Future e⁺e⁻ Collider Positron Injection Requirements

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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 10¹⁰, 1.21 GeV damping ring (2 bunches stored)

SuperKEKB: 4 x 7 GeV, ~50 Hz, 2 e+ bunch, 0.1-0.5 x 10¹⁰, 1.5 GeV damping ring (4 bunches stored)





BABAR Detector

SLC

Electrons

Future Circular Ring e+e- Colliders

FCCee:

91-365 GeVLow field magnetsTop-up injection,Up to 12,000 bunches

CEPC:

91-360 GeVLow field magnetsTop-up injectionUp to 11951 bunches



Future Linear Colliders with Bunch Trains

ILC:

0.25-1 TeV

 $\mathsf{SC}\,\mathsf{RF}$

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



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





ReLiC

Wakefield Driven Colliders

PWFA-I C: 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

Figure 1: Layout of a 1 TeV PWFA Linear Collider



Future collider positron requirements

Collider	Status	Colliding	Colliding	Injection	Injection	Injection	Replacement	Total Inj	Total Inj
		e+ / bunch	bunches	e+ bunches	pulses/sec	e+ bunches	e+ fraction	e+/pulse	e+/sec
		(x10^10)	to fill	per pulse		per second	per second	(x10^10)	(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
С3	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



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

ERLC (2 sec on then 4 sec off)

Required Damping Ring Lengths

											Calculated	Ratio	[
Collider	e+ DR	Number	e+ bunch	Number	Number	Number	Total	Damping	Number	e+ DR	e+ DR	Lengths	
	Energy	e+/bunch	spacing	trains	e+ trains	e+ bunches	e+ bunches	time	damp times	Circum	Circum	act/calc	
	(GeV)	(x10^10)	(m) in DR	per/sec	stored	per train	stored	(msec)	stored	(m)	(m)		
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	
													Γ
FCCee	1.54	2.2	15	200	8	2	16	11.6	3.8	241.8	240	1.0	Γ
CEPC	1.1	4.4	18.4	200	4	2	8	11.4	3.6	147	147.2	1.0	Γ
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	Γ
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 ma	nipulation n	eeded and	assumes Cl	LIC DR								Γ
		-											

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.

Positron production performances in different past/present/future colliders

* Under study

Colliders Parameters		SLC	LEP	SuperKEKB	CLIC 380 GeV/ 3 TeV	ILC baseline	ILC alternative	CEPC	FCC-ee baseline	
e- beam energy at target [GeV]		33	0.2	3.5	5/5	126.5	3.0	4	6	
e- bunch [10 ¹⁰] for e+		3-5	20	6.25	0.52 / 0.44	2	2.5	6.25	3.5 *	
Bunch/pulse		1	1	2	352 / 312	1312	1312	1	2	
Repetition rate [Hz]		120	100	50	50 / 50	5	5	50	200	
Target Scheme	γ producti on mode	conventional	conventiona I	conventional	Oriented crystal (channeling)	Helical undulator	conventional	conventional	conventional / oriented crystal	
	Target material	W74-Re26	W74-Re26	w	Radiator (W) + converter (W74-R326)	Ti alloy 2KW	W or Wre 18 KW	w	W74-Re26 \ radiator (w) + converter (W74- Re26)	
Target mobility		moving tumbling 1 Hz	fixed	fixed	fixed	moving rotating wheel 100 m/s	moving rotating wheel 5 m/s	fixed	fixed *	
Capture system		AMD	QWT	AMD	AMD	AMD	AMD	AMD	AMD	
Capture frequency linac [GHz]		2.856	2.999	2.856	1.999	1.3	1.3	3 2.860 2		
DR energy [GeV]		1.15	0.5	1.1	2.86	5	5	1.1	1.54	
e+/s@injector exit [10 ¹²]		6	0.12	2.5	100	130 130		0.3	6	
e+ yield @ DR		0.8-1.2	0.006	0.4	1	1.74	1.28	> 0.3	>1*	