Injection time for the collider rings

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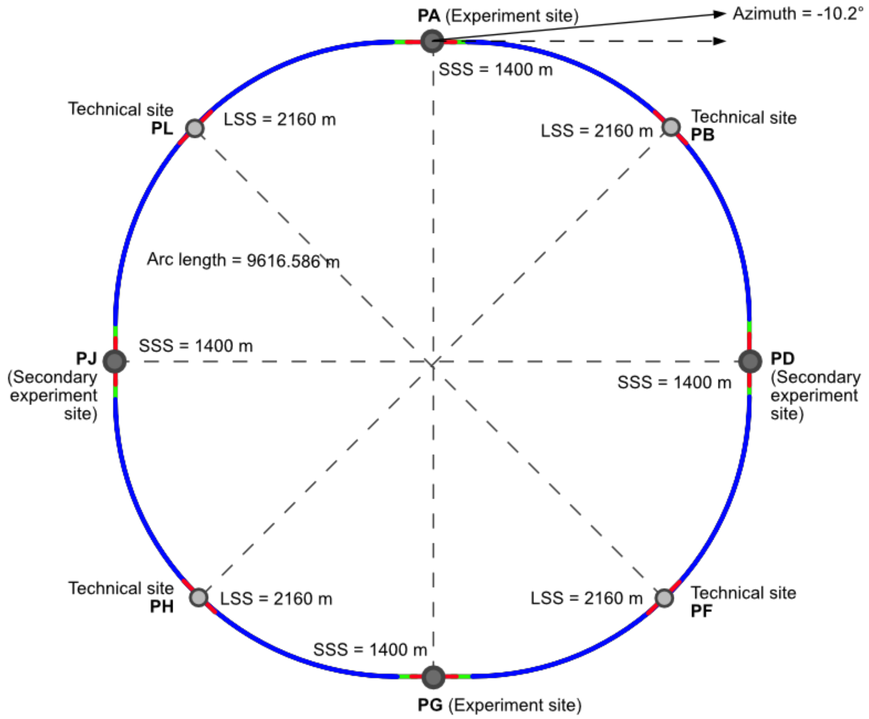
The 4 IP layout

- The new layout “31” series has been presented by J. Gutleber in the last optics meeting.
  - 8 surface sites, 4 IP.
  - complete period-4 + mirror symmetries.
- Let us choose “PA31-1.0” for the baseline, for the time being.
  - The adaptation to other variants, if necessary, will be minor.
  - An update “PA31-2.0” has been proposed with a change in the length of IP straights. The optics will adapt it soon with several other changes.



PA31-1.1 & 1.6 fallback alternatives

J. Gutleber

Scenario	PA31-1.0	PA31-1.1	PA31-1.6
Number of surface sites	8 (potential additional small access shafts at CERN or for ventilation at sites with long access tunnels, e.g. PF)		
Number of arc cells		42	
Arc cell length		213.04636573 m	
SSS@IP (PA, PD, PG, PJ)	1400 m	1400 m	1410 m
LSS@TECH (PB, PF, PH, PL)	2160 m	2100 m	2110 m
Azimuth @ PA (0 = East)	-10.75°	-10.45°	-10.2°
Sum of arc lengths		76 932.686 m	
Total length	91 172.686 m	90 932.686 m	91 052.686 m

“latest” (Nov. 24, 2022) parameters

FUTURE CIRCULAR COLLIDER

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	90.836848			
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		10000	880	248	40
Bunch population	[10^{11}]	2.43	2.91	2.04	2.37
Horizontal emittance ε_x	[nm]	0.71	2.16	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.32	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	100 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.563 / 53.600		100.565 / 98.595	
Energy spread (SR/BS) σ_δ	[%]	0.038 / 0.132	0.069 / 0.154	0.103 / 0.185	0.157 / 0.221
Bunch length (SR/BS) σ_z	[mm]	4.38 / 15.4	3.55 / 8.01	3.34 / 6.00	1.94 / 2.74
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	2.1 / 9.2
Harmonic number for 400 MHz		121648			
RF freuqeuncy (400 MHz)	MHz	400.793257			
Synchrotron tune Q_s		0.0370	0.0801	0.0328	0.0826
Long. damping time	[turns]	1168	217	64.5	18.5
RF acceptance	[%]	1.6	3.4	1.9	3.0
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y [a]		0.0023 / 0.135	0.011 / 0.125	0.014 / 0.131	0.093 / 0.140
Luminosity / IP	[10^{34}/cm^{2}s]	182	19.4	7.26	1.25
Lifetime (q + BS + lattice)	[sec]	840	–	< 1065	< 4062
Lifetime (lum)	[sec]	1129	1070	596	741

[a] incl. hourglass.

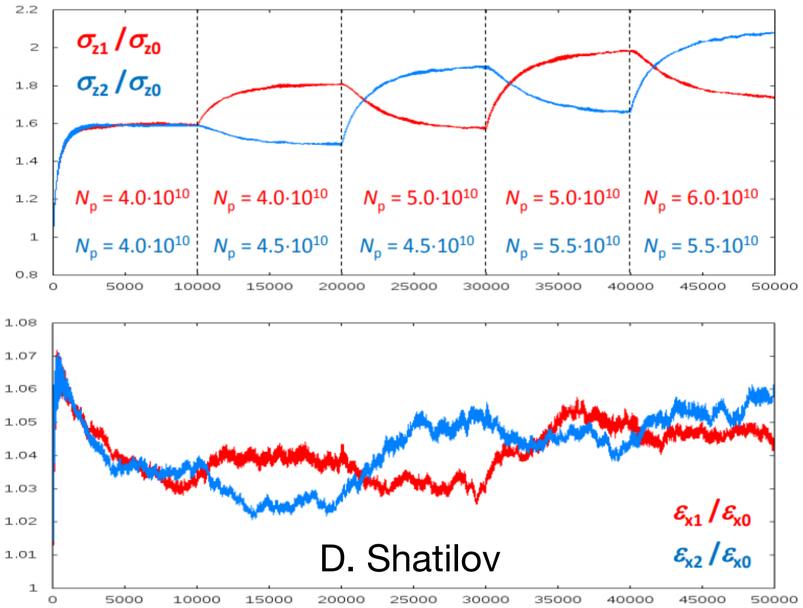
- 4 IP
- Reduced circumference
- further change of circumference is expected according to the placement study.

