LHC beam behaviour ...

(beam dynamics part, an attempt)

W. Herr

Beam behaviour in 2009 running

More precise: behaviour of stored (quiet) beam(s) (others are covered in separate presentations)

- Behaviour with one beam
- Behaviour with two beams
  - Some beam-beam observations have been reported ..
  - Do we already observe beam-beam effects ?
- Any obstacles for high luminosity at 3.5 TeV ??

Single beam behaviour (at low intensity)

- **Possible issues: life time and beam loss due to e.g.:**
  - **Non-optimized parameters (tunes, chromaticity, coupling ...) systematic studies required**
  - **Non-linear imperfections at injection energy**
  - **...**
  - **???**
- **For LEP addicts: this is a hadron machine ...**
  - **Practically no damping**
  - **Noise !**

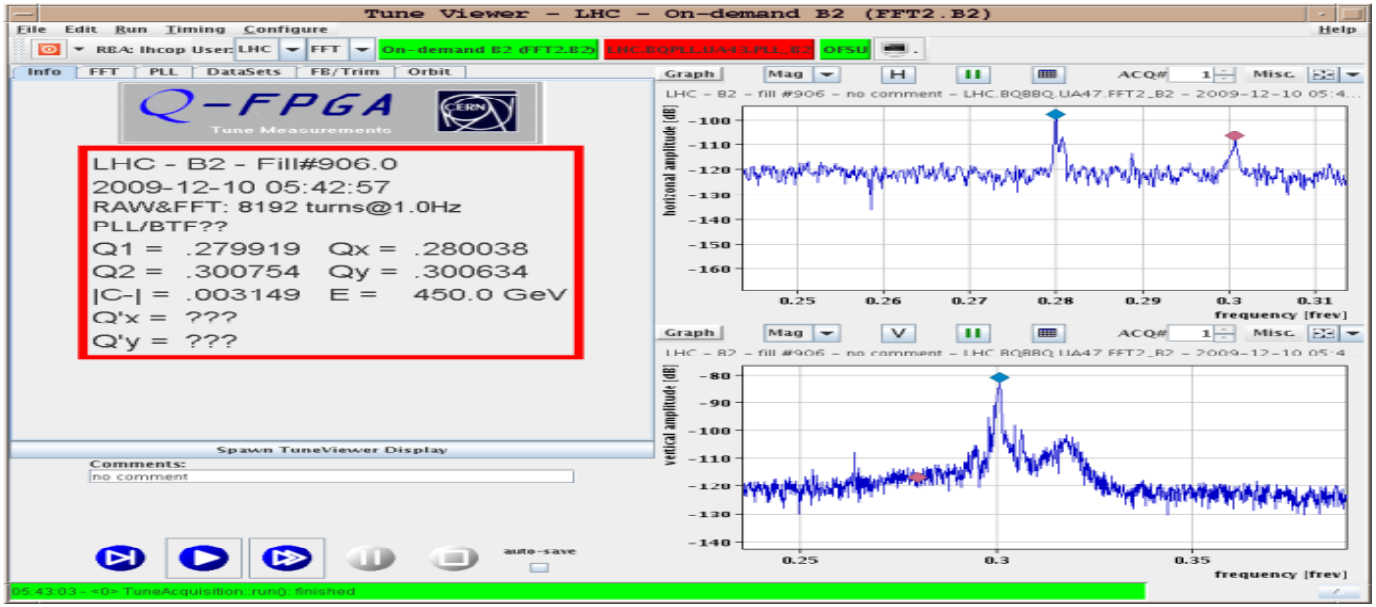
Single beam behaviour

- **Life time at injection without (much) optimization astonishingly good**
  - **Non-linear imperfections well understood and well corrected**
  - **Emittances smaller than expected**
  - **Non-linear imperfections not as relevant as believed**
  - **...**

Tunes used

- **Originally: nominal tunes (0.28, 0.31) used**
- **Appearance of vertical 'noise' around 0.31**
- **Vertical tune lowered to $\approx$ 0.30**
- **Horizontal and vertical tunes swapped**
- **Systematic study needed**
- **Good news: seems robust to tune changes**
- **Bad news: this will change !**

Tune diagram and used tune



- Appearance of vertical 'noise' around 0.31
- Collisions will make it appear in both beams
- Needs to be solved (potential obstacle)

