
# Operational considerations on the stability of colliding beams

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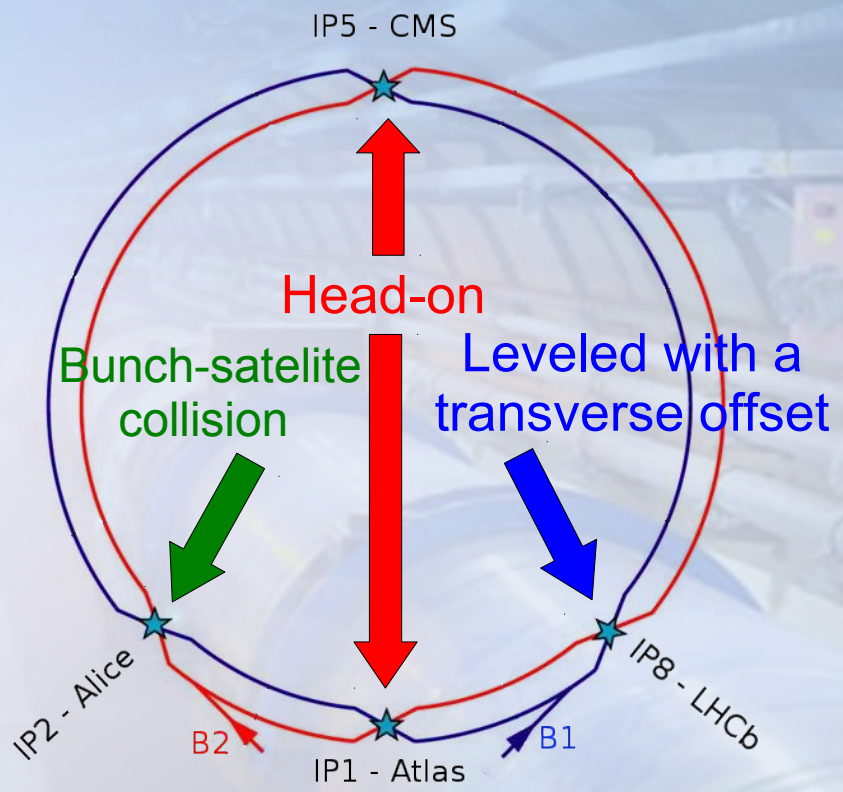
# Operational considerations on the stability of colliding beams

- The LHC layout and filling schemes
- Octupoles and long range beam-beam
- Bringing the beams into collision
- Luminosity levelling with a transverse offset

# LHC configuration

- Alice and LHCb request lower luminosity
- ATLAS and CMS request few non-colliding bunches
- Asymmetric filling

