Crossing Schemes Considerations and Beam-Beam Work plan

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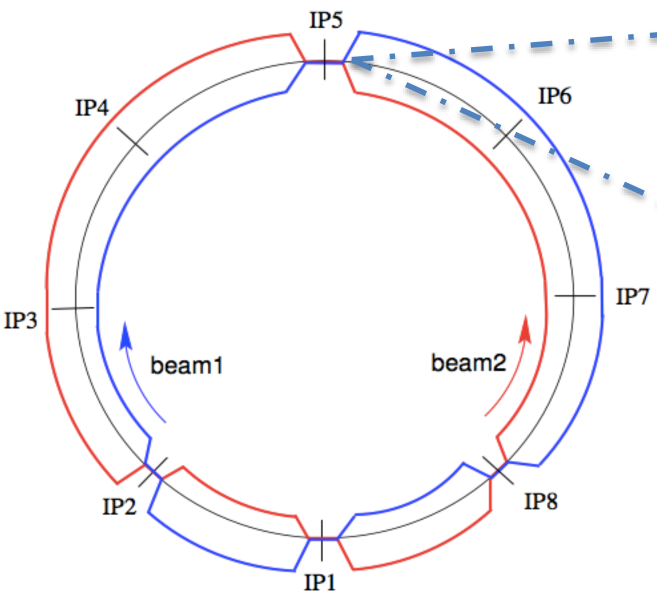
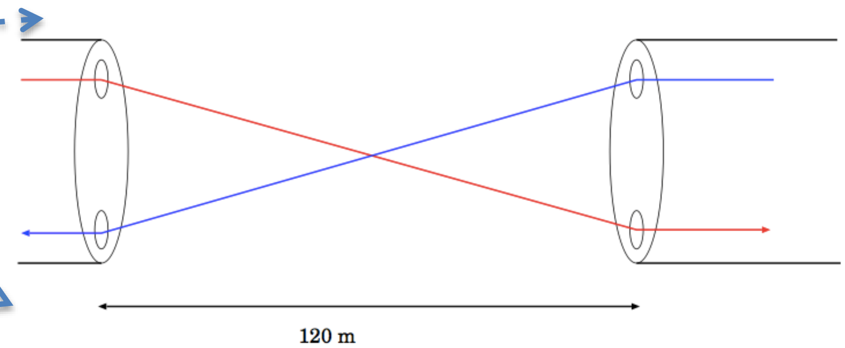
Circular colliders Long-Range interactions crossing angle schemes: LHC

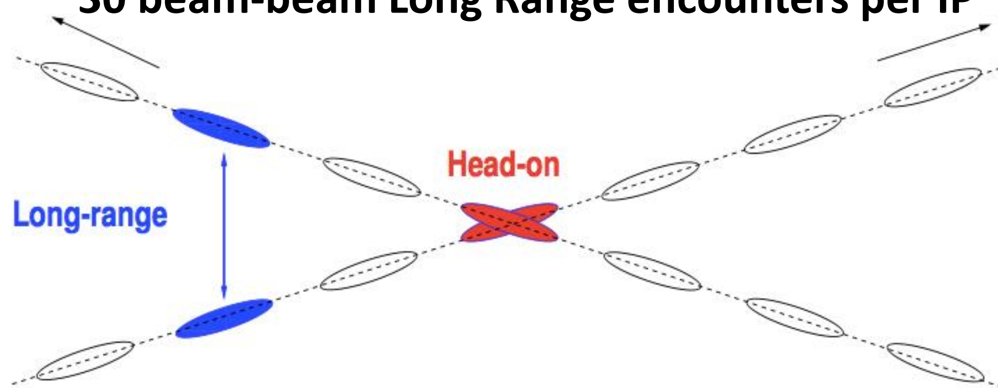
LHC collider: 2808 bunches
4 Head-On and 120 Long-Range Interactions localized





25 ns bunch spacing → beams will meet every 3.75 m
30 beam-beam Long Range encounters per IP

Separation is typically 7-12 σ



Several localized long range interactions 120
Need local separation (crossing angle)
Two horizontal and Two vertical crossing angles

What do long range interactions do?

- Cause effects on closed orbit, tune shift, tune spread, chromaticity…
- Break the symmetry between the planes, much more resonances are excited
- Mostly affect particles at large amplitude
- PACMAN effects complicates the picture

FCC crossing schemes: beam-beam effects

Why we start with HV crossing in the FCC?

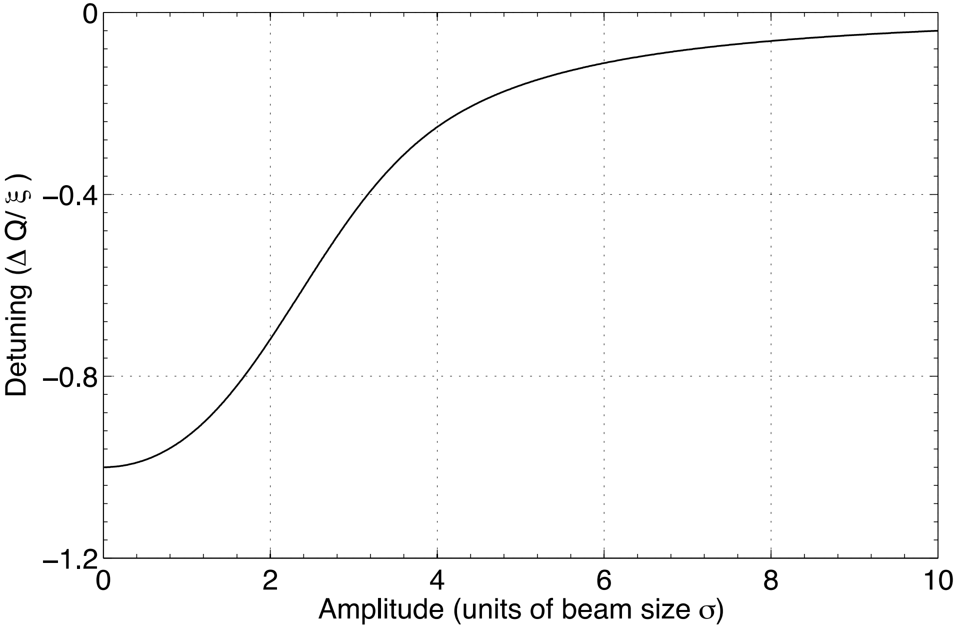
W. Herr, "Features and Implications of different LHC crossing schemes", LHC Project Report 628 (2003)

HV crossing between the two main experiments ATLAS (V crossing) and CMS (H crossing) is preferred!

This scheme allows to passively compensate several effects of Long-Range beam beam coming from these two main experiments which are opposite in azimuthal and same bunch pairs see same long-range interactions

Head-on detuning with amplitude and footprints

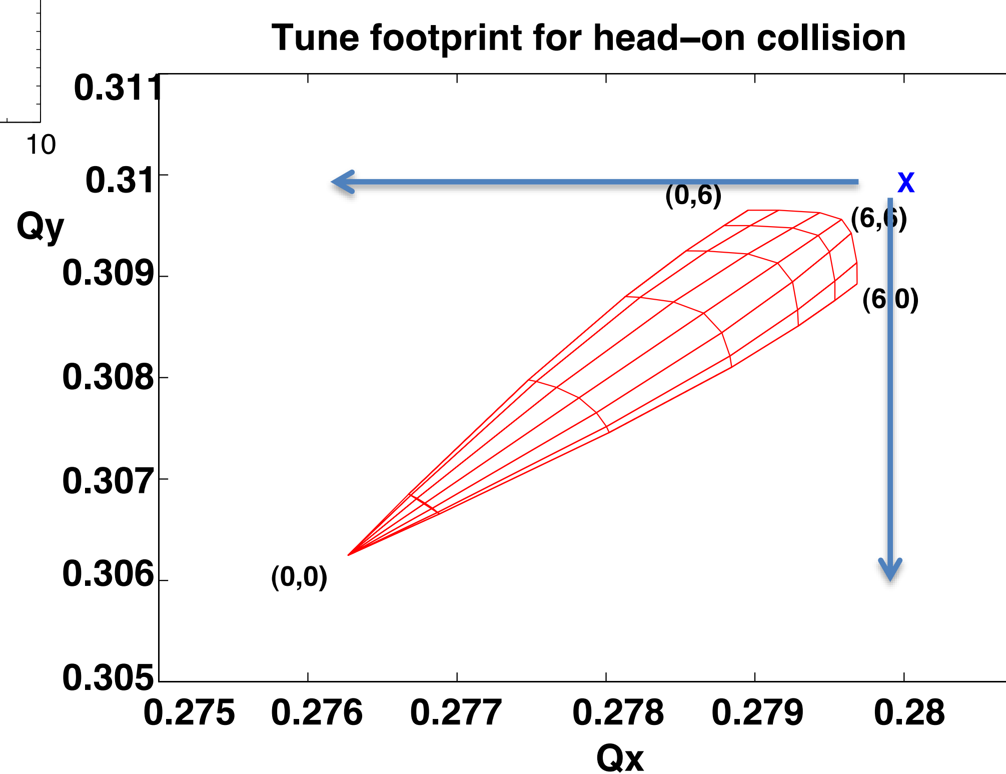
1-D plot of detuning with amplitude



And in the other plane?

