LHC commissioning

Presented by : H. Burkhardt

Procedures : Magali Gruwé

for the LHC Commissioning Working Group

with input from

W. Herr for separation and beam-beam

Simon White, Walter Venturini and Nicholas Sammut looking at details of separation bumps and magnet model

LHC commissioning

phase A.7 - 450 GeV, collisions

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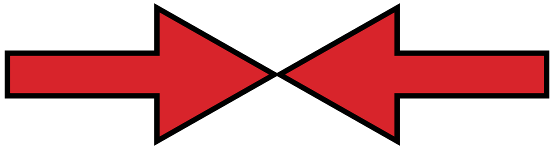

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Commissioning Phases A

Phase	Phase	Procedures	LTC Presenter	Date	
injection and first turn	A.1	Magali	Brennan	7.03	✓
circulating beam, RF capture	A.2	Magali	Gianluigi	14.03	✓
450 GeV, intial commissioning	A.3	Verena	Rhodri	28.03	✓
450 GeV, optics meas	A.4	Stefano	Frank	11.04	✓
450 GeV, increase intensity	A.5	Laurette	Jan	25.04	✓
450 GeV, two beam operation	A.6	Walter/Verena	Ralph	4.07	✓
450GeV, collisions	A.7	Magali	Helmut	10.10	
snapback and ramp	A.8	Reyes	Mike	9.05	✓
top energy checks with beam	A.9	Walter	Frank	6.06	✓
top energy, collisions (pilot physics)	A.10	Reyes	Helmut	20.06	✓
squeeze	A.11	Stefano	Massimo	23.05	✓
top energy, physics runs	A.12				
bring on experiments magnets	A. ?	N.N.	Helmut	?	

generally Phase A : not more than

43 - 156 bunches, no crossing angle ; 4 - 9 × 10^{10} p / bunch

A.1 - 10 : injection optics, no squeeze, $\beta^*_{1, 2, 5, 8}$ = 11, 10, 11, 10 m

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+ bring on experiments magnets	A. ?	N.N.	Helmut	LHCCWG 20 Nov. ?	

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Staged commissioning

Staged commissioning of high luminosity operation of LHC at points 1 and 5

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$Eventrate / Cross = \frac{L \sigma_{TOT}}{k_b f}$$

Machine parameters		450GeV	Commission hardware for high energy operation	Stage A		Stage B		Stage C		Installation of phase II collimators and full beam dump diluters	Stage D	
		Target		Target	Limit	Target	Limit	Target	Limit		Target	Limit
spacing	ns	2021		2021	566	75	75	25	25		25	25
bunch length	m	0.1124		0.0755	0.0755	0.0755	0.0755	0.0755	0.0755		0.0755	0.0755
crossing angle	urad	0		0	0	250	250	285	285		285	285
bunch intensity		4.00E+10		4.00E+10	9.00E+10	4.00E+10	9.00E+10	5.00E+10	5.00E+10		9.00E+10	1.15E+11
bunches		43		43	156	936	936	2808	2808		2808	2808
energy	eV	4.50E+11		7.00E+12	7.00E+12	7.00E+12	7.00E+12	7.00E+12	7.00E+12		7.00E+12	7.00E+12
F		1.00		1.00	1.00	0.96	0.92	0.90	0.84		0.90	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		3.75E-04	3.75E-04
beta*	cm	1100		200	200	200	100	100	55		100	55
luminosity	/cm2s	7.16E+28		6.12E+30	1.12E+32	1.28E+32	1.24E+33	1.13E+33	1.91E+33		3.65E+33	1.01E+34
total inel cross section	cm2	6.00E-26		6.00E-26	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		0.01		0.76	3.85	0.73	7.09	2.14	3.63		6.94	19.18
protons per beam		1.72E+12		1.72E+12	1.40E+13	3.74E+13	8.42E+13	1.40E+14	1.40E+14		2.53E+14	3.23E+14
current per beam	mA	3.09E+00		3.09E+00	2.53E+01	6.74E+01	1.52E+02	2.53E+02	2.53E+02		4.55E+02	5.81E+02
energy per beam	Joules	1.24E+05		1.93E+06	1.57E+07	4.19E+07	9.43E+07	1.57E+08	1.57E+08		2.83E+08	3.62E+08
beam size	um	293.3		31.7	31.7	31.7	22.4	22.4	16.6		22.4	16.6

