
ERL Statistics

ERL Panel Kick-off Meeting
25 February 2021

			Activities Completed		Activities Ongoing			
			JLab FEL	CEBAF 1-Pass	cERL	Recuperator	CBETA 1/4 Pass	s-Dalincac 1/2 Pass
			Jefferson lab, USA	Jefferson Lab, USA	KEK, Japan	BINP, Russia	Cornell, USA	TU Darmstadt, Germany
ERL	Top energy	MeV	165	1045	17.6	40	42/159	22.5/34.2
	Beam power	kW	1300	104.5	20	200	2.9/0.3	2.6
Source	Gun Energy	keV	100	100	500	300	350	125/250
	Bunch charge	pC	270	0.06	0.77	1500		
	Current	mA	8.5	0.1	1	10	0.07, 0.002	0.00, /0.0001
	Polarization		No	No	No	No	No	Yes/No
Injector	Beam energy	MeV	9	25/45	2.9	1.5	6	2.5/3.8
	Emittance	μm	8	0.05		20		
Acceleration	Energy gain/linac	MeV	156	2 X 500		10		
	RF Frequency	MHz	1497	1497	1300	180	1300	3000
	Bunch repetition rate	MHz		1497				
	Total Linac Current	mA	17	0.2	2	10, 30, 70	0.56, 0.016	0.004, 0.0002
	Harmonic frequency	MHz	N/A	N/A	N/A	N/A	N/A	N/A
	Macropulse length	μsec	CW	CW	CW	CW, copper	CW	
	Bunch charge	pC	270	0.06	0.77	1500		
	Normalized Emittance	μm	10	0.05	0.29/0.26	20		
	Gradient	MV/m	12	12		0.4	16	
	Quality factor	$\times 10^{10}$	1	1		4×10^{-6}		
	RF controls		Analog	Analog				
	Beam loss	nA	100		<0.01%			
Arcs	Multi-pass		1 + 1	1 + 1	1 + 1	1, 3, or 7 turns	(1 + 1) / (4 + 4)	(1 + 1) / (2 + 2)
	Optics design		Bates bends	Achromatic, isochronous		180-degree achromatic bends	FFAG	
	Beam loss	%	$<1 \times 10^{-4}$			1%		
Interaction Region	β_x, β_y	cm	~6, ~6	N/A	N/A	~300	N/A	N/A
	Beam size	μm	50	N/A	N/A		N/A	N/A
	Beam Divergence	μrad	Not measured	N/A	N/A		N/A	N/A
	Magnets		Standard, warm	N/A	N/A	undulators and quadrupoles	N/A	N/A
Dump	Dump beam energy	MeV	11	25/45	3	1.5		
	Dump power	kW	100	4.5	2.9	15	0.4, /0.012	
	Max CW current recovered	mA	8.5	0.1		20	0.0, 2×10^{-6}	
Comment			Highest power achieved Highest current and bunch charge achieved in SC ERL mode; Highest Injector energy	Highest energy achieved	Highest gun voltage achieved	Highest current and bunch charge achieved in ERL mode	Highest gun current achieved, 75 mA, but not in ERL mode. Highest number of passes achieved	Highest current in multipass ERL
			Interaction Region at 100 MeV, 0.6 mA				FFAG Arcs	

