

HIGH-ENERGY COLLIDER PARAMETERS:  $e^+e^-$  Colliders (I)

Updated in early 2012 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). The table shows parameter values as achieved by January 1, 2012. Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy;  $H$  and  $V$  indicate horizontal and vertical directions; s.c. stands for superconducting. Parameters for the defunct SPEAR, DORIS, PETRA, PEP, SLC, TRISTAN, and VEPP-2M colliders may be found in our 1996 edition (Phys. Rev. **D54**, 1 July 1996, Part I).

	VEPP-2000 (Novosibirsk)	VEPP-4M (Novosibirsk)	BEPC (China)	BEPC-II (China)	DAΦNE (Frascati)
Physics start date	2010	1994	1989	2008	1999
Physics end date	—	—	2005	—	—
Maximum beam energy (GeV)	1.0	6	2.5	1.89 (2.3 max)	0.510
Delivered integrated luminosity per exp. ( $\text{fb}^{-1}$ )	0.030	0.027	0.11	3.74	$\approx 4.7$ in 2001-2007 2.7 w/crab-waist
Luminosity ( $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ )	100	20	12.6 at 1.843 GeV 5 at 1.55 GeV	649	453
Time between collisions ( $\mu\text{s}$ )	0.04	0.6	0.8	0.008	0.0027
Full crossing angle ( $\mu$ rad)	0	0	0	$2.2 \times 10^4$	$5 \times 10^4$
Energy spread (units $10^{-3}$ )	0.64	1	0.58 at 2.2 GeV	0.52	0.40
Bunch length (cm)	4	5	$\approx 5$	$\approx 1.5$	low current: 1 at 15mA: 2
Beam radius ( $10^{-6}$ m)	125 (round)	$H$ : 1000 $V$ : 30	$H$ : 890 $V$ : 37	$H$ : 380 $V$ : 5.7	$H$ : 260 $V$ : 4.8
Free space at interaction point (m)	$\pm 1$	$\pm 2$	$\pm 2.15$	$\pm 0.63$	$\pm 0.295$
Luminosity lifetime (hr)	continuous	2	7–12	1.5	0.2
Turn-around time (min)	continuous	18	32	26	2 (topping up)
Injection energy (GeV)	0.2–1.0	1.8	1.55	1.89	on energy
Transverse emittance ( $10^{-9}\pi$ rad-m)	$H$ : 250 $V$ : 250	$H$ : 200 $V$ : 20	$H$ : 660 $V$ : 28	$H$ : 144 $V$ : 2.2	$H$ : 260 $V$ : 2.6
$\beta^*$ , amplitude function at interaction point (m)	$H$ : 0.06 – 0.11 $V$ : 0.06 – 0.10	$H$ : 0.75 $V$ : 0.05	$H$ : 1.2 $V$ : 0.05	$H$ : 1.0 $V$ : 0.015	$H$ : 0.26 $V$ : 0.009
Beam-beam tune shift per crossing (units $10^{-4}$ )	$H$ : 750 $V$ : 750	500	350	327	440
RF frequency (MHz)	172	180	199.53	499.8	356
Particles per bunch (units $10^{10}$ )	16	15	20 at 2 GeV 11 at 1.55 GeV	4.1	$e^-$ : 3.2 $e^+$ : 2.1
Bunches per ring per species	1	2	1	88	100 to 105 (120 buckets)
Average beam current per species (mA)	150	80	40 at 2 GeV 22 at 1.55 GeV	725	$e^-$ : 1500 $e^+$ : 1000
Circumference or length (km)	0.024	0.366	0.2404	0.23753	0.098
Interaction regions	2	1	2	1	1
Magnetic length of dipole (m)	1.2	2	1.6	outer ring: 1.6 inner ring: 1.41	outer ring: 1.2 inner ring: 1
Length of standard cell (m)	12	7.2	6.6	outer ring: 6.6 inner ring: 6.2	n/a
Phase advance per cell (deg)	$H$ : 738 $V$ : 378	65	$\approx 60$	60–90 non-standard cells	—
Dipoles in ring	8	78	40 + 4 weak	84 + 8 weak	8
Quadrupoles in ring	20	150	68	134+2 s.c.	48
Peak magnetic field (T)	2.4	0.6	0.903 at 2.8 GeV	outer ring: 0.677 inner ring: 0.766	1.2