Beam-beam effects in 2009 running

- Maximum 16 bunches per beam
- No bunch trains - no crossing angle
  - No long range parasitic encounters
  - Only head-on beam-beam effects

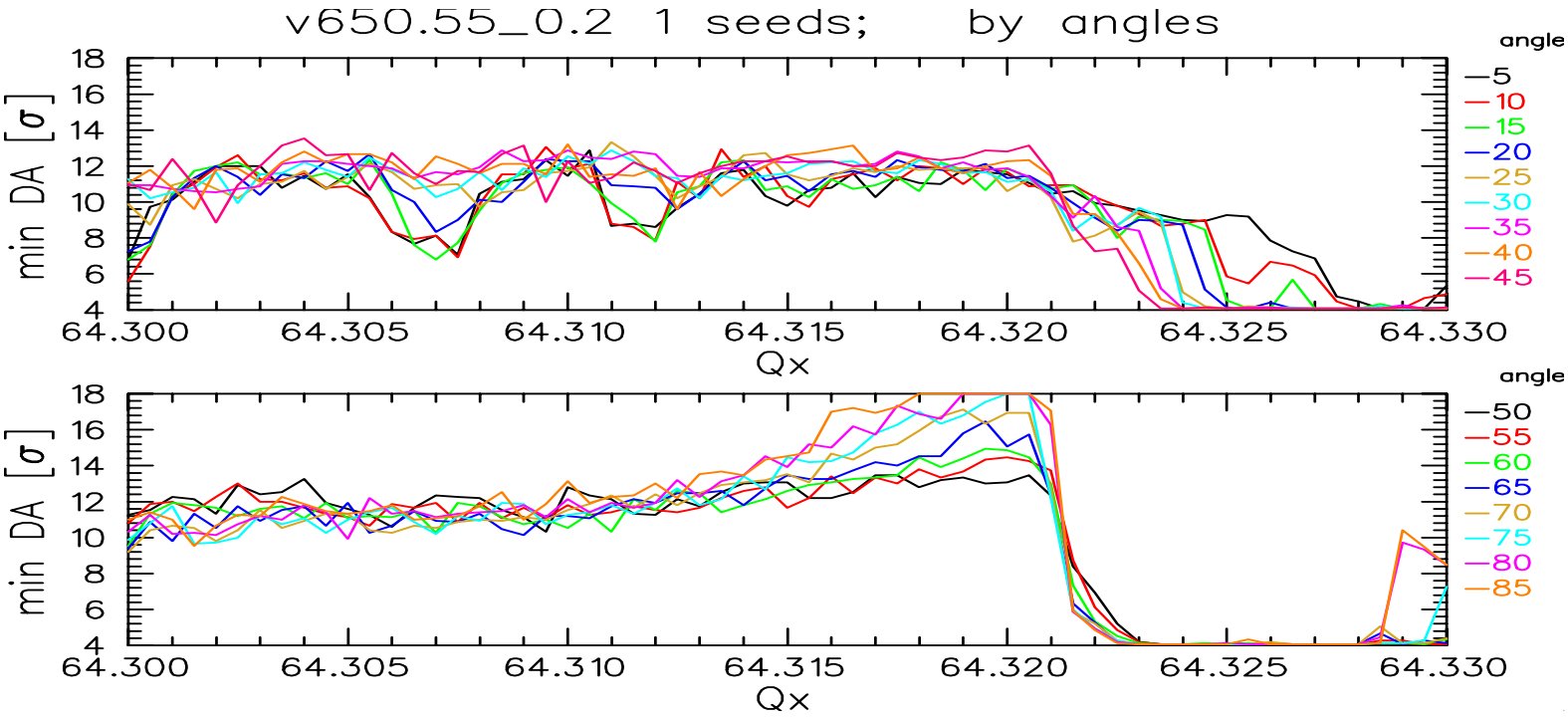
Beam-beam effects in 2009 running

- **Remember: Head on beam-beam effects do not depend on energy and β^***
  - **Only on intensity and normalized emittance !**
  - **With nominal emittance and N $\approx$ 2·10^{10}**
  - **Linear beam-beam parameter about $\xi \approx$ 0.0006**
  - $cos(2\pi(Q + \Delta Q)) = cos(2\pi Q) - 2\pi\xi sin(2\pi Q)$
  - **For our tunes: $\Delta Q \approx \xi$ per IP**
  - **Visible effects expected**

