Calculating self-consistent beam-beam effects and deriving tolerances

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beam-beam effects

- Tolerances imposed by beam-beam effects on:
  - Crossing and separation scheme (long range)
  - Bunch to bunch fluctuations (beam size, intensity, head-on and long range)
  - Systematic bunch to bunch fluctuations
  - Collision offset ($\leq$ 0.1 σ)
  - Collision scheme (number of head-on and long range)

beam-beam effects

- Head on effects:
  - → Mainly from beam size mismatch and offset (lifetime and emittance growth)
- Long range effects:
  - → Can change beam separation
  - → Requires self-consistent treatment
- Done with the TRAIN[1)] program

[1)] H. Grote, W. Herr "Self-consistent orbits with beam-beam effects"

TRAIN[1)] program:

- It allows:
  - → Any filling and collision scheme
  - → Bunch to bunch variations of intensity and ϵ (random and/or systematic)
- It does:
  - → Compute self-consistent orbits for all bunches
  - → Tunes and chromaticities for all bunches
  - → Optimize overall luminosity (adjustment at individual IPs)
- Compute bunch by bunch luminosities for each IP

[1)] H. Grote, W. Herr "Self-consistent orbits with beam-beam effects"

Filling scheme (used in many other programs)

Filling scheme can be specified like (present nominal):

```
#Number of groups
8
72 0  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 30 0   0 0
72 1  8 0  72 1  8 0  72 1   8 0 72 1  39 0
```

Collision definition

Collision definition done in MAD (using macros), to set:

```
!   set +1 for head on, 0 for off
 on_ho1  = +1 * ho_charge;
 on_ho2  = +1 * ho_charge;
 on_ho5  = +1 * ho_charge;
 on_ho8  = +1 * ho_charge;
!   set +1 for parasitic on, 0 for off
 on_lr1l = +1; on_lr1r = +1;
 on_lr2l = +1; on_lr2r = +1;
 on_lr5l = +1; on_lr5r = +1;
 on_lr8l = +1; on_lr8r = +1;
```

Prepares beam-beam elements at all *potential* encounters, collision schedule defined by filling scheme

Procedure 1

- Run MADX with desired optics and collision
- Provides optics and sectormaps between all encounters
- Define input parameters for TRAIN such as:
  - Filling scheme
  - Bunches to observe (i.e. print detailed results)
  - Definition of fluctuations etc.

Procedure 2

TRAIN algorithm:

- **Read optics, sector maps and filling schemes**
- **Find initial closed orbit (beam-beam off)**
- **Beam size for beam-beam from unperturbed (rather: theoretical) β functions and specified emittances**
- **Iterate in double loop over all bunches (beam-beam on), inner loop with fixed separation ($\equiv$ fixed beam-beam kicks)**
- **If it converged: update encounters (i.e. bunch orbits) and iterate outer loop until all orbits are stable**

Procedure 3

TRAIN algorithm:

- **Now orbits for all bunches (both beams) are known**
- **Then track each bunch pair through second order maps from MADX**
- **Find tunes, chromaticities, offsets at IPs etc.**
- **Optimize overall luminosity by adjusting orbit at each IP (i.e. simulate separation scan)**

TRAIN output

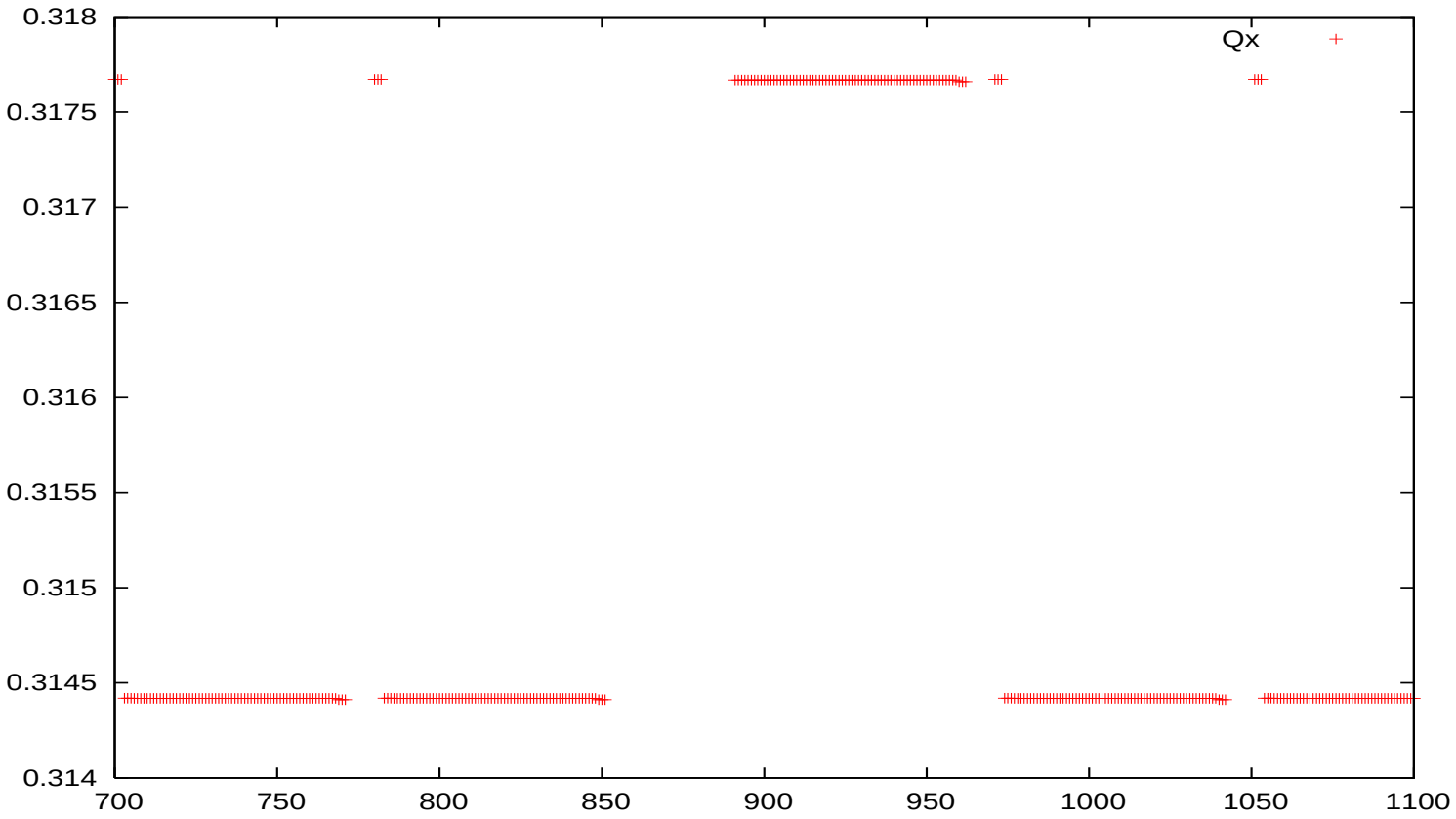
- Orbit and slope for all bunches (both beams) at all IPs
- Tune, chromaticities and dispersion for all bunches
- Luminosity at each IP for every bunch encounter