			Projects in Progress					Studies		
			CEBAF 5-Pass	bERLinPro	MESA	EIC Cooler	PERLE	DICE	DIANA	FCC-ee ERL
			Jefferson Lab, USA	HZB, Germany	U Mainz, Germany	BNL, USA	IJCLab, France	TU Darmstadt, Germany	STFC, UK	BNL, USA
ERL	Top energy	MeV	7584	50	105	22.3/54.1/150	500	400, 130	900	300
	Beam power	MW	0.758	5	0.1	22.3/54.1/150	10	4.8, 0.52	10	48
Source	Gun Energy	keV	100	2000	100	400	350/200	300	400	
	Bunch charge	pC	0.06	77	1	1	500	15 - 75, 5	100	19,000
	Current	mA	0.1	100	1	100	20	12, 4	12.5	0.16
	Polarization		Yes	No	Yes	No	Yes & No	Yes & No	No	Possible
Injector	Beam energy	MeV	84	6	5	5	7	7 - 10	7	2,000
	Emittance (normalized)	μm	0.05	< 1	<1	< 3	6	< 1	0.3	8, 0.008
Acceleration	Energy gain/linac	MeV	2 x 750	50	2 x 50	17.3/49.1/145	2 x 82	(2 x 66), (2 x 33)	2 x 150	2 x 44,550
	RF Frequency	MHz	1497	1300	1300	591	801.58	801.58	750	750
	Bunch repetition rate									
	Total Linac current	mA	1	200	2	200	120	45 - 225, 10		
	Harmonic frequency	MHz	N/A	N/A	N/A	1773	N/A	N/A	125	1500, 2250
	Macropulse length	μsec	CW	CW	CW	CW	CW	not defined	CW	CW
	Bunch charge	pC	0.06	77	1	1	500	90 - 450, 20	100	19,000
	Emittance	μm	0.05	≤ 1	<1	< 3	6	< 1	0.5	8, 0.008
	Gradient	MV/m	12 - 17.5		12.5 MV/m	20	21	18	18	20
	Quality factor	$\times 10^{10}$	1		>1.25		>1	1	3	~ 1
	RF controls		Analog/digital		MTCA (digital)	TBD		SEL/PLL	DLLRF	FPGA
	Beam loss	nA		<10^-5	<10^-5	TBD		< 1E-5 (relative)	1.00E-07	<0.00001
Arcs	Multi-pass		5 + 5	1 + 1	1 + 1	1 + 1	3 + 3	3 (2)	3 + 3	4 + 4
	Optics design		Achromatic, isochronous		MBA	R56 canceling bending, Bates	Flexible Momentum Compaction	MBA, separated transport	MBA	small-gap FODO
	Beam loss	%			<10^-3	TBD		< 1E-5 (relative)	1.00E-07	<10^-7
Interaction Region	β_x, β_y	cm	N/A	N/A	$\sim 1\text{m}$	40/40		52, 72	50, 400	100, 0.2
	Beam size	μm	N/A	N/A	100	1330, 550/200		22, 24	15 - 50	4.7, 0.0052
	Beam Divergence	μrad	N/A	N/A	100	4		490/360	10 - 30	3.7, 2.6
	Magnets		N/A	N/A	Copper	Copper		Chicane for IP	PM	Head-on collisions
	Dump beam energy	MeV	84	2	5	5	7	7 - 10	< 10	N/A
Dump	Dump power	kW	8.4	200	5	500	140	(84-120), (2- 40)	< 100	N/A
	Max CW current recovered	mA	0.1		0.999mA			12, 4	12.5	0.16
Comment			Highest energy proposed Highest number of passes proposed	Highest gun current proposed			Highest multiturn power proposed	DICE stage II given, values for DICE stage I in "()"	Potentially front-end of UK-XFEL	

High Level Table

			Current Record Achieved	Approved Project Goal	Projects in Progress Goal	LHeC / FCC-eh	TRL now	TRL in 5 Years
ERL	Top energy	GeV	1.05	7.5		50	6	6
	Beam power	MW	1.3		10	1000	5	5
Source	Gun Energy	keV	450			220 - 350	9	9
	Current	mA	9(*20)	100	20	120	3	6
Injector	Beam energy	MeV	6	84	7 - 10	7	9	9
Acceleration	RF Frequency	MHz	1300 - 1500	591 - 1497	801.58	801.58	7	9
	Total Linac current	mA	18 (20*)	100	200	720	3	6
	Bunch charge	pC	270 (1500*)		500	500	4	6
	Normalized emittance	μm	10 @ 270pC		6 @ 500pC	30 @ 500pC	5	7
	Gradient	MV/m	12	17.5	18	19.73	9*	9*
	Quality factor	$\times 10^{10}$	1	>1.25	3	>1	9*	9*
	Multi-pass		4 + 4	5 + 5	3 + 3	3 + 3	8	8
Interaction Region	β_x, β_y	cm	6, 6			7 - 10, 7 - 10	7	7
	Beam size	μm	50			6, 6	3	3
Dump	Dump power	kW	100	500		840	3	5
			* Charge reached in low-frequency, copper cavities				* achieved in commercially procured cavities for LCLS II	