CLIC Luminosity Experimental Programme

Daniel Schulte for the CLIC Team

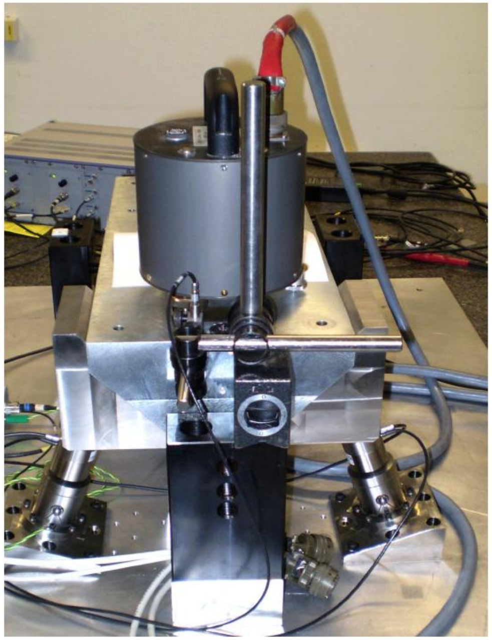
Status of Luminosity Studies

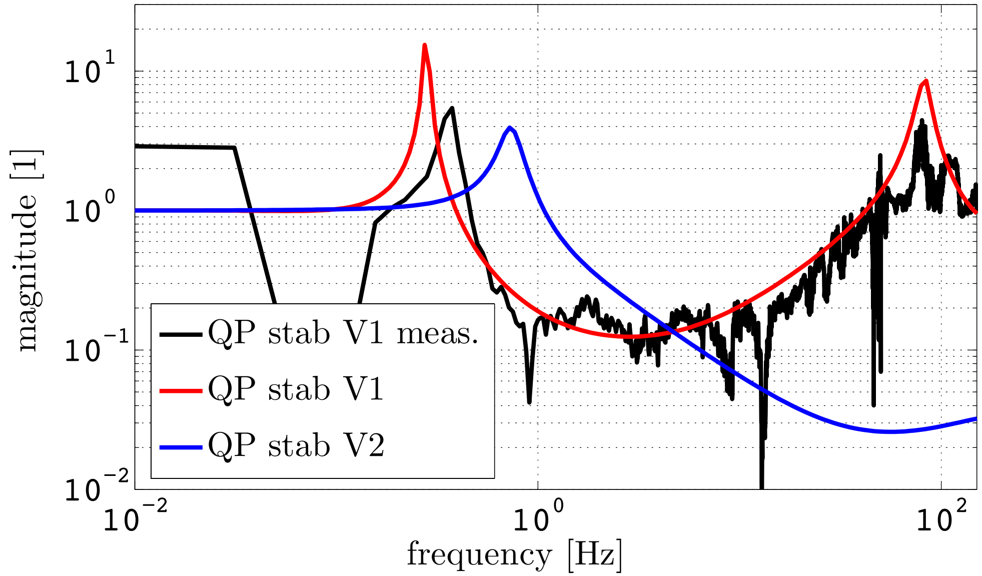
- Our assessment of the luminosity is largely based on
  - Using models of machine components, which are often based on measurements
    - This is the result from the technical workpackages, the structure studies and CTF3
    - Some measurement involve a beam, some do not
  - Using models of imperfections, which are also partly based on measurements
  - Using models of the relevant physics
    - Some effects are quite complex, e.g. electron cloud
    - Some were found as we went along, e.g. wakefields penetrating from the PETS into the main lianc accelerating structures
  - Using models of beam-based correction techniques
    - We developed and are still developing novel techniques
    - Some are very hard to design, e.g. beam delivery system tuning
  - An implementation in a simulation code or in a theoretical calculation

