Experimental Verification of the CLIC Two-beam Scheme, Status and Outlook

R. Corsini for the CLIC Collaboration

Talk Outline:

1. Status of CLIC feasibility benchmarks in the CLIC test facility CTF3 (including last year’s highlights)

2. Plans for CTF3 in 2013 and beyond

3. Further steps towards CLIC
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Main linac gradient

Drive beam scheme

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CLIC Feasibility Issues
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High current, full beam-loading operation

Operation of isochronous lines and rings

Beam recombination and current multiplication by RF deflectors

12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

- CTF3 layout and CLIC Feasibility Issues
- Linac
- Injector
- Delay Loop
- Combiner
- Ring
- CALIFES
- Probe Beam Injector
- TBL
- TBTS
- CLEX

4 A, 1.4us 120 MeV
30 A, 140 ns 120 MeV
30 A, 140 ns 60 MeV
High current, full-loaded linac operation

- 95% RF to beam efficiency measured
- No instabilities

Dipole modes suppressed by slotted iris damping (first dipole’s Q factor < 20) and HOM frequency detuning

RF pulse at structure input

1.5 µs beam pulse

RF pulse at output
Beam recombination

- Fast bunch phase switch in SHB system
- Operation of isochronous rings and beam lines
Streak camera images of the beam, illustrating the bunch combination process in the ring.

333 ps
Streak camera images of the beam, illustrating the bunch combination process in the ring
Achievements – Drive Beam Generation

Streak camera images of the beam, illustrating the bunch combination process in the ring.
Beam recombination

- Factor 4 - OK
- Factor 8
  - basic principle demonstrated
  - need improvement (pulse shape, stability, losses, emittance)

Beam recombination - Emittance

Best results in CLEX
for factor 4: $\epsilon_H = 250$ um $\epsilon_V = 140$ um
for factor 8: $\epsilon_H = 640$ um $\epsilon_V = 170$ um

Different turns are ~ ok, no unknown effects
Emittance increase due to non perfect orbit
2011 Highlights - Beam Stability

Repeatibility and long term current stability improved
Pulse charge stability measured at end of the linac better than CLIC requirements

Charge stability – Factor 4

Several feed-back loops operational, for temperature, RF phase and power and gun current.
Nine Power Extraction & Transfer Structures (PETS) installed and commissioned in 2011 (13 PETS installed in 2012)

Full beam transport to end-of-line spectrometer, stable beam

Power produced (70 MW/PETS) fully consistent with drive beam current (21 A) and measured deceleration.

More than half a GW of 12 GHz power!

Beam deceleration, measured in spectrometer and compared with expectations

~ 30 MeV
26%
PETS operated routinely above **200 MW** peak RF power providing reliably pulses ~ **100 MW** peak to accelerating structure.

About twice the power needed to demonstrate **100 MV/m** acceleration in a two-beam experiment with TD24 structure.

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12 GHz RF power in PETS

**135 MW**

**CLIC target pulse**
Two-Beam Acceleration demonstration in TBTS

Up to 145 MV/m measured gradient

Good agreement with expectations (power vs. gradient)

Maximum stable probe beam acceleration measured: 31 MeV

⇒ Corresponding to a gradient of 145 MV/m
Break-down kicks & Break-down physics/statistics

- kicks on horizontal and vertical planes between 0.02 and 0.2 mrad;
- kicks corresponding to a transverse momentum between 10 and 40 keV/c (measurements at NLCTA within 30 keV/c, Dolgashev et al., LINAC 2004);

Histogram of number of pulses between breakdows, showing the presence of clusters.

Input Power: 50 MW
Pulse length 220 ns.

Farabolini, A. Palaia
Demonstration of PETS on-off mechanism

- Considered a feasibility issue

- Ability to:
  - Switch off power from individual PETS to accelerating structure in case of breakdown
  - Reduce substantially power in PETS, to cope with PETS breakdowns

- PETS on-off principle fully tested

- Conditioned at high power (135 MW - nominal) by recirculation
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Simulation vs. experiment
CTF3 Achievements – What is still missing for feasibility studies – Drive Beam Generation

- **Transverse rms emittance**
  - 100 π mm mrad (end of linac)
  - Sub-Harmonic bunching with fast (< 6ns) 180° phase switch (8.5% satellites)

- **Bunch length control**
  - < 1 mm rms (end of linac)
  - Full beam loading (95% transfer) high current acceleration (up to 5 A)

- **Beam current stability**
  - ~ 0.1 % end-of-linac, ~ 0.2 % combiner ring

- **Ring isochronicity**
  - $\alpha_p < 10^{-4}$

- **Factor 2 combination in Delay Loop**
  - (from 3.5 to 7 A)

- **Control of ring length to better than 0.5 mm**

- **Bunch train recombination factor 4 in Combiner Ring**
  - (from 3 to 12 A)

- **Beam current stability**
  - ~ 0.2 % for fully combined beam

**DB generation, 2012:**

- Improve beam quality for factor 8 beam
  - (emittance, bunch length, stability)
CTF3 Achievements – Two-Beam issues

TBL:
• 13 PETS start 2012
• 14 or more PETS end 2012?

