FCC Week,
28 June - 2 July 2021

LHeC Racetrack as Injector to FCC-ee

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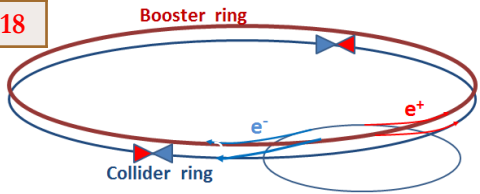
Content

- Brief overview of **FCCee injector**
  - Design **principle**
  - **Layout** and **parameters**
- **LHeC recirculating linac injector** (RLI) for FCCee
  - Basic **considerations** and tentative **parameters**
- **Conclusions** and **future work**

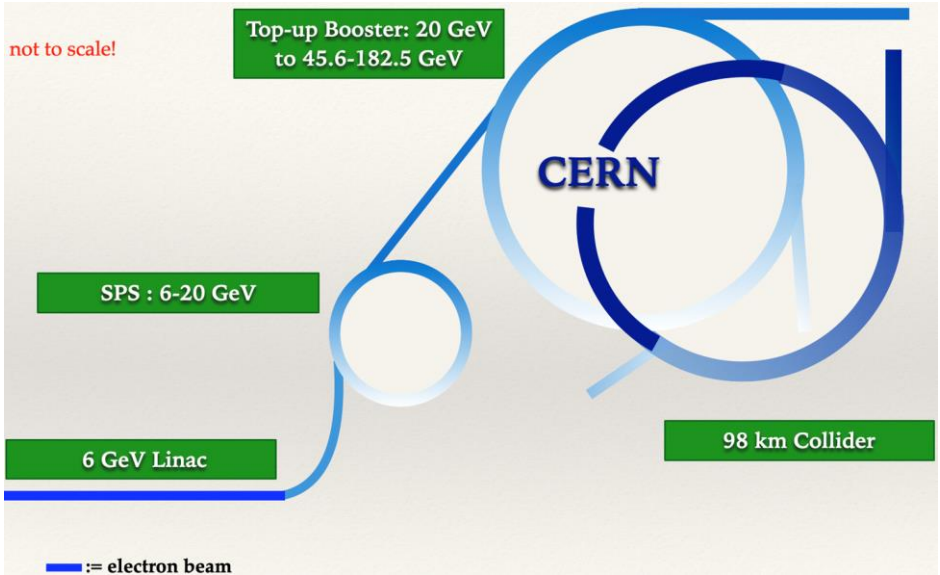
FCC-ee Collider Parameters

parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10^{34} cm^{-2}s^{-1}]	**230**	**28**	**8.5**	**1.55**
beam lifetime Bhabha/BS [min]	**68 / >200**	**49 / >1000**	**38 / 18**	**40 / 18**

Due to extremely **high luminosity**, **beam lifetime limited** to ≤ **20 min** (radiative Bhabha scattering, beamstrahlung) maintaining constant luminosity and beam current requires quasi-continuous "**top-up injection**" (demonstrated @ PEP-II, KEKB, SuperKEKB, light sources) → **full-energy booster** (same tunnel)

