Update on PACMAN effects

X. Buffat, T. Pieloni, A. Gorzawski

WP2 meeting – 18.04.2017

Content

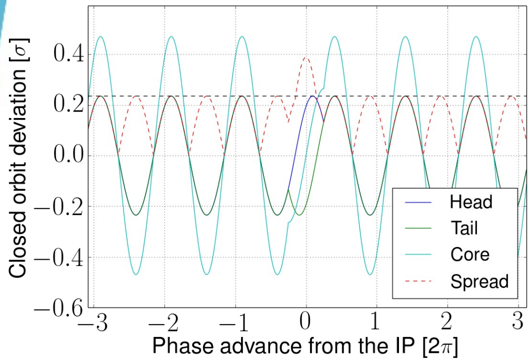
- Brief overview of the effects expected
- Orbit effects
- Tune effects
- TRAINS : Status and plans
- Summary

Order of magnitudes

- Beam-beam interactions have an impact on the orbit and linear (and non-linear) optic functions :

Orbit

(Long-range or head-on with an offset)



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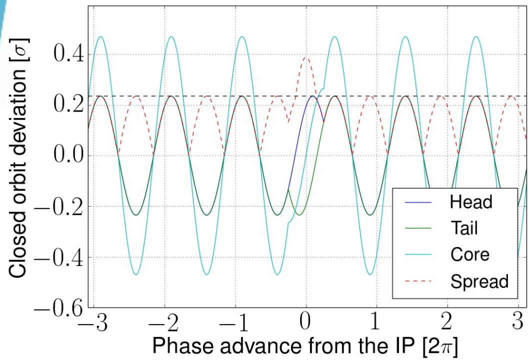
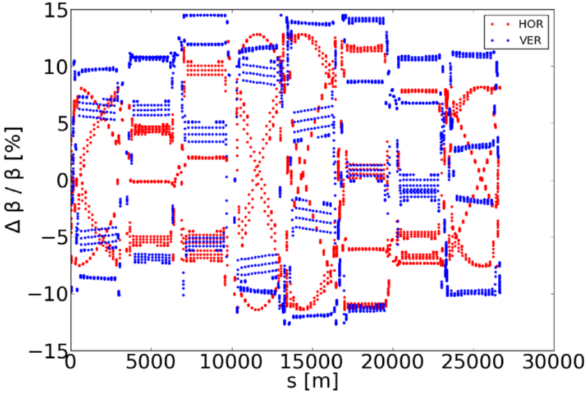


β-function

(Mainly head-on interactions)

C. Tambasco



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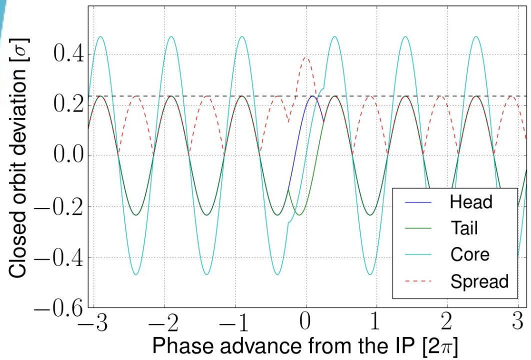

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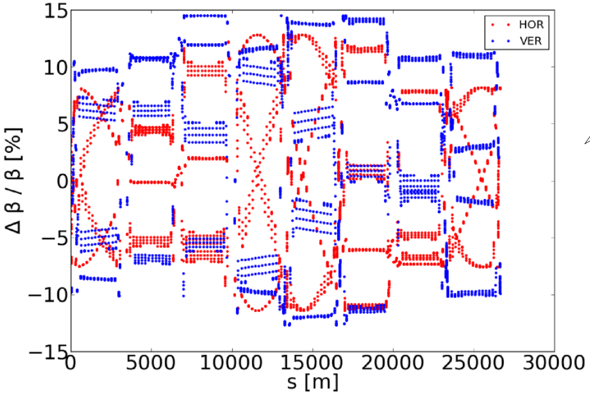

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Tune ~ -0.01 (per IP)

Chromaticity ~ ± 2 units (IPs 1 and 5)

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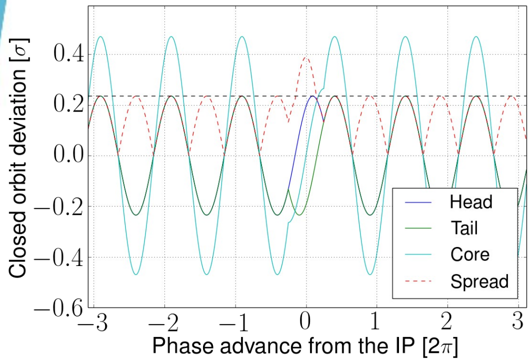

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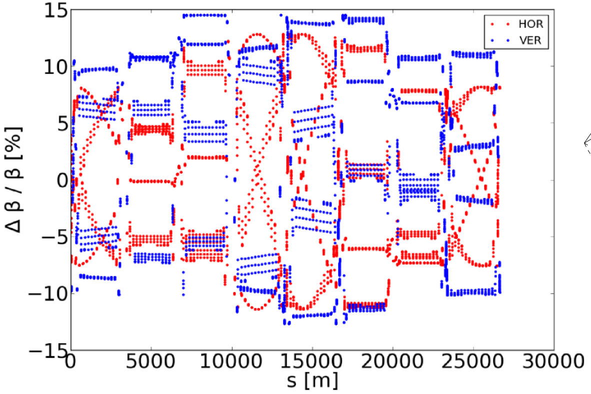

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- Tune ~ ±0.004 (per IR)
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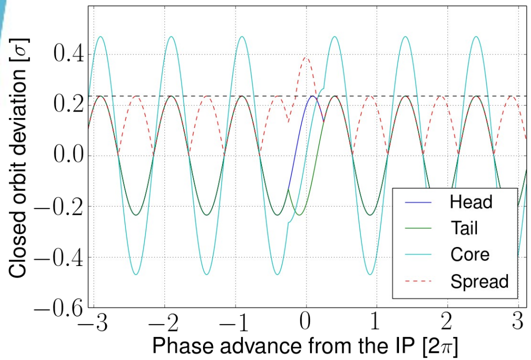

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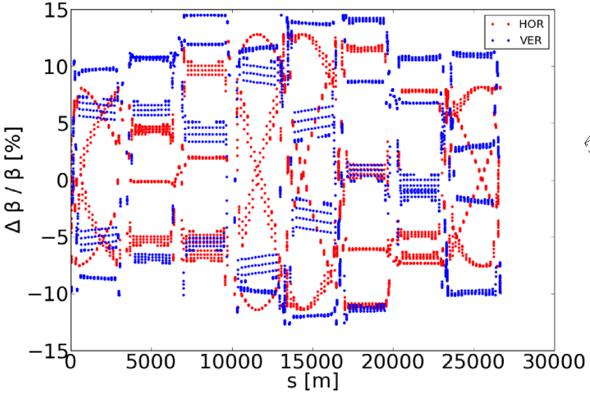

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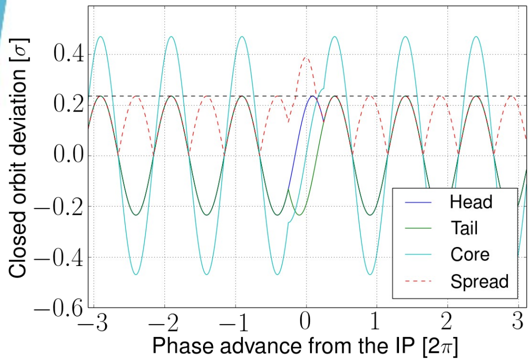