Possible beam-beam effects in 2009 running

- **Global tune change of the opposing beam by about $\Delta Q \approx 0.0006 \cdot N_{ip}$**
  - **Tune of second beam not optimized, lower lifetime possible**
  - **These are typical tune changes done during $Sp\bar{p}S$ operation (and Tevatron ...)**

Tune sensitivity with beam-beam



- **Dynamic aperture: tune scan with beam-beam for the LHC ...**

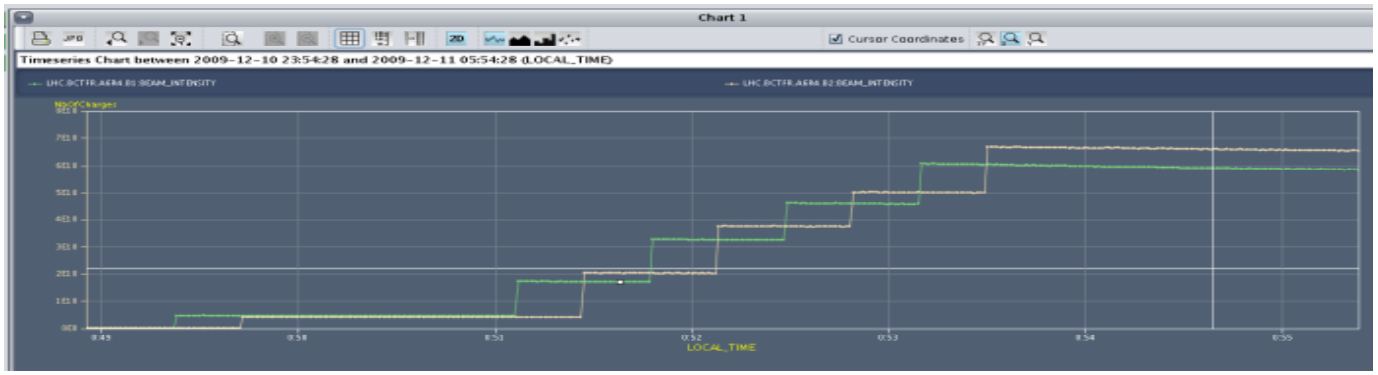
Possible beam-beam effects in 2009 running

- **Global tune change of the opposing beam by about $\Delta Q \approx 0.0006 \cdot N_{ip}$**
  - **Tune of second beam not optimized, lower lifetime possible**
  - **These are typical tune changes done during $Sp\bar{p}S$ operation**
  - **Lesson: we need the tune space for optimization !**
- **Loss of dynamic aperture due to non-linear beam-beam effects**
  - **Very unlikely for this intensity, ... unless**

Possible beam-beam effects in 2009 running

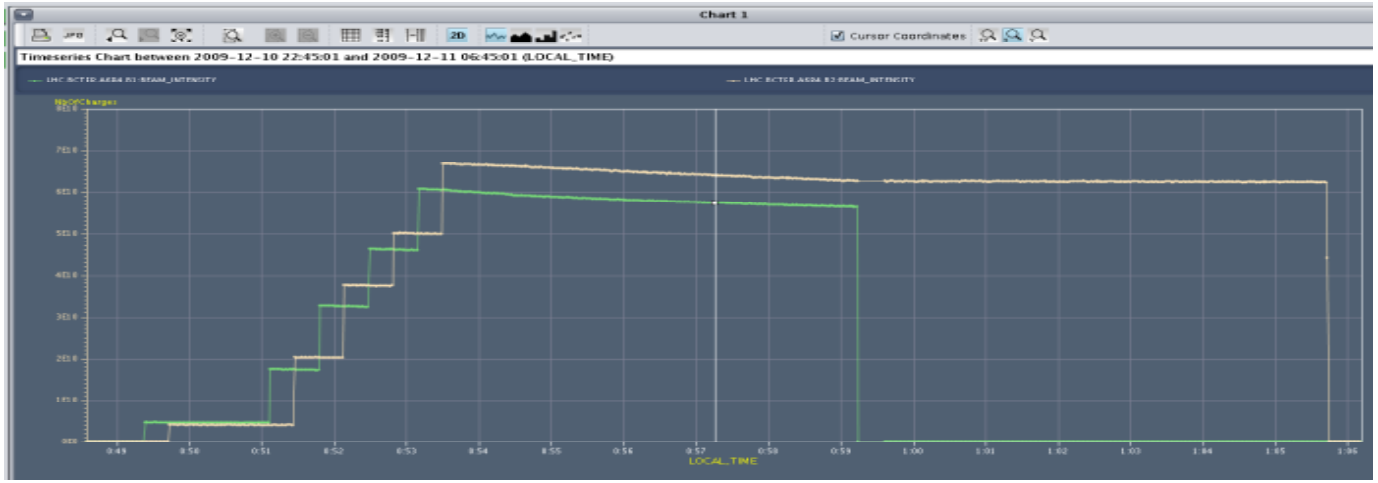
- **Unequal beam sizes**
  - **Leads to bad lifetime of <u>one</u> beam (β-beat can become a problem)**
  - **Was a problem $Sp\bar{p}S$ and HERA operation**
- **Offset collisions**
  - **Leads to emittance growth and tune changes**
- **Noise (e.g. ripple, tune or orbit modulation, ...)**
  - **Leads to emittance growth and reduced life time**

