Putting the beams into collision

Summary with links to existing material + comments

http://lhccwg.web.cern.ch/lhccwg/ and http://lhc-commissioning.web.cern.ch

2008 commissioning procedures - remain valid

Stage A, pilot physics run, 43x43 - 156x156 ; no crossing angle needed
LTC 10/10/2007 Phase A.7 - Collisions at 450 GeV ; EDMS
LTC 20/06/2007 Phase A.10 - Top energy: collisions ; EDMS

Stage B, with crossing angle
used to be 75 ns with up to 936 bunches;
now 50 ns with 144 - 432 bunches in 2009/2010 run - update commissioning pages
principle see LHC-PROJECT-NOTE-415 from July 2008

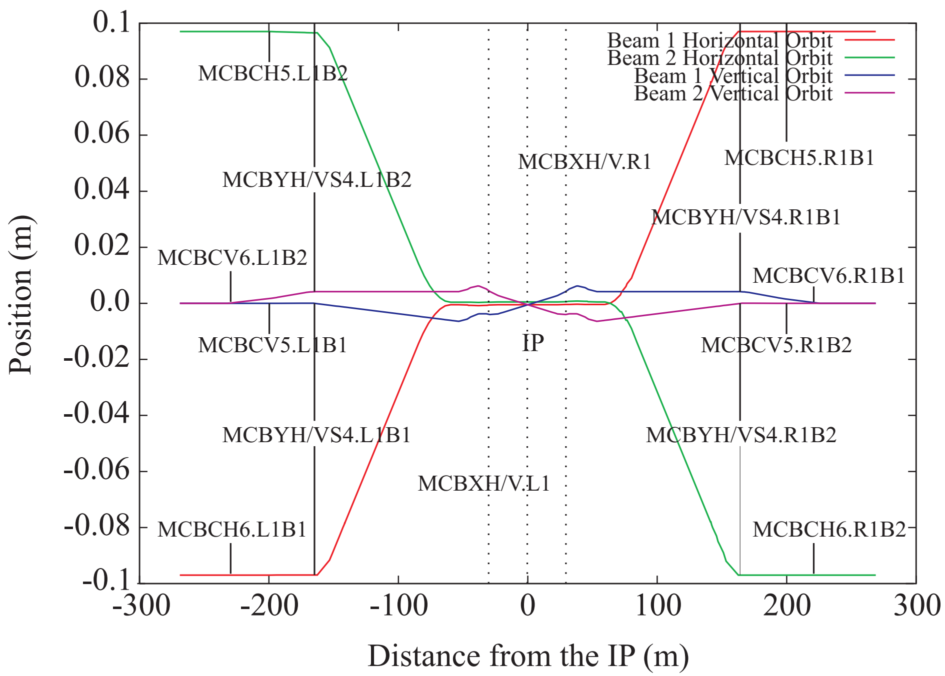
2009 / 2010 run :
Chamonix 2009 with W. Herr *Options and preferences for proton running* slides and in proceedings

other links and refs : LHC Programme Coordination LPC wikis LHCOP Separation scans
my earlier presentation : LHCCWG 06/09/2006

“LHC BEAM PARAMETERS FOR FIRST PHYSICS RUN AT 5 TEV”, LHC-OP-ES-0011, EDMS

IP-bumps

presented in this WG by Simon White on 21/04/2009



MCBX in triplet - important for crossing angle and aperture at injection

collapse bump by combination of MCBC, MCBY and MCBX or ramp down MCBX first

Separation scans, optimization with MCBC, MCBY on one beam

How (and why) do we use MCBX for crossing angles and separation bumps slides by W. Herr LCU meeting 21/04/2009

