Collective beam-beam effects in the LHC

Proposed topics for IPAC 2012

The LHC in 2011/2012

- Energy was 3.5 TeV, now 4.0 TeV

- Limitations from machine protection, aperture and electron cloud:

  - Bunch spacing 50 ns (max. 1380 bunches)
  - Larger $\beta^* = 1.0$ m (2012: 0.6 m)

- Emittances <u>smaller</u> than nominal ($\approx$ 1.5 - 2.5 μm)

- In very first collisions at injection energy: nominal beam-beam parameter/tune shift exceeded !

- How far can we push the beam-beam parameter ?

Observations: head-on beam-beam effects I

- **First dedicated experiment with few bunches**

- **Test <u>maximum beam-beam parameter</u> (at injection energy) - head-on only**

  - ▷ **Intensity $1.9 \cdot 10^{11}$ p/bunch**

  - ▷ **Emittances 1.1 - 1.2 μm**

  - ▷ **Achieved:**
    $\xi = 0.017$ for single collision ($\approx$ 5 times nominal !)
    $\xi = 0.034$ for two collision points (IP1 and IP5)

  - ▷ **No obvious emittance increase or lifetime problems during collisions (maximum ξ not yet found)**

Strong-strong: coherent modes

- Coherent beam-beam modes have been observed colliding few bunches

- Provide high degree of symmetry
  - ▷ Demonstrated by analysis of sum and difference signals between bunches (X. Buffat, IPAC11)
  - ▷ Symmetry breaking suppresses modes as expected

- But not (yet) a problem for operation
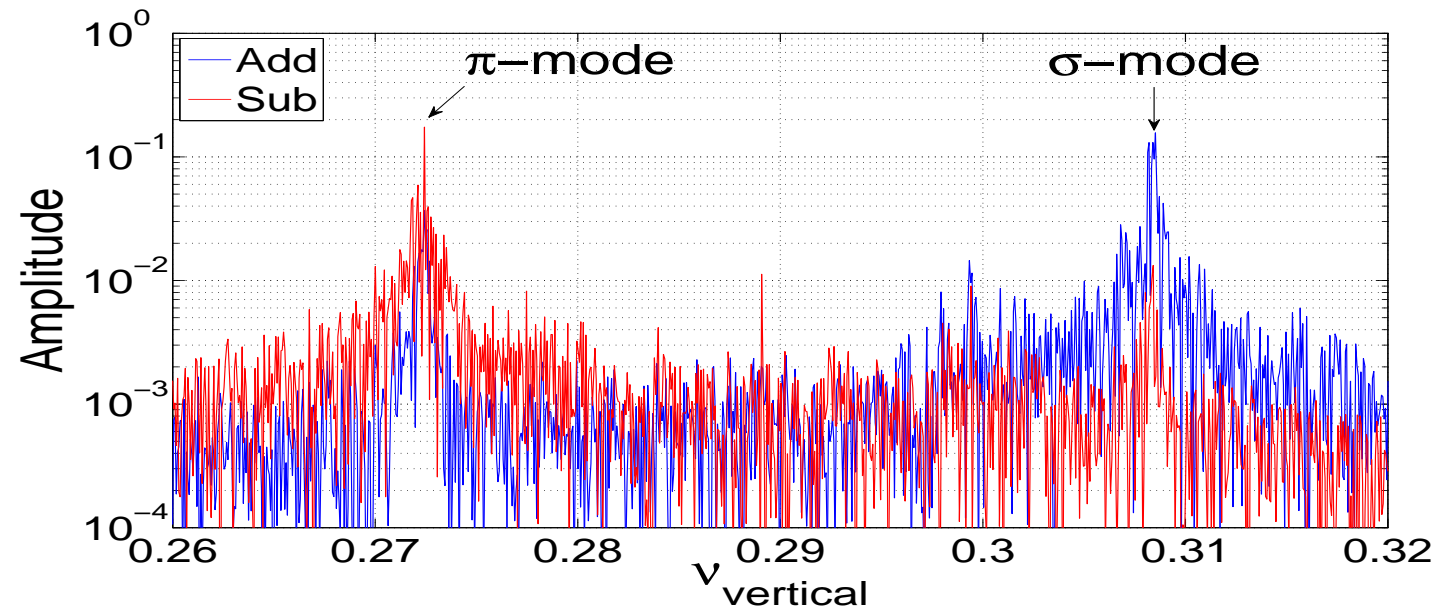
- Transverse feedback used