4 on 4 bunches



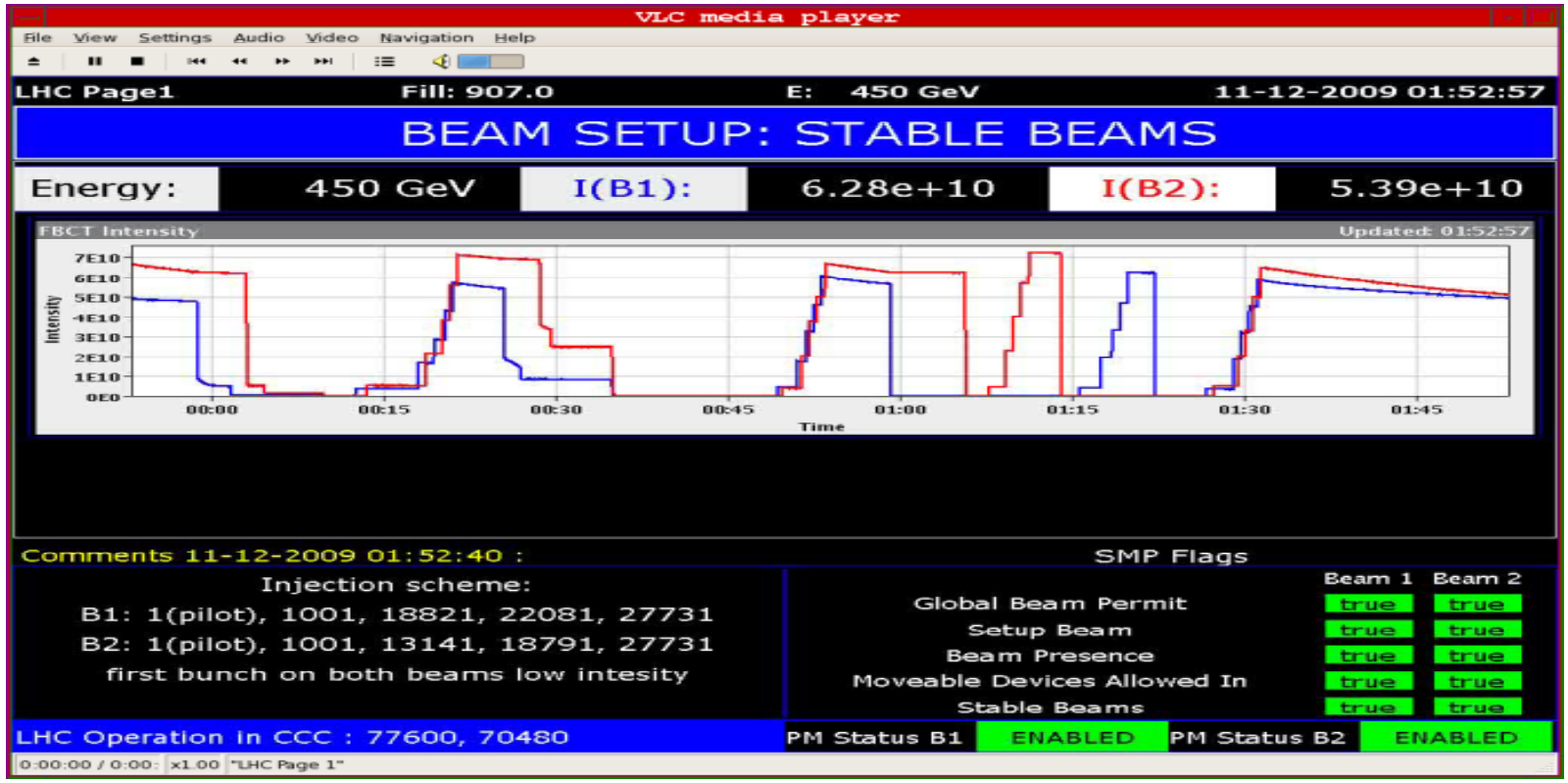
- **Injection process 4 bunches on 4 bunches, without separation**

