FCC CDR Volume 4 - Lepton Collider (Concise, short)

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Also available at: `http://cds.cern.ch/tbd`

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Executive Summary

This is the executive summary of the report.

Todo list

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Chapter 1

Physics Discovery potential

PATRICK JANOT: 10 pages

1.1 Introduction

FCC-ee, a discovery-oriented collider Recall open questions requiring new physics and various aspects of how physics can make progress, and the fact that scale and couplings are unknown. Note that precision measurements, violation of established symmetries, new rare processes have historically be precursors towards discovery of new particles. FCC-ee offers high rates, extreme precision and very clean, well-defined, precisely predictable environment. In the present situation any non-trivial deviation from the well-defined SM would be a major discovery. Forward reference to Section 2, with mention of the extraordinary luminosity delivered by FCC-ee. Give one (or a few) examples of new physics model, with predictions of deviations and/or new particles, then give a more general list of possibilities. Complementarity and synergies with FCC-hh

1.2 Precision electroweak measurements

Z, W, top, with ancillary measurements (QED, S, âĂę)

1.3 The Higgs Boson

1.4 Rare processes

Includes both quark and lepton flavours

1.5 New particle discovery potential

1.6 Requirements for the collider

Operation model: Centre-of-mass energies and integrated luminosities Transverse polarization and beam energy calibration Beam energy spread (and measurement) Beam-induced backgrounds (in particular synchrotron radiation) Instantaneous luminosity and number of interaction regions

1.7 Requirements for the detector

Luminosity measurement Flavour tagging (b, c, g) Muon momentum and direction resolution; acceptance determination Particle identification and Particle Flow capabilities (includes magnetic field) Comment on the possibility of large detector size.

1.8 Requirements for theory

Precision Manpower plan

Chapter 2

Collider Design and Performance

KATSUNOBU OIDE: 10 pages

2.1 Design goals and basic choices

Overview (top-up injection, crossing angle, crab waist, double ring, asymmetric IP, and low emittance optics)-> Four to five orders of magnitude above LEP-1/LEP2 in luminosity performance, similar to target luminosity of SuperKEKB, and 75Running modes, collision energies, integrated luminosity, energy calibration Site considerations, technology choices, injector considerations

2.2 Parameter Optimisation

Beam current, synchrotron radiation, collective effects, beamstrahlung, beam-beam, bunch length, emittance Energy calibration Injection scheme, filling patterns for transient beam loading etc. Layout and insertion choices Beam parameters for different running modes Design Parameters âĂŞ Table

2.3 Design Challenges and Approaches

FCC-ee vs LEP/LEP2 and SuperKEKB - synchrotron radiation (IR and arcs) Crab waist, beamstrahlung Synchrotron radiation, tapering and common section for top running Beam lifetime and top-up injection Energy efficiency (RF system, magnets)

2.4 Optics Design and Beam Dynamics

-Integral optics -Filling factor, tapering -Dynamic aperture -Tolerances and optics tuning – Misalignments, magnet errors and BPM errors, tolerances and tuning requirements, vertical emittance reach

2.5 Machine detector interface

Overall layout of the Interaction region Magnet systems (quadrupoles, solenoids, compensation- and shielding solenoids) Luminometer (what is the high rate monitor for the accelerator operation) Synchrotron radiation Beamstrahlung, radiative Bhabha scattering, and Touschek

2.6 Collective effects

Impedance budgets Single- and multi-bunch instabilities Feedback requirements Beam-beam effects including beamstrahlung

2.7 Energy calibration and polarization

Spin matching and self polarization, running scheme Polarimeter and wigglers Other equipment for monitoring and energy spread measurement Possible options for longitudinal polarization (snakes, injection etc.)

