

# Introductory remarks

João Guimarães da Costa (Beijing)

August 30, 2017



中國科學院高能物理研究所

*Institute of High Energy Physics  
Chinese Academy of Sciences*




# News

- New weekly meeting time:
  - Wednesday, 3 pm Beijing time
- Repository for text (GIT) → See Li Gang's talk
- **Timescale for CDR:**
  - Draft text from each subgroup: September 30
    - Shared with others via GIT repository
  - First draft for internal review
    - November 1 (available for CEPC international workshop)
- **Next steps for each detector subgroups:**
  - Need outline structure from each subgroup
  - Need specific names of editors, in addition to conveners
  - Review detector geometry as defined by simulation group



# Agenda

Wednesday, 30 August 2017

|               |   |   |
|---------------|---|---|
| 15:00 - 15:10 | Introduction 10'  | ▼ |
|               | Speaker: Joao Guimaraes Costa   |   |
| 15:10 - 15:20 | CDR Text and Git repository 10'   | ▼ |
|               | Speaker: LI Gang ( EPC.IHEP )   |   |
| 15:20 - 15:30 | Simulation 10'  | ▼ |
|               | Speakers: Mr. Manqi Ruan (IHEP), Dr. Gang LI (Experimental Physics Division, Institute of High Energy Physics)                              |   |
|               | Material: <a href="#">Slides</a>                          |   |
| 15:30 - 15:50 | Status of dual readout calorimeter work and simulation 20'  | ▼ |
|               | Speaker: Roberto Ferrari (INFN)   |   |
| 15:50 - 16:10 | Status of drift chamber work and simulation 20'   | ▼ |
|               | Speaker: Francesco Grancagnolo (INFN-Lecce)   |   |
| 16:10 - 16:30 | Status of general simulation integration for IDEA 20'   | ▼ |
|               | Speaker: Giovanni Tassielli   |   |
| 16:30 - 16:40 | Calo 10'  | ▼ |
|               | Speakers: Haijun Yang (Shanghai Jiao Tong University), Prof. Tao HU (IHEP), Dr. Jianbei Liu (University of Science and Technology of China) |   |
| 16:40 - 16:50 | Vertex 10'  | ▼ |
|               | Speakers: Prof. Qun OUYANG (IHEP), Mr. Xiangming Sun (CCNU), Prof. Meng Wang (Shandong University)  |   |
| 16:50 - 17:00 | Tracker 10'   | ▼ |
|               | Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)   |   |

## Next week:

- MDI, magnet and Muon reports
- Discussion of detector requirements

# Detector and Physics: Conceptual Design Report

- **May ~~1~~<sup>3</sup>, 2017: Monday, P&D meeting**
  - \* Decide on editors and timescale *today!*
  - ✓ \* Establish SVN/git repository area
- **September 30: Text for all subsections finalized**
  - \* Includes R&D results available until this date
  - \* All text committed to repository
- **October 31: Version for internal review finalized**
  - \* Harmonization of text across chapters
  - \* Finalize introduction and other common aspects (references, authors, etc)
- **December 20: Version for external review ready**
- **March 1, 2018: Release to public**

still about one year  
of work

*Preliminary*

*From April Meeting*

# Extra Slides

---



# Possible CDR outline

## 1. CEPC Physics Potential

1. Higgs physics
2. Electroweak precision physics
3. Searches for physics beyond the Standard Model
4. Flavor physics



Theory group

Preliminary

## 2. Experimental conditions and detector requirements

1. The CEPC experimental environment
  1. Beam backgrounds, polarization, etc
2. Detector requirements for  $e^+e^-$  physics
  1. Track momentum and jet energy resolution, flavor tagging, particle identification

3. Basic description of Detector Concepts
  - TPC tracking system (baseline)
  - All-silicon tracking
  - Drift chamber and DR calorimeter

## 3. Vertex detectors

## 4. Tracking system

1. Detailed tracker concepts
  1. The TPC tracking system
  2. The All-Silicon tracking system
  3. The Drift Chamber tracking system
2. Beam induced backgrounds in tracking system
3. Performance