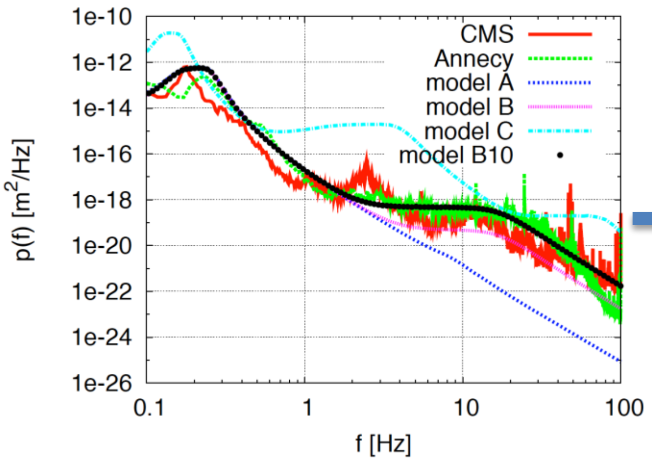
- We also have some integrated beam tests
  - Mainly for damping rings, beam delivery system, drive beam

- Based on these studies we feel confident that we can achieve high luminosity in CLIC
  - We think CLIC is feasible, “There is a solution”

Example of Luminosity Prediction: Active Stabilisation







Code

Machine model
Beam-based feedback

Luminosity achieved/lost [%]	B10
No stab.	53%/68%
Current stab.	108%/13%
Future stab.	118%/3%

Close to/better than target

Future of Luminosity Studies

- Now need to move from feasibility to performance studies
  - Moving from “There is a solution” to “This is the most cost effective solution with reasonable risk”
- This requires
  - More precise quantitative predictions
  - More detailed modelling of the machine
  - Understanding of operational constraints
  - More experimental verification of predictions
- It will allow
  - To define margins more precisely, which has a strong cost impact
  - To compare different implementations of components for risk
  - Make sure that all operational constraints are respected
- An experimental programme is essential for this stage
  - On the component and imperfections model level
  - Integrated beam tests address the operational issues
  - They confirm that we did not miss some important effect
  - Are an essential and time consuming step to turn a theoretical solution into something practical

Plan for Luminosity Session

- Will discuss a few not foreseen measurements/experiments without beam that should be done urgently
  - Will not mention any foreseen experiments
- Will touch on the existing/short term experimental programme with beam
- Will discuss the integrated beam experiment wishes for 2016-
  - The main focus of the session

- Introduction
  - Hermann Schmickler, Daniel Schulte
- Damping ring experimental programme
  - Yannis Papaphilippou
- Main linac experimental programme
  - Andrea Latina
- Beam delivery system experimental programme
  - Philip Bambade
- Individual items
  - J. Snuverink: Magnetic stray fields
  - Alexandra Andersson: Phase reference system
  - Sergio Calatroni: Main linac vacuum
  - Mauro Pivi: Use of PEP-II for damping ring tests
  - Mauro Pivi: collimator tests at End Station A

Some Missing Models/Components

- Dynamic (and static) magnetic stray fields can impact the beam strongly but we lack an evaluation of the fields
  - Require measurement campaign
- The dynamic vacuum in the main linac needs to be <1nTorr
  - Hard to achieve in RF structures
  - Hard to verify dynamic vacuum in constrained environment
  - Some interest in Helsinki (Kenneth Oesterberg)?
- We need a relative timing reference system with a precision of O(10-50fs) across 50km
  - Activity for FELs are for smaller distances
- The wake monitor accuracy should be 3.5um but hard to verify
  - Activity on the design but need a plan for accuracy testing
- Temperature and other drifts are important since they will change the machine
  - Need a systematic evaluation of temperature and other drift effects

Current Beam Test Plan

- Large integrated drive beam test in CTF3
  - Confirmation of feasibility
- Prototype drive beam facility CLIC0
  - More confirmation of components and full performance

