Impact of crossing angle reduction: Simulations and observations

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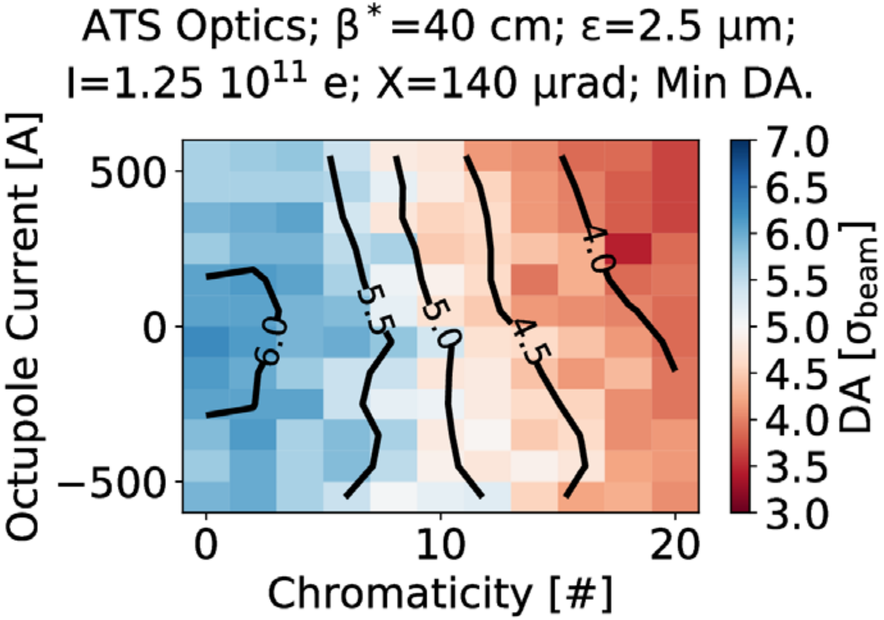
LRBB Wire MiniWorkshop, Divonne Les Bains, 20th March 2017

Outline

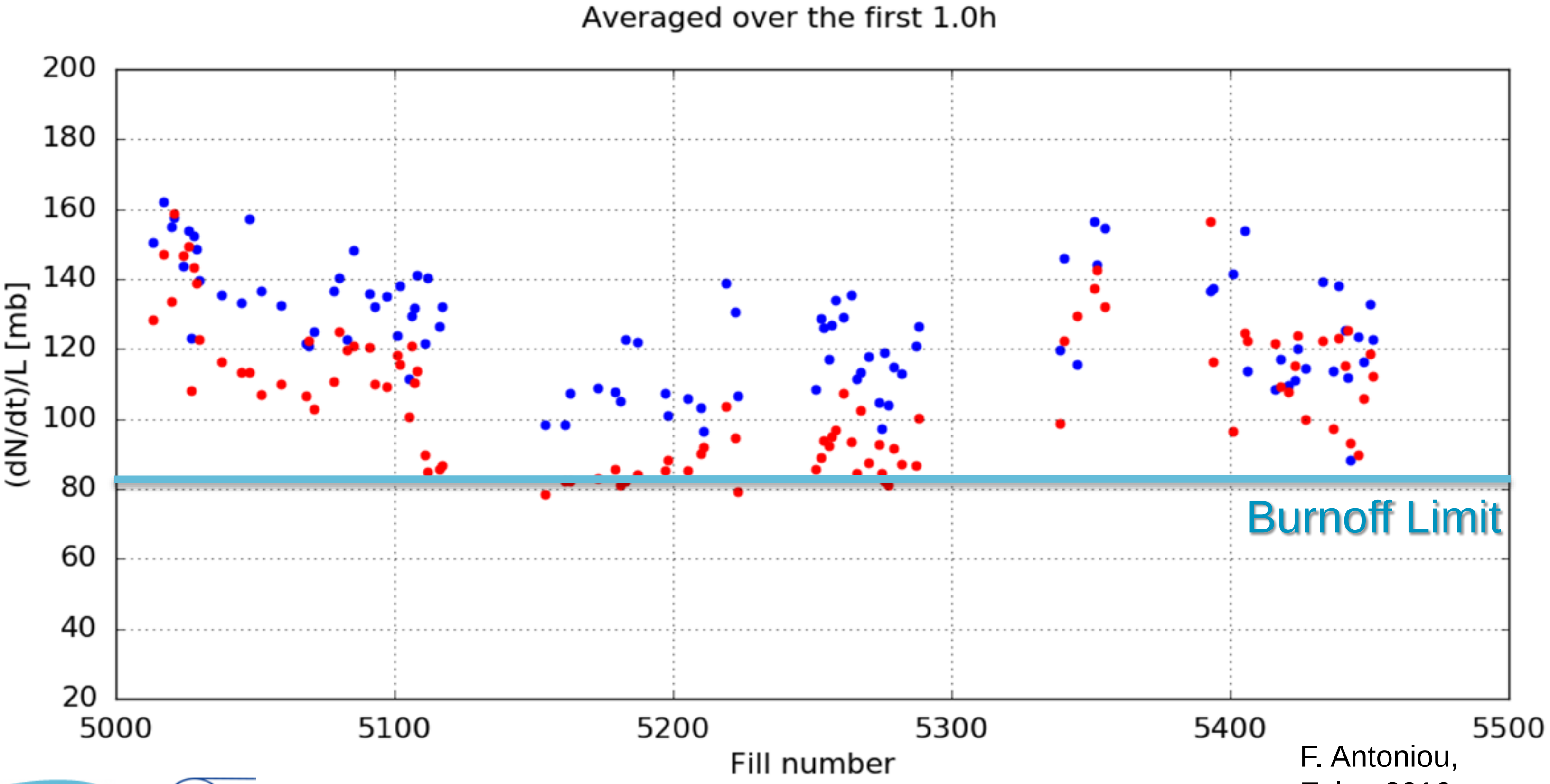
- Observables from simulations and experience during 2016 with review of factors affecting DA and beam lifetime
- Review of 2016 MD on LRBB with 2 trains
- Considerations and simulations for measurements with broken IP1-IP5 H-V beam-beam compensation

Setting the Stage: DA Scans

- DA multi-parametric response used as a tool to approach limits when optimizing performances.
- Not a perfect tool:
  - 1M turns are only 90 s of machine time
  - The initial longitudinal action is fixed
  - Does not take into account the actual beam phase space distribution, diffusion…
- Still capable of capturing relevant aspects of the dynamics.
- In 2016 this was put under great stress and confidence was gained.