## HIGH-ENERGY COLLIDER PARAMETERS: $e^+e^-$ Colliders (II)

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	CESR (Cornell)	CESR-C (Cornell)	LEP (CERN)	ILC (TBD)	CLIC (TBD)
Physics start date	1979	2002	1989	TBD	TBD
Physics end date	2002	2008	2000	—	—
Maximum beam energy (GeV)	6	6	100 - 104.6	250 (upgradeable to 500)	1500 (first phase: 250)
Delivered integrated luminosity per exp. ( $\text{fb}^{-1}$ )	41.5	2.0	0.221 at Z peak 0.501 at 65 – 100 GeV 0.275 at >100 GeV	—	—
Luminosity ( $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ )	1280 at 5.3 GeV	76 at 2.08 GeV	24 at Z peak 100 at > 90 GeV	$1.5 \times 10^4$	$6 \times 10^4$
Time between collisions ( $\mu\text{s}$ )	0.014 to 0.22	0.014 to 0.22	22	$0.55^\dagger$	$0.0005^\ddagger$
Full crossing angle ( $\mu$ rad)	$\pm 2000$	$\pm 3300$	0	14000	20000
Energy spread (units $10^{-3}$ )	0.6 at 5.3 GeV	0.82 at 2.08 GeV	0.7→1.5	1	3.4
Bunch length (cm)	1.8	1.2	1.0	0.03	0.0044
Beam radius ( $\mu\text{m}$ )	$H$ : 460 $V$ : 4	$H$ : 340 $V$ : 6.5	$H$ : 200 → 300 $V$ : 2.5 → 8	$H$ : 0.474 $V$ : 0.0059	$H$ : 0.045 * $V$ : 0.0009
Free space at interaction point (m)	$\pm 2.2$ ( $\pm 0.6$ to REC quads)	$\pm 2.2$ ( $\pm 0.3$ to PM quads)	$\pm 3.5$	$\pm 3.5$	$\pm 3.5$
Luminosity lifetime (hr)	2–3	2–3	20 at Z peak 10 at > 90 GeV	n/a	n/a
Turn-around time (min)	5 (topping up)	1.5 (topping up)	50	n/a	n/a
Injection energy (GeV)	1.8–6	1.5–6	22	n/a	n/a
Transverse emittance ( $10^{-9}\pi$ rad-m)	$H$ : 210 $V$ : 1	$H$ : 120 $V$ : 3.5	$H$ : 20–45 $V$ : 0.25 → 1	$H$ : 0.02 $V$ : $7 \times 10^{-5}$	$H$ : $2.2 \times 10^{-4}$ $V$ : $6.8 \times 10^{-6}$
$\beta^*$ , amplitude function at interaction point (m)	$H$ : 1.0 $V$ : 0.018	$H$ : 0.94 $V$ : 0.012	$H$ : 1.5 $V$ : 0.05	$H$ : 0.01 $V$ : $5 \times 10^{-4}$	$H$ : 0.0069 $V$ : $6.8 \times 10^{-5}$
Beam-beam tune shift per crossing (units $10^{-4}$ )	$H$ : 250 $V$ : 620	$e^-$ : 420 ( $H$ ), 280 ( $V$ ) $e^+$ : 410 ( $H$ ), 270 ( $V$ )	830	n/a	7.7
RF frequency (MHz)	500	500	352.2	1300	11994
Particles per bunch (units $10^{10}$ )	1.15	4.7	45 in collision 60 in single beam	2	0.37
Bunches per ring per species	9 trains of 5 bunches	8 trains of 3 bunches	4 trains of 1 or 2	1312	312 (in train)
Average beam current per species (mA)	340	72	4 at Z peak 4→6 at > 90 GeV	6 (in pulse)	1205 (in train)
Beam polarization (%)	—	—	55 at 45 GeV 5 at 61 GeV	$e^-$ : > 80% $e^+$ : > 60%	$e^-$ : 70% at IP
Circumference or length (km)	0.768	0.768	26.66	31	48
Interaction regions	1	1	4	1	1
Magnetic length of dipole (m)	1.6–6.6	1.6–6.6	11.66/pair	n/a	n/a
Length of standard cell (m)	16	16	79	n/a	n/a
Phase advance per cell (deg)	45–90 (no standard cell)	45–90 (no standard cell)	102/90	n/a	n/a
Dipoles in ring	86	84	3280 + 24 inj. + 64 weak	n/a	n/a
Quadrupoles in ring	101 + 4 s.c.	101 + 4 s.c.	520 + 288 + 8 s.c.	n/a	n/a
Peak magnetic field (T)	0.3 / 0.8 at 8 GeV	0.3 / 0.8 at 8 GeV, 2.1 wigglers at 1.9 GeV	0.135	n/a	n/a