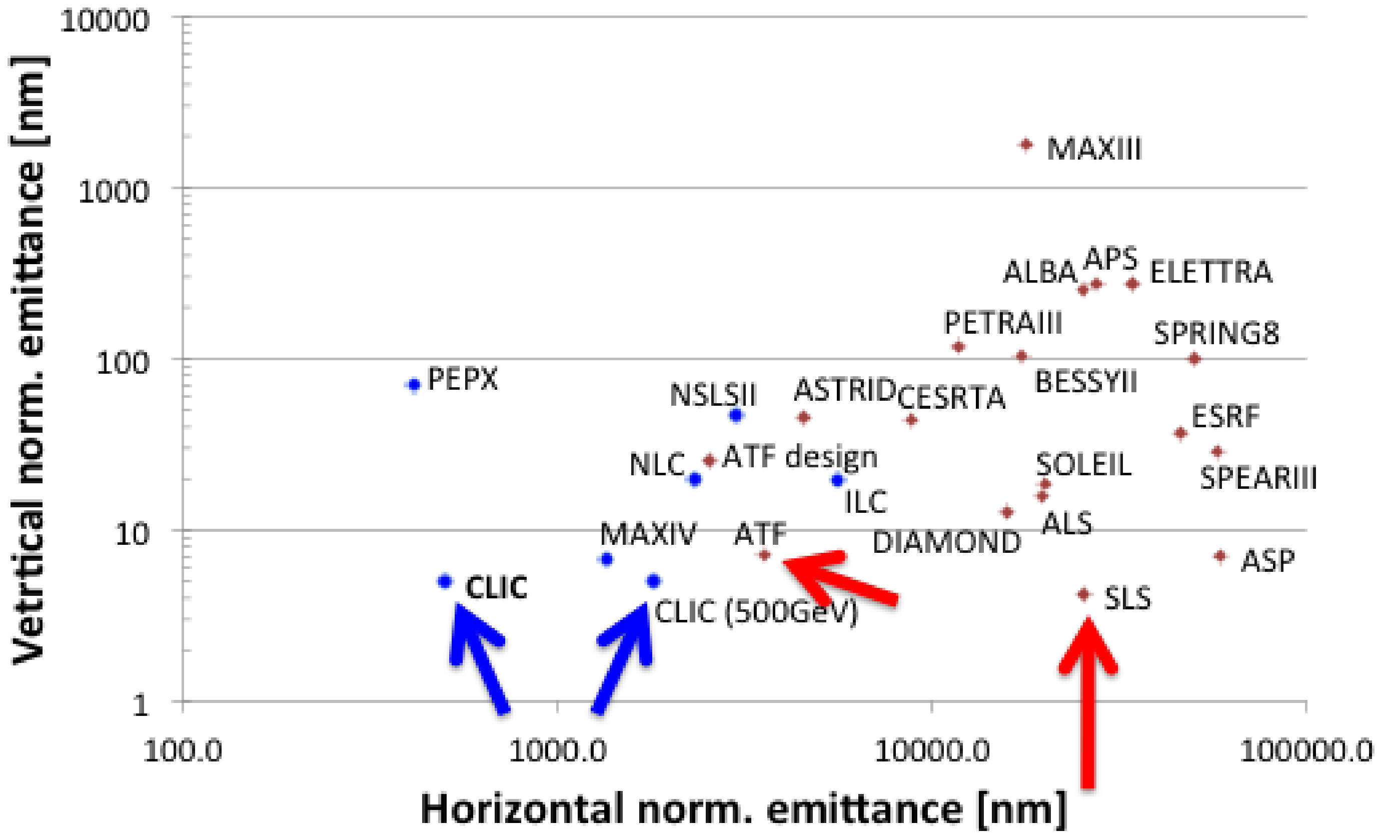
- Until 2016 mainly a parasitic programme for the main beam
  - Limited experimental work at existing rings
  - Involvement in ATF2 and potentially ATF3
  - CTF3 module (and structure) tests
  - Experiments at existing linacs, e.g. FACET
  - In general little hardware investment
- From 2020 main beam in main linac tests at the end of CLIC0 project
  - With a small injector

Damping Ring Consideration

Many design issues
- lattice design
- dynamic aperture
- tolerances
- intra-beam scattering
- space charge
- wigglers
- RF system
- vacuum
- electron cloud
- kickers

- Damping ring design is consistent with target performance
- Light sources have comparable performances