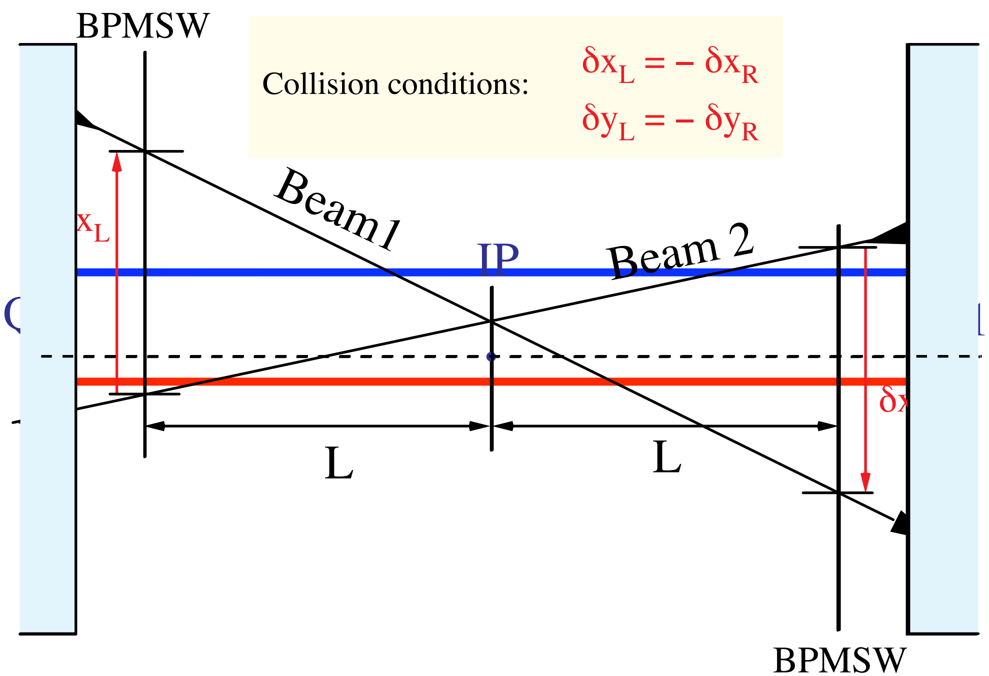
Get LHC beams colliding : BPM resolution

measured with special (beam-) directional stripline couplers BPMSW

at about 21 m L/R from IP in front of Q1,   2 each in IR

adjust orbits such, that the beam 1 and 2 difference left/right of the IP is the same

beams must then collide. This is independent of mechanical offsets and crossing angles



Beam sizes at the IP @ 5 TeV

β* [m]	σ* [μm]
11	88.0
3	45.9
1	26.5

$\frac{\delta x}{\sigma_x}$	$\frac{\delta y}{\sigma_y}$	$\mathcal{L}/\mathcal{L}_0$
0	0	1.0000
0.1	0	0.9975
0.2	0	0.9901
0.3	0	0.9778
0.4	0	0.9608
0.5	0	0.9394
0.5	0.5	0.8825
1	0	0.7788
1	1	0.6065
2	0	0.3679
2	2	0.1353

Both beams move with MCBX.   Optimisation in physics always on single beam with MCBC, MCBY

Expected resolution for small separation and 0 crossing angle ; in each plane.

~ 50 μm using selected, paired electronics ; otherwise ~ 100 - 200 μm
beam 1 and beam 2 have separate electronics

~ 10 μm with extra BPMWF button pick-ups. Installed in 1&5, for large bunch spacing,

EDMS doc 976179

Resolution each plane

$$\delta_{\rm IP} = \sigma_{\rm BPM}$$

Some beam parameters

Beam-beam tune shift parameter ξ
for head-on collisions
depends on intensity
(not energy, β*)

LHC round beams, const ε_N $\sigma_{x,y} = \sqrt{\beta_{x,y}\,\epsilon_N/\gamma}$

$$\xi = \frac{r_c\,N}{4\pi\,\epsilon_N}$$

N	ξ
5×10^9	0.000163
4×10^{10}	0.00130
1.15×10^{11}	0.00374

at the design emittance

Beam sizes and initial separation
at the IP @ 5 TeV

β* [m]	**σ* [μm]**	**n_σ**
11	**88.0**	**11.4**
3	**45.9**	**21.8**
1	**26.5**	**37.7**