http://lhccwg.web.cern.ch/lhccwg/overview_index.htm

From R. Bailey, LHCCWG

Beam commissioning to 450 GeV and 7 TeV collisions

		Rings	Total [days]
1	Injection and first turn	2	4
2	Circulating beam	2	3
3	450 GeV – initial commissioning	2	4
4	450 GeV – detailed optics studies	2	5
5	450 GeV increase intensity	2	6
6	450 GeV - two beams	1	1
7	450 GeV - collisions	1	2
8a	Ramp - single beam	2	8
8b	Ramp - both beams	1	2
9	7 TeV – top energy checks	2	2
10a	Top energy collisions	1	1
	TOTAL TO FIRST COLLISIONS (beam time)		30
11	Commission squeeze	2	6
10b	Set-up physics - partially squeezed	1	2
	TOTAL TO PILOT PHYSICS RUN (beam time)		44

23 days

14 days

R.Bailey, September 2007

LHC commissioning - collisions @ 450 GeV

- **more general discussion of few issues at the end**
- **first going through the commissioning procedures on the web ; mostly a shortened version of what we already discussed for collisions at 7 TeV**

Phase A.7

- **description (objectives)**
- **entry conditions**
- **machine setup**
- **procedure**
- **exit conditions**
- **problems**
- **questions**

http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA7/menu.htm

Description

This phase can be sub-divided into three steps / objectives

1. **Get beams into collisions (at 450 GeV)**
2. **Minimise residual separation (BPM)**
3. **First look at backgrounds and luminosity (experiments)**

http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA7/phase.htm

Entry conditions

	Entry condition
E.A.7.1	**Machine protection for 450 GeV**
E.A.7.2	**2 beams operation (phase A.6)**
E.A.7.3	**Good Vacuum for low background**
E.A.7.4	**Collimators at injection settings**
E.A.7.5	**Power circuits**
.01	Correctors should be available and calibrated; bumps should be commissioned
.02	Octupoles ON (leave feedbacks ON if needed)
.03	All experimental magnets OFF
E.A.7.6	**High level controls**
.01	Separation scan application debugged and available
.02	Online FiDeL magnetic model available via LSA for the correctors participating in the bumps
.03	Online display of the beam parameters: current, lifetime, tune, chroma, orbit, etc.
.04	Online display of BLMs
.05	Off-line preparation of bumps or, alternatively, possibility to do dynamic bump calculation
E.A.7.7	**BI**
.01	BPM commissioned and good calibration
.02	BLMs commissioned and calibrated
.03	BCT commissioned and calibrated
.04	Wire scanners commissioned
E.A.7.8	**Beam parameters under control**
.01	Good beam lifetime (about 1 hour)
.02	Orbit
.03	Tune (collision tunes) and tune coupling
.04	Chromaticity
E.A.7.9	**Communication with experiments**
.01	DIP operational
.02	Regular scheduled meetings
.03	TV-screen status page (pages 1)
E.A.7.10	**Beams should be synchronized** [Note 1]

Note 1 : Δ T<1 ns at IR between beam 1/2 based on BPMs

http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA7/site_collection/entryConditions.htm

Procedure ; overview

Step	Activity	Who	Priority
A.7.1	**Get Beams into Collision in the X,Y plane**	OP	1
.01	Separator bumps at nominal 0 at all IPs (get settings from best knowledge; beams should be already fairly close).		
.02	Measure beam displacement at the IP using BPMs.		
.03	Adjust beam separation such that the beam 1 and beam 2 difference left/right of the IP is the same. Do this for one IP at the time.		
.04	Monitor lifetime for all the bunches/empty buckets/abort gap; monitor beam losses.		
.05	"Watch" background.		
.06	Change mode from ADJUST to STABLE BEAMS (if lifetime and background under control).		
.07	Start counting delivered luminosity; logging into database (~ Hz).		
A.10.2	**Measure and correct longitudinal position**	OP/RF	2
.01	Shift RF phase to monitor the longitudinal position		
A.10.3	**Monitor lifetime, beam losses and keep background low and stable (no spikes)**	OP	1
A.10.4	**Monitor luminosity during the fill provided by the experiments**	OP	2

http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA7/site_collection/procedure.htm