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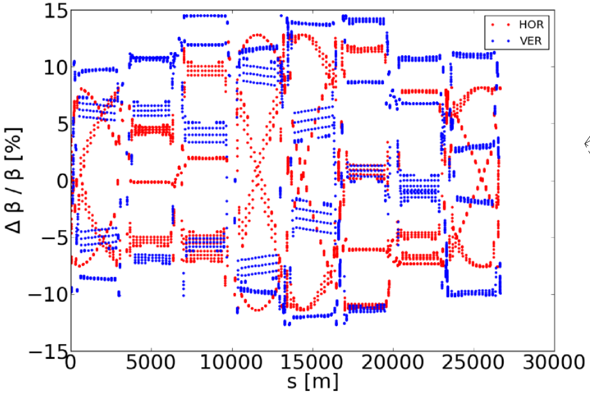

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→ Many more details in T. Pieloni @ HiLumi meeting 2014 and ref. therein

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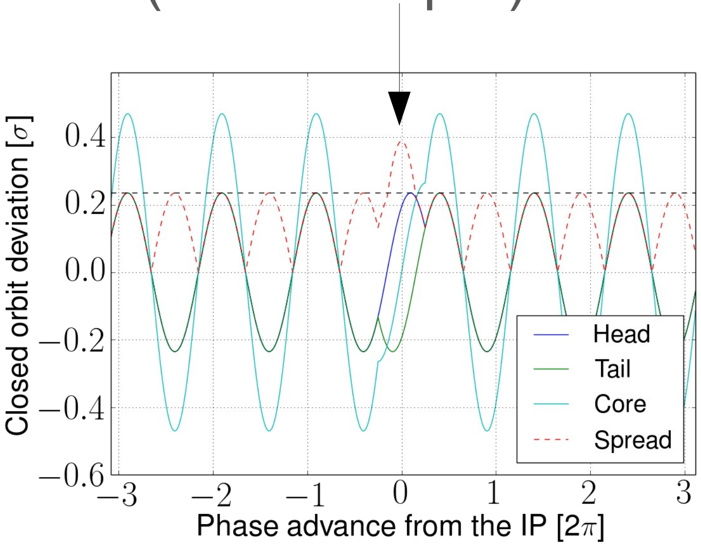
Orbit effects : Impact on luminosity

- Due to the symmetry between the two beams, the offset at the IP result in head-on collision, but the luminous region is displaced transversally with a bunch by bunch spread of 0.4 σ (→ 3 to 5 µm)



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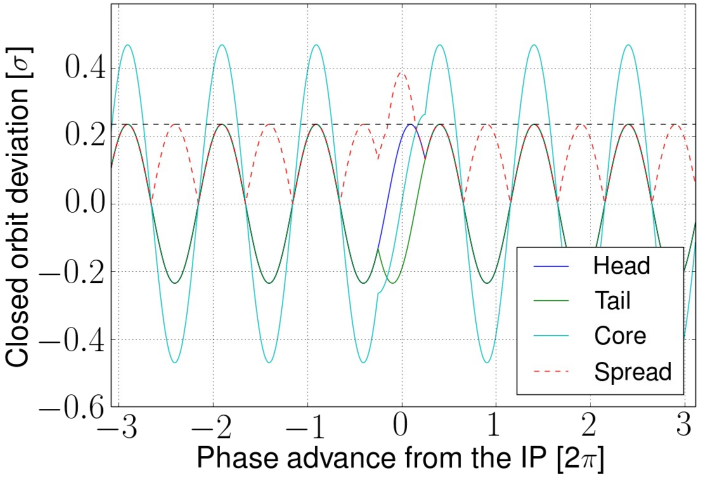
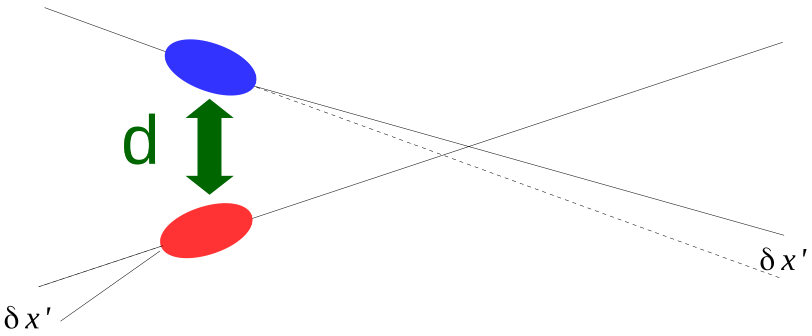


- With the worst phase advances between IPs (φ_1=1/4+Q/2+n/2, φ_2=φ_1+m/2), this can lead to a full separation of 0.4 σ between the beams in other IPs → 4 % reduction of the luminosity of PACMAN bunches → ~0.6 % reduction of the total luminosity
- If needed it could be mitigated with equal phase advances between IPs in the two beams respectively
- The maximum orbit spread is proportional to *1/d*, with *d* the normalised separation at the LRs

  3m and 170 μrad in IP8 → 0.15 σ

  10m and 170 μrad in IP2 → 0.08 σ

Need for self-consistency



Weak-strong approach :

$$\delta x = \Delta x_{coh}'(d)\beta\cot(\pi Q)$$

Strong-strong approach :

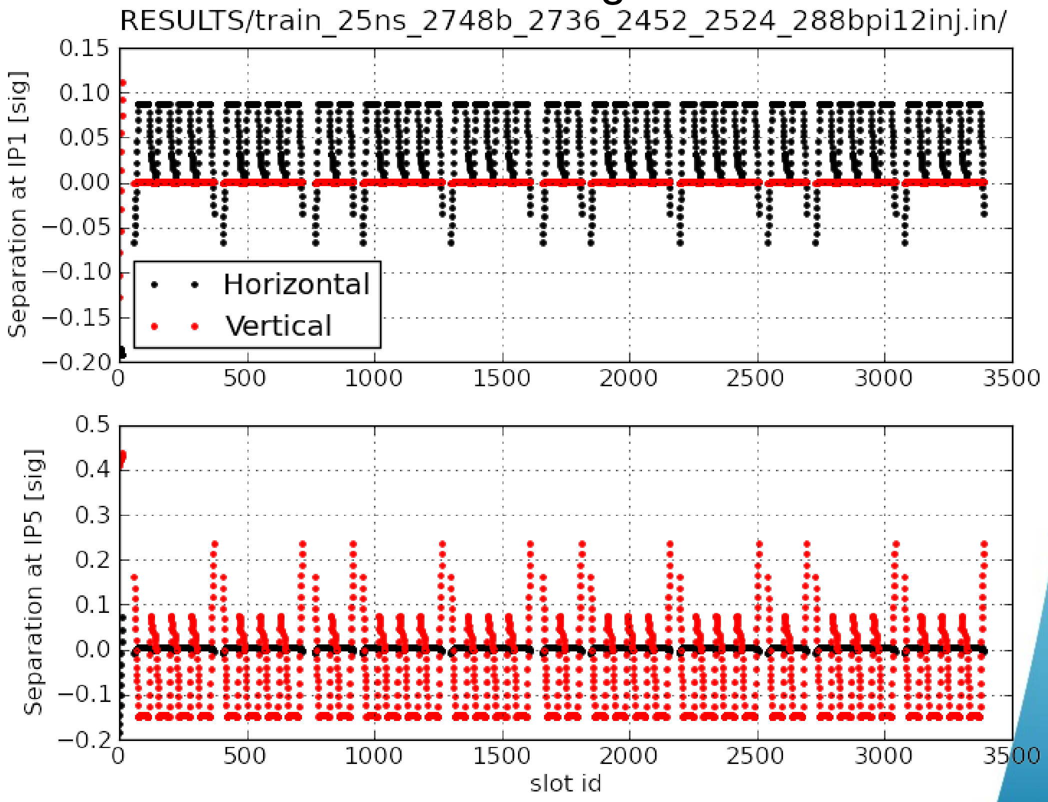
$$\begin{cases} \delta x_{B1} = \Delta x_{coh}'(d + \delta x_{B1} + \delta x_{B2})\beta_{B1}\cot(\pi Q_{B1}) \\ \delta x_{B2} = \Delta x_{coh}'(d + \delta x_{B1} + \delta x_{B2})\beta_{B2}\cot(\pi Q_{B2}) \end{cases}$$

