CLIC Detector & Physics
Introduction
Introduction to the CLIC accelerator
CLIC physics programme highlights
Timeline and plans
European Strategy for Particle Physics
Compact Linear Collider: CLIC

$e^+e^-$ collider with $\sqrt{s}$ up to 3 TeV

100 MV/m accelerating gradient needed for compact (~50km) machine
Based on normal-conducting accelerating structures and a two-beam acceleration scheme

CLIC foreseen as a staged machine:
- Stage 1 baseline: $\sqrt{s}=380$ GeV:
  precision SM physics: Higgs and top
  Energies of subsequent stages motivated by physics
- Stages 2 & 3 baseline: 1.5 TeV, 3 TeV
Compact Linear Collider (CLIC)

- **380 GeV** - 11.4 km (CLIC380)
- **1.5 TeV** - 29.0 km (CLIC1500)
- **3.0 TeV** - 50.1 km (CLIC3000)

Locations:
- CLIC380
- CLIC1500
- CLIC3000
- CERN
- Geneva
CLIC collaborations

http://clic.cern/

CLIC/CTF3 accelerator collaboration
>70 institutes from 31 countries
http://clic-study.web.cern.ch/

CLIC accelerator studies:
• CLIC accelerator design & development
• Construction and operation of CTF3

CLIC detector and physics (CLICdp)
30 institutes from 18 countries
http://clicdp.web.cern.ch/

Focus of CLIC-specific studies on:
• Physics prospects & simulation studies
• Detector optimization + R&D for CLIC
Delay loops create drive beam bunch-structure.

Low energy high current drive beam -> high energy low current main beam.

CTF3 test facility at CERN has demonstrated drive beam generation and two-beam acceleration scheme (up to 135MV/m measured).

High bunch-charge density -> beamstrahlung Incoherent $e^+e^-$ pairs and $\gamma\gamma$->hadrons.
1.5 TeV is the maximum energy that can be reached with one drive-beam complex.
CLIC staging

- Detector
- BDS
- Accelerator 100 MV/m
- Accelerator 72 MV/m

- Drive beam
- Main beam

- Luminosity spectrum at $\sqrt{s} = 3\,\text{TeV}$

- Luminosity

- Polarization: up to $\pm 80\%$ electron polarization; positron polarization a possible upgrade.
CLIC detector and physics

Requirements:

High precision:
- jet energy resolution
- momentum resolution
- impact parameter resolution
- timing resolution

• Small bunch size results in strong beam-beam interactions
• High background levels at low $p_T$, $\theta$
• Reject beam induced backgrounds with timing and $p_T$ cuts
• Requires high granularity (space and time) detector

CLIC detector requirements

See dedicated talk by Emilia Leogrande today

CLICdp working towards demonstrators for the main technical challenges
Physics motivations

- Precision Higgs
- Precision top
- BSM
Higgs highlights in e^{+}e^{-}

Separation of bb/cc/gg final state possible in e^{+}e^{-}, using excellent detector

Model-independent Higgs coupling measurements from recoil mass

Access to Higgs self-coupling $g_{HHH}$ at 3 TeV; simultaneous extraction with $g_{HHWW}$

Precision Higgs mass

<table>
<thead>
<tr>
<th>Dataset</th>
<th>$\Delta m_{H}$ (unpolarised)</th>
<th>$\Delta m_{H}$ (p(e^{-}))</th>
</tr>
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<tbody>
<tr>
<td>1.4 TeV</td>
<td>47 MeV</td>
<td>35 MeV</td>
</tr>
<tr>
<td>3 TeV</td>
<td>44 MeV</td>
<td>33 MeV</td>
</tr>
<tr>
<td>1.4 + 3 TeV</td>
<td>32 MeV</td>
<td>24 MeV</td>
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</table>

HL-LHC projection: $\Delta m_{H} = 50$ MeV

arXiv:1310.8361
Higgs highlights

Each stage contributes significantly: first stage provides crucial model-independent Z coupling measurement, and couplings to most fermions and bosons; higher stages improve them, and add t, μ, γ couplings

~20 individual analyses
Higgs highlights

Precision significantly better than HL-LHC
Precision comparable with HL-LHC

‘model-dependent’ assumes fractional shift in $\kappa$ is equal for u,c,t ; for d,s,b ; and for e,\(\mu\),\(\tau\) ; and no Higgs decay to invisible/exotic particles

Top physics highlights

- Intending threshold scan around 350 GeV (10 points, ~1 year) as well as main stage 1 baseline $\sqrt{s}=380$ GeV
- sensitive to top mass, width and couplings
- observe 1S ‘bound state’ $\Delta m_t \sim 50–75$ MeV

- FCNC decays
- couplings to Z and $\gamma$
- cross-section and $A_{FB}$
  -> resolved, semi-resolved, and boosted
- combined EFT interpretation
over to you!
Timeline

2013 - 2019 Development Phase
Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase
Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase
Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions
Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start
Ready for construction; start of excavations

2035 First Beams
Getting ready for data taking by the time the LHC programme reaches completion
Towards industrialization of the accelerator components

Requirements:
- Alignment
- Special tooling
- Clean environment

Suppliers:
- 3 qualified companies for brazing/bonding operations, supervision by CERN;
- Collaborators.