# Possible CDR outline

Preliminary

5. Calorimetry
  1. Particle flow calorimeter
    1. Hadronic calorimeter
    2. Electromagnetic calorimeter
  2. Dual readout calorimeter
  3. Calorimeter performance
6. Detector magnet system
7. Muon system
  1. Conceptual design of muon system
  2. Muon reconstruction algorithm and system performance
8. Readout electronics and data acquisition (?)
9. CEPC interaction region and detector integration (MDI)
10. Physics performance
  1. Simulation and reconstruction
  2. Luminosity measurement
  3. Energy measurement
  4. Performance of low-level physics observables
  5. Detector benchmark processes
11. Future plans and R&D prospects





# Work towards CDR

- Need to integrate work done in **Detector subgroups** with work done by **Simulation subgroup**
- Decide and review final options for detector to be simulated:
  - This will be our baseline detector!
    - Deviations from “Full Simulation” should be clearly explained in the CDR
    - Need to agree upon details now, before moving with large scale CDR work
- **Suggestions:**
  - Discuss within detector groups to decide what designs should be put forward as baseline
  - Common meetings between each detector subgroup and simulation subgroup to clarify details
  - Decisions need to be documented in **short notes** made available for review by CEPC colleagues (these can then turn into parts of the CDR)
  - Detector subgroups should provide manpower to aid on any needed improvements on digitization and geometry
  - Integrate international partners in discussions. We are planning **one** CDR with an integrated structure





# CLIC: Example of Vertex Section

|          |  |           |
|----------|--|-----------|
| <b>4</b> | <b>Vertex Detectors</b>  | <b>83</b> |
| 4.1      | Introduction . . . . .   | 83        |
| 4.2      | Physics Requirements . . . . .                                   | 83        |
| 4.3      | Simulation Layouts . . . . .                                     | 84        |
| 4.4      | Performance Optimisation Studies . . . . .                       | 85        |
| 4.4.1    | Performance of the Baseline Configurations . . . . .             | 86        |
| 4.4.2    | Dependence on Single-Point Resolution . . . . .                  | 87        |
| 4.4.3    | Dependence on Arrangement of Layers . . . . .                    | 87        |
| 4.4.4    | Material Budget . . . . .  | 89        |
| 4.5      | Beam-Induced Backgrounds in the Vertex Detector Region . . . . . | 89        |
| 4.5.1    | Beam-Pipe Layout and Design . . . . .                            | 90        |
| 4.5.2    | Hit Densities in the Vertex Region . . . . .                     | 91        |
| 4.5.3    | Radiation Damage . . . . .                                       | 92        |
| 4.6      | Integration, Assembly and Access Scenarios . . . . .             | 92        |
| 4.6.1    | Assembly and Integration . . . . .                               | 92        |
| 4.6.2    | Pixel Cooling . . . . .  | 93        |
| 4.7      | Sensor and Readout-Technology R&D . . . . .                      | 95        |
| 4.7.1    | Requirements of a CLIC Vertex Detector Sensor . . . . .          | 95        |
| 4.7.2    | Technology Options . . . . .                                     | 95        |
| 4.7.3    | Vertexing Technological Developments . . . . .                   | 96        |



# CLIC: Example of Calorimeter Section

|          |  |            |
|----------|--|------------|
| <b>6</b> | <b>Calorimetry</b>   | <b>125</b> |
| 6.1      | A Particle Flow Calorimeter for TeV Energies . . . . .                   | 125        |
| 6.1.1    | Tungsten as Absorber for the ECAL and HCAL . . . . .                     | 125        |
| 6.1.2    | Time Stamping Considerations . . . . .                                   | 126        |
| 6.1.3    | Readout Technologies . . . . .   | 128        |
| 6.2      | Electromagnetic Calorimeter . . . . .                                    | 129        |
| 6.2.1    | ECAL Readout Technologies . . . . .                                      | 130        |
| 6.2.2    | ECAL Prototypes . . . . .  | 130        |
| 6.2.3    | ECAL Testbeam Results . . . . .  | 131        |
| 6.3      | Hadronic Calorimeter . . . . .   | 132        |
| 6.3.1    | Basic Layout . . . . .   | 132        |
| 6.3.2    | HCAL Readout Technologies for Scintillator and Gaseous Options . . . . . | 132        |
| 6.3.3    | HCAL Test Beam Results . . . . .   | 133        |
| 6.3.4    | Tungsten Design and Engineering Studies . . . . .                        | 138        |
| 6.4      | Calorimeter Performance under CLIC Conditions . . . . .                  | 138        |
| 6.4.1    | ECAL Performance for High Energy Electrons . . . . .                     | 139        |
| 6.4.2    | Timing Resolution . . . . .  | 139        |
| 6.4.3    | Jet Energy Resolution . . . . .  | 140        |
| 6.5      | Future Calorimeter R&D for CLIC . . . . .                                | 141        |



