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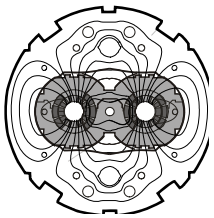

the
Large
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Engineering Specification

LHC BEAM PARAMETERS FOR FIRST PHYSICS RUN AT 5 TEV

Abstract

This document describes the LHC beam parameters for the 5 TeV physics run.

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History of Changes

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1	2008-06-27	All	Submission for engineering check.
2	2008-07-08		Approved version

Table of Contents

1. INTRODUCTION

The nominal parameters of the LHC (as quoted in the LHC design report) are challenging both for the machine and the experiments. A staged approach to commissioning the LHC with proton beams has been proposed in:

http://ab-div.web.cern.ch/ab-div/Conferences/Chamonix/Chamx2006/PAPERS/RB_1_01.pdf

This approach is aimed at finding a balance between robust operations (efficiency and machine protection) and satisfying the experiments (luminosity and event pileup). The number of bunches, bunch intensity and β^* are the key parameters varied throughout the period of commissioning to ensure safe and efficient operation. The physics energy will be determined by the performance of the magnets during hardware commissioning.

The LHC commissioning will be carried out in 4 stages, as shown in the following table.

Stage A	**Pilot physics run**	Physics aim 43x43 bunches; maximum 156x156 bunches; no crossing angle
Stage B	**Intermediate physics run**	Physics aim 75 ns bunch spacing; possible initial physics aim 96x96 bunches (bunch intensity 1 x 10^{10} protons); maximum aim 936x936 bunches (maximum 9 x 10^{10} protons per bunch). 250 µrad crossing angle.
Stage C	**25 ns run I**	Intensity per bunch 5 x 10^{10} protons (initial 1 x 10^{10}); physics aim 2808 x 2808 bunches. 285 µrad crossing angle.
Stage D	**25 ns run II**	Push towards nominal performance

Beam characteristics and performance levels in points 1 and 5 are summarised for the various stages in the following table.

Machine parameters		Stage A		Stage B		Stage C			Stage D
		Target	Limit	Target	Limit	Target	Limit		Nominal
spacing	ns	2021	566	75	75	25	25		25
bunch length	m	0.0755	0.0755	0.0755	0.0755	0.0755	0.0755		0.0755
crossing angle	urad	0	0	250	250	285	285		285
bunch intensity		4.00E+10	9.00E+10	4.00E+10	9.00E+10	5.00E+10	5.00E+10		1.15E+11
bunches		43	156	936	936	2808	2808		2808
energy	eV	7.00E+12	7.00E+12	7.00E+12	7.00E+12	7.00E+12	7.00E+12		7.00E+12
F		1	1	0.96	0.92	0.9	0.84		0.84
normalised emittance	cm	3.75E-04	3.75E-04	3.75E-04	3.75E-04	3.75E-04	3.75E-04		3.75E-04
beta*	cm	200	200	200	100	100	55		55
luminosity	/cm^{2}s	6.12E+30	1.12E+32	1.28E+32	1.24E+33	1.13E+33	1.91E+33		1.01E+34
total inel cross section	cm^2	6.00E-26	6.00E-26	6.00E-26	6.00E-26	6.00E-26	6.00E-26		6.00E-26
event rate per cross		0.76	3.85	0.73	7.09	2.14	3.63		19.18
protons per beam		1.72E+12	1.40E+13	3.74E+13	8.42E+13	1.40E+14	1.40E+14		3.23E+14
current per beam	mA	3.09E+00	2.53E+01	6.74E+01	1.52E+02	2.53E+02	2.53E+02		5.81E+02
energy per beam	Joules	1.93E+06	1.57E+07	4.19E+07	9.43E+07	1.57E+08	1.57E+08		3.62E+08
beam size	um	31.7	31.7	31.7	22.4	22.4	16.6		16.6

Installation of phase II collimators and full beam dump

The stages themselves consist of phases, shown for Stage A in the following table.

Phase A.1	**First turn**	Injection commissioning and threading
Phase A.2	**Circulating pilot**	Establish circulating beam, closed orbit, tunes, RF capture
Phase A.3	**450 GeV initial commissioning**	System commissioning (instrumentation, beam dump)
Phase A.4	**450 GeV optics**	Beta beating, dispersion, coupling, non-linear field quality, aperture
Phase A.5	**450 GeV, increasing intensity**	Prepare the LHC for unsafe beam
Phase A.6	**450 GeV, two beam operation**	
Phase A.7	**450 GeV, collisions**	
Phase A.8	**Snap-back and ramp**	Single beam
Phase A.9	**Top energy checks**	Single beam, 2 beams
Phase A.10	**Top energy, collisions**	
Phase A.11	**Squeeze**	Commissioning the Betatron squeeze in all IP's
Phase A.12	**Experimental magnets**	Beam commissioning with experimental magnets ON

The first commissioning run will be carried out at a lower-than-nominal energy in order to speed up the hardware commissioning by minimising the number of training quenches of the main dipoles. The selected energy is 5 TeV. The change in the value of the top energy has an impact on the set of beam parameters. Therefore, a review was performed and a new set of beam parameters proposed [1-4].