4 on 4 bunches



- Dump of one beam improved lifetime of remaining beam

Filling with 4.5 on 4.5 bunches



- Dump of one beam improved lifetime of remaining beam

4 on 4 bunches

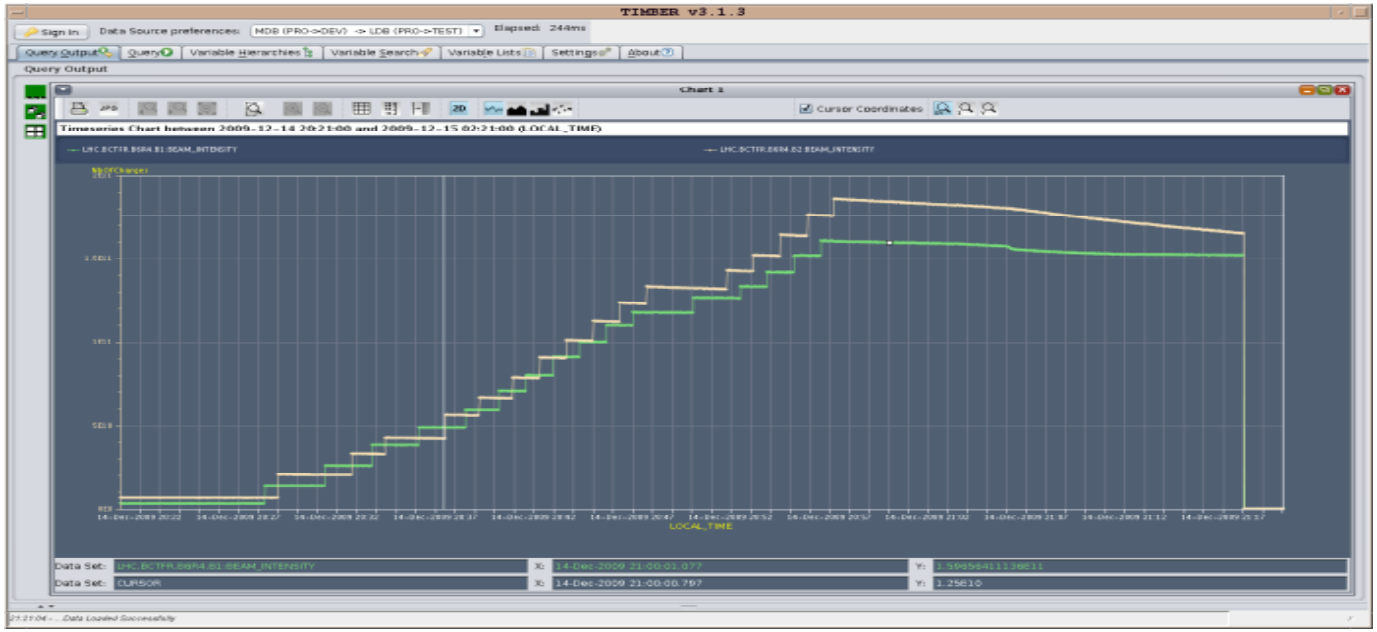
- **Do we expect anything like that ?**
  - **Any second beam in the machine changes beam parameters !**
  - **Therefore: dumping one beam can (should !) make the other beam better or worse (depending on the potd) (this is not LEP)**
- **But: which one of the bunches ???**

Are 4 on 4 bunches interesting ?