$^\dagger$ Time between bunch trains: 200ms.

$^\ddagger$ Time between bunch trains: 20ms.

\*Effective beam size including non-linear and chromatic effects.

## HIGH-ENERGY COLLIDER PARAMETERS: $e^+e^-$ Colliders (III)

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	KEKB (KEK)	PEP-II (SLAC)	SuperB (Italy)	SuperKEKB (KEK)
Physics start date	1999	1999	TBD	2015
Physics end date	2010	2008	—	—
Maximum beam energy (GeV)	$e^-$ : 8.33 (8.0 nominal) $e^+$ : 3.64 (3.5 nominal)	$e^-$ : 7–12 (9.0 nominal) $e^+$ : 2.5–4 (3.1 nominal) (nominal $E_{cm} = 10.5$ GeV)	$e^-$ : 4.2 $e^+$ : 6.7	$e^-$ : 7 $e^+$ : 4
Delivered integrated luminosity per exp. ( $\text{fb}^{-1}$ )	1040	557	—	—
Luminosity ( $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ )	21083	12069 (design: 3000)	$1.0 \times 10^6$	$8 \times 10^5$
Time between collisions ( $\mu\text{s}$ )	0.00590 or 0.00786	0.0042	0.0042	0.004
Full crossing angle ( $\mu$ rad)	$\pm 11000^\dagger$	0	$\pm 33000$	$\pm 41500$
Energy spread (units $10^{-3}$ )	0.7	$e^-/e^+$ : 0.61/0.77	$e^-/e^+$ : 0.73/0.64	$e^-/e^+$ : 0.64/0.81
Bunch length (cm)	0.65	$e^-/e^+$ : 1.1/1.0	0.5	$e^-/e^+$ : 0.5/0.6
Beam radius ( $\mu\text{m}$ )	H: 124 ( $e^-$ ), 117 ( $e^+$ ) V: 1.9	H: 157 V: 4.7	H: 9 ( $e^-$ ), 7 ( $e^+$ ) V: 0.04	$e^-$ : 11 (H), 0.062 (V) $e^+$ : 10 (H), 0.048 (V)
Free space at interaction point (m)	+0.75/−0.58 (+300/−500) mrad cone	$\pm 0.2$ , $\pm 300$ mrad cone	$\pm 0.35$	$e^-$ : +1.20/−1.28, $e^+$ : +0.78/−0.73 (+300/−500) mrad cone
Luminosity lifetime (hr)	continuous	continuous	continuous	continuous
Turn-around time (min)	continuous	continuous	continuous	continuous
Injection energy (GeV)	$e^-/e^+$ : 8/3.5	2.5–12	$e^-/e^+$ : 4.2/6.7	$e^-/e^+$ : 7/4