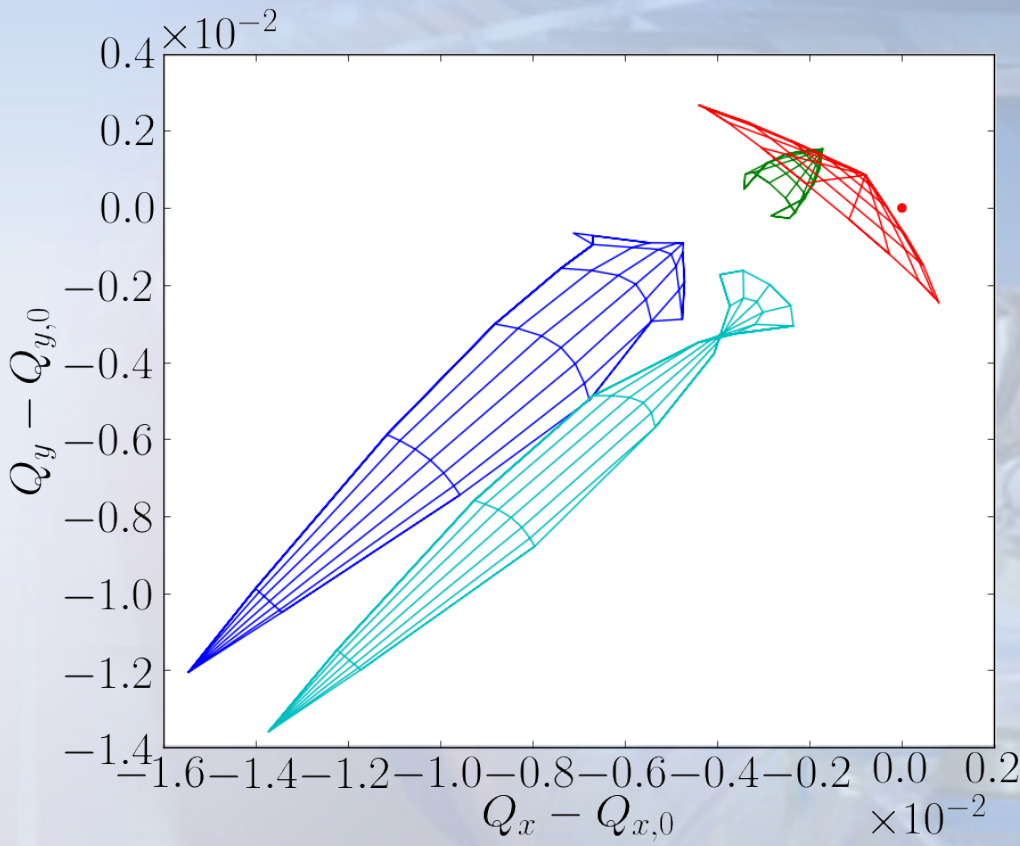



12b 36b

144b

# (super-)Pacman

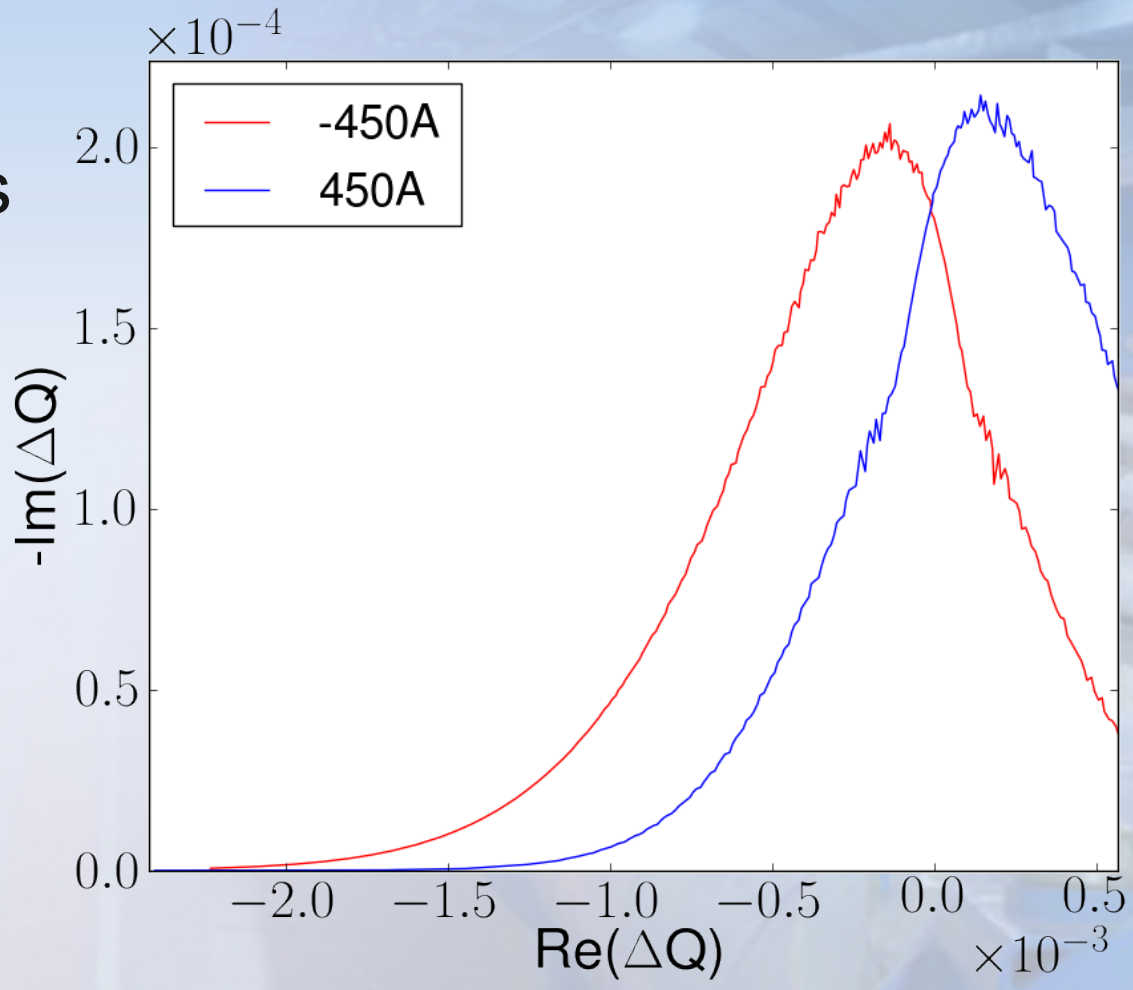
- In this configuration, bunches experience very different beam-beam interactions
- 1 single bunch unstable among 1374 can cause a beam dump



# Octupole and long range

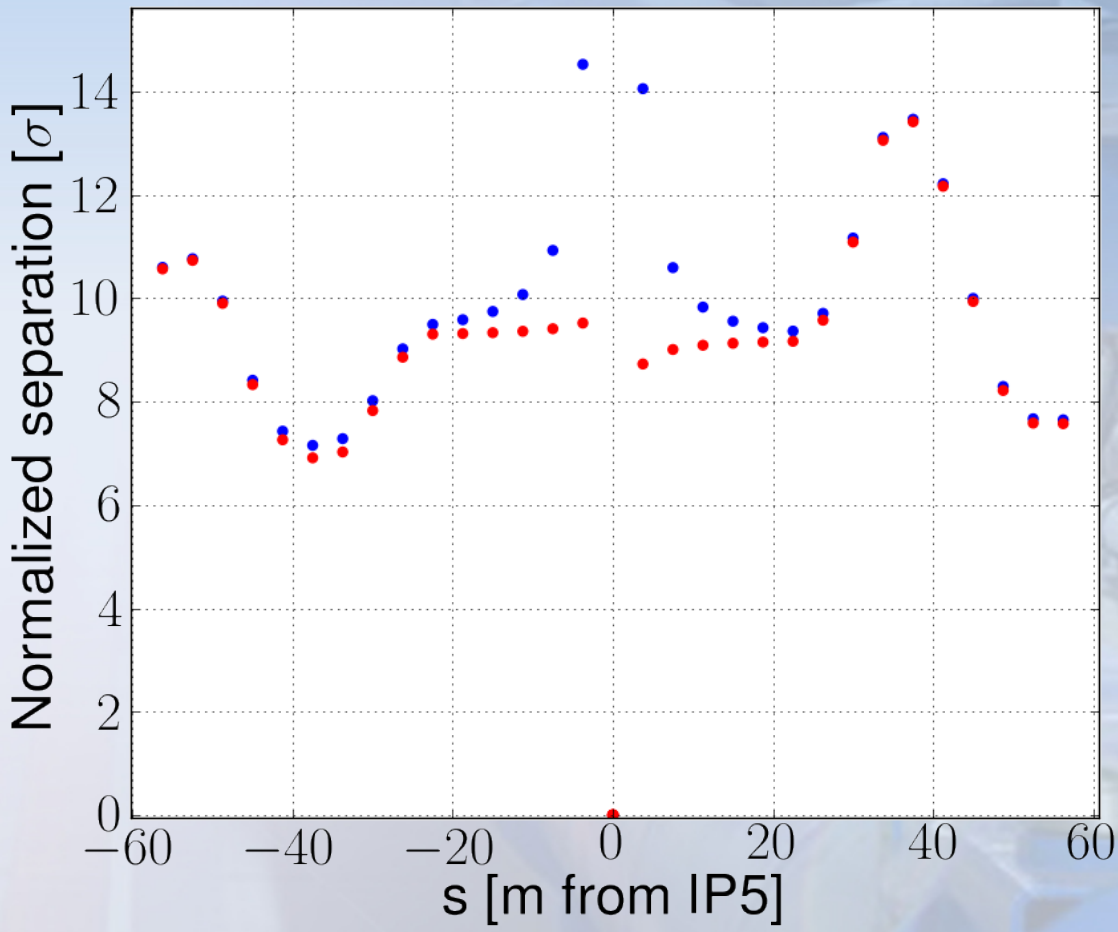
- In the absence of beam-beam, detuning is ensured by octupoles
  (They can be powered with two polarities)
- Re(ΔQ) of impedance modes are expected to be negative