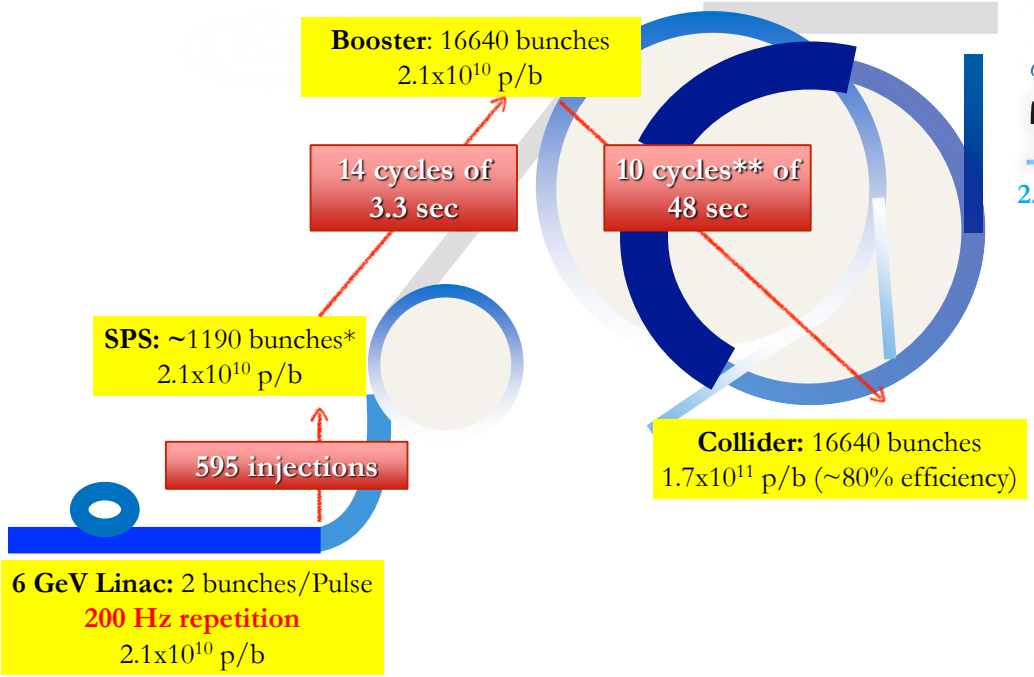


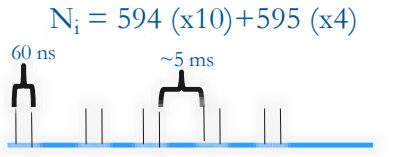
Conceptual Design of FCCee injectors

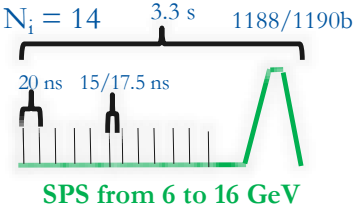


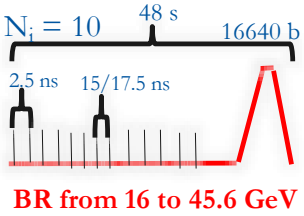
- **S-Band linac** (as in SLAC and SuperKEKB) @ **6 GeV** with **positron** generation @ **4.46 GeV** and **Damping Ring** @ **1.54 GeV**
- **Modified SPS** as pre-booster ring up to **20 GeV** (now **16 GeV**)
- **Top-up booster** shares tunnel with collide and accelerates e+/e- beam to final energies

Filling scheme for Z-pole









* **198** mini-trains with **6** b (**20 ns**) and **71/126** mini-train gaps (15/17.5 ns), kicker gap of **120 ns**

** **10 cycles** for either species keep charge imbalance within ±5% needed to prevent beam-beam flip-flop ("bootstrapping")

FCCee injector parameters

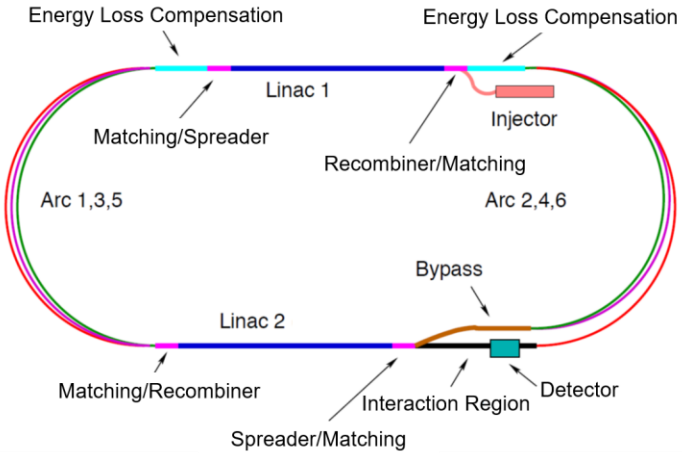
Accelerator	FCCee-Z		FCCee-W		FCCee-H		FCCee-tt	
Energy [GeV]	45.6		80		120		182.5	
Type of filling	Full	Top-up	Full	Top-up	Full	Top-up	Full	Top-up
LINAC # bunches, with 2.8 GHz RF	2				1			
LINAC repetition rate [Hz]	200		100					
LINAC/PBR bunch population [10^{10}]	2.13	1.06	0.94	0.56	0.94	0.56	1.38	0.83
# of LINAC injections	594/595		500		328		48	
PBR bunch spacing [ns]	15/17.5/20 ns		22.5		67.5		450	
# PBR cycles	14		2		1			
PBR # of bunches	1188/1190		1000		393		50	
PBR cycle time [s]	3.3		5.4		3.6		0.8	
PBR duty factor	0.76		0.49		0.23		0.05	
BR # of bunches	16640		2000		328		48	
BR cycle time [s]	47.9		13		6.9		5.7	
#of BR cycles	10	1	20	1	20	1	20	1
# of injections/collider bucket	10	1	20	1	20	1	20	1
Total number of bunches	16640		2000		328		48	
Filling time (both species) [sec]	958.8	95.9	520	26	277.2	13.9	227.7	11.4
Injected bunch population [10^{10}]	2.13	1.06	1.44	1.44	1.13	1.13	1.38	0.83

