

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

Updated in early 2008 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). For existing (future) colliders the latest achieved (design) values are given. Quantities are, where appropriate, r.m.s.;  $H$  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	2008	1994	1989	2008	1999
Physics end date	—	—	2005	—	2008
Maximum beam energy (GeV)	1.0	6	2.2	1.89 (2.3 max)	0.700
Luminosity ( $10^{30}$ cm <sup>-2</sup> s <sup>-1</sup> )	100	20	12.6 at 1.843 GeV/beam 5 at 1.55 GeV/beam	1000	150 (500 achievable)
Time between collisions ( $\mu$ s)	0.04	0.6	0.8	0.008	0.0027
Full crossing angle ( $\mu$ rad)	0	0	0	$2.2 \times 10^4$	$(2.5 \text{ to } 3.2) \times 10^4$
Energy spread (units $10^{-3}$ )	0.64	1	0.58 at 2.2 GeV	0.52	0.40
Bunch length (cm)	4	5	$\approx 5$	1.3	low current: 1 high current: 3
Beam radius ( $10^{-6}$ m)	125 (round)	$H$ : 1000 $V$ : 30	$H$ : 890 $V$ : 37	$H$ : 380 $V$ : 5.7	$H$ : 800 $V$ : 4.8
Free space at interaction point (m)	$\pm 1$	$\pm 2$	$\pm 2.15$	$\pm 0.63$	$\pm 0.40$
Luminosity lifetime (hr)	continuous	2	7–12	1.5	0.7
Turn-around time (min)	continuous	18	32	26	0.8 (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	$H$ : 300 $V$ : 1
$\beta^*$ , 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	$H$ : 0.25 $V$ : 0.009
Beam-beam tune shift per crossing (units $10^{-4}$ )	$H$ : 750 $V$ : 750	500	350	400	250
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	4.8	$e^-$ : 3.3 $e^+$ : 2.4
Bunches per ring per species	1	2	1	93	120 (incl. 10 bunch gap)
Average beam current per species (mA)	150	80	40 at 2 GeV 22 at 1.55 GeV	910	$e^-$ : 1800 $e^+$ : 1300
Circumference or length (km)	0.024	0.366	0.2404	0.23753	0.098
Interaction regions	2	1	2	1	2
Magnetic length of dipole (m)	1.2	2	1.6	Outer ring: 1.6 Inner ring: 1.41	1
Length of standard cell (m)	12	7.2	6.6	Outer ring: 6.6 Inner ring: 6.2	12
Phase advance per cell (deg)	$H$ : 738 $V$ : 378	65	$\approx 60$	60–90 no standard cell	360
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	1.7