  → negative polarity is preferable



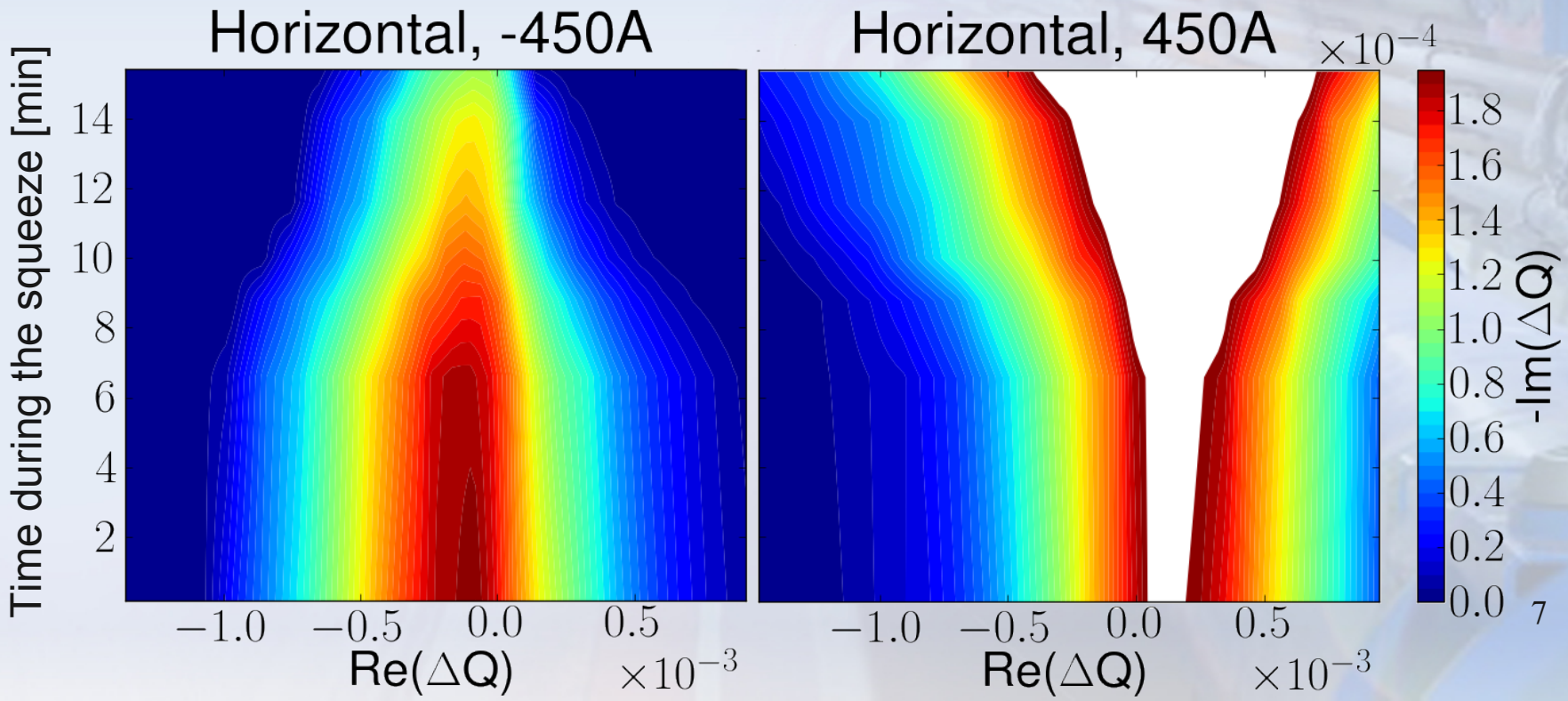
# Octupole and long range

- At the end of the squeeze, the long-range interactions are already in place

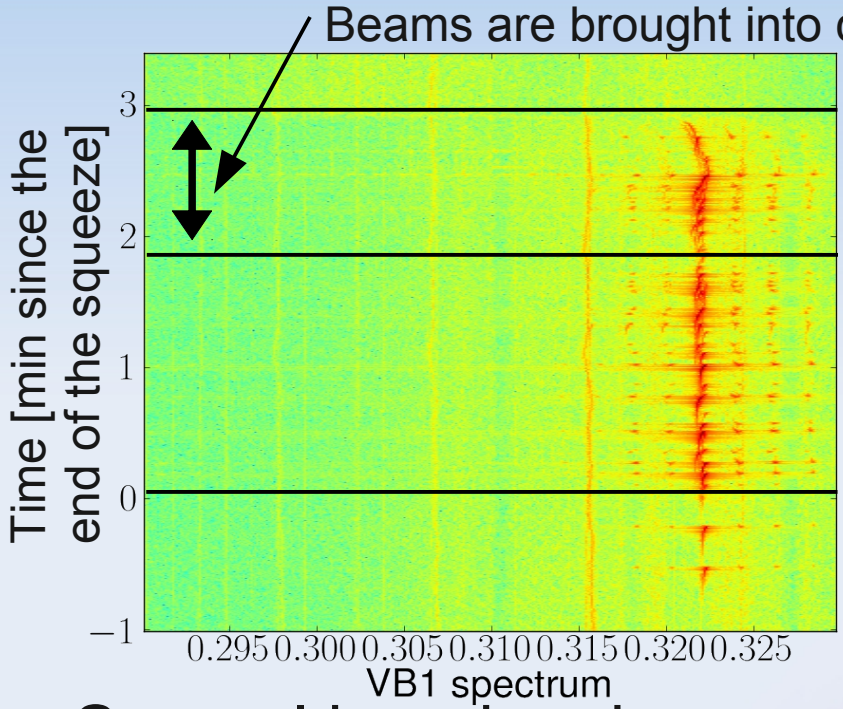


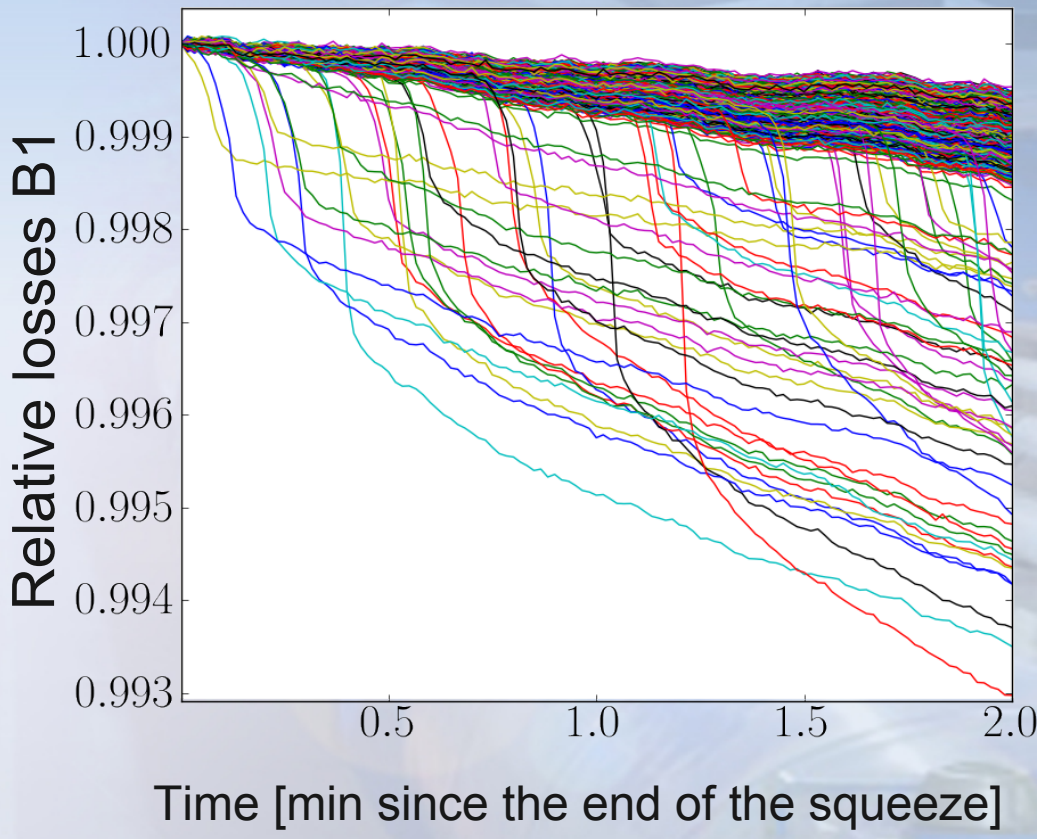
# Octupole and long range

- In this configuration the positive polarity is preferable