THE SAME DERIVATION

same tune spread

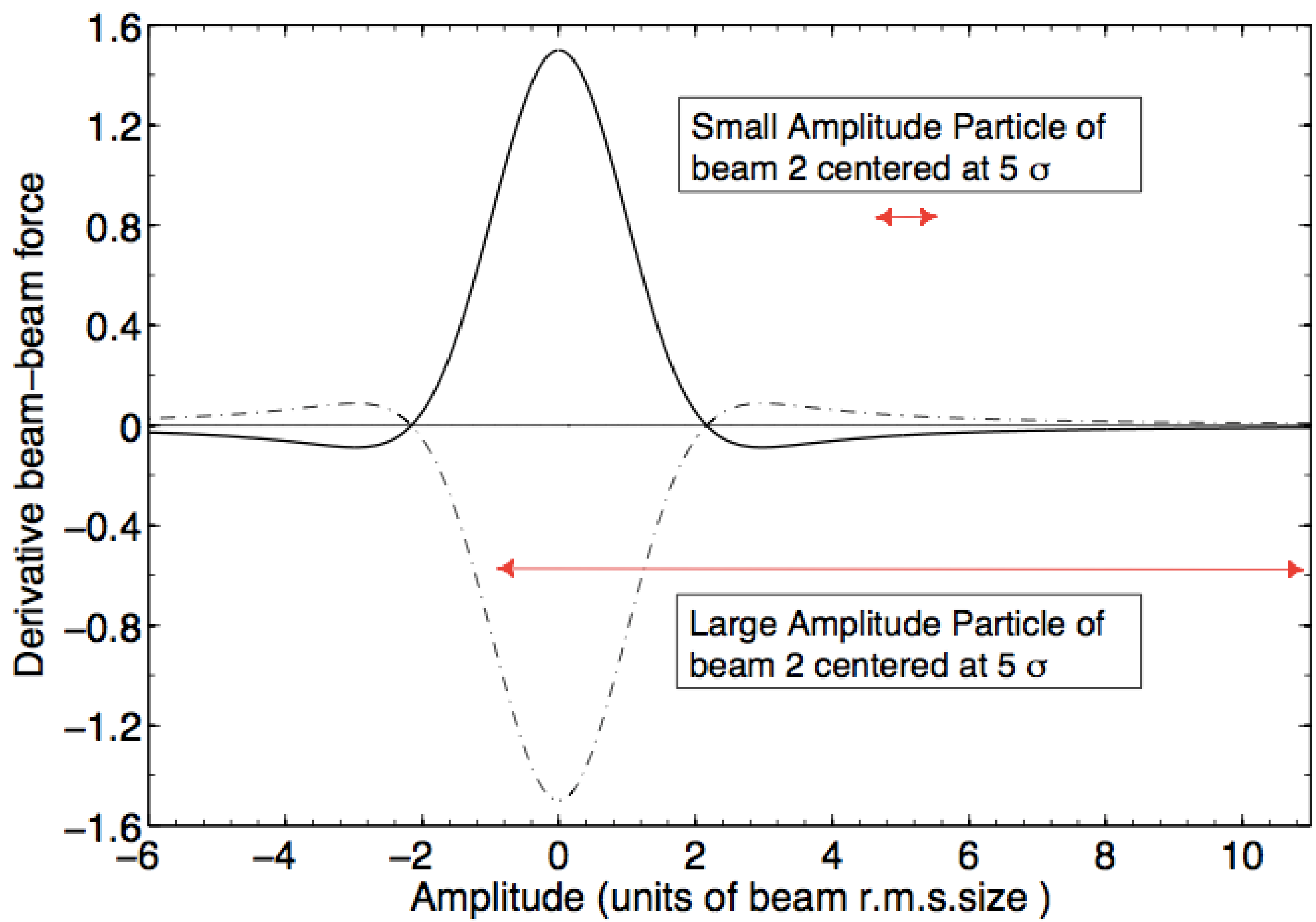


FOOTPRINT

2-D mapping of the detuning with amplitude of particles

Long Range detuning with amplitude

1-D plot of detuning with amplitude for opposite and equally charged beams

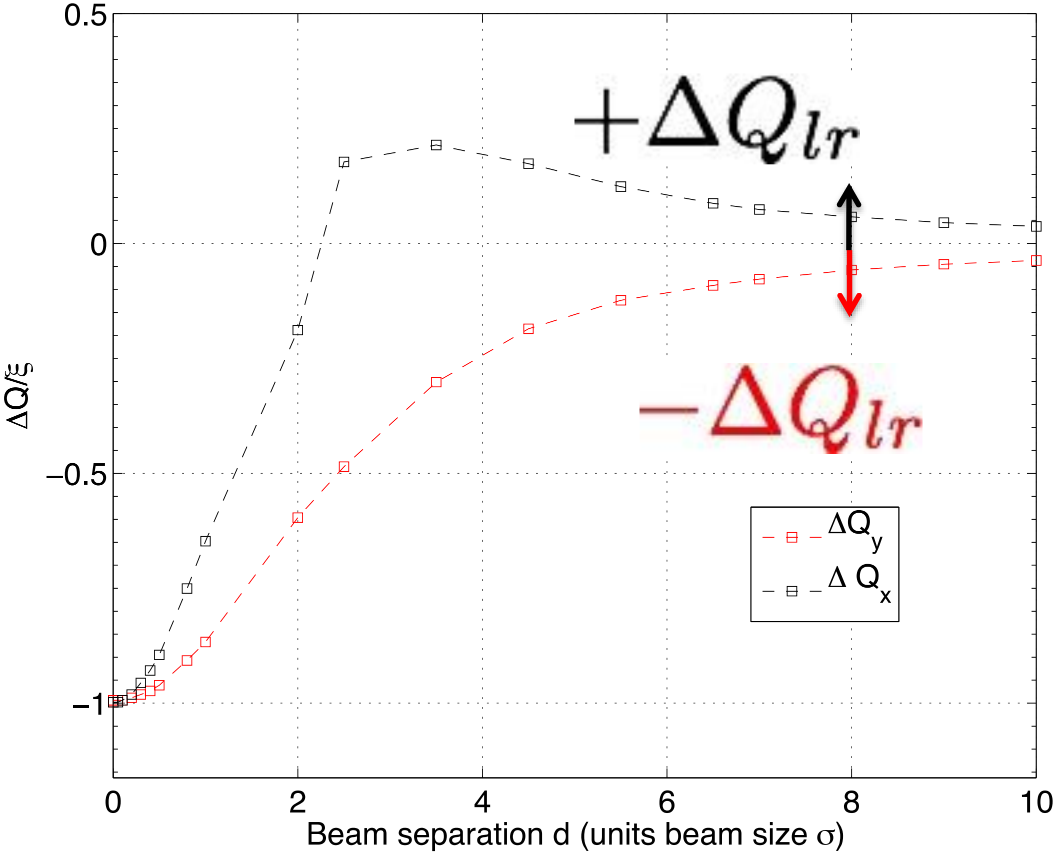


Maximum tune shift for large amplitude particles

Smaller tune shift detuning for zero amplitude particles and opposite sign

Long Range detuning with amplitude

Horizontal plane separation

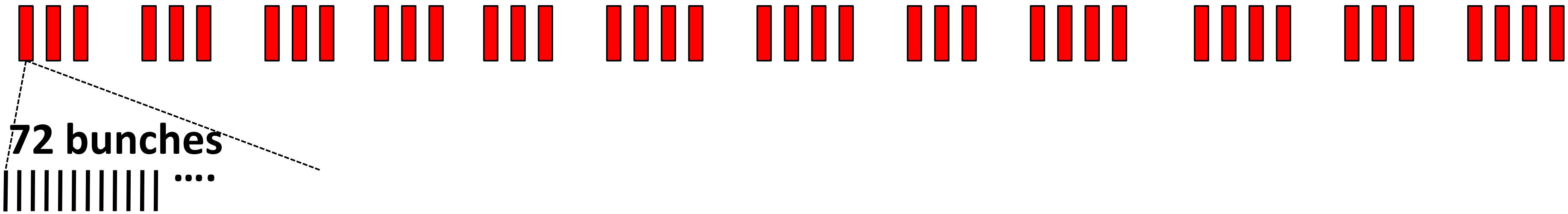


Tune shift as a function of separation in horizontal plane
In the horizontal plane long range tune shift
In the vertical plane opposite sign!

Alternating crossing HV will profit of the opposite sign of the tune shift →
Passive compensation of this shift