Example

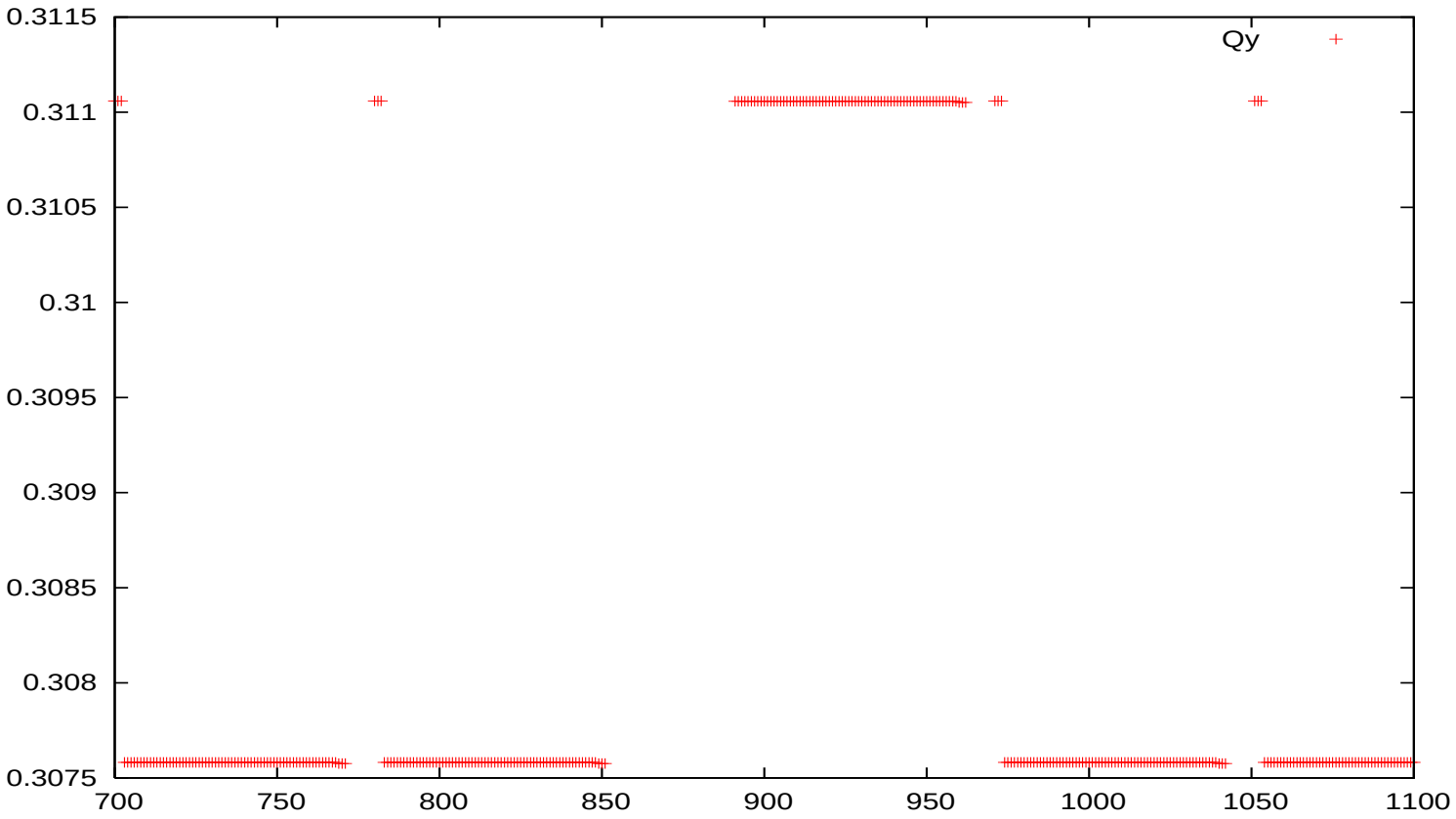
- **Simplest example:**
  - **Nominal filling scheme**
  - **Only head on (?)**
  - **No bunch to bunch fluctuations**
- **Should see effect of abort gap and offset collision point in LHCb, i.e. SUPERPACMAN effects** [1)]

[1)] W. Herr, LHC Project Report 49 (1996)

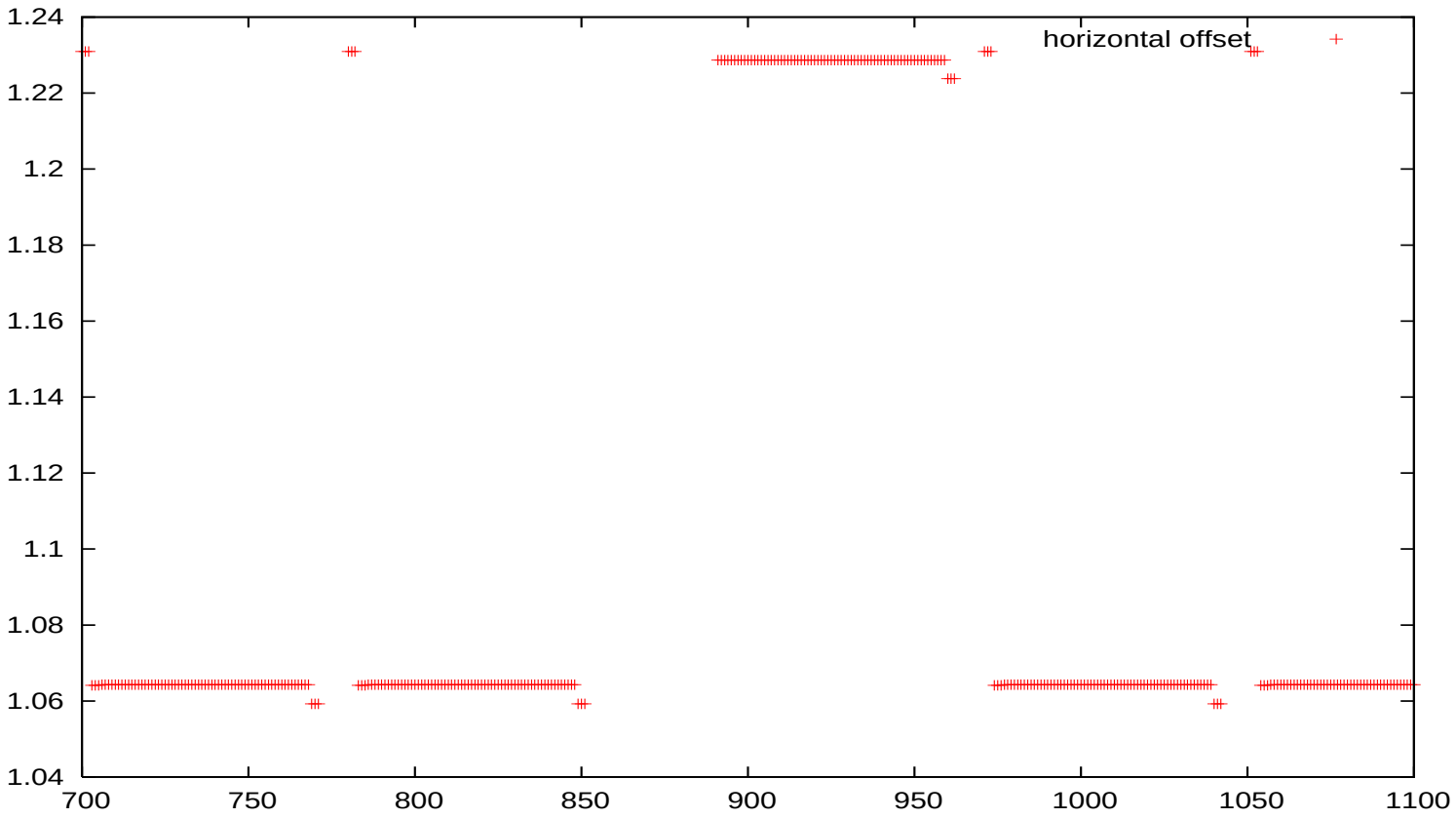
Horizontal tune (head on only)



Vertical tune (head on only)



Horizontal offset - IP1 (head on only)