- Need to solve a set of coupled non-linear equations (one per bunch)
- TRAIN implements an iterative method based on MAD-X to converge towards a self-consistent solution
- In hadron colliders (weak beam-beam interactions), the self-consistent solution is usually close to the weak-strong solution

Self-consistent computations, IPs 1 and 5

- No septation in the crossing plane of each IP
- Separations at the IPs remain below 0.3 σ, in agreement with the theoretical model
- Need to adjust the orbit to obtain the highest luminosity (lumiscans)
- Large difference between the two IPs highlighted during T. Pieloni's presentation

Nominal filling scheme



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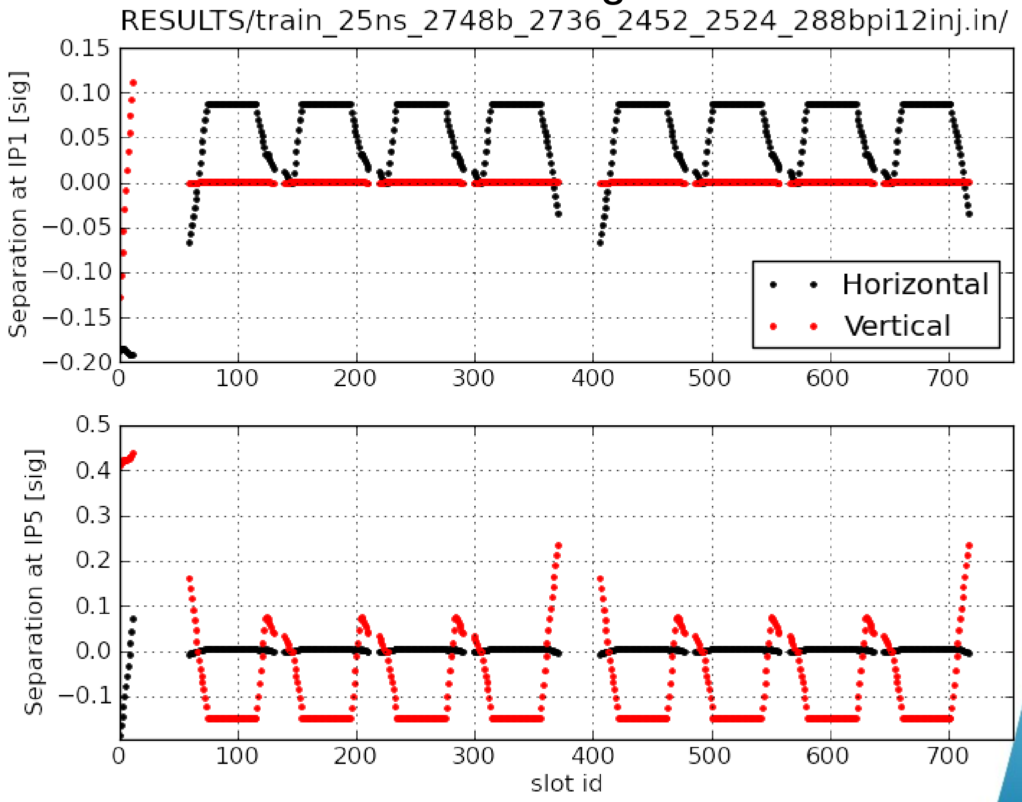
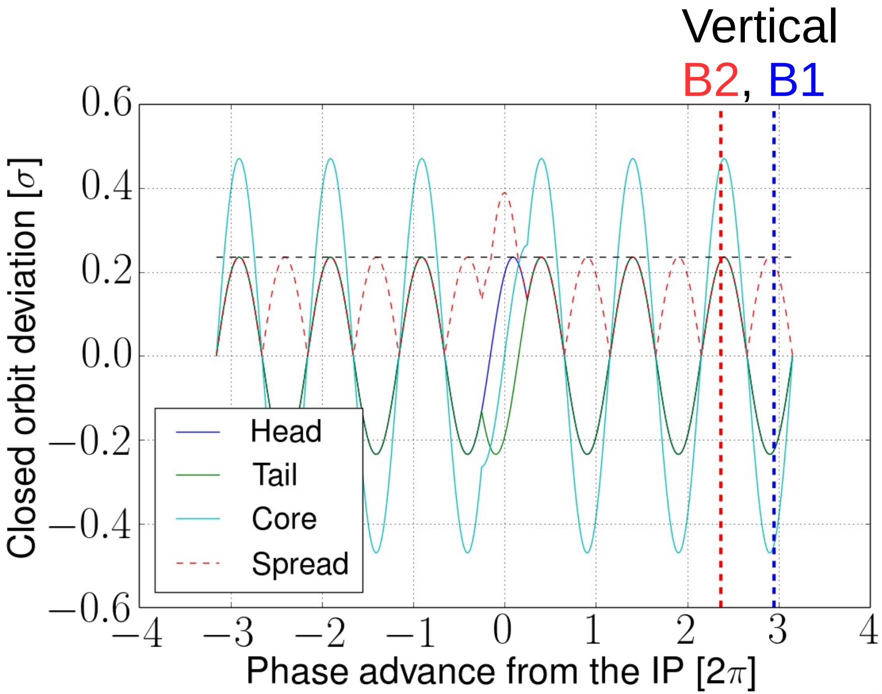


Difference between IPs 1 and 5

- The difference in phase advance between the IPs is more critical in the vertical plane, therefore the orbit effect is stronger in IP5 (since it is caused by the vertical crossing angle in IP1)



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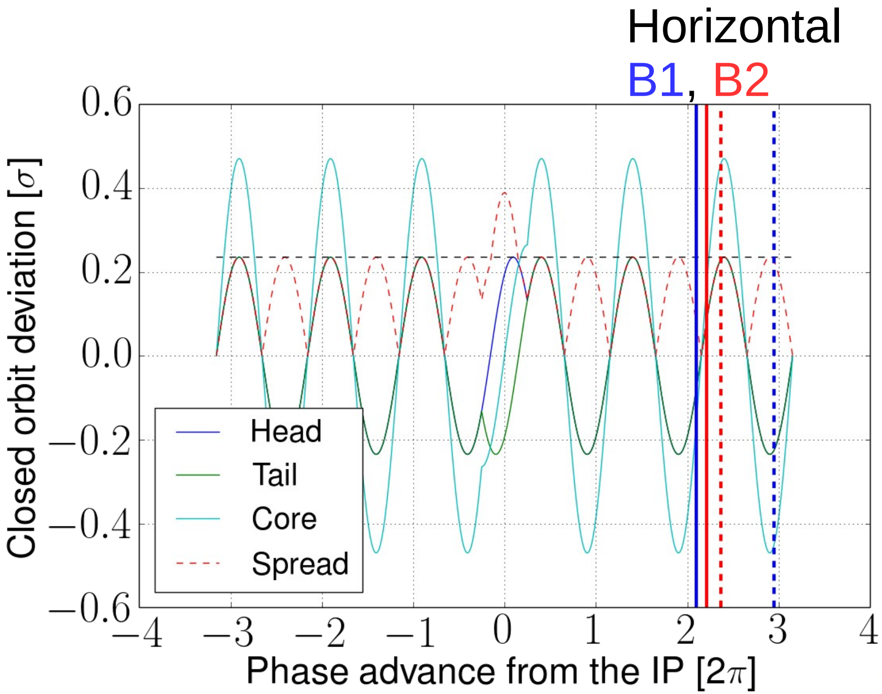
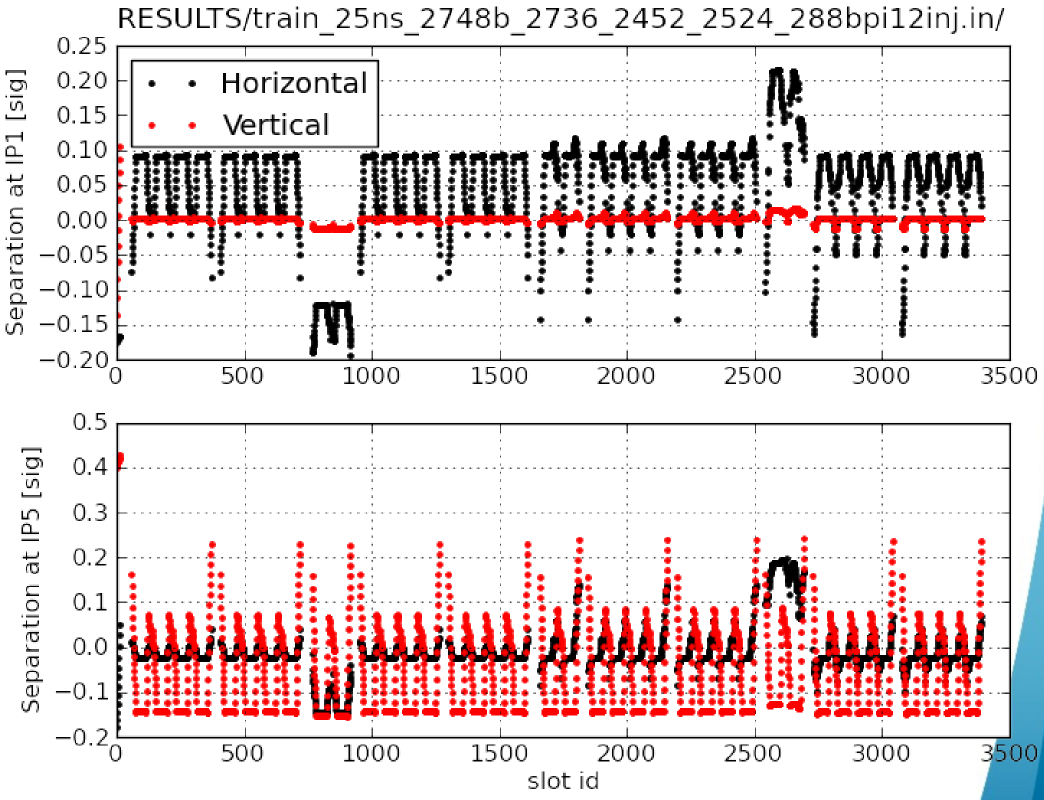


