Future e^+e^- Collider Positron Injection Requirements

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U.S. DEPARTMENT OF ENERGY
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SLAC NATIONAL ACCELERATOR LABORATORY

Topics

Snowmass-2022 survey of proposed e+e- colliders
Overview of proposed e+e- colliders
Positron bunch parameters
Bunch trains
Damping requirements in storage rings
Formula for required DR length
Required Damping Ring lengths
Summary

Information from the Snowmass2022 ITF

Report of the Snowmass'21 Collider Implementation Task Force

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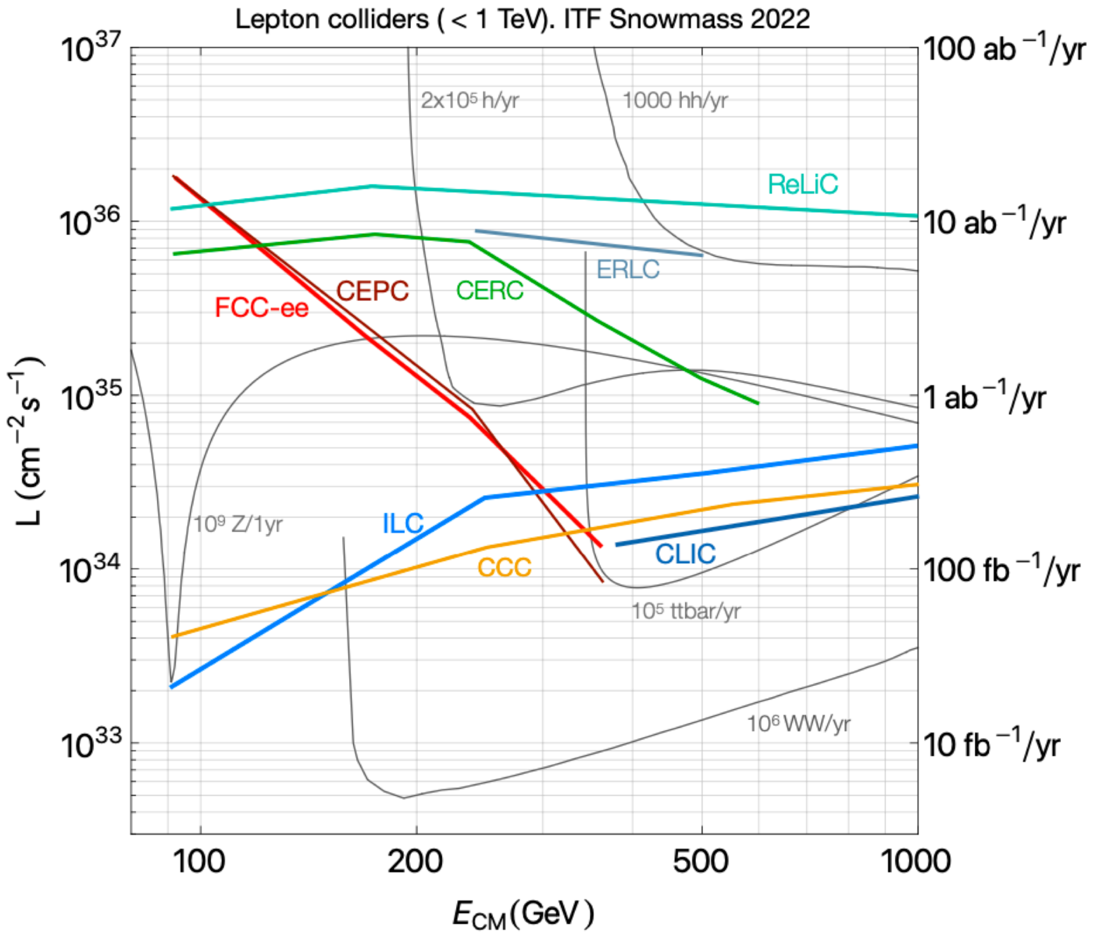
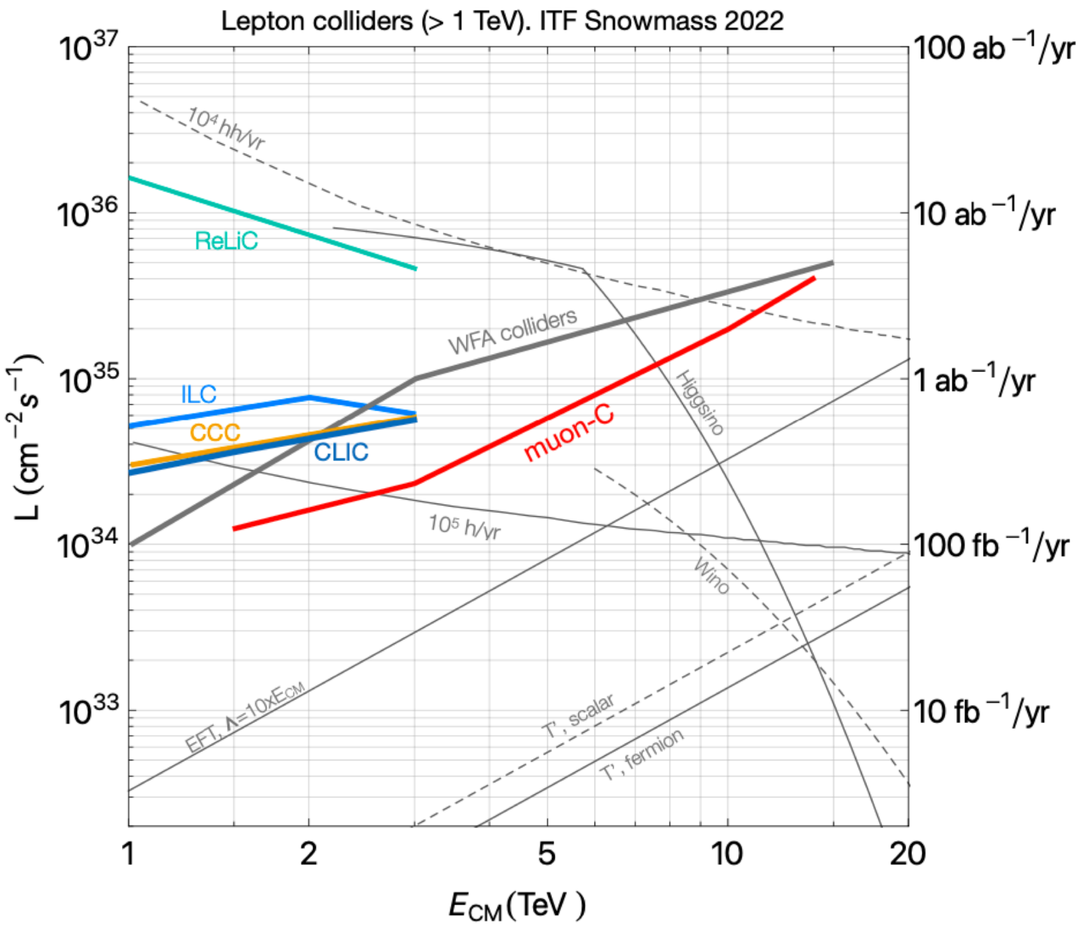
Abstract