But not all parameters are similar



Should verify emittances with more similar beam conditions

Damping Ring Experiments

- Small zero current emittance
  - Has been shown in vertical plane, reasonably close in horizontal
- Collective effects
  - Intra-beam scattering
    - Experiment at SLS, but difficult to separate from other collective effects
  - Electron cloud
    - Small secondary emission yield seems universally required and achievable (1.3)
    - But small photo-emission yield is not obvious (0.001 e/γ)
  - …
- Wigglers
  - Simulation is not straightforward
  - Very challenging magnet
  - Hard to shield from synchrotron radiation
  - Test planned at ANKA
- Extraction kickers
  - In particular impedance and amplifier stability
  - Tests planned in ALBA and maybe ATF
- RF system
  - Strong variation in beam-loading
  - Demanding stability requirement
  - Test to be defined

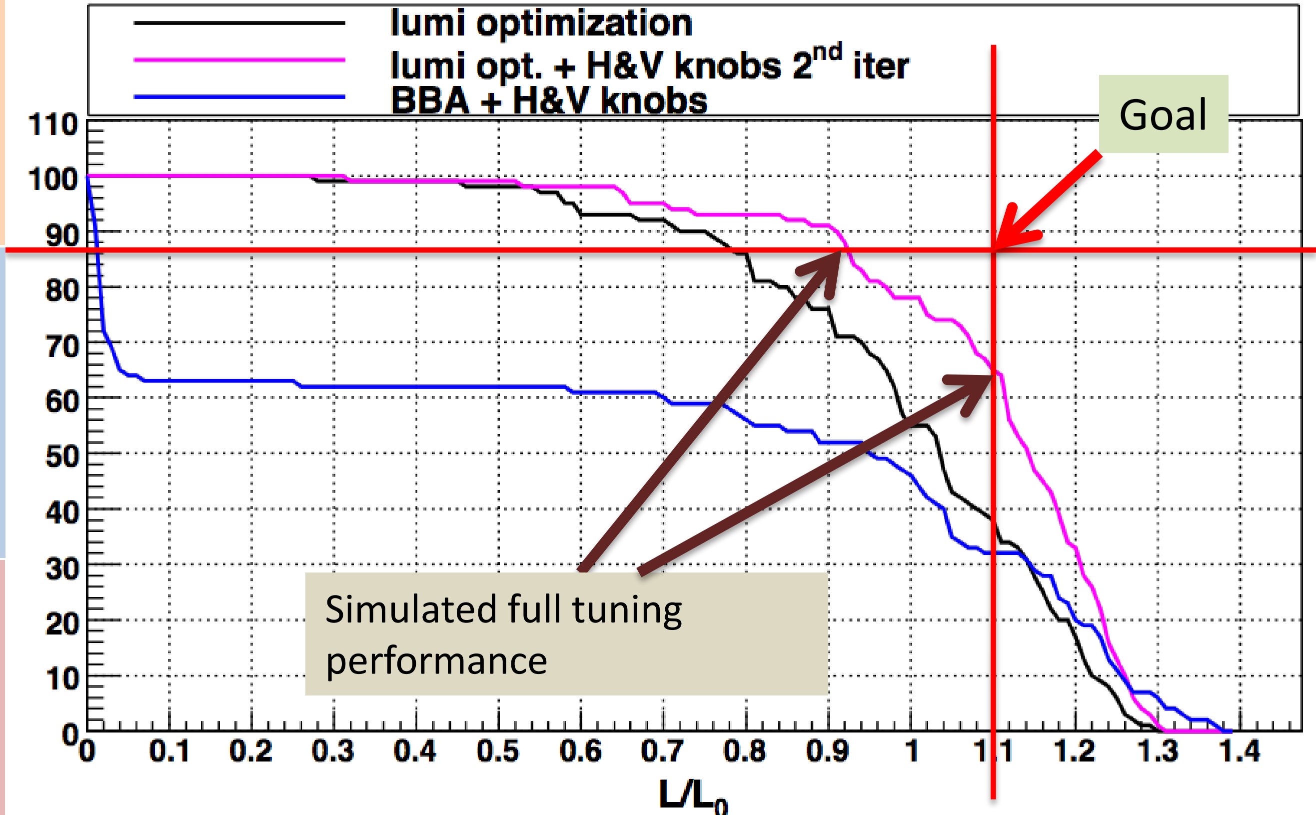
Beam Delivery System Consideration

Main design issues
- chromaticity
- non-linear effects
- synchrotron radiation
- tuning
- stability

