Strong–strong and coherent beam–beam effects

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Coherent beam–beam and Impedance

- Beam–beam and Impedance by Simon White
- Coherent modes in LHC by Xavier Buffat
- Coherent modes in Tevatron by Giulio Stancari

Instrumentation and observations

- Digitized BPM signals by Giulio Stancari
- Orbit effects in LHC by Michaela Schaumann
- Ultrafast orbit effects by Tobias Baer
- BTF measurements by Paul Görgen
Impedance and beam-beam

→ Scan the head-on beam-beam parameters at Q' = 0.0 and constant wake

→ The beam-beam interaction shifts the π-mode down faster: coupling between modes 0 and -1 could occur at lower intensity

→ Although the analytical model predicts also coupling between σ-mode and mode +1 it is not observed in tracking simulations
Single bunch: Head-on & long range

Full head-on has a clear stabilizing effect even without chromaticity, octupoles or damper
Multi bunch: complexity

COMBI code for 36x36 bunches colliding in one IP

Courtesy of T. Pieloni
Stable single bunch mode in dedicated experiment

- Single bunch, 450 GeV
  - $\xi \sim 0.01$ per IP
  - Modes are visible but usually stable
  - Transverse feedback is off
Comparison with simulation

- Bunch parameters are too different to measure the Yokoya factor

- Good agreement with self-consistent multiparticle tracking (COMBI)
  - Measured tunes, intensities and emittances used as input
Coherent instabilities in standard operation

- Candidate of beam-beam and impedance mode at small separation while bringing the beams into collision (Fill 2808, July 2012)

- Not distinguishable from a single beam instability, with incoherent transmission of the signal to the other beam, via the beam-beam force (Using instrumentation available at the time)
Evolution of frequency spectra during collider store (narrow span)

BPM measurement
1.7-GHz Schottky

Fractional tune

BeamBeam3D calculation [horiz.]
BeamBeam3D calculation [vert.]
Rigid-bunch model
1 bunch: 62,500 turns
12 bunches: 12,382 turns

10 bits,
8 GS/s
125-ps period
150 samples per bucket

**subtracted average**

**difference signal**

**BPM**

**phase**

**amplitude**

**rf hybrid**

**A**

**A-B**

**B**

**A+B**

**revolution marker**

**trigger**

**ch1**

**digitizer**

**23 dB**
Comparison with Schottky detectors

1.7-GHz Schottky
- width dominated by momentum spread
- distorted by coherent lines

Special Tevatron Store 7893
3 bunches per beam

21-MHz Schottky
- no single-bunch capability
- cross talk: H and V, p and p-bar

this device
- very high resolution
- interpretation of lines is indirect

Michaela Shaumann – Observed Beam–Beam Induced Orbit Effects at LHC

**Measurement of the Orbit-Kick due to Beam-Beam - Scan IP1**

- $\chi^2 / \text{ndf} = 0.6255 / 7$
- $p_0 = 8.99 \times 10^5 \pm 1.34 \times 10^6$
- $p_1 = 0.0001771 \pm 2.652 \times 10^{-5}$

**measurement**

**Orbit due to BB-Kick at a separation of 100\,\mu m for Scan in IP5**

**measurement**

**Measurement of the Orbit-Kick due to Beam-Beam - Scan IP5**

- $\chi^2 / \text{ndf} = 3.006 / 7$
- $p_0 = 1.022 \times 10^6 \pm 4.353 \times 10^9$
- $p_1 = 0.0002487 \pm 9.135 \times 10^{-6}$

**measurement**

**Orbit due to BB-Kick at a separation of 100\,\mu m for Scan in IP5**

**measurement**
In operation the BPM resolution is not enough to resolve beam-beam effects, only during a dedicated experiment it was possible to observe relative orbit changes bunch-by-bunch and around the ring while reducing the crossing angle.

Bunch with no HO or LR collisions w.r.t. reference bunch of same conditions. Bunch with 3 HO (in IP 1,2,5) and 16 LR w.r.t. reference bunch with no HO or LR.
Beam dump trigger by B2 LL-RF (cryo problem).

*Unusual single-turn losses on B1 in before beam dump.*

Signal from B1 diamond BLM in IR7.

\[300\text{mV} \times 1380\text{b} \approx 0.6\text{ Gy/s}\]


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First Turn Horizontal

- Phase of oscillation very well explained.
- Simulated oscillation amplitude 40% smaller than measured amplitude.
- Good agreement between simulations of Gaussian beam and particle in bunch centre.

Simulation and measurement for bunches with full long range interactions. Not all BPMs have a valid acquisition, in some areas data is only available for BPMs at low beta function.
Counter-Measure against incoherent spread from beam-beam: electron lens

- Reduction of beam-beam tune spread
  - Need lens shaped like beam-beam interaction to compensate
  - Can be done by electron beam of correct profile (not by magnets)
  - Installation 2013

Elens cartoon modified from “RHIC electron lenses” slides by W. Fischer et al.
Conclusion and Outlook

- Working BTF model in code
- Analytic Theory for Elens BTF
- Strength recovery using fit
- Split tunes under special conditions
- Should be usable as elens diagnostics
  - Now we need to look more at beam-beam
  - And test this against a more suitable measurement
Coherent beam–beam and Impedance

- Good start in treating beam–beam and impedance, lots of work ahead, some very promising results

Instrumentation and observations

LHC needs many observables to help unravel the rich structure of this «universal» machine – on to 25 ns and beyond!

Diagnostics

- does not have to be interesting
- does not have to be 120% right
- IT HAS TO BE USABLE AND BE USED