# Agenda

## Wednesday, 3 May 2017

- |               |  |   |
|---------------|--|---|
| 15:00 - 15:20 | <b>Introduction 20'</b><br>Speaker: Joao Guimaraes Costa   | ▼ |
| 15:20 - 15:40 | <b>MDI 20'</b><br>Speaker: Dr. Hongbo ZHU (IHEP)   | ▼ |
| 15:40 - 16:00 | <b>Vertex 20'</b><br>Speakers: Prof. Qun OUYANG (IHEP), Mr. Xiangming Sun (CCNU), Prof. Meng Wang (Shandong University)  | ▼ |
| 16:00 - 16:20 | <b>Tracker 20'</b><br>Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)  | ▼ |
| 16:20 - 16:40 | <b>Calo 20'</b><br>Speakers: Haijun Yang (Shanghai Jiao Tong University), Prof. Tao HU (IHEP), Dr. Jianbei Liu (University of Science and Technology of China) | ▼ |
| 16:40 - 17:00 | <b>Muon 20'</b><br>Speaker: Prof. Liang Li (Shanghai Jiao Tong University)   | ▼ |
| 17:00 - 17:20 | <b>Magnet 20'</b><br>Speakers: Mr. Zian ZHU (高能所), Dr. Feipeng NING (高能所)  | ▼ |
| 17:20 - 17:40 | <b>Simulation 20'</b><br>Speakers: Mr. Manqi Ruan (IHEP), Dr. Gang LI (Experimental Physics Division, Institute of High Energy Physics)                        | ▼ |



# Detector Pre-CDR Outline

|          |  |           |
|----------|--|-----------|
| <b>1</b> | <b>Introduction</b>  | <b>1</b>  |
| 1.1      | The CEPC-SPPC Study Group and the Preliminary CDR            | 1         |
| 1.2      | The Case for the CEPC-SPPC in China                          | 2         |
| 1.3      | The Science in the preCDR                                    | 2         |
| 1.4      | The Accelerator and the Experiment                           | 3         |
| <b>2</b> | <b>Overview of the Physics Case for CEPC-SPPC</b>            | <b>5</b>  |
| 2.1      | New Colliders for a New Frontier                             | 7         |
| 2.2      | The Electroweak Phase Transition                             | 18        |
| 2.3      | Naturalness of the Electroweak Scale                         | 27        |
| 2.4      | Dark Matter  | 40        |
| <b>3</b> | <b>Higgs Physics at the CEPC</b>                             | <b>57</b> |
| 3.1      | Introduction   | 57        |
| 3.2      | Simulation and Reconstruction                                | 59        |
| 3.2.1    | Detector Simulation and Software Chain                       | 59        |
| 3.2.2    | Detector Performance   | 60        |
| 3.3      | Higgs Boson Measurements                                     | 62        |
| 3.3.1    | Production Cross Sections of Signal and Background Processes | 62        |
| 3.3.2    | $\sigma(ZH)$ and $m_H$ Measurements                          | 64        |
| 3.3.3    | Production Rates of Individual Higgs Boson Decay Modes       | 68        |
| 3.3.4    | Measurements of Branching Ratios                             | 76        |
| 3.3.5    | Measurement of Higgs Boson Width                             | 77        |
| 3.3.6    | Summary of the Higgs Measurements                            | 78        |