- Design is OK
- Imperfection mitigation comes close to target (L ≥ 110% L_0, probability 90%)

- But design is complex
- Convergence of tuning procedure is slow in simulations O(10^4) iterations
- Very sensitive to dynamic effects
- Requires very advanced instrumentation and component design

Probability to achieve more than L/L_0 [%]



Need to verify the beam performance in real system

ATF2 is a good model

BDS Experiments

- Programme is focused on ATF2
  - Past experiment at FFTB

- Tuning of ATF2 is big step toward tuning of CLIC BDS
- Many instruments and components are being developed for ATF2
  - Excellent BPMs, fast feedback systems, magnets
- Ground motion experiment
  - Compare ground motion sensors and beam measurements
  - Compromised by low repetition rate and different ground motion spectrum (changes importance of different sensor frequency bands)

- Main issues
  - The availability of ATF2/ATF3
  - And a potential change of our system design
  - May obtain O(40nm) beamsize (O(25nm) with upgrade), CLIC has 2.3nm at 500GeV and 1nm at 3TeV
  - No active stabilisation against ground motion in ATF2; but this is mandatory for CLIC, so we would like to test it

Main Linac Considerations

Emittiance growth at 500GeV after DFS

Imperfection	**With respect to**	**Value**	$\Delta\varepsilon_y$ **1-2-1**[nm]	$\Delta\varepsilon_y$ **DFS** [nm]	$\Delta\varepsilon_y$ **RF** [nm]
girder end point	articulation point	5 μm	0.62	0.62	0.02
roll	longitudinal axis	100 μrad	0.23	0.23	0.23
BPM offset	wire reference	14 μm	340.86	7.11	0.08
cavity offset	girder axis	14 μm	3.19	3.19	0.01
cavity tilt	girder axis	141 μrad	0.10	0.43	0.41
BPM resolution		0.1 μm	0.00	0.51	0.01
wake monitor	structure centre	3.5 μm	0.00	0.00	0.21
all			353.88	16.27	0.95

Main design issues

- Wakefields
- BPM alignment
- wake monitors
- structure tilt
- BPM resolution
- quadrupole roll
- quadrupole stability
- vacuum

