Impact of crossing angle reduction: Simulations and observations

F. Antoniou, S. Fartoukh, G. Iadarola, S. Papadopoulou, Y. Papaphilippou, D. Pellegrini

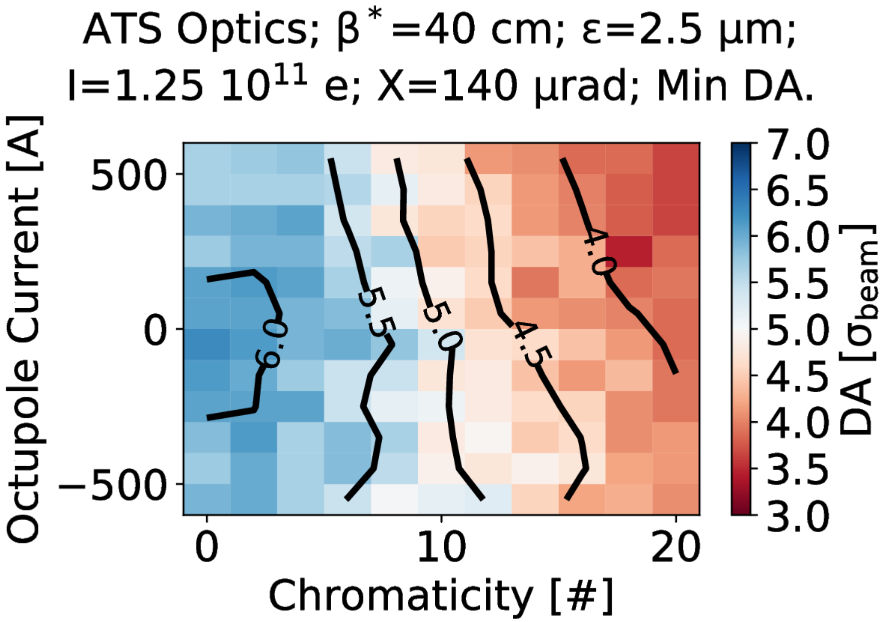
LRBB Wire Workshop, Divonne Les Bains, 20th March 2017