  - Effect of other lattice non-linearities are not included
  - Different for almost every bunch



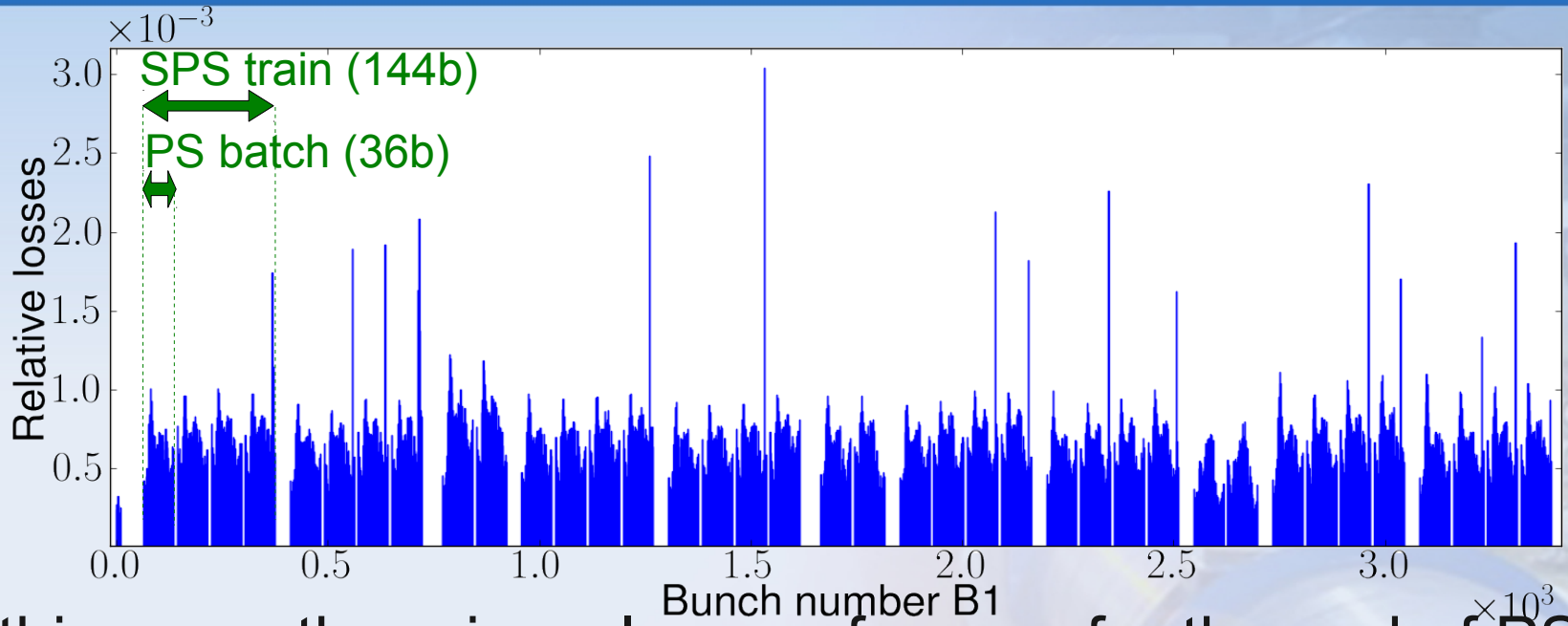
# Observation of instabilities at the end of the squeeze




- Several bunches became unstable at different times near the end of the squeeze to head-on collision
- Q'~10, $ADT_{gain}$ = 50 turns, $I_{octupoles}$ = +533 A