Overview of 2016 losses at beginning of SB



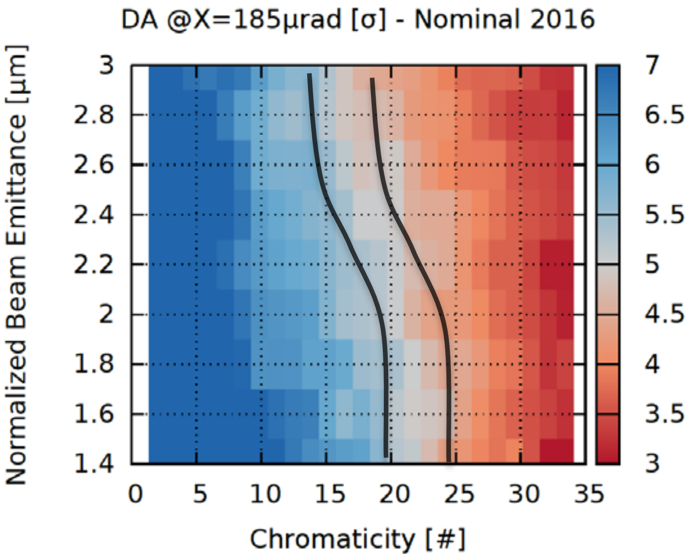
F. Antoniou, Evian 2016

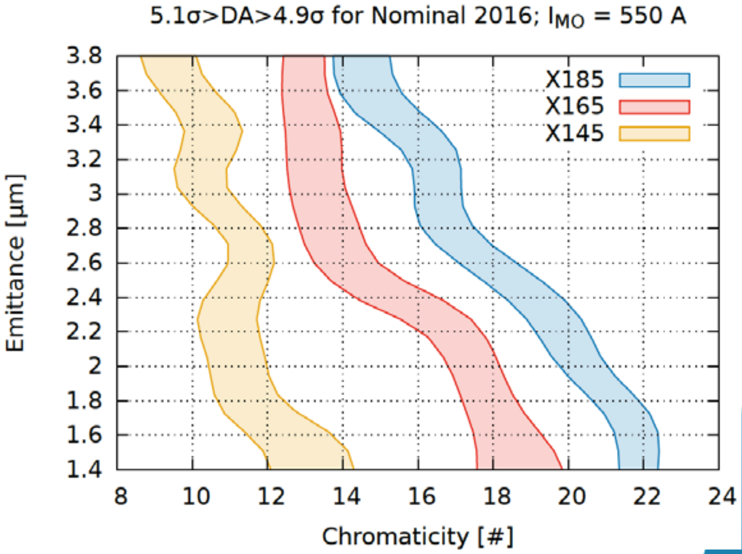
Switch to BCMS Bunches

For the LHC this means ε: 3.75 → ~2.50 µm

1. Stronger head on beam-beam: $\xi = \frac{r_e N \beta^*}{4\pi\gamma\sigma^2} = \frac{r_e N}{4\pi\gamma\varepsilon} \propto \varepsilon^{-1}$
2. Less sampling of non-linearities (including LRs): $\left(\sigma = \sqrt{\frac{\beta^*\varepsilon}{\gamma}} \propto \varepsilon^{1/2}\right)^m$

We are in a regime where 2. prevails





Y. Papaphilippou et al.
LMC, 6 Jul 2016

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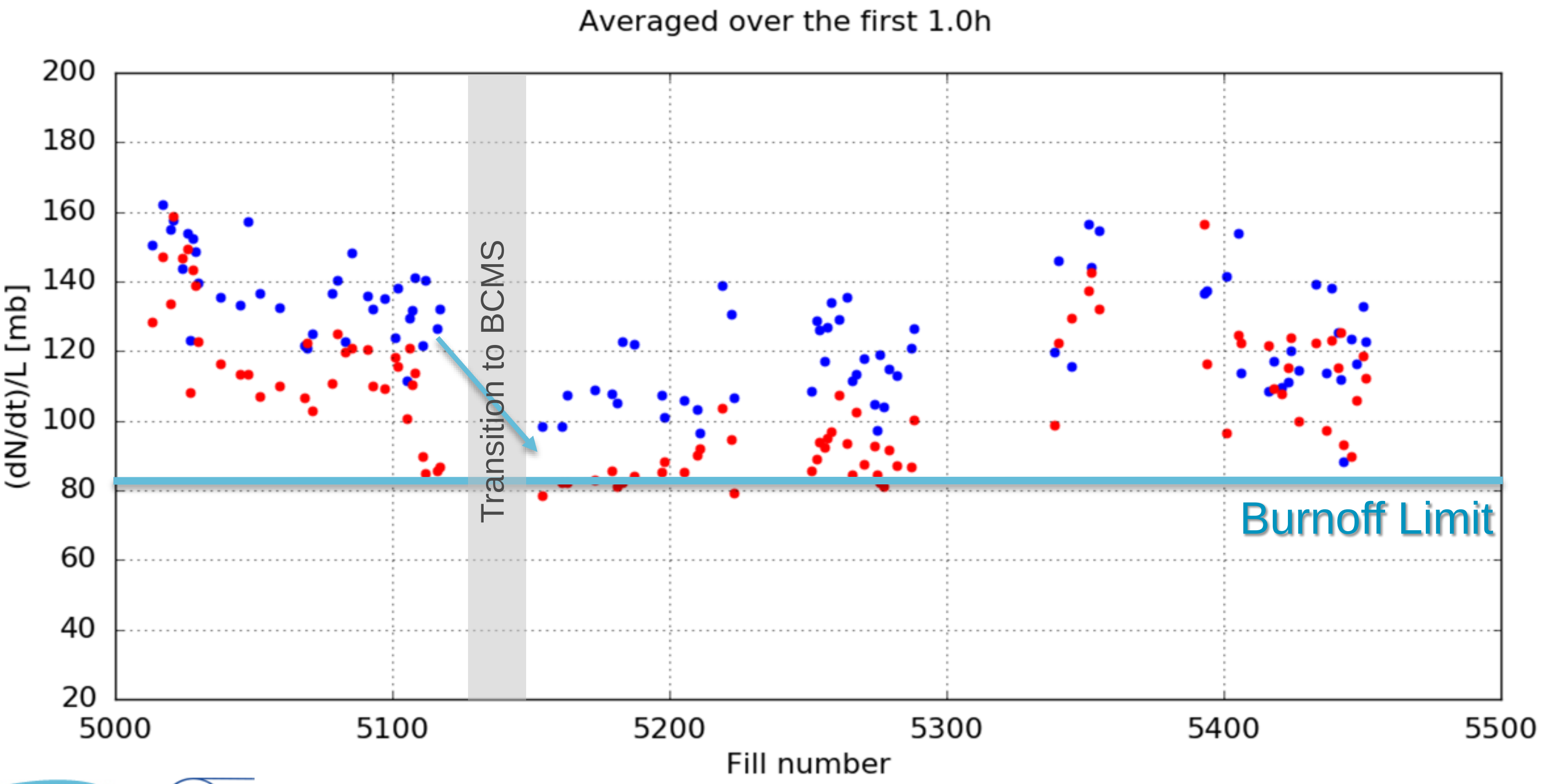
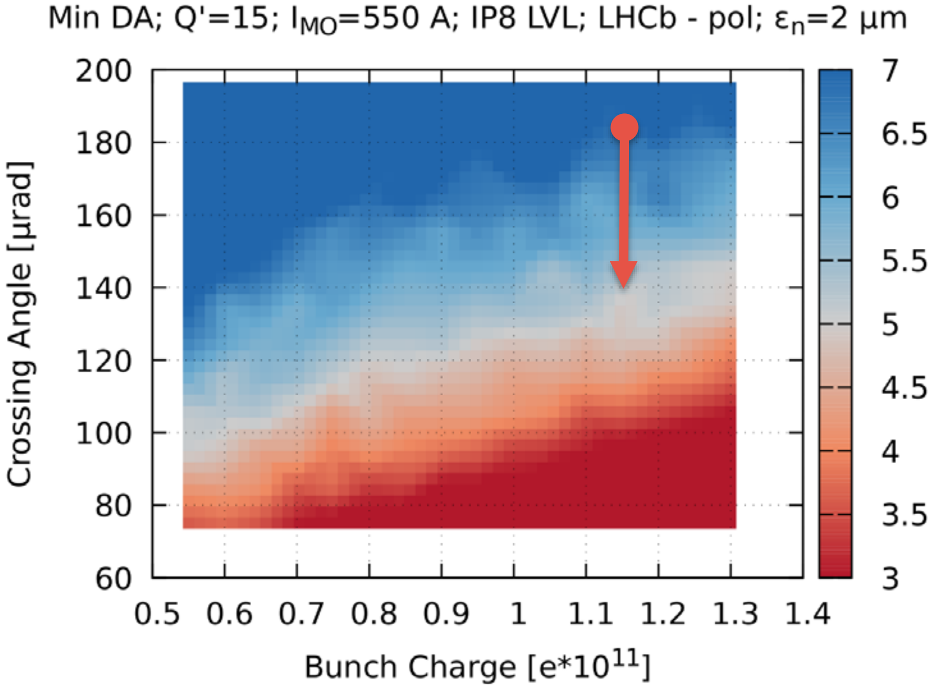
Switch to BCMS Bunches



Reduction of Crossing Angle

- The DA used to be on the conservative side due to limited intensity from the SPS and injection kicker
- Even more margin due to the smaller emittance
- Reduction of Crossing was the next natural step:

  185 μrad → 140 μrad
- About 5σ DA in beam units.