Coherent beam-beam modes
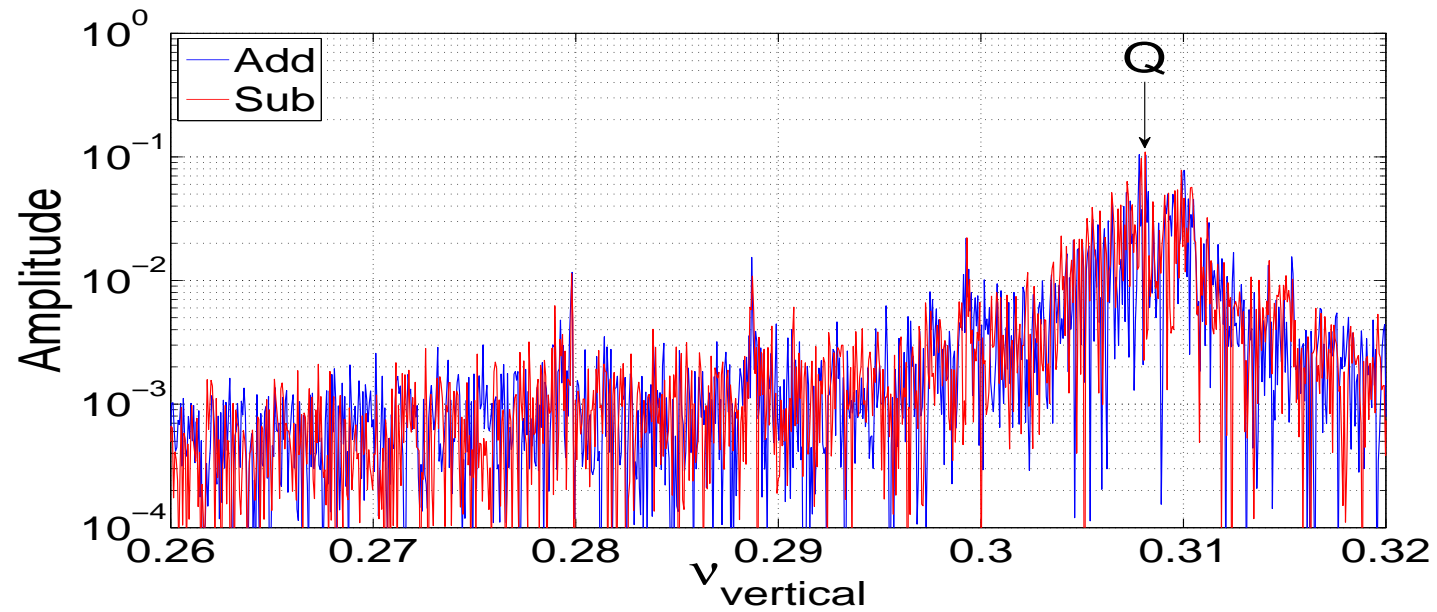
Courtesy X. Buffat

- Signal without beam-beam collisions

Coherent beam-beam modes

Courtesy X. Buffat

- Sum and difference signals

- Clearly observed and identified coherent beam-beam modes

Beam-beam Orbit effects

▣ **Strong beam-beam interaction with static offset produces coherent dipole kick**