Complications

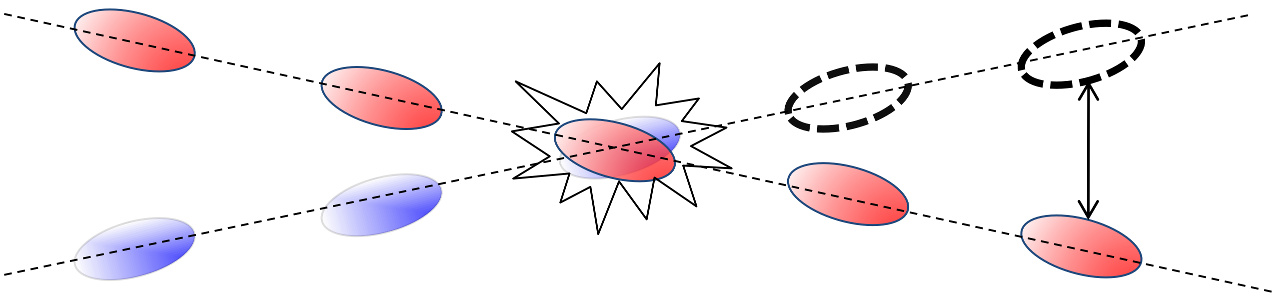
PACMAN bunches



Pacman:

miss long range BBI

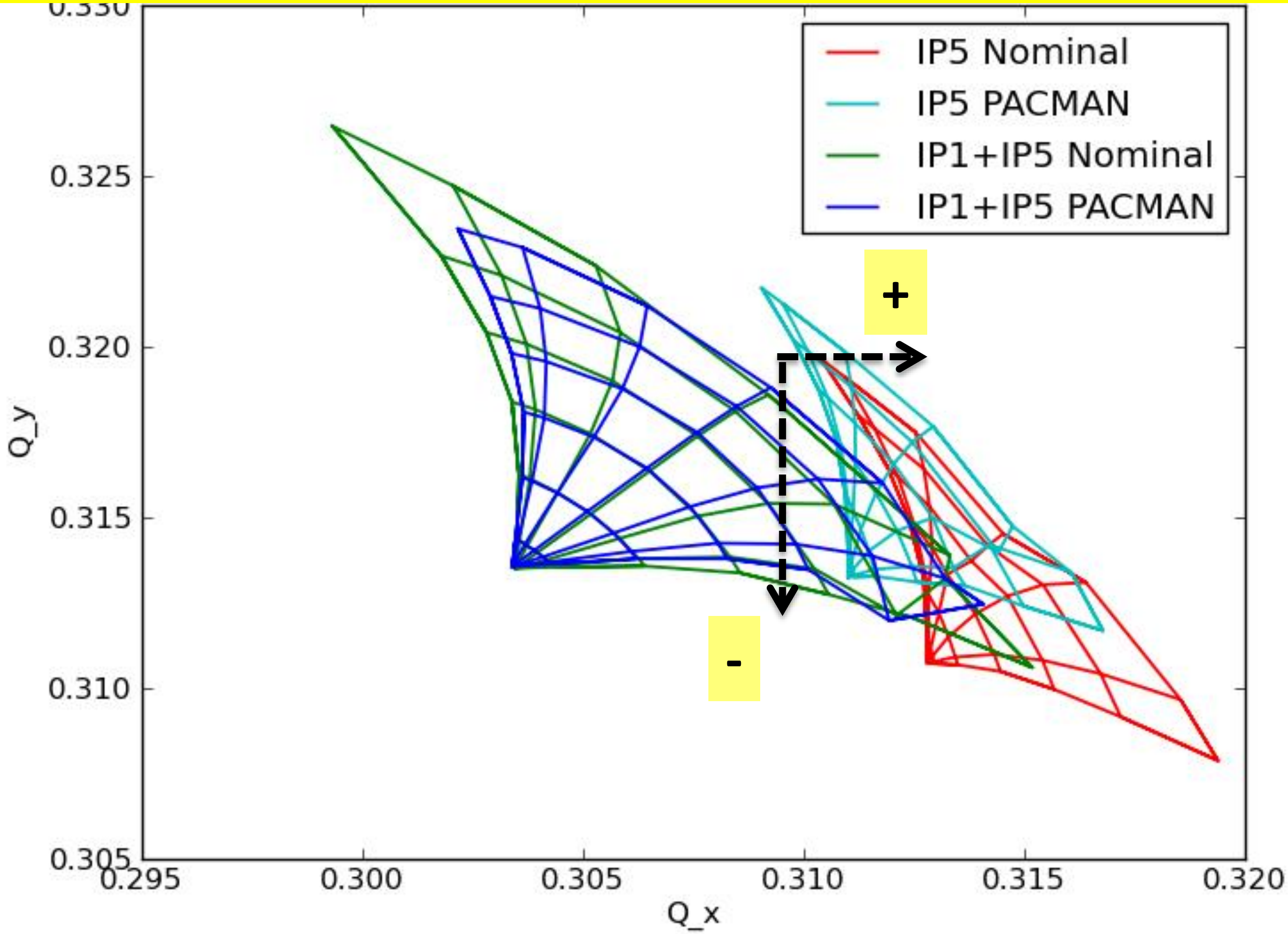
(120-40 LR interactions)