TBTS, 2012:
• Continue studies with two new structures
• Wakefield monitors

CTF3 Achievements – What is still missing for feasibility studies – CLEX

9 PETS
21 A beam
26% deceleration

13 PETS installed
≥ 40% deceleration expected this year

16 PETS + spectrometer installed to verify transport of a 28 A beam with up to 50% of energy extracted.

Beam-powered test of a PETS to nominal parameters (135 MW, 240 ns) with external recirculation (10 A) and without (20 A) – including probe beam
Improved power & drive beam energy loss measurements

Break-down kick measurements
PETS On-off mechanism demonstration

Probe beam acceleration to 100 MV/m. (up to 145 MV/m measured)

Beam-powered test of a PETS with external recirculation to 250 MW, <200 ns - ~15 A beam current Power & drive beam energy loss measurements.
Not just a single experiment – series of related studies:

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

Close link to collaborating partners:

- INFN-LNF: Phase monitors, stripline kickers
- Oxford University/JAI: feedback electronics, amplifiers
Upgrade TBL to a test facility relevant for future CLIC program

- 12 GHz power production for structure conditioning
  - Working experience with a real decelerator
  - Beam dynamics studies, pulse shaping, feedbacks, etc

Timeline:

- Last batch of PETS will be adapted to high-power testing (using internal recirculation)
- One (or two slots) tested at beginning of 2013
- Gradual increase of slots to 4-8 slots and rep rate to 25-50 Hz

Improved PETS design, mini-tank + input coupler

Accelerating structure under test

Beam
• Phase monitor tests – 3 monitors installed in summer 2012

• First system tests planned in summer 2013
Beam loading reduces field locally in the structure
⇒ is it the break-down rate lower (or higher)?

- CLEX probe beam has only limited current/pulse length, CLEX Drive beam has limited rep rate
  ⇒ use CTF3 drive beam and klystron driven X-band structure
- Reactivate the old ‘30 GHz PETS’ line, lower DB current, can reach 50 Hz
- Measure BDR with/without beam to get a direct comparison

Present schedule:  Install in winter shutdown 2012-2013
Run experiment in 2013
CTF3 beyond 2012 – Two Beam Modules in CLEX

3D model of integration of the first CLIC Module in CLEX (2013)

Module T0

CLEX - Three two-beam modules (2014)

TBTS PETS tank

G. Riddone
CTF3 beyond 2012 – Two Beam Modules in CLEX

3D model of integration of the first CLIC Module in CLEX (2013)

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CLEX - Three two-beam modules (2014)

Drive Beam line

Main Beam line

G. Riddone
3D model of integration of the first CLIC Module in CLEX (2013)  
Module T0

CLEX - Three two-beam modules (2014)

Present schedule:  
First module installation in summer 2013 (At least one year of testing)  
Module string installation late 2014
CTF3 program in 2012-2017

Consolidation, energy upgrade, increased rep-rate CLIC Diagnostics tests

Beam loading/BDR experiment

Phase feed-forward, DB quality, DB stability studies

Two-Beam Modules, Wake-field monitors, Two-beam studies RF pulse shaping

Power production, high-power testing, RF conditioning with DB & further decelerator tests
New facility – Drive Beam Front-End (2012-2016)

**Build and commission Drive Beam front-end with nominal CLIC parameters**

- Essential R&D to assess drive beam injector (critical for performance)
- Develop RF unit for the drive beam linac (critical for cost/efficiency)
- Preparation for full CLIC Zero facility
CLIC Zero

- Beam driven processing/qualifying facility for X-band structures/modules
- Significant size series production of cost and performance critical hardware – drives industrialization needed for CLIC
- Demonstrate nominal drive beam generation (full combination, full pulse length) & two-beam acceleration/deceleration over a significant distance
- Most hardware re-usable for CLIC
- Other possible uses (outside the CLIC scope) presently being investigated
CONCLUSIONS

Feasibility of the CLIC Two-Beam scheme has been established in the CLIC Test Facility CTF3

• Original experimental program basically completed

• Drive Beam generation demonstrated – emittance and stability to be further improved this year

• Nominal parameters for RF production & two-beam acceleration reached and exceeded – 150 MV/m gradient measured with beam

• Deceleration by 26% of a 21 A beam of the drive beam with no losses, expect > 40% this year

CTF3 experimental program for the next five years established and under way

• Drive beam phase feed-forward experiment

• Beam loading / breakdown experiment

• High-power testing of structures in TBL

• Full fledged two-beam modules tested with beam in CLEX

First steps towards the next stage in the study

• Drive beam front-end facility (2012-2016)

• Preparation of CLIC Zero
Thank you for your attention and many thanks to the CLIC Collaboration for the impressive work.