The revised beam parameters are reported in the next section for three scenarios within Stage A, namely

1. Collisions at 450 GeV of 2 bunches.
2. Collisions at 5 TeV of 43 bunches.
3. Collisions at 5 TeV of 156 bunches.

In the case of scenarios 2. and 3. various collision schedules can be given (see Ref. [5] for more details). The selected one is also given as a reference.

2. TABLES OF BEAM PARAMETERS

The key parameters for the scenario 1., i.e., collisions of 2 bunches at 450 GeV are reported in Table 1.

Table 1: Key parameters for scenario 1. In all cases full crossing angles are quoted.

Parameter	Unit	Injection		Collision	
Net crossing angle IP1 & IP5	μrad	0.00		0.00	
Crossing angle from spectrometer bump in IP2	μrad	0.00		0.00	
Crossing angle from external bump in IP2	μrad	0.00		0.00	
Net effective crossing angle IP2	μrad	0.00		0.00	
Crossing angle from spectrometer bump in IP8	μrad	0.00		0.00	
Crossing angle from external bump in IP8	μrad	0.00		0.00	
Net effective crossing angle IP8	μrad	0.00		0.00	
Separation IP1 & IP5	mm	5.00		0.00	
Transverse IP shift (crossing plane)	mm	0.00		0.00	
Separation IP2	mm	4.00		0.00	
Transverse IP shift (crossing plane)	mm	1.50		1.50	
Separation IP8	mm	4.00		0.00	
Transverse IP shift (crossing plane)	mm	2.00		2.00	
Beta * IP1 & IP5	m	11.00		11.00	
Beta * IP2	m	10.00		10.00	
Beta * IP8	m	10.00		10.00	
Crossing/Separation plane IP1		NA/H		NA/H	
Crossing/Separation plane IP2		NA/H		NA/H	
Crossing/Separation plane IP5		NA/V		NA/V	
Crossing/Separation plane IP8		NA/V		NA/V	
Energy	TeV	0.45		0.45	
Number of bunches		2		2	
Bunch intensity		1.00×10^{10}		1.00×10^{10}	
Longitudinal emittance (2σ)	eVs	0.50		0.50	
RF Voltage	MV	8	16	8	16
RMS bunch length	cm	8.57	7.09	8.57	7.09
Normalised transverse emittance (1σ)	μm	3.50		3.50	

A list of derived beam parameters for the scenario 1., i.e., collisions of 2 bunches at 450 GeV are reported in Table 2.

Table 2: Derived parameters for scenario 1 (due to zero crossing angle the two options for bunch length do not have any impact on the derived parameters).

Derived parameters	Unit	Injection	Collision
Protons per beam		2.00×10^{10}	2.00×10^{10}
Current per beam	mA	0.04	0.04
Stored energy per beam	MJ	0.001	0.001
Relativistic Gamma		479.60	479.60
Beam size IP1 & IP5	mm	0.283	0.283
Beam size IP2	mm	0.270	0.270
Beam size IP8	mm	0.270	0.270
Geometric factor IP1 & IP5			1.000
Geometric factor IP2			1.000
Geometric factor IP8			1.000
Number of bunches crossing in IP1 & IP5			2
Number of bunches crossing in IP2			1
Number of bunches crossing in IP8			1
Luminosity in IP1 & IP5	$cm^{-2}\ s^{-1}$		2.23×10^{26}
Luminosity in IP2	$cm^{-2}\ s^{-1}$		1.23×10^{26}
Luminosity in IP8	$cm^{-2}\ s^{-1}$		1.23×10^{26}
Events per crossing IP1 & IP5 (60 mbarn)			0.0006
Events per crossing IP2 (60 mbarn)			0.0007
Events per crossing IP8 (60 mbarn)			0.0007

The key parameters for the scenario 2., i.e., collisions of 43 bunches at 5 TeV are reported in Table 3.

Table 3: Key parameters for scenario 2. In all cases full crossing angles are quoted.