## Detector Pre-CDR Outline

|          |   |            |          |   |            |
|----------|---|------------|----------|---|------------|
| 3.4      | Coupling Extractions and Combinations                     | 80         | 6.6.2    | Technologies  | 203        |
| 3.4.1    | Coupling Fits   | 80         | 6.6.3    | Future R&D  | 205        |
| 3.4.2    | Higgs Self-coupling                                       | 84         | 6.7      | Detector Magnet System  | 206        |
| 3.5      | Implications  | 86         | 6.7.1    | General Design Considerations   | 206        |
| <b>4</b> | <b>Electroweak Precision Physics at the CEPC</b>          | <b>97</b>  | 6.7.2    | Solenoid Design   | 207        |
| 4.1      | $W, Z$ Measurements at the CEPC                           | 97         | 6.7.3    | Coil Manufacturing and Assembly   | 213        |
| 4.1.1    | $Z$ Pole Measurements                                     | 98         | 6.7.4    | Ancillaries   | 213        |
| 4.1.2    | $W$ Mass Measurement                                      | 103        | 6.7.5    | Magnet Tests and Field Mapping  | 214        |
| 4.2      | CEPC Electroweak Oblique Parameter Fit                    | 105        | 6.7.6    | Iron Yoke Design  | 214        |
| 4.2.1    | The Precision Challenge for Theorists                     | 107        | 6.7.7    | Future R&D  | 216        |
| 4.2.2    | A General To Do List for a Successful Electroweak Program | 108        | 6.8      | Machine-Detector Interface  | 217        |
| 4.3      | Implications for New Physics                              | 110        | 6.8.1    | Interaction Region Layout   | 217        |
| 4.3.1    | Natural Supersymmetry and EWPT                            | 110        | 6.8.2    | Detector Backgrounds  | 218        |
| 4.3.2    | Composite Higgs scenarios                                 | 113        | 6.8.3    | Luminosity Instrumentation  | 223        |
| 4.3.3    | Fermionic Higgs Portal                                    | 114        | 6.8.4    | Mechanical Integration  | 224        |
| <b>5</b> | <b>Flavor Physics at the CEPC</b>                         | <b>125</b> | 6.9      | Detector Facilities at the Experiment Area                              | 225        |
| 5.1      | Introduction  | 125        | 6.9.1    | General Considerations  | 225        |
| 5.2      | Beauty and Charm Transitions                              | 127        | 6.9.2    | Underground Caverns and Access  | 225        |
| 5.3      | Very Rare Decays  | 129        | 6.9.3    | Surface Building and Facilities   | 226        |
| 5.4      | CPV in $\tau$ Decays and Production                       | 130        | 6.9.4    | Safety Features   | 228        |
| 5.5      | Charged Lepton Flavor Violation                           | 133        | <b>7</b> | <b>New Physics Searches at SPPC</b>                                     | <b>237</b> |
| 5.6      | Summary   | 136        | 7.1      | Supersymmetry   | 237        |
| <b>6</b> | <b>The CEPC Detector</b>                                  | <b>145</b> | 7.2      | New Resonances  | 251        |
| 6.1      | Detector Overview   | 145        | 7.3      | New Phenomena of Standard Model Physics                                 | 264        |
| 6.2      | Vertex Detector   | 148        | 7.4      | Running Electroweak Couplings as a Probe of New Physics                 | 277        |
| 6.2.1    | Performance Requirements and Detector Challenges          | 148        | 7.5      | B+L Violation at High Energies  | 280        |
| 6.2.2    | Baseline Design   | 148        | 7.6      | Higgs and New Physics   | 283        |
| 6.2.3    | Detector Performance                                      | 149        | <b>8</b> | <b>Future Heavy-ion and Electron-Ion Collision Program</b>              | <b>335</b> |
| 6.2.4    | Sensor Options  | 152        | 8.1      | Introduction  | 335        |
| 6.2.5    | Mechanics and Integration                                 | 154        | 8.2      | QCD and Strong Interaction Matter                                       | 338        |
| 6.2.6    | Critical R&D  | 155        | 8.3      | Bulk Properties of Matter in Heavy-ion Collisions                       | 341        |
| 6.2.7    | Summary   | 156        | 8.4      | Jet Quenching in Heavy-ion Collisions                                   | 345        |
| 6.3      | Silicon Tracker   | 157        | 8.5      | Medium Modification of Open Heavy Mesons                                | 354        |
| 6.3.1    | Baseline Design   | 157        | 8.6      | $J/\psi$ Production   | 356        |
| 6.3.2    | Tracker Performance                                       | 160        | 8.7      | Summary   | 359        |
| 6.3.3    | Critical R&D  | 160        | 8.8      | Physics Perspective at Future Electron-Proton or Electron-Ion Colliders | 360        |
| 6.4      | Main Tracking Detector – TPC                              | 163        | <b>9</b> | <b>Summary</b>  | <b>381</b> |
| 6.4.1    | Design and Challenges                                     | 163        | <b>A</b> | <b>International Review</b>   | <b>383</b> |
| 6.4.2    | Alignment and Calibration                                 | 173        | A.1      | Report of Review of CEPC-SppC Detector preCDR                           | 384        |
| 6.4.3    | Critical R&D  | 174        | A.1.1    | Introduction  | 384        |
| 6.5      | Calorimetry System  | 181        | A.1.2    | Observations  | 384        |
| 6.5.1    | Electromagnetic Calorimeter                               | 181        | A.1.3    | Addressing the questions in the charge                                  | 384        |
| 6.5.2    | Hadronic Calorimeter                                      | 189        | A.2      | R&D topics suggested by the Committee                                   | 386        |
| 6.6      | Muon System   | 200        | A.3      | Committee members   | 389        |
| 6.6.1    | Baseline Design   | 200        |          |   |            |



