

32. High-Energy Collider Parameters

High-Energy Collider Parameters: e^+e^- Colliders (I)

Table 32.1: Updated in March 2026 with numbers received from representatives of the colliders (contact E. Pianori, LBNL). The table shows the parameter values achieved by December 2025. 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, 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 (2.474 max)	0.510
Delivered integrated luminosity per exp. (fb ⁻¹)	1	0.05	0.11	53.5	≈ 4.7 in 2001-2007 ≈ 2.7 w/crab-waist ≈ 6.8 2014-2018* ≈ 0.4 2021-2022† ≈ 1.1 2023-2024‡
Luminosity (10 ³⁰ cm ⁻² s ⁻¹)	90 at 890 MeV 42 at 550 MeV 4 at 300 MeV 0.4 at 200 MeV	20	12.6 at 1.843 GeV 5 at 1.55 GeV	1096	453
Time between collisions (μs)	0.04	0.6	0.8	0.006	0.0027
Full crossing angle (μ rad)	0	0	0	2.2 × 10 ⁴	5 × 10 ⁴
Energy spread (units 10 ⁻³)	0.71	1	0.58 at 2.2 GeV	0.52	0.40
Bunch length (cm)	4	5	≈ 5	1.35	low current: 1 at 15mA: 2
Beam radius (10 ⁻⁶ m)	125 (round)	H:1000 V:30	H:890 V:37	H:347 V:4.5	H:260 V:4.8
Free space at interaction point (m)	±0.5	±2	±2.15	±0.63	±0.295
Luminosity lifetime (hr)	continuous	2	7–12	1.5	0.2
Turn-around time (min)	continuous	18	32	4 (topping up)	2 (topping up)
Injection energy (GeV)	on energy (0.16–1.0)	1.8	1.55	on energy	on energy
Transverse emittance (10 ⁻⁹ m)	H:150 V:150	H:200 V:20	H:660 V:28	H:121 V:1.56	H:260 V:2.6
β*, amplitude function at interaction point (m)	H:0.04 - 0.11 V:0.04 - 0.11	H:0.75 V:0.05	H:1.2 V:0.05	H:1.0 V:0.0135	H:0.26 V:0.009
Beam-beam tune shift per crossing (units 10 ⁻⁴)	1100 at 890 MeV	500	350	383	440/894 (crab-waist run/test)
RF frequency (MHz)	172	180	199.53	499.8	368.667
Particles per bunch (units 10 ¹⁰)	12	15	20 at 2 GeV 11 at 1.55 GeV	3.8	e ⁻ : 3.2 e ⁺ : 2.1
Bunches per ring per species	1	2	1	119	100 to 110 (120 buckets)
Average beam current per species (mA)	240	80	40 at 2 GeV 22 at 1.55 GeV	910	e ⁻ : 1250 e ⁺ : 800
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)	1.1	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:745 V:385	65	≈ 60	60–90 non-standard cells	—
Dipoles in ring	8	78	40 + 4 weak	84 + 8 weak	8
Quadrupoles in ring	24 + 4 s.c.	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

*KLOE-2

†SIDDHARTINO

‡SIDDHARTA-2

High-Energy Collider Parameters: e^+e^- Colliders (II)

Table 32.2: Updated in March 2020 with numbers received from representatives of the colliders (contact E. Pianori, LBNL). The table shows the parameter values achieved. 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. ILC and CLIC parameters are documented in the Accelerator physics of colliders review.