Exit conditions

collisions at 450 GeV

http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA7/site_collection/exitConditions.htm

Problems

1. LHC Luminosity monitor angular acceptance insufficient at 450 GeV, signal/background ratio poor, ~ no coincidences to distinguish background / collisions. Need experiments to confirm we have collisions.
2. BRANs in IP1 and IP5 : poor signal level / threshold ratio
3. Separation scans : hysteresis effects in separation scans, discussed later.
4. Poor intensity lifetime :
   - check/optimize working point
5. Emittance growth :
   - check nothing kicks the beam
   - vibration (low frequency FFT)
   - minimize RF noise
6. Backgrounds increasing :
   - check orbit, aperture, vacuum
7. Low luminosity :
   - re-optimize-check / adjust separation

http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA7/site_collection/problems.htm

Questions / Pending Actions

currently nothing noted

http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/phaseA7/site_collection/questions.htm

Now the more general discussion

- get beams colliding, requirements, expected tolerances
- first look at backgrounds
- hysteresis
- number of bunches

Get beams colliding ; requirements on separation

Luminosity with separation

$$\frac{\mathcal{L}}{\mathcal{L}_0} = \exp\left[-\left(\frac{\delta x}{2\sigma_x}\right)^2 - \left(\frac{\delta y}{2\sigma_y}\right)^2\right]$$

$\frac{\delta x}{\sigma_x}$	$\frac{\delta y}{\sigma_y}$	$\mathcal{L}/\mathcal{L}_0$
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

Required, in radius roughly **:**

$\delta_r < 2\ \sigma$ to see collisions

$\delta_r < 0.5\ \sigma$ to optimise luminosity and equalise between experiments

$\sqrt{2}$ better in each plane x, y : $\delta_{x,y} < 1.4\ \sigma$ and $\delta_{x,y} < 0.35\ \sigma$

Eb, TeV	β*	σ*	$\delta_{x,y}$	$\delta_{x,y}$
TeV	m	µm	µm	µm
0.45	11	293	414	104
7	11	74.4	105	26
7	2	31.7	45	11
7	0.55	16.6	23	6

with ~ 50 µm BPM resolution ok, even without BRAN

Beam beam tune shift

head-on b.b. tune shift

$$\xi_x = \frac{r_c \, N \, \beta_x^*}{2\pi \, \gamma \, \sigma_x \, (\sigma_x + \sigma_y)} \qquad \xi_y = \frac{r_c \, N \, \beta_y^*}{2\pi \, \gamma \, \sigma_y \, (\sigma_x + \sigma_y)}$$

calculated, using the classical particle radius, here for the proton $r_c = r_p = 1.5347 \times 10^{-18}$ m

In the LHC we have by design round beams with $\sigma = \sigma_x = \sigma_y, \; \beta^* = \beta_x^* = \beta_y^*$

so that $$\xi = \frac{r_c \, N \, \beta^*}{4\pi \, \gamma \, \sigma^2}$$

in terms of the normalised emittance $\sigma = \sqrt{\beta \epsilon_N / \gamma}$ we get simply $$\xi = \frac{r_c \, N}{4\pi \, \epsilon_N}$$

numerically

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

independent of beam energy and β*
just a function of bunch intensity
which does not vary too much

at 4×10^{10} intensity not expected to be a major problem ; should be observable as change of the tune spectrum ; potentially useful for optimization

First look at running conditions and backgrounds

Allowing to give a first look at background signals in the detectors as we reduce the separation and start to see collisions, and then to see how the conditions evolve during some hours of ~ stable running will be quite interesting.