2.8 Injection and extraction

Top-up injection - Injection schemes, injection section, kickers, septa, optics, bootstrapping Beam abort - Extraction section, kickers, septa, optics, beam dump channel and beam dump

2.9 Machine performance and operation aspects

Operation model Luminosity performance Possible running schedule Machine protection

2.10 Monochromatization

2.11 Running at other energies

Chapter 3

Collider Technical Systems

EDITOR TBA: 25 pages

3.1 Main RF systems including staging and RF R and D

3.2 Vacuum system and e-cloud mitigation

3.3 Beam instrumentation and feedback systems

3.4 Beam dumping, beam injection and beam transfer systems

3.5 Other key technologies

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3.6 Radiation Environment

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VOLKER MERTENS: 10 pages

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EDITOR TBA: 15 pages

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Rquirements, constraints, layout and architecture

5.6.2 Proximity Cryogenics and Heat Loads

Temperature levels, cooling scheme, operating modes, transients, cryo-distribution, instrumentation

5.6.3 Cryogenic Plants

Refrigeration cycle, transients, operating [?] modes

5.6.4 Cryogen Inventory and Storage

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5.8 Person Transport

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YANNIS PAPAPHILIPPOU: 10 pages

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PATRICK JANOT: 25 pages

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Includes geometrical constraints, simulation of beam-induced backgrounds, shielding optimization,

7.2 The luminometer

Common to both detectors. Includes constraints from MDI, positioning, design, impact of beam induced backgrounds, and luminosity measurement

7.3 The vertex detector

Likely to be common to both detectors, Includes constraints from MDI, positioning, design, impact of beam induced backgrounds, consequences on readout electronics and cooling, and b/c tagging performance

7.4 The all-silicon detector design

7.5 The IDEA concept

Subsystems description, compliance with requirements, impact of beam induced backgrounds. basic performance, need for additional wok, RandD, test beam

7.6 Magnet System

Solenoid outside the calorimeters Thin Solenoid inside the calorimeters and its implications on detector performance

7.7 Constraints on readout systems

Number of channels, event size (dominated by backgrounds), trigger considerations, etc

7.8 Infrastructure Requirements

Engineering design for the luminometer mechanical support Water cooling power Electric power Gas

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THOMAS OTTO: 5 pages

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123 ein Text

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VOLKER MERTENS: 5 pages

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JOHANNES GUTLEBER: 3 pages

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C Superconducting SPS

Appendices B

Experiment Parameter Tables

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Glossary

Arc A circular collider is composed of bent cells called arcs that are separated by straight sections (see LSS). An arc half-cell forms the periodic part of the arc lattice (see lattice).

Beam pipe Volumes of different shape (e.g. cylindrical, conical, flanges and bellows) and material (e.g. metallic, ceramic) used to transport the beam. The contained ultrahigh-vacuum reduces beam-gas interactions to a level at which the beam lifetime is acceptable.

Beam screen Perforated tube inserted into the cold bore of the superconducting magnets in order to protect the cold bore from synchrotron radiation and ion bombardment.

Beamline A series of functional elements, such as magnets and vacuum pipe, which carry the beam from one portion of the accelerator to another.

Beta function An optical function proportional to the square of the local transverse beam size. The beta function details how the beam width changes around the accelerator. There are separate Îš functions for the x and y planes.

Bunch A group of particles captured inside a longitudinal phase space bucket.

CERN European Organisation for Nuclear Research.

Collimator A device that removes beam particles at large amplitudes. They are used to keep beam-losses low and to protect critical elements of the accelerator.

Collision A close encounter of particles during which dynamic quantities such as energy, momentum, and charge may be exchanged.

Critical temperature Temperature Tc below which characteristics of superconductivity appear. The value varies from material to material and depends on the magnetic field.

Cryo magnet Complete magnet system integrated into one cryostat, including main magnet coils, collars and cryostat, correction magnets and powering circuits.

Cryogenic system A system that operates below a temperature set by convention at 150 K (-123.15°C).

Dark matter Invisible matter that makes up 26% of the universe and which can only be detected from its gravitational effects. Only 4% of the matter in the Universe are visible. The remaining 70% are accounted to dark energy.

Dipole A magnet with two poles, like the north and south poles of a horseshoe magnet. Dipoles are used in particle accelerators to keep particles moving in a circular orbit.

