# Tune shifts and orbits caused by incoherent beam-beam effects

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# Which LHC model is being used ?

- **Based on LHC version 5**
- **No matched optics for ring 2, therefore assuming:**
  - **Perfect anti-symmetry at IP1, IP2, IP5, and IP8**
- **Head-on collisions at IP1, IP5, and IP8**
- **Halo collision at IP2**
- **Vertical crossing at IP1, IP2, and IP8**
- **Horizontal crossing at IP5**
- **Crossing angles between** $\pm 100\mu rad$ **and** $\pm 150\mu rad$
- **All footprints calculated at injection tunes and then moved because of the tune-finding procedure**

# Which LHC ? continued

- **At each of IP1, IP2, IP5, + IP8: 14 parasitic crossings either side**
- **4D (MAD standard) and 6D (Hirata) thin beam-beam elements, but all tracking always 6D (MAD)**
  - **Head-on split into five in both cases**
  - **Parasitic not split**
- **"Pacman effect": simulated by switching all parasitic off left of each IP**
- **Low-beta quadrupoles in triplets:**
  - **Split in four at IP1 and IP2, in two at IP2 and IP8**
  - **Latest Web error tables**

# Last additions

Several questions arising during the workshop are answered below (at least in part).

- Qestion: is there an emittance blow-up beyond 10000 turns? Tracking with:
  - LHC collision at $\pm 150 \mu rad$, all 4D beam-beam elements present
  - full error table for triplet quadrupoles including systematic and random, KEK at IP1 and IP8, FNAL at IP2 and IP5
  - tracking one particle at $5\sigma$ and $7\sigma$ each, $\Phi = 45^\circ$, $\Delta_p = 2\sigma$ over 100000 turns
  - resulted in no observable emittance growth (see slide)
- Qestion: do the triplet errors allow angles higher than $\pm 150 \mu rad$? Tracking with the LHC above, particle amplitudes $7\sigma$, showed loss of the particles above $\Phi = 45^\circ$ for $\pm 175 \mu rad$ (and for $\pm 200 \mu rad$). However, with the fractional tunes swapped, i.e. $Q_x = 63.32$, $Q_y = 59.31$ the particles survived at $\pm 175 \mu rad$ and were only lost at $\pm 200 \mu rad$ above $\Phi = 45^\circ$.
- Qestion: what effect has a missing head-on collision? The footprint (see slide) shows that at least the tune shift poses no problem.

# Twiss parameters

| pos. | $\beta_x$ [m] | $\beta_y$ [m] | x[mm] | y[mm] | $x_p$ [mm] | $y_p$ [mm] | $\alpha_h$ [$\mu rad$] | $\alpha_v$ [$\mu rad$] |
|---|---|---|---|---|---|---|---|---|
| IP1 | 0.5 | 0.5 | 0 | 0 | -0.002 | 0 | 0 | $\pm$150 |
| IP2 | 15 | 10 | 0.195 | 0 | - | - | - | $\pm$100 |
| IP5 | 0.5 | 0.5 | 0 | 0 | 0 | -0.002 | $\pm$150 | 0 |
| IP8 | 13 | 15 | 0 | 0 | - | - | 0 | $\pm$100 |

**Table 1: Main Twiss parameters of the nominal LHC collision machine**

| $Q_x$ | $Q_y$ | $Q_s$ | $U_{RF}$ [MV] |
|---|---|---|---|
| 63.31 | 59.32 | 0.002 | 16 |

**Table 2: Main Twiss parameters of the nominal LHC collision machine**

# Tune shift for head-on

| angle | type | IP1 ho | IP1 all | IP5 ho | IP5 all | IP1+5 ho | IP1+5 all |
|---|---|---|---|---|---|---|---|
| $\pm 150\mu$ | $\Delta Q_x$ | -0.00306 | -0.0057 | -0.0025 | -0.0003 | -0.0055 | -0.00595 |
| $\pm 150\mu$ | $\Delta Q_y$ | -0.0025 | -0.0003 | -0.00306 | -0.0057 | -0.0056 | -0.00599 |
| $\pm 100\mu$ | $\Delta Q_x$ | -0.0033 | -0.0100 | -0.00354 | +0.0019 | -0.0062 | -0.0074 |
| $\pm 100\mu$ | $\Delta Q_y$ | -0.0030 | +0.00191 | -0.00264 | -0.0093 | -0.0062 | -0.0072 |
| $\pm 50\mu$ | $\Delta Q_x$ | -0.0034 | -0.02676 | -0.0038 | +0.0117 | -0.0066 | -0.0181 |
| $\pm 50\mu$ | $\Delta Q_y$ | -0.0032 | +0.01188 | -0.0028 | -0.0265 | -0.0067 | -0.0083 |