# CLIC Detector CDR - an example

## Contents

|   |           |  |   |    |
|---|-----------|--|---|----|
| <b>Table of Contents</b>  | <b>3</b>  | 2.5  | Timing Requirements at CLIC                         | 66 |
| <b>Executive Summary</b>  | <b>9</b>  | 2.5.1  | Timing in Physics Reconstruction at CLIC            | 68 |
| <b>1 CLIC Physics Potential</b>                                 | <b>15</b> | 2.6  | Detector Benchmark Processes                        | 70 |
| 1.1 Introduction  | 15        | 2.6.1  | Light Higgs Production $e^+e^- \rightarrow h\nu\nu$ | 70 |
| 1.2 Higgs   | 16        | 2.6.2  | Heavy Higgs Production                              | 70 |
| 1.2.1 The Higgs Boson in the Standard Model                     | 18        | 2.6.3  | Production of Right-Handed Squarks                  | 71 |
| 1.2.2 The Higgs Bosons of the MSSM                              | 19        | 2.6.4  | Chargino and Neutralino Pair Production             | 71 |
| 1.2.3 Higgs Bosons in other Extensions                          | 22        | 2.6.5  | Slepton Production                                  | 72 |
| 1.3 Supersymmetry   | 23        | 2.6.6  | Top Pair Production at 500 GeV                      | 72 |
| 1.3.1 CLIC potential for Heavy SUSY                             | 25        | <b>3 CLIC Detector Concepts</b>                            | <b>75</b>   |    |
| 1.3.2 Reconstructing the High-Scale Structure of the Theory     | 27        | 3.1 Rationale  | 75  |    |
| 1.3.3 Testing the Neutralino Dark Matter Hypothesis             | 28        | 3.2 High Energy CLIC Environment                           | 75  |    |
| 1.4 Higgs Strong Interactions                                   | 30        | 3.3 Design Principles                                      | 75  |    |
| 1.5 $Z'$ , Contact Interactions and Extra Dimensions            | 33        | 3.4 Subsystems   | 76  |    |
| 1.6 Impact of Beam Polarisation                                 | 37        | 3.5 Detector Parameters                                    | 80  |    |
| 1.7 Precision Measurements Potential                            | 40        | <b>4 Vertex Detectors</b>                                  | <b>83</b>   |    |
| 1.8 Discussion and Conclusions                                  | 42        | 4.1 Introduction   | 83  |    |
| <b>2 CLIC Experimental Conditions and Detector Requirements</b> | <b>51</b> | 4.2 Physics Requirements                                   | 83  |    |
| 2.1 The CLIC Experimental Environment                           | 51        | 4.3 Simulation Layouts                                     | 84  |    |
| 2.1.1 The CLIC Beam   | 51        | 4.4 Performance Optimisation Studies                       | 85  |    |
| 2.1.2 Beam-Induced Backgrounds                                  | 52        | 4.4.1 Performance of the Baseline Configurations           | 86  |    |
| 2.1.3 Beam Polarisation at CLIC                                 | 56        | 4.4.2 Dependence on Single-Point Resolution                | 87  |    |
| 2.2 Detector Requirements for $e^+e^-$ Physics in the TeV Range | 57        | 4.4.3 Dependence on Arrangement of Layers                  | 87  |    |
| 2.2.1 Track Momentum Resolution                                 | 57        | 4.4.4 Material Budget                                      | 89  |    |
| 2.2.2 Jet Energy Resolution                                     | 58        | 4.5 Beam-Induced Backgrounds in the Vertex Detector Region | 89  |    |
| 2.2.3 Impact Parameter Resolution and Flavour Tagging           | 59        | 4.5.1 Beam-Pipe Layout and Design                          | 90  |    |
| 2.2.4 Forward Coverage  | 60        | 4.5.2 Hit Densities in the Vertex Region                   | 91  |    |
| 2.2.5 Lepton ID Requirements                                    | 60        | 4.5.3 Radiation Damage                                     | 92  |    |
| 2.2.6 Summary of Requirements for Physics Reconstruction        | 61        | 4.6 Integration, Assembly and Access Scenarios             | 92  |    |
| 2.3 Basic Choice of Detector Concepts for CLIC                  | 61        | 4.6.1 Assembly and Integration                             | 92  |    |
| 2.3.1 The Particle Flow Paradigm                                | 61        | 4.6.2 Pixel Cooling  | 93  |    |
| 2.3.2 Detector Design Considerations                            | 62        | 4.7 Sensor and Readout-Technology R&D                      | 95  |    |
| 2.4 Impact of Backgrounds on the Detector Requirements          | 63        | 4.7.1 Requirements of a CLIC Vertex Detector Sensor        | 95  |    |
| 2.4.1 Impact on the Vertex Detector                             | 63        | 4.7.2 Technology Options                                   | 95  |    |
| 2.4.2 Impact on the Central Tracking Detector                   | 63        | 4.7.3 Vertexing Technological Developments                 | 96  |    |
| 2.4.3 Backgrounds in the ECAL and HCAL                          | 64        | <b>5 CLIC Tracking System</b>                              | <b>101</b>  |    |
| 2.4.4 Background Summary  | 66        | 5.1 Introduction   | 101   |    |
|   |           | 5.2 Tracker Concepts                                       | 101   |    |
|   |           | 5.2.1 The TPC-Based CLIC_ILD Tracking System               | 102   |    |





