based alignment
  - Design: collimation, dumps, emittance measurement stations, couplers (mini-workshop this morning)
- Experiments should continue, new experiments and hardware tests should be envisaged
  - FLASH and XFELs: testing bunch compression and beam-based alignment (tuning bumps?), phase stability, CTF3 phase stability
  - FONT@ATF2 for feed-forward expertise
  - NML, STF, FLASH: Tests of Girder Pitch Optimisation?