# Bunch selectivity



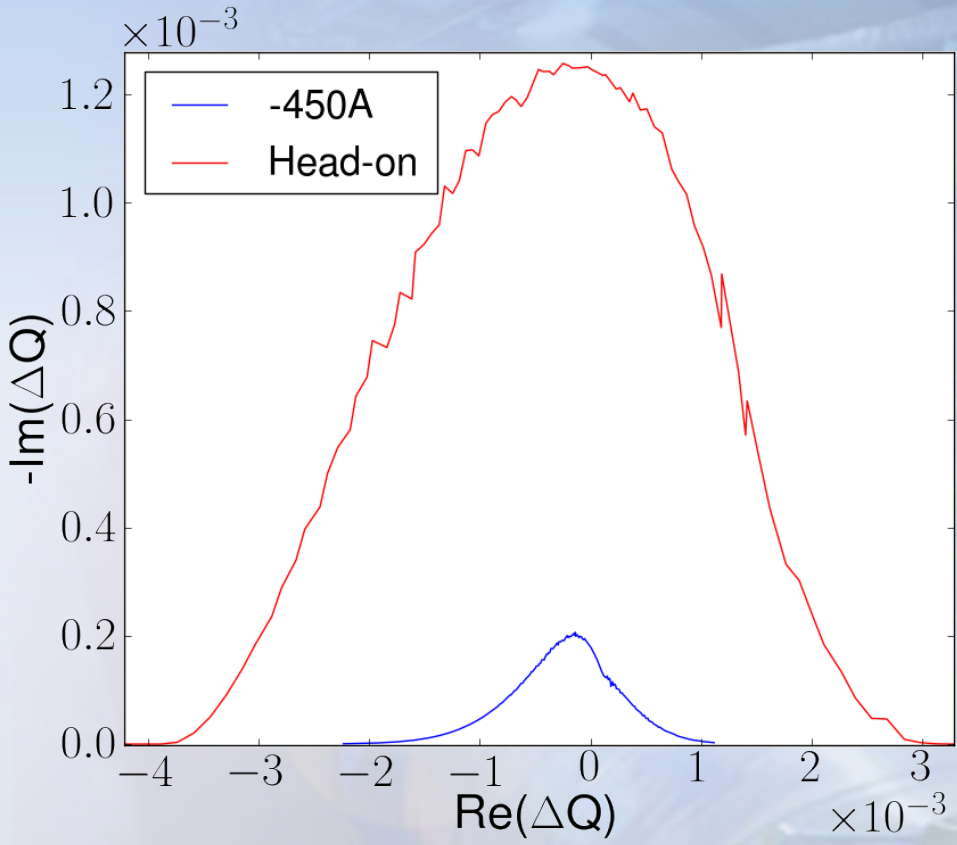

- In this case, there is a clear preferance for the end of PS batches and SPS trains
  - It was not the case for all fills
- The bunch selection cannot be explain beam-beam only
  - Bunches with similar beam-beam configuration do not behave similarly

# Conclusions and outlooks on long-range and octupoles

- Long-range beam-beam can reduce the stability diagram provided by octupoles
  - This may cause problems during the squeeze, during which the long-range encounters become important
- Instabilities at the end of the squeeze in the LHC can not be explained by the interplay of long-range and octupole detuning only
  - Are there other important source of detuning ?
  - Are these insabilities really single bunch ?
  - Are there other processes in place ?

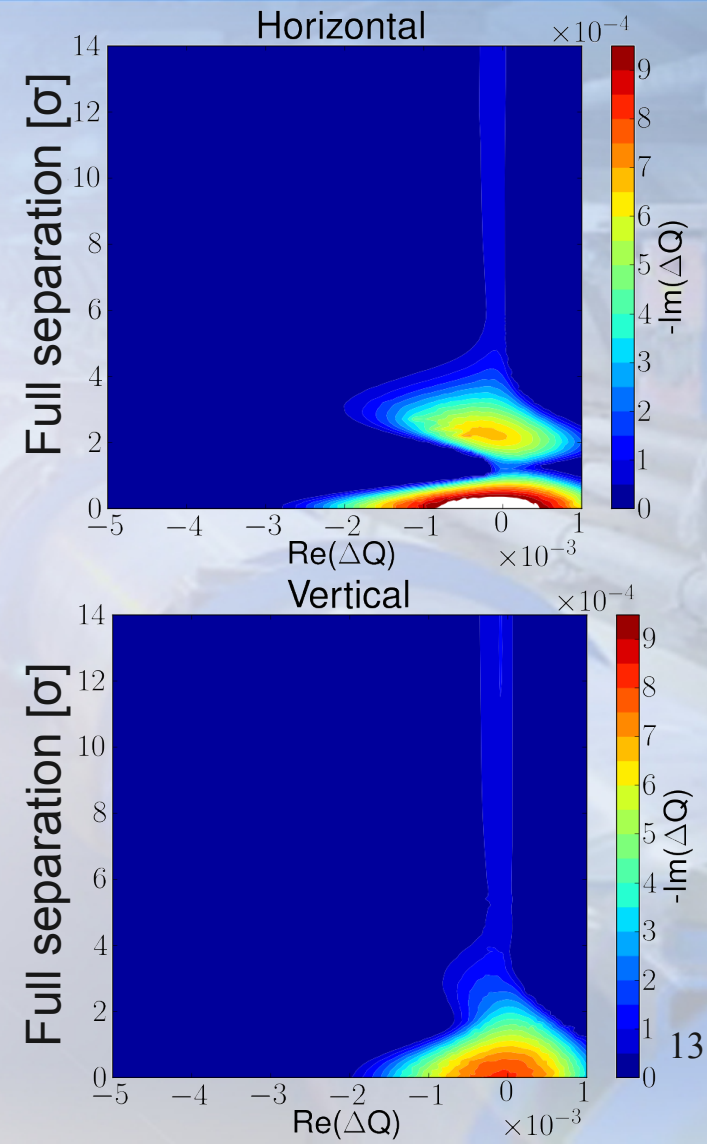
# Head-on interaction

- Stability diagram from head-on beam-beam interaction is usually much larger than with other sources of detuning
- No instabilities observed in the LHC for bunches colliding head-on
  - Colliding during the squeeze is considered for operation after LS1