Self-consistent computations, IPs 2 and 8

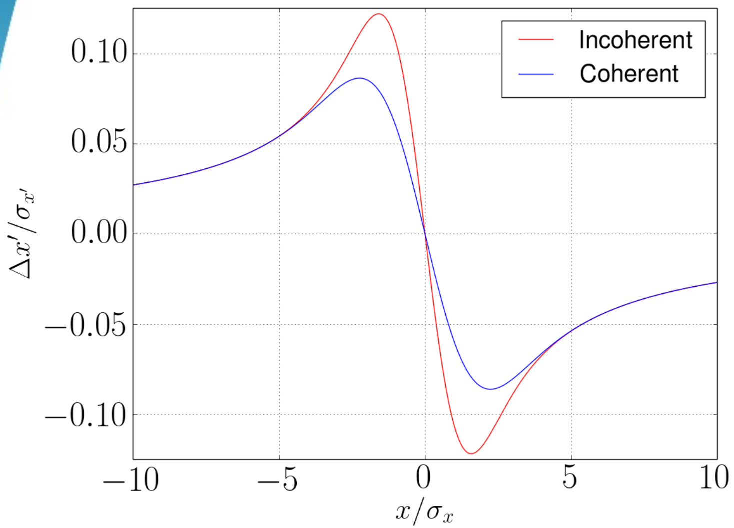
- Long-ranges in IP8 result in separations in the horizontal plane ~0.15 σ

  → Close to the worst phase advance wrt the main IPs

- Long-ranges in IP2 result in separations in the vertical planes well below 0.08 σ



The effect of levelling with an transverse offset

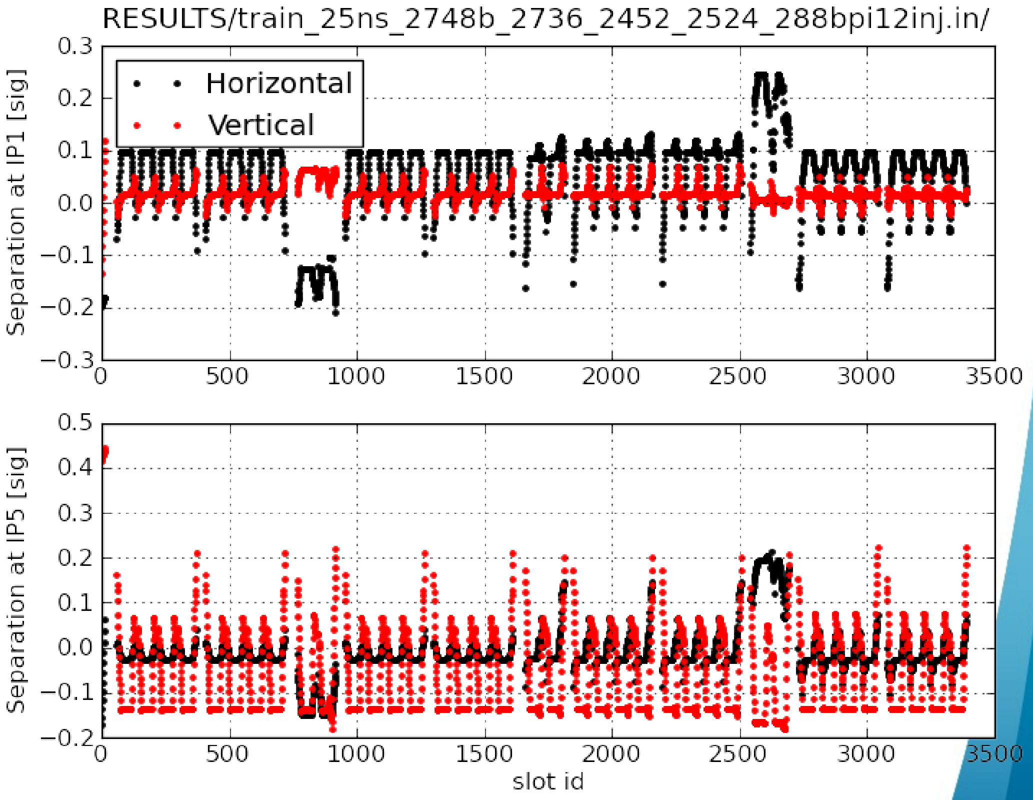


Max 0.1 σ per IP
at around 2 σ total separation
→ Within the leveling range
of IPs 2 and 8

- Coherent beam-beam kick (averaged over the distribution of particle)

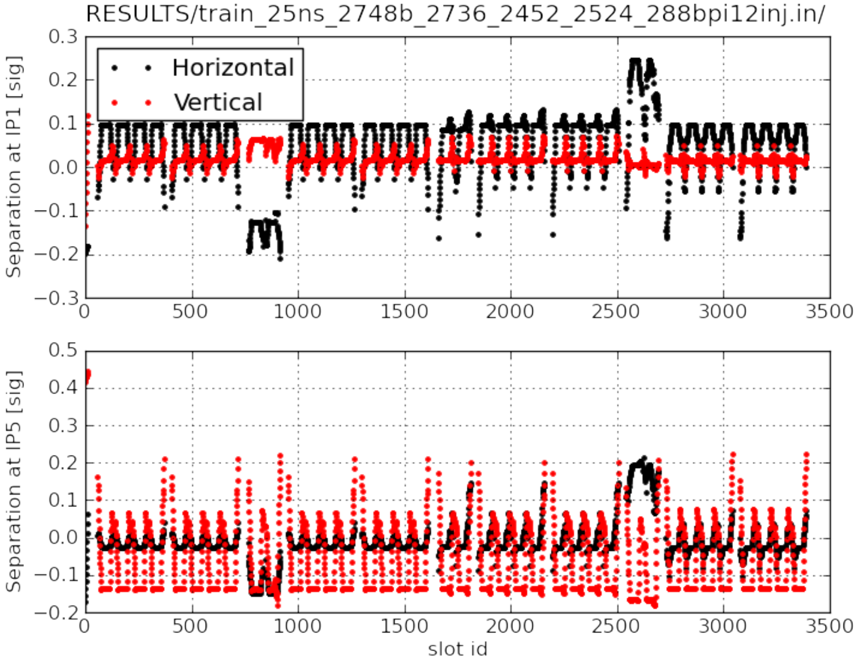
Self-consistent computations, offset levelling in IPs 2 and 8

