Beam-beam tests at injection energy

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Introduction and motivation presented at the LPC

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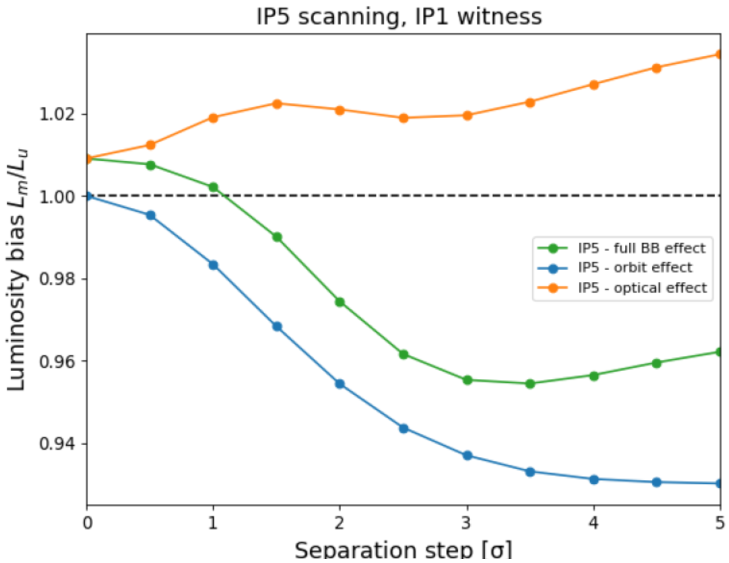
What do we know - BB impact on luminosity

- Beam-beam (BB) interaction affects the luminosity measurement, two effects can be corrected for:
    - dynamic beta causing optical distortion, hence change in transverse beam widths, and in bunch density profile distribution → overlap changes
    - orbit shift caused by the deflection

- Extended simulation campaigns with COMBI and B*B to study these effects

- As a result, luminosity measured in VdM conditions can be corrected:
    - Single IP parametrization based on the Beam-beam parameter and unperturbed tunes was derived
    - Bias caused by additional collisions (Witness IP) can be mimicked with equivalent coherent BB tune shift used in the Single IP parametrization

- Following tests designed to verify the simulation results (BB parameter, tunes, phase advances)



Strategy

- Prior to the following BB Tests, characterization and validation of the phase knobs needs to be performed by OMC (details on slide 4),
- Parasitic measurements will be performed during the non-linearity tests that are planned around the stable beams period at injection energy,
- BB Tests with optimized phase knob to maximize the observed effect:
  - Test 1: step function measurement with 2 IPs in collision - quick and repetitive measurement of relative luminosity change at the witness IP, and verify phase dependency of effects for further tests,
  - Test 2: full separation scans program,
  - Test 3: filling scheme for collision in 3 IPs to test multi-IP parametrization
- Possibility of repeating the tests with standard injection optics if phase knob not successful (the biggest effect in Test 3).

Knob Validation

OMC & OP (Rogelio Tomas, Matteo Solfaroli)

KNOB name in control system: LHCBEAM/LUMI_BB_PHASE

Beams: pilot bunch
Collimators: coarse settings

Measurements:

- Orbit, chroma and coupling with necessary corrections per knob setting
- AC dipole to measure phase advance between IPs and beta-beating around the machine
- k-modulation in IR1&5 to measure beta*

Time estimate ~ 40min / knob setting to be used, 2-3 steps

Max. effect IP1 -> IP5 , summary		
Beam 1		
	Δμ_x [2π]	Δμ_y [2π]
IP1-IP5	30.97655	29.64851
IP1-IP5_adj	30.9	29.9
change	-0.077	0.251
Beam 2		
	Δμ_x [2π]	Δμ_y [2π]
IP1-IP5	31.06197	29.76189
IP1-IP5_adj	30.9	29.9
change	-0.162	0.138

Test 1

Machine setup: special optics with optimized phase knob $\Delta\mu_{IP1-IP5}=0.9$, no crossing-angles at IP1 and IP5, no orbit feedback, reduced octupole current, chroma and ADT

Measure relative luminosity changes at non-scanning IP - CMS and ATLAS, assuming ~0.6-1% precision (60 s/step), multiple tests with quick scans to avoid emittance change and drifting.
Test for BB parameter range (0.008-0.012) → expected impact to Luminosity >3% per IP.

Observables:

- luminosity - IP1, IP5,
- bunch to bunch intensities (FBCT),
- orbits (DOROS, arc BPMs, ADT),
- gated tune spectra per bunch (BBQ) at each step, and total tune drift before/after collisions + during the test at full separation at all IPs,
- beam sizes (WS,BSRT).