The Snowmass'21 Implementation Task Force has been established to evaluate the proposed future accelerator projects for performance, technology readiness, schedule, cost, and environmental impact. Corresponding metrics has been developed for uniform comparison of the proposals ranging from Higgs/EW factories to multi-TeV lepton, hadron and *ep* collider facilities, based on traditional and advanced acceleration technologies. This report documents the metrics and processes, and presents evaluations of future colliders performed by Implementation Task Force.

ITF: Lepton Colliders < 1 TeV and > 1 TeV





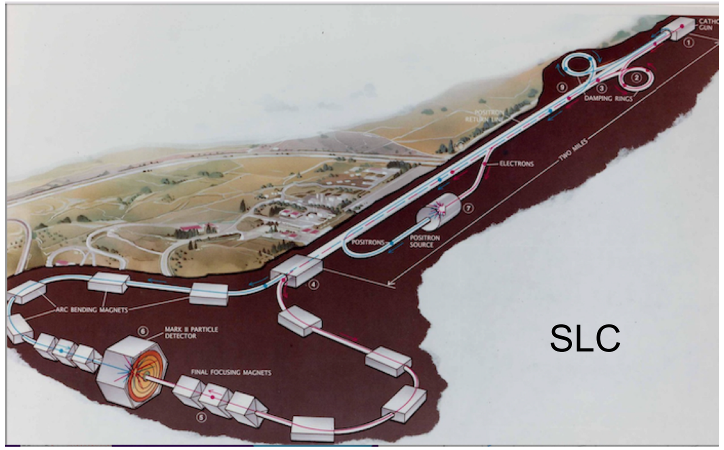
Past/Present Positron Source Results

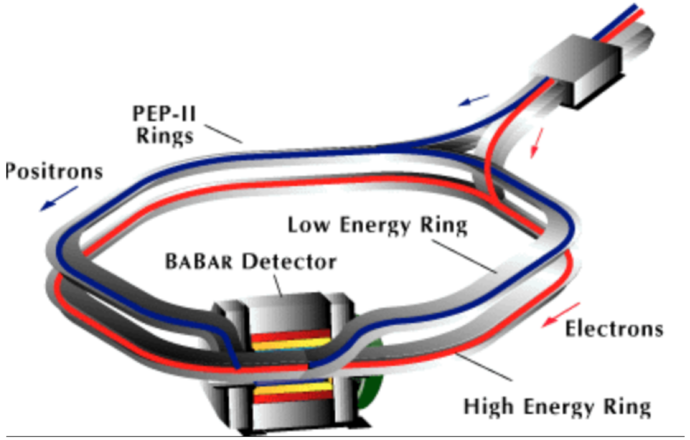
SLC: 91 GeV, 120 Hz, 1 e+ bunch, 5 x 10^{10}, 1.21 GeV damping ring (2 bunches stored)

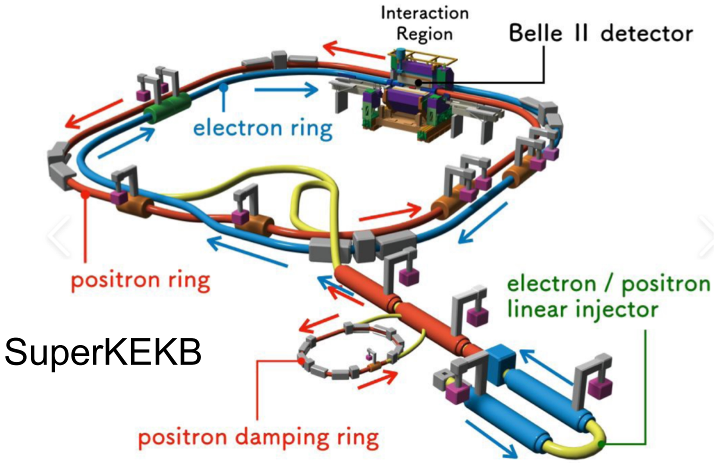
LEP: 103 GeV, 100 Hz, 1 e+ bunch, 0.5 GeV damping ring (# bunches stored)