Transverse emittance ( $10^{-9}\pi$ rad-m)	$e^-$ : 24 (57*) (H), 0.61 (V) $e^+$ : 18 (55*) (H), 0.56 (V)	$e^-$ : 48 (H), 1.8 (V) $e^+$ : 24 (H), 1.8 (V)	$e^-$ : 2.5 (H), 0.006 (V) $e^+$ : 2.0 (H), 0.005 (V)	$e^-$ : 4.6 (H), 0.013 (V) $e^+$ : 3.2 (H), 0.0086 (V)
$\beta^*$ , amplitude function at interaction point (m)	$e^-$ : 1.2 (0.27*) (H), 0.0059 (V) $e^+$ : 1.2 (0.23*) (H), 0.0059 (V)	$e^-$ : 0.50 (H), 0.012 (V) $e^+$ : 0.50 (H), 0.012 (V)	$e^-$ : 0.032 (H), 0.00021 (V) $e^+$ : 0.026 (H), 0.00025 (V)	$e^-$ : 0.025 (H), $3 \times 10^{-4}$ (V) $e^+$ : 0.032 (H), $2.7 \times 10^{-4}$ (V)
Beam-beam tune shift per crossing (units $10^{-4}$ )	$e^-$ : 1020 (H), 900 (V) $e^+$ : 1270 (H), 1290 (V)	$e^-$ : 703 (H), 498 (V) $e^+$ : 510 (H), 727 (V)	20 (H), 950 (V)	$e^-$ : 12 (H), 807 (V) $e^+$ : 28 (H), 881 (V)
RF frequency (MHz)	508.887	476	476	508.887
Particles per bunch (units $10^{10}$ )	$e^-/e^+$ : 4.7/6.4	$e^-/e^+$ : 5.2/8.0	$e^-/e^+$ : 6.5/5.1	$e^-/e^+$ : 6.53/9.04
Bunches per ring per species	1585	1732	978	2500
Average beam current per species (mA)	$e^-/e^+$ : 1188/1637	$e^-/e^+$ : 1960/3026	$e^-/e^+$ : 1900/2400	$e^-/e^+$ : 2600/3600
Beam polarization (%)	—	—	$> 80$ ( $e^-$ )	—
Circumference or length (km)	3.016	2.2	1.258	3.016
Interaction regions	1	1	1	1
Magnetic length of dipole (m)	$e^-/e^+$ : 5.86/0.915	$e^-/e^+$ : 5.4/0.45	$e^-/e^+$ : 0.9/5.4	$e^-/e^+$ : 5.9/4.0
Length of standard cell (m)	$e^-/e^+$ : 75.7/76.1	15.2	40	$e^-/e^+$ : 75.7/76.1
Phase advance per cell (deg)	450	$e^-/e^+$ : 60/90	360 (V), 1080 (H)	450
Dipoles in ring	$e^-/e^+$ : 116/112	$e^-/e^+$ : 192/192	$e^-/e^+$ : 186/102	$e^-/e^+$ : 116/112
Quadrupoles in ring	$e^-/e^+$ : 452/452	$e^-/e^+$ : 290/326	$e^-/e^+$ : 290/300	$e^-/e^+$ : 466/460
Peak magnetic field (T)	$e^-/e^+$ : 0.25/0.72	$e^-/e^+$ : 0.18/0.75	$e^-/e^+$ : 0.52/0.25	$e^-/e^+$ : 0.22/0.19

$^\dagger$ KEKB was operated with crab crossing from 2007 to 2010.

\*With dynamic beam-beam effect.