- Design is OK
- Imperfection mitigation achieves target

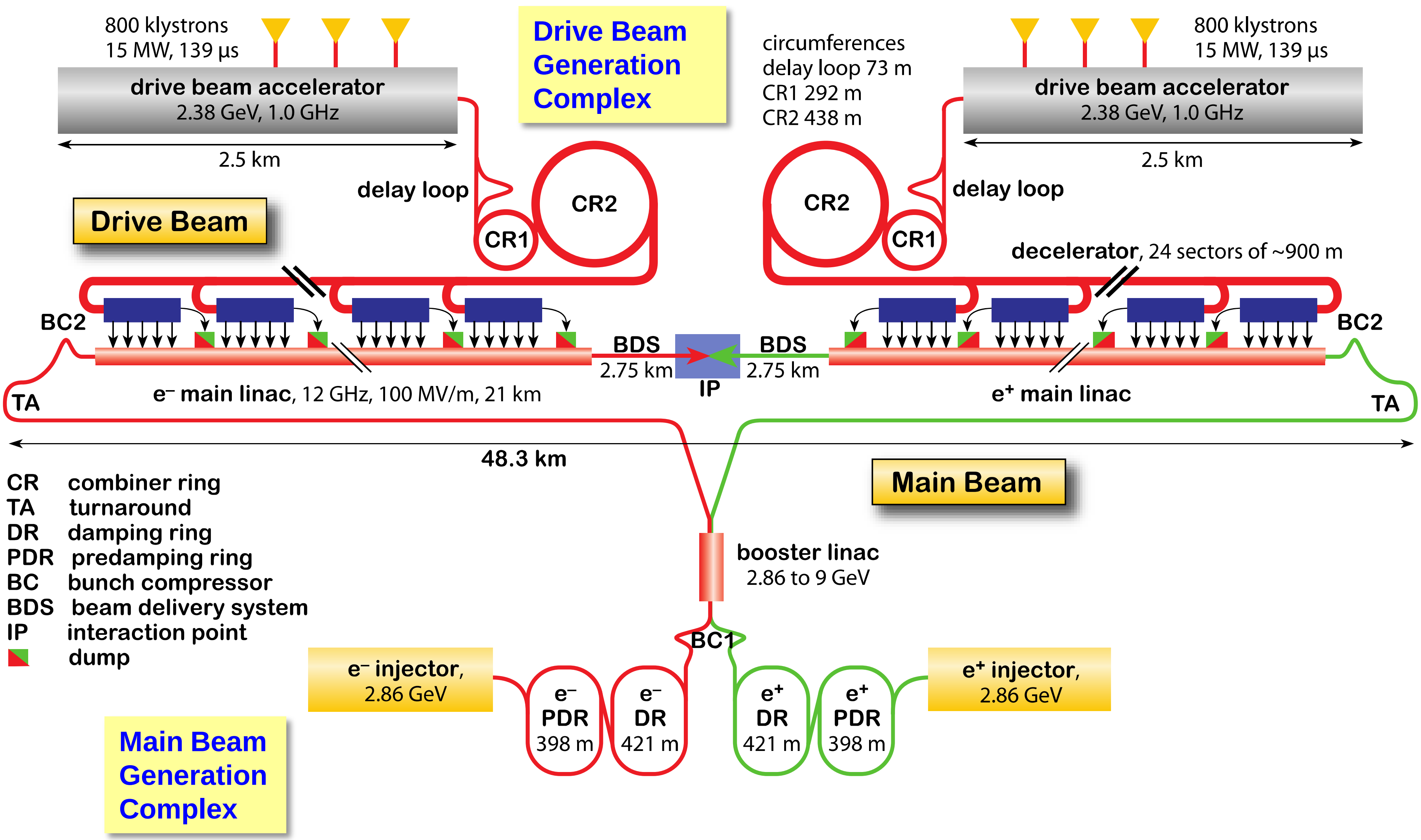
- DFS has not been tested
- many effects were discovered during the studies, so maybe we miss one
- emittances are unprecedented in linacs (10nm vs. >1µm)

Main Linac Exeriments

- Two beam test stand
  - A single structure but gives important information
- Three modules are in preparation for beam tests
  - Will allow to test modules better
  - But need to define additional tests, e.g. BPM accuracy, wakemonitor accuracy, …
- Currently have experiment at FACET
  - Others can be envisaged
  - But far from our target emittance and hardware configuration

- Will have about 100m of linac at CLIC0
  - But will only come at the end of CLIC0

