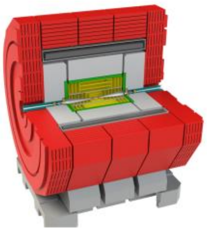
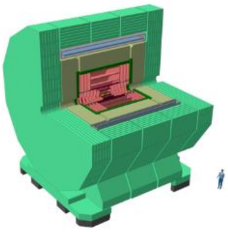
31/8/2020

Detector optimisation and detector technology R&D for the CLIC detector and for the CLD detector of FCC-ee





Snowmass21 Letter of Interest

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on behalf of the CLICdp collaboration and of the CLD detector study

Introduction:

The recent update of the European Strategy for Particle Physics allocates its highest priority to a future electron-positron Higgs factory. This conclusion is motivated by a number of physics arguments, such as precision Higgs physics, top-quark physics, electroweak observables and a broad scope for other precision measurements. Four high-energy electron-positron colliders have been proposed for construction. Linear colliders offer the advantage of reaching very high energies, up to 1 TeV for the ILC and up to 3 TeV for CLIC, while circular colliders, FCC-ee and CEPC, offer unprecedented luminosities at the 91 GeV Z-peak. Both linear and circular colliders can operate at energies close to the highest Higgs and top-antitop production cross sections. The ILC and CEPC are proposed for construction in Asia (Japan, China), while CLIC [1] and FCC-ee [2] are proposed for construction in Europe (CERN). In light of the European Strategy, CERN is continuing to invest in the key CLIC accelerator technologies while in parallel carrying out a feasibility study for FCC.

The CLICdp collaboration[2] has developed the CLICdet [3] detector concept and is actively engaged in the corresponding detector technology development. The CLICdet development has strongly benefitted from an integrated effort on detector optimisation studies, full simulation software development and relevant hardware R&D. In recent years, members of the CLICdp collaboration and the FCC collaboration have adapted the CLIC detector concept for operation at FCC-ee. The resulting CLD [4] concept was scaled from the CLICdet concept, taking FCC-ee experimental conditions and design constraints into account. The CLD detector was optimised in view of the FCC-ee Higgs and top physics energy stages (250 GeV – 365 GeV) and its performance was validated.

The four Higgs factories have a tradition of grassroot collaboration. Many of the active scientists participate in detector and physics studies for more than one future electron-positron collider. For

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example, detector optimisation and physics studies for several detector concepts, including CLICdet and CLD, are based on the iLCSoft [5] software suite for full simulation and event reconstruction. Software developments are ongoing to bring the software suites for all future Higgs factories together in the Key4hep [6] software infrastructure. Similarly, several detector concepts for future e^+e^- colliders are based on particle-flow analysis (PFA) with highly granular calorimetry. High granularity calorimeters are developed by the CALICE [7] collaboration for various central calorimeter technologies, and by the FCAL [8] collaboration for compact silicon-based forward calorimetry.

The CLICdet and CLD detector concepts

CLICdet and CLD are general purpose e^+e^- detector concepts. Their design was driven by jet energy resolution (through PFA), together with high-performance tracking in view of precision measurements of single particles and jet flavour identification. The reconstruction of individual particles in a dense environment through FPA is also essential for the suppression of particles from beam-induced background in e^+e^- colliders.

Going outward from the interaction point, the CLICdet [3] and CLD [4] concepts comprise:

- Vertex detector, based on silicon pixel technology, aiming for ~3 μm single point resolution, ~5 ns hit time resolution, ~0.2%X_0 (CLICdet) to 0.3%X_0 (CLD) material per layer, 6 layers;
- Main tracker, based on silicon (macro-)pixel technology, aiming for ~7 μm single point resolution, ~5 ns hit time resolution, 1-2%X_0 material per layer, 6-7 layers;
- Electromagnetic calorimeter, with tungsten absorbers and silicon active layers; cell size 5×5 mm^2, 40 layers;
- Hadronic calorimeter, with steel absorbers and scintillator active layers with SiPM readout, cell size 3×3 cm^2, 60 layers (CLICdet) and 44 layers (CLD);
- Superconducting solenoid, 4 Tesla (CLICdet) and 2 Tesla (CLD);
- Muon identification detector, based on cost-effective RPC pads or scintillator bars;
- Forward calorimetry, with tungsten absorbers and silicon (macro-)pixels, 40 layers.

Detector technology R&D

The CLICdp collaboration has been engaged in detector technology R&D for many years as described in detail in [9]. In the domain of calorimetry, the technology development is carried out in the framework of the CALICE and FCAL collaborations. We therefore refer to Snowmass21 LoI submissions by the CALICE and FCAL collaborations for the corresponding technology descriptions and future prospects. Development of the silicon vertex detector and main tracker for CLIC is embedded in the CLICdp collaboration. In view of its challenging requirements, in particular for achieving the combination of requirements at the same time, different technology approaches are being studied in detail [9]:

- Hybrid silicon detectors with thin pixel sensors (50 μm), DC-coupled to readout ASICs (in 65 nm technology) for the vertex detector;
- Hybrid silicon detectors with thin active pixel sensors (in HV-CMOS technology), AC-coupled to readout ASIC (in 65 nm technology) for the vertex detector;
- Fully monolithic CMOS detectors, in HR-CMOS, HV-CMOS and SoI technologies, for the CLIC main tracker and the vertex detector;
- Interconnect technology development: (fine-pitch bump bonding, anisotropic conductive film (ACF), flip-chip capacitive coupling with glue, through-silicon via (TSV);
- Engineering studies of power pulsing, lightweight supports and air cooling.

All the above detector technology developments are equally relevant for the CLD detector, although requirements can deviate (e.g. on aspects of power pulsing and vertex cooling). The FCC-ee duty cycle is different from the CLIC case, and the FCC-ee timing requirements are likely more relaxed. In general, the requirements for the CLD detector still need to be studied in further detail, in particular for the 91 GeV FCC-ee energy stage.

Future work and possible Snowmass21 participation

We invite colleagues from the US and elsewhere to participate in our detector optimisation and detector technology activities for the CLD and CLICdet detectors. These detectors are based on silicon tracking technologies and PFA calorimetry. They offer ample room for further developments and optimisation, also in view of promising new technologies and experiences from the LHC upgrades. For example, the rapidly evolving field of monolithic semiconductor detectors offers good prospects for matching the challenging vertex detector requirements. Furthermore, recent progress with ultrafast detectors with O(few-10 ps) hit time resolution will offer opportunities for improved particle identification. Support for these activities can be made available. In particular the CLD and CLICdet detector have fully functional and flexible software tools for detector descriptions (DD4hep) [10], event generation (WHIZARD 2), simulation and reconstruction (iLCSoft / Key4hep). Support for the hardware studies can be provided, for example, in the form of access to testing infrastructures and to a suite of silicon simulation [11] and test beam reconstruction [12] packages.

Examples of activities:

- Simulation studies towards further optimisation of aspects of the CLD and CLICdet detectors;
- Adaptation of the CLD detector for running at the Z-peak;
- Exploration of particle identification prospects in view of new technologies (e.g. improved particle identification when adding high-precision timing layers);
- Exploration of innovative event reconstruction methods (e.g. methods developed for LHC) in an e^+e^- environment;
- Silicon pixel detector developments (hybrid, monolithic) and corresponding engineering studies in modules, electronics and mechanics;
- Physics benchmarking (note that opportunities in this area are described in separate LoI’s submitted by CLIC and FCC-ee)
- Etc.

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