Outline

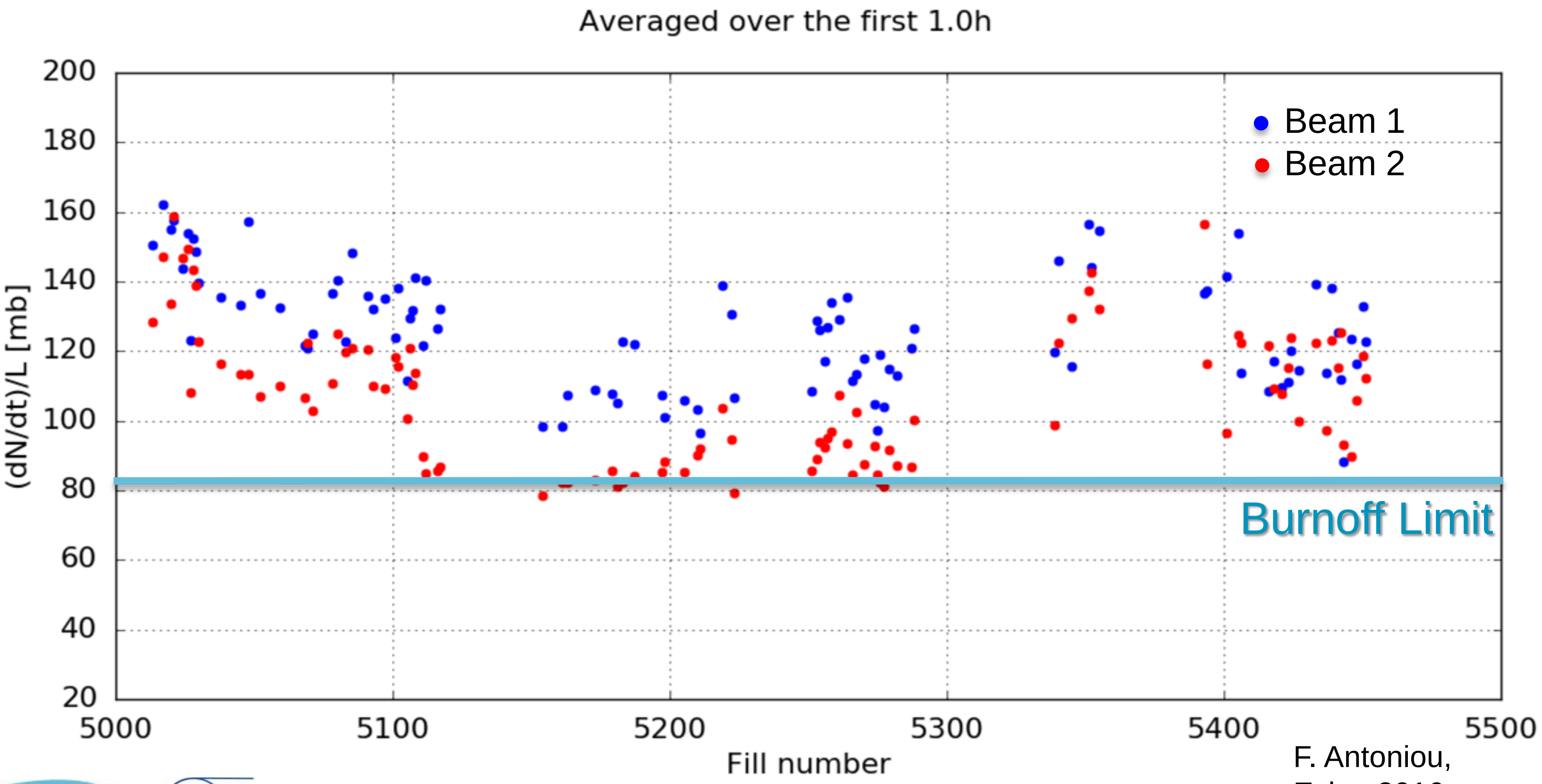
- Observables from simulations and experience during 2016 with review of factors affecting DA and beam lifetime
- Review of 2016 MD on LRBB with 2 trains
- Considerations and simulations for measurements with broken IP1-IP5 H-V beam-beam compensation

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.
  - Errors not included, adding some uncertainty.