Dynamic aperture Maximum transverse oscillation amplitude that guarantees stable particle motion over a given number of turns. If the motion amplitude of a particle exceeds this threshold, the betatron oscillation of the particle will not have any bounds, and the motion will become unstable, leading to loss of the particle. It is expressed in multiples of the beam size together with the associated number of turns. Unlike the physical aperture, dynamic aperture separating stable and unstable trajectories is not a hard boundary.

Electron-cloud A cloud of electrons generated inside an accelerator beam pipe due to gas ionization, photoemission from synchrotron radiation, or âĂIJbeam-induced multipactingâĂİ via electron acceleration in the field of the beam and secondary emission. Electron clouds may cause single- and multi-bunch beam instabilities as well as additional heat load on the beam screen inside the cold magnets.

Electroweak symmetry breaking Although electromagnetism and the weak force have the same strength at high energies, electromagnetism is much stronger than the weak force in our everyday experience. The mechanism by which, at low energies, a single unified electroweak force appears as two separate forces is called electroweak symmetry breaking.

Emittance The area in phase space occupied by a particle beam. The units are mm-milliradians for transverse emittance and eV·sec for longitudinal emittance.

Experimental insertion region Place in the particle collider foreseen to host the interaction region in which the two beams are brought to collision and the surrounding particle physics experiments.

FCC Future Circular Collider is a feasibility study aiming at the development of conceptual designs for future energy and high-intensity frontier particle colliders based on a technically feasible and affordable circular layout permitting staged implementation.

FCC-hh Future circular energy-frontier hadron-hadron collider reaching up to 100 TeV centre-of-mass collision energies at luminosities of $5 - 10x10^{34}cm^{-2}s^{-1}$. Operation with protons and ions is envisaged.

Hadron A subatomic particle that contains quarks, antiquarks, and gluons, and so experiences the strong force. The proton is the most common hadron.

Higgs boson An elementary particle linked with a mechanism to model, how particles acquire mass.

HL-LHC High Luminosity upgrade of the LHC to a levelled constant luminosity of $5x10^{34}cm^{2}s^{-1}$. A dedicated FP7 design study (HiLumi LHC DS) precedes the upgrade implementation.

HTS High Temperature Superconductors have critical temperatures above 77 K.

Impedance A quantity that characterizes the self-interaction of a charged particle beam, mediated by the beam environment, such as the vacuum chamber, RF cavities, and other elements encountered along the accelerator or storage ring.

Kelvin Unit of measurement for temperature (K) using as null point the absolute zero, the temperature at which all thermal motion ceases. 0 K = -273.15°Celsius.

Lattice The arrangements of quadrupoles, dipole magnets, drift spaces and higher-order magnetic elements in the optical description of an accelerator.

LEP The Large ElectronâĂŞPositron Collider, which was operated at CERN until 2000.

Lepton A class of elementary particles that do not experience the strong force. The electron is the most common lepton.

LHC The Large Hadron Collider is a circular particle collider for protons and heavy ions with a design centre-of-mass energy of 14 TeV for proton-proton collisions at a peak luminosity of $1x10^{34}cm^{2}s^{-1}$ at CERN in Geneva, Switzerland.

Linac A LINear ACcelerator for charged particles in which a number of successive radiofrequency cavities that are powered and phased such that the particles passing through them receive successive increments of energy.

LSS Long Straight Section: quasi-straight segments of a circular collider, which are available for beam interactions or utility insertions (e.g. injection, extraction, collimation, RF).

LTS Low Temperature Superconductors have critical temperatures below 77 K.

Luminosity Luminosity is the rate of collision events normalized to the cross section. It is expressed as inverse square centimetre and inverse second ($cm^{-2}s{-}1$) or barn (1 barn = $10^{-24}cm^2$).

MDI The Machine Detector Interface refers to the topics and regions where the beamlines of the accelerator overlap with the physics experimentâĂŹs detector. Key elements include mechanical support of final beamline elements, luminosity monitoring, feedback, background suppression and radiation shielding.