	CESR (Cornell)	CESR-C (Cornell)	LEP (CERN)	SLC (SLAC)
Physics start date	1979	2002	1989	1989
Physics end date	2002	2008	2000	1998
Maximum beam energy (GeV)	6	6	100 - 104.6	50
Delivered integrated luminosity per experiment (fb^{-1})	41.5	2.0	0.221 at Z peak 0.501 at 65 – 100 GeV 0.275 at >100 GeV	0.022
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	2.5
Time between collisions (μs)	0.014 to 0.22	0.014 to 0.22	22	8300
Full crossing angle (μ rad)	± 2000	± 3300	0	0
Energy spread (units 10^{-3})	0.6 at 5.3 GeV	0.82 at 2.08 GeV	0.7→1.5	1.2
Bunch length (cm)	1.8	1.2	1.0	0.1
Beam radius (μm)	H:460 V:4	H:340 V:6.5	H:200→300 V:2.5→8	H:1.5 V:0.5
Free space at interaction point (m)	± 2.2 (± 0.6 to REC quads)	± 2.2 (± 0.3 to PM quads)	± 3.5	± 2.8
Luminosity lifetime (hr)	2–3	2–3	20 at Z peak 10 at > 90 GeV	—
Turn-around time (min)	5 (topping up)	1.5 (topping up)	50	120 Hz (pulsed)
Injection energy (GeV)	1.8–6	1.5–6	22	45.64
Transverse emittance (10^{-9} m)	210 1	120 3.5	H:20–45 V:0.25→1	H:0.5 V:0.05
β^* , amplitude function at interaction point (m)	1.0 0.018	0.94 0.012	1.5 0.05	0.0025 0.0015
Beam-beam tune shift per crossing (10^{-4}) or disruption	250 620	e^- : 420 (H), 280 (V) e^+ : 410 (H), 270 (V)	830	0.75 (H) 2.0 (V)
RF frequency (MHz)	500	500	352.2	2856
Particles per bunch (units 10^{10})	1.15	4.7	45 in collision 60 in single beam	4.0
Bunches per ring per species	9 trains of 5 bunches	8 trains of 3 bunches	4 trains of 1 or 2	1
Average beam current per species (mA)	340	72	4 at Z peak 4→6 at > 90 GeV	0.0008
Beam polarization (%)	—	—	55 at 45 GeV 5 at 61 GeV	e^- : 80
Circumference or length (km)	0.768	0.768	26.66	1.45 +1.47
Interaction regions	1	1	4	1
Magnetic length of dipole (m)	1.6–6.6	1.6–6.6	11.66/pair	2.5
Length of standard cell (m)	16	16	79	5.2
Phase advance per cell (deg)	45–90 (no standard cell)	45–90 (no standard cell)	102/90	108
Dipoles in ring	86	84	3280 + 24 inj. + 64 weak	460+440
Quadrupoles in ring	101 + 4 s.c.	101 + 4 s.c.	520 + 288 + 8 s.c.	—
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	0.597

High-Energy Collider Parameters: ep , e^+e^- Colliders (III)

Table 32.3: Updated in March 2026 with numbers received from representatives of the colliders (contact E. Pianori, LBNL). The table shows the parameter values achieved by December 2025. Design parameters for SuperKEKEB may be found in our 2018 edition (Phys. Rev. **D98**, 030001 (2018)) 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.