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

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	CESR (Cornell)	CESR-C (Cornell)	KEKB (KEK)	PEP-II (SLAC)	LEP (CERN)	ILC (TBD)
Physics start date	1979	2002	1999	1999	1989	TBD
Physics end date	2002	2008	—	2008	2000	—
Maximum beam energy (GeV)	6	6	$e^- \times e^+ : 8 \times 3.5$	$e^- : 7-12$ (9.0 nominal) $e^+ : 2.5-4$ (3.1 nominal) (nominal $E_{cm} = 10.5$ GeV)	100 - 104.6	250 (upgrade-able to 500)
Luminosity ( $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ )	1280 at 5.3 GeV/beam	76 at 2.08 GeV/beam	17120	12069 (design: 3000)	24 at $Z^0$ 100 at $> 90$ GeV	$2 \times 10^4$
Time between collisions ( $\mu\text{s}$ )	0.014 to 0.22	0.014 to 0.22	0.00590 or 0.00786	0.0042	22	$0.3^{\ddagger}$
Full crossing angle ( $\mu$ rad)	$\pm 2000$	$\pm 3300$	$\pm 11000^{\dagger}$	0	0	14000
Energy spread (units $10^{-3}$ )	0.6 at 5.3 GeV/beam	0.82 at 2.08 GeV/beam	0.7	$e^-/e^+ : 0.61/0.77$	0.7 $\rightarrow$ 1.5	1
Bunch length (cm)	1.8	1.2	0.65	$e^-/e^+ : 1.1/1.0$	1.0	0.03
Beam radius ( $\mu\text{m}$ )	$H : 460$ $V : 4$	$H : 340$ $V : 6.5$	$H : 110$ $V : 1.9$	$H : 157$ $V : 4.7$	$H : 200 \rightarrow 300$ $V : 2.5 \rightarrow 8$	$H : 0.639$ $V : 0.0057$
Free space at interaction point (m)	$\pm 2.2$ ( $\pm 0.6$ to REC quads)	$\pm 2.2$ ( $\pm 0.3$ to PM quads)	$+0.75/-0.58$ ( $+300/-500$ ) mrad cone	$\pm 0.2$ , $\pm 300$ mrad cone	$\pm 3.5$	$\pm 3.5$
Luminosity lifetime (hr)	2-3	2-3	continuous	continuous	20 at $Z^0$ 10 at $> 90$ GeV	n/a
Turn-around time (min)	5 (topping up)	1.5 (topping up)	continuous	continuous	50	n/a
Injection energy (GeV)	1.8-6	1.5-6	$e^-/e^+ : 8/3.5$	2.5-12	22	n/a
Transverse emittance ( $\pi$ rad-nm)	$H : 210$ $V : 1$	$H : 120$ $V : 3.5$	$e^- : 24$ ( $H$ ), 0.61 ( $V$ ) $e^+ : 18$ ( $H$ ), 0.56 ( $V$ )	$e^- : 48$ ( $H$ ), 1.5 ( $V$ ) $e^+ : 24$ ( $H$ ), 1.5 ( $V$ )	$H : 20-45$ $V : 0.25 \rightarrow 1$	$H : 0.02$ $V : 8 \times 10^{-5}$ (at 250 GeV)
$\beta^*$ , amplitude function at interaction point (m)	$H : 1.0$ $V : 0.018$	$H : 0.94$ $V : 0.012$	$e^- : 0.56$ ( $H$ ), 0.0059 ( $V$ ) $e^+ : 0.59$ ( $H$ ), 0.0065 ( $V$ )	$e^- : 0.50$ ( $H$ ), 0.012 ( $V$ ) $e^+ : 0.50$ ( $H$ ), 0.012 ( $V$ )	$H : 1.5$ $V : 0.05$	$H : 0.02$ $V : 0.0004$
Beam-beam tune shift per crossing (units $10^{-4}$ )	$H : 250$ $V : 620$	$e^- : 420$ ( $H$ ), 280 ( $V$ ) $e^+ : 410$ ( $H$ ), 270 ( $V$ )	$e^- : 750$ ( $H$ ), 560 ( $V$ ) $e^+ : 1150$ ( $H$ ), 1010 ( $V$ )	$e^- : 703$ ( $H$ ), 498 ( $V$ ) $e^+ : 510$ ( $H$ ), 727 ( $V$ )	830	n/a
RF frequency (MHz)	500	500	508.887	476	352.2	1300
Particles per bunch (units $10^{10}$ )	1.15	4.7	$e^-/e^+ : 6.1/7.5$	$e^-/e^+ : 5.2/8.0$	45 in collision 60 in single beam	2
Bunches per ring per species	9 trains of 5 bunches	8 trains of 3 bunches	1389	1732	4 trains of 1 or 2	2625
Average beam current per species (mA)	340	72	$e^-/e^+ : 1330/1650$	$e^-/e^+ : 1960/3026$	4 at $Z^0$ 4 $\rightarrow$ 6 at $> 90$ GeV	9 (in pulse)
Beam polarization (%)	—	—	—	—	55 at 45 GeV 5 at 61 GeV	$e^- : > 80\%$ $e^+ : > 60\%$
Circumference or length (km)	0.768	0.768	3.016	2.2	26.66	31
Interaction regions	1	1	1	1	4	1
Magnetic length of dipole (m)	1.6-6.6	1.6-6.6	$e^-/e^+ : 5.86/0.915$	$e^-/e^+ : 5.4/0.45$	11.66/pair	n/a
Length of standard cell (m)	16	16	$e^-/e^+ : 75.7/76.1$	15.2	79	n/a
Phase advance per cell (deg)	45-90 (no standard cell)	45-90 (no standard cell)	450	$e^-/e^+ : 60/90$	102/90	n/a
Dipoles in ring	86	84	$e^-/e^+ : 116/112$	$e^-/e^+ : 192/192$	3280+24 inj. + 64 weak	n/a
Quadrupoles in ring	101 + 4 s.c.	101 + 4 s.c.	$e^-/e^+ : 452/452$	$e^-/e^+ : 290/326$	520+288 + 8 s.c.	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	$e^-/e^+ : 0.25/0.72$	$e^-/e^+ : 0.18/0.75$	0.135	n/a

$^{\dagger}$ KEKB is operating with crab crossing since February 2007.

$^{\ddagger}$ Time between bunch trains: 200ms.

