INDUSTRIAL TECHNOLOGIES FOR RF SYSTEMS IN CLIC

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BRIEF INTRODUCTION TO CLIC
CLIC LAYOUT

Main LINAC \(\rightarrow\) Two Beam Module

Drive Beam

- \(\epsilon^-\) main linac, 12 GHz, 100 MV/m, 21 km
- Booste linac 2.86 to 9 GeV
- \(\epsilon^-\) injector, 2.86 GeV

Main Beam

- \(\epsilon^-\) PDR 389 m
- \(\epsilon^-\) DR 427 m
- \(\epsilon^+\) PDR 389 m
- \(\epsilon^+\) DR 427 m
- \(\epsilon^+\) injector, 2.86 GeV

819 klystrons
- 15 MW, 142 \(\mu\)s
- Drive beam accelerator 2.4 GeV, 1.0 GHz

Delay loop CR1 293 m
- CR2 439 m

Decelerator, 24 sectors of 878 m

DAMPING RINGS

CR1
- Combiner ring
- Turnaround
- Damping ring
- Predamping ring
- Bunch compressor
- BDS (beam delivery system)
- IP (interaction point)
- Dump

CR2
- Combiner ring
- Turnaround
- Damping ring
- Predamping ring
- Bunch compressor
- BDS (beam delivery system)
- IP (interaction point)
- Dump

\(\epsilon^-\) SIDE

\(\epsilon^+\) SIDE

\(\approx 1\) km

\(\approx 100\) m

Drive Beam Loops

Main Beam Loops

Interaction Region

Damping Rings

Drive Beam Dumps

LHC

INJECTION TUNNEL
COLLABORATION

58 institutes from 28 countries
CLIC TIMELINE

2013-18
Development phase
• Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors

2018-19 Decisions
• On the basis of LHC data and Project Plans (for CLIC and other potential projects as FCC), take decisions about next project(s) at the Energy Frontier.

+5 years preparation Phase
• Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement. Prepare detailed Technical Proposals for the detector-systems.

2024-25
Construction Start
• Ready for full construction and main tunnel excavation.

Construction phase
• Stage 1 construction of CLIC, in parallel with detector construction. Preparation for implementation of further stages.

Commissioning
• Becoming ready for data-taking as the LHC programme reaches completion.
TWO-BEAM PRINCIPLE

- Drive Beam (DB)
  - quadrupole
  - accelerating structures

- Main Beam (MB)
  - quadrupole

- Power extraction and transfer structures (PETS)
  - RF
  - 12 GHz, 68 MW
  - BPM
  - Accelerating structures (AS)
COMPACT ACCELERATION

RF accelerating gradient

- CLIC
- ILC
- XFEL
- Swiss FEL

CLIC BDR Criteria

- $E_0$ scaled to 180 ns & $BDR = 3 \times 10^{-7}$
- $E_0$ scaled to 180 ns
- meas.
Main parameters of CLIC module

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Unit 1</th>
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<tbody>
<tr>
<td>Module length</td>
<td>2010</td>
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<tr>
<td>PETS length</td>
<td>308</td>
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<td>PETS aperture</td>
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<td>PETS gradient</td>
<td>6.5</td>
<td>MV/m</td>
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<td>PETS power</td>
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<tr>
<td>AS length</td>
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<td>AS aperture</td>
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<tr>
<td>AS gradient</td>
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<td>MV/m</td>
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<td>AS power</td>
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<tr>
<td>Vacuum level</td>
<td>$10^{-9}$</td>
<td>mbar</td>
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OTHER MODULE SYSTEMS

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<tr>
<th>Number of elements in CLIC</th>
<th>3 TeV</th>
<th>380 GeV</th>
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<td>PETS</td>
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<td>Accelerating Structures</td>
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<td>Loads</td>
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<td>Quadrupoles</td>
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<td>Dipoles</td>
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<td>Beam position monitors</td>
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<td>Girders</td>
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<td>Cam movers</td>
<td>14090</td>
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RF SYSTEM

MAGNETS

VACUUM SYSTEM

ALIGNEMENT, STABILISATION AND SUPPORT SYSTEM
CLIC TECHNOLOGIES IN INDUSTRY
X-BAND COPPER STRUCTURES

- Diamond-tool ultraprecision machining
- Turning and milling
- Very strict qualification based on visual inspection and CMM metrology
- VDL (NL), LT-Ultra (DE), Yvon Boyer (FR), DMP (ES), Morikawa (JP), KERN (DE)
ULTRA PRECISION MACHINING

Cell shape accuracy:
zone A - 0.005 mm
zone B - 0.02 mm

Flatness - 0.001 mm

Surface roughness:
zone A Ra 0.025 μm
zone B Ra 0.1 μm
BONDING AND BRAZING

- Bonding and brazing with H2 atmosphere
- Qualification of the oven involving pollution tests with SEM
- Bodycote (FR), Reuter (DE), TMD (UK), MHI (JP)
- Potential extension to vacuum brazing following structure manufacture from PSI
- Electron-beam-welding of hard copper under investigation
SURFACE TREATMENT