PEP-II: 3.1 x 9 GeV, ~10 Hz, 1 e+ bunch, 0.2-1 x 10^{10}, 1.21 GeV damping ring (2 bunches stored)

SuperKEKB: 4 x 7 GeV, ~50 Hz, 2 e+ bunch, 0.1-0.5 x 10^{10}, 1.5 GeV damping ring (4 bunches stored)







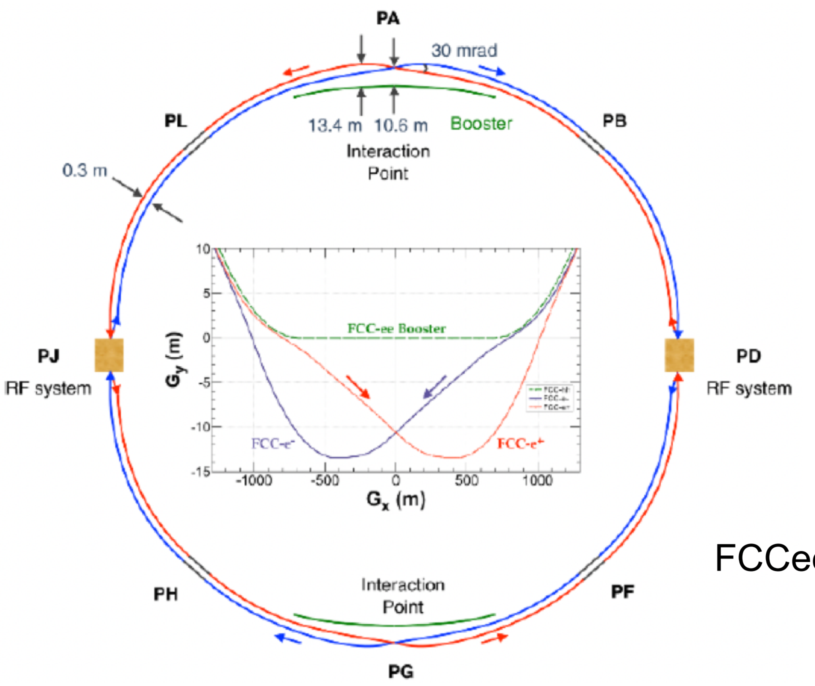
Future Circular Ring e+e- Colliders

FCCee:

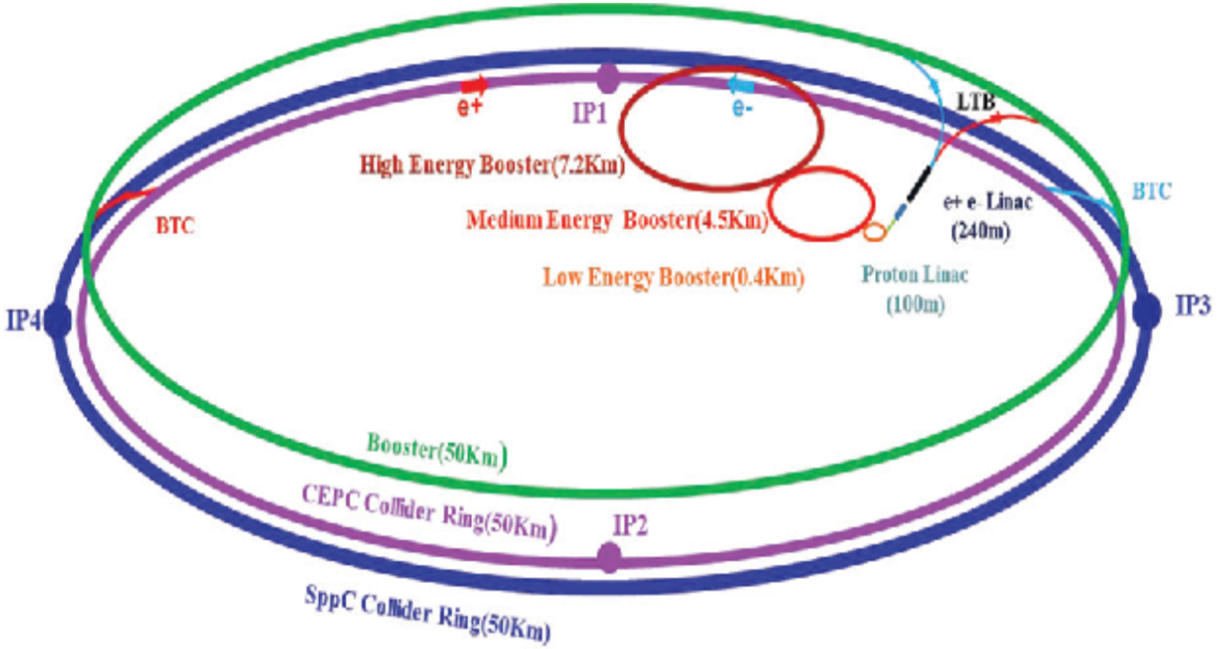
- 91-365 GeV
- Low field magnets
- Top-up injection,
- Up to 12,000 bunches