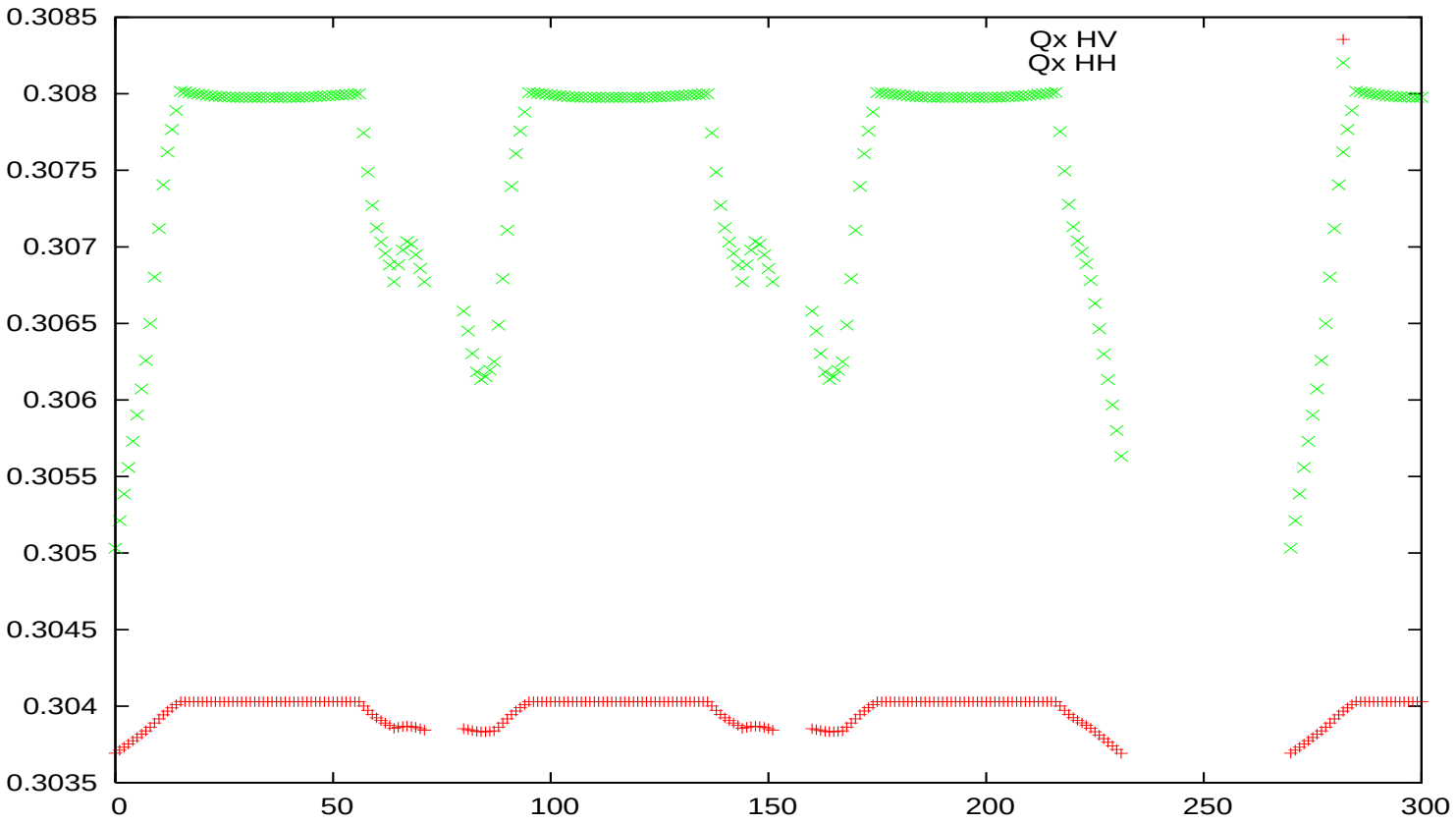


Example

- Next example:
  - Nominal filling scheme
  - Head on and long range in IP1 and IP5
  - No bunch to bunch fluctuations
- Should see effect of alternating crossing[1)]

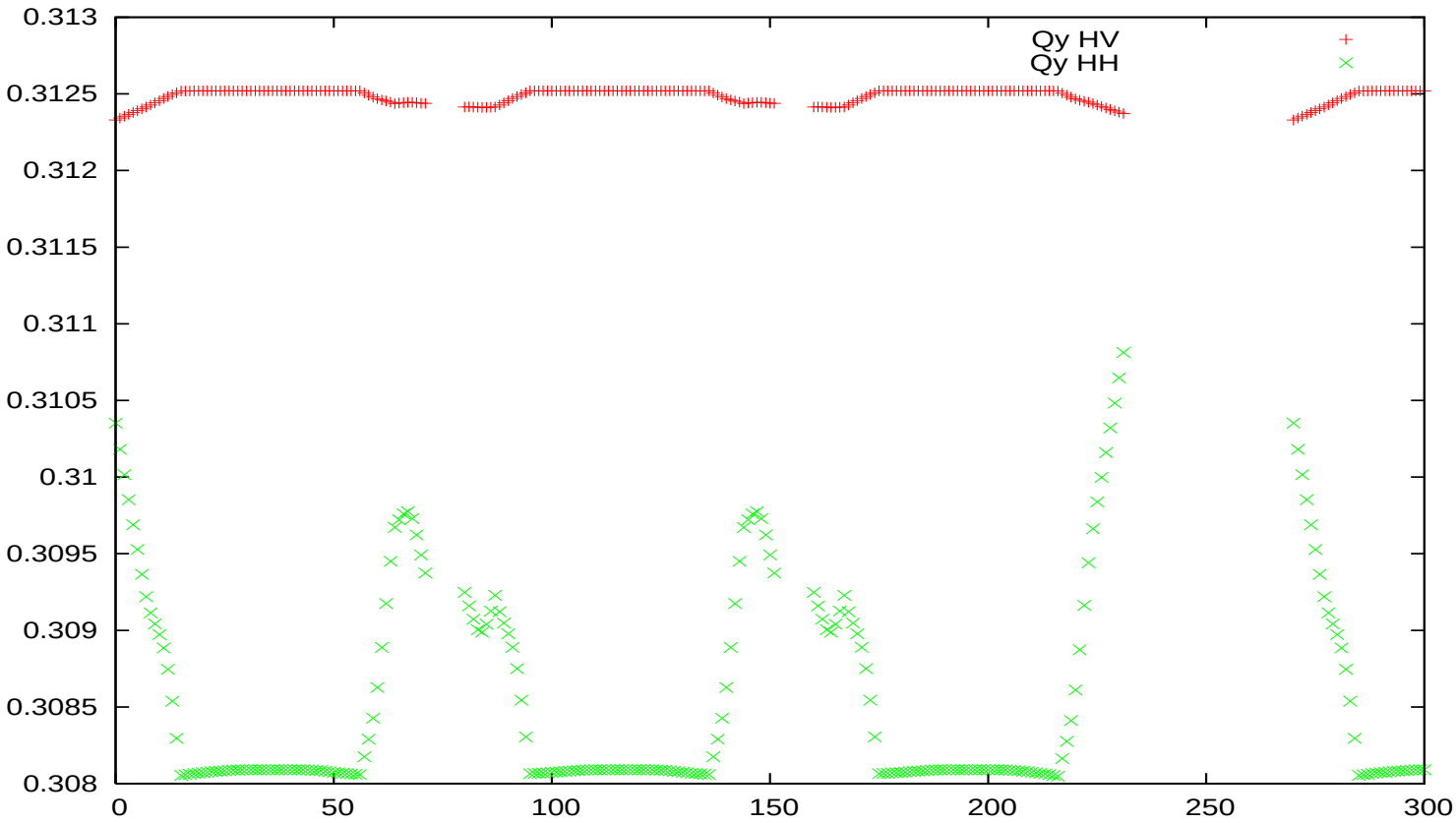
[1)] W. Herr, LHC Project Report 628 (2003)

Horizontal tune (HO + LR) - IP1 and IP5



1) W. Herr, LHC Project Report 628 (2003)