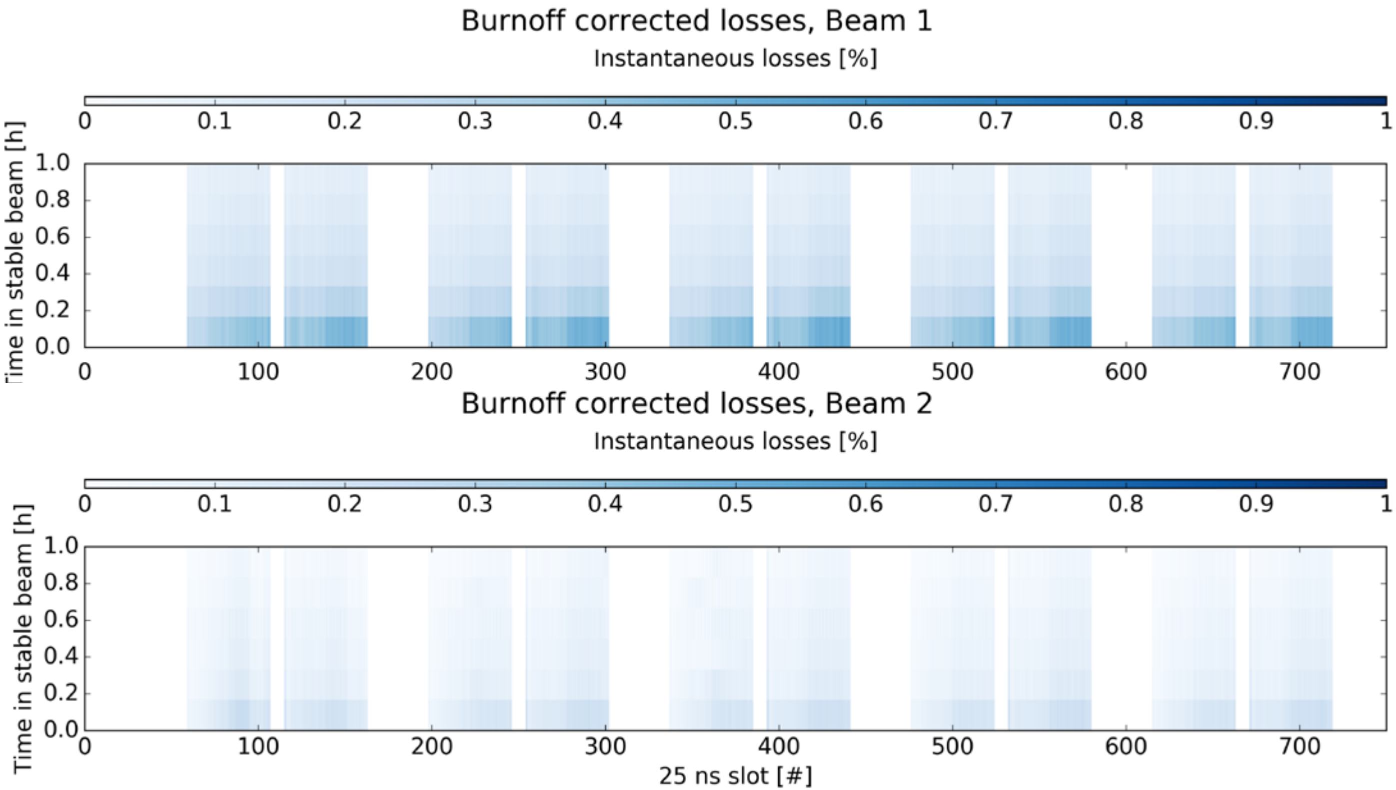


D. Pellegrini et al.
LBOC, 16 Aug 2016

Reduction of Crossing Angle

Losses over 10 minute windows at beginning of Stable Beam.

Average over many fills with Xing=185urad

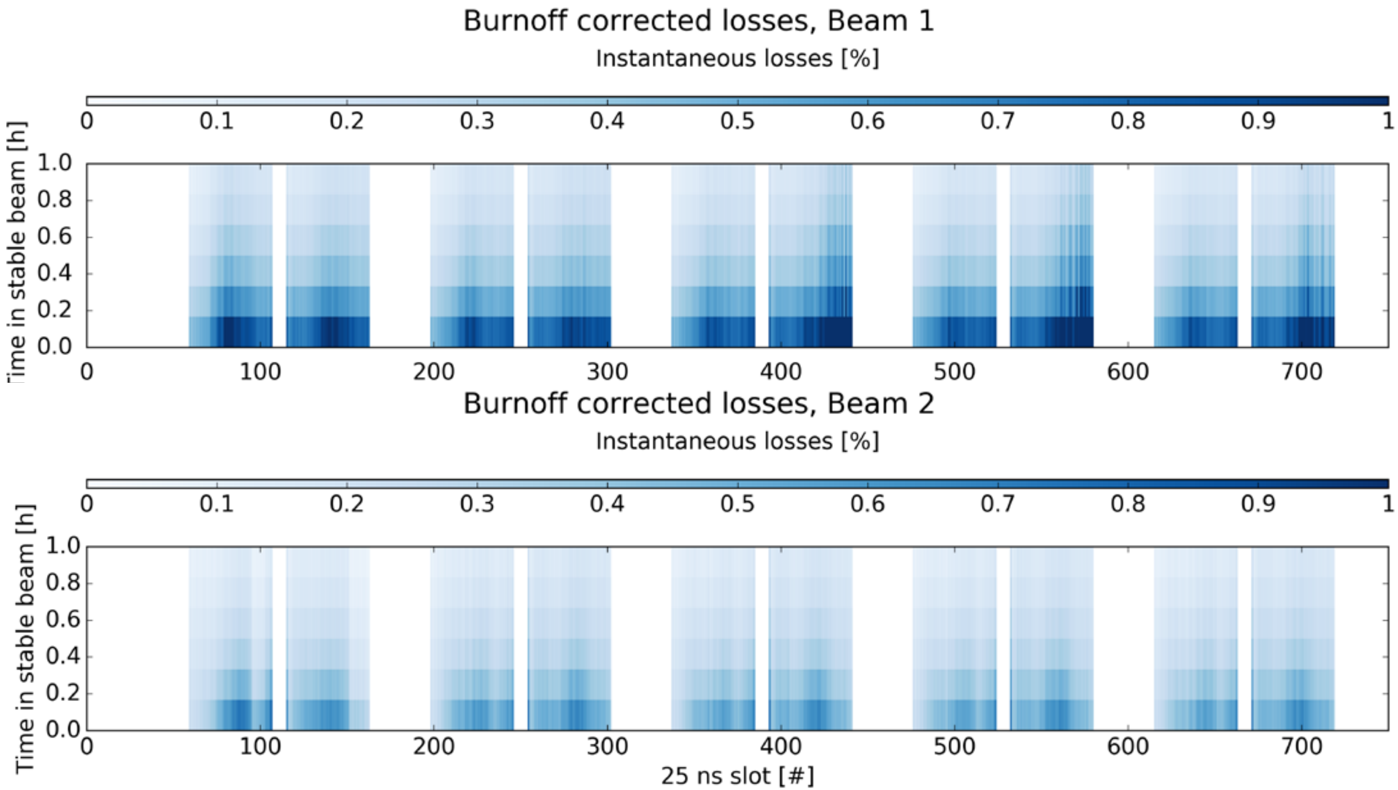


Minor traces of e-cloud are visible.