Different number of long-ranges → Different bunch families

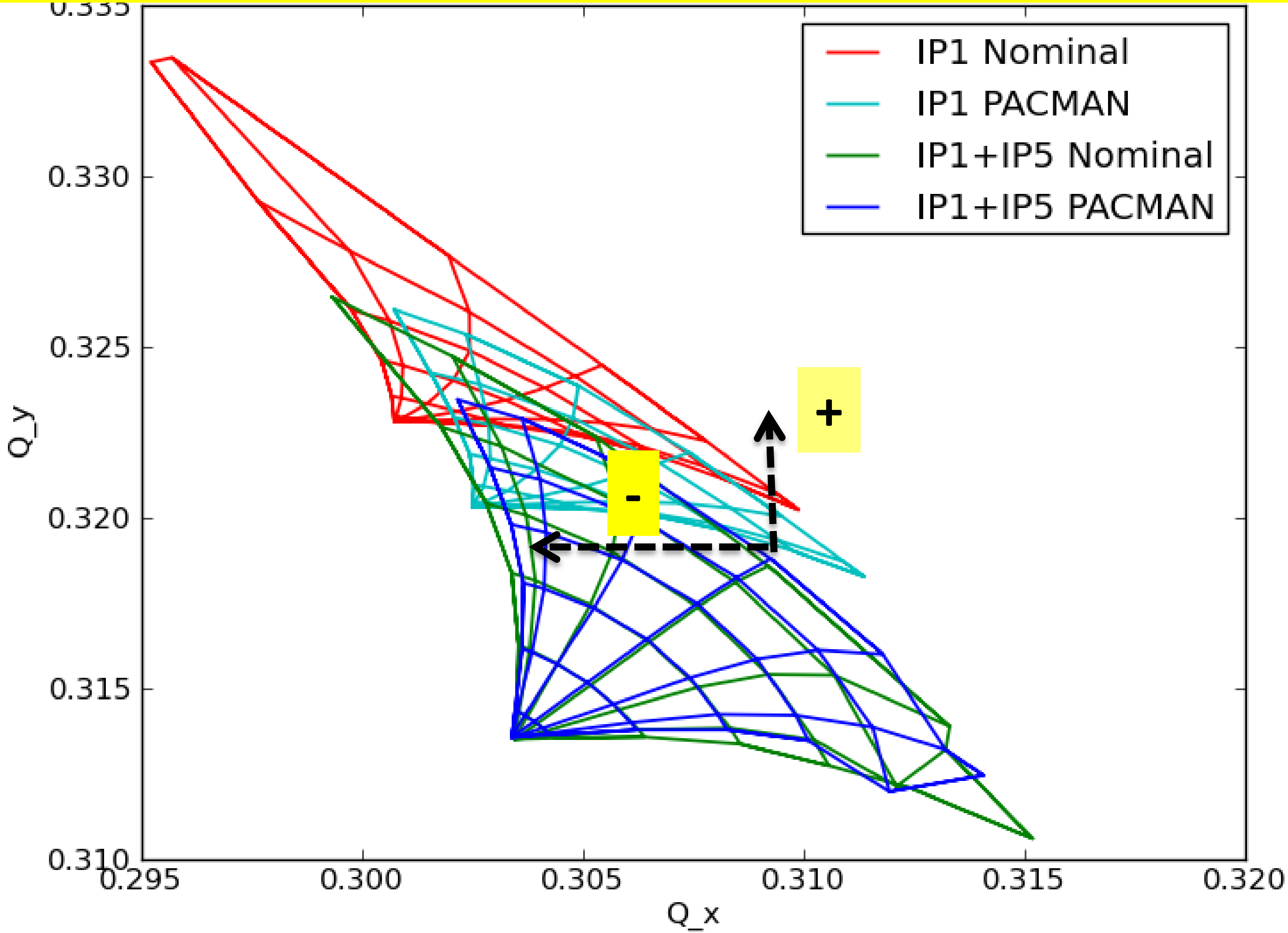
Footprints: tune shift and pacmans

HV crossing scheme versus H crossing



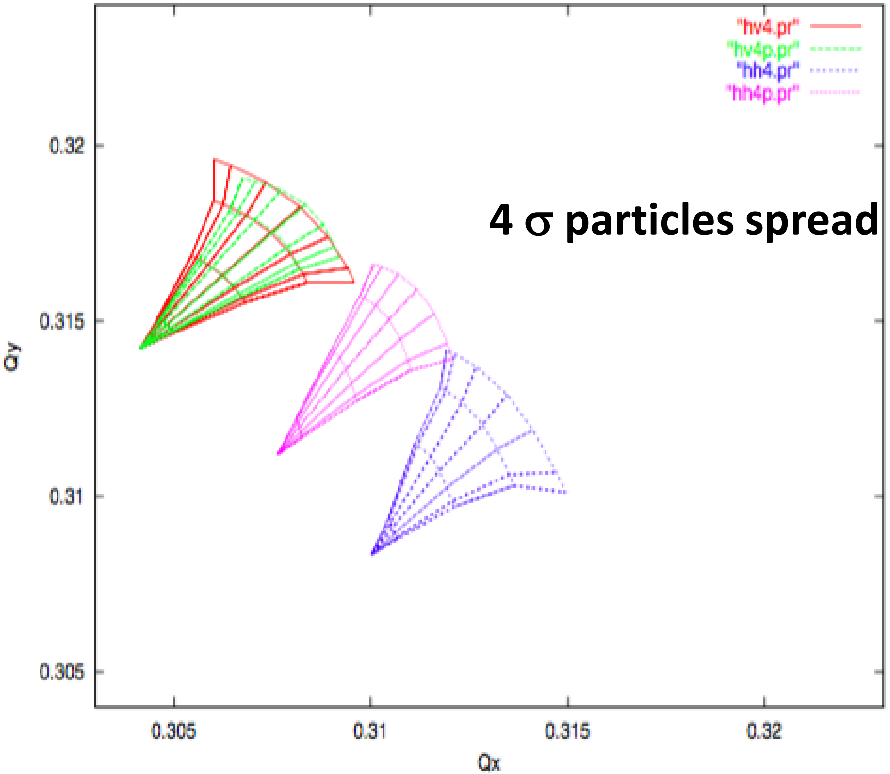
Footprints: tune shifts and Pacmans

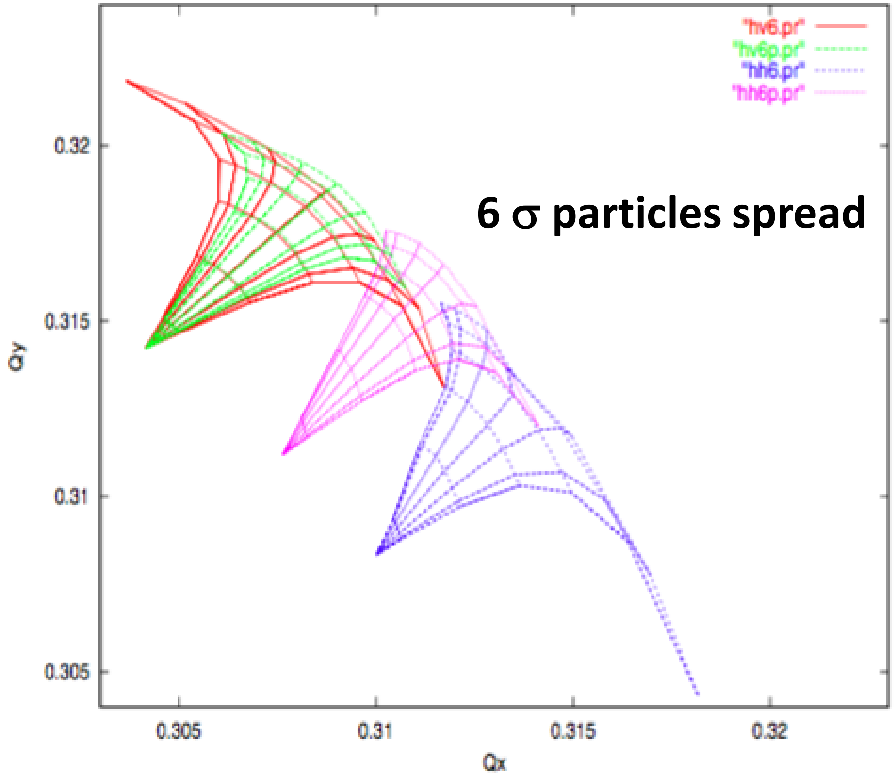
HV crossing scheme versus V crossing



Footprints: tune spread and pacmans

HV crossing scheme versus HH crossing





W. Herr

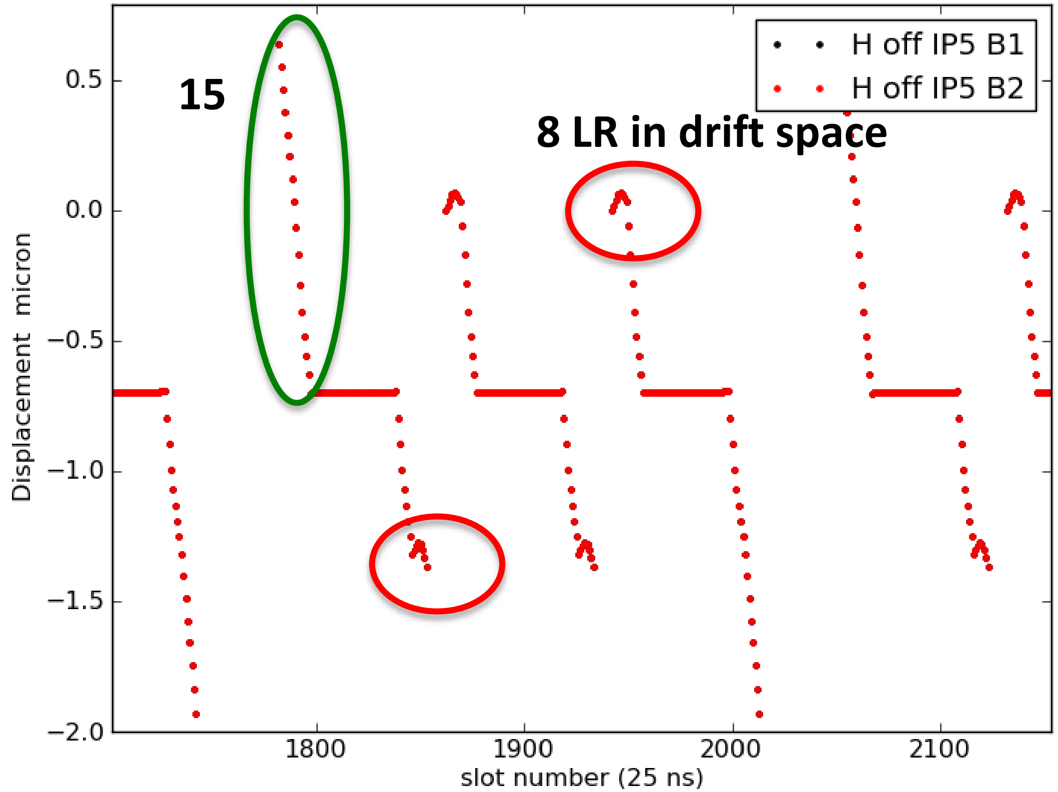
H crossing: Example LHC

- **Intensity 1.15e11 ppb**
- **Emittance 3.75 (16.6 μm at IP)**
- **Nominal LHC optic β* 0.55 collision**
- **15 LR per side of IP**
- **IP5 only: H crossing (285 μrad)**
- **Nominal LHC filling scheme 25 ns**

LHC filling scheme:

38-39 empty slots for LHC injection kicker
And 8 empty slots between trains of 72
due to SPS injection kicker

Orbit variation of 1 μm due to long-range deflection



Repeat all studies for FCC

LHC H or HH crossing

IP1 and IP5 HH crossing 2 time the effect

The long-range interactions in IP5(CMS) only in H plane: **tune shifts 0.0015 in tune units**

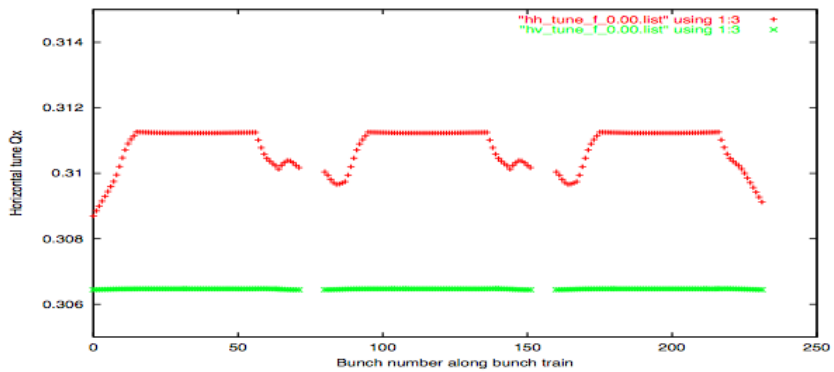
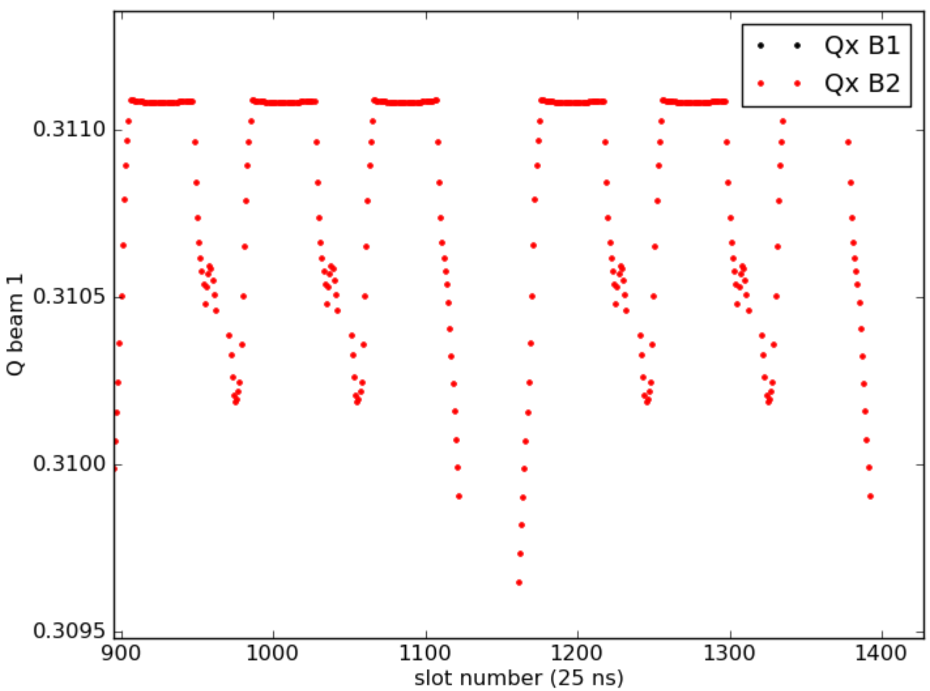
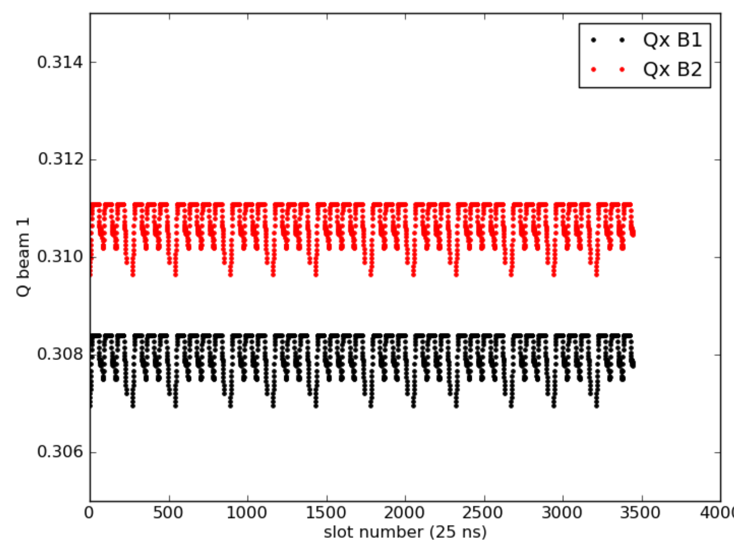
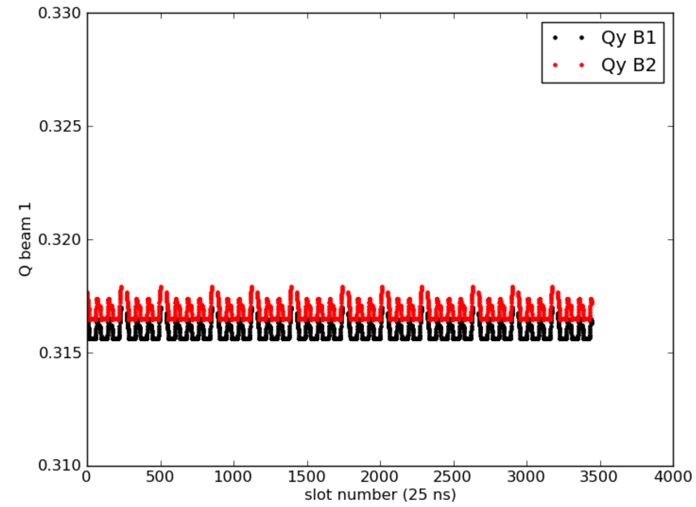