Vertical tune (HO + LR) - IP1 and IP5

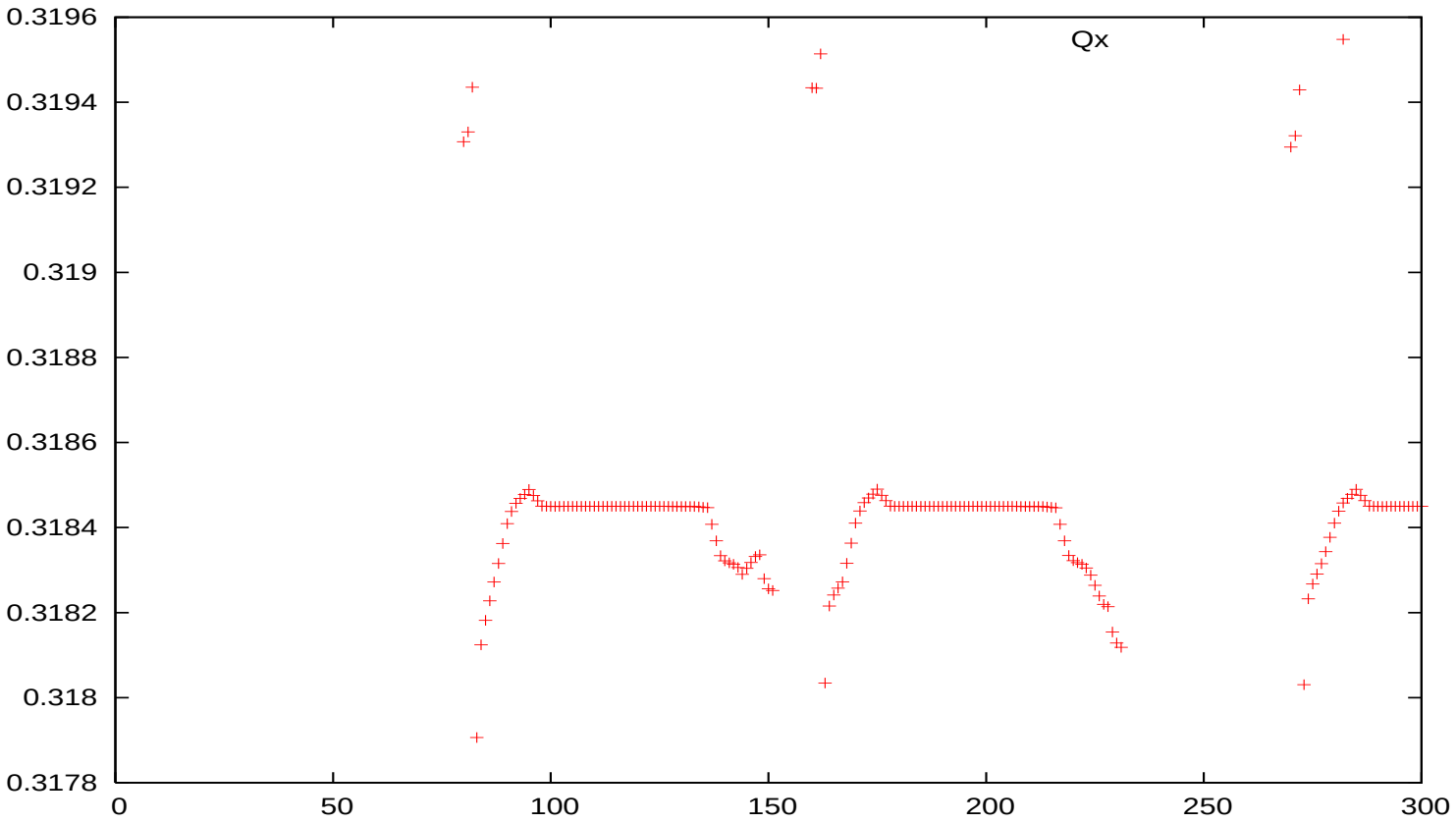


1) W. Herr, LHC Project Report 628 (2003)

All IPs

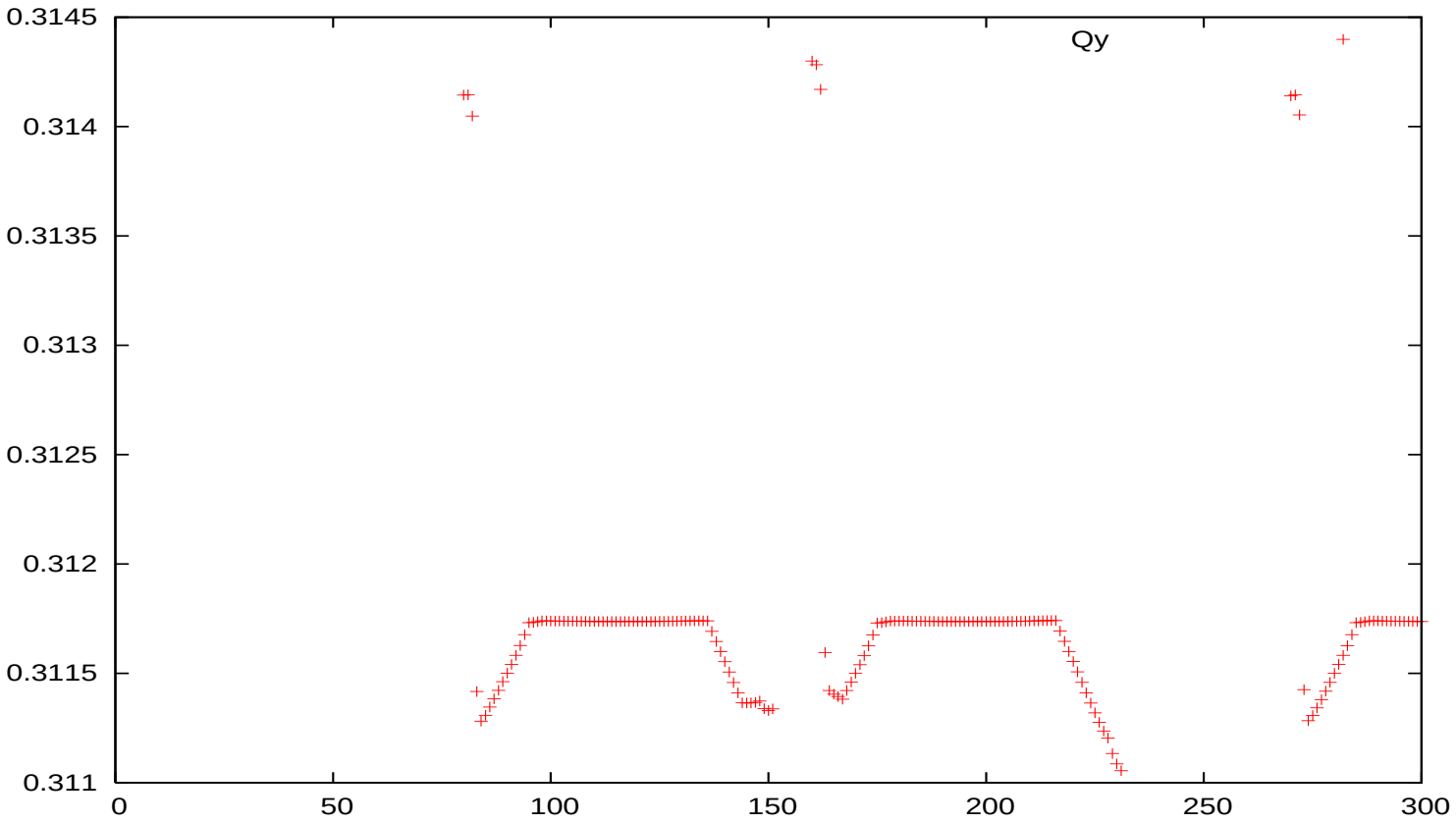
- Next example:
  - Nominal filling scheme
  - Head on and long range in all IPs
  - No bunch to bunch fluctuations
- Should see effect of gaps etc.