CEPC:

- 91-360 GeV
- Low field magnets
- Top-up injection
- Up to 11951 bunches



FCCee



Future Linear Colliders with Bunch Trains

ILC:

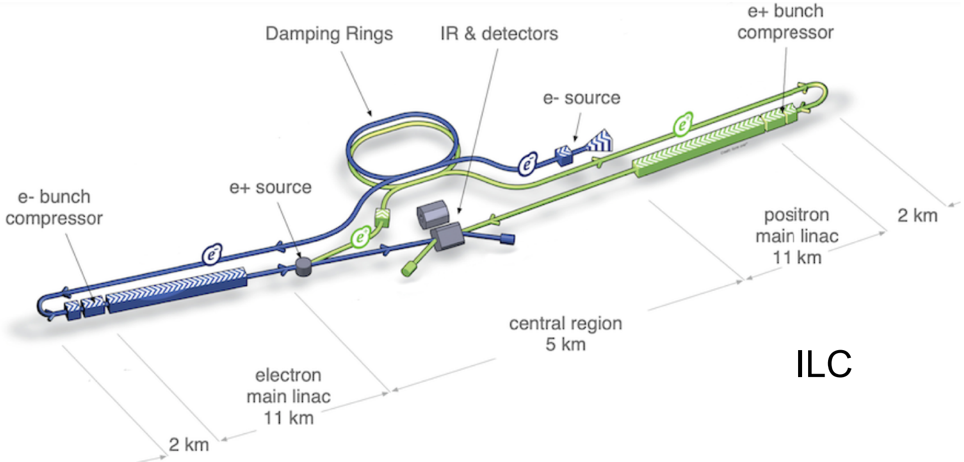
- 0.25-1 TeV
- SC RF
- Collisions up to 5 Hz with trains of 1312/2625 bunches
- Possible extension to 10 Hz with 2625 bunch trains

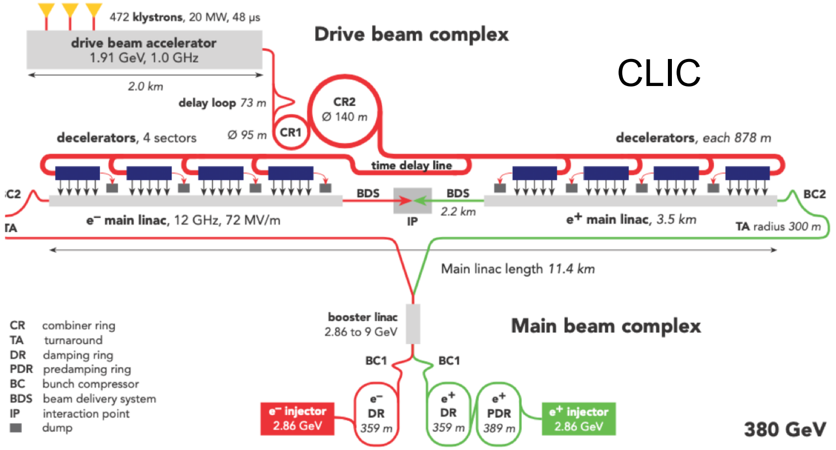
CLIC:

- 0.25-3 TeV
- Cu RF with two beam acceleration
- Collisions at 50 Hz with trains of 352 bunches

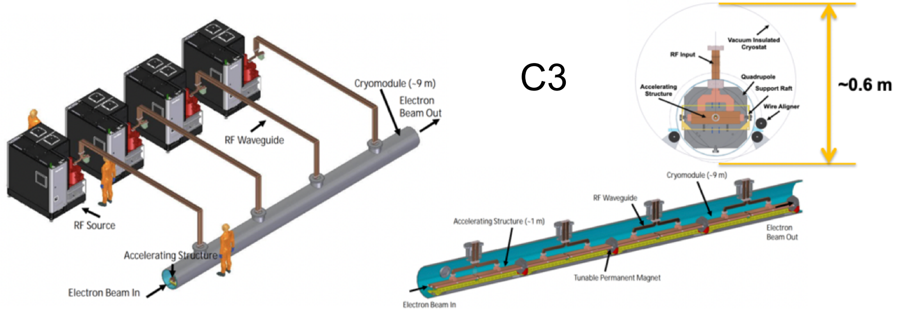
CCC (C3):

- 0.25 – 1 TeV,
- Cold Copper RF structures
- Collisions at 120 Hz with trains of 133 bunches





- C^3 technology: Modularized linac technology based on liquid N2 cooled c-band cavity.
- Each cryomodule (CM) is about 9 m long and has 4 rafts.
- Each raft has 2 accelerator structures and one quadrupole magnet
- Each cryomodule (CM) can reach up to 1 GeV.