For a separation of d = ± 0.5mm
n_σ = 2 d / **σ*** full separation in units of σ

5 TeV. Lumi reduction by
±142.5μrad crossing angle

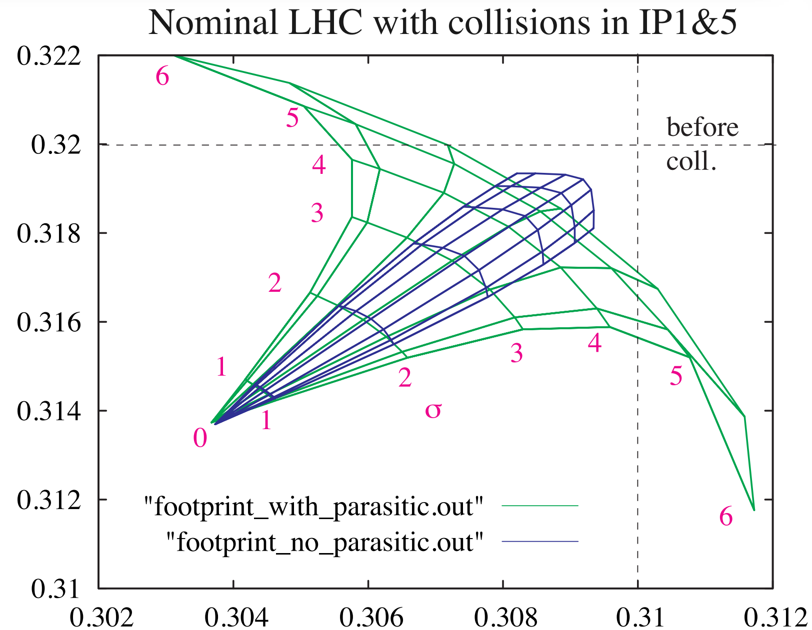
β* [m]	**σ* [μm]**
11	**1.0075**
3	**1.027**
1	**1.079**

Hourglass effect
for nominal σ_z = 7.55 cm

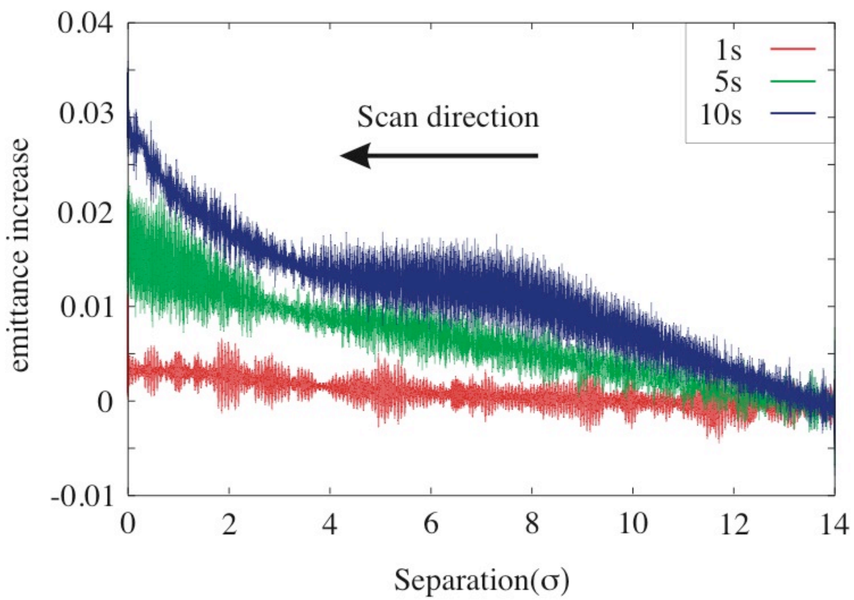
β^*	r	$H(r)$
10.	132.	0.999972
2.	26.5	0.999289
1.	13.2	0.997174
0.55	7.28	0.990833