Horizontal tune (HO + LR) - all IPs



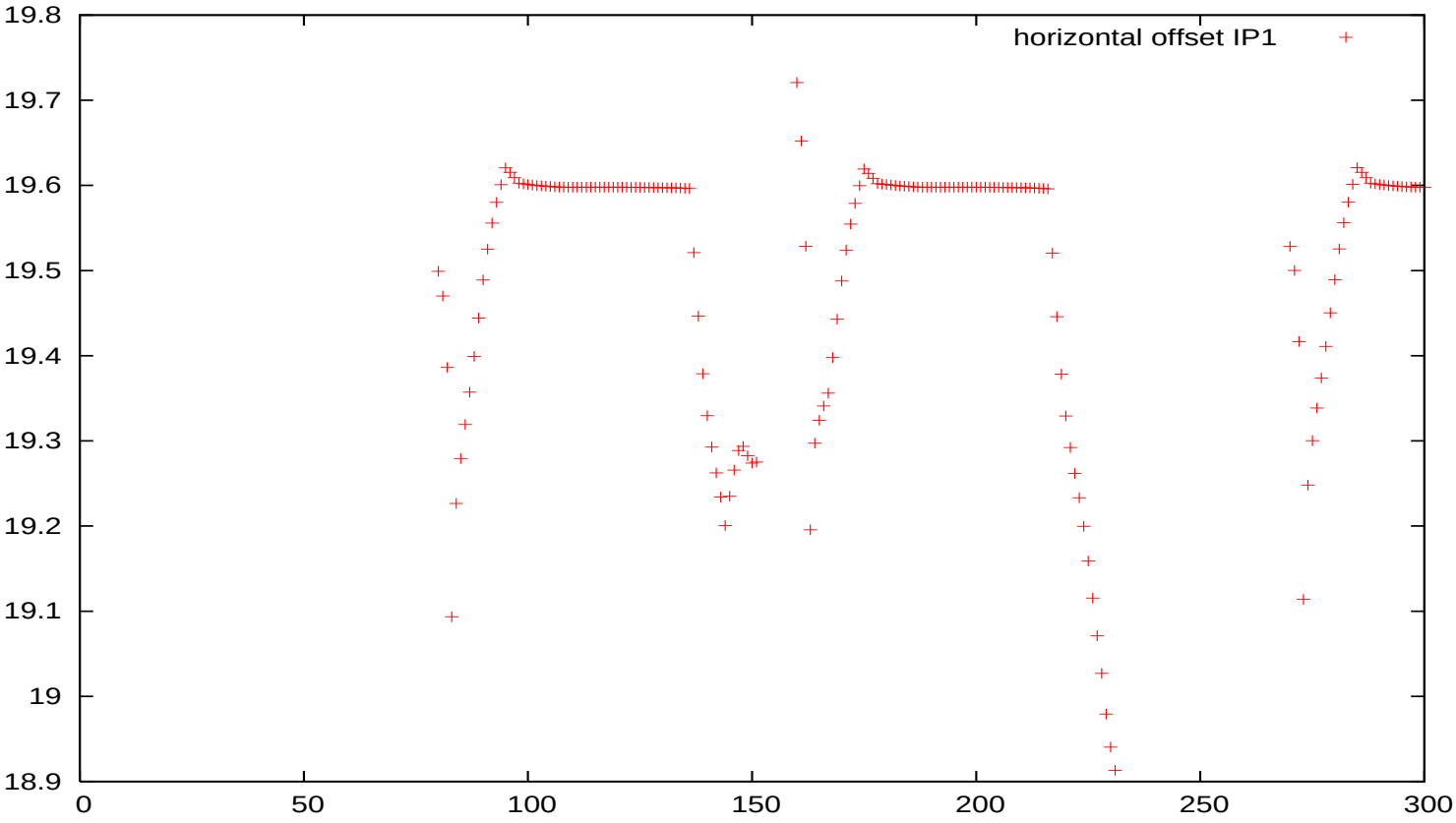
[1] W. Herr, LHC Project Report 628 (2003)

Vertical tune (HO + LR) - all IPs



1) W. Herr, LHC Project Report 628 (2003)

Horizontal offset in IP1 - all IPs

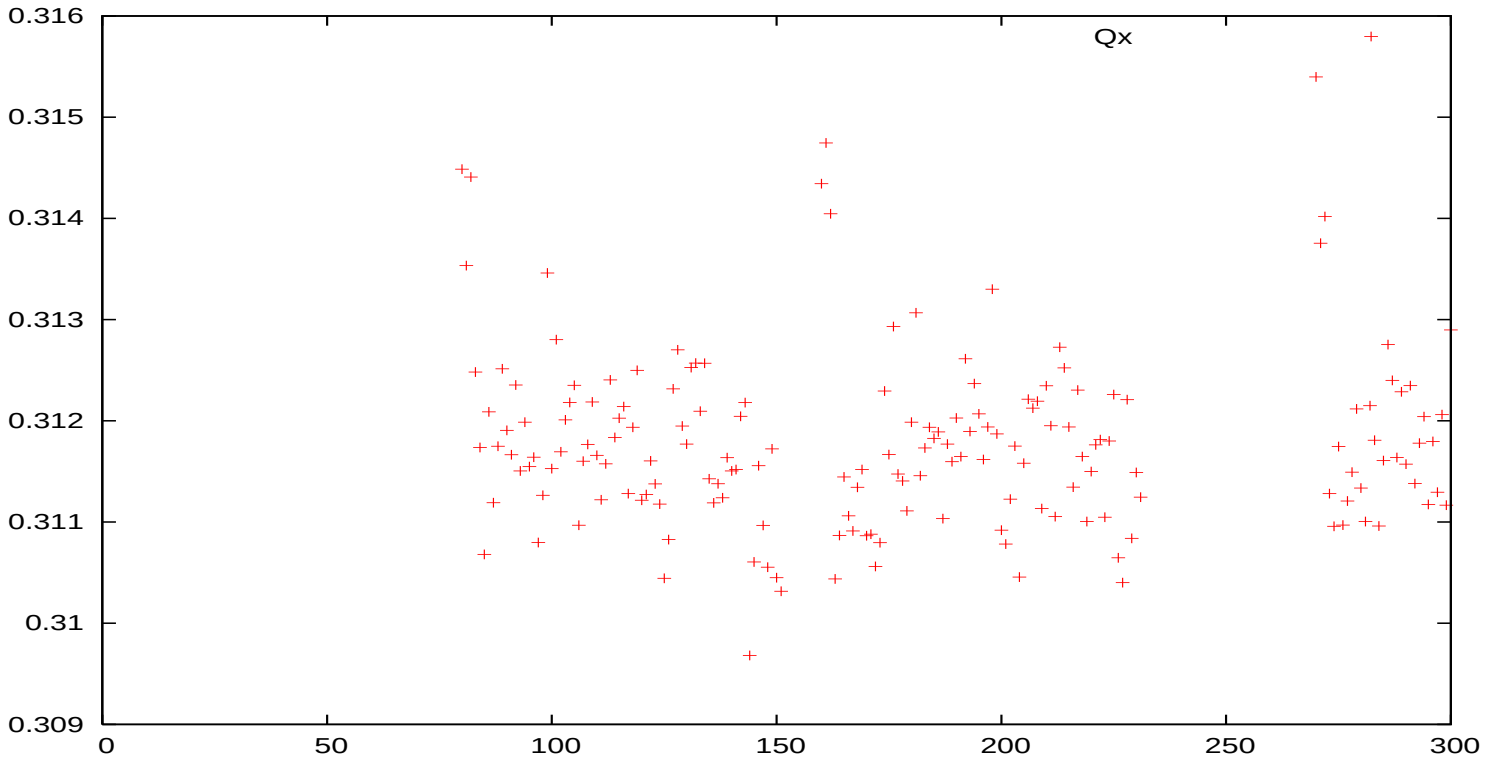


[1] W. Herr, LHC Project Report 628 (2003)

Adding fluctuations

- Nominal filling scheme
- Head on and long range in all IPs
- Bunch to bunch fluctuations:
  - → On intensities and emittances
  - → Can be Gaussian or any defined distribution
  - → Can be flat or defined shapes along bunch train

