Short introduction to the FCC(-*ee*) project and scope of the Flavour Physics Working Group.

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Some links where useful bibliography can be found

- References for the FCC project:

  Kick-off meeting on February 2014 (wrap-up talk):
  http://indico.cern.ch/event/282344/contribution/46/material/slides/1.pdf

- First look at the FCC-*ee* Physics Case:

  arXiv:1308.6176 / JHEP01 (2014) 164.

- References for the FCC-*ee* machine in:

  http://tlep.web.cern.ch/content/accelerator-studies

Starting from the former European HEP strategy 2013

Summary: European Strategy Update 2013

Design studies and R&D at the energy frontier

…."to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update":

d) ***CERN should undertake design studies for accelerator projects in a global context,***

- *with emphasis on* ***proton-proton and electron-positron high-energy frontier machines****.*
- *These design studies should be coupled to a vigorous accelerator* ***R&D programme, including high-field magnets and high-gradient accelerating structures****,*
- ***in collaboration with national institutes, laboratories and universities worldwide.***

- **http://cds.cern.ch/record/1567258/files/esc-e-106.pdf**

CERN

Future Circular Collider Study
Michael Benedikt
FCC Kick-Off 2014

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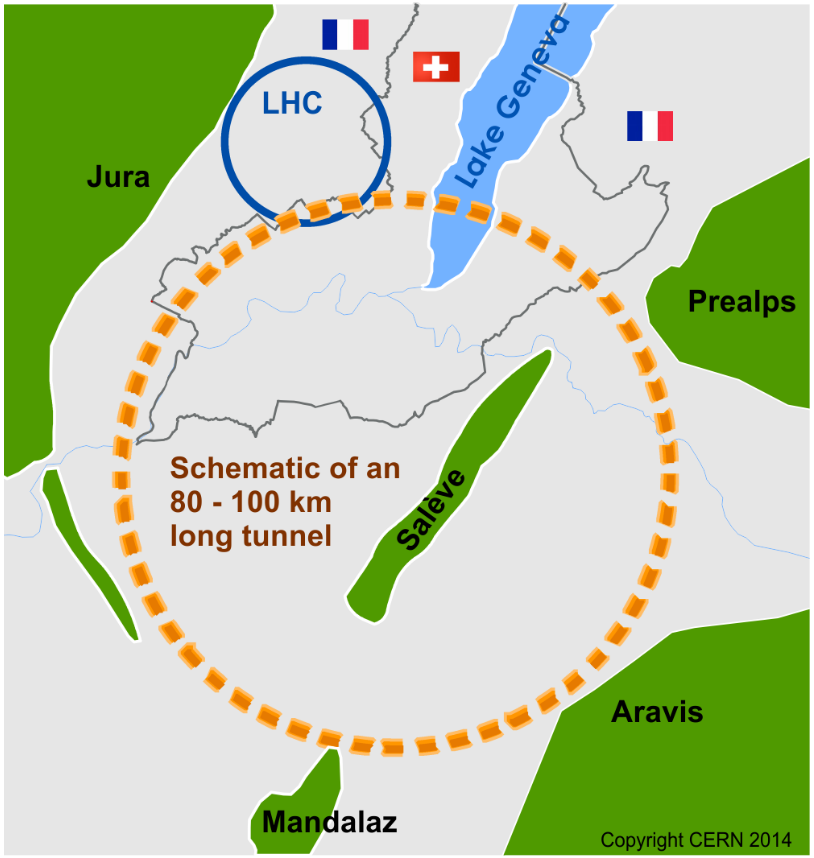
- At the time the LHC Run II will have delivered its results, have an educated vision of the reach of future machines for the next round of the European Strategy in 2018.

Future Circular Colliders Project - Scope

- Forming an international collaboration to study:
- 100 TeV *pp*-collider (FCC-*hh*) as long term goal, defining infrastructure requirements.
- e^+e^- collider (FCC-*ee*) as potential intermediate step.
- *p-e* (FCC-*he*) as an option.
- 80-100 km infrastructure in Geneva area.



- Conceptual design report and cost review for the next european strategy → 2018.