Would allow to diagnose and possibly help against later surprises

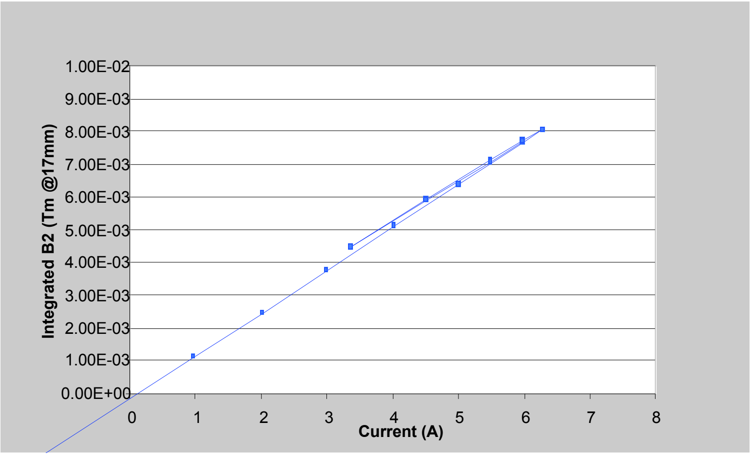
Record and analyse :

background (experiments) and lifetime

bunch by bunch variations

look for parasitic bunches and collisions

Separation bump and hysteresis



W. Venturini
Chamonix/Divonne Jan 2006

being studied and measured in detail by
Simon White, Walter Venturini and Nicholas Sammut

my current understanding - to be confirmed :

nominal separation at injection : about 14 σ or 4 mm
MCBC currents between 0.18 and 2.52 A, mean 0.83 Amp IP1
MCBY currents between 0.26 and 4.44 A, mean 2.36 Amp IP1
maximum current ~ 80 A
Careful : hysteresis can be as much as ± few % of the maximum excitation
or potentially of the order of what is needed for separation !

For 450 GeV commissioning including collisions :
degauss corrector magnets and avoid any large excitation
hysteresis then rather negligible

Number of bunches

Luminosity rather low 1.66×10^{27} $cm^{-2}s^{-1}$ per crossing at 4×10^{10} / bunch

Aim for 43×43 to 156×156 to get to 7.1×10^{28} — 2.6×10^{29} $cm^{-2}s^{-1}$

What is the minimal number of bunches to get collisions ?