  ➤ Orbit changes due to beam-beam kick

  ➤ Used for LEP: deflection scan

  ➤ Expect strong effect for reduced separation

▣ **What about orbits for PACMAN bunches ?**

  ➤ Different kicks - different orbits

  ➤ Cannot be fully compensated by alternating crossing schemes (but minimized and made symmetric) !
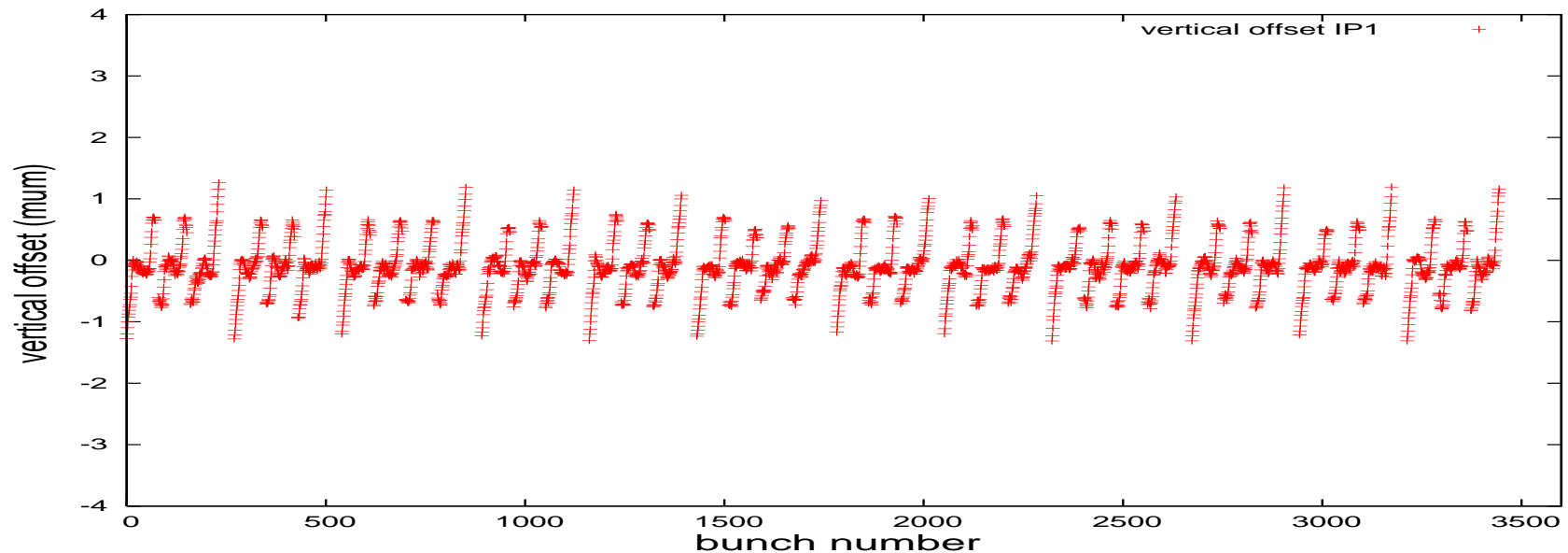
Orbit effects measured

Absolute amount of the change in position w.r.t. to bunch 100 at BPM.6L1.B1, B1-HOR
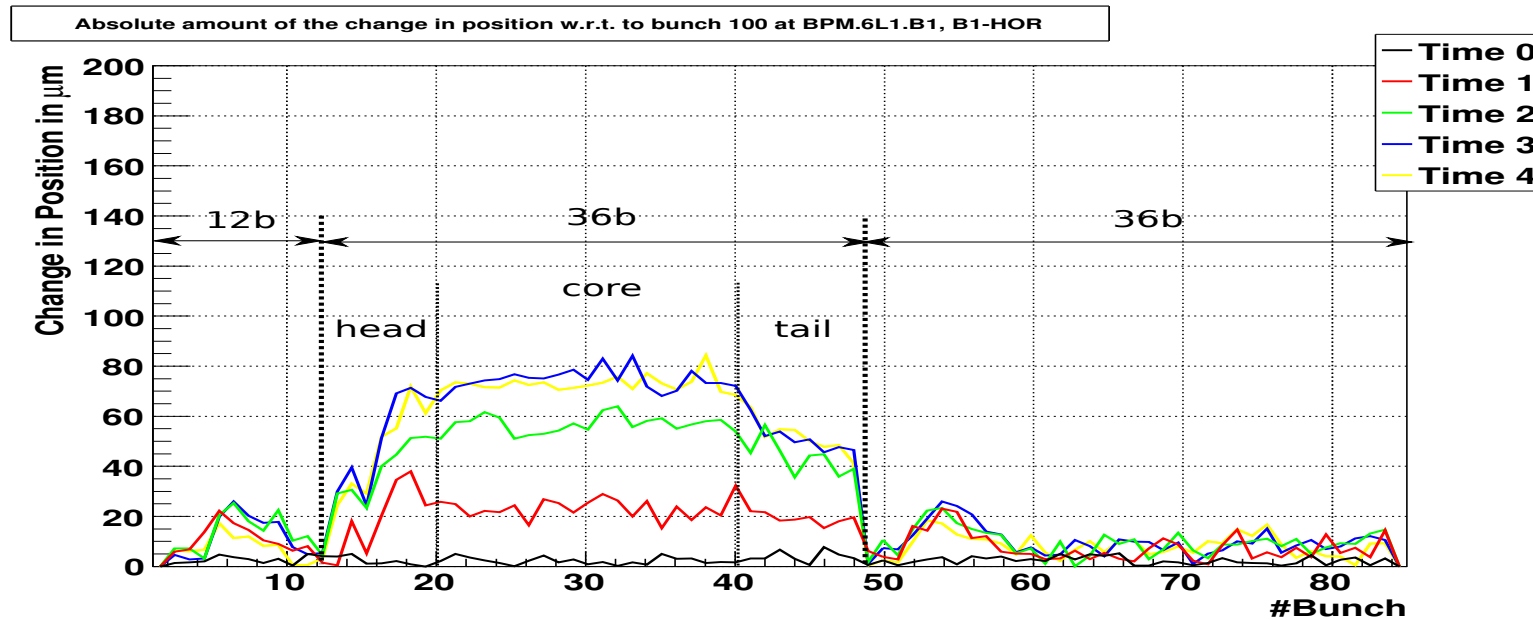
Courtesy M. Schaumann