Future Circular Collider Project - Scope

- 80-100 km infrastructure in Geneva area: A flavour of the location:

First look at the physics case of TLEP

The TLEP Design Study Working Group

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JHEP01(2014)164

Abstract: The discovery by the ATLAS and CMS experiments of a new boson with mass around 125 GeV and with measured properties compatible with those of a Standard-Model Higgs boson, coupled with the absence of discoveries of phenomena beyond the Standard Model at the TeV scale, has triggered interest in ideas for future Higgs factories. A new circular e^+e^- collider hosted in a 80 to 100 km tunnel, TLEP, is among the most attractive solutions proposed so far. It has a clean experimental environment, produces high luminosity for top-quark, Higgs boson, W and Z studies, accommodates multiple detectors, and can reach energies up to the $t\bar{t}$ threshold and beyond. It will enable measurements of the Higgs boson properties and of Electroweak Symmetry-Breaking (EWSB) parameters with unequalled precision, offering exploration of physics beyond the Standard Model in the multi-TeV range. Moreover, being the natural precursor of the VHE-LHC, a 100 TeV hadron machine in the same tunnel, it builds up a long-term vision for particle physics. Altogether, the combination of TLEP and the VHE-LHC offers, for a great cost effectiveness, the best precision and the best search reach of all options presently on the market. This paper presents a first appraisal of the salient features of the TLEP physics potential, to serve as a baseline for a more extensive design study.

- This initial study focused primarily on the Higgs Physics (w/ full simulation but CMS detector).
- EWK precision tests examined from LEP (Z, W) or LC (top) extrapolations.
- Flavour Physics was just mentioned. A deeper study is necessary.

FCC-*ee* “fundamentals”

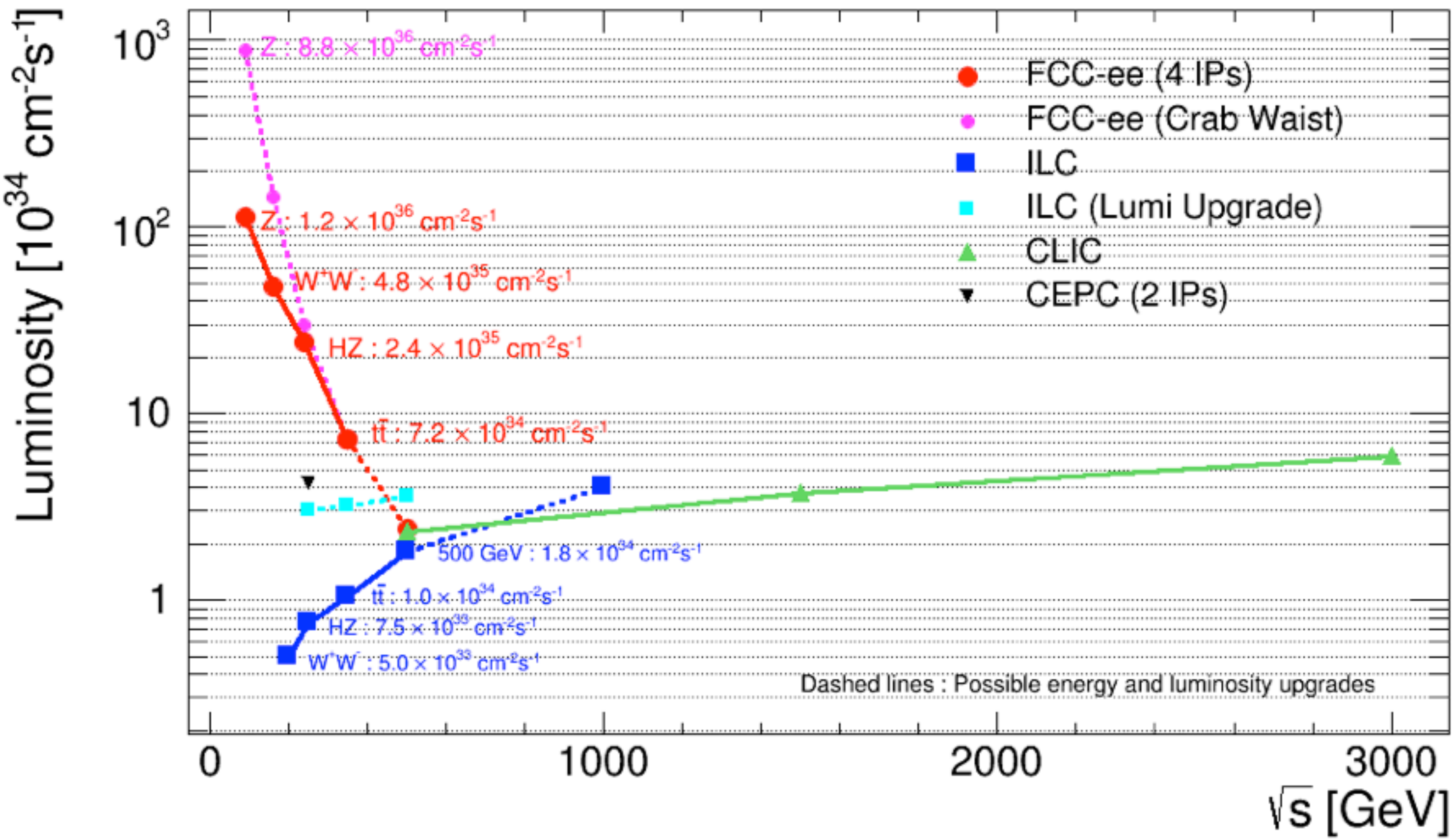
- Physics from the *Z* pole to top pair production (90 - 400 GeV), crossing *WW* and *ZH* thresholds (and even $e^+e^- \rightarrow H(126)$).