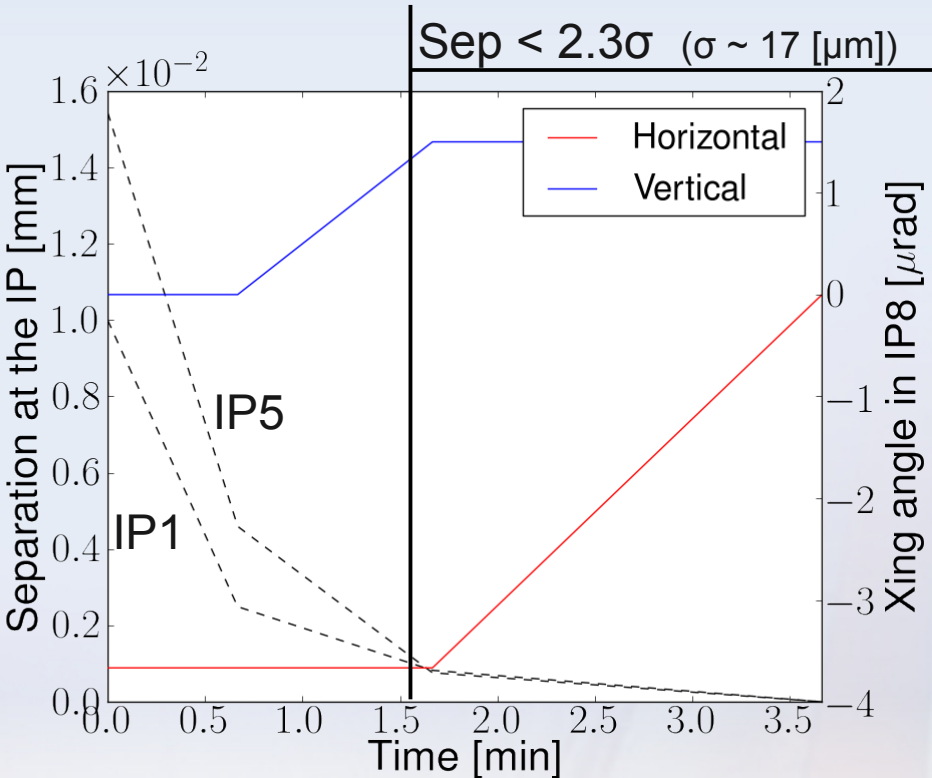
# Collision with a transverse offset

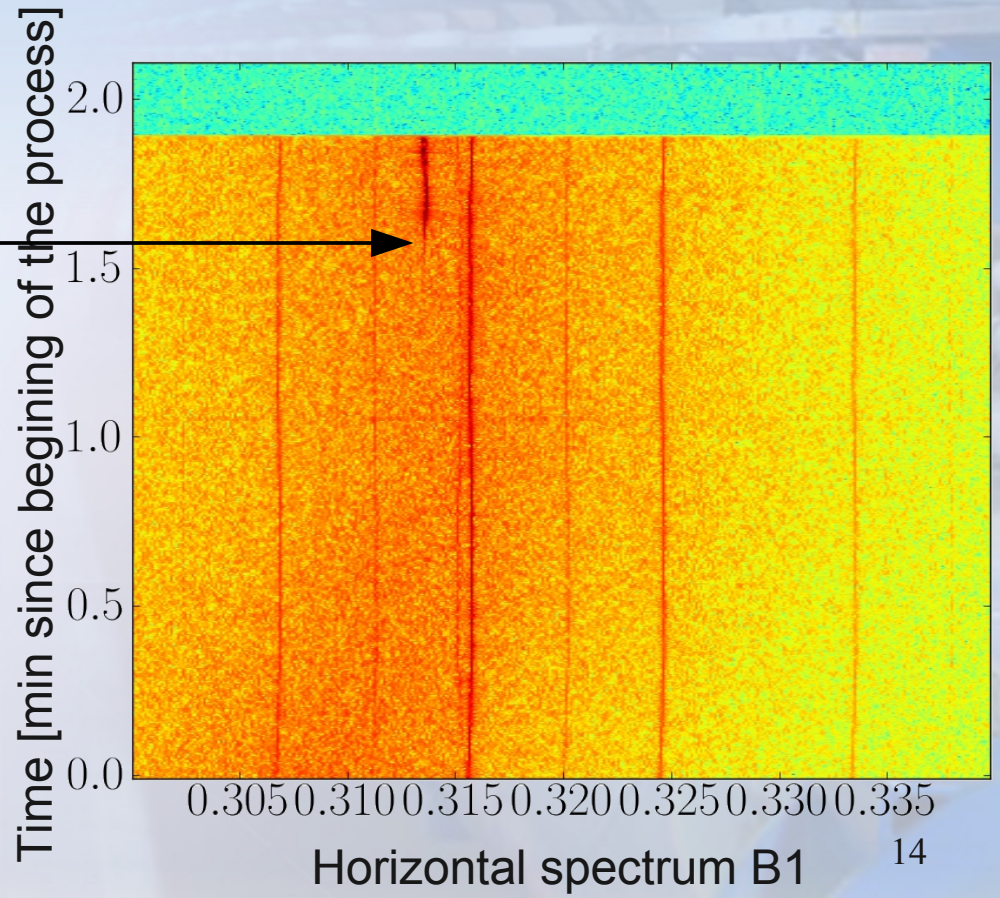
- Example :
  - All Long-range in all IPs, 50ns bunch spacing
  - Intensity 1.5E11
  - Emittance 2E-6 [μrad]
  - $I_{oct}$ = - 450A
  - Separation at IP1 in horizontal plane
- There exists a critical separation at which the stability diagram is minimum
- Two consequences on operation :
  - Going into collision
  - Leveling with a transverse offset



# Observation of instabilities
## Bringing the beams into collision

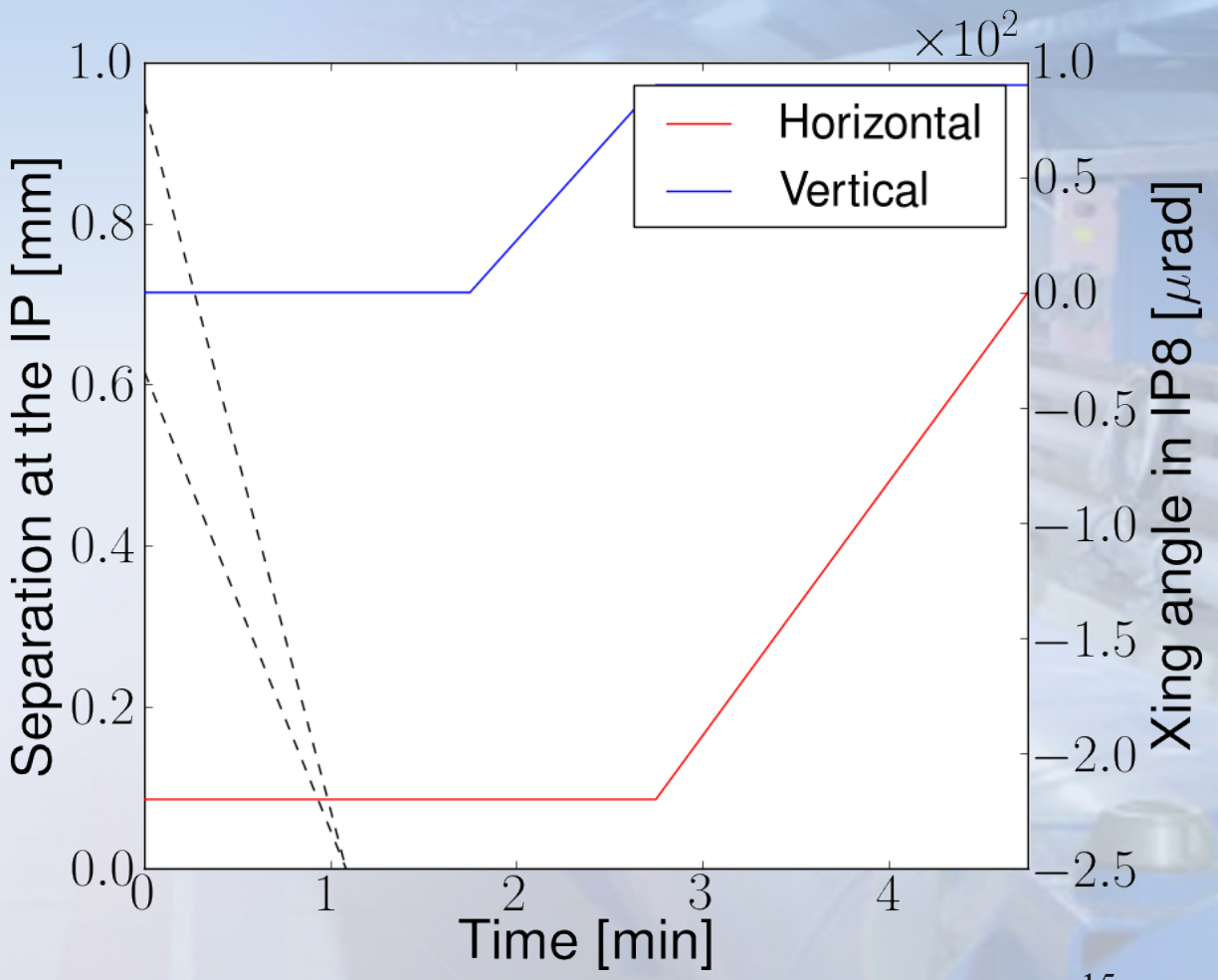
- The process that brings the beams to collision was lengthend in 2012 to tilt the Xing angle in IP8
  - Significant time is spent at separations in the critical region