Parameter	Unit	Injection		Collision	
Net crossing angle IP1 & IP5	μrad	0.00		0.00	
Crossing angle from spectrometer bump in IP2	μrad	2177.78		196.00	
Crossing angle from external bump in IP2	μrad	0.00		0.00	
Net effective crossing angle IP2	μrad	2177.78		196.00	
Crossing angle from spectrometer bump in IP8	μrad	4200.00		378.00	
Crossing angle from external bump in IP8	μrad	0.00		0.00	
Net effective crossing angle IP8	μrad	4200.00		378.00	
Separation IP1 & IP5	mm	5.00		0.00	
Transverse IP shift (crossing plane)	mm	0.00		0.50	
Separation IP2	mm	4.00		0.00	
Transverse IP shift (crossing plane)	mm	1.50		0.00	
Separation IP8	mm	4.00		0.00	
Transverse IP shift (crossing plane)	mm	2.00		0.00	
Beta * IP1 & IP5	m	11.00		3.00	
Beta * IP2	m	10.00		10.00	
Beta * IP8	m	10.00		6.00	
Crossing/Separation plane IP1		NA/H		NA/H	
Crossing/Separation plane IP2		V/H		V/H	
Crossing/Separation plane IP5		NA/V		NA/V	
Crossing/Separation plane IP8		H/V		H/V	
Energy	TeV	0.45		5.00	
Number of bunches		43		43	
Bunch intensity		4.00×10^{10}		4.00×10^{10}	
Longitudinal emittance (2σ)	eVs	1.00*		1.00	
RF Voltage	MV	8	16	8	16
RMS bunch length	cm	13.19	10.51	6.49	5.41
Normalised transverse emittance (1σ)	μm	3.50		3.75	

Possible alternative collision schedules for the scenario 2., i.e., collisions of 43 bunches at 5 TeV are reported in Table 4 (see also Ref. [5] for more details).

Table 4: Collision schedules for scenario 2. The collision schedule retained for the parameters tables is the one in column “E”.

Alternative collision schedules	A	B	C	D	E
IP1	43	39	43	43	**43**
IP2	42	38	34	21	**4**
IP5	43	39	43	43	**43**
IP8	0	4	4	11	**19**

* This value represents the upper bound for the longitudinal emittance after filamentation occuring during the injection process.

A list of derived beam parameters for the scenario 2., i.e., collisions of 43 bunches at 5 TeV are reported in Table 5.

Table 5: Derived parameters for scenario 2 (due to non-zero crossing angle the two options for bunch length have an impact on the derived parameters).

Derived parameters	Unit	Injection		Collision	
Protons per beam		1.72×10^{12}		1.72×10^{12}	
Current per beam	mA	3.09		3.09	
Stored energy per beam	MJ	0.12		1.38	
Relativistic Gamma		479.60		5328.90	
Beam size IP1 & IP5	mm	0.283		0.046	
Beam size IP2	mm	0.270		0.084	
Beam size IP8	mm	0.270		0.065	
RMS bunch length	cm	13.19	10.51	6.49	5.41
Geometric factor IP1 & IP5				1.000	1.000
Geometric factor IP2				0.997	0.998
Geometric factor IP8				0.983	0.988
Number of bunches crossing in IP1 & IP5				43	
Number of bunches crossing in IP2				4	
Number of bunches crossing in IP8				19	
Luminosity in IP1 & IP5	$cm^{-2}\ s^{-1}$			2.92×10^{30}	2.92×10^{30}
Luminosity in IP2	$cm^{-2}\ s^{-1}$			8.12×10^{28}	8.12×10^{28}
Luminosity in IP8	$cm^{-2}\ s^{-1}$			6.33×10^{29}	6.36×10^{29}
Events per crossing IP1 & IP5 (60 mbarn)				0.36	0.36
Events per crossing IP2 (60 mbarn)				0.11	0.11
Events per crossing IP8 (60 mbarn)				0.18	0.18

A list of derived beam parameters related to damping and IBS for the scenario 2., i.e., collisions of 43 bunches at 5 TeV are reported in Table 6.

Table 6: Derived parameters for damping and IBS for scenario 2

IBS effects			
Longitudinal emittance growth time	h		44
Transverse emittance growth time	h		158
Synchrotron radiation effects			
Power radiated per proton	W		4.80×10^{-12}
Power radiated/m in arc	W/m		3.09×10^{-4}
Power radiated per ring	W		5.41
Critical energy of photons	eV		16.09
Longitudinal emittance damping time	h		35.35
Transverse emittance damping time	h		70.70

The key parameters for the scenario 3., i.e., collisions of 156 bunches at 5 TeV are reported in Table 7.

Table 7: Key parameters for scenario 3. In all cases full crossing angles are quoted.