- Two rings (top-up injection) to cope with high current and large number of bunches at operating points up to *ZH*.

- Not a straightforward extrapolation of LEP. Many Challenges:
  - Brehmsstrahlung@IP limit the beam lifetime at top energy.
  - Polarization of the beams (at least natural one for beam energy measurement - EWK precision measurements)
  - ...

- Baseline design for machine parameters given as back-up slides.

Luminosity figure



Physics reach related to the luminosity figure - EWPT

X	Physics	Present precision		TLEP stat Syst Precision	TLEP key	Challenge
M_Z MeV/c2	Input	91187.5 ±2.1	Z Line shape scan	0.005 MeV <±0.1 MeV	E_cal	QED corrections
Γ_Z MeV/c2	$\Delta\rho$ (T) (no $\Delta\alpha$!)	2495.2 ±2.3	Z Line shape scan	0.008 MeV <±0.1 MeV	E_cal	QED corrections
R_l	α_s, δ_b	20.767 ± 0.025	Z Peak	0.0001 ± 0.002 - 0.0002	Statistics	QED corrections
N_ν	Unitarity of PMNS, sterile ν's	2.984 ±0.008	Z Peak Z+γ(161 GeV)	0.00008 ±0.004 0.001	->lumi meast Statistics	QED corrections to Bhabha scat.
R_b	δ_b	0.21629 ±0.00066	Z Peak	0.000003 ±0.000020 - 60	Statistics, small IP	Hemisphere correlations
A_{LR}	$\Delta\rho$, ε_3, $\Delta\alpha$ (T, S)	0.1514 ±0.0022	Z peak, polarized	±0.000015	4 bunch scheme	Design experiment
M_W MeV/c2	$\Delta\rho$, ε_3, ε_2, $\Delta\alpha$ (T, S, U)	80385 ± 15	Threshold (161 GeV)	0.3 MeV <1 MeV	E_cal & Statistics	QED corections
m_{top} MeV/c2	Input	173200 ± 900	Threshold scan	10 MeV	E_cal & Statistics	Theory limit at 100 MeV?

Physics reach related to the luminosity figure - Higgs

Table 1-20. *Expected precisions on the Higgs couplings and total width from a constrained 7-parameter fit assuming no non-SM production or decay modes. The fit assumes generation universality ($\kappa_u \equiv \kappa_t = \kappa_c$, $\kappa_d \equiv \kappa_b = \kappa_s$, and $\kappa_\ell \equiv \kappa_\tau = \kappa_\mu$). The ranges shown for LHC and HL-LHC represent the conservative and optimistic scenarios for systematic and theory uncertainties. ILC numbers assume (e^-, e^+) polarizations of $(-0.8, 0.3)$ at 250 and 500 GeV and $(-0.8, 0.2)$ at 1000 GeV. CLIC numbers assume polarizations of $(-0.8, 0)$ for energies above 1 TeV. TLEP numbers assume unpolarized beams.*