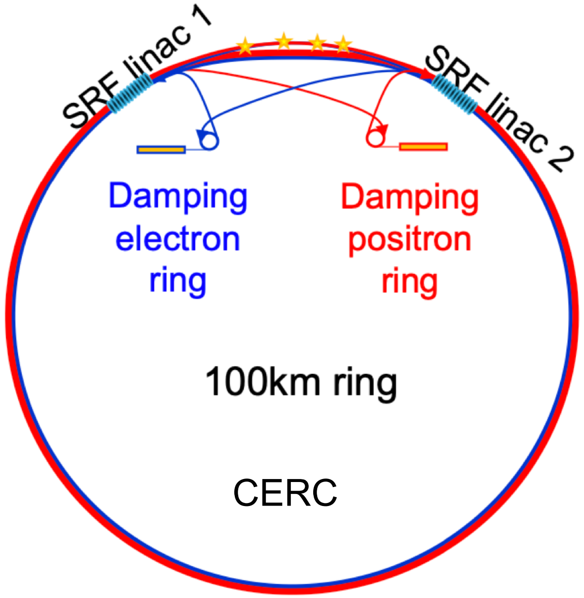


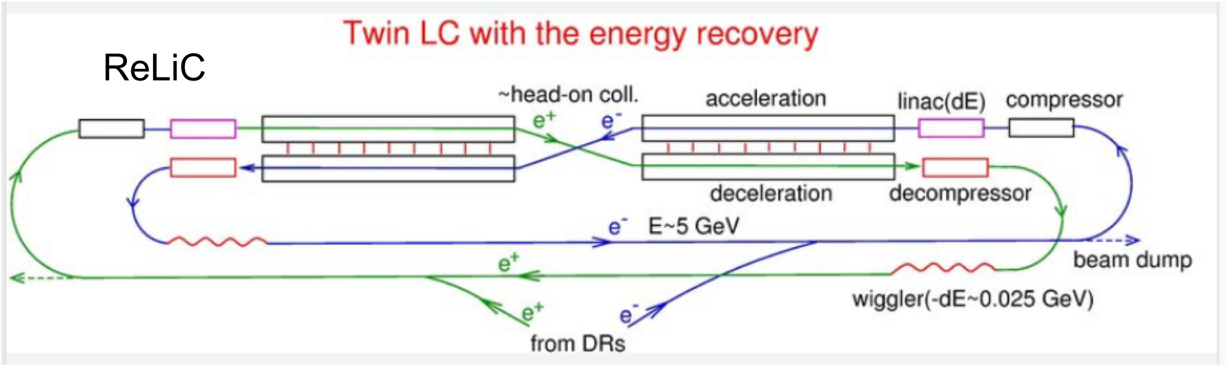
Energy Recovery e+e- Colliders

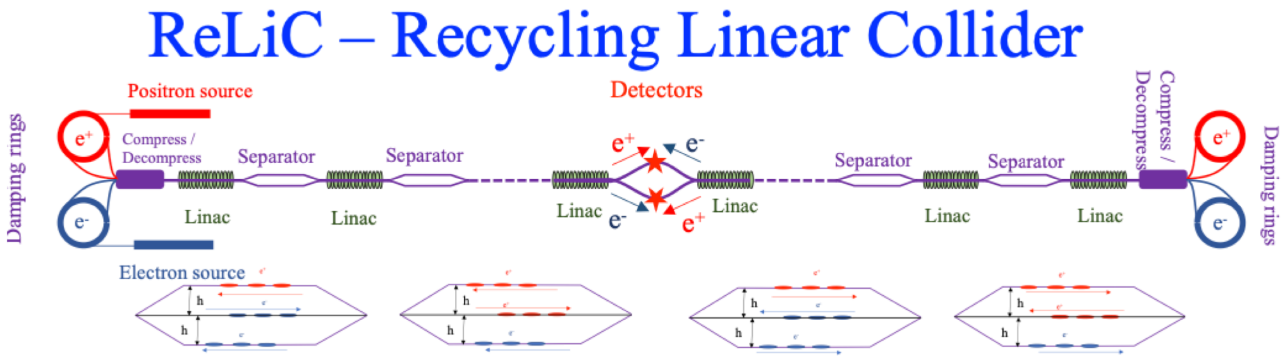
CERC:
- 91-600 GeV
- Four pass SC linac (up/down)
- Collisions to 297 kHz
- ~800 bunches

ERLC:
- 91-1500 GeV
- Two bore SC two beam accelerator
- 2 sec on then 4 sec off
- ~53,000 bunches

ReLiC:
- 91-3000 GeV
- SC RF with energy recovery
- Collisions to 25 kHz
- 21 bunches per train, ~22000 total







Wakefield Driven Colliders

PWFA-LC: 1-3 TeV

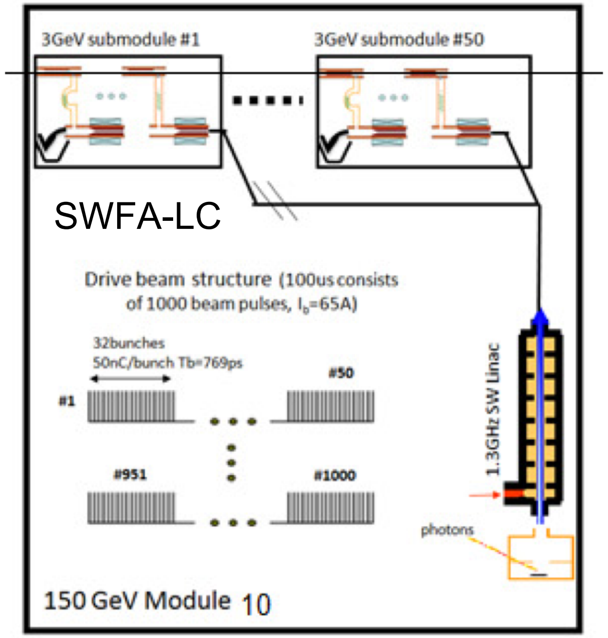
- Electron driven plasma wakes
- Single bunch acceleration
- 10-20 kHz collisions