Nb3Sn A metallic chemical compound of niobium (Nb) and tin (Sn). A LTS with TC = 18.3 K that can withstand magnetic field intensities up to 30 Teslas.

NEG Non-Evaporable Getter materials are mostly porous alloys or powder mixtures of Al, Zr, Ti, V and iron (Fe). They help to establish and maintain vacuums by soaking up or bonding to gas molecules that remain within a partial vacuum.

Optics An optical configuration refers to a powering scheme of the magnets. There can be several different optics for a single lattice configuration. Different optics exist for instance for injection and for luminosity operation corresponding to different $\beta*$ values in the experimental insertions.

Phase Space A six-dimensional space consisting of a particle's position (x, y, z) and divergence (x/, y/, z/). Phase space is represented in two dimensions by plotting position on the horizontal axis and the corresponding divergence on the vertical axis.

Quench The change of state in a material from superconducting to resistive. If uncontrolled, this process damages equipment due to thermal stress induced by the extremely high-currents passing through the material.

RAMS Reliability, Availability, Maintainability and Safety. Four non-functional key characteristics that determine the performance and total cost of technical systems.

RF cavity An electromagnetically resonant cavity used to convey energy (accelerate) to charged particles as they pass through by virtue of the electric field gradient across the cavity gap(s). Radio Frequency is a rate of oscillation in the range of around 3 kHz to 300 GHz.

SC coating A very thin layer of SuperConducting material on normal-conducting material (e.g. copper). Used for various purposes such as quench avoidance of a neighbouring superconductor, reduction of production costs due to use of cheaper support material and impedance reduction.

Standard Model The Standard Model explains how the basic building blocks of matter interact, governed by four fundamental forces.

Strand A superconducting strand is a composite wire containing several thousands of superconducting filaments (e.g. Nb_3Sn) dispersed in a matrix with suitably small electrical resistivity properties (e.g. copper).

Strong force One of four known fundamental forces (the others are the weak force, electromagnetism and gravity). The strong force is felt only by quarks and gluons, and is responsible for binding quarks together to make hadrons. For example, two up quarks and a down quark are bound together to make a proton. The strong interaction is also responsible for holding protons and neutrons together in atomic nuclei.

Superconducting cable Superconducting cables are formed from several superconducting strands in parallel, geometrically arranged in the cabling process to achieve well-controlled cable geometry and dimensions, while limiting the strand deformation in the process. Cabling several strands in parallel results in an increase of the current carrying capability and a decrease of the inductance of the magnet, easing protection.

Superconductivity A property of some materials, usually at very low temperatures that allows them to carry electricity without resistance.

Synchrotron A circular machine that accelerates subatomic particles by the repeated action of electric forces generated by RF fields at each revolution. The particles move in constant circular orbits by magnetic forces that continually increase in magnitude.

Synchrotron Radiation Electromagnetic radiation generated by acceleration of relativistic charged particles in a magnetic or electric field. Synchrotron radiation is the major mechanism of energy loss in synchrotron accelerators and contributes to electron-cloud build-up.

Tesla Unit of magnetic field strength. 1 T is the field intensity generating one newton (N) of force per ampere (A) of current per meter of conductor.

TeV Tera electron Volts (10^{12} eV). Unit of energy. 1 eV is the energy given to an electron by accelerating it through 1 Volt of electric potential difference.

Tevatron A 2 TeV proton on anti-proton collider that was operated at Fermilab in Batavia, Illinois (USA) until 2011. The top quark was discovered using this collider.

Vacuum Pressures much below atmospheric pressure.

Weak force A force carried by heavy particles known as the W and Z bosons. The most common manifestation of this force is beta decay, in which a neutron in a nucleus is transformed into a proton, by emitting an electron and a neutrino. Weak neutral current is a very weak interaction mediated by the Z boson that is independent of the electric charge of a particle. Particles can exchange energy through this mechanism, but other characteristics of the particles remain unchanged.

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