**Table 3: LHC tune shifts for different crossing angles; only IP1 and IP5 have beam-beam elements and separation bumps.**

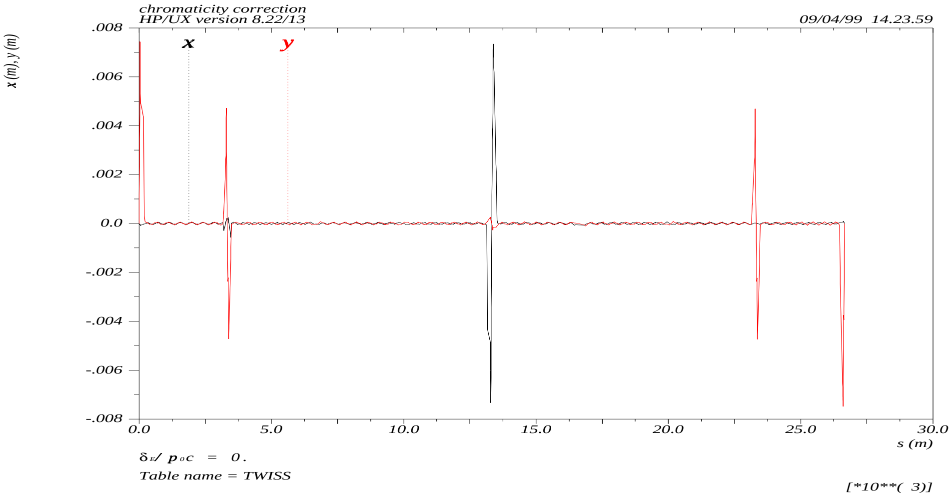
# Conclusion

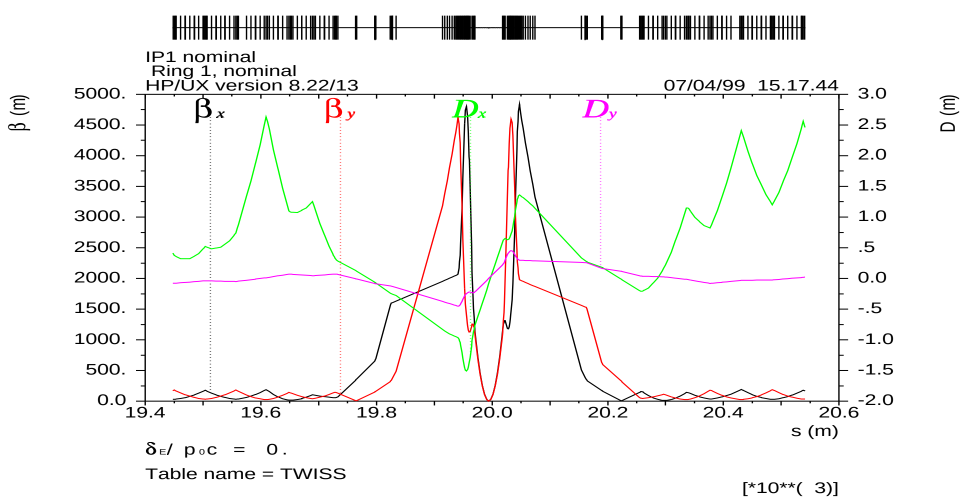
- **The tune shifts caused by 4D and 6D beam-beam elements are very similar**
- **The full, and the pacman footprints with or without the b10 in the low-beta quadrupoles stay within the "magic square"** $0.01 \times 0.01$ **at a crossing angle of** $\pm 150 \mu rad$
- **Reducing the angle to** $\pm 125 \mu rad$ **creates already rather large footprints**
- **The tracking at lower angles shows the increasing influence of the beam-beam force**
- **Therefore, as long as the b10 allows it: the bigger the angle, the better**