Reduction of Crossing Angle

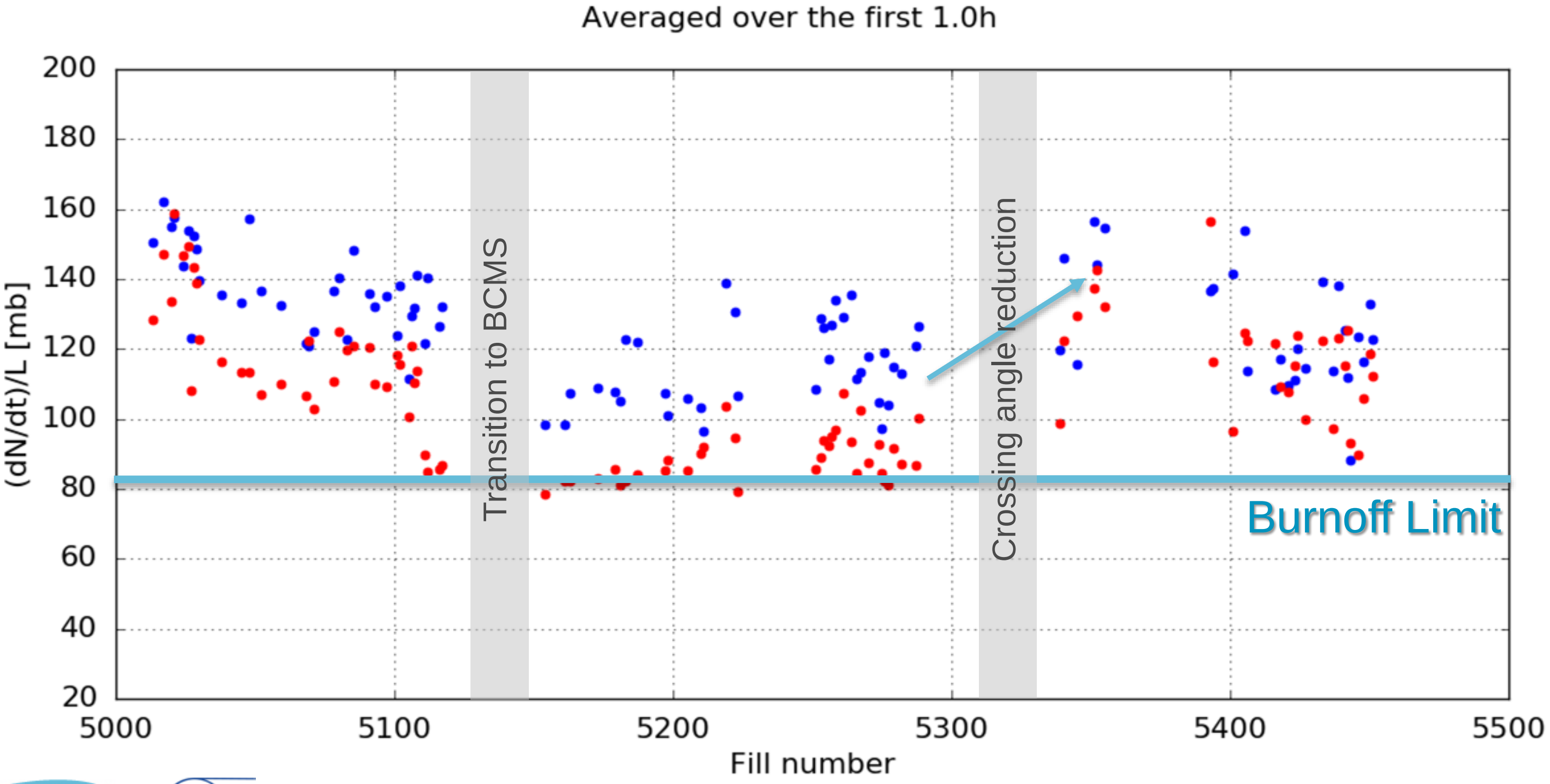
Losses over 10 minute windows at beginning of Stable Beam.

Average over many fills with Xing=140urad



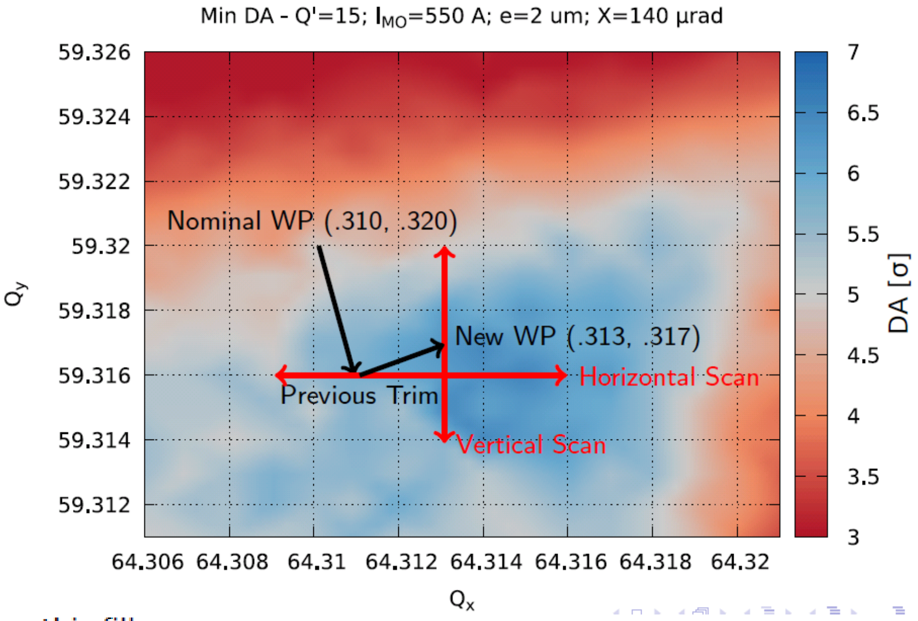
Traces of e-cloud and of LRs are visible.