Parameter	Unit	Injection		Collision	
Net crossing angle IP1 & IP5	μrad	0.00		0.00	
Crossing angle from spectrometer bump in IP2	μrad	2177.78		196.00	
Crossing angle from external bump in IP2	μrad	0.00		0.00	
Net effective crossing angle IP2	μrad	2177.78		196.00	
Crossing angle from spectrometer bump in IP8	μrad	4200.00		378.00	
Crossing angle from external bump in IP8	μrad	0.00		0.00	
Net effective crossing angle IP8	μrad	4200.00		378.00	
Separation IP1 & IP5	mm	5.00		0.00	
Transverse IP shift (crossing plane)	mm	0.00		0.50	
Separation IP2	mm	4.00		0.00	
Transverse IP shift (crossing plane)	mm	1.50		0.00	
Separation IP8	mm	4.00		0.00	
Transverse IP shift (crossing plane)	mm	2.00		0.00	
Beta * IP1 & IP5	m	11.00		3.00	
Beta * IP2	m	10.00		10.00	
Beta * IP8	m	10.00		6.00	
Crossing/Separation plane IP1		NA/H		NA/H	
Crossing/Separation plane IP2		V/H		V/H	
Crossing/Separation plane IP5		NA/V		NA/V	
Crossing/Separation plane IP8		H/V		H/V	
Energy	TeV	0.45		5.00	
Number of bunches		156		156	
Bunch intensity		9.00×10^{10}		9.00×10^{10}	
Longitudinal emittance (2σ)	eVs	1.00*		1.00	
RF Voltage	MV	8	16	8	16
RMS bunch length	cm	13.19	10.51	6.49	5.41
Normalised transverse emittance (1σ)	μm	3.50		3.75	

Possible alternative collision schedules for the scenario 3., i.e., collisions of 156 bunches at 5 TeV are reported in Table 8 (see also Ref. [5] for more details).

Table 8: Collision schedules for scenario 3. The collision schedule retained for the parameters tables is the one in column “C”.

Alternative collision schedules	A	B	C
IP1	156	156	**156**
IP2	152	76	**16**
IP5	156	156	**156**
IP8	0	36	**68**

* This value represents the upper bound for the longitudinal emittance after filamentation occuring during the injection process.

A list of derived beam parameters for the scenario 3., i.e., collisions of 156 bunches at 5 TeV are reported in Table 9.

Table 9: Derived parameters for scenario 3 (due to non-zero crossing angle the two options for bunch length have an impact on the derived parameters).

Derived parameters	Unit	Injection		Collision	
Protons per beam		1.40×10^{13}		1.40×10^{13}	
Current per beam	mA	25.26		25.26	
Stored energy per beam	MJ	1.01		11.25	
Relativistic Gamma		479.60		5328.90	
Beam size IP1 & IP5	mm	0.283		0.046	
Beam size IP2	mm	0.270		0.084	
Beam size IP8	mm	0.270		0.065	
RMS bunch length	cm	13.19	10.51	6.49	5.41
Geometric factor IP1 & IP5				1.000	1.000
Geometric factor IP2				0.997	0.998
Geometric factor IP8				0.983	0.988
Number of bunches crossing in IP1 & IP5				156	
Number of bunches crossing in IP2				16	
Number of bunches crossing in IP8				68	
Luminosity in IP1 & IP5	$cm^{-2}\ s^{-1}$			5.36×10^{31}	5.36×10^{31}
Luminosity in IP2	$cm^{-2}\ s^{-1}$			1.64×10^{30}	1.64×10^{30}
Luminosity in IP8	$cm^{-2}\ s^{-1}$			1.15×10^{31}	1.15×10^{31}
Events per crossing IP1 & IP5 (60 mbarn)				1.83	1.83
Events per crossing IP2 (60 mbarn)				0.55	0.55
Events per crossing IP8 (60 mbarn)				0.90	0.90

A list of derived beam parameters related to damping and IBS for the scenario 3., i.e., collisions of 156 bunches at 5 TeV are reported in Table 10.

Table 10: Derived parameters for damping and IBS for scenario 3

IBS effects			
Longitudinal emittance growth time	h		20
Transverse emittance growth time	h		70
Synchrotron radiation effects			
Power radiated per proton	W		4.80×10^{-12}
Power radiated/m in arc	W/m		6.96×10^{-4}
Power radiated per ring	W		12.18
Critical energy of photons	eV		16.09
Longitudinal emittance damping time	h		35.35
Transverse emittance damping time	h		70.70

3. REFERENCES

[1] M. Giovannozzi, “Beam Parameters for 5 TeV Operation in 2008”, 43th LHC Commissioning Working Group meeting, 8 April 2008.

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[3] R. Bailey, “Pilot run beam parameters and filling schemes“ 9th LHC Programme Coordination meeting, 6 May 2008.

[4] R. Bailey, “Parameters and Performance for 2008 and 2009“ 90th LHC Technical Committee meeting, 7 May 2008.

[5] M. Ferro Luzzi, W. Herr, T. Pieloni, to be published.