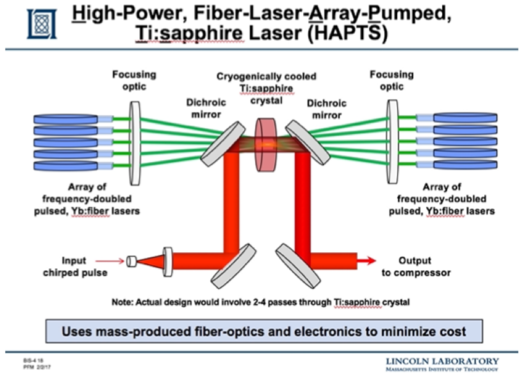
LWFA-LC: 1-15 TeV

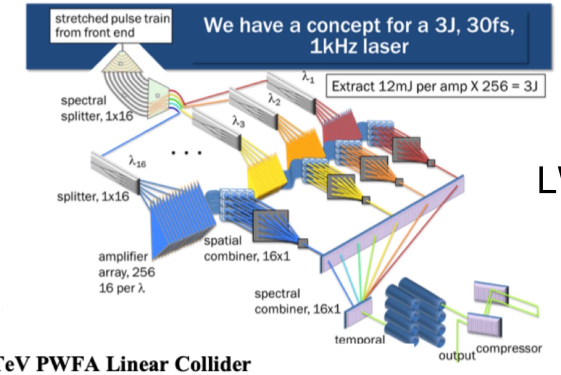
- Laser driven plasma wakes with very high power lasers
- Single bunch acceleration
- 47 kHz collisions

SWFA-LC: 1-3 TeV

- Electron driven structure wakes in dielectric WG at 26 GHz
- Collides at 5 Hz with trains of 208 bunches

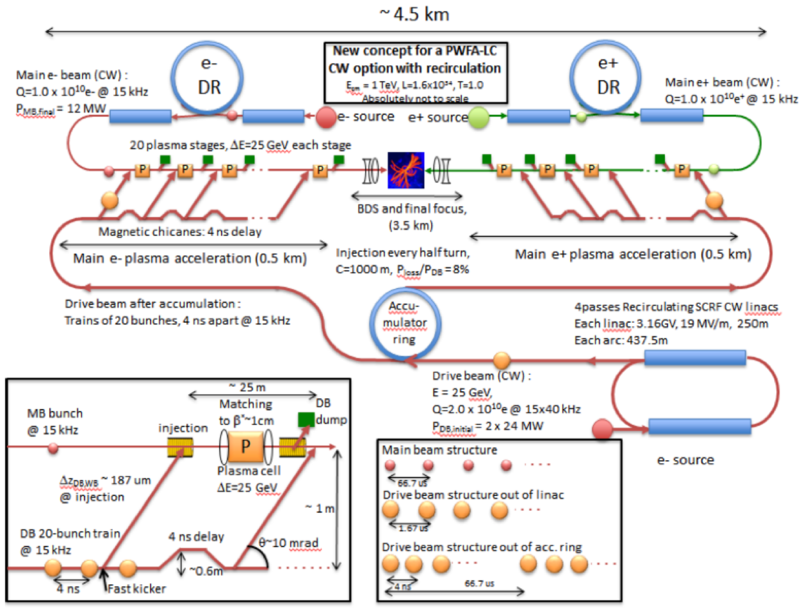






LWFA-LC

Figure 1: Layout of a 1 TeV PWFA Linear Collider



Future collider positron requirements

Collider	Status	Colliding e+ / bunch (x10^10)	Colliding bunches to fill	Injection e+ bunches per pulse	Injection pulses/sec	Injection e+ bunches per second	Replacement e+ fraction per second	Total Inj e+/pulse (x10^10)	Total Inj e+/sec (x10^12)
LEP	Past	43.00	8	1	100	100	Ramped	0.12	0.12
SLC	Past	5.00	120	1	120	120	1.000000	5.00	6.00
PEP-II	Past	8.50	1732	1	30	30	0.001019	0.50	0.15
SuperKEKB	Ongoing	4.10	2151	2	50	100	0.002268	0.20	0.20
FCCee	Designed	20.20	12000	2	200	400	0.002475	1.50	6.00
CEPC	Designed	14.00	19918	2	100	200	0.001348	1.88	3.76
ILC	Designed	2.00	6560	1312	5	6560	1.000000	2.00	131.20
ILC (extend)	Designed	2.00	26250	2625	10	26250	1.000000	2.00	525.00
CLIC	Designed	0.57	17600	352	50	17600	1.000000	0.57	100.32
C3	Concept	0.63	15960	133	120	15960	1.000000	0.63	100.55
CERC	Concept	8.10	800	8	100	800	0.001235	1.00E-02	0.08
ERLC	Concept	0.50	53000	53	100	5300	0.000200	1.00E-03	0.05
ReLiC	Concept	1.00	22000	22	100	2200	0.000100	1.00E-03	0.02
PWFA-LC	Initial	1.00	10000	1	10000	10000	1.000000	1.00	100.00
PWFA-LC (ext)	Initial	1.00	20000	1	20000	20000	1.000000	1.00	200.00
LWFA-LC	Initial	0.12	47000	1	47000	47000	1.000000	0.12	56.40
SWFA-LC	Initial	0.31	23100	231	100	23100	1.000000	0.31	71.61

Damping Ring Parameters

Damping ring length depends on several parameters.
There are many damping ring designs.