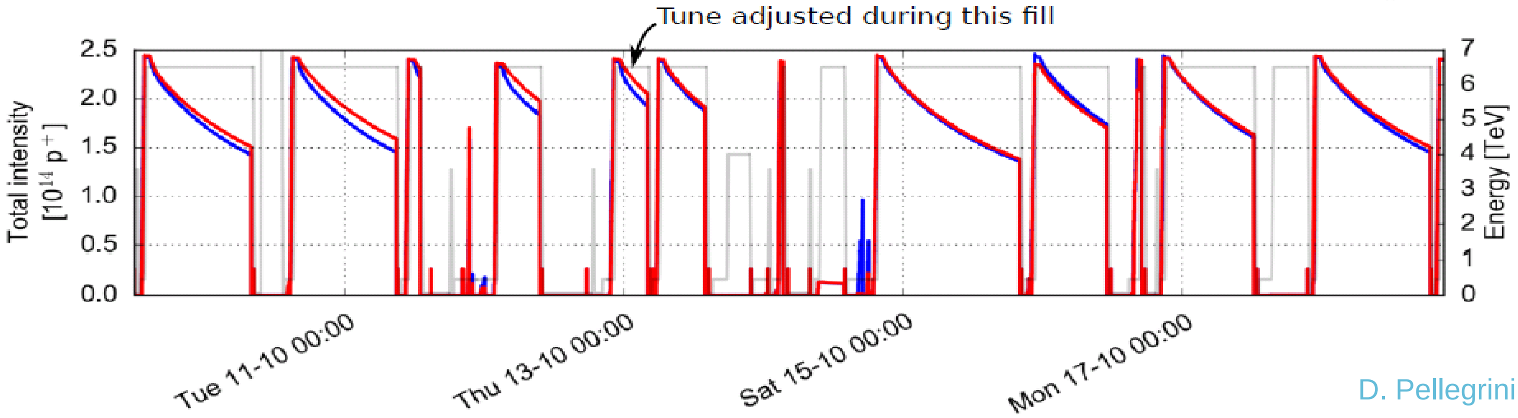
Reduction of Crossing Angle



Tune Adjustment

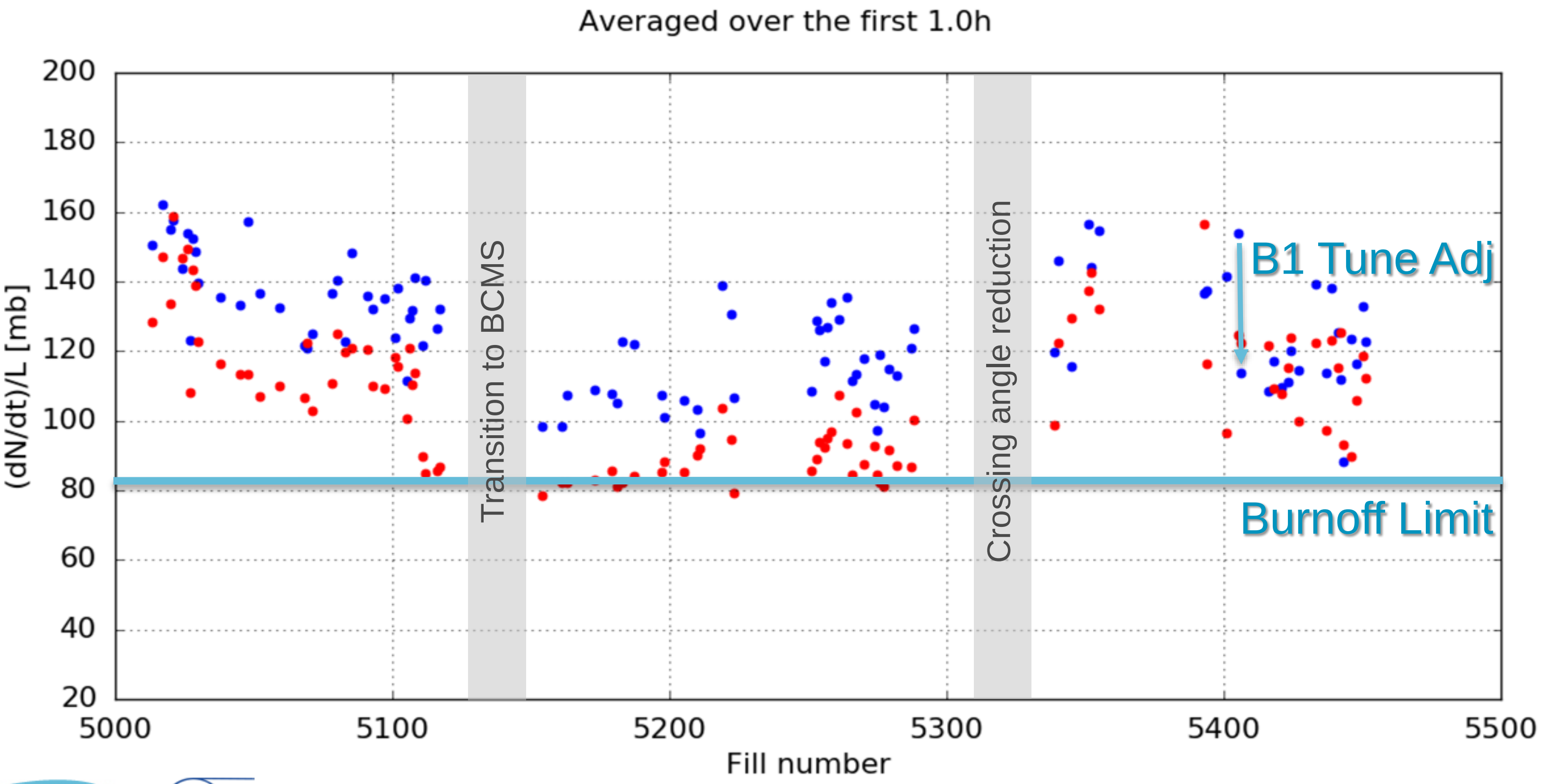
- Beam1 typically showed smaller lifetime.
- DA Tune scans pointed out that the nominal WP is sub-optimal
- The tune of Beam1 was adjusted in operation according to predictions
- Beam1 lifetime was recovered





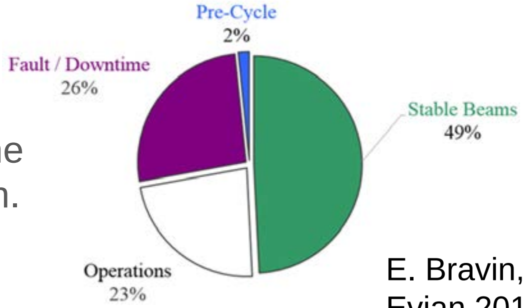
D. Pellegrini et al.
LMC, 19 Oct 2016

Tune Adjustment

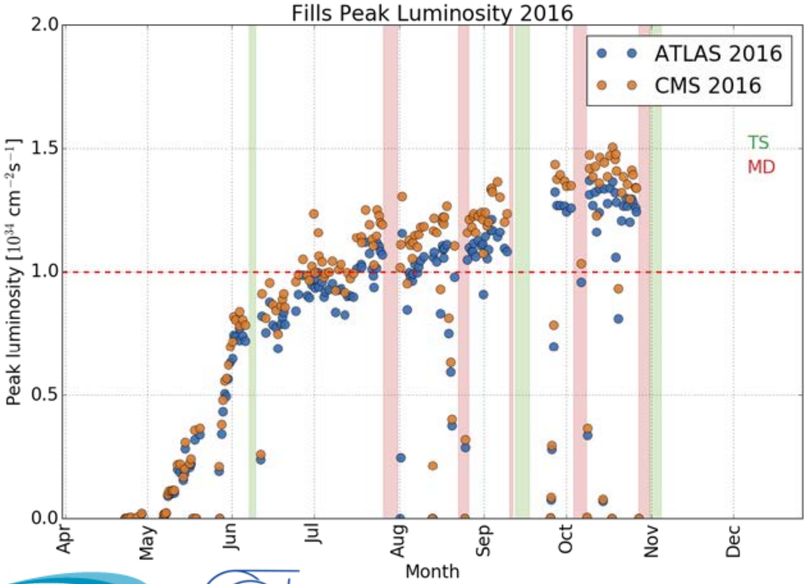


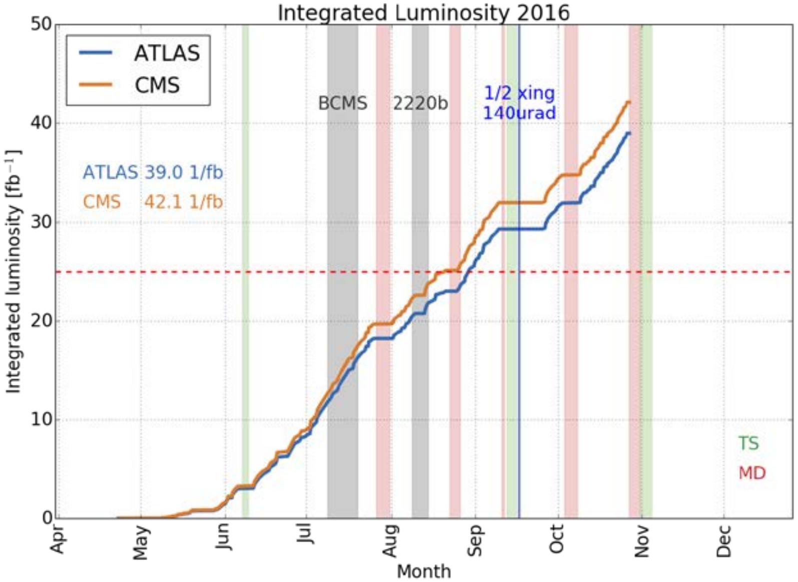
2016 Outcome

- Peak luminosity at the end of the run.
- The three-day period with maximum integrated luminosity also at the end of the run in spite of higher losses and less focus on production.
- Control and understanding of the sensitivity to many parameters from operational experience.



E. Bravin, Evian 2016

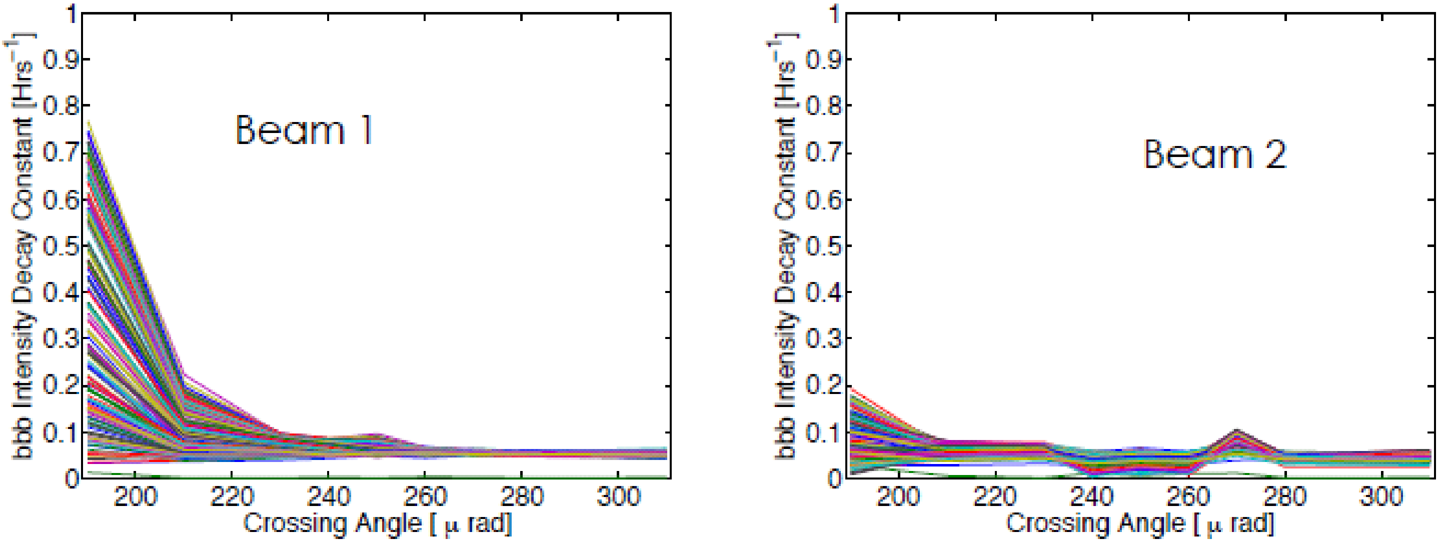




MD on LR Separation

- Test performed during MD on fill 5137 by T. Pieloni et al. with symmetric trains in conditions similar to SB (strong-strong scenario).
- The crossing angle was reduced in steps during collision, lifetime was closely monitored.
- The impact of LR was observed especially in B1, while B2 was not so sensitive.