Overview of 2016 losses at beginning of SB



F. Antoniou, Evian 2016

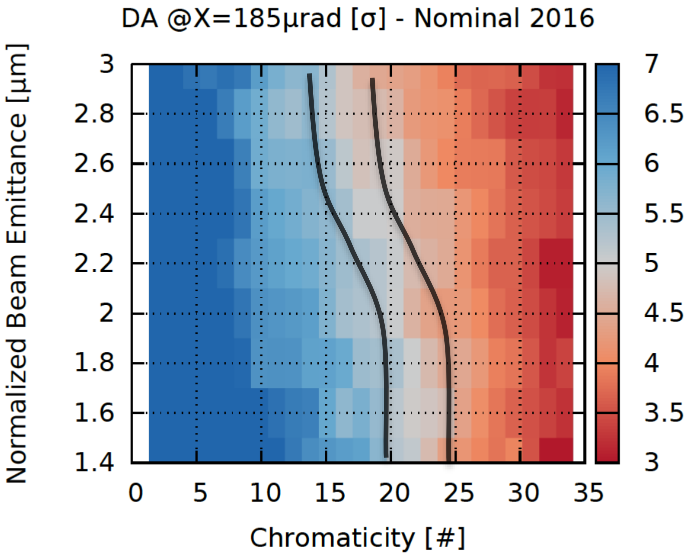
Switch to BCMS Bunches

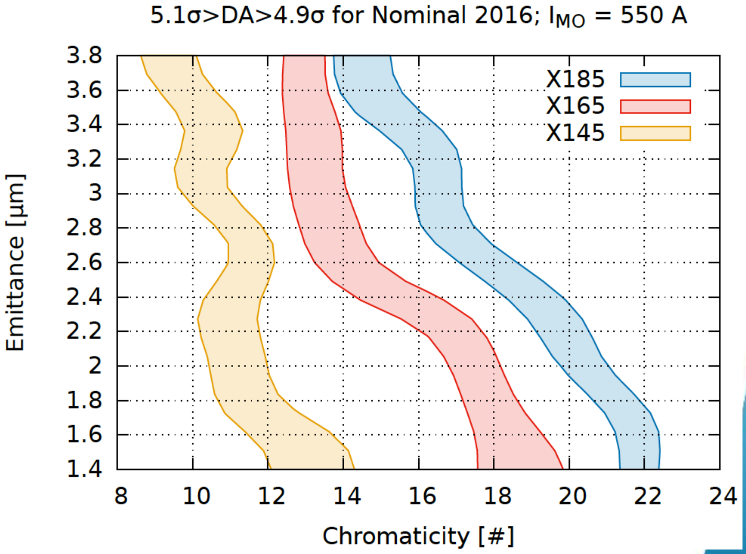
For the LHC this means ε: 3.75 → ~2.50 μm

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): $\left(\sigma = \sqrt{\frac{\beta\varepsilon}{\gamma}} \propto \varepsilon^{1/2}\right)^m$