- **Accidentally yes, with the present filling scheme*):**
  - **2 bunches with 1, 1 bunch with 2, 1 bunch with 4 collisions**
  - **Ideal situation to study and observe beam-beam effects (but inefficient for physics)**
  - **... provided we get close to nominal intensities !**
  - **... provided we can measure individual bunches !**

*) **equal number of collisions in all experiments**

16 on 16 bunches



- Injection of 16 on 16 bunches
- Separation bump on (except IP8)

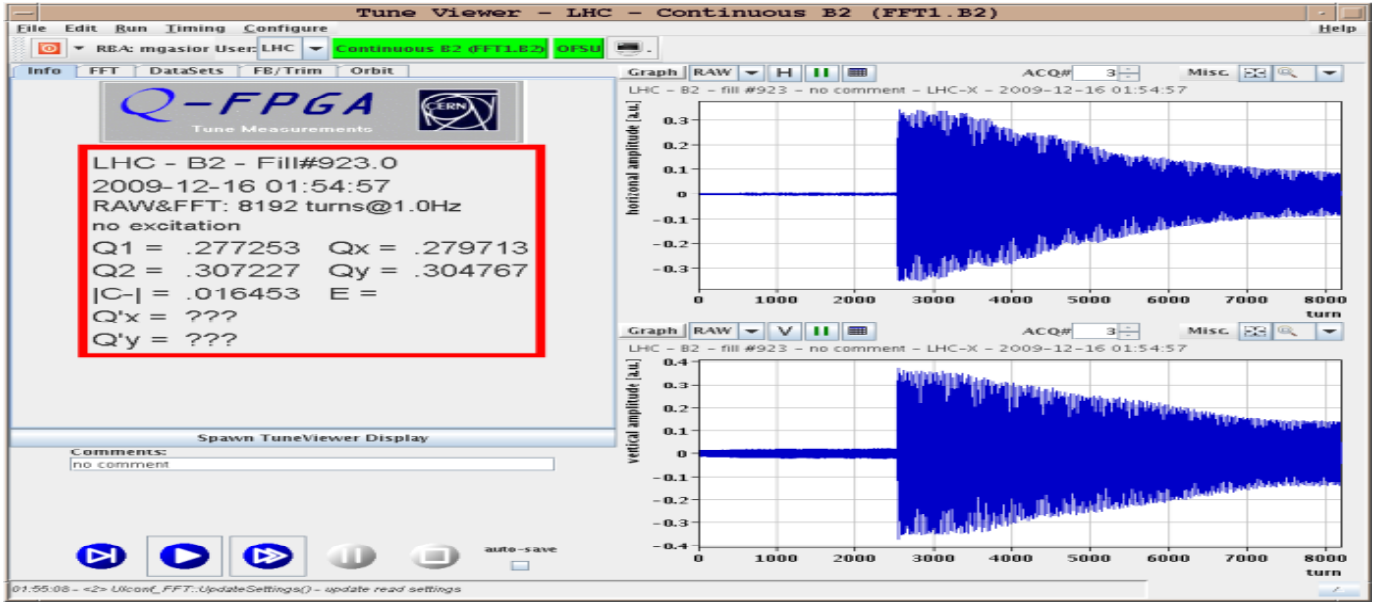
16 on 16 bunches

- Injection of 16 on 16 bunches
- In case of life time problems:
  - From which bunch ?
  - Remember:

    8 bunches see 1 collision !