- The separation in IPs 1 and 5 due to the levelling with an offset in IPs 2 and 8 is negligible even at the maximum of the coherent kick, due to a favourable phase advance



Filling schemes - BCMS

Nominal



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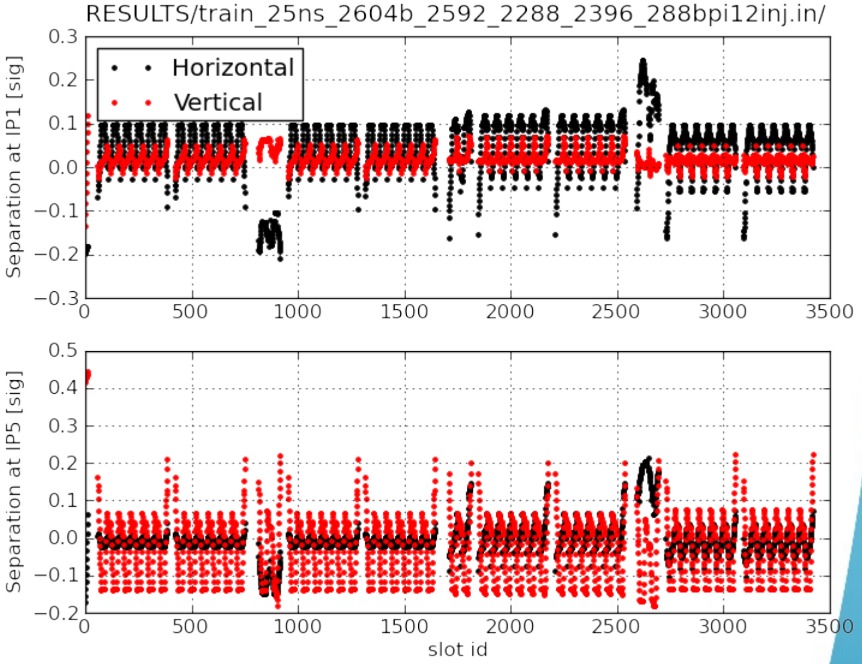


- Maximum orbit shifts are identical with the BCMS beams, but the number of PACMAN bunches is higher → slightly higher impact on luminosity

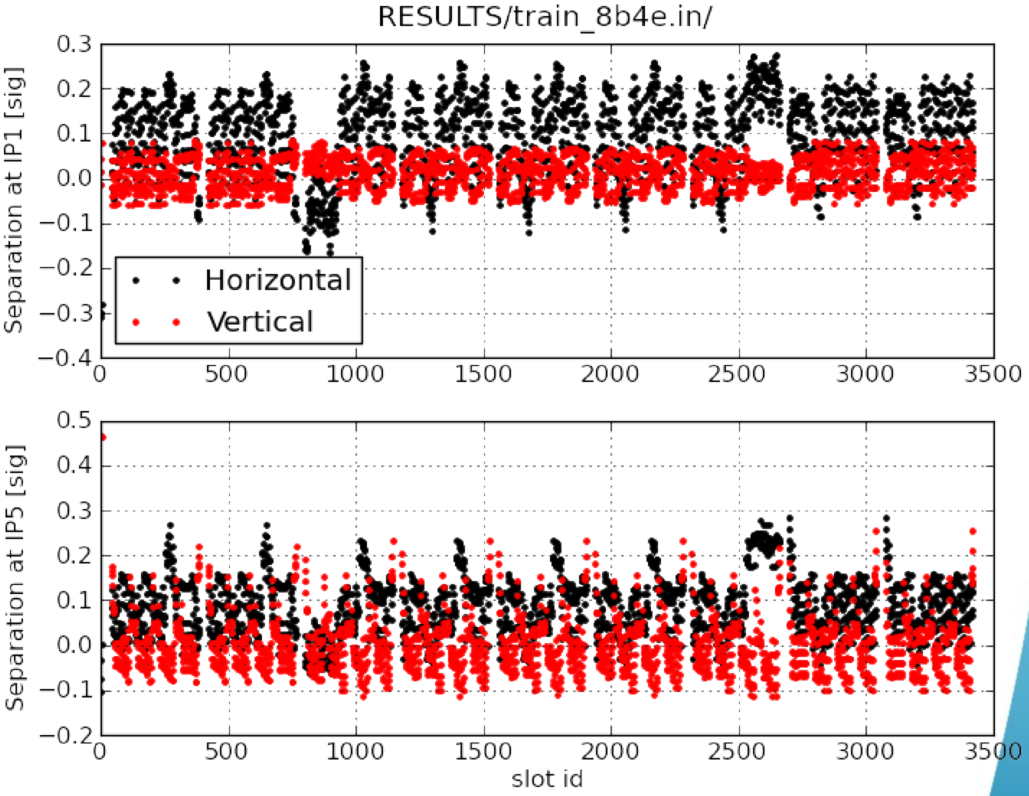
Filling schemes - 8b4e

- All bunches are PACMAN bunches

  → Similar bunch by bunch spread due the higher intensity

  → Higher impact on luminosity

- Exact impact to be evaluated including the orbit optimisation, nevertheless the order of magnitude will remain ~ 1 %