Desired parameters:

A) Damping time
B) Number of damping times needed
C) Number of bunches in the bunch train
D) Number of bunch trains stored at the same time
E) Beam energy

Cost of the damping ring systems has two components:

Power component: Pulse rate, drive e- energy, drive beam number of particles

Length component: Number of stored bunches, train length, bunches per train, damping times

Damping Ring Length

The damping ring length (minimum) is given by:

(Needed to add gaps for extraction, injection, ECI, beam loading, …)

$$L_{DR} = s_b \times N_{sb} = s_b \times N_{bt} \times N_{bpt}$$

Where:

Sb = bunch separation

Nsb = number of stored bunches

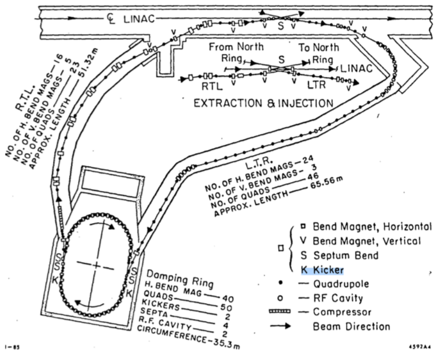
Nbt = number of stored bunch trains

Nbpt = number of bunches per train

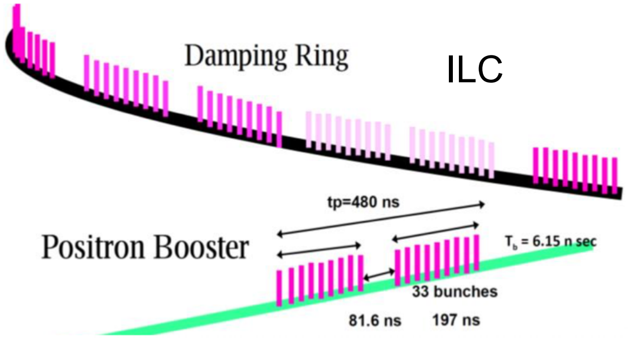
Future Collider Positron Damping Rings

Proposed e+ damping rings come in many designs:

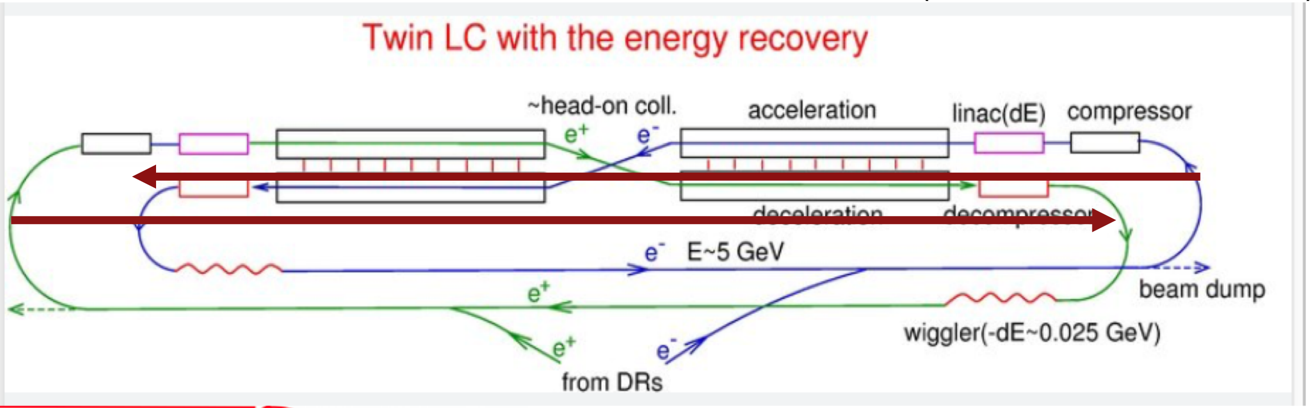
SLC



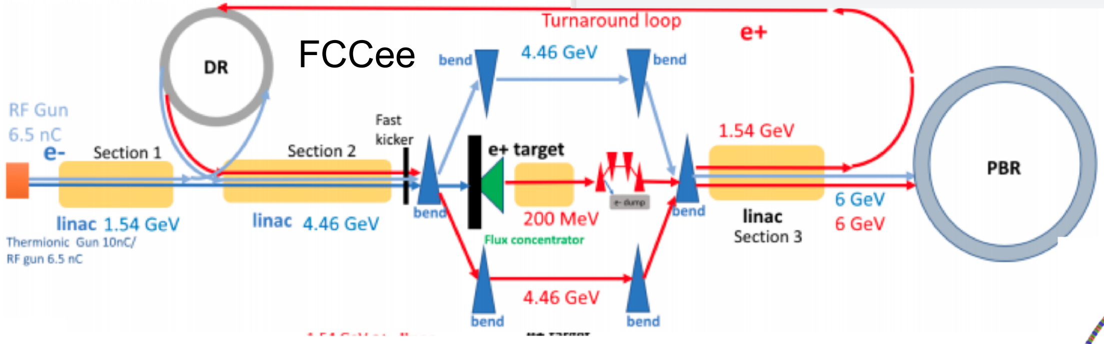
ILC



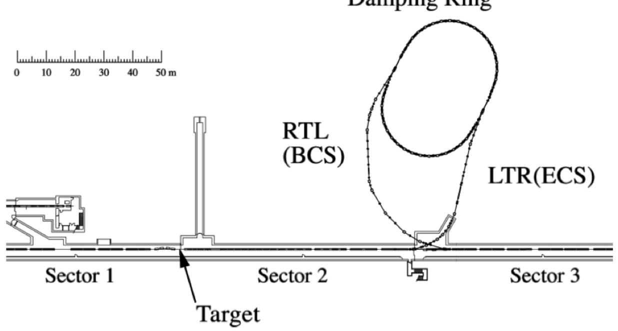
ERLC (2 sec on then 4 sec off)