Test 1

Beams: 2 single bunches per beam of same brightness

→ small emittances ~1.5 um and intensities 1e11 ppb, $\xi = 0.008$

→ all bunches colliding at IP1 and IP5 only

Operational Steps:

a) WS measurement
b) Optimize head on at both IPs, measure reference luminosity L_u at the witness IP5
c) separate IP1 in one step as much as possible (3 nominal σ per beam) in the horizontal plane, measure luminosity change at the witness IP
d) collapse IP1 to head-on with optimization, remeasure L_u
e) repeat steps a-d 3 times for each scanning direction (both negative and positive nominal separation, using automatic-scan procedure with pre-validated sequence)
f) repeat steps a-e for the vertical plane (automatic-scan procedure)
g) repeat steps a-f for IP1 as witness
h) repeat steps a-g at higher intensity ~1.5e11 if time allows

Total time estimate: 4 h (min. 2 x 2 x 2 x 10 min)

Test 2

Machine setup: special optics with optimized knob $\Delta u_{IP1\text{-}IP5}$=0.9, no crossing-angles at IP1 and IP5, no orbit feedback, reduced octupole current, chroma and ADT

Measure Luminosity at non-scanning IP - CMS and ATLAS involved, full separation scan program: both transverse planes, with 13 separation steps (30 or 60 s/step tbd after first collisions), single-beam excursion +/- 3 nominal σ. Test for BB parameter range (0.008-0.012) → expected impact to Luminosity >3% per IP.

Observables:

- beam separation dependence of luminosity at both the witness and the scanning IP,
- bunch to bunch intensities (FBCT),
- orbits (DOROS, ADT),
- gated tune spectra per bunch (BBQ) at each step, and total tune drift before/after collisions + during the test at full separation at all IPs,
- beam sizes (WS,BSRT).

Test 2

Beams: ~4 bunches per beam with uniform parameters

→ small emittances ~1.5 um and intensities around 1e11 ppb (tbd after Test 1 observations).

→ all bunches colliding at IP1 and IP5 only

Operational Steps:

a) WS measurement,
b) Optimize head-on at IP1 and IP5, define reference luminosity at the witness IP5 (L_u)
c) Transverse scan in horizontal plane at IP1 → Measure luminosity change at witness IP5, at the scanning IP1 measure convoluted beam size (Capsigma)
d) Go back to head-on, reoptimize IP1 & IP5, and remeasure reference luminosity
e) repeat steps a-d in both scanning directions
f) repeat steps a-e for the vertical plane
g) refill and repeat steps a-f for IP1 as witness
h) repeat a-g with the intermediate knob setting

Time estimates: 2 knobs x 2 IPs x 2h

Test 3

Machine setup: optics tbd after previous tests, no crossing-angles at IP1 and IP5, standard crossing-angles at IP2 (~1mrad), IP8 (~1mrad), no orbit feedback, reduced octupole current, chroma and ADT.

Measure Luminosity at non-scanning IP - ATLAS, ALICE and CMS involved, quick scan program.

Observables:

- luminosity - IP1, IP2, and IP5,
- bunch to bunch intensities (FBCT),
- orbits (DOROS, arc BPMs, ADT),
- gated tune spectra per bunch (BBQ) at each step, and total tune drift before/after collisions + during the test at full separation at all IPs,
- beam sizes (WS,BSRT).

If tests with the knob not successful - this test to be repeated at nominal optics.

Test 3

Beams: 4 single bunches per beam of same brightness

→ small emittances ~1.5 um and intensities 1.25e11 ppb, ξ = 0.01

→ all bunches colliding at IP1, IP2 and IP5 (filling scheme 4b_4_4_0_BeamBeamV4),

(LR @ 11.25 m in IP8, distance ~35σ for 1 mrad crossing-angle)

Operational Steps:

a) WS measurement,
b) Optimize head on at all IPs, measure reference luminosity L_u at the witness IP5
c) separate IP2 in single step as much as possible (3 nominal σ per beam) in the horizontal plane, measure luminosity change at the witness IP5 and IP1
d) separate 2nd IP - IP1, observe further luminosity change at the witness IP5
e) collapse IP2 to head-on with optimization at witness IP only,
f) collapse IP1 to head-on with optimization at witness IP only, remeasure L_u
g) repeat steps a-f 3 times
h) repeat steps a-g for the vertical plane
i) repeat steps a-h for IP1 as witness

Time estimate: 4 h