中国科学院高能物理研究所

# CLIC Detector CDR - an example

|          |  |            |
|----------|--|------------|
| 5.2.2    | The All-Silicon CLIC_SiD Tracking System                         | 107        |
| 5.3      | Beam-Induced Backgrounds in the Tracking Region                  | 111        |
| 5.3.1    | Occupancies in the Barrel Strip Detectors of CLIC_ILD            | 111        |
| 5.3.2    | Occupancies in the Forward Strip Detectors of CLIC_ILD           | 111        |
| 5.3.3    | Occupancies in the TPC   | 112        |
| 5.3.4    | Radiation Damage in the Silicon Strip Detectors of CLIC_ILD      | 113        |
| 5.4      | Performance  | 114        |
| 5.4.1    | Tracking Performance of the TPC-based CLIC_ILD Tracking System   | 114        |
| 5.4.2    | Tracking Performance of the All-Silicon CLIC_SiD Tracking System | 118        |
| <b>6</b> | <b>Calorimetry</b>   | <b>125</b> |
| 6.1      | A Particle Flow Calorimeter for TeV Energies                     | 125        |
| 6.1.1    | Tungsten as Absorber for the ECAL and HCAL                       | 125        |
| 6.1.2    | Time Stamping Considerations                                     | 126        |
| 6.1.3    | Readout Technologies   | 128        |
| 6.2      | Electromagnetic Calorimeter                                      | 129        |
| 6.2.1    | ECAL Readout Technologies  | 130        |
| 6.2.2    | ECAL Prototypes  | 130        |
| 6.2.3    | ECAL Testbeam Results  | 131        |
| 6.3      | Hadronic Calorimeter   | 132        |
| 6.3.1    | Basic Layout   | 132        |
| 6.3.2    | HCAL Readout Technologies for Scintillator and Gaseous Options   | 132        |
| 6.3.3    | HCAL Test Beam Results   | 133        |
| 6.3.4    | Tungsten Design and Engineering Studies                          | 138        |
| 6.4      | Calorimeter Performance under CLIC Conditions                    | 138        |
| 6.4.1    | ECAL Performance for High Energy Electrons                       | 139        |
| 6.4.2    | Timing Resolution  | 139        |
| 6.4.3    | Jet Energy Resolution  | 140        |
| 6.5      | Future Calorimeter R&D for CLIC                                  | 141        |
| <b>7</b> | <b>Detector Magnet System</b>                                    | <b>145</b> |
| 7.1      | Introduction   | 145        |
| 7.2      | The magnetic field requirements                                  | 145        |
| 7.3      | Solenoid Coil Design   | 147        |
| 7.4      | Conductor Options  | 149        |
| 7.5      | Anti-Solenoid Design   | 149        |
| 7.6      | The Ring Coils on the Endcap Yoke of the CLIC_ILD Detector       | 151        |
| 7.7      | Magnet Services and Push-Pull Scenario                           | 151        |
| <b>8</b> | <b>Muon System at CLIC</b>                                       | <b>155</b> |
| 8.1      | Introduction   | 155        |
| 8.1.1    | Muon System Requirements   | 155        |