Facility	LHC	HL-LHC	ILC500	ILC500-up	ILC1000	ILC1000-up	CLIC	TLEP (4 IPs)
$\sqrt{s}$ (GeV)	14,000	14,000	250/500	250/500	250/500/1000	250/500/1000	350/1400/3000	240/350
$\int \mathcal{L}dt$ (fb^{-1})	300/expt	3000/expt	250+500	1150+1600	250+500+1000	1150+1600+2500	500+1500+2000	10,000+2600
κ_γ	5 – 7%	2 – 5%	8.3%	4.4%	3.8%	2.3%	–/5.5/<5.5%	1.45%
κ_g	6 – 8%	3 – 5%	2.0%	1.1%	1.1%	0.67%	3.6/0.79/0.56%	0.79%
κ_W	4 – 6%	2 – 5%	0.39%	0.21%	0.21%	0.2%	1.5/0.15/0.11%	0.10%
κ_Z	4 – 6%	2 – 4%	0.49%	0.24%	0.50%	0.3%	0.49/0.33/0.24%	0.05%
κ_ℓ	6 – 8%	2 – 5%	1.9%	0.98%	1.3%	0.72%	3.5/1.4/<1.3%	0.51%
$\kappa_d = \kappa_b$	10 – 13%	4 – 7%	0.93%	0.60%	0.51%	0.4%	1.7/0.32/0.19%	0.39%
$\kappa_u = \kappa_t$	14 – 15%	7 – 10%	2.5%	1.3%	1.3%	0.9%	3.1/1.0/0.7%	0.69%

The FCC-*ee* design study organisation

- Physics coordination: A. Blondel and P. Janot (experimental studies), J. Ellis, C. Grosjean (phenomenology studies).

FCC-ee Experiments : A four-year study (4)

- Eleven working groups have been set up to this end
  - WG1: Electroweak physics at the Z pole (R. Tenchini)
  - WG2: Di-boson production and W mass measurement (R. Tenchini)
  - WG3: H(126) properties (M. Klute, K. Peters)
  - WG4: Top quark physics (P. Azzi)
  - WG5: QCD and $\gamma\gamma$ physics (D. d'Enterria, P. Skands)
  - WG6: Flavour physics (S. Monteil, J. Kamenik)
  - WG7: Experimental signatures of new physics (M. Pierini, C. Rogan)
  - WG8: Experimental environment (N. Bacchetta)
  - WG9: Offline software and computing (F. Gianotti, P. Janot)
  - WG10: Online software (C. Leonidopoulos)
  - WG11: Detector designs (A. Cattai, G. Rolandi)