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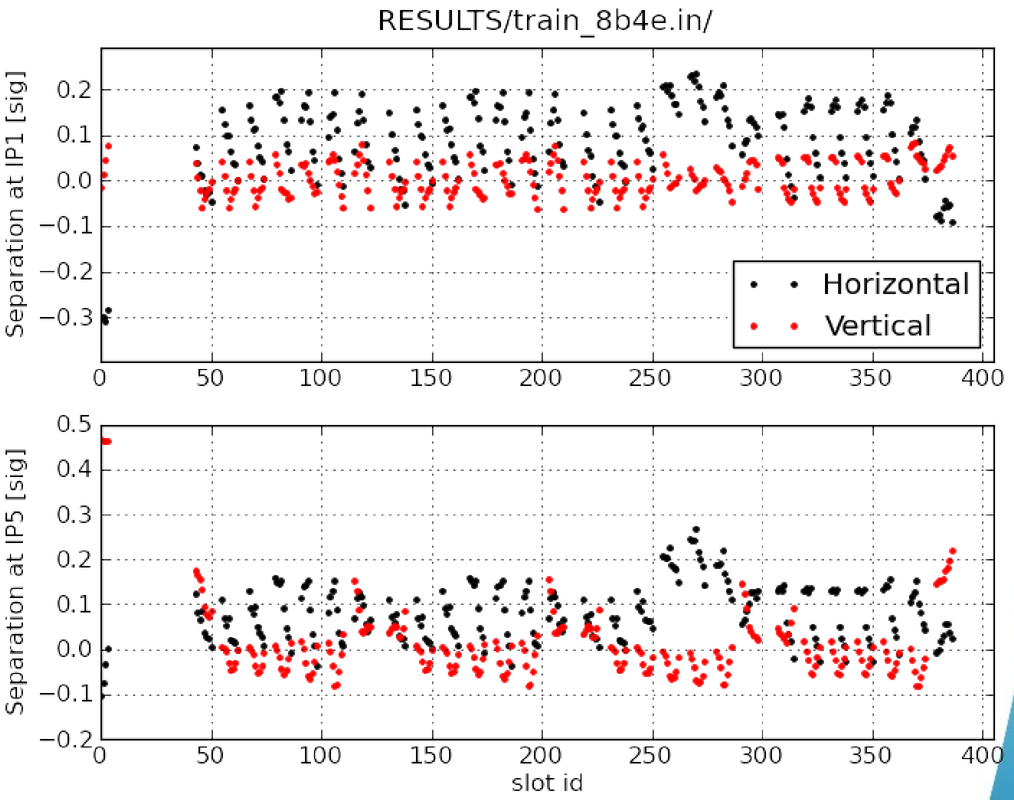
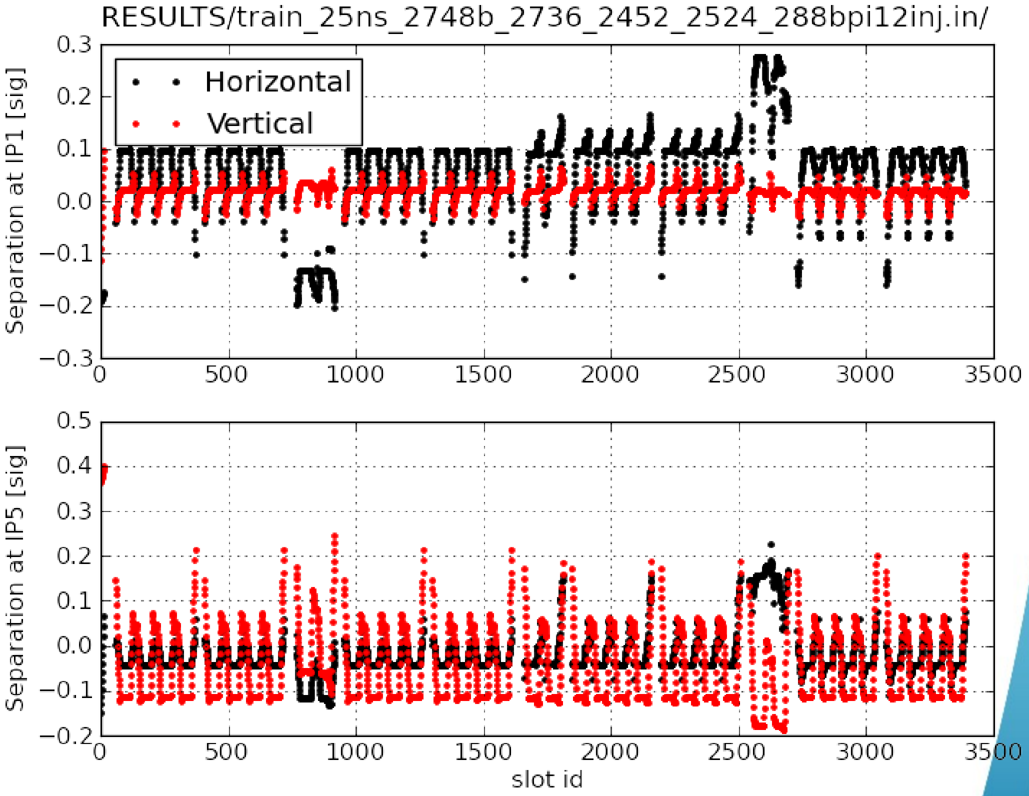


Flat optics – 10/40cm

- The orbit effect is defined by the separation in the crossing plane → With a flat optics the effect is reduced by 14 % due to the larger normalised separation

Nominal



Other aspects of orbit effects

- The operation with DC wires cannot compensate for the orbit spread → Identical impact as an orbit optimisation
- The orbit spread can be mitigated at only certain locations by adjusting the phase advances

  → The effect remains within crab cavity tolerances (R. Calaga)

  → The effect remains negligible for aperture considerations (R. De Maria)

  → Collimation at low amplitude (hollow e-lens) ?

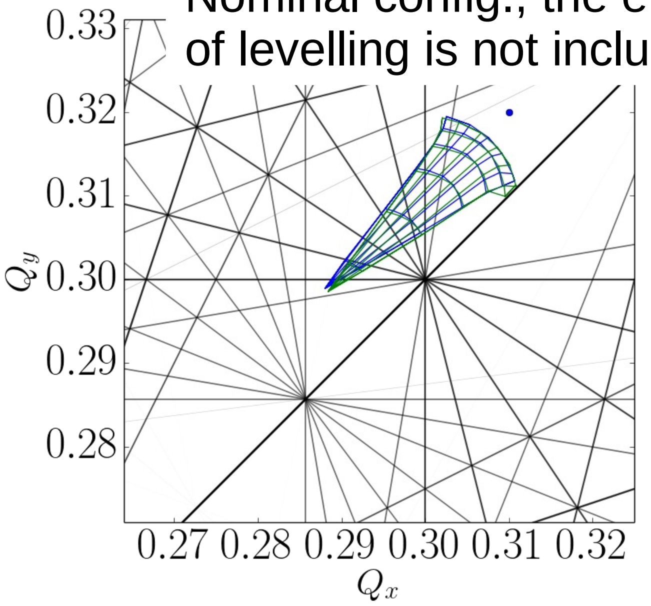
  → Others ?
- The offset at the IPs within the ranges expected (<1 σ) are not a concern for loss of Landau damping

Tune and tune spread : The effect of IPs 2 and 8

- Long-range effects are weak in those IPs (baseline)
- Super-PACMAN effect from head-on or offset collision have a significant effect on the tune shift and spread

→ May have an important impact on DA

Nominal config., the effect of levelling is not included



HO and LR in IP15

HO and LR in all IPs:

IP2 and 8 separated

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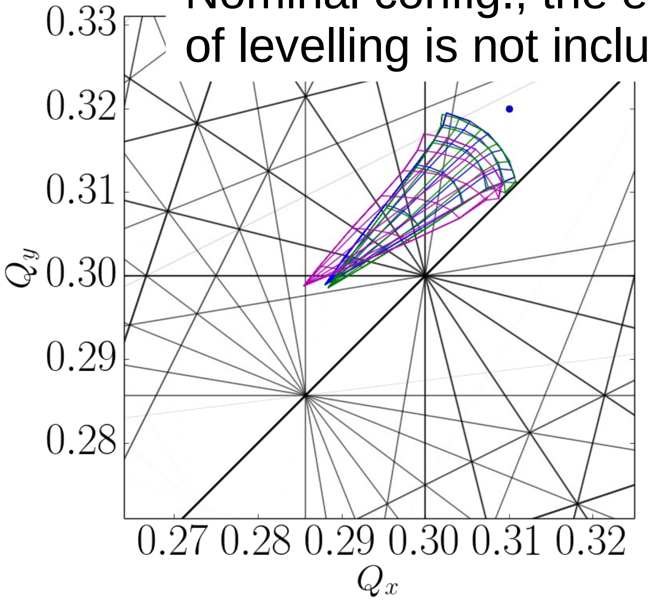

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IP8 at 2 σ (full)

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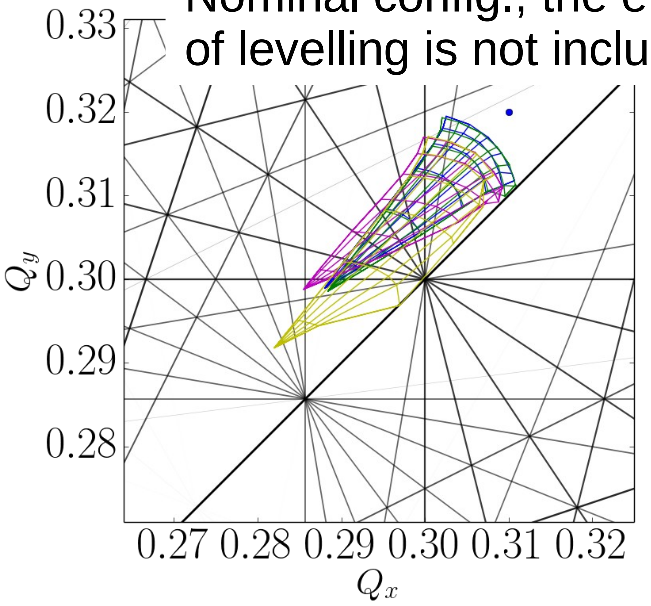