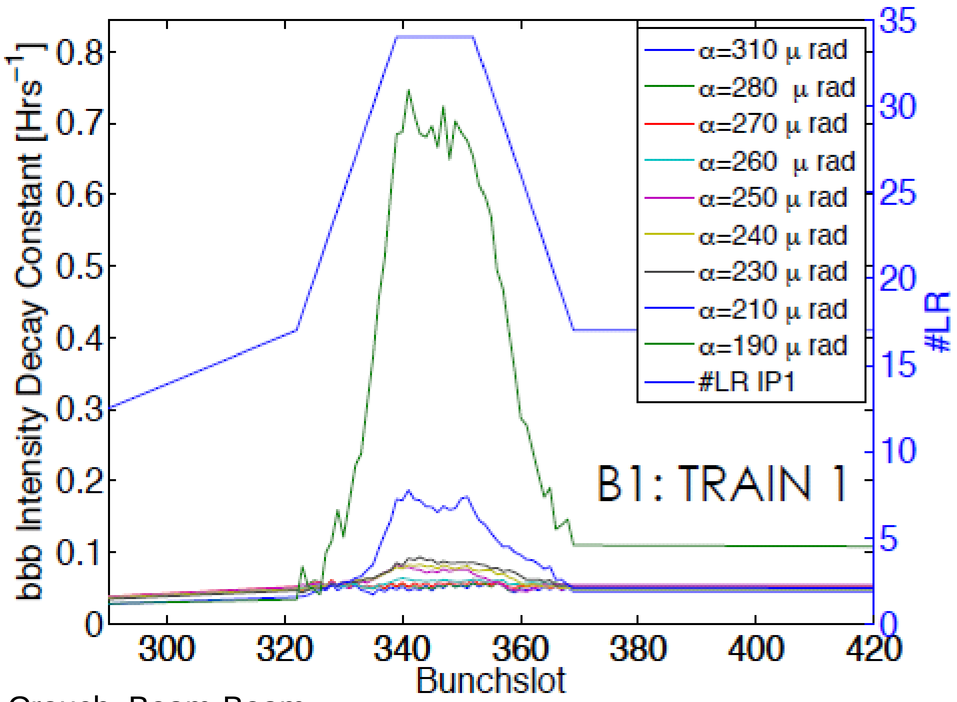
Outcome of MD on LR Separation



M. Crouch, Beam-Beam and Luminosity Meeting, 14 Oct 2016

- The encounters at minimum separation can possible have an impact on the symmetry due to different Left and Right beta functions (S. Fartouck)
- The faster intensity decay of B1 steers towards a week-strong scenario.

Losses VS Bunch Slot

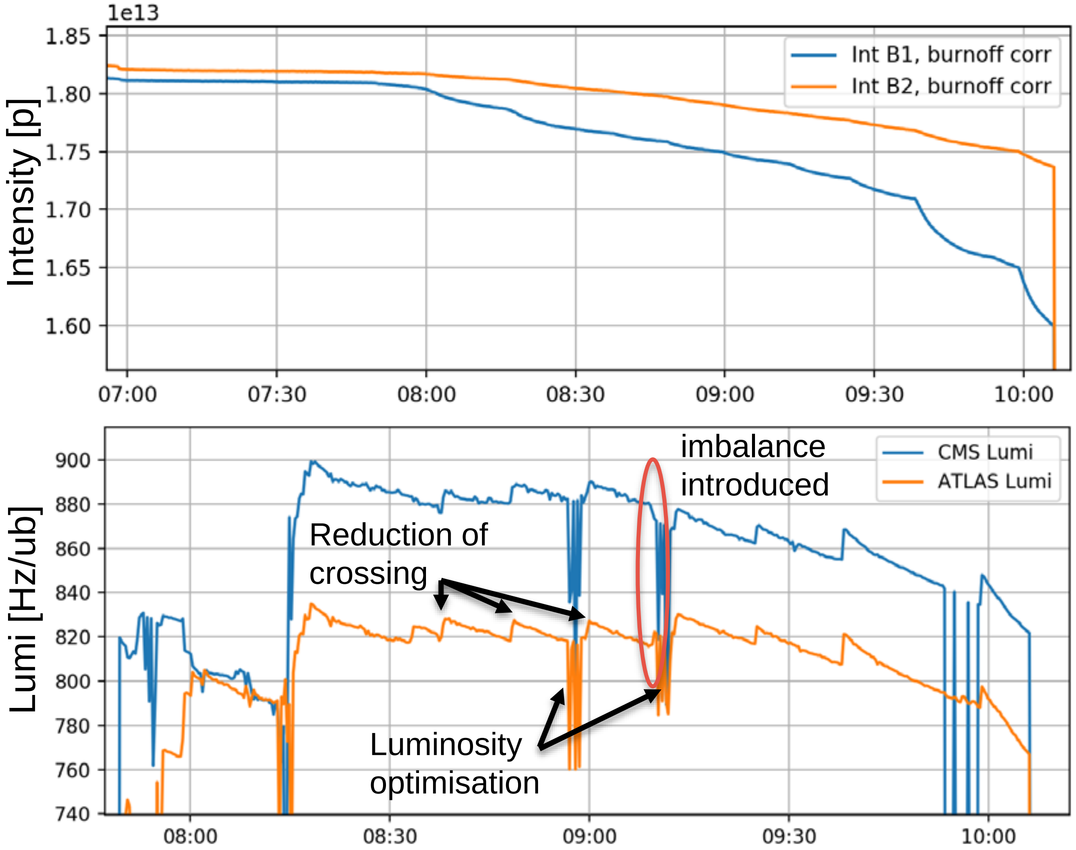


M. Crouch, Beam-Beam and Luminosity Meeting, 14 Oct 2016

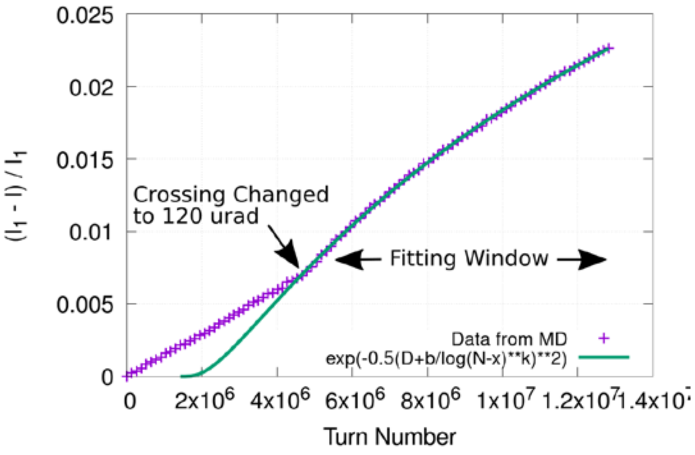
- Signature of LR interactions are observed in B1 as a dependency of the lifetime over the bunch slot.
- B2 does not show a clear dependency until the smallest crossing angle.