## HIGH-ENERGY COLLIDER PARAMETERS: $ep$ , $\bar{p}p$ , $pp$ Colliders

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	HERA (DESY)	TEVATRON* (Fermilab)	RHIC (Brookhaven)	LHC (CERN)		
Physics start date	1992	1987	2001	2009	2012 (expected)	nominal
Physics end date	2007	2011	—	—		
Particles collided	$ep$	$p\bar{p}$	$pp$ (polarized)	$pp$		
Maximum beam energy (TeV)	$e$ : 0.030 $p$ : 0.92	0.980	0.25 48% polarization	3.5	4.0	7.0
Delivered integrated luminosity per exp. ( $\text{fb}^{-1}$ )	0.8	12	up to 0.14 at 100 GeV/n up to 0.15 at 200 GeV/n	up to 5.6	—	—
Luminosity ( $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ )	75	431	145 (pk) 90 (avg)	$3.7 \times 10^3$	$5 \times 10^3$	$1.0 \times 10^4$
Time between collisions (ns)	96	396	107	49.90	49.90	24.95
Full crossing angle ( $\mu$ rad)	0	0	0	240	$\approx 300$	$\approx 300$
Energy spread (units $10^{-3}$ )	$e$ : 0.91 $p$ : 0.2	0.14	0.15	0.116	0.116	0.113
Bunch length (cm)	$e$ : 0.83 $p$ : 8.5	$p$ : 50 $\bar{p}$ : 45	70	9	9	7.5
Beam radius ( $10^{-6}$ m)	$e$ : 110( $H$ ), 30( $V$ ) $p$ : 111( $H$ ), 30( $V$ )	$p$ : 28 $\bar{p}$ : 16	90	26	20	16.6
Free space at interaction point (m)	$\pm 2$	$\pm 6.5$	16	38	38	38
Initial luminosity decay time, $-L/(dL/dt)$ (hr)	10	6 (avg)	5.5	8	8	14.9
Turn-around time (min)	$e$ : 75, $p$ : 135	90	200	$\approx 180$	$\approx 180$	$\approx 180$
Injection energy (TeV)	$e$ : 0.012 $p$ : 0.040	0.15	0.023	0.450	0.450	0.450
Transverse emittance ( $10^{-9}\pi$ rad-m)	$e$ : 20( $H$ ), 3.5( $V$ ) $p$ : 5( $H$ ), 5( $V$ )	$p$ : 3 $\bar{p}$ : 1	15	0.7	0.6	0.5
$\beta^*$ , ampl. function at interaction point (m)	$e$ : 0.6( $H$ ), 0.26( $V$ ) $p$ : 2.45( $H$ ), 0.18( $V$ )	0.28	0.6	1.0	0.6	0.55
Beam-beam tune shift per crossing (units $10^{-4}$ )	$e$ : 190( $H$ ), 450( $V$ ) $p$ : 12( $H$ ), 9( $V$ )	$p$ : 120 $\bar{p}$ : 120	50	23	60	34
RF frequency (MHz)	$e$ : 499.7 $p$ : 208.2/52.05	53	accel: 9 store: 28	400.8	400.8	400.8
Particles per bunch (units $10^{10}$ )	$e$ : 3 $p$ : 7	$p$ : 26 $\bar{p}$ : 9	16.5	15	15	11.5
Bunches per ring per species	$e$ : 189 $p$ : 180	36	109	1380	1380	2808
Average beam current per species (mA)	$e$ : 40 $p$ : 90	$p$ : 70 $\bar{p}$ : 24	180	374	374	584
Circumference (km)	6.336	6.28	3.834	26.659		
Interaction regions	2 colliding beams 1 fixed target ( $e$ beam)	2 high $\mathcal{L}$	6 total, 2 high $\mathcal{L}$	4 total, 2 high $\mathcal{L}$		
Magnetic length of dipole (m)	$e$ : 9.185 $p$ : 8.82	6.12	9.45	14.3		
Length of standard cell (m)	$e$ : 23.5 $p$ : 47	59.5	29.7	106.90		
Phase advance per cell (deg)	$e$ : 60 $p$ : 90	67.8	84	90		
Dipoles in ring	$e$ : 396 $p$ : 416	774	192 per ring + 12 common	1232 main dipoles		
Quadrupoles in ring	$e$ : 580 $p$ : 280	216	246 per ring	482 2-in-1 24 1-in-1		
Magnet type	$e$ : C-shaped $p$ : s.c., collared, cold iron	s.c. $\cos\theta$ warm iron	s.c. $\cos\theta$ cold iron	s.c. 2 in 1 cold iron		
Peak magnetic field (T)	$e$ : 0.274, $p$ : 5	4.4	3.5	8.3		

\*Additional TEVATRON parameters:  $\bar{p}$  source accum. rate:  $25 \times 10^{10} \text{ hr}^{-1}$ ; max. no. of  $\bar{p}$  stored:  $3.4 \times 10^{12}$  (Accumulator),  $6.1 \times 10^{12}$  (Recycler).