Figure 30: Horizontal tune variation along the batch. Horizontal-horizontal crossing in red, vertical-horizontal crossing in green.

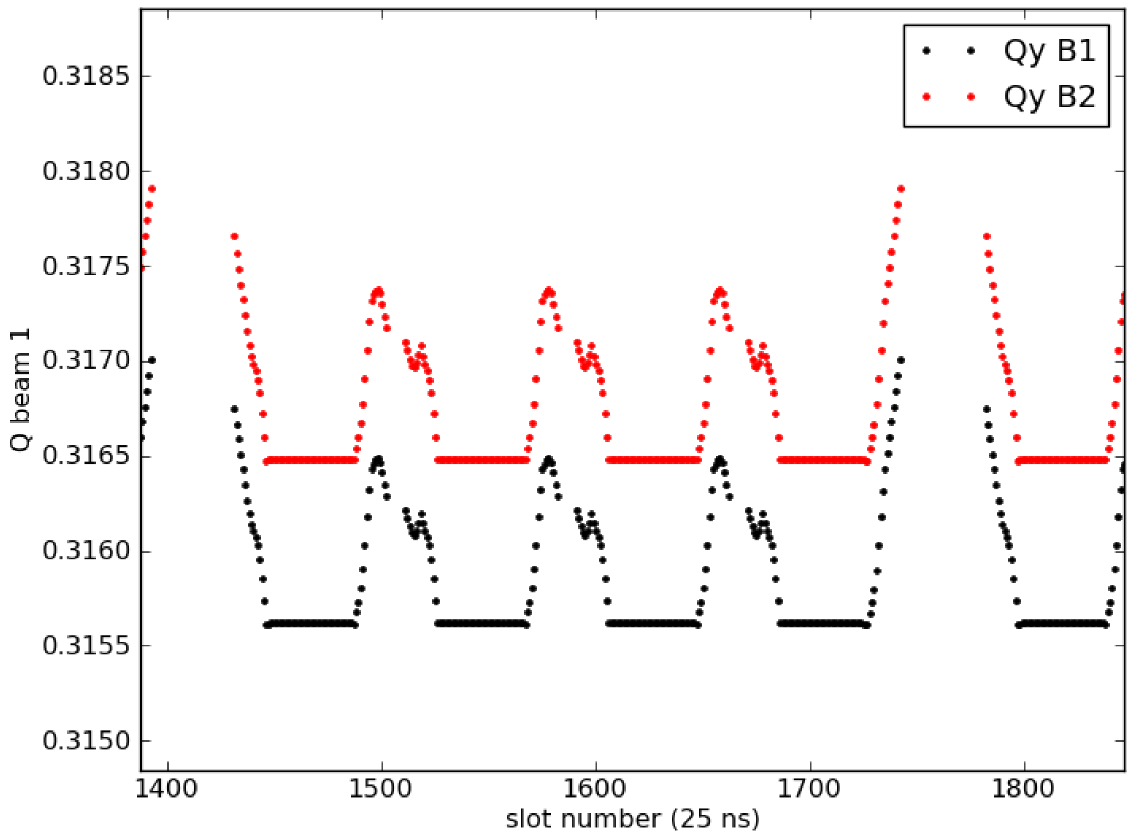




LHC IP5: Qy

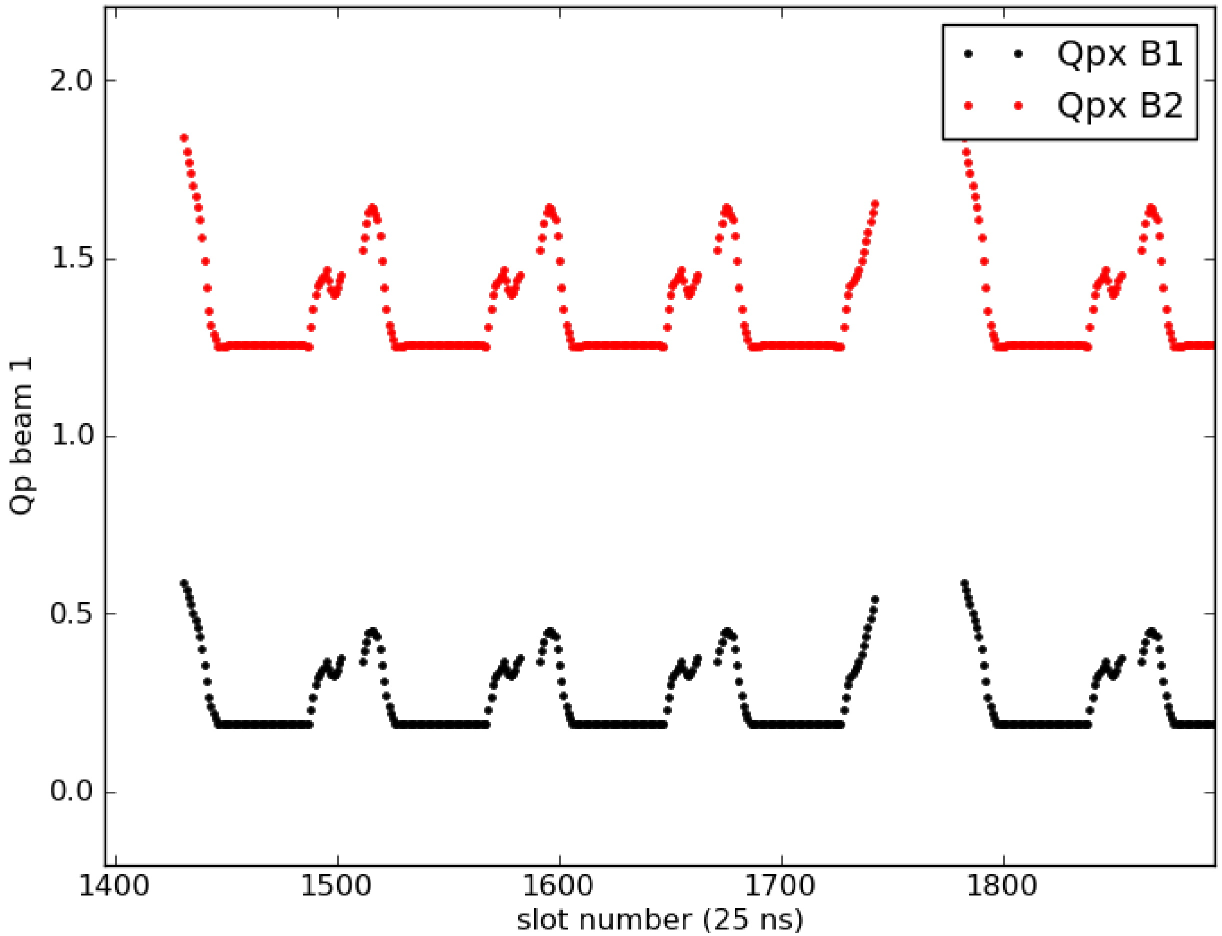


The long-range interactions in IP5 only in H plane: **tune shifts 0.0015 in tune units**