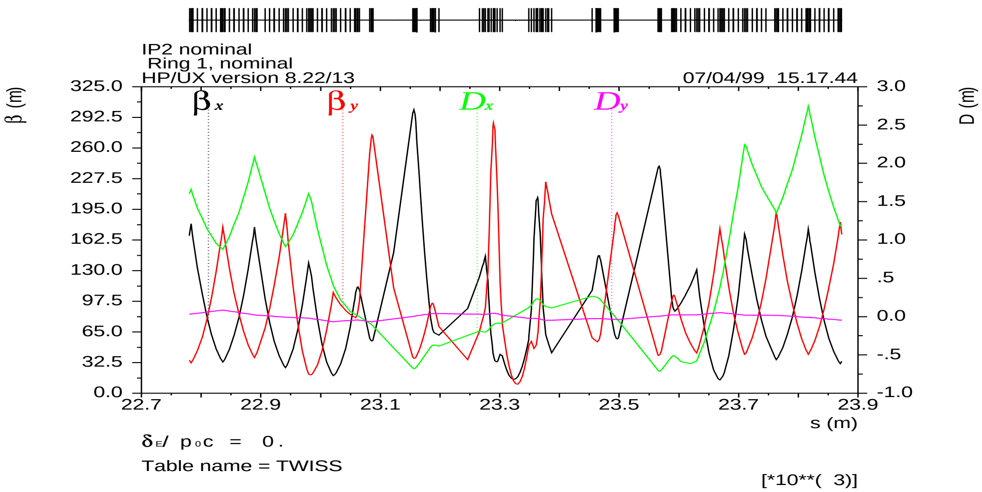
## Figure captions

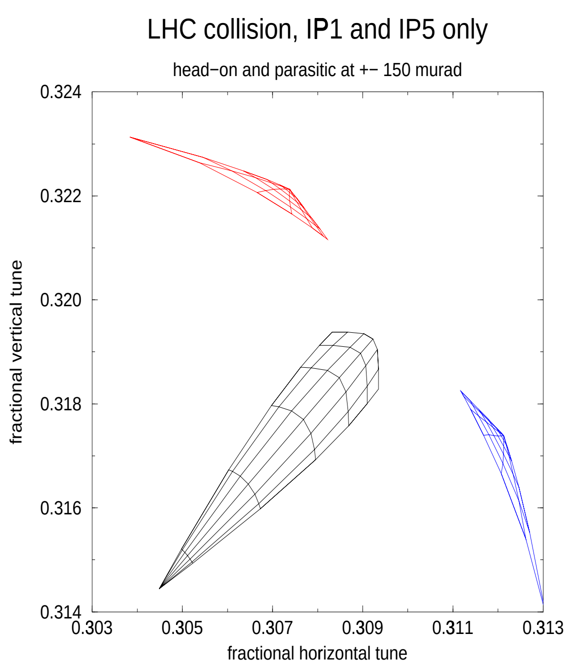
1. Orbit of nominal LHC collision with full beam-beam at $\pm 150 \mu rad$
2. Same as above, Twiss parameters near IP1
3. Same as above, Twiss parameters near IP2
4. Footprints of head-on in IP1+IP5, parasitic in IP1, and in IP5
5. Full footprints for two angles
6. Full and pacman footprints at nominal angle
7. Full footprints with and without b10 at nominal angle
8. Full footprints with and without missing head-on at IP1
9. Tracking for 100000 turns: full beam-beam and b10 errors, one particle at $5 sigma$, one at $7\sigma$