- Copper coating on stainless steel.
- Need to respect dimensioning
- Technology transfer from CERN
- Thermocompact (FR), BACMI (FR), Multivalent (NL)

- Vacuum baking at 10-8 for 1-2 days
- Big furnace
- Bodycote (FR), COMEB (IT), MHI (JP)
COMPONENTS

- Traditional machining of copper and stainless steel parts
- Brazing of copper to SS, copper to copper and copper to SiC
- Copper sintering
- Relative small series tested to 60 MW peak power
- CINEL (IT), VDL (NL), BACMI (FR), CECOM (IT), Reuter (DE), Nihon (JP), COMEB (IT), Viztrotech (KR)
OPEN HARDWARE

- https://www.ohwr.org/

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ADDITIVE MANUFACTURING

- 3D printing in Titanium for lossy parts like loads or low power components
- Parallel development at CERN and in industry
- SWISSto12 (CH), 3T RPD (UK), Concept Laser (DE), INITIAL (FR), Protoshop (DE)
- Currently under test for high power operation
KYSTRON-BASED CLIC AND X-BAND TEST FACILITY.

New possibilities open thanks to the availability of power sources at 12 GHz.
PULSED KLYSTRONS

CPI (US) VKX-8311A @ 11.9942 GHz
50 MW peak power, 1.5 μs pulse length
50 Hz rep. rate

Based on SLAC XL5 klystron
developed by SLAC from SLS XL4

TOSHIBA (JP) E37113 @ 11.9942 GHz
6 MW peak power, 5 μs pulse length
400 Hz rep. rate
Developed by Toshiba on CERN contract

THALES (FR) MBKTH1803 @ 1.0 GHz
21 MW peak power, 10 μs pulse length
10 Hz rep. rate
Developed by THALES on CERN contract

RF measurements with directional coupler.
MODULATORS

- High Voltage Pulsed modulators.
- Maximum pulse voltage ripple 0.25%
- Pulse to pulse stability 0.1%
- Scardinova (SE) modified K1 and K2 modulators for Xboxes
- ETH-Zurich development in collaboration with CERN for drive beam.
- Pulse transformer built by Pikatron (CH)
New **Solid State Amplifier** 400 W AM61-12S-60-56-PR SN001 by Microwave Amps (UK)
Two new units at 1 kW!

**Radiabeam (US)** faraday cups

**Killerbee** high stability RF cables from Megaphase (US)
Thales (FR)
CPI (US)
Toshiba (JP)

Bodycote (FR)
Reuter (DE)
TMD (UK)

SWISSto12 (CH)
3T RPD (UK)
Concept Laser (DE)
INITIAL (FR)
Protoshop (DE)

VDL (NL)
LT-Ultra (DE)
Yvon Boyer (FR)
DMP (ES)
Morikawa (JP)
KERN (DE)

Thermocompact (FR)
BACMI (FR)
Multivalent (NL)

CINEL (IT)
VDL (NL)
BACMI (FR)
CECOM (IT)
Reuter (DE)
Nihon (JP)
COMEB (IT)
Viztrotech (KR)

Scandinova (SE)
Jema (ES)
Picatron (CH)
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<thead>
<tr>
<th>Location</th>
<th>Facility</th>
<th>Power</th>
<th>Location</th>
<th>Facility</th>
<th>Power</th>
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<tr>
<td><strong>CERN</strong></td>
<td>XBox-1 test stand</td>
<td>50 MW</td>
<td><strong>Australia</strong></td>
<td>Test stand</td>
<td>2x6 MW</td>
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<td>Xbox-2 test stand</td>
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<td>Linearizer for Fermi</td>
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<td>KEK</td>
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<td>SLAC</td>
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<td>Deflector for SwissFEL</td>
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<td>Deflector for Sinbad</td>
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<td>Linearizer for Compton source</td>
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<td>4(8)x50 MW</td>
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<td>SINAP</td>
<td>Linearizer for soft X-ray FEL</td>
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<td>Groningen</td>
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<td>Deflectors for soft X-ray FEL</td>
<td>3x50 MW</td>
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CONCLUSIONS

- Fruitful collaboration between CLIC and the industry
  - Encouraging the industry to reach new challenges on their own proprietary technology (Modulators, Klystrons, additive manufacturing, etc)
  - Transferring the knowledge acquired in research through prototypes and small series (Accelerating structures and components)
  - Licensing (open hardware) certified components for own manufacturing
- Not only by CERN but all the members of CLIC collaboration
- Not only in Europe but world-wide
- Not only CLIC but many other laboratories and universities