Beam-beam in Hadron colliders

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Beam-beam observations in the SPS

- In SPPbarS the beams were not matched.
- The tune spread at injection was dominated by space charge for proton and BB for pbar.
- Without the Hseparation only 3 bunches per beam could be stored. With the pretzel the number of bunches per beam passed to 6.
- The average BB LR separation was 3 sigma at injection 6 sigma at collision.
- Without separation and with 6+6 bunches, the pbar beam was lost in less than 5 second.
- The space charge at the injection was cured with longer bunch in the 200 MHz bucket and installing the 100 MHz RF system.
- During the squeeze it was difficult to keep the tunes constant and the temperature of the final focusing quads played an important role.
- In SPS going to lower emittances increases significantly the background.
- Some diffusion studies were performed using scrapers: diffusion rate increased significantly with amplitudes.
- The effect of the beam separation (50% less separation -> x5 more background) and of the crossing angle (no significant effect) were investigated .
- Noise and tune modulation had a very negative impact.
- Low chromaticity was very useful.

Beam-beam observations in the Tevatron

- It was already clear in TeV Run I that the BB would put the beam on dangerous resonances. (emittance blew up, there were halo formation and beam losses, entangling significant reduction of the luminosity lifetime)
- With the installation of the HV separators helical separation become possible.
- Orbit and tune variation along the train was observed and it was in good agreement with the simulation.
- In TeV Run II the bunches were 36+36. The operations were very difficult.
- The long-range was important during injection, ramp and squeeze.
- The chromaticity played an important role (it was important to minimise it, p. 12/43).
- The total measured HO tune shift went beyond 0.02 (p. 15/43)
- 5th, 12th and 7th resonance were dangerous, by matching the beam emittances (blow-up of pbar) the beam losses were reduced.
- At the end of Run II the contribution due to the BB effect of the integrated luminosity was 22-32%.
- Possible solution to alleviate the BB effects were: Increase separation, Reduce Q' and Q'', Use transverse damper and octupoles, stabilise orbit and tune, Improve diagnostics, use e-lens compensation.

Beam-beam observations in RHIC

- The maximum p-p HO tune shift was 0.018.
- The worst resonance were 3rd and 10th.
- The luminosity decay is fitted with a double exponential: a short an long time constant was observed. Just after the first collisions a shortening of the longitudinal emittance and a shrinking of the transverse emittance was observed together with beam losses.
- This effect increased in bunches with 2 HO collisions.
- The beam-beam effect reduced the off- momentum acceptance of the machine and its transverse dynamic aperture.
- The second part of the luminosity decay is dominated by IBS.
- Chromatic effects of the low beta* play an important role together with the 10 Hz oscillation of the triplets.

Beam-beam effects in HERA (p-lepton)

- In HERA were no LR encounters or PACMAN bunches.
- The beams dimensions a the IPs were matched For elliptical beam partial separation or crossing angle at the IPs was very problematic.
- The BB interaction affected negatively the lepton polarisation. This was related to be due to the tune shift.
- The choice of the Q working point was crucial.
- For the p-beam the coupling and the chromaticity was important.

General conclusions

- The mismatch between the beam sizes can increase the detrimental effect on the BB.
- Reducing the BBLR separation below 5-6 sigma has severe impact on the beam lifetime.
- A crucial knob to reduce the BB induced losses is to lower chromaticity.
- Regarding the HO tune shift limit, it is not possible to extract a general rule since it depends strongly on the observable chosen to define it (experiment background, luminosity lifetime) and on the noise and tune stability of the single machine.

In LHC the transverse damper can work during collision too but additional diagnostic is needed for a better understanding of the BB effect.