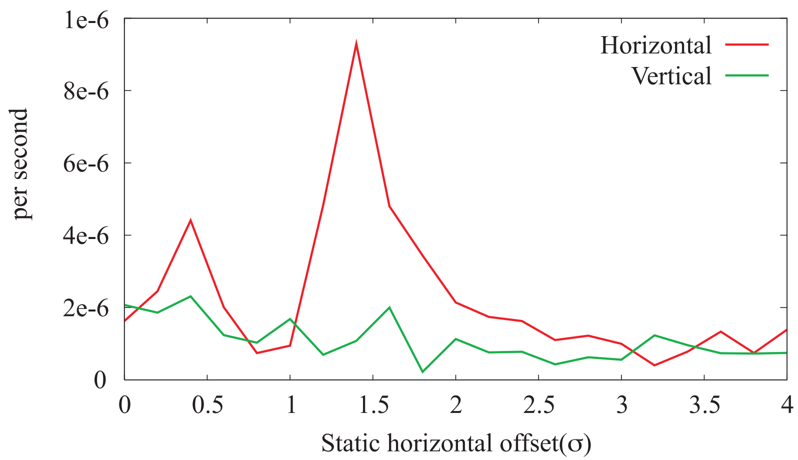
Crossing angle and parasitic beam-beam

Can be completely avoided up to 156 bunches
Then gradually becoming an issue
would be good to gain first experience on this
in the 2009 / 2010 run
Nominal, IP1/5 : each 30 parasitic collisions ~ 9σ
Parasitic b.b. effects reduce with fewer bunches
or increased crossing angle



Simulation : IP5 colliding. IP1 going into collision
by ramping down the horizontal separation





close to head on beam-beam :
peaks in blow up at 0.5 and 1.5 σ

Some ref.
W. Herr, M. Zorzano LHC Project Report 462 ; Tatiana Pieloni thesis
Figures above from S. M. White, H. Burkhardt, S. Fartoukh, T. Pieloni, *Optimization of the LHC Separation Bumps Including Beam-Beam Effects WE6PFP018*, PAC'09

Luminosity, Background, Lifetime

Going into collisions :
initially, probably also later for every step in commissioning towards higher intensity/luminosity
- one experiment at a time + measure / tune

interesting for background to distinguish between main sources
- collisions related
- beam gas
- halo

General sequence :
injection, ramp, squeeze - adjust tune, orbit, chromaticity .. → Pre-collision
If lifetime ok, experiments could consider to start taking data

Collapse separation - measure and optimize if needed

Separation scans to centre collisions - when and how often - to be seen

On demand : larger separation scans to calibrate luminosity

First year of LHC operation : learn about background - try to go to $\beta^* = 1$ m with crossing angle
Discussed in LBS. Experiments : 1st priority simulate / understand backgrounds without external crossing angle

Hardware commissioning and tests

For information. From informal discussions and emails - to my knowledge.

Coordinated by G. Arduini, with J. Wenninger, R. Schmidt et al.

The three types of (corrector) magnets involved in bringing beams into collisions are :

MCBC, MCBY and MCBX, 1 of each left and right, or together 6 magnets per IP.

A full test at one IP would need two adjacent sectors cold and available for tests - for which we may have to wait until August.

Proceed in several steps and start with first steps asap (June ?).

1. Test of MCBX by Christine, Bob et al.

Measure and optimize collapsing time. Simon White + HB will provide input on which current range will be of interest.

2. Test of MCBC and MCBY, Mirko et al.

Try to get maximum dI/dt and acceleration. Currents will depend on details. SW and HB can provide a range if required.

3. Software and online model - mostly independent of the hardware tests 1. and 2. - can be done in parallel

Walter, Reyes, Federico, Simon et al.

Prepare knobs for 4 (without MCBX) and 6 magnet (with MCBX) bumps - Federico, Gabriel, Simon.

For tests allow to have one side off. OP group, Walter + Reyes, are encouraged to think about the operational procedure to collapse the separation bumps. There is a linear relation between separation and magnet strength. The ramp in terms of current versus time instead requires a detailed (non-linear) model. Further improve hysteresis / online model for the MCBX, Walter et al.

after progress with 1.-3. :

4. Combined tests, collapsing separation bumps

ramp together MCBC, MCBY, MCBX - could be done first with 3 magnets, just on one side of an IP, like right of IP2 if sector 2-3 would be the first available for tests.

β*, crossing angle and separation

to my knowledge - would be good to agree on an update for the 2009/2010 run

Separation and crossing angle at top energy when going into collisions "pre-collision conditions" :

Injection β* = 11 m in IP1/5 ; 10 m in IP2/8 Separation ±2 mm; crossing angle ±170 μrad IP1/5

Ramp & squeeze - baseline to keep about constant tune shift, scaling crossing angle with $1/\sqrt{\beta^*}$
Squeeze of the crossing scheme in IR1 & IR5, S. Fartoukh, LOC meeting 11/10/2005, slides,
gives scaling laws, essentially scaling crossing angle with $1/\sqrt{\beta^*}$
at that time starting squeeze from 17 m, ± 40 μrad, separation to ±0.5mm,
final crossing angle ±142.5 μrad at β* = 0.55 m and 7 TeV, shift 0.5 mm

Reduce separation during ramp or latest before squeeze to ±0.5mm, then keep constant during squeeze

Existing : squeeze files for range of β* (example IR1 : 9, 7, 5, 4, 3.5, 2.5, 2.0, 1.5, 1.1, 0.8, .. m) with knobs for separation on_sep and crossing angle on_x.