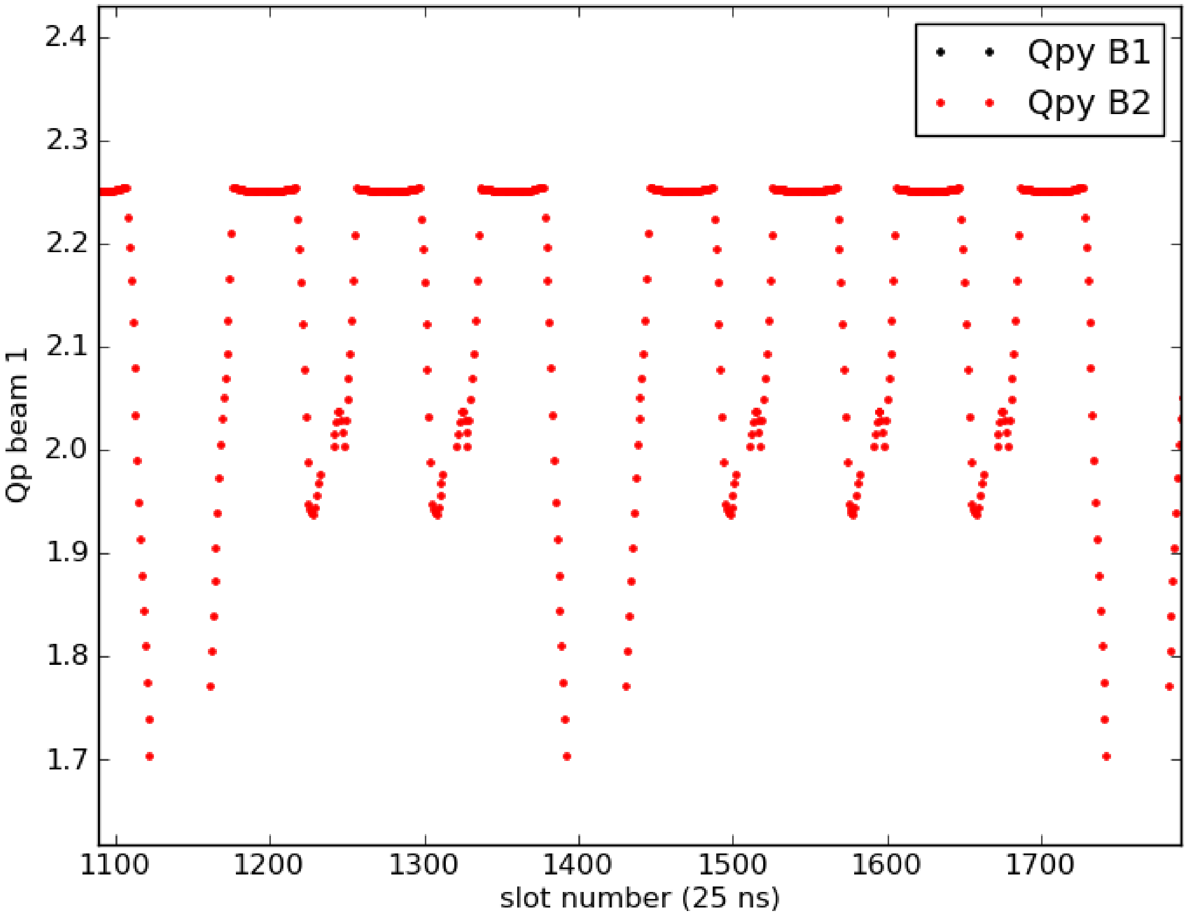
LHC IP5:Qpx

The long-range interactions in IP5 only in H plane: **Q' spread of less than 1 unit**



LHC IP5: Qpy

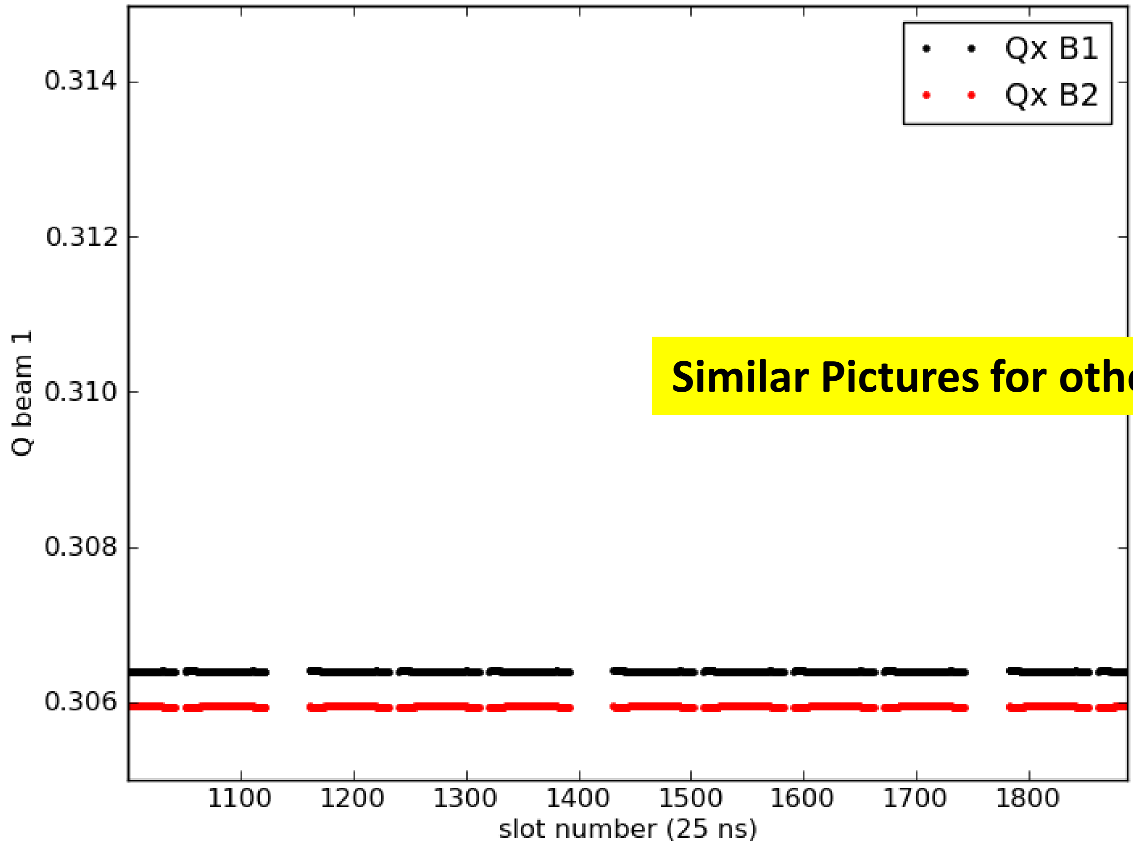
The long-range interactions in IP5 only in V plane: **Q’ spread of less than 1 unit**



Alternating crossing: HV

The long-range interactions in IP5 only in H and IP1 in V compensates the bunch by bunch variations of :

- the tune shift
- chromaticity



Similar Pictures for other plane and chroma.

H crossing: Example LHC

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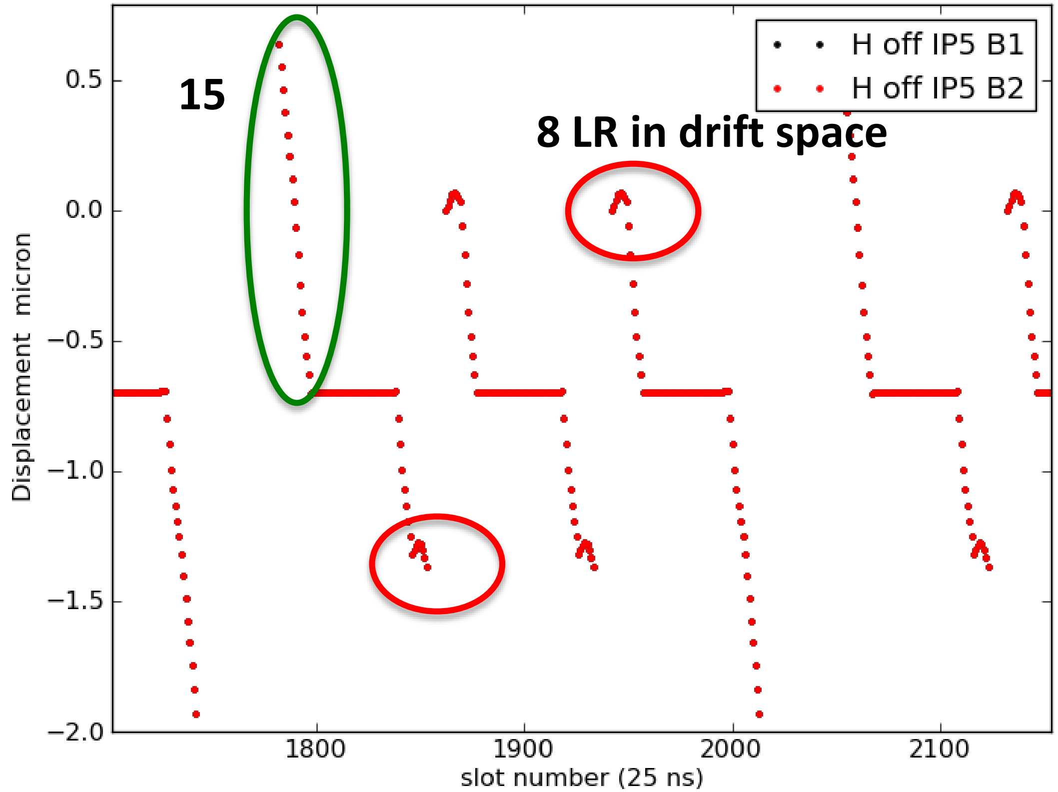