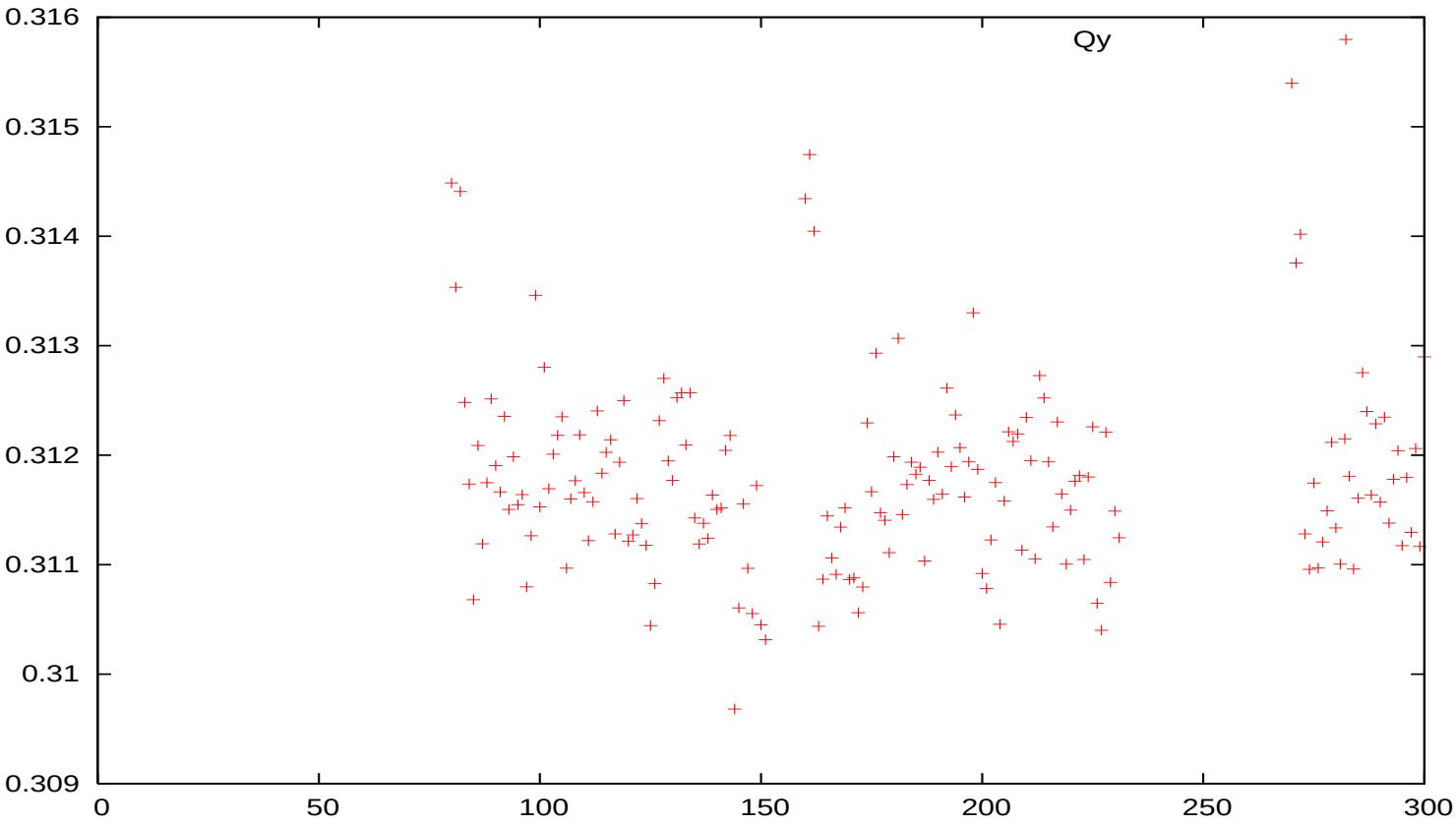
Horizontal tune (HO + LR)



→ **Intensity 10% and emittance 20%**

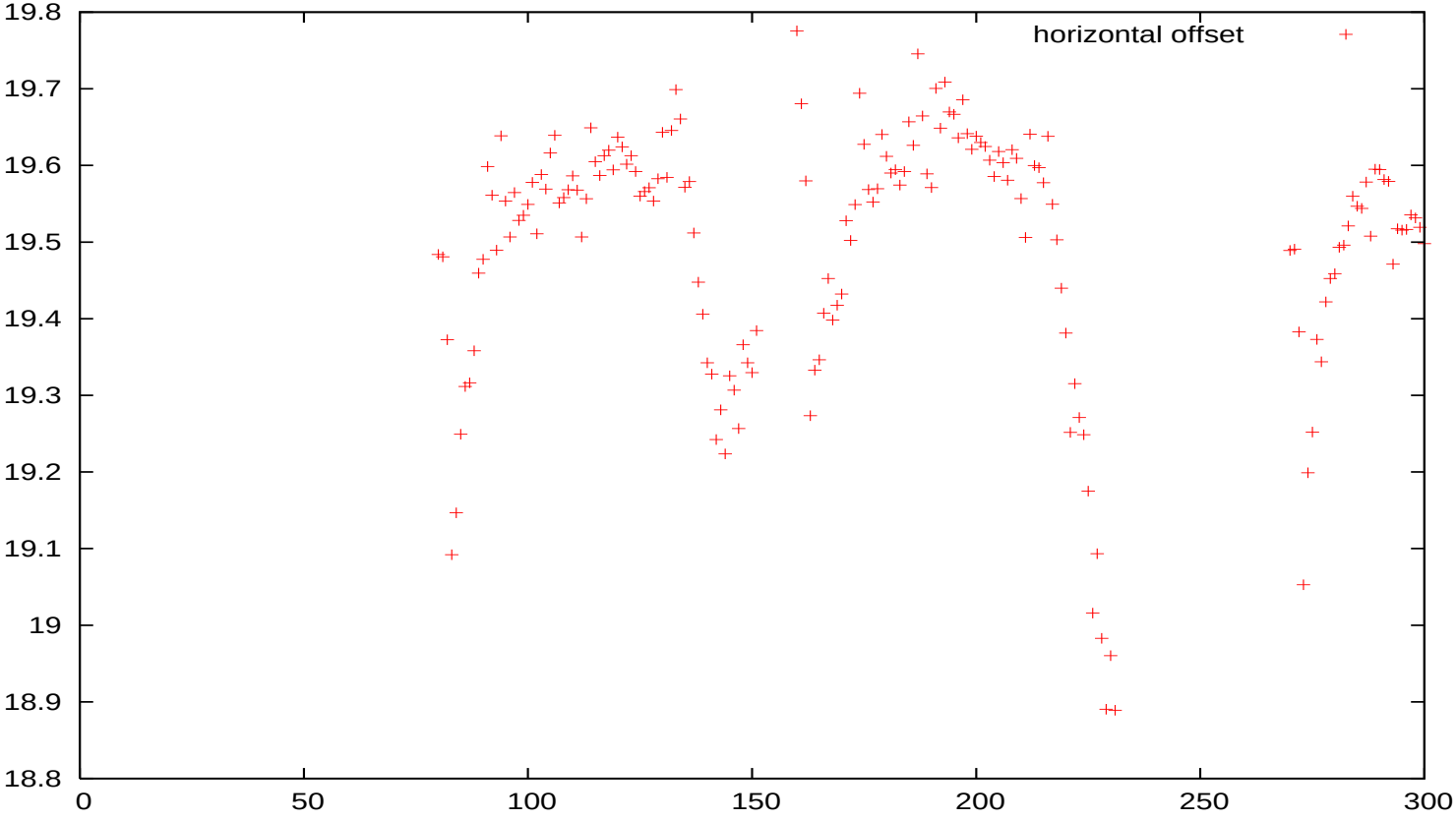
1) W. Herr, LHC Project Report 628 (2003)

Vertical tune (HO + LR)



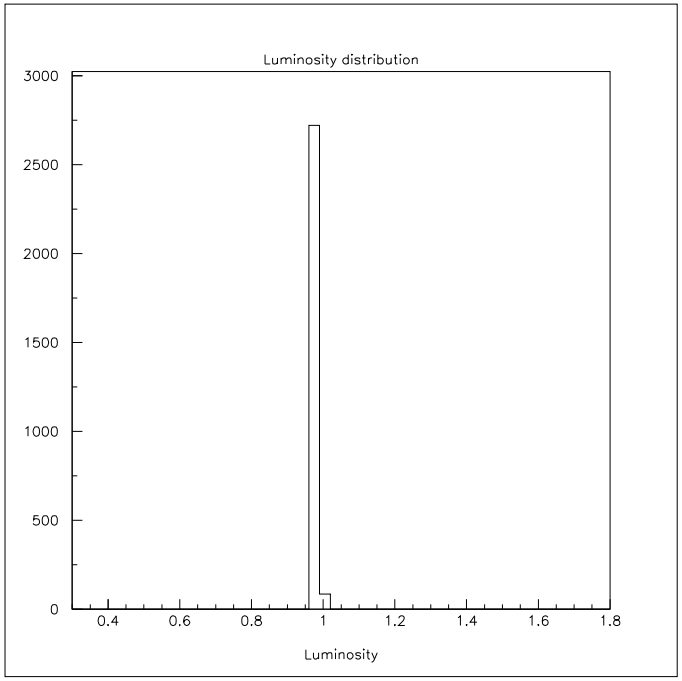
[1] W. Herr, LHC Project Report 628 (2003)