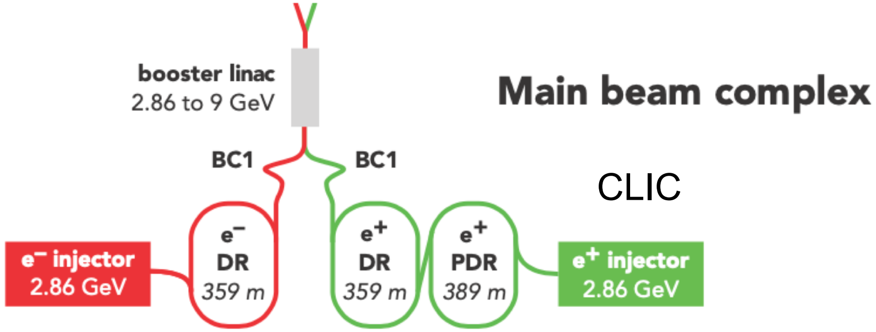


FCCee



SuperKEKB





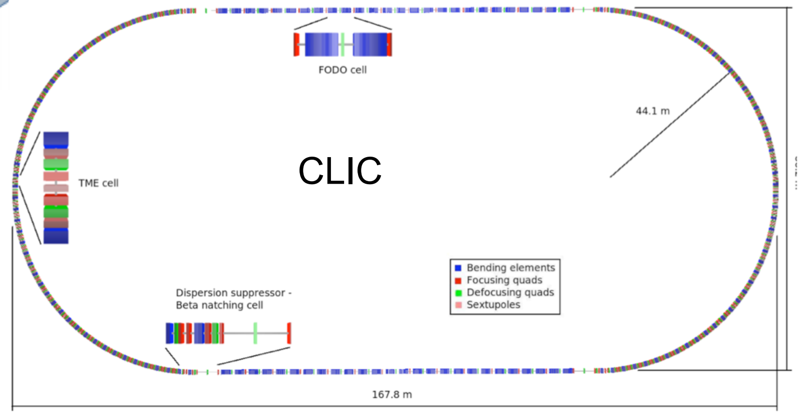


Fig. 3.15: Schematic layout of the CLIC main Damping Rings.

Required Damping Ring Lengths

Collider	e+ DR Energy (GeV)	Number e+/bunch (x10^10)	e+ bunch spacing (m) in DR	Number trains per/sec	Number e+ trains stored	Number e+ bunches per train	Total e+ bunches stored	Damping time (msec)	Number damp times stored	e+ DR Circum (m)	Calculated e+ DR Circum (m)	Ratio Lengths act/calc
LEP	0.60	2.5	15.7	0.089	8	1	8	34.0	330	125.66	125.6	1.0
SLC	1.21	5	17.6	120	2	1	2	3.1	5.5	35.3	35.3	1.0
PEP-II*	1.21	8.5	17.6	30	2	1	2	3.1	5.5	35.3	35.3	1.0
SuperKEKB	1.1	4.1	28.8	50	2	2	4	10.9	3.7	135.5	115.2	1.2
FCCee	1.54	2.2	15	200	8	2	16	11.6	3.8	241.8	240	1.0
CEPC	1.1	4.4	18.4	200	4	2	8	11.4	3.6	147	147.2	1.0
ILC	5	2	1.85	5	1	1312	1312	23.9	8.3	3200	2427.2	1.3
CLIC PDR	2.86	0.43	0.5	50	2	312	624	2.7	10	389.2	312	1.2
CLIC DR	2.86	0.41	0.5	50	2	312	624	2.0	10	427.5	312	1.4
C3**	~3	0.63	1.6	120	3	133	399	2.0	10	650	638.4	1.0
CERC**	2-8	8.1	1.6	800	8	2	16	2.0	10	27	25.6	1.1
ERLC**	5	0.50	1.6	5300	106	1	106	2.0	10	170	169.6	1.0
ReLiC**	2.5	1.00	1.6	2200	2	22	44	2.0	10	75	70.4	1.1
PWFA-LC**	~3	1.00	1.6	15000	300	1	300	2.0	10	500	480	1.0
LWFA-LC**	~3	0.12	1.6	47000	940	1	940	2.0	10	1550	1504	1.0
SWFA-LC***	~3	0.31	1.6	5	20	231	4620	2.0	10	7500	7392	1.0
*	Used SLC e+ source at low rate											
**	Assumes CLIC DR											
***	Bunch manipulation needed and assumes CLIC DR											

Conclusions

Bunch pulse structure of the collider drives the technical design of the positron complex.

Total number of positrons/second drives the target and capture section design.

Number of simultaneously stored positron bunches dominates the damping ring length.

Some of the advanced colliders need new and enhanced concepts for positron production.