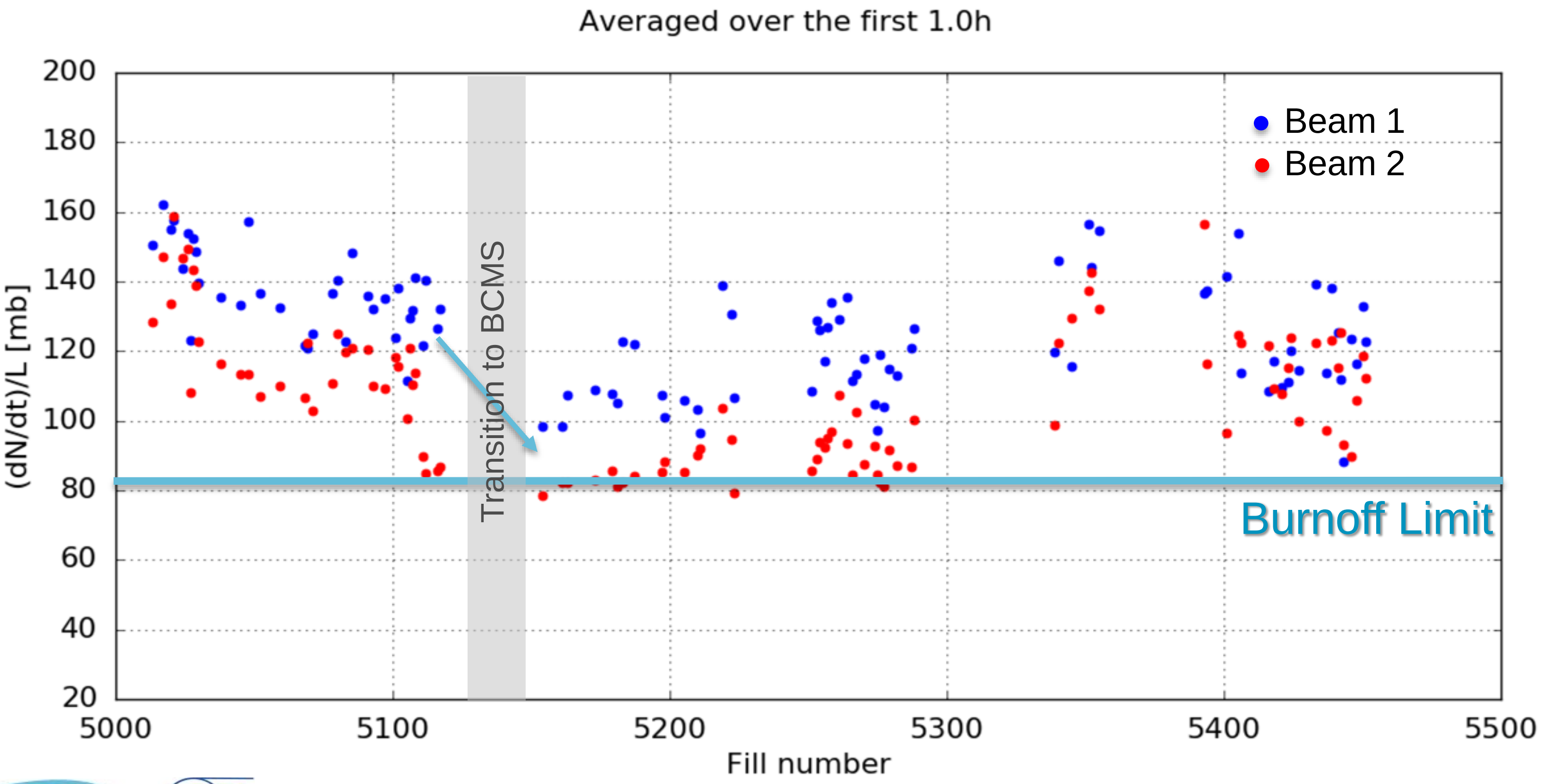
We are in a regime where 2. prevails





Y. Papaphilippou et al.
LMC, 6 Jul 2016

Switch to BCMS Bunches

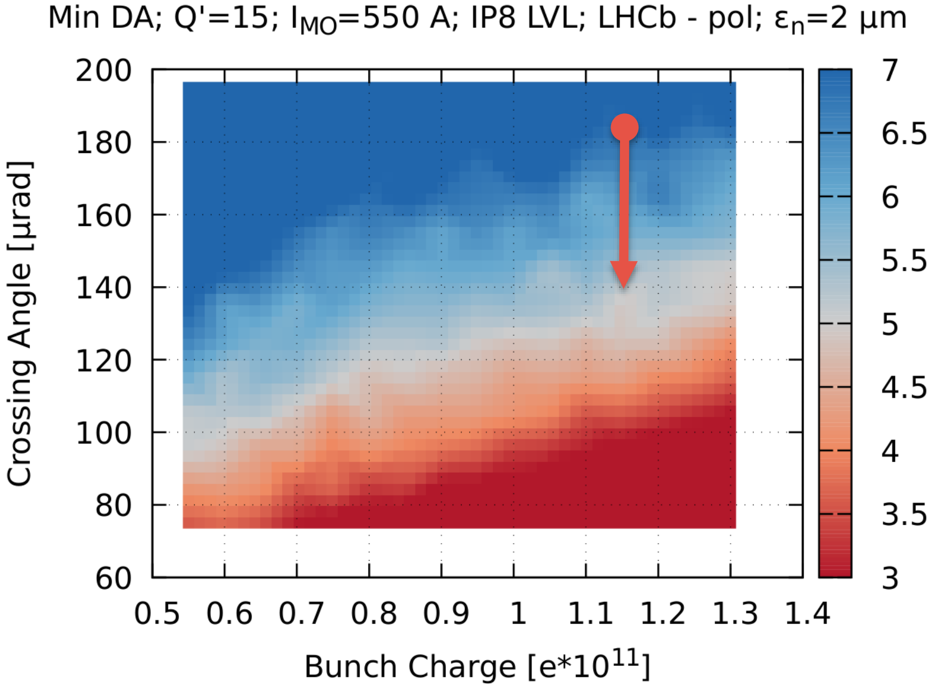


Reduction of Crossing Angle

- 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.