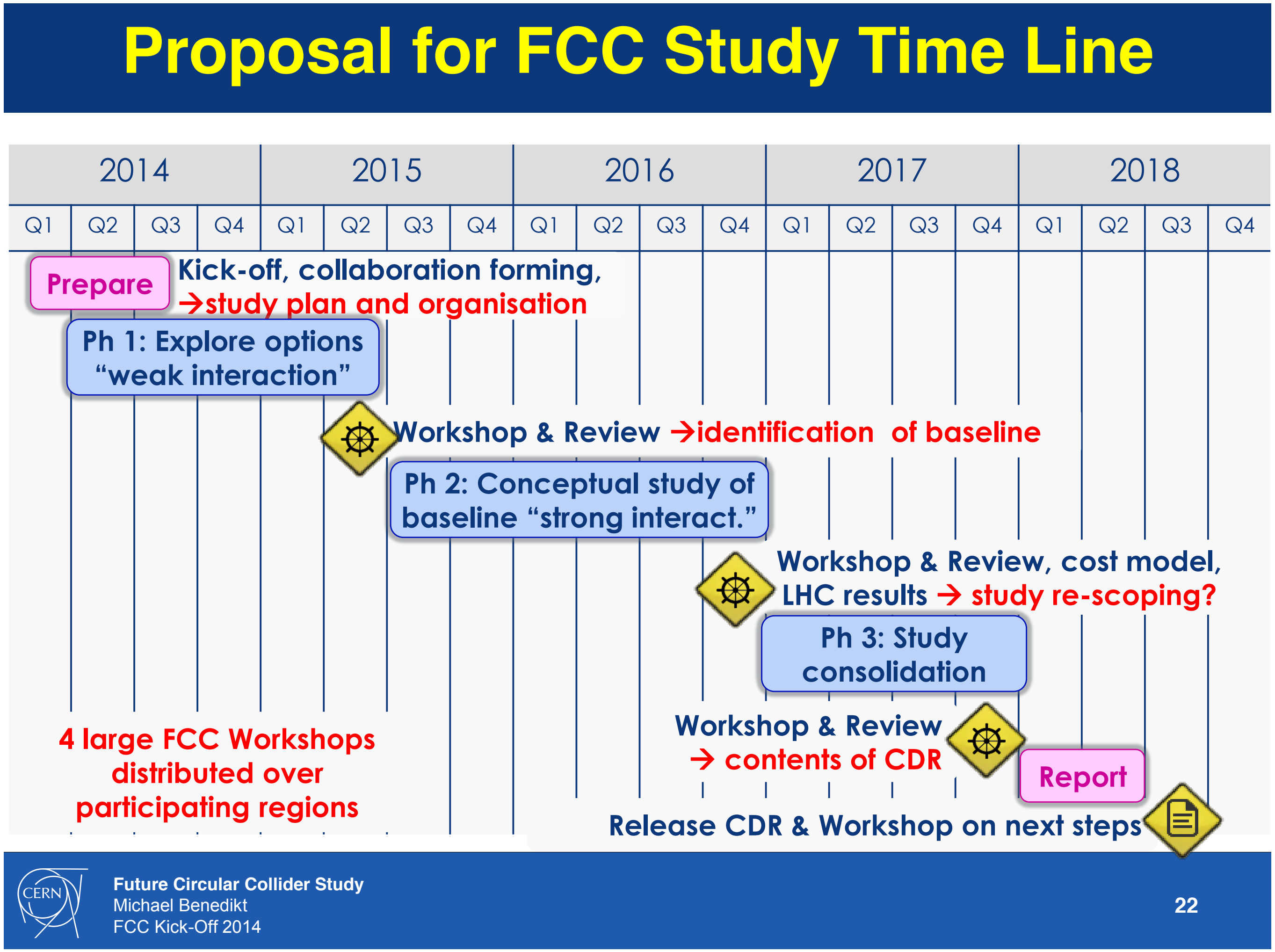
- The groups are not closed entities / boxes

➔ Each group is expected to work closely with all the others

Keeping strong links with the relevant machine and theory groups

Patrick Janot — FCC-ee Physics Workshop: Goals of the first year 19-Jun-2014 — 5

Global timeline for the FCC(*-ee)* design study



Scope of the Flavour Physics working

- Understand the experimental precision with which rare decays of *c*- and *b*-hadrons and CP violation in the heavy-quark sector could be measured with 10^{12} Z, as well as the potential sensitivity to new physics, and compare to the ultimate potential of the (soon to be) running LHCb upgrade and Belle II experiments. Examine the relevance of a dedicated PID (π / K / p separation) detector,

- The very same objective stands for the rare lepton decays.

- Examine the physics reach of lepton flavour violating processes and neutrino-related Physics unique to the FCC-*ee*.

- Have a platform to think of beyond standard observables.

- "What would like to do/see with/in 10^{12} / 10^{13} Z?" makes a nice playground to start with.

Scope of this first meeting

FCC-ee Flavour Physics vidyo meeting #1

Wednesday, 3 September 2014 from **16:00** to **18:30** (Europe/Zurich)
at **CERN**

Manage

Description This kick-off meeting for the Flavour Physics Working Group activity is mainly intended to discuss, criticize and enhance with new ideas the so far roughly tailored Flavour Physics case for the FCC-ee project. Ideally, the outcome of this meeting could be to get a hierarchy of the most relevant processes to be experimentally studied.