	HERA (DESY)	KEKB (KEK)	PEP-II (SLAC)	SuperKEKB (KEK)
Physics start date	1992	1999	1999	2018
Physics end date	2007	2010	2008	—
Particles collided	ep	e^+e^-	e^+e^-	e^+e^-
Maximum beam energy (TeV)	e : 0.030 p : 0.92	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)	e^- : 7 e^+ : 4
Delivered integrated luminosity per exp. (fb^{-1})	0.8	1040	557	712
Luminosity ($10^{30} \text{ cm}^{-2}\text{s}^{-1}$)	75	21083	12069 (design: 3000)	5.1×10^4
Time between collisions (ns)	96	5.9 or 7.86	4.2	4.2
Full crossing angle (μ rad)	0	$\pm 11000^*$	0	± 41500
Energy spread (units 10^{-3})	e : 0.91 p : 0.2	e^-/e^+ : 0.67/0.73	e^-/e^+ : 0.61/0.77	e^-/e^+ : 0.64/0.81
Bunch length (cm)	e : 0.83 p : 8.5	0.65	e^-/e^+ : 1.1/1.0	e^-/e^+ : 0.6/0.6
Beam radius (μm)	e : 110 (H), 30 (V) p : 111 (H), 30 (V)	H: 124 (e^-), 117 (e^+) V: 1.9	157 4.7	e^- : 16.6 (H), 0.27 (V) e^+ : 15.5 (H), 0.27 (V)
Free space at interaction point (m)	± 2	+0.75/−0.58 (+300/−500) mrad cone	± 0.2 , ± 300 mrad cone	e^- : +1.20/−1.28 e^+ : +0.78/−0.73 (+300/−500) mrad cone
Initial luminosity decay time, $-L/(dL/dt)$ (hr)	10	continuous	continuous	continuous
Turn-around time (min)	e : 75, p : 135	continuous	continuous	continuous
Injection energy (GeV)	e : 12 p : 40	e^-/e^+ : 8.0/3.5 (nominal)	e^-/e^+ : 9.0/3.1 (nominal)	e^-/e^+ : 7/4
Transverse emittance (10^{-9} m)	e : 20 (H), 3.5 (V) p : 5 (H), 5 (V)	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^- : 4.6 (H), 0.05 (V) e^+ : 4.0 (H), 0.05 (V)
β^* , amplitude function at interaction point (m)	e : 0.6 (H), 0.26 (V) p : 2.45 (H), 0.18 (V)	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^- : 0.060 (H), 1×10^{-3} (V) e^+ : 0.060 (H), 1×10^{-3} (V)
Beam-beam tune shift per crossing (units 10^{-4})	e : 190 (H), 450 (V) p : 12 (H), 9 (V)	e^- : 1020 (H), 900 (V) e^+ : 1270 (H), 1290 (V)	e^- : 703 (H), 498 (V) e^+ : 510 (H), 727 (V)	e^- : 15 (H), 270 (V) e^+ : 20 (H), 360 (V)
RF frequency (MHz)	e : 499.7 p : 208.2/52.05	508.887	476	508.887
Particles per bunch (units 10^{10})	e : 3 p : 7	e^-/e^+ : 4.7/6.4	e^-/e^+ : 5.2/8.0	e^-/e^+ : 3.37/4.37
Bunches per ring per species	e : 189 p : 180	1585	1732	2346
Average beam current per species (mA)	e : 40 p : 90	e^-/e^+ : 1188/1637	e^-/e^+ : 1960/3026	e^-/e^+ : 1259/1632
Beam polarization (%)	—	—	—	—
Circumference or length (km)	6.336	3.016	2.2	3.016
Interaction regions	2 colliding beams 1 fixed target (e beam)	1	1	1
Magnetic length of dipole (m)	e : 9.185; p : 8.82	e^-/e^+ : 5.86/0.915	e^-/e^+ : 5.4/0.45	e^-/e^+ : 5.9/4.0
Length of standard cell (m)	e : 23.5 p : 47	e^-/e^+ : 75.7/76.1	15.2	e^-/e^+ : 75.7/76.1
Phase advance per cell (deg)	e : 60 p : 90	450	e^-/e^+ : 60/90	450
Dipoles in ring	e : 396 p : 416	e^-/e^+ : 116/112	e^-/e^+ : 192/192	e^-/e^+ : 116/112
Quadrupoles in ring	e : 580 p : 280	e^-/e^+ : 452/452	e^-/e^+ : 290/326	e^-/e^+ : 466/460
Peak magnetic field (T)	e : 0.274; p : 5	e^-/e^+ : 0.25/0.72	e^-/e^+ : 0.18/0.75	e^-/e^+ : 0.22/0.19

*KEKB was operated with crab crossing from 2007 to 2010.

 † With dynamic beam-beam effect.

High-Energy Collider Parameters: $\bar{p}p$, pp Colliders

Table 32.4: Updated in March 2026 with numbers received from representatives of the colliders (contact E. Pianori, LBNL). The table shows the parameter values achieved by December 2025. Parameters for the defunct $S\bar{p}p\bar{S}$ collider may be found in our 2002 edition (Phys. Rev. **D66**, 010001 (2002)). 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.