Repeat all studies for FCC

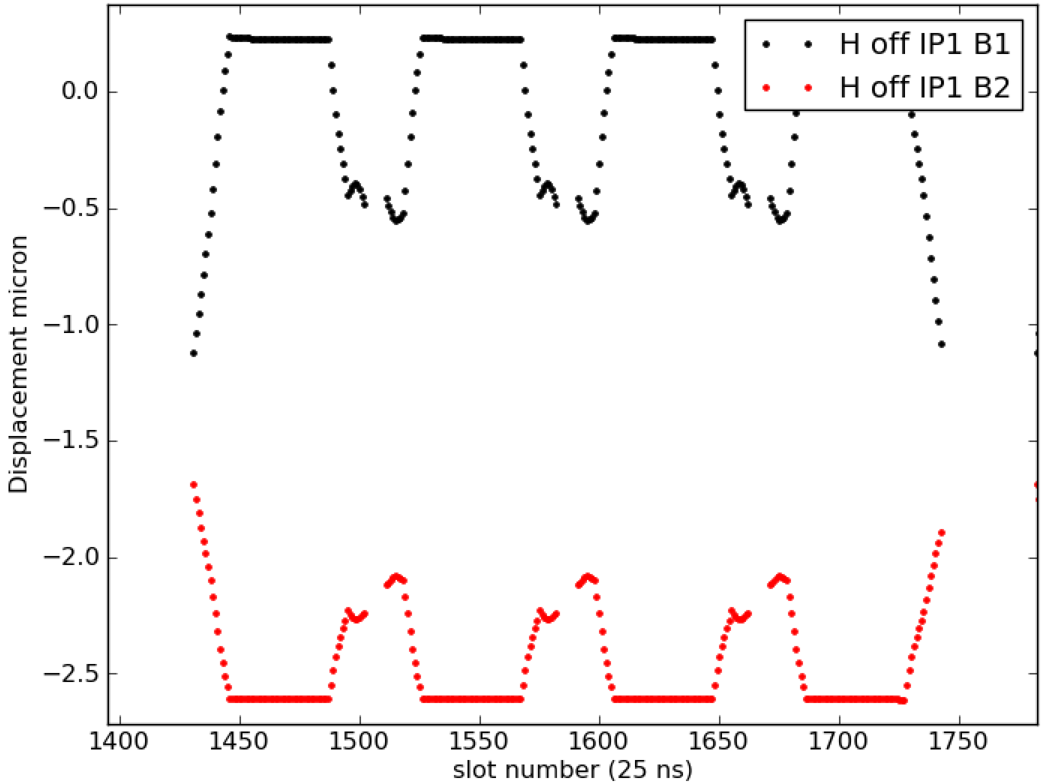
IP5&IP1 Collisions HV crossing: we observe in IP1

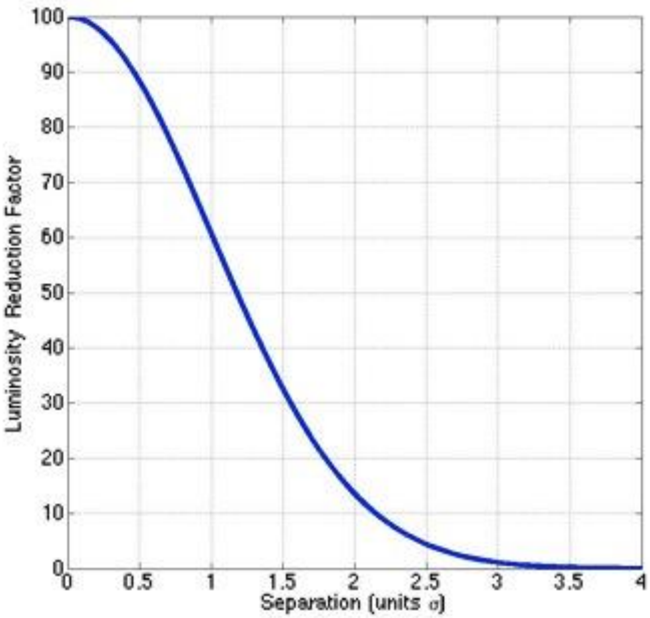
The long-range interaction in IP5 in Vertical plane result in **displacements in IP1 of maximum 1 μm**

→ Offset at head-on collision of less than 0.1 σ

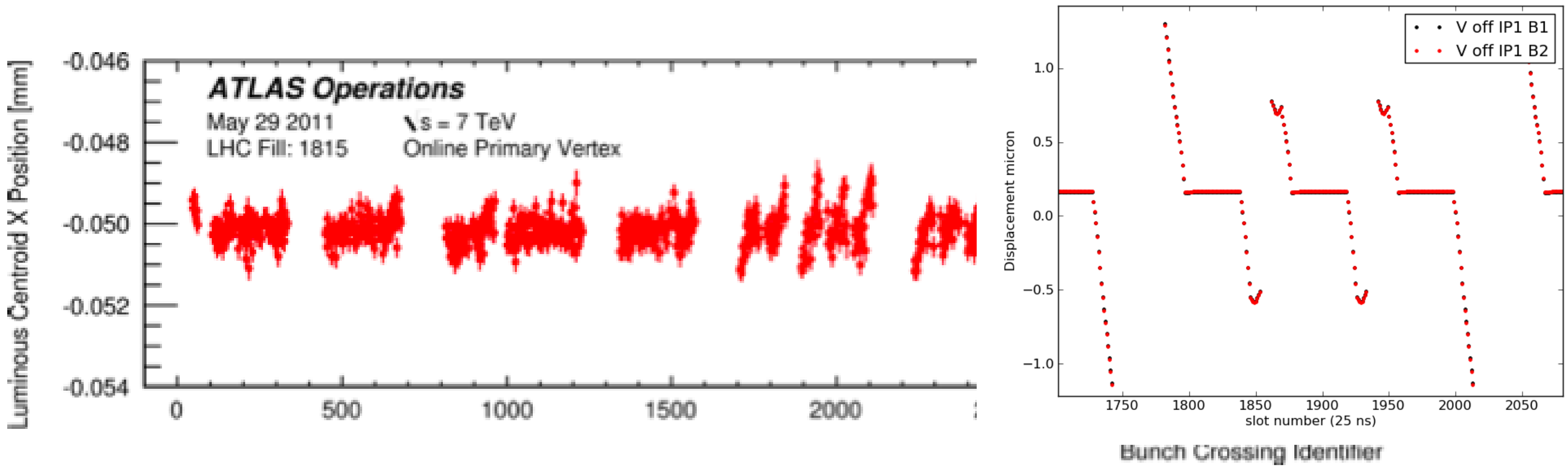
Orbit Effects are NOT COMPENSATED!
→ Luminosity reduction due to transverse offset

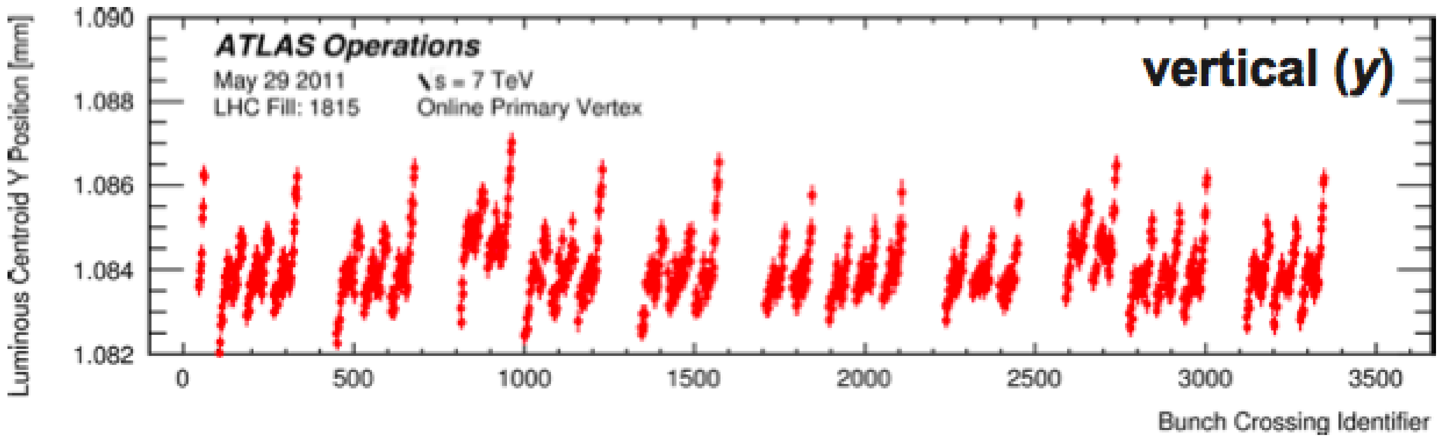
$$L = L_0 \cdot e^{-\frac{d^2}{4\sigma_x^2}}$$