Injection time for each specie (20 GeV Linac, 4 IP)

- Bunch charge does not change from the linac through BR. It is accumulated only in the collider.
- Booster has a copy of collider bunch pattern, and injects all bunches to the collider in one turn.
- The booster operates alternatively on e+ & e-.
- For the injection from scratch, collider can accumulate the maximum bunch charge from linac up to 50% of the collision bunch charge.
- Beyond 50%, the injected bunch charge is limited by the flip-flop condition (6 - 10% of the collision bunch charge).
- Once the collision starts, the necessary bunch charge injected each time will be all different for each bunch, with 0 - 100% variation.

Injection

- From scratch:
  - “Bootstrap” (D. Shatilov) is necessary to maintain the balance between bunch charges of two beam.
    - Charge imbalance by ±5% (Z) - ±3% (others) is allowed between *four* colliding bunches.
- Top-up:
  - Maintain the charge imbalance within the allowed range.
    - Thus the amount of injected charge must be different bunch by bunch, with *0 to 100%* deviation, since the lifetime can be different for each bunch.
- Pilot bunches:
  - Esp. at Z and W, non-colliding pilot bunches have special rolls:
    - At the beginning of each fill, first the polarizing wigglers are turned on. Then pilot bunches are injected.
    - Wait for ≳ 1 hour to polarize pilot bunches.
    - Turn off wigglers
    - Start filling colliding bunches with the bootstrapping.
- Once one beam is aborted, it is not possible to maintain the other beam. The other beam must be aborted ASAP.



Injection time for each specie (20 GeV Linac, 4 IP)

	Z	WW	ZH	tt
Collider energy [GeV]	45.6	80	120	182.5
Collider & BR bunches / ring	10000	880	248	40
Collider particles / bunch N_b [10^{10}]	24.3	29.1	20.4	23.7
Allowable charge imbalance Δ [±%]	5	3		
Injector particles / bunch N_{max} [10^{10}]	≦ 3.0 *			
Bootstrap particles / bunch [10^{10}] $= 2N_b\Delta$	2.43	1.746	1.224	1.422
# of BR ramps (up to 1/2 stored current, with N_{max})	3	3	3	4
# of BR ramps (bootstrap with $2N_b\Delta$)	6	8	6	7
BR ramp time (up + down) t_{ramp} [s]	0.6	1.5	2.5	4.1
Linac bunches / pulse	2			
Linac pulses needed n_p	5000	440	124	20
Linac repetition frequency [Hz] f_{rep}	200	50		
Collider filling time from scratch [s]	**230.4**	**113.3**	**44.82**	**49.5**
Collider filling time for top-up [s] = $n_p/f_{rep} + t_{ramp}$	**25.6**	**10.3**	**4.98**	**4.5**
Lum. lifetime (2 IP) [s]	2258			
BS lifetime (2 IP) [s]	100000	100000	2130	8124
Lattice lifetime (2 IP) [s]	1260	2400	3000	3600
Collider lifetime (2 IP) τ_2 [s]	802.2	2140	465.7	885.7
Collider top-up interval (between e+ and e-)(2 IP) [s] = $\tau_2\Delta$	**40.1**	**64.2**	**13.971**	**26.571**
Lum. lifetime (4 IP) [s]	1129	1070	596	741
BS lifetime (4 IP) [s]	100000	100000	1065	4062
Lattice lifetime (4 IP) [s]	840	1600	2000	2400
Collider lifetime (4 IP) τ_4 [s]	479.3	1070	382.1	542.8
Collider top-up interval (between e+ and e-)(4 IP) [s] = $\tau_4\Delta$	**24.0**	**32.1**	**11.463**	**16.284**

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Injection time for each specie (w/ PBR, 4 IP)

	Z	WW	ZH	tt
Collider energy [GeV]	45.6	80	120	182.5
Collider & BR bunches / ring	10000	880	248	40
Collider particles / bunch [10^{10}] N_b	24.3	29.1	20.4	23.7
Injector particles / bunch [10^{10}]	≦ 3.0			
Bootstrap particles / bunch [10^{10}]	2.43	1.746	1.224	1.422
# of BR ramps (up to 1/2 stored current)	3	3	3	4
# of BR ramps (bootstrap)	6	8	6	7
BR ramp time (up + down) [s]	0.6	1.5	2.5	4.1
# of PBR cycles	14			7
PBR ramp time (up + flat top + down) [s]	0.5			
PBR bunches / ring	715	63	18	6
Linac bunches / pulse	2			
Linac pulses	358	32	9	3
Linac repetition frequency [Hz]	200	50		
PBR injection time [s]	1.79	0.64	0.18	0.06
Collider filling time from scratch [s]	**293.94**	**192.06**	**108.18**	**88.22**
Collider filling time for top-up [s]	**32.66**	**17.46**	**12.02**	**8.02**
Allowable charge imbalance Δ [±%]	5	3		
Lum. lifetime (2 IP) [s]	2258			
BS lifetime (2 IP) [s]	100000	100000	2130	8124
Lattice lifetime (2 IP) [s]	1260	2400	3000	3600
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