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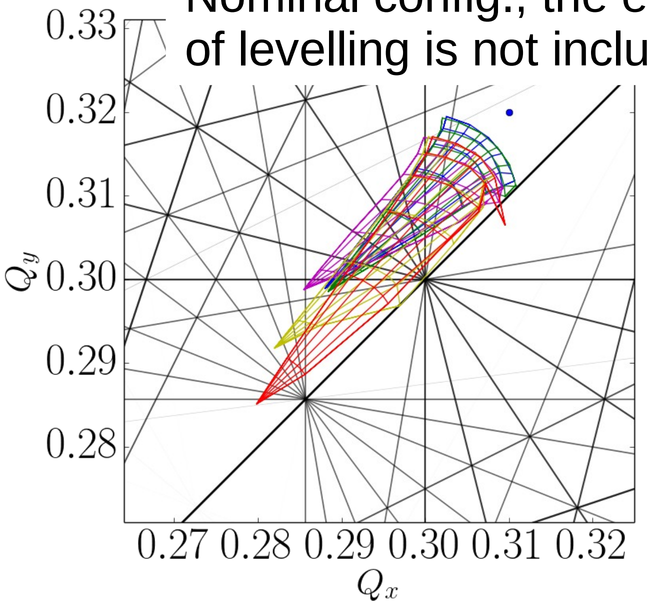

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IP8 head-on

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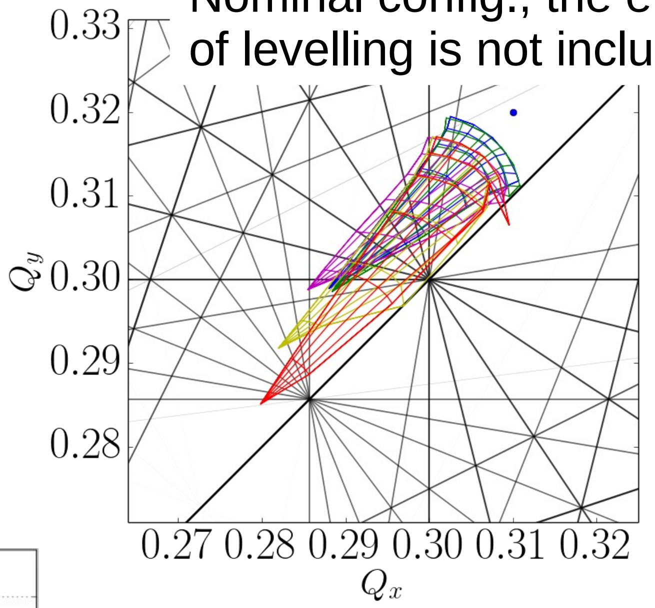

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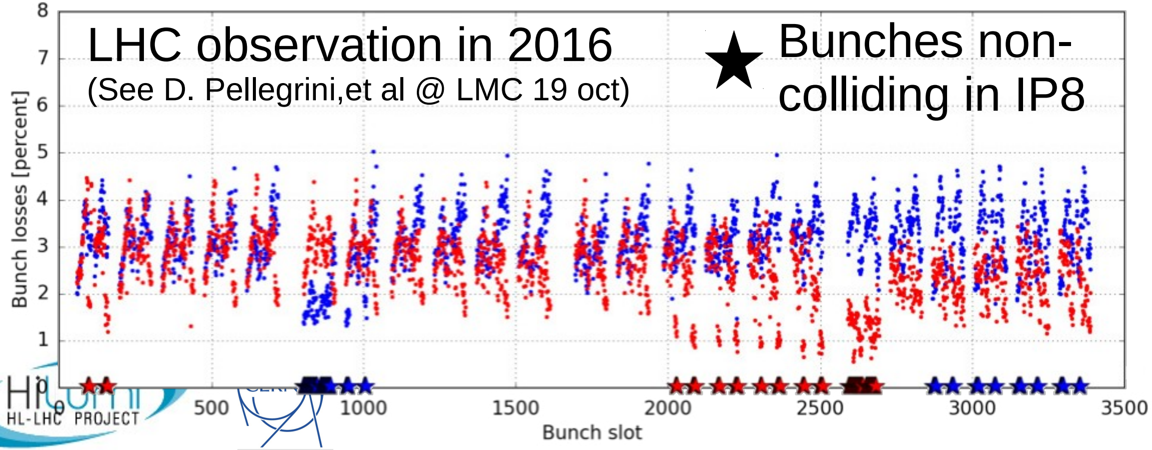
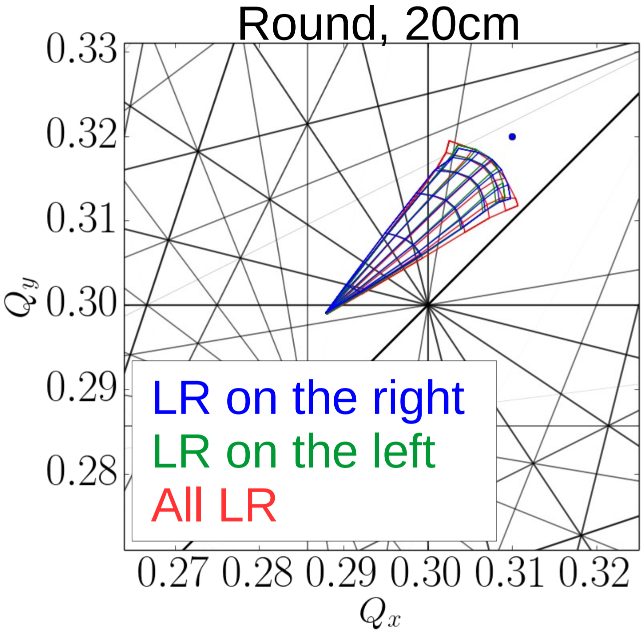


Tune : Flat optics

- The alternating crossing angle mitigates the tune shift perpendicular to the diagonal