Intensity and Luminosity

- Intensity decay compatible with the observed lifetimes
- Luminosity imbalance commonly observed in the 2016 Run
- Luminosity exchange at 9:10 – origin and implications are not clear

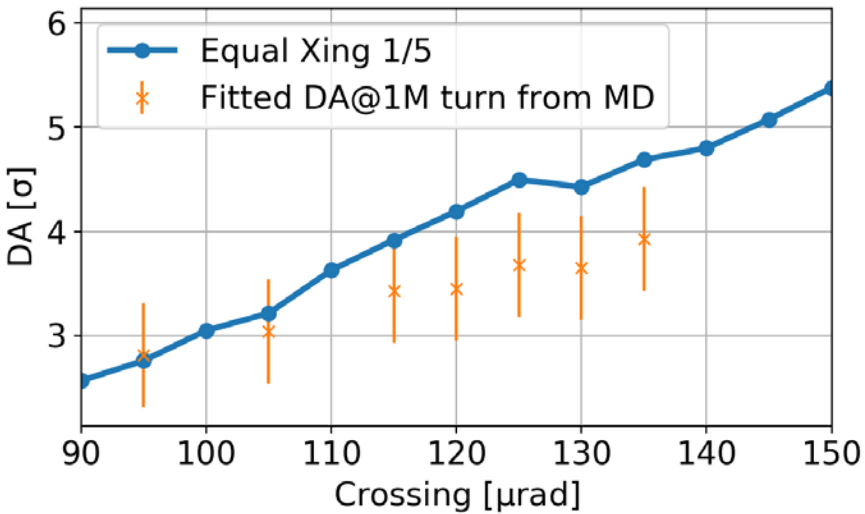


Fitting DA scaling laws



- DA scaling law fitted with inverse logarithm for Gaussian bunches (M. Giovannozzi, PRST-AB, 2012)
- Extra fitting parameter (horizontal shift) introduced to increase agreement at low number of turns
- Scaling law used extract DA@1M turns

ATS2017; β^*=40 cm; Q'=15; I_{MO}=500 A;
ε=2.5 µm; I=1.25 10^{11} p; X=150 µrad; Avg DA.



- Delicate fit, different sets of parameters giving good agreement, DA@1M turns is more robust
- Extra losses (eg burnoff) play a crucial role
- Uncertainty on the beam size
- Global fit: pacman bunches are (erroneously) equally threated
- Some agreement with simulations although the many uncertainties present

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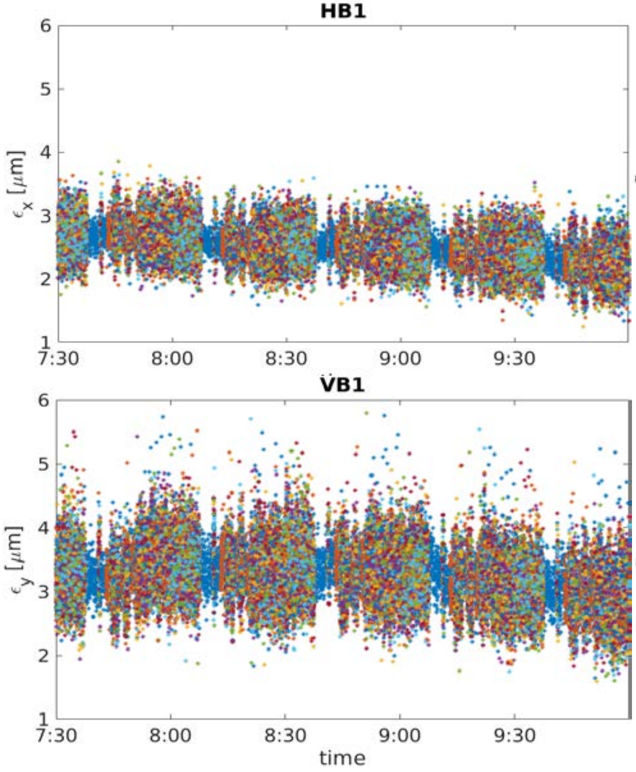
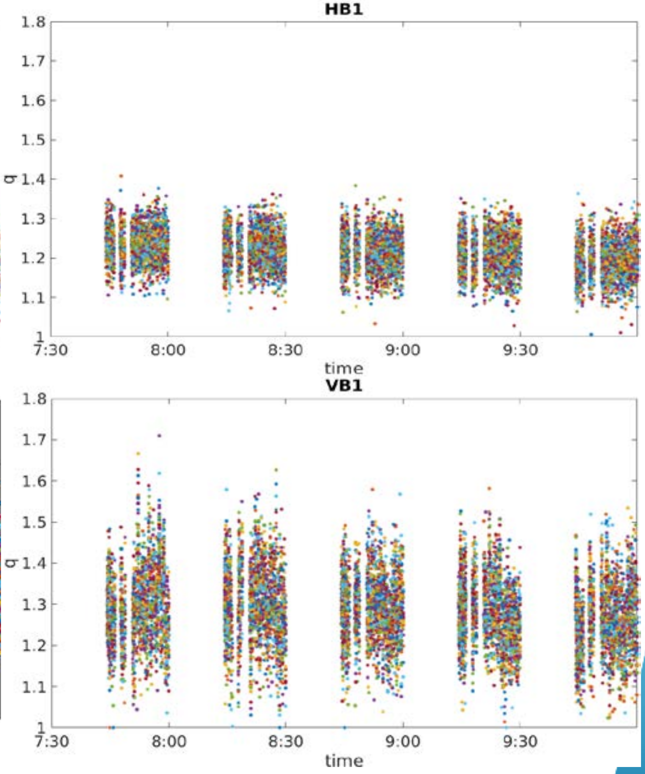
Transverse Profile analysis with q-Gaussian

- Need to disentangle IBS, SR and tail cleaning
- Filtering and spectral cleaning, but poor instrumental data
- Tails appears to sustain themselves
- Hard to draw conclusions

Emittance evolution



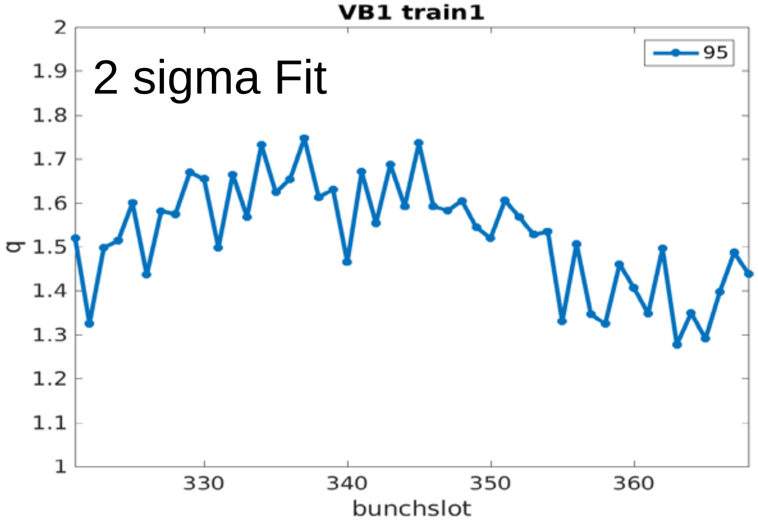
Tails evolution

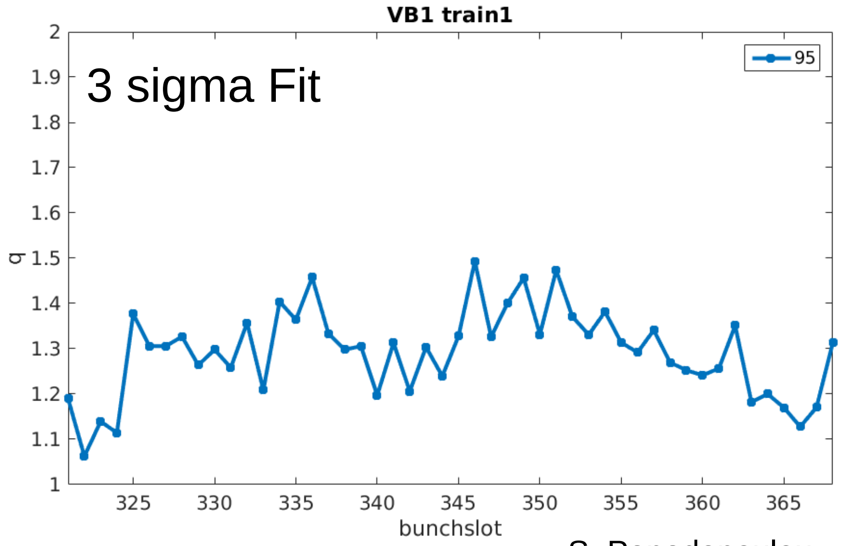


S. Papadopoulou

Transverse Profile analysis with q-Gaussian

- No clear dependence of tails on the bunch slot.
- Noise and sensitivity to fit range.