Ultimate CLIC Test Facility

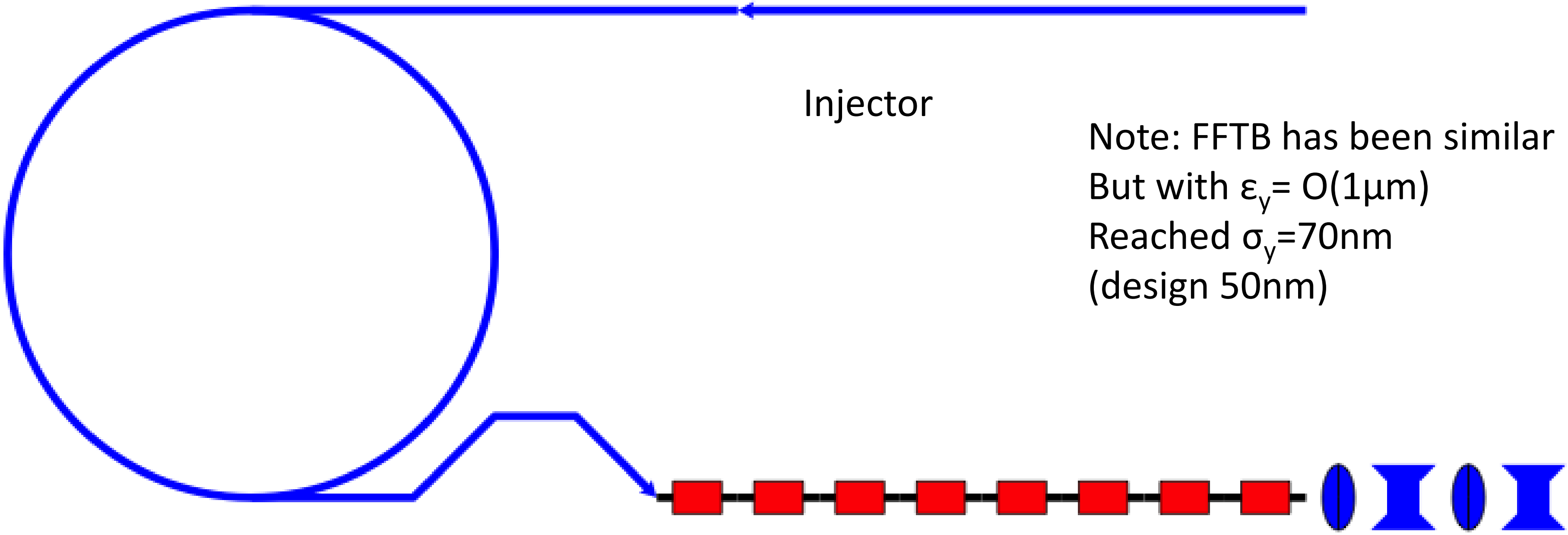


Some Considerations

- Would like to test a significant length of main linac
  - CLIC0 can feed 50 modules
  - Would like 108 modules, i.e. 108 quadrupoles, ~11 betatron wavelengths, ~220m
  - Would provide 3 DFS correction bins, ballistic alignment sensitivity, some distance for wakefield bump
  - Static emittance growth from wakefields is roughly constant per cell, i.e. expect O(11%/6%) of full CLIC (at 500GeV/3TeV) effect for 108 modules
  - Would like O(10nm) vertical emittance to test emittance growth
    - Best linacs have O(1µm) at reasonable charges
    - Photoinjector can do O(1µm) for 1nC, 150nm for 20pC at LCLS
    - Even Swiss FEL plans for 0.4-0.6µm for 0.2nC @ C-band, better at smaller charges
      - Very interesting
    - Will ideally have a ring or novel injector

- Would like an integrated test of low emittance generation and preservation
  - System chain is important, e.g. use bunch compressor for main linac alignment, main linac RF jitter is important for BDS, …

Dream Test Facility Scheme



Injector

Note: FFTB has been similar
But with ε_y= O(1µm)
Reached σ_y=70nm
(design 50nm)