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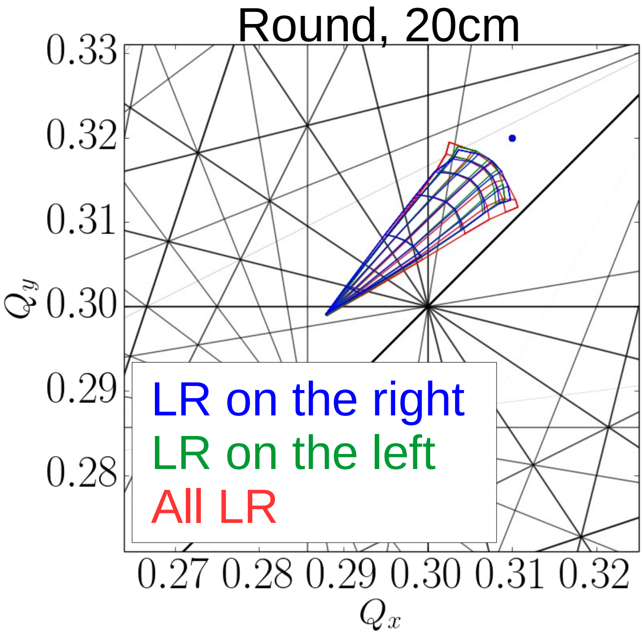
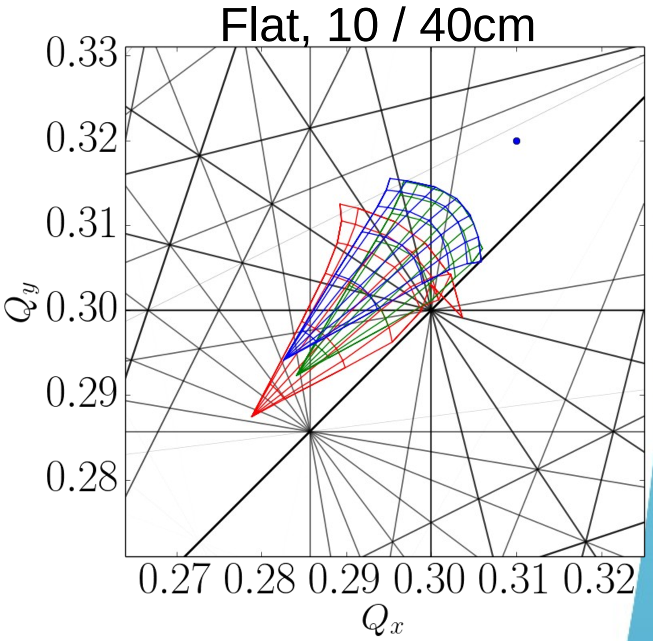
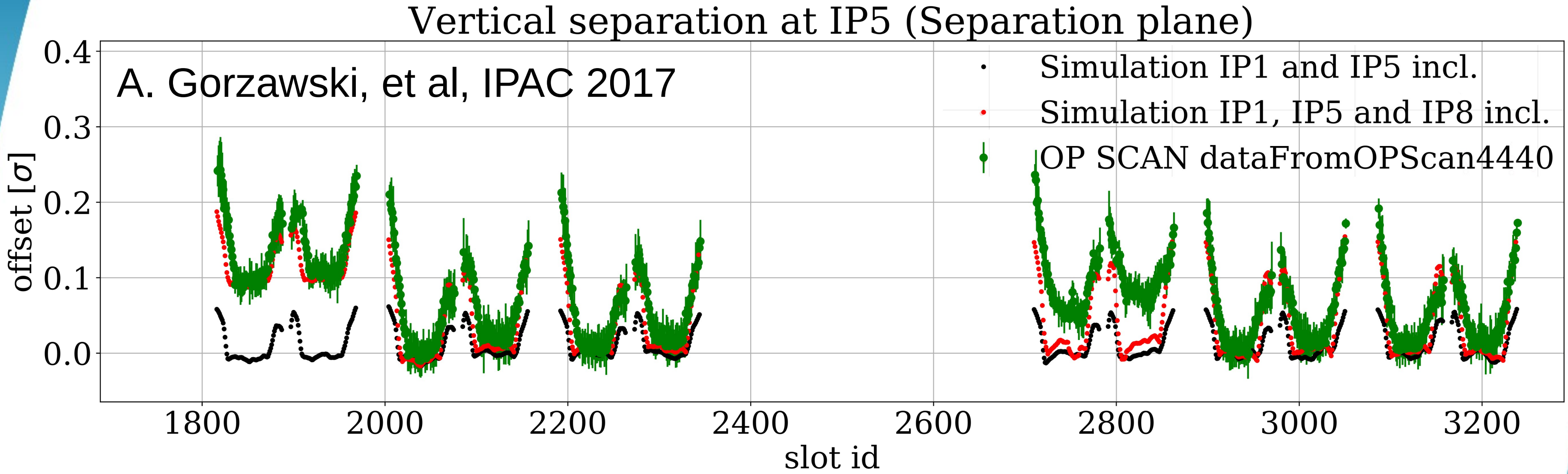




- PACMAN tune shifts along the diagonal are unavoidable with flat beams due the asymmetry in the β at the location of the long-range interaction
- May have an important impact on DA

TRAIN - Comparison to LHC data



- Offset at the IP reconstructed from OP scan (2015 run) matches TRAIN prediction including the effect of beam-beam interactions in IR8
- Good agreement was also shown when comparing to ATLAS vertex detector measurement of the luminous centroid (2011) and during VdM scans 2012 (See T. Pieloni @ HiLumi meeting 2014)

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TRAIN – Status and plans

- The orbit effect predicted by TRAIN was benchmarked against theoretical predictions and tested experimentally at several occasions
- It is the only tool capable of fully assessing PACMAN effects (orbit, tune and chromaticity) including the optics and arbitrarily complex filling schemes
- Lack of luminosity optimisation mechanisms, preventing accurate evaluation of the luminosity loss
- Lack of flexibility (Fixed number of long-ranges, impossibility to single out interactions, difficulty to add observations point outside of beam-beam interactions)
- The convergence is not robust, leading to failures in several configurations

  → Could not yet evaluate chromaticity effects with HL-LHC lattice and nominal filling scheme
- These aspects will be addressed by a TECH starting in September, and by EPFL thanks to synergies with FCC-hh (and FCC-ee ?)

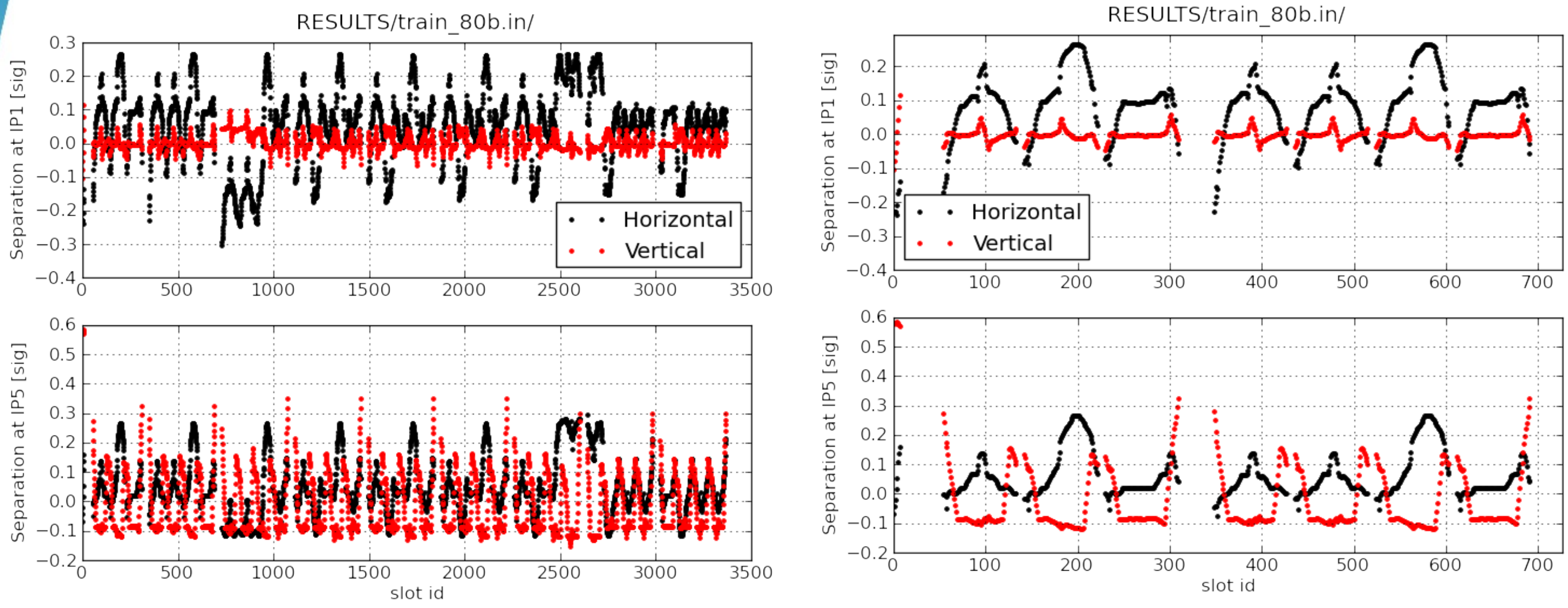
  → The potential of a new version based on MAD-NG will be assessed

Summary

- Orbit and tune effects computed with TRAIN are consistent with weak-strong analytical estimation → self-consistency do not play a major role
- In the new baseline scenario, the orbit effects are not mitigated by β* levelling, since the initial normalised beam-beam separation is reduced
- The luminosity degradation due to orbit effects remains below 1 % with all the filling schemes foreseen : Shall we consider a mitigation by adjusting the phase advances between IPs of the two beams ? Are other systems affected ?
- The tune effects due to offset collision in levelled IPs is not negligible
- The flat optics results in PACMAN tune shifts, mainly along the diagonal

  → Both have to be addressed with DA simulations
- Significant maintenance is needed on TRAIN to improve its usability and to assess all details of the HL-LHC scenarios

BACKUP – Orbit effect with nominal optics and the 80b filling scheme



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BACKUP – Orbit effect with nominal optics, long-range in IPs 1 and 5