1×1 bunch is sufficient to get collisions in two opposite IPs : IP1&5

with

2×2 bunches we can get collisions at IP1&5 and IP2 and IP8 incl. offset

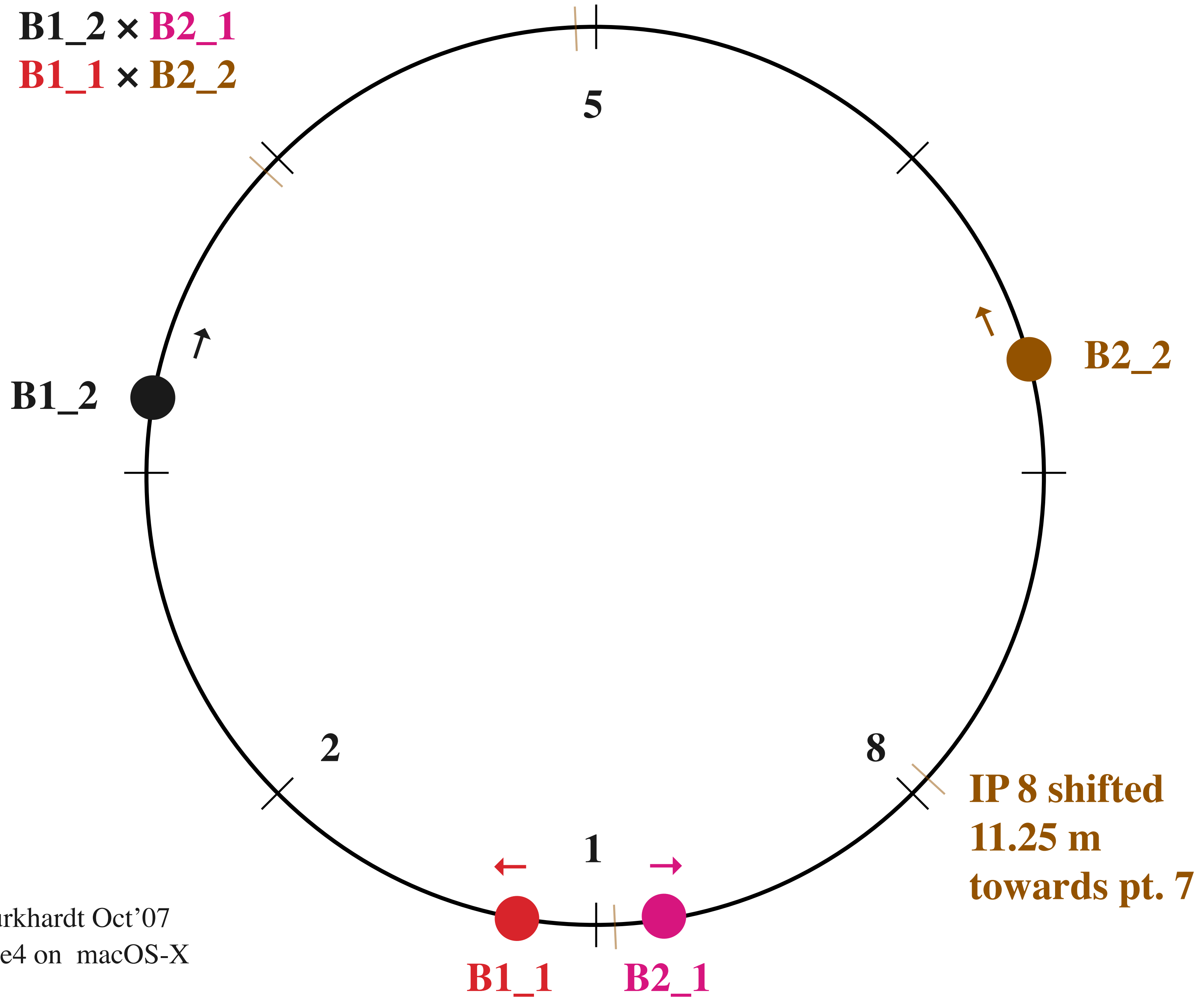
see animation next slide ➽

3×3 allows for unique pairs colliding in IP1&5 and IP2, IP8 separately

Lit.: W. Herr, LHC Project Note 344, BEAMX program

2 × 2 bunch collisions

IP1 & 5 : B1_1 × B2_1 + B1_2 × B2_2 (offset)
IP2 : B1_2 × B2_1
IP8 : B1_1 × B2_2



H. Burkhardt Oct'07
Keynote4 on macOS-X

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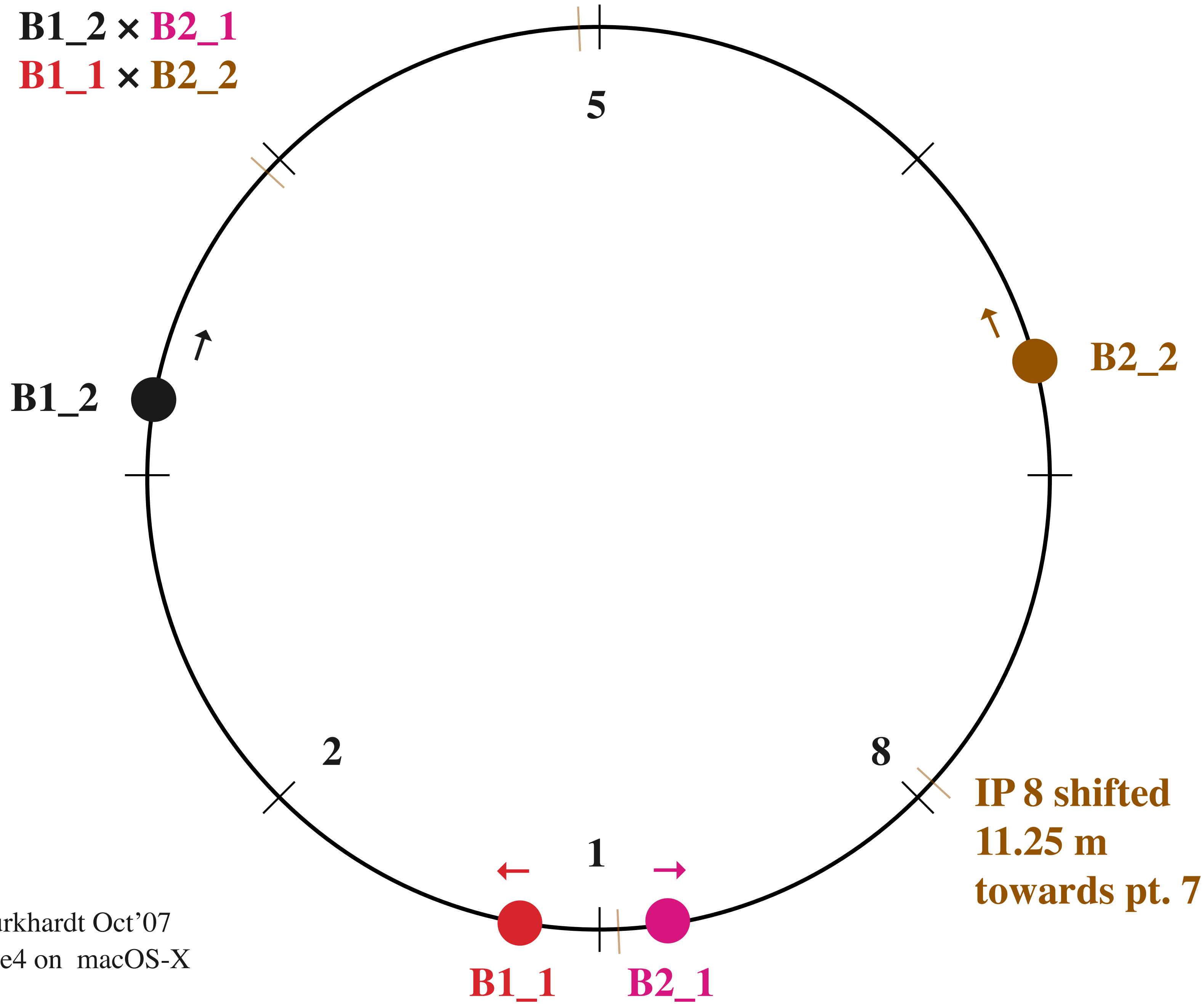

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Backup Slides

Parameter Range

and single **bunch luminosities** as relevant for lumi / separation scan statistics

Event rates for σ = 10 mb, which is about the cross section with high energy neutrons in the BRAN

ϵ_N μm	ϵ nm	p GeV/c	β^* m	σ^* μm	N_p	$\mathcal{L}$ cm^{-2}s^{-1}	$\dot{N} = \mathcal{L}\,\sigma$ Hz	$\frac{\dot{N}}{f_{\rm rev}}$	ξ