	TEVATRON* (Fermilab)	RHIC Brookhaven	LHC (CERN)			
			2009 (Run 1)	2015 (Run 2)	2022 (Run 3)	2030 (HL-LHC)
Physics start date	1987	2001	—			
Physics end date	2011	2026	—			
Particles collided	$p\bar{p}$	pp (polarized)	pp			
Maximum beam energy (TeV)	0.980	0.255 55% polarization	4.0	6.5	6.8	7.0
Max. delivered integrated luminosity per exp. (fb^{-1})	12	0.38 at 100 GeV 1.3 at 250/255 GeV	23.3 at 4.0 TeV 6.1 at 3.5 TeV	160	340	250/y
Luminosity ($10^{30} \text{ cm}^{-2} \text{ s}^{-1}$)	431	245 (pk) 160 (avg)	7.7×10^3	2.1×10^4	2.2×10^4 (leveled)	5.0×10^4 (leveled)
Time between collisions (ns)	396	107	49.90	24.95	24.95	24.95
Full crossing angle (μ rad)	0	0	290	$320 \rightarrow 260^\dagger$	$320 \rightarrow 240^\dagger$	500
Energy spread (units 10^{-3})	0.14	0.15	0.1445	0.11	0.11	0.11
Bunch length (cm)	p : 50 \bar{p} : 45	60	9.4	8	9.7	7.6
Beam radius (10^{-6} m)	p : 28 \bar{p} : 16	85	18.8	8.5^\ddagger	5.7^\ddagger	7^\ddagger
Free space at interaction point (m)	± 6.5	16	38	38	38	38
Initial luminosity decay time, $-L/(dL/dt)$ (hr)	6 (avg)	7.5	≈ 6	8.4	12 §	≈ 12 (leveled)
Turn-around time (min)	90	25	180	150	120 ¶	150
Injection energy (TeV)	0.15	0.023	0.450	0.450	0.450	0.450
Transverse emittance (10^{-9} m)	p : 3 \bar{p} : 1	11	0.59	0.29	0.22	0.33
β^* , ampl. function at interaction point (m)	0.28	0.65	0.6	$0.3 \rightarrow 0.25^\parallel$	$1.2/1.2 \rightarrow 0.5/0.15^{**}$	$1 \rightarrow 0.15^\parallel$
Beam-beam tune shift per crossing (units 10^{-4})	p : 120 \bar{p} : 120	73	72	45	137 §	104
RF frequency (MHz)	53	accel: 9 store: 28	400.8	400.8	400.8	400.8
Particles per bunch (units 10^{10})	p :26 \bar{p} :9	18.5	16	11	18	22
Bunches per ring per species	36	111	1380	2556 2544 (i.r. $1/5^{\dagger\dagger}$)	2460 (total) 2464 (i.r. $1/5^{\dagger\dagger}$)	2760 2748 (i.r. $1/5^{\dagger\dagger}$)
Average beam current per species (mA)	p :70 \bar{p} :24	257	400	510	800	1094
Circumference (km)	6.28	3.834	26.659			
Interaction regions	2 high \mathcal{L}	6 total, 2 high \mathcal{L}	4 total, 2 high \mathcal{L}			
Magnetic length of dipole (m)	6.12	9.45	14.3			
Length of standard cell (m)	59.5	29.7	106.90			
Phase advance per cell (deg)	67.8	84	90			
Dipoles in ring	774	192 per ring + 12 common	1232 main dipoles			
Quadrupoles in ring	216	246 per ring	482 2-in-1 24 1-in-1			
Magnet types	s.c., $\cos\theta$ warm iron	s.c., $\cos\theta$ cold iron	s.c., 2-in-1 cold iron			
Peak magnetic field (T)	4.4	3.5	8.3 ‡†			

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

† Variable crossing angle decreasing during the fill with the reduction in bunch population

‡ Minimum beam radius during levelling

§ Value at start of levelling

¶ Most likely value as observed in 2025

$^\parallel$ β^* levelling

** levelled, \times / \parallel values

†† Number of bunches colliding at the interaction regions (i.r.) 1 (ATLAS) and 5 (CMS).

‡† Value for design beam energy of 7 TeV.