Video Services Vidyo public room : FCC-ee_Flavour_Physics_vidyo_meeting__1__ More Info | **Join Now!**

Wednesday, 3 September 2014

16:00 - 16:15 Introduction to the FCC-ee project and scope of Flavour Physics working group *15'*
Speaker: Stephane Monteil (Univ. Blaise Pascal Clermont-Fe. II (FR))

16:15 - 16:35 About some of the benchmark modes *20'*
Speakers: Stephane Monteil (Univ. Blaise Pascal Clermont-Fe. II (FR)), Jernej F. Kamenik (Jozef Stefan Institute)

16:35 - 16:55 Ideas for Flavour studies at FCC-ee *20'*
Speaker: Ulrich Andreas Haisch (University of Oxford (GB))

16:55 - 17:15 Additional phenomenological thoughts on the scope of the WG *20'*
Speaker: Jernej F. Kamenik (Jozef Stefan Institute)

17:15 - 17:30 Thoughts on Lepton Flavour Violation studies at FCC-ee *15'*
Speaker: Valentina De Romeri (CNRS)

Scope of this first meeting

- A preliminary attempt has been made to figure out a hierarchy of relevance of the Physics processes to be studied. This is examined in the anticipated landscape of Flavours after the LHCb upgrade and Belle2 experimental programs completion.

- This attempt focused on “conservative” benchmark modes.

- We’d like for this first meeting that the global approach and selected modes are discussed, criticized, amended, enhanced ...

- Possible exploration studies will be in addition presented by Uli and Valentina.

FCC-*ee* machine parameters - baseline design back-ups

FCC-*ee* machine parameters - baseline design

	LEP1	LEP2	Z	W	H	tt
Circumference [km]	26.7		100			
Bending radius [km]	3.1		11			
Beam energy [GeV]	45.4	104	45.5	80	120	175
Beam current [mA]	2.6	3.04	1450	152	30	6.6
Bunches / beam	12	4	16700	4490	1360	98
Bunch population [10^{11}]	1.8	4.2	1.8	0.7	0.46	1.4
Transverse emittance ε - Horizontal [nm] - Vertical [pm]	 20 400	 22 250	 29.2 60	 3.3 7	 0.94 1.9	 2 2
Momentum comp. [10^{-5}]	18.6	14	18	2	0.5	0.5
Betatron function at IP β^* - Horizontal [m] - Vertical [mm]	 2 50	 1.2 50	 0.5 1	 0.5 1	 0.5 1	 1 1
Beam size at IP σ^* [μm] - Horizontal - Vertical	 224 4.5	 182 3.2	 121 0.25	 26 0.13	 22 0.044	 45 0.045
Energy spread [%] - Synchrotron radiation - Total (including BS)	 0.07 0.07	 0.16 0.16	 0.04 0.06	 0.07 0.09	 0.10 0.14	 0.14 0.19
Bunch length [mm] - Synchrotron radiation - Total	 8.6 8.6	 11.5 11.5	 1.64 2.56	 1.01 1.49	 0.81 1.17	 1.16 1.49

FCC-*ee* machine parameters - baseline design

	LEP1	LEP2	Z	W	H	tt
Bunch length [mm] - Synchrotron radiation - Total	8.6 8.6	11.5 11.5	1.64 2.56	1.01 1.49	0.81 1.17	1.16 1.49
Energy loss / turn [GeV]	0.12(1)	3.34	0.03	0.33	1.67	7.55
SR power / beam [MW]	0.3(1)	11	50			
Total RF voltage [GV]	0.24	3.5	2.5	4	5.5	11
RF frequency [MHz]	352		800			
Longitudinal damping time τ_E [turns]	371	31	1320	243	72	23
Energy acceptance RF [%]	1.7	0.8	2.7	7.2	11.2	7.1
Synchrotron tune Q_s	0.065	0.083	0.65	0.21	0.096	0.10
Polarization time τ_p [min]	252	4	11200	672	89	13
Hourglass factor H	1	1	0.64	0.77	0.83	0.78
Luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	0.002	0.012	28.0	12.0	6.0	1.8
Beam-beam parameter - Horizontal - Vertical	0.044 0.044	0.040 0.060	0.031 0.030	0.060 0.059	0.093 0.093	0.092 0.092
Luminosity lifetime [min](2)	1250	310	213	52	21	15
Beamstrahlung critical	No		No	No	Yes	Yes

(1) Does not take into account the contribution of damping and emittance wigglers.
(2) The luminosity lifetime corresponds to 4 IPs.