|           |   |            |
|-----------|---|------------|
| 8.1.2     | Background Conditions   | 155        |
| 8.2       | Conceptual Design of the Muon System                              | 155        |
| 8.2.1     | Muon System Layers  | 156        |
| 8.2.2     | Muon Layer Design   | 157        |
| 8.3       | Muon Reconstruction Algorithm and System Performance              | 159        |
| 8.3.1     | Reconstruction Algorithm  | 159        |
| 8.3.2     | Reconstruction Performance  | 159        |
| <b>9</b>  | <b>Very Forward Calorimeters</b>                                  | <b>161</b> |
| 9.1       | Introduction  | 161        |
| 9.2       | Optimisation of the Forward Region                                | 163        |
| 9.3       | The Luminosity Calorimeter (LumiCal)                              | 164        |
| 9.3.1     | Remarks on systematic uncertainties to the luminosity measurement | 167        |
| 9.4       | The Beam Calorimeter (BeamCal)                                    | 167        |
| <b>10</b> | <b>Readout Electronics and Data Acquisition System</b>            | <b>171</b> |
| 10.1      | Introduction  | 171        |
| 10.2      | Overview of Subdetectors and their Implementation Scheme          | 172        |
| 10.2.1    | Overview of Subdetectors  | 172        |
| 10.2.2    | Implementation Example for a Pixel Detector                       | 172        |
| 10.2.3    | Implementation Example for the TPC Pad Readout                    | 174        |
| 10.2.4    | Implementation Example for the Analog Calorimeter Readout         | 175        |
| 10.3      | Power Delivery and Power Pulsing                                  | 176        |
| 10.3.1    | Motivation  | 176        |
| 10.3.2    | Implementation of Powering Schemes for CLIC Detectors             | 177        |
| 10.3.3    | Stability and Reliability Issues                                  | 178        |
| 10.4      | DAQ Aspects   | 180        |
| 10.5      | Summary   | 181        |
| <b>11</b> | <b>CLIC Interaction Region and Detector Integration</b>           | <b>185</b> |
| 11.1      | Introduction  | 185        |
| 11.2      | Detector Layout   | 185        |
| 11.2.1    | Overall Dimensions and Weights                                    | 185        |
| 11.2.2    | Magnets, Shielding and the Return Yoke                            | 187        |
| 11.2.3    | Services Integration  | 190        |
| 11.3      | Push-Pull Operation   | 191        |
| 11.4      | Underground Experimental Area                                     | 192        |
| 11.5      | Forward Region  | 194        |
| 11.5.1    | Forward Region Layout   | 195        |
| 11.5.2    | Alignment   | 195        |
| 11.5.3    | QD0 Stabilisation Requirements                                    | 196        |
| 11.6      | Detector Opening and Maintenance                                  | 196        |