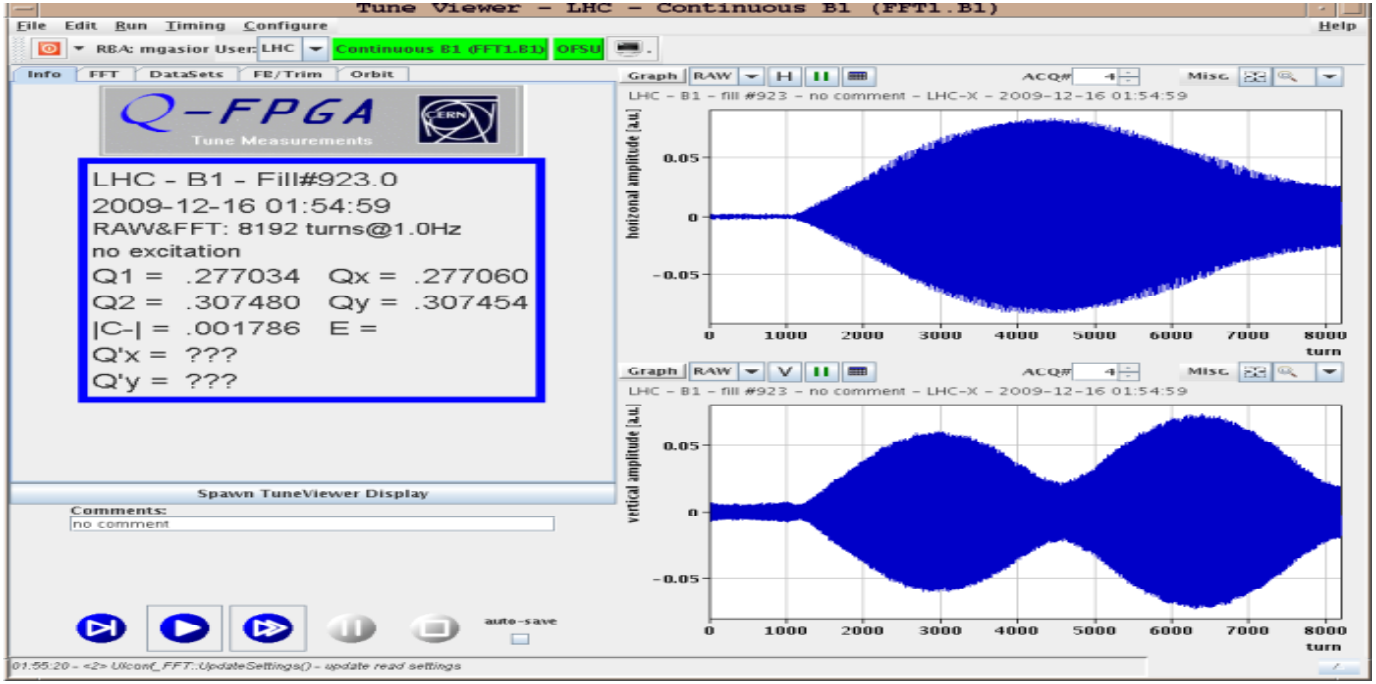
    8 bunches see 3 collisions !
- Single bunch diagnostics needed to study details
  - Life time, available in LDB
  - Collision schedule and details (from web page)

Coupling through beam-beam kick



- **Beam 2 was kicked**

Coupling through beam-beam kick



- Beam 1 was observed

Coupling through beam-beam kick

- **Do we expect it ?**
- **When can it happen ?**
- **Do we have to worry (e.g. emittance increase) ?**

Coupling through beam-beam kick

- **Do we expect it ?**
  - **Sure, beam gives a dipolar (coherent) kick to the other beam, see e.g. W.Herr, CERN-SL/91-34 (1991)**
  - **Depends on intensity**
  - **Amplitude small**

Coupling through beam-beam kick

- **When can it happen ?**
  - **When the beams are colliding (head on)**
  - **(Few) long range interactions to small for a visible effect**
  - **Only reproducible when beams are colliding well**

Coupling through beam-beam kick

- **Do we have to worry ?**
  - **When we have stable (quiet) beams - no**
  - **When the beams are moving (ramp, squeeze) - yes**
- **Therefore:**
  - **Separate the beams unless you really want collisions (especially for higher intensities, i.e. above $2 - 3 \cdot 10^{10}$ p/bunch)**
  - **Separate the beams for measurements (unless you measure Beam-Beam-Transfer-Function, e.g. see RHIC)**