For discussion and follow up

- **agree on optics with default pre-collision separation** (± 0.5mm would work) **and crossing angles in collision at all planned β*** including 1 and 3 m **at 5 TeV** (squeeze files with on_x ≈ 1)

Strategy for :

- **orbit feedback, proposed by JW et al., could also correct for hysteresis ?**
- **simple trim functions in LSA or online model ?**

Backup Slides

Massi's table and Parameters for Background Simulation

Steps for luminosity increase during the 2009-2010 LHC pp run

	900 GeV	first high-energy coll.		Pilot physics run							
				no external crossing angle			with external crossing angle				
step	1	2	3	4	5	6	7	8	9	...	units
fill scheme	2x2	=	=	43x43	156x156	156x156	50ns@144	50ns@288	50ns@432	...	
E	**0.45**	**5**	=	=	=	=	=	=	=	...	TeV
k_b	2	=	=	**43**	**156**	=	**144+12**	**288+12**	**432+12**	...	bunches
N	5	=	=	=	=	9	=	=	=	...	10^{10} p/bunch
$N_{\rm Alice}$	5	=	=	=	=	=	1	=	=	...	10^{10} p/bunch
β^*(IP1,5)	11	=	2	=	=	1	3	=	=	...	m
β^*(IP2)	10	=	=	=	=	=	3	=	=	...	m
β^*(IP8)	10	=	2	=	=	3	4	=	=	...	m
$I/I_{\rm nom}$	0.031	=	=	0.67	2.42	4.3	4.05	8.1	12.1	...	%
$E_{\rm stored}$	0.0072	0.08	=	1.72	6.24	11.1	10.5	20.8	31.2	...	MJ
$\alpha_{\rm net}$(IP1,5)	0	0	=	=	=	=	300	=	=	...	μrad
$\alpha_{\rm net}$(IP2)	0	200	=	=	=	=	300	=	=	...	μrad
$\alpha_{\rm net}$(IP8)	0	380	=	=	=	=	620	=	=	...	μrad
n_{bb}(IP1,5)	1	=	=	43	156	156	144	288	432	...	colliding pairs
n_{bb}(IP2)	1	=	=	4	=	=	12	=	=	...	colliding pairs
n_{bb}(IP8)	1	=	=	19	72	=	138	276	414	...	colliding pairs
L(IP1,5)	0.0026	0.029	0.16	6.9	24.9	161.5	48.3	96.5	145	...	10^{30} cm^{-2}s^{-1}
L(IP2)	0.0029	0.032	=	0.13	=	=	0.05	=	=	...	10^{30} cm^{-2}s^{-1}
L(IP8)	0.0029	0.032	0.15	2.8	10.8	23.7	32.7	65.4	98.1	...	10^{30} cm^{-2}s^{-1}
μ(IP1,5)	0.012	0.19	1.07	=	=	6.9	2.24	=	=	...	
μ(IP2)	0.013	0.21	=	=	=	=	0.028	=	=	...	
μ(IP8)	0.013	0.21	1.0	=	=	2.3	1.58	=	=	...	
Time for physics	~shifts	~days		~weeks		~months					

Definitions: μ = average number of inelastic interactions per crossing
n_{bb} = number of colliding pairs at given IP
$\alpha_{\rm net}$ = net crossing angle

Assumptions: Longitudinal emittance $\epsilon = 0.5$ nm $\cdot$ 7 TeV$/E$
Inelastic cross section: $\sigma_{\rm inel} = 52$ and 75 mb for $\sqrt{s} = 0.9$ and 10 TeV

Estimates: Beam commissioning time* for reaching step 6 $\approx$ six weeks
Beam commissioning time* to go from step 6 to step 7 $\approx$ two weeks
Total expected physics running time: of the order of $5 \cdot 10^6$ s

* with machine available