High-Energy Collider Parameters: Heavy Ion Colliders

Table 32.5: Updated in March 2026 with numbers received from representatives of the collider (contact E. Pianori, LBNL) The table shows the parameter values achieved. For the LHC, only maximum values over all experiments per operational mode are provided. 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)		
Physics start date	2000	2012 / 2018 / 2018 / 2012 / 2004 2021 / 2014 / 2002 / 2015 / 2015	2010	2012 / 2025	2017 / 2025
Physics end date	2026		—		
Particles collided	Au Au	U U / Zr Zr / Ru Ru / Cu Au / Cu Cu O O / h Au / d Au / p Au / p Al	Pb Pb	p-Pb / p-O	Xe-Xe / O-O / Ne-Ne
Max. beam energy (TeV/n)	0.1	0.1	2.68	p:6.5, Pb:2.56 p:6.8, O:3.4	2.72 / 2.68 / 2.68
$\sqrt{s_{NN}}$ (TeV)	0.2	0.2	5.36	8.16 / 9.62	5.44 / 5.36 / 5.36
Max. delivered int. nucleon-pair lumin. per exp. (pb^{-1})	2639 (at 100 GeV/n)	21 / 36 / 36.9 / 167 / 60 8.2 / 43 / 169 / 124 / 63 (all at 100 GeV/n)	125.5	40.4 / 0.77	0.05 / 2.4 / 0.4
Luminosity ($10^{27} \text{ cm}^{-2} \text{ s}^{-1}$)	pk: 15.5 avg: 8.7	pk: 0.4 / 4.8 / 3.8 / 12 / 21 450 / 170 / 850 / 880 / 7600 avg: 0.6 / 2.2 / 2.1 / 10 / 8 230 / 100 / 500 / 450 / 3800	6.4 (leveled)*	900 / 660	0.4 / 91 / 45
Time between collisions (ns)	107	107 / 107 / 107 / 107 / 321 107 / 107 / 107 / 107 / 107	49.9	99.8 / 149.7 / 998	5500 / 998 / 998
Full crossing angle ($\mu \text{ rad}$)	0	0	156	280 / 120	300 / 200 / 200
Energy spread (units 10^{-3})	0.75	0.75	0.13	0.11 / 0.16	0.11 / 0.16 / 0.16
Bunch length (cm)	30	30	9.6	p:9, Pb:11.5 p:9.9, O:9.9	11 / 9.9 / 9.9
Beam radius (10^{-6} m)	114 [†]	123 [†] / 87 [†] / 88 [†] / 163 [†] / 145 [†] 100 [†] / 136 [†] / 124 [†] / 147 [†] / 128 [†]	20	p: 19, Pb:19 p:10, O:16	12 / 15 / 18
Free space at inter. point (m)	16	16	38	38	38
Initial luminosity decay time, $-L/(dL/dt)$ (hr)	1	-0.35 [‡] / ∞^{\S} / ∞^{\S} / ∞^{\ddagger} / 1.8 ∞ / 0.6 / ∞^{\ddagger} / 0.5 / 0.25	∞	$\approx 2 / 7$	$\approx 6 / 17 / 25$
Turn-around time (min)	30	60 [¶] / 40 [¶] / 40 [¶] / 160 [¶] / 90 [¶] 45 [¶] / 45 [¶] / 90 [¶] / 60 [¶] / 50 [¶]	134	150 / 335	180 / 107 / N/A
Injection energy (TeV/n)	0.011	0.011	0.177	p:0.45, Pb:0.177 p:0.45, O:0.225	0.188 / 0.225 / 0.225
Transverse emittance (10^{-9} m)	19 [†]	22 [†] / 10.7 [†] / 11.2 [†] / 38 [†] / 23 [†] 12 [†] / 19 [†] / 22 [†] / 26 [†] / 21 [†]	0.80	p:0.29, Pb:0.29 p:0.18, O:0.51	0.3 / 0.46 / 0.62
β^* , ampl. function at interaction point (m)	0.7	0.7 / 0.7 / 0.7 / 0.7 / 0.9 0.7 / 1.0 / 0.7 / 0.8 / 0.8	0.5	0.5 / 1.0	0.4 / 0.5 / 0.5
Beam-beam tune shift per crossing (units 10^{-4})	39 [†]	6 [†] / 18 [†] / 21 [†] / 14 [†] , 14 [†] / 30 [†] / 34 [†] 42 [†] , 22 [†] / 40 [†] , 27 [†] / 53 [†] , 41 [†] / 80 [†] , 59 [†]	4.26	15 / 20.6	$\approx 10 / 10.6 / 6.8$
RF frequency (MHz)	accel: 28, store: 197		400.8	400.8 / 400.8	400.8 / 400.8 / 400.8
Particles per bunch (units 10^{10})	0.20	0.03 / 0.1 / 0.1 / 0.4, 0.13 / 0.45 / 0.85 4.5, 0.13 / 13, 0.20 / 22.5, 0.16 / 24, 1.1	0.0248 (r.m.s.)	p:2.6, Pb:0.022 p:3.0, O:0.39	0.027 / 0.29 / 0.20
Bunches per ring per species	111	111 / 111 / 111 / 111 / 37 106 / 111 / 111 / 111 / 111	1240	p:540, Pb:684 p:52, O:52	16 / 62 / 62
Average beam current per species (mA)	224	38 / 56 / 61 / 160, 138 / 60 / 95 125, 143 / 181, 213 / 313, 176 / 334, 199	45.4	p:16, Pb:15 p:2.21, O:2.83	0.54 / 2.56 / 2.20
Circumference (km)	3.834		26.659		
Interaction regions	6 total, 2 high \mathcal{L}		4 total, 3 high \mathcal{L}		
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 / 84 / 84 / 84 / 84 / 84 93 / 84(d), 93 / 84(p), 93 / 84(p), 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		

* Operational values in 2025 exceed HL-LHC projections from previous editions.

[†] Initial value, increases (decreases) without (with) cooling.

[‡] Negative or infinite decay time is effect of cooling.

[§] luminosity leveled to flat after set to target value, with cooling.

[¶] measured minimum, not theoretical.