# CLIC Detector CDR - an example

|   |            |
|---|------------|
| <b>12 Physics Performance</b>   | <b>201</b> |
| 12.1 Simulation and Reconstruction                                      | 201        |
| 12.1.1 Event Generation   | 201        |
| 12.1.2 Detector Simulation  | 202        |
| 12.1.3 Event Reconstruction   | 202        |
| 12.1.4 Treatment of Background  | 202        |
| 12.2 Luminosity Spectrum  | 203        |
| 12.2.1 Luminosity Spectrum Measurement using Bhabha Events              | 203        |
| 12.2.2 Systematic Effects due to Uncertainty of the Luminosity Spectrum | 205        |
| 12.3 Performance for Lower Level Physics Observables                    | 205        |
| 12.3.1 Particle Identification Performance                              | 205        |
| 12.3.2 Muon and Electron Energy Resolution                              | 206        |
| 12.3.3 Jet Reconstruction   | 208        |
| 12.3.4 Flavour Tagging  | 212        |
| 12.4 Detector Benchmark Processes                                       | 213        |
| 12.4.1 Light Higgs Decays to Pairs of Bottom and Charm Quarks           | 213        |
| 12.4.2 Light Higgs Decay to Muons                                       | 217        |
| 12.4.3 Heavy Higgs Production   | 220        |
| 12.4.4 Production of Right-Handed Squarks                               | 223        |
| 12.4.5 Stopped Searches   | 226        |
| 12.4.6 Chargino and Neutralino Production at 3 TeV                      | 230        |
| 12.4.7 Top Pair Production at 500 GeV                                   | 234        |
| 12.5 Summary  | 237        |
| <b>13 Future Plans and R&amp;D Prospects</b>                            | <b>241</b> |
| 13.1 Introduction   | 241        |
| 13.2 Activities for the next Project Phase                              | 241        |
| 13.2.1 Simulation Studies and Detector Optimisation                     | 241        |
| 13.2.2 Physics at CLIC  | 242        |
| 13.2.3 Software Development   | 242        |
| 13.2.4 Vertex Detector  | 243        |
| 13.2.5 Silicon Tracking   | 243        |
| 13.2.6 TPC-based Tracking   | 243        |
| 13.2.7 Calorimetry  | 244        |
| 13.2.8 Electronics and Power Delivery                                   | 244        |
| 13.2.9 Magnet and Ancillary Systems                                     | 245        |
| 13.2.10 Engineering and Detector Integration                            | 245        |
| <b>Summary</b>  | <b>247</b> |
| <b>Appendix</b>   | <b>249</b> |

|  |            |
|--|------------|
| <b>A Acronyms</b>  | <b>251</b> |
| <b>B Simulation and Reconstruction Parameters</b>                    | <b>255</b> |
| B.1 PFO Lists at 3 TeV   | 255        |
| B.2 PFO Lists at 500 GeV   | 257        |
| B.3 PYTHIA Parameters  | 258        |
| <b>C Cost Methodology for a CLIC Detector</b>                        | <b>259</b> |
| C.1 Introduction   | 259        |
| C.2 Scope of Detector Costing  | 259        |
| C.3 Guiding Principles   | 259        |
| C.4 Relative Distribution of Cost among the Main Detector Components | 260        |
| C.5 Cost Sensitivity Analysis  | 261        |