# Mitigation
## execution speed

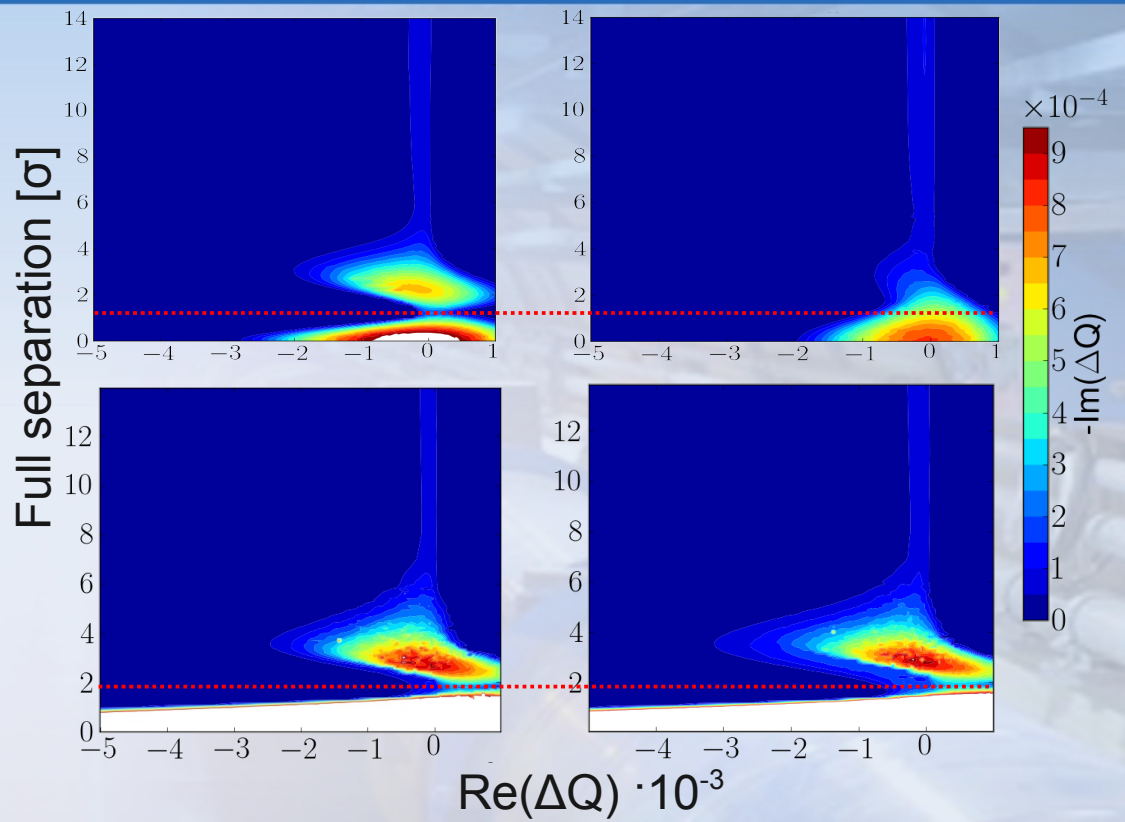
- The beam process was then split into two part, first collide, then tilt
  - Only few seconds spent at small separation



# Mitigation
## IP synchronisazion

IP1 only :

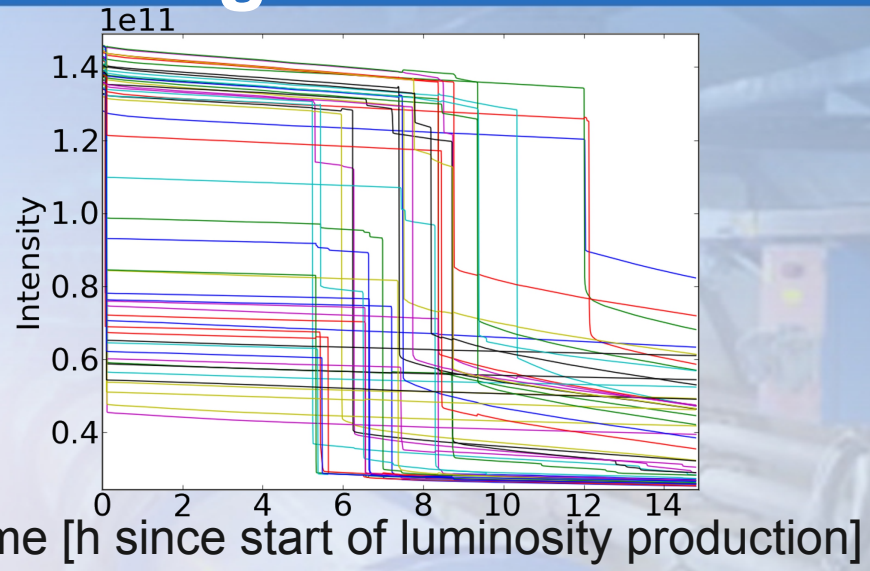
All IPs synchronously :