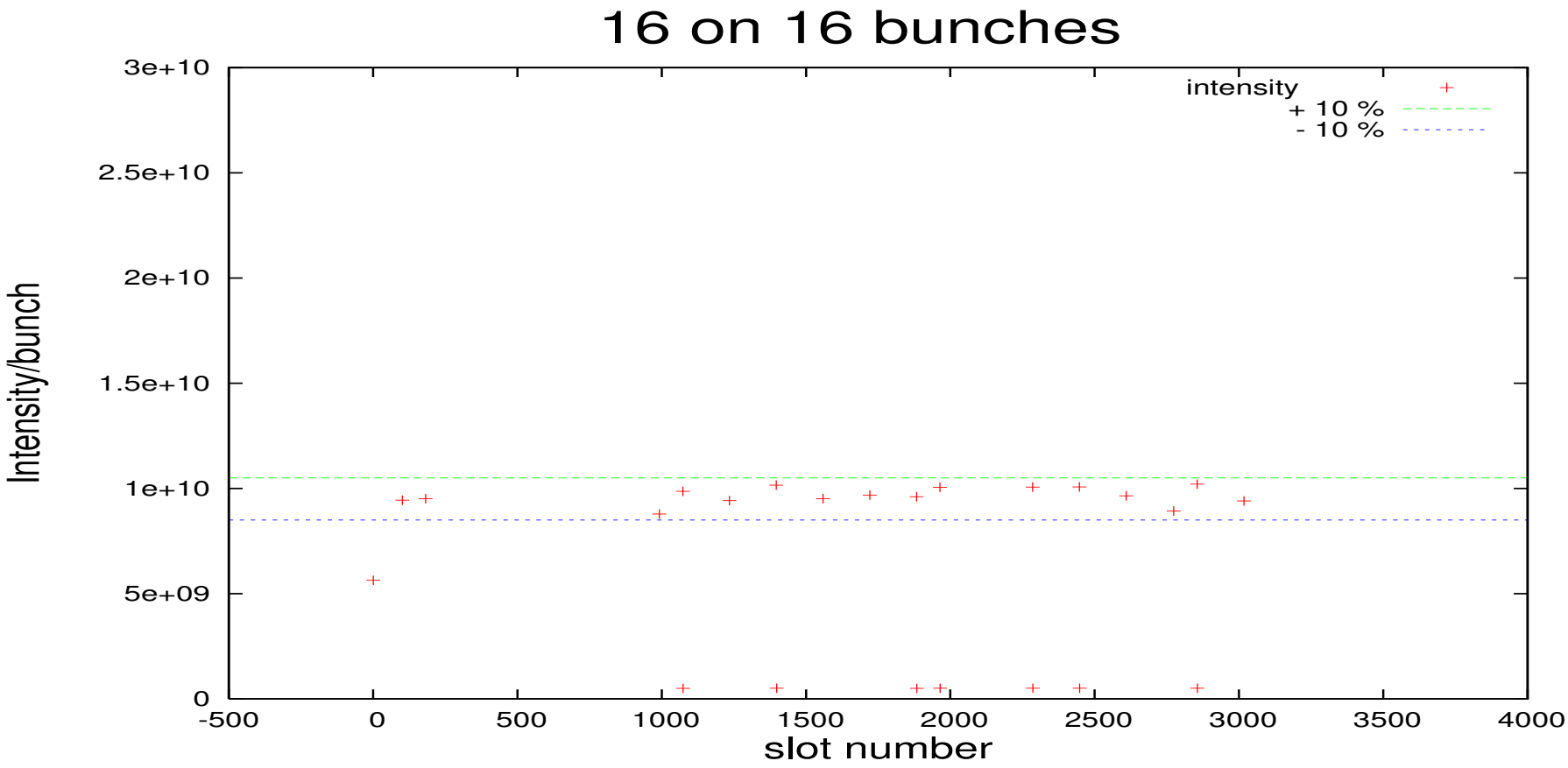
Beam-beam effects

- Do we have coherent beam-beam effects ?
  - Additional peaks have been reported
  - Tune change much too small to distinguish coherent modes
  - Tune spread not yet dominated by beam-beam interaction

Beam-beam effects

- **Do we have beam-beam effects ? YES (thank God !)**
- **Do we have beam-beam problems ? NO**

Filling with 16 on 16 bunches



Filling with 16 on 16 bunches

- Observations:
  - Spread of intensities well within limit
  - Hope for the same for higher intensities and larger number of bunches

→ Might want some display of bunch intensities

"Multi-bunch" filling

- Setting up of injection very easy even for rather unsymmetric scheme
- Data shown extracted from logging data base and processed
  - Offset by one slot and some ghost data in next slot
  - Fully sufficient for data analysis and online model applications
- Procedures very efficient and allow optimized filling schemes (web page in preparation)

Towards high luminosity at 3.5 TeV

- **Eventually higher intensity and more bunches**
  - **Requires single bunch measurements**
  - **Good control of basic parameters, including correction of β-beating (potential obstacle)**
- **Issues:**
  - **Total stored energy (machine protection)**
  - **Aperture (minimum β^*)**
  - **Number of bunches and crossing angle (long range effects)**

→ **Possible scenarios: later**