3.75	7.82	450	11	293.3	5×10^9	2.60×10^{25}	0.26	0.000023	0.000 16
3.75	7.82	450	11	293.3	4×10^{10}	1.66×10^{27}	16.64	0.0015	0.001 30
2.5	5.21	450	11	239.4	4×10^{10}	2.49×10^{27}	24.94	0.0022	0.001 95
3.75	7.82	450	11	293.3	1.15×10^{11}	1.37×10^{28}	138	0.0122	0.003 74
3.75	0.503	7000	11	74.36	5×10^9	4.00×10^{26}	4.00	0.00036	0.000 16
3.75	0.503	7000	11	74.36	4×10^{10}	2.56×10^{28}	256	0.0228	0.001 30
3.75	0.503	7000	11	74.36	9×10^{10}	1.30×10^{29}	1296	0.115	0.002 93
3.75	0.503	7000	2	31.71	1.15×10^{11}	1.11×10^{30}	11087	0.986	0.003 74
3.75	0.503	7000	0.55	16.63	1.15×10^{11}	3.54×10^{30}	35400	3.15	0.003 74

Commissioning Phase A aims for 43 - 156 bunches. No crossing angle

Nominal longitudinal LHC beam parameters V4.0 , LHC design report (f_{rf} = 400.8 MHz) :

V_{rf} = 8 MV σ_E / E = 4.716e-4 σ_Z = 11.24 cm σ_T = 0.375 ns 450 GeV

V_{rf} = 16 MV σ_E / E = 1.129e-4 σ_Z = 7.55 cm σ_T = 0.252 ns 7 TeV