S. Papadopoulou

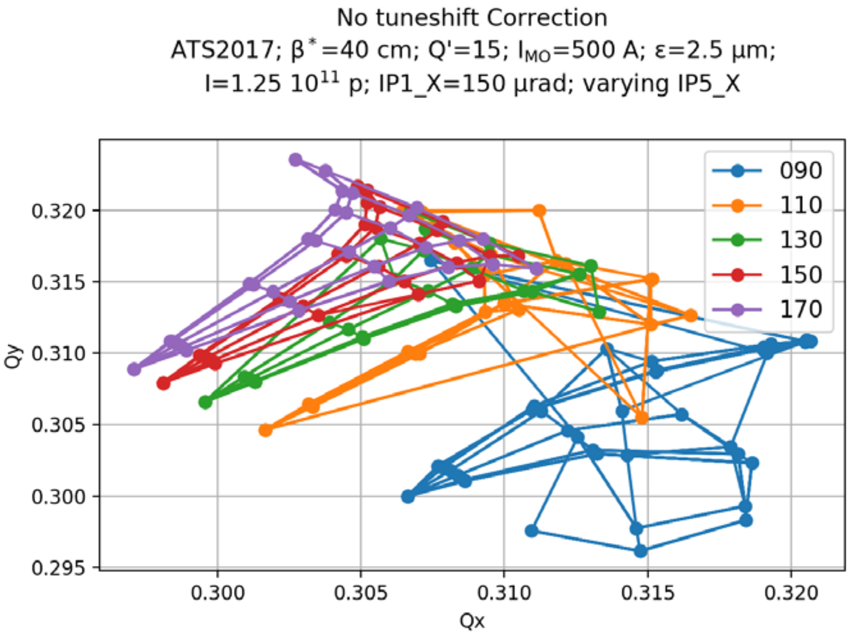
Perturbation of Single IP: scenario

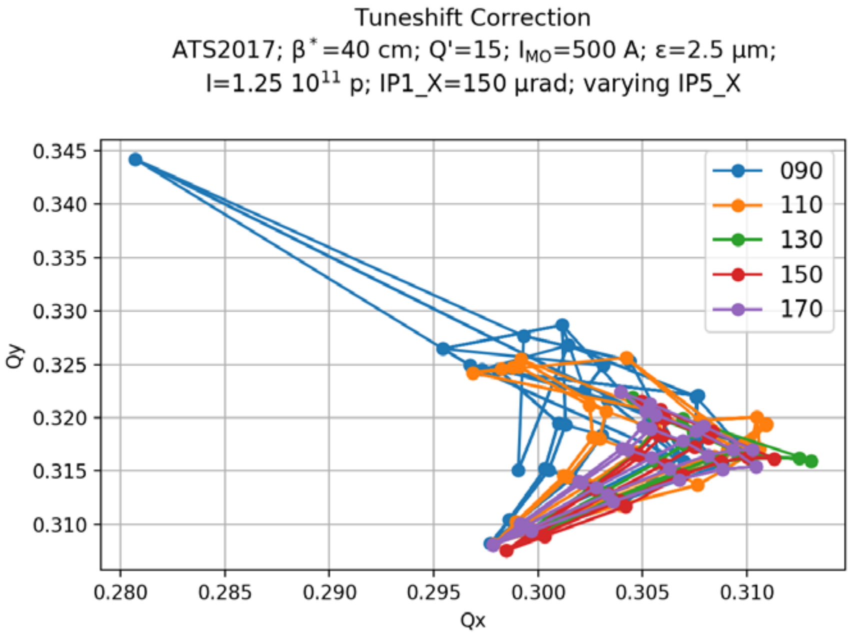
- In 2017 the wire is available only in IP5.
- Explore the possibility to perturb IP5 only (crossing reduction) and compensate with the wire, eventually with IP1 unsqueezed.
- The HO also changes with the crossing: need to compensate with the optics.
- Weak beam probing the potential of a strong train: reduce cross talks and coherent interactions.

Considerations for measurments with wire

- Moving from small to large DA may require long time before DA losses appear again
  - one could use the data immediately after the change to evaluate non-DA losses (Burnoff, Beam-Gas, …)
  - the transition point may not be clear
- Operate the crossing and the wire (almost) simultaneously trying to preserve the lifetime.
- Switch off the wire and observe the impact on the lifetime.
- The perturbations of tune, orbit, chromaticity, need to be very well compensated, both for wire and Xing.
- Setup, test and feedforward of the impact of the wire – See Guido’s talk.

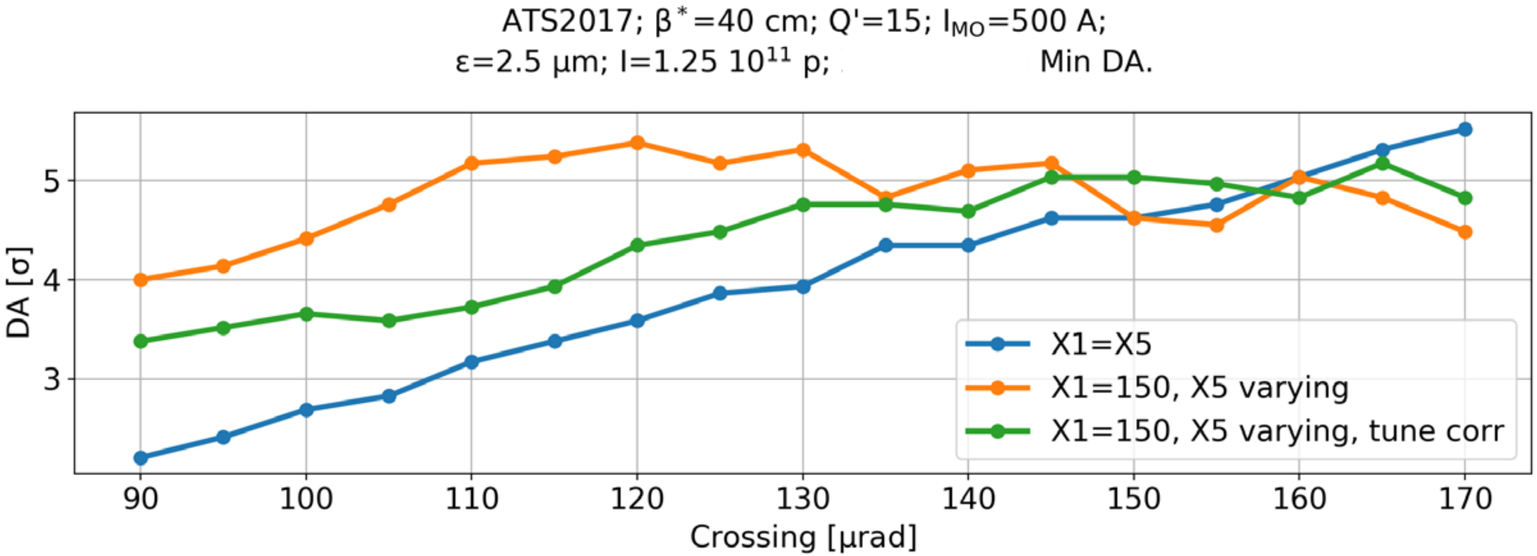
Footprints when moving Xing in IP5 only





- The tuneshift of the core of the beam (also due to HO) is adjusted to less than 0.001 by trimming the optics.
- The wire (not included) is expected to improve the footprint at large amplitudes (see Sasha's Talk)

DA with asymmetric IPs, no wire



- The case without tune correction shows a big improvement (the DA favours tunes close to the diagonal).
- The case with tune correction is still better than the symmetric IPs.
- Each of this curves is a tricky MD with many pitfalls (X1=X5 already attempted, see later …).
- Need to clarify what happens in each case when the wire is turned on/off.
- One wants the best condition to test the impact of the wire, but an MD on tuneshift should be avoided!

Conclusions

- Robust technique for DA investigation based on multiparametric scans:
  - prediction and steering of the LHC operation during 2016 Run
  - Explored sensitivities to tune, crossing angle, intensity, chromaticity, octupoles, emittance
- MD on LRBB gives additional insight but some aspects remains unknown
- Breaking the IP1/5 symmetry appears tricky:
  - Detailed knowledge of the dynamics is required
  - Optics has to be adjusted to compensate for masking effects

Thank you!