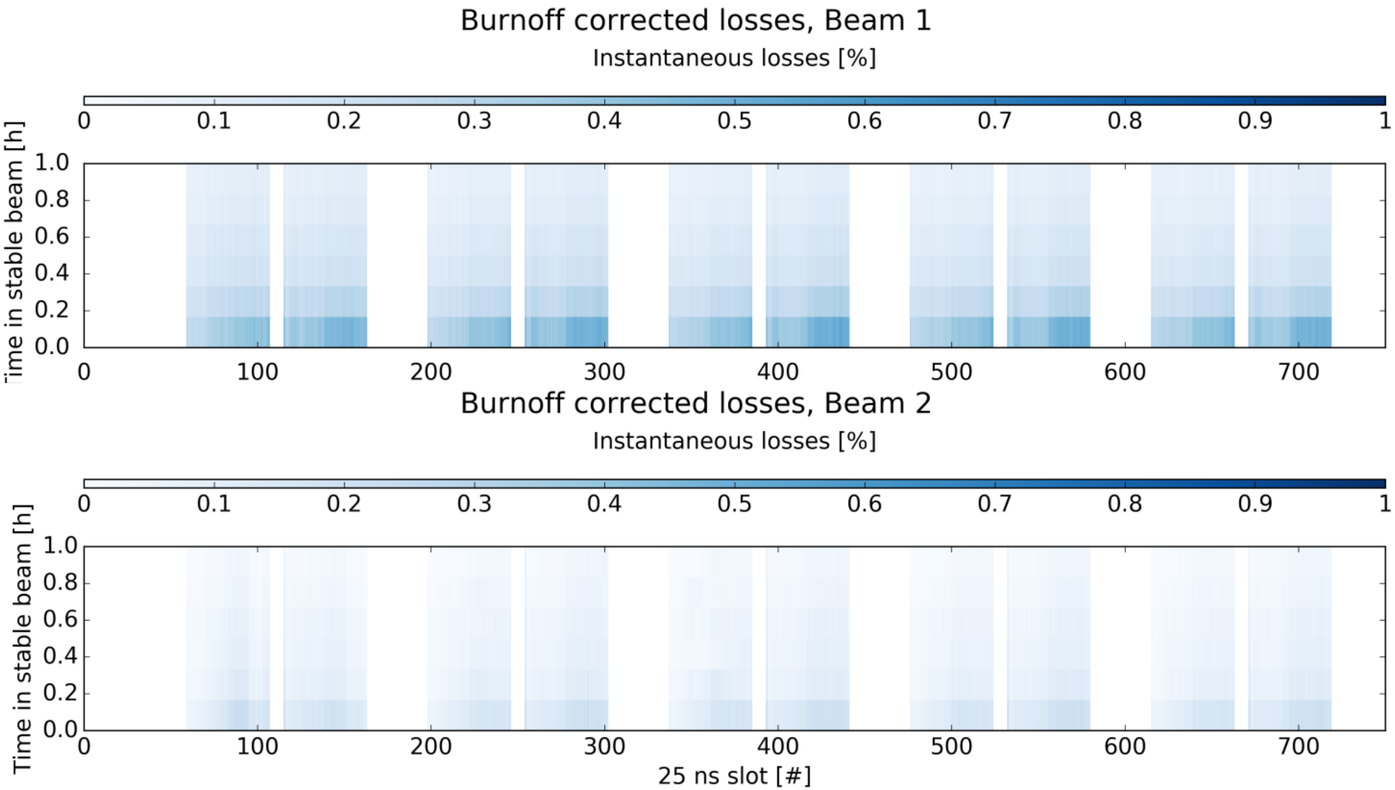
D. Pellegrini et al.
LBOC, 16 Aug 2016



Reduction of Crossing Angle

Losses calculated as % of total intensity over 10 minute windows at beginning of Stable Beam.