FCCee injector parameters

Accelerator	FCCee-Z	
Energy [GeV]	45.6	
Type of filling	Full	Top-up
LINAC # bunches, with 2.8 GHz RF	2	
LINAC repetition rate [Hz]	200	
LINAC/PBR bunch population [10^{10}]	2.13	1.06
# of LINAC injections	594/595	
PBR bunch spacing [ns]	15/17.5/20 ns	
# PBR cycles	14	
PBR # of bunches	1188/1190	
PBR cycle time [s]	3.3	
PBR duty factor	0.76	
BR # of bunches	16640	
BR cycle time [s]	47.9	
#of BR cycles	10	1
# of injections/collider bucket	10	1
Total number of bunches	16640	
Filling time (both species) [sec]	958.8	95.9
Injected bunch population [10^{10}]	2.13	1.06

- **Injector linac** provides average **current < 1.4 μA**
- This is **~4 orders** of **magnitude lower** then **average current** of **LHeC ERL (20 mA)**
- PBR (SPS) **duty factor** of **76%** for FCCee-Z
- **BR cycle time** of **~48 sec** dominated by injection

LHeC ERL parameters



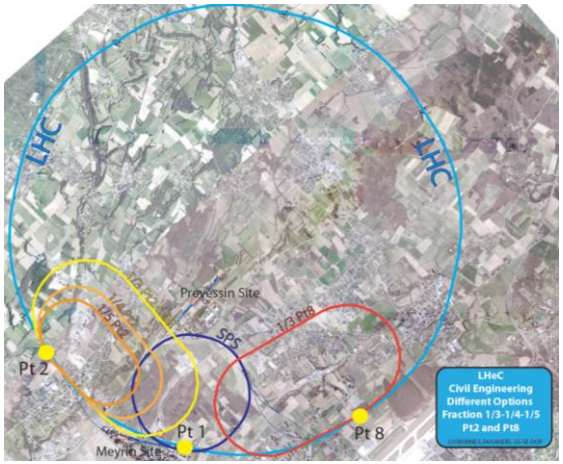
Parameter	Unit	Value
Injector energy	GeV	0.5
Total number of linacs		2
Number of acceleration passes		3
Maximum electron energy	GeV	49.19
Bunch charge	pC	499
Bunch spacing	ns	24.95
Electron current	mA	20
Transverse normalized emittance	μm	30
Total energy gain per linac	GeV	8.114
Frequency	MHz	801.58
Acceleration gradient	MV/m	19.73
Cavity iris diameter	mm	130
Number of cells per cavity		5
Cavity length (active/real estate)	m	0.918/1.5
Cavities per cryomodule		4
Cryomodule length	m	7
Length of 4-CM unit	m	29.6
Acceleration per cryomodule (4-CM unit)	MeV	289.8
Total number of cryomodules (4-CM units) per linac		112 (28)
Total linac length (with with spr/rec matching)	m	828.8 (980.8)
Return arc radius (length)	m	536.4 (1685.1)
Total ERL length	km	5.332

- Based on **2 SRF Linacs (~800 MHz)** with **3 recirculating arcs,** total **length** of **~5.3 km** (~1/5 of LHC), reaching **energy** of **~49 GeV** (longer version for reaching **60 GeV)**
- Bunch **intensity** of **~500 pC** (~**3x10^9 p/b**) for **~25ns spacing**, **average current** of **20 mA**
- Could be used for **full energy top-up injector** for FCCee-Z and **pre-injector** for other collider energies
- Small footprint **PERLE-like version** could be used as **pre-injector** to (P)BR~**6-20GeV**