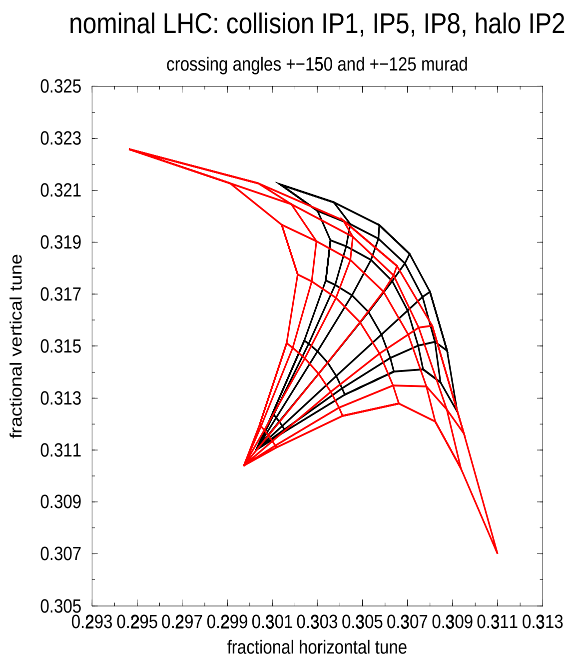
# Figures

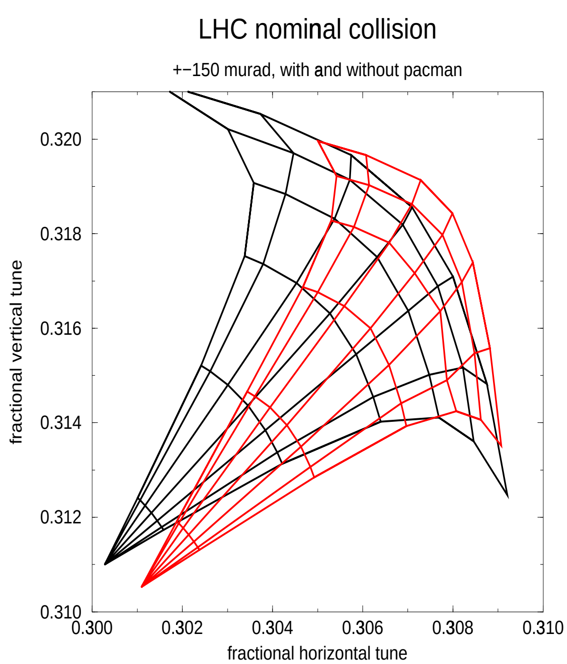

chromaticity correction
HP/UX version 8.22/13
09/04/99 14.23.59
x (m), y (m)
x
y
.008
.006
.004
.002
0.0
-.002
-.004
-.006
-.008
0.0
5.0
10.0
15.0
20.0
25.0
30.0
s (m)
δE/ p0c = 0.
Table name = TWISS
[*10**( 3)]

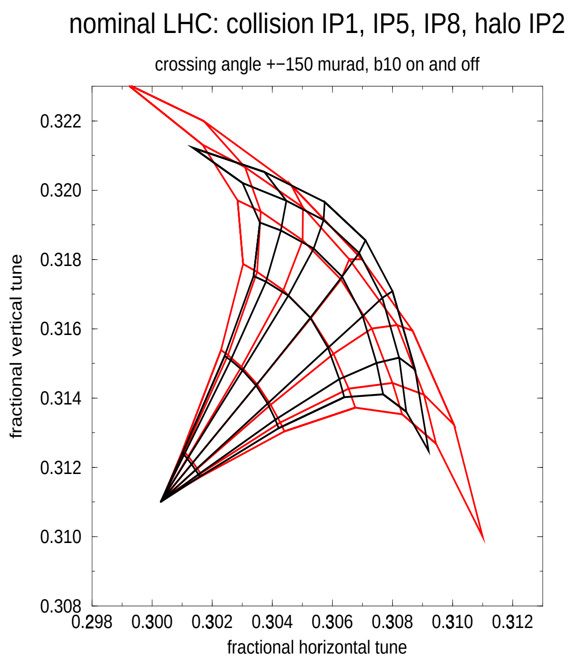

IP1 nominal
Ring 1, nominal
HP/UX version 8.22/13
07/04/99 15.17.44
β (m)
D (m)
βx
βy
Dx
Dy
5000.
4500.
4000.
3500.
3000.
2500.
2000.
1500.
1000.
500.
0.0
3.0
2.5
2.0
1.5
1.0
.5
0.0
-.5
-1.0
-1.5
-2.0
19.4
19.6
19.8
20.0
20.2
20.4
20.6
s (m)
δE/ p0c = 0.
Table name = TWISS
[*10**( 3)]