- Orbit changes for different steps in separation

- Measurement at on BPM

- Changes only for bunches colliding in IP1 and IP5
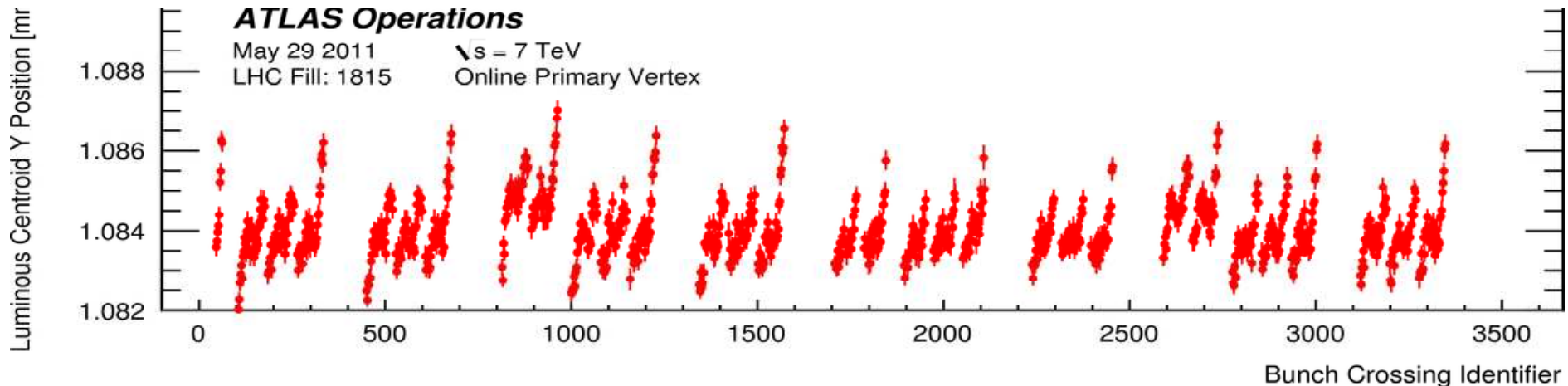
PACMAN Orbit effects: calculation

➡ In regular operation: offsets expected at collision point

➡ Predicted orbits from self-consistent computation, here vertical IP1 (H. Grote, W. Herr, 2001)

➡ Cannot be resolved with beam position measurement, but ..

PACMAN Orbit effects: observation

➡ **Measurement of vertex centroid by ATLAS (IP1)**

➡ **Qualitatively: follows exactly predicted behaviour**

➡ **Must be kept under control (sufficient separation) !**