Low emittance ring,
e.g. 3rd generation light source,
damping ring test facility

Main linac with bunch compressor
Powered with drive beam or X-band klystrons

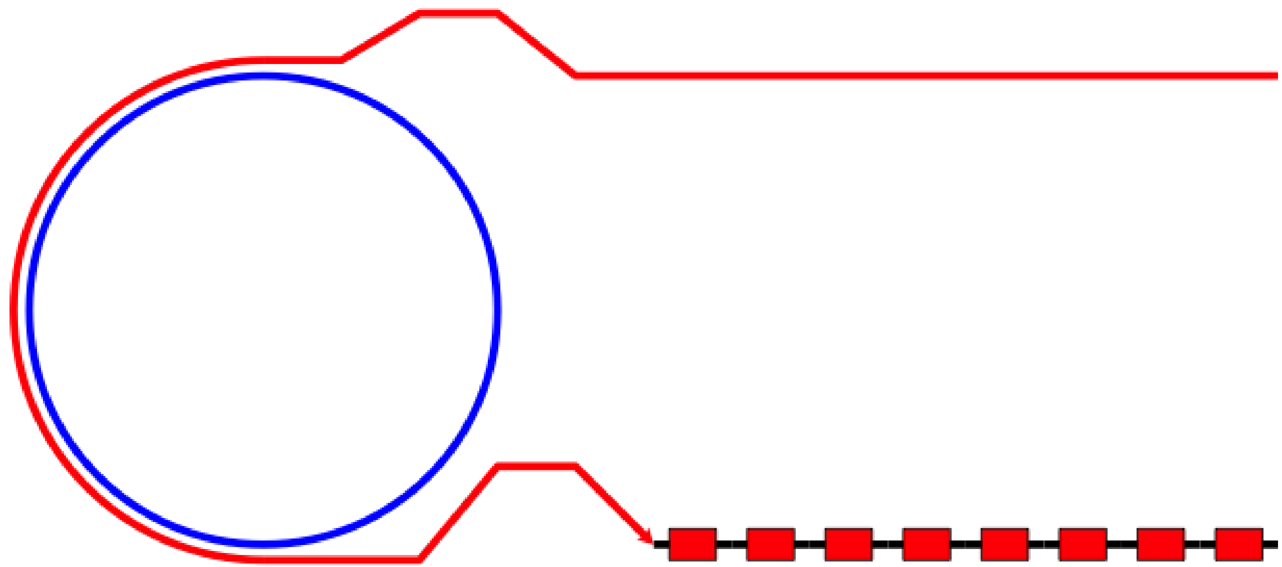
BDS test facility

Example options: SPS as damping ring (combined with CLIC0?),
FACET with improved damping ring? ATF, PEP-II, ESRF, SLS, SPRING-8, …

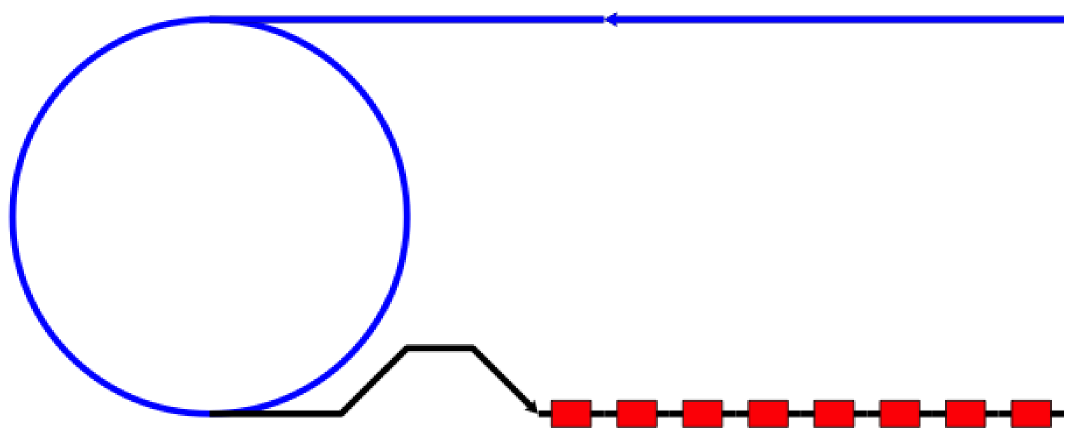
User Facility Operation

Bypassing the damping ring, one can use the linac as a 4th generation light source

Maybe some benefit in using ring and linac together as light soruce or for other experiments, e.g. ATF3 programme



The ring can still be used almost independently, e.g. as a light source



Example Parameters

- 3TeV structure, 108 quadrupoles, 324 super-structures, 2GeV initial energy, 250μm bunch length, 0.8*3.7e9 particles
  - Amplification of jitter emittance -> 4.7
  - 3.5um cavity scatter -> 0.14nm
  - 14um BPM scatter -> 14nm
  - Could use other structures and adjust bunch charge

- A power unit consists of
  - A pair of 50MW X-band klystrons with pulse length 1.6us
  - A pulse compressor with compression factor 6 -> 244ns +
  - Power gain is about 4.2
  - Splitter into three superstructures (6 structures)
  - i.e. 70MW/structure

- Significant cost could be reduced by
  - Not power all structures
  - Using different structures
  - Contribution from user community

Conclusion

- A number of fundamental measurements remain to be done for CLIC
  - E.g. magnetic stray fields, main linac vacuum
  - Please volunteer
- Components need to be developed and verified
  - Timing reference over 50km
  - Please volunteer
- Integrated drive beam tests go from feasibility studies to detailed prototyping
- Integrated main beam tests have been largely parasitic
  - Programme foreseen for the next years but limited by availability and performances of facilities
  - Should start to think about performance testing also for main beam
  - A very good test facility looks like a 3rd and a 4th generation light source chained together
  - Can we include collisions?
  - But can we find a cheaper option? SwissFEL and independent damping ring tests?

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