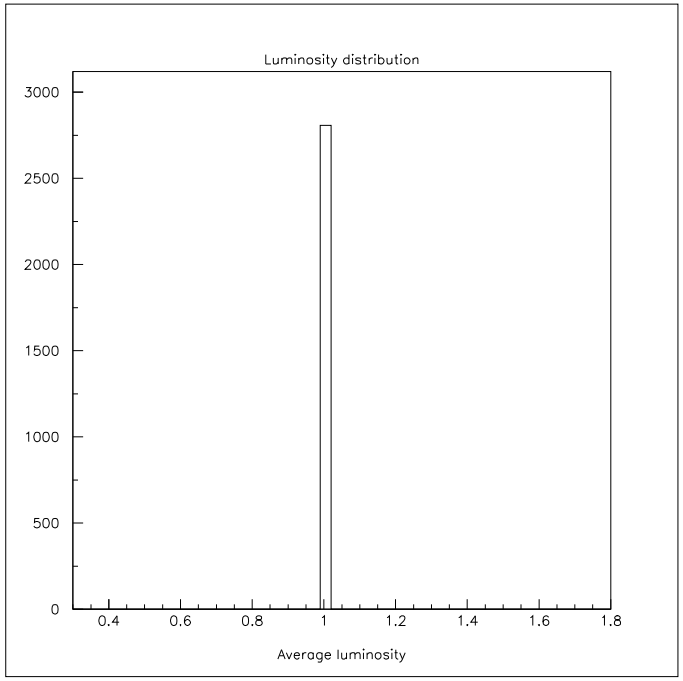
Horizontal offset - IP1



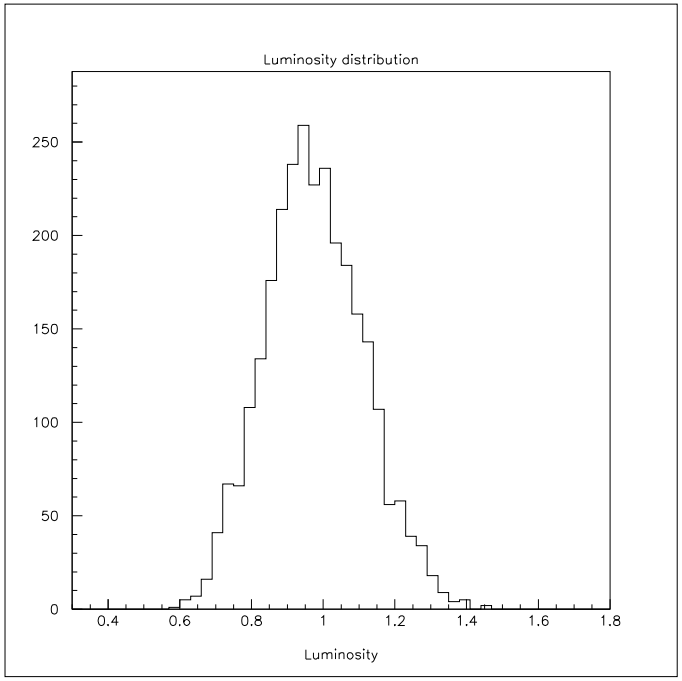
[1] W. Herr, LHC Project Report 628 (2003)

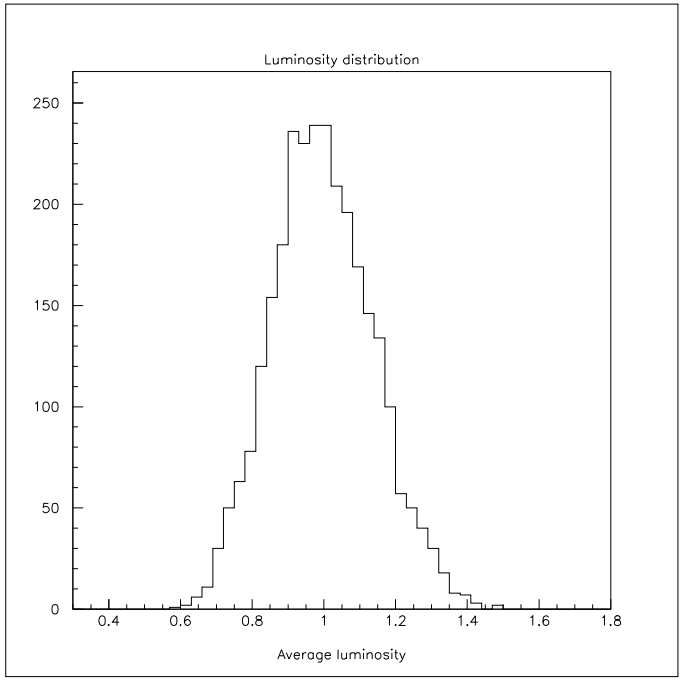
Luminosity - IP1





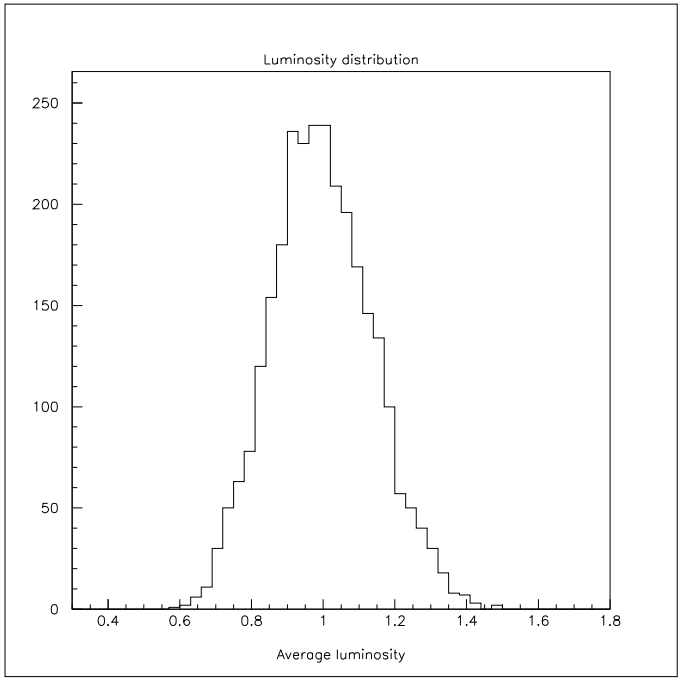
Luminosity - IP1

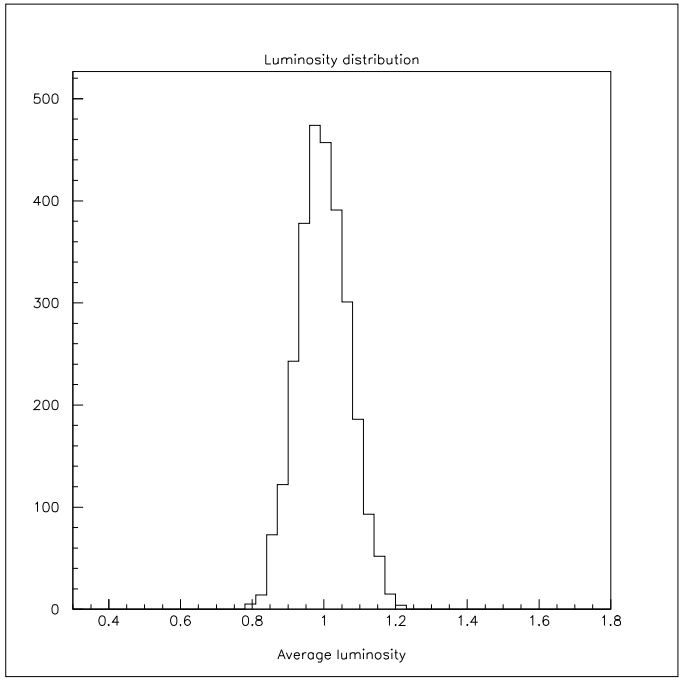




Intensity fluctuations 10% - before and after optimization ...