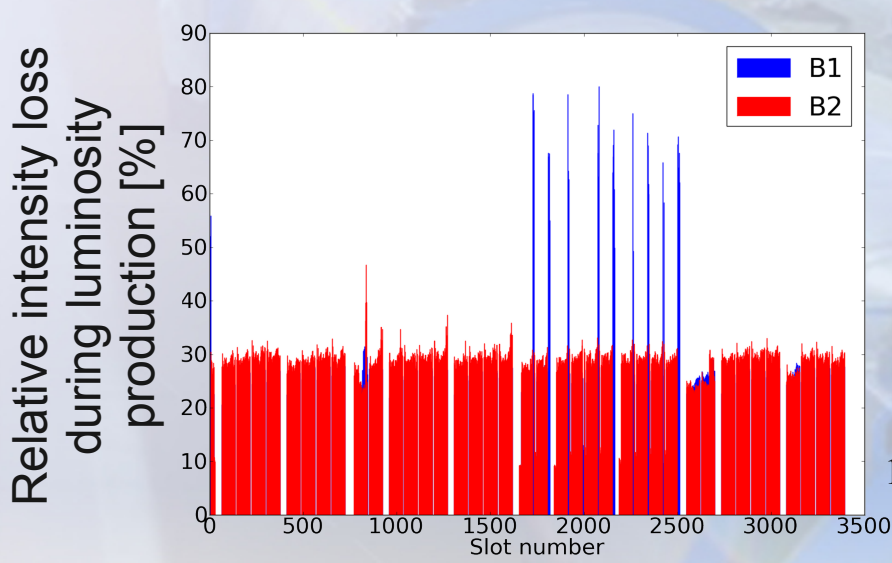



- By going into collision one IP after the other, i.e. one plane after the other, the minimum of stability is not reached in one of the plane
- Self consistent simulation suggests that the stability is shared between the two planes (S.M. White)
- Requires a good control of the horizontal and vertical separation bump of each IP

# Observation of instabilities
## Luminosity leveling

- Single bunches become unstable one after the other during luminosity production
- These bunches are colliding only in IP8, with a tranverse offset
- Their partners in beam 2 are colliding head-on in IP1 and 5
  - They are stable



# Observation of instabilities
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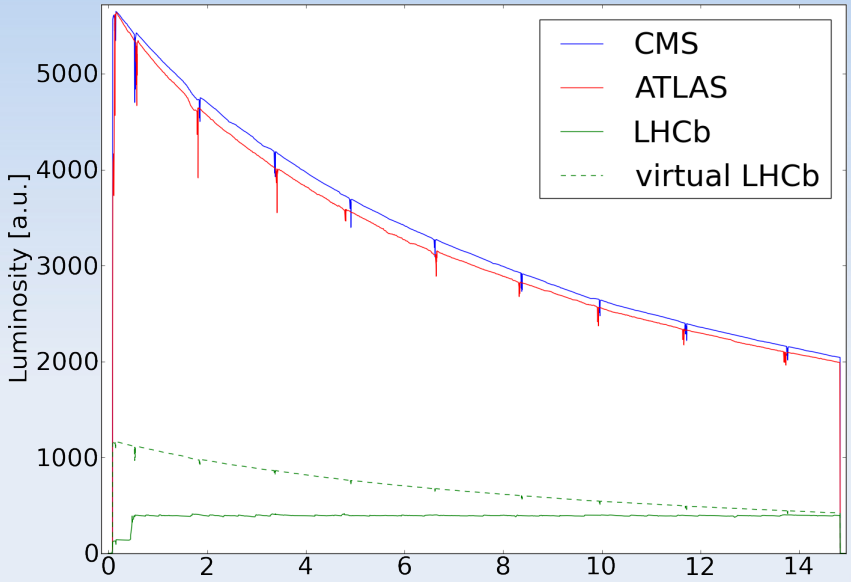
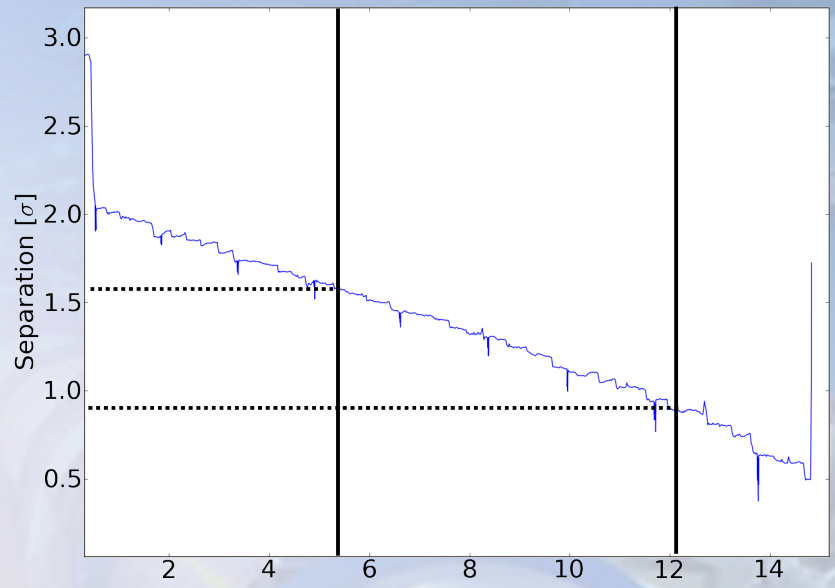



Time [h since start of luminosity production]




Time [h since start of luminosity production]

- The IP8 private bunches have different collision schedules and have slightly different parameters

  → they become unstable at different separations

# Mitigations

- Ensure at least one head-on collision for each bunch
  - Symmetric filling scheme, i.e. all bunches collide in IP1 and 5. (Note : Nominal filling scheme is symmetric)
  - Level luminosity with β*
- Ensure stability of these bunches by other means
  - The instability was not seen during last part of the 2012 run with high chromaticy, high damper gain and positive octupole polarity
  - Not yet clear if mitigations techniques available will still be sufficient in future scenarios
  - Stabilizing techniques can deteriorate the luminosity liftime of the other bunches

# Summary

- Detuning from beam-beam has to be taken in account in the computation of stability diagram during and since the end of the squeeze
  - Instabilities at the end of the squeeze observed in the LHC in 2012 can not be explain by this effect only
- Bunches with head-on collision were always stable
  - One should ensure one head-on collision for every bunch (e.g. by colliding during the squeeze)
- There exist a critical separation, around 1σ, at which the stability diagram is drastically reduced
  - One should avoid to remain in this configuration for a time > rise time of impedance driven instabilities