Encouraging other uses of CLIC accelerator technology:
SwissFEL, CompactLight
AC Power

<table>
<thead>
<tr>
<th>$\sqrt{s}$ [TeV]</th>
<th>$P_{\text{nominal}}$ [MW]</th>
<th>$P_{\text{waiting for beam}}$ [MW]</th>
<th>$P_{\text{stop}}$ [MW]</th>
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</thead>
<tbody>
<tr>
<td>0.38</td>
<td>252</td>
<td>168</td>
<td>30</td>
</tr>
<tr>
<td>1.5</td>
<td>364</td>
<td>190</td>
<td>42</td>
</tr>
<tr>
<td>3.0</td>
<td>589</td>
<td>268</td>
<td>58</td>
</tr>
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</table>

-> working on optimization and power reduction

Preliminary cost estimate (380GeV)
Civil engineering implementation
The ESU is crucial for determining the future activities of CLIC

The formal submission is due mid-December 2018
- the input material needs to be in good shape by the summer

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**CLICdp reports serving as ingredients for a CLIC summary report:**

- Updated Baseline for a Staged Compact Linear Collider (380 GeV, 1.5 TeV, 3 TeV) ✔
- Higgs Physics at the CLIC Electron-Positron Linear Collider ✔
- The new optimised CLIC detector model CLICdet ✔✔
  - CLICdp note [CLICdp_Note_2017-001](https://www.clincollider.org/detector)
- An overview of CLIC top physics
  - CLIC top physics publication => complete draft ✔
- Extended BSM studies (hopefully also motivated by LHC discoveries)
  - CLIC BSM overview publication in 2018 ✔
- CLIC R&D report => with main CLIC technology demonstrators ✔
  - Summary publication(s) in 2018
- Plan for the period ~2019-2025 in case CLIC would be supported by next strategy

Detector description note done ✔
Detector performance note in progress ✔

is prepared ✔
2 The Standard Model EFT (Francesco)

2.1 The EFT Framework

2.2 Higgs and Gauge
   - Summary of Higgs results (with new H trilinear)
   - Drell–Yan (revised analysis from Andrea&Jorge)
   - Dibosons (improved analysis from Francesco&Philipp&al)
   - WW>HH? WW>WW? (existing papers)
   - BSM interpretation (general Universal, Composite Higgs) (Oleksii&Gauthier)

2.3 Top
   - ttH (from top report)
   - Top Pair Production (existing papers)
   - WW>tt (Andrea&Christophe&Tevong&Zhang)
   - BSM interpretation (general Top-philic, Top compositeness, top partners (Oleksii&Gauthier))

3 Direct Searches (Michael and Roberto)

3.1 EWSB
   - Closing SUSY Holes: Summary of previous studies Compressed spectra
   - Extra Scalars (in progress Sala, Tesi, Redigolo, Buttazzo)
   - SUSY limits from loops
   - Extended Higgs Sectors (Santos)
   - Discovering Naturalness: scenarios that can be truly first seen at CLIC and/or that can be established. (existing literature, plus Reece, Fan)

3.2 Dark Matter
   - Neutralino DM
   - Co-annihilation scenarios (Plascencia, Sakurai)
   - Minimal (milli-charged) DM
   - Non-WIMP scenarios

3.3 New Neutrinos and see-saw mediators
   - Gauge-Charged see-saw mediators (Ghezzi, Pruna, Panizzi, Mitra)
   - Singlet see-saw mediators

3.4 EW Baryogenesis (J. M. No)

4 Flavour Physics

4.1 FCNC
   - Direct probes by high-energy q q? (including top), maybe also mu-tau, e-tau
   - Exotic top decays and interplay with the above

4.2 BSM impact of Light quark Yukawa determination

4.3 LFUV anomaly
As an extra step in our preparations, CLICdp Advisory Board will meet 17–18 April at CERN

-> a ‘sounding board’ for CLIC ESU preparation

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute</th>
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<tbody>
<tr>
<td>Dave Charlton (chair)</td>
<td>Univ. Birmingham</td>
</tr>
<tr>
<td>Juan ALCARAZ MAESTRE</td>
<td>CIEMAT, Madrid</td>
</tr>
<tr>
<td>Freya BLEKMAN</td>
<td>Vrije Univ. Brussels</td>
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<tr>
<td>Keisuke FUJII</td>
<td>KEK</td>
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<tr>
<td>Christophe GROJEAN</td>
<td>DESY</td>
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<td>Matthew McCullough</td>
<td>CERN</td>
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<td>Sven MENKE</td>
<td>MPI Munich</td>
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<tr>
<td>Roger RUSACK</td>
<td>Univ. Minnesota, Minneapolis</td>
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<td>Peter SCHLEPER</td>
<td>Univ. Hamburg</td>
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<tr>
<td>Joao VARELA</td>
<td>LIP and Univ. Lisbon</td>
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<tr>
<td>Vincenzo VAGNONI</td>
<td>Bologna Univ. and INFN</td>
</tr>
<tr>
<td>Pippa WELLS</td>
<td>CERN</td>
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Give feedback and recommendations on ongoing activities and ESU presentation

Focus on CLIC detector & physics (but will inform on status of CLIC accelerator)

Stronger focus on the physics than on the detectors/technology
We are relying on your studies to show where CLIC could give unique/best sensitivity, to make the best possible case for the machine!

Thank you!