## HIGH-ENERGY COLLIDER PARAMETERS: Heavy Ion Colliders

Updated in early 2012 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). The table shows parameter values as achieved by January 1, 2012. For LHC, the parameters expected at the ALICE experiment for running in 2012 and nominal values are also given. Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy; s.c. stands for superconducting; pk and avg denote peak and average values.

	RHIC (Brookhaven)			LHC (CERN)		
	2000	2004	2002	2010	2012 (expected)	nominal
Physics start date	2000	2004	2002	2010	2012 (expected)	nominal
Physics end date	—			—		
Particles collided	Au Au	Cu Cu	d Au	Pb Pb	p Pb	Pb Pb
Maximum beam energy (TeV/n)	0.1	0.1	0.1	1.38	<i>p</i> : 4 <i>Pb</i> : 1.58	2.76
$\sqrt{s_{NN}}$ (TeV)	0.2	0.2	0.2	2.76	5.0	5.5
Delivered int. nucleon-pair lumin. per exp. ( $\text{pb}^{-1}$ )	up to 568 (at 100 GeV/n)	up to 65 (at 100 GeV/n)	up to 103 (at 100 GeV/n)	$\approx 7.4$	—	—
Luminosity ( $10^{27} \text{ cm}^{-2}\text{s}^{-1}$ )	5.0 (pk) 3.0 (avg)	20 (pk) 0.8 (avg)	270 (pk) 140 (avg)	0.5	85	1.0
Time between collisions (ns)	107	321	107	199.6	99.8	99.8
Full crossing angle ( $\mu$ rad)	0	0	0	140	160	$\leq 100$
Energy spread (units $10^{-3}$ )	0.75	0.75	0.75	0.11	0.11	0.11
Bunch length (cm)	30	30	30	9.7	<i>p</i> : 9 <i>Pb</i> : 9.7	7.9
Beam radius ( $10^{-6}$ m)	135	145	145	50	23	15.9
Free space at interaction point (m)	16	16	16	38	38	38
Initial luminosity decay time, $-L/(dL/dt)$ (hr)	1.2	1.8	1.5	5	$\approx 8$	$10.9 - 3.6^{\ddagger}$
Turn-around time (min)	100	145	145	180	$\approx 200$	$\approx 180$
Injection energy (TeV)	0.011 TeV/n	0.011 TeV/n	0.012 TeV/n	0.177 TeV/n	<i>p</i> : 0.45 TeV/n <i>Pb</i> : 0.177 TeV/n	0.177 TeV/n
Transverse emittance ( $10^{-9}\pi$ rad-m)	23	23	25	1.0	0.9	0.5
$\beta^*$ , ampl. function at interaction point (m)	0.75	0.9	0.85	1.0	0.6	0.5
Beam-beam tune shift per crossing (units $10^{-4}$ )	16	30	d: 21 Au: 17	3	4	2
RF frequency (MHz)	accel: 28 store: 197	accel: 28 store: 197	accel: 28 store: 197	400.8	400.8	400.8
Particles per bunch (units $10^{10}$ )	0.13	0.45	d: 10 Au: 0.1	0.011 (r.m.s.)	<i>p</i> : 1.1 <i>Pb</i> : 0.008	0.007
Bunches per ring per species	111	37	95	356	560	592
Average beam current per species (mA)	145	60	d: 119 Au: 94	6.85	<i>p</i> : 11 <i>Pb</i> : 9.9	6.12
Circumference (km)	3.834			26.659		
Interaction regions	6 total, 2 high $\mathcal{L}$			1 dedicated +2	3 high $\mathcal{L}$ +1	1 dedicated +2
Magnetic length of dipole (m)	9.45			14.3		
Length of standard cell (m)	29.7			106.90		
Phase advance per cell (deg)	93	84	d: 84 Au: 93	90		
Dipoles in ring	192 per ring + 12 common			1232 main dipoles		
Quadrupoles in ring	246 per ring			482 2-in-1 24 1-in-1		
Magnet type	s.c. $\cos\theta$ cold iron			s.c. 2 in 1 cold iron		
Peak magnetic field (T)	3.5			8.3		

$\ddagger$ For 1 - 3 experiments.