Luminosity - IP1



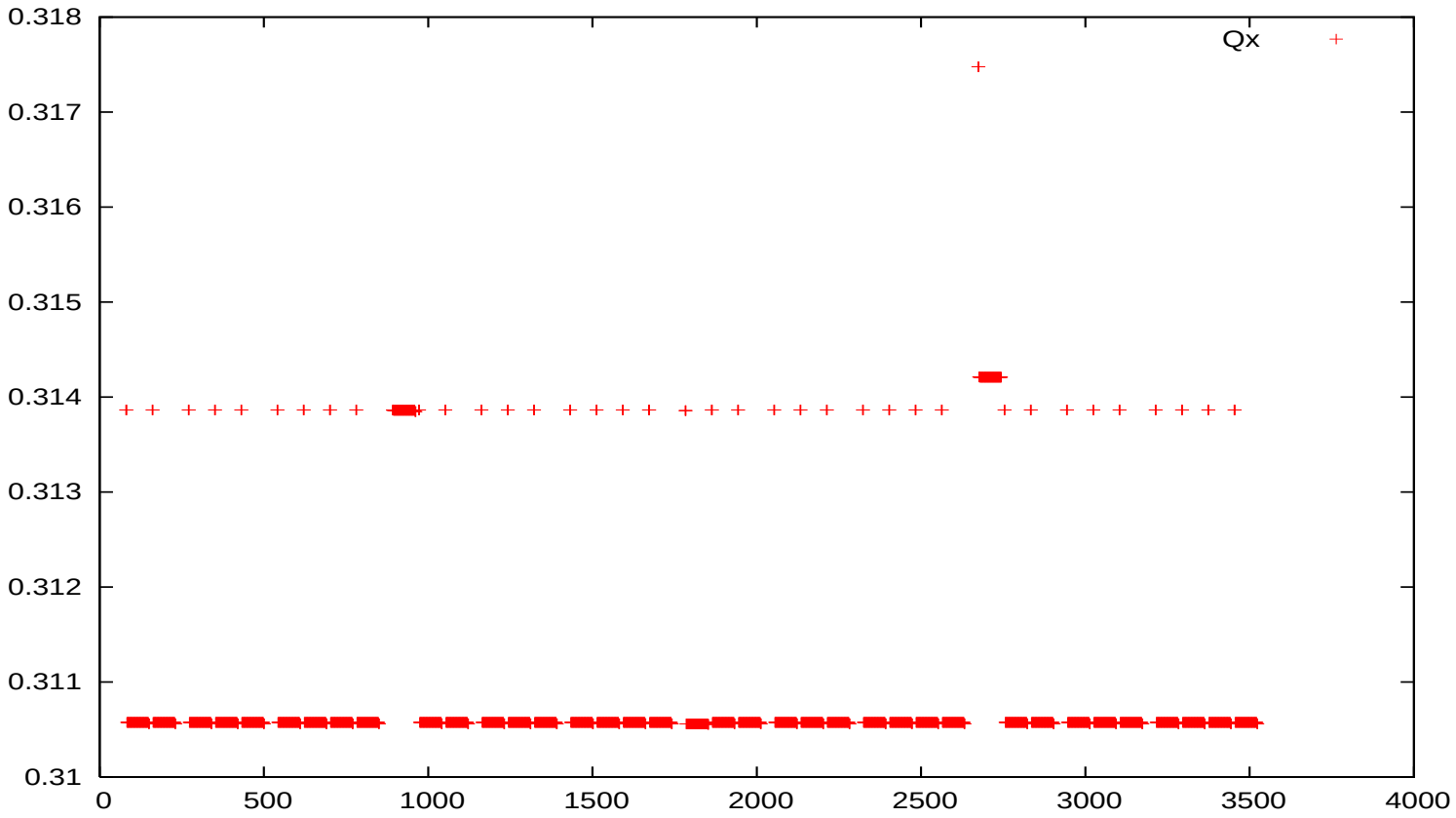


Intensity fluctuations 10% and 5%

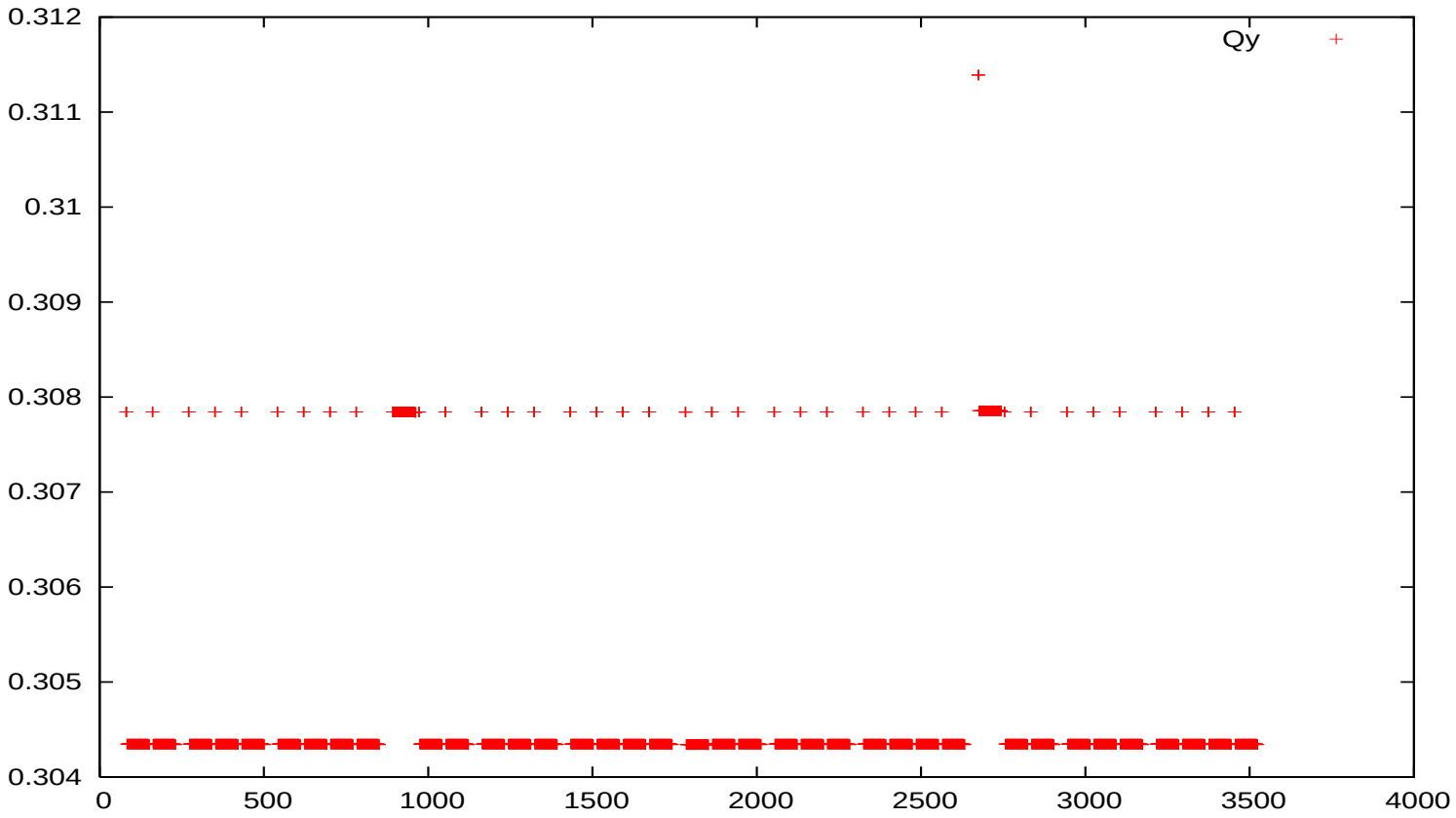
Tolerances

- TRAIN program used to determine bunch to bunch tolerances
- Was used to define configuration (e.g. filling scheme)
- If operational requirements change: redo analysis ...
- Can be used on machine with imperfections
- Interface to MADX tracking (input) exists

Horizontal tune (head on only)



Vertical tune (head on only)



Horizontal offset - IP1 (head on only)