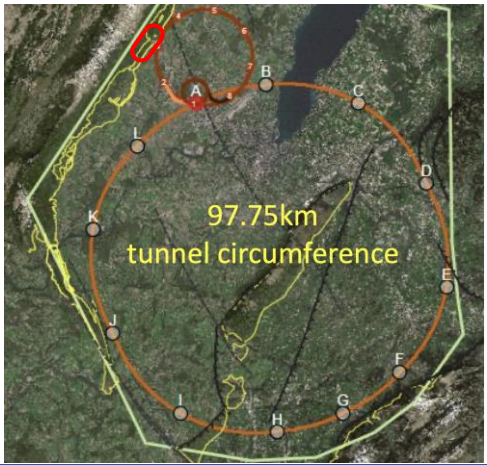
ERL Configuration for LHC and FCC

- Common **hardware** and **infrastructure**: one could use **FCC-ee pre-series SRF**
- Installation near **point L** to minimize **transfer line length**
- Would be used as **re-circulating linac** (**RLI**) not ERL mode

Different Size Variations:
e.g LHeC and HE-LHC-eh



Interaction region 'L' as baseline choice for FCC-eh



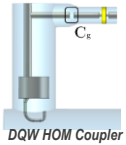
PERLE SRF system

PERLE SRF System development

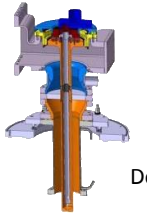
Courtesy to F. Marhauser

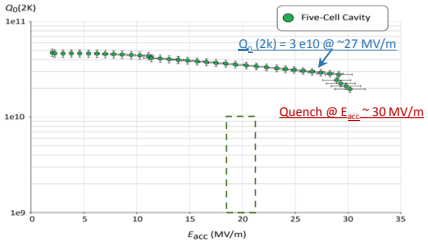
Design and prototyping of a **full dressed SRF cavity**: demonstration of level of SRF performance required in CW operation, high-average current environment, adequate damping of **HOM**.

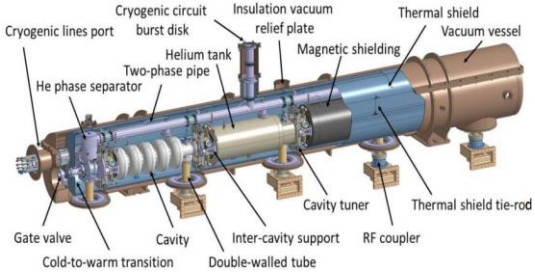
HOM coupler study



DQW HOM Coupler







Linac cryomodule design: study the possibility of **SPL cryomodule adaptation** to PERLE need, **complete design of a cryomodule** for PERLE later.

Design and prototyping of an **input power coupler**

Filling scheme for Z

- **RLI @ ~800 MHz** accelerating **832 bunches** with **17.5 ns** bunch spacing (compatible with collider)
  - **Other bunch structures** can be envisaged, compatible with present bunch structure collider considerations (see talk of **D. Shatilov**)
- Injected **20** times @ **45.6 GeV** into collider rise (**accumulation cycle**), for filling **16640** buckets with required gaps for injection/dump kicker
- For **70 accumulating cycles** need bunch population of **3×10^9** for ultra-fast filling (< 1sec), reaching required collider **1.7×10^{11}** with 80% injection efficiency
  - Intensity can be **significantly reduced** lowering power while still allowing full filling in a few seconds
- Very comfortable parameters also for **top-up,** allowing RLI to provide **beam** to **other users**
- For other collider energies, injection in the booster for top-up is necessary, with **feasible intensities** and filling time of a **few secs**

Tentative injector parameters with RLI @ 50 GeV (high power)

Accelerator	FCCee-Z		FCCee-W		FCCee-H		FCCee-tt	
Energy [GeV]	45.6		80		120		182.5	
Type of filling	Full	Top-up	Full	Top-up	Full	Top-up	Full	Top-up
RLI # bunches (800 GHz RF)	832		1000		328		48	
RLI bunch population [10^9]	3.0	0.15	1.3	0.04	1.9	0.06	2.8	0.08
RLI injections	1400		140		100		100	
#of BR cycles	-		1		1		1	
# of injections/collider bucket	70		1		1		1	
Total number of bunches	16640		2000		328		48	
Filling time (both species) [sec]	0.3	0.3	5.8	5.8	4.9	4.9	8.0	8.0

Summary – next steps

- **RLI** very attractive option for FCCee injector
- Several **synergies** with respect to **technology** (SRF) but also **physics** (FCCee, FCCeh, other physics program for a high flux electron beam facility)
- Next **steps**
  - Refine **parameters** to include **low power/energy** options
  - **Positron production** scheme (including damping ring)
  - Detailed **beam dynamics design**