Can we cross check with data? ATLAS vertex detector 2011 data





Courtesy of R. Bartoldus and W. Kozanecki ATLAS collaboration

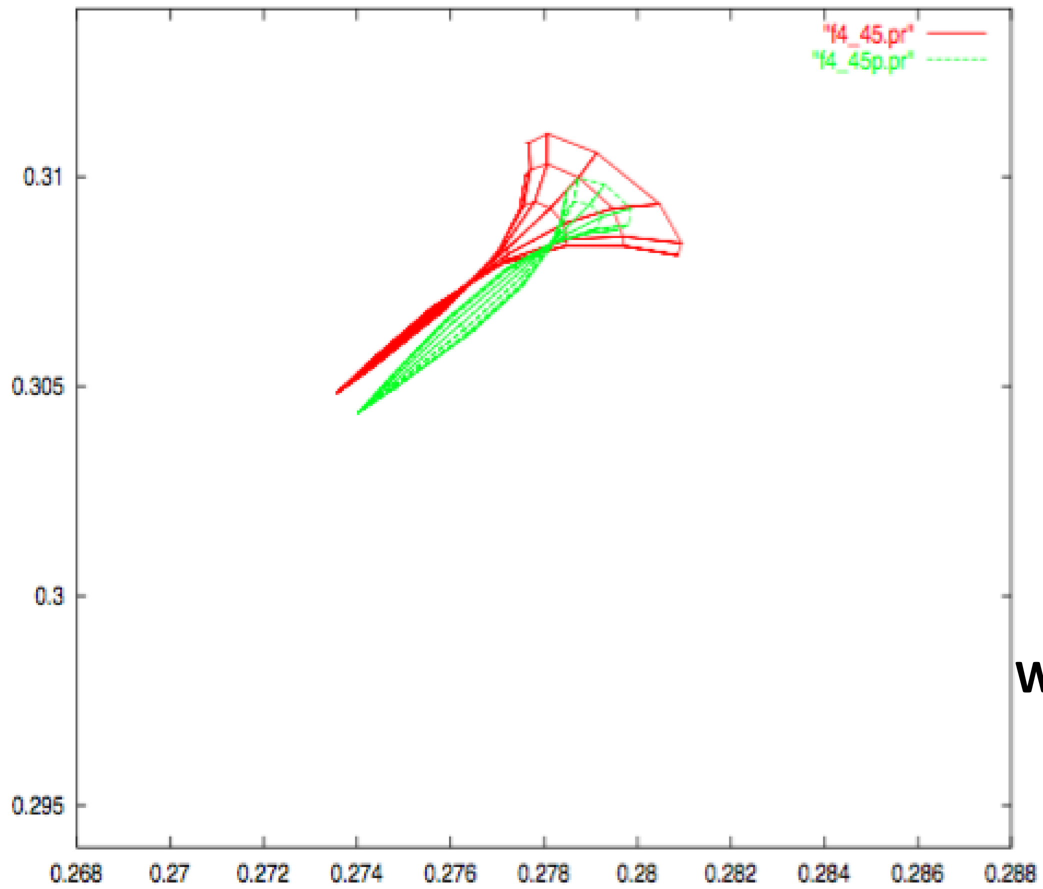
Vertical centroid displacement can be measured and we can check few cases

45 degrees HV crossing scheme

45 degrees HV crossing scheme can also reduce the **spread in H and V plane**

Could this be an option for FCC?

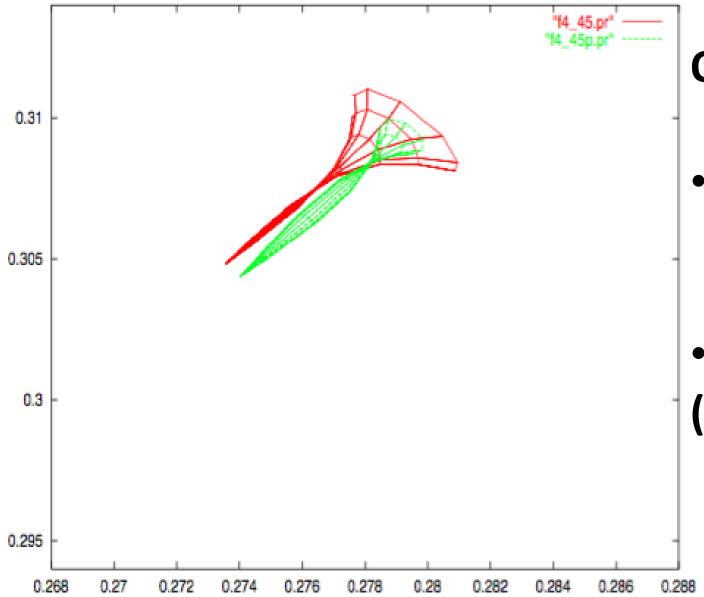
How does it behaves with Octupoles, sextupoles ?



W. Herr for the LHC

45 degrees HV crossing scheme

45 degrees HV crossing scheme can also reduce the **spread**
For the LHC it was dropped because of worries of strong coupling!
We had tested the head-on tilted angle in LHCb in 2012….no-problem!
Could give a lot of flexibility → energy deposition??!
Need investigations on pros and cons….



Open questions:

- **Does it perform better → DA studies needed**
  - **Octupoles, chromaticity….**
- **Strong coupling – is this an issue in the triplets? (Optics team)**
  - **Beam-beam introduces coupling…**
  - **Can we correct for it**

We would like to explore also a possible scheme with tilted HV angle crossing scheme

Beam-Beam plans :

- Explore the parameter space available for the FCC for a **HV** crossing scheme
  - Different L* : **45**, 36, 61
  - Define Scaling laws for Dynamical Aperture versus:
    - **Bunch Intensities**
    - Bunch Emittances (**round** versus flat)
    - Crossing angles
      - **Effective→ Luminosity Impact**
      - External → Aperture Limits

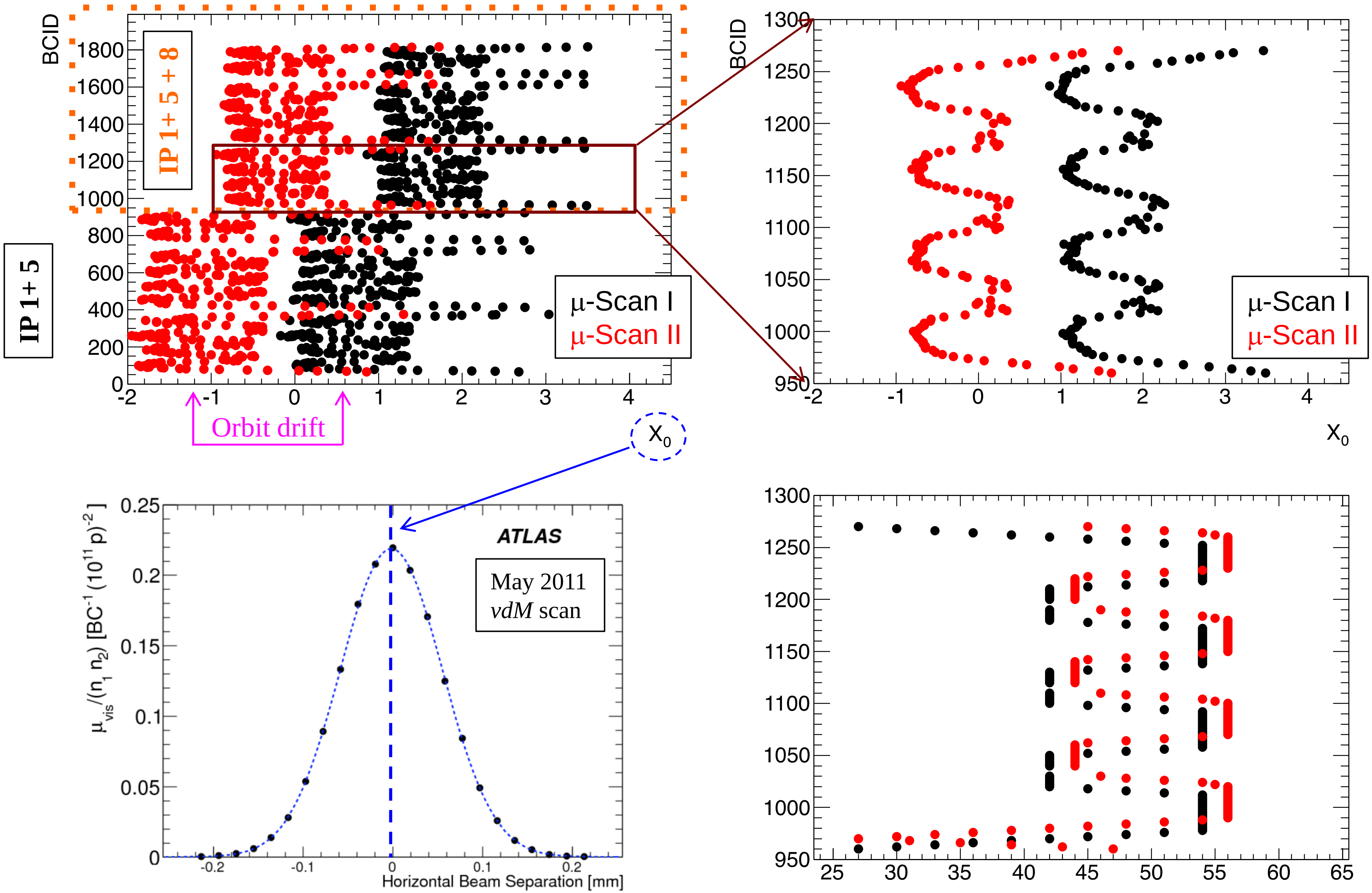
- Long-Range Studies: Orbit Effects, Tune shift, Chromaticity:
  - Intensity scans (maximum intensity)
  - Crossing angle Scan (define minimum angle)
  - Different crossing schemes effects: HV, HH, VV, HV 45 degrees

Beam-Beam plans:

Explore the limits:

- Sensitivity and margins on DA (working point, multipolar errors, modulation, noise, chromaticity, octupoles)
- Optics: flat
- Possible active compensations schemes: crab cavities, multipoles, wires, e-lenses
- Impact of external noise
- 5 ns bunch spacing

ATLAS data 2012 April VdM Horizontal plane



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