Average over several fills with Xing=185urad

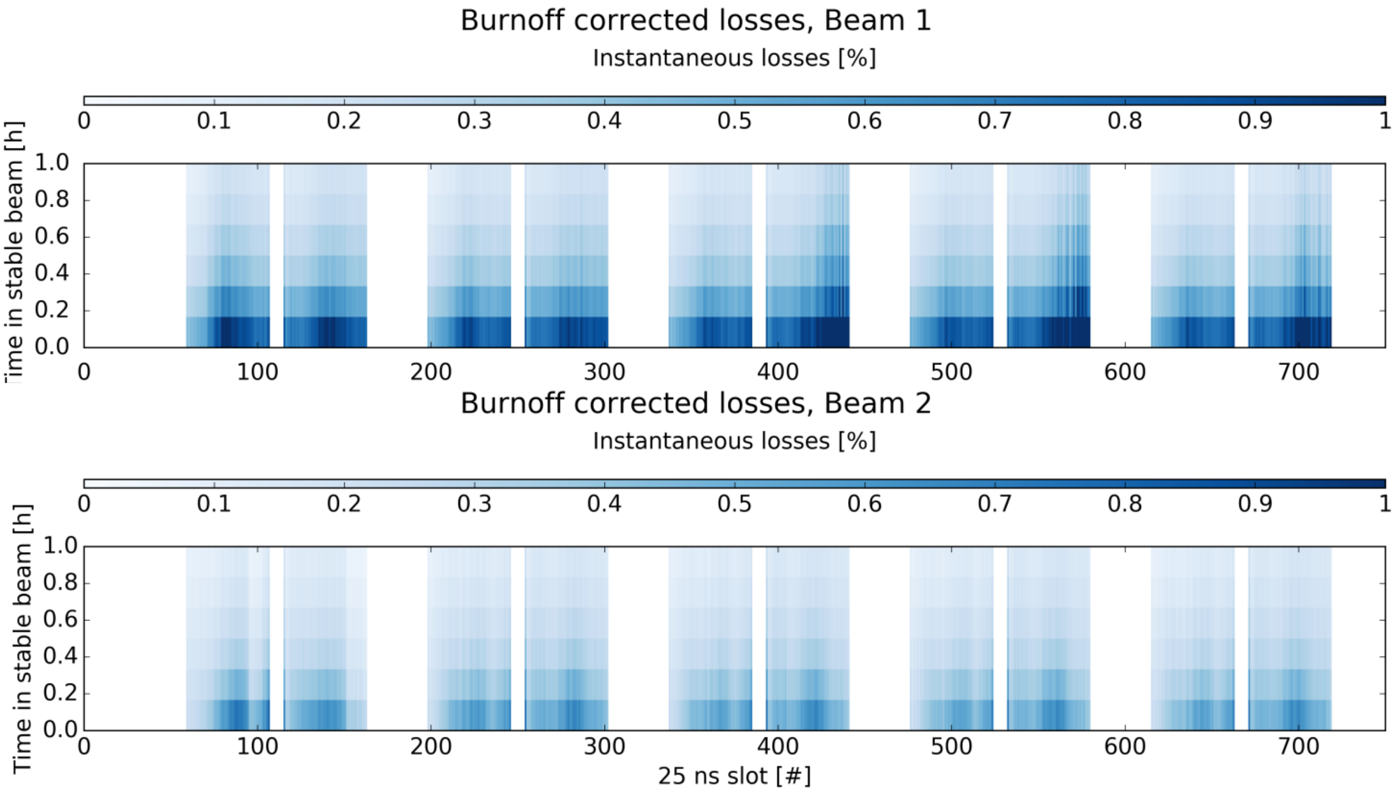


Minor traces of e-cloud are visible.

Reduction of Crossing Angle