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

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	HERA (DESY)	TEVATRON* (Fermilab)	RHIC (Brookhaven)				LHC (CERN)	
	1992	1987	2001	2000	2004	2002	2008	2009
Physics start date	1992	1987	2001	2000	2004	2002	2008	2009
Physics end date	2007	—	—				—	
Particles collided	$ep$	$p\bar{p}$	$pp$ (pol.)	Au Au	Cu Cu	d Au	$pp$	Pb Pb
Maximum beam energy (TeV)	$e$ : 0.030 $p$ : 0.92	0.980	0.1 60% pol	0.1 TeV/n	0.1 TeV/n	0.1 TeV/n	7.0	2.76 TeV/n
Luminosity ( $10^{30}$ cm $^{-2}$ s $^{-1}$ )	75	286	35 (pk) 20 (ave)	0.0030 (pk) 0.0012 (ave)	0.020 (pk) 0.0008 (ave)	0.23 (pk) 0.11 (ave)	$1.0 \times 10^4$	$1.0 \times 10^{-3}$ ( $5.4 \times 10^{-5}$ ) <sup>†</sup>
Time between collisions (ns)	96	396	107	107	321	107	24.95	99.8 (1347) <sup>†</sup>
Full crossing angle ( $\mu$ rad)	0	0	0				$\approx 300$	$\leq 100$ (0) <sup>†</sup>
Energy spread (units $10^{-3}$ )	$e$ : 0.91 $p$ : 0.2	0.14	0.45	0.75	0.75	0.65	0.113	0.11
Bunch length (cm)	$e$ : 0.83 $p$ : 8.5	$p$ : 50 $\bar{p}$ : 45	100	30	30	25	7.55	7.94
Beam radius ( $10^{-6}$ m)	$e$ : 280( $H$ ), 50( $V$ ) $p$ : 265( $H$ ), 50( $V$ )	$p$ : 28 $\bar{p}$ : 16	165 ( $\beta^*=1$ m)	145 ( $\beta^*=1$ m)	145 ( $\beta^*=0.9$ m)	155 ( $\beta^*=2$ m)	16.6	15.9 (22.5) <sup>†</sup>
Free space at interaction point (m)	$\pm 2$	$\pm 6.5$	16				38	38
Initial luminosity decay time, $-L/(dL/dt)$ (hr)	10	6 (average)	3.9	1.5	1.8	1.8	14.9	10.9 - 3.6 <sup>‡</sup> (22 - 7.5) <sup>†‡</sup>
Turn-around time (min)	$e$ : 75, $p$ : 135	150	155	150	145	145	60	
Injection energy (TeV)	$e$ : 0.012 $p$ : 0.040	0.15	0.023	0.011 TeV/n	0.011 TeV/n	0.012 TeV/n	0.450	0.1774 TeV/n
Transverse emittance ( $10^{-9}\pi$ rad-m)	$e$ : 20( $H$ ), 3.5( $V$ ) $p$ : 5( $H$ ), 5( $V$ )	$p$ : 3 $\bar{p}$ : 1	28	26	23	28	0.5	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	$> 1.0$	$> 0.8$	$> 0.9$	$> 0.85$	0.55	0.5 (1.0) <sup>†</sup>
Beam-beam tune shift per crossing (units $10^{-4}$ )	$e$ : 190( $H$ ), 450( $V$ ) $p$ : 12( $H$ ), 9( $V$ )	$p$ : 120 $\bar{p}$ : 120	56	15	30	$d$ : 21 Au: 17	34	—
RF frequency (MHz)	$e$ : 499.7 $p$ : 208.2/52.05	53	accel: 28 store: 28	accel: 28 store: 197	accel: 28 store: 197	accel: 28 store: 197	400.8	400.8
Particles per bunch (units $10^{10}$ )	$e$ : 3 $p$ : 7	$p$ : 26 $\bar{p}$ : 9	13.5	0.11	0.45	$d$ : 10 Au: 0.1	11.5	0.007
Bunches per ring per species	$e$ : 189 $p$ : 180	36	111	103	37	95	2808	592 (62) <sup>†</sup>
Average beam current per species (mA)	$e$ : 40 $p$ : 90	$p$ : 70 $\bar{p}$ : 24	187	112	60	$d$ : 119 Au: 94	584	6.12 (0.641) <sup>†</sup>
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 $\mathcal{L}$				2 high $\mathcal{L}$ +1	1 dedicated +2
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			$d$ : 84 Au: 93	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:  $25 \times 10^{10}$  hr $^{-1}$ ; max. no. of  $\bar{p}$  stored:  $3.1 \times 10^{12}$  (Accumulator),  $4.6 \times 10^{12}$  (Recycler).

<sup>†</sup> Numbers in parentheses refer to settings for "Early" PbPb running.

<sup>‡</sup> For 1 - 3 experiments.