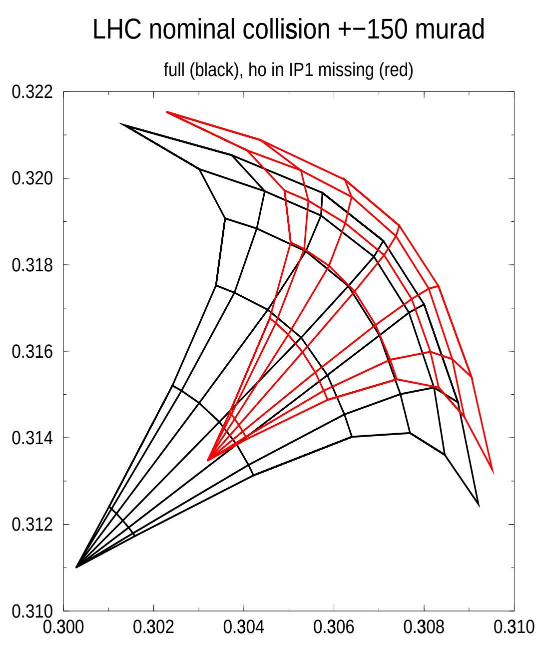

IP2 nominal
Ring 1, nominal
HP/UX version 8.22/13
07/04/99 15.17.44
β (m)
D (m)
βx
βy
Dx
Dy
325.0
292.5
260.0
227.5
195.0
162.5
130.0
97.5
65.0
32.5
0.0
3.0
2.5
2.0
1.5
1.0
.5
0.0
-.5
-1.0
22.7
22.9
23.1
23.3
23.5
23.7
23.9
s (m)
δE/ p0c = 0.
Table name = TWISS
[*10**( 3)]

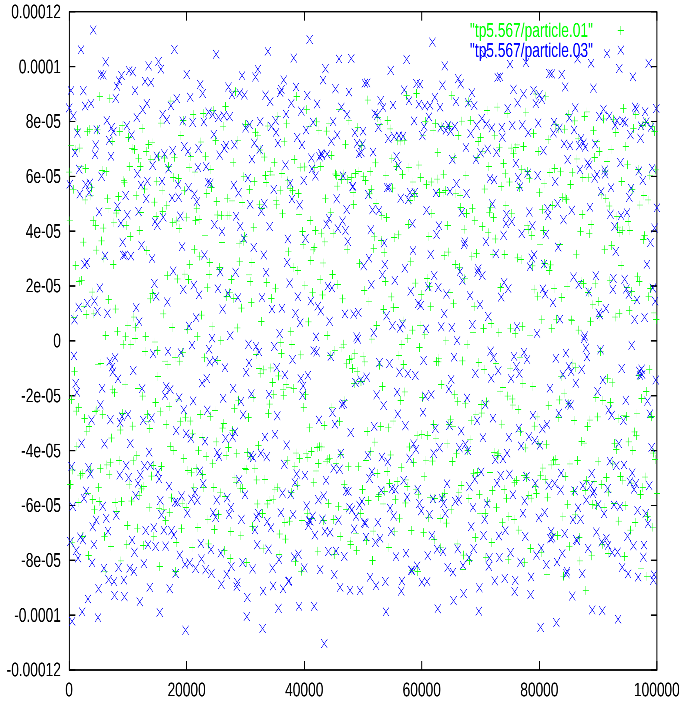

LHC collision, IP1 and IP5 only
head−on and parasitic at +− 150 murad
fractional vertical tune
fractional horizontal tune
0.324
0.322
0.320
0.318
0.316
0.314
0.303
0.305
0.307
0.309
0.311
0.313


nominal LHC: collision IP1, IP5, IP8, halo IP2
crossing angles +−150 and +−125 murad
fractional vertical tune
fractional horizontal tune
0.325
0.323
0.321
0.319
0.317
0.315
0.313
0.311
0.309
0.307
0.305
0.293 0.295 0.297 0.299 0.301 0.303 0.305 0.307 0.309 0.311 0.313


LHC nominal collision
+−150 murad, with and without pacman
fractional vertical tune
fractional horizontal tune
0.320
0.318
0.316
0.314
0.312
0.310
0.300 0.302 0.304 0.306 0.308 0.310


nominal LHC: collision IP1, IP5, IP8, halo IP2
crossing angle +−150 murad, b10 on and off
fractional vertical tune
fractional horizontal tune
0.322
0.320
0.318
0.316
0.314
0.312
0.310
0.308
0.298
0.300
0.302
0.304
0.306
0.308
0.310
0.312


LHC nominal collision +−150 murad
full (black), ho in IP1 missing (red)
0.322
0.320
0.318
0.316
0.314
0.312
0.310
0.300
0.302
0.304
0.306
0.308
0.310


"tp5.567/particle.01"
"tp5.567/particle.03"
0.00012
0.0001
8e-05
6e-05
4e-05
2e-05
0
-2e-05
-4e-05
-6e-05
-8e-05
-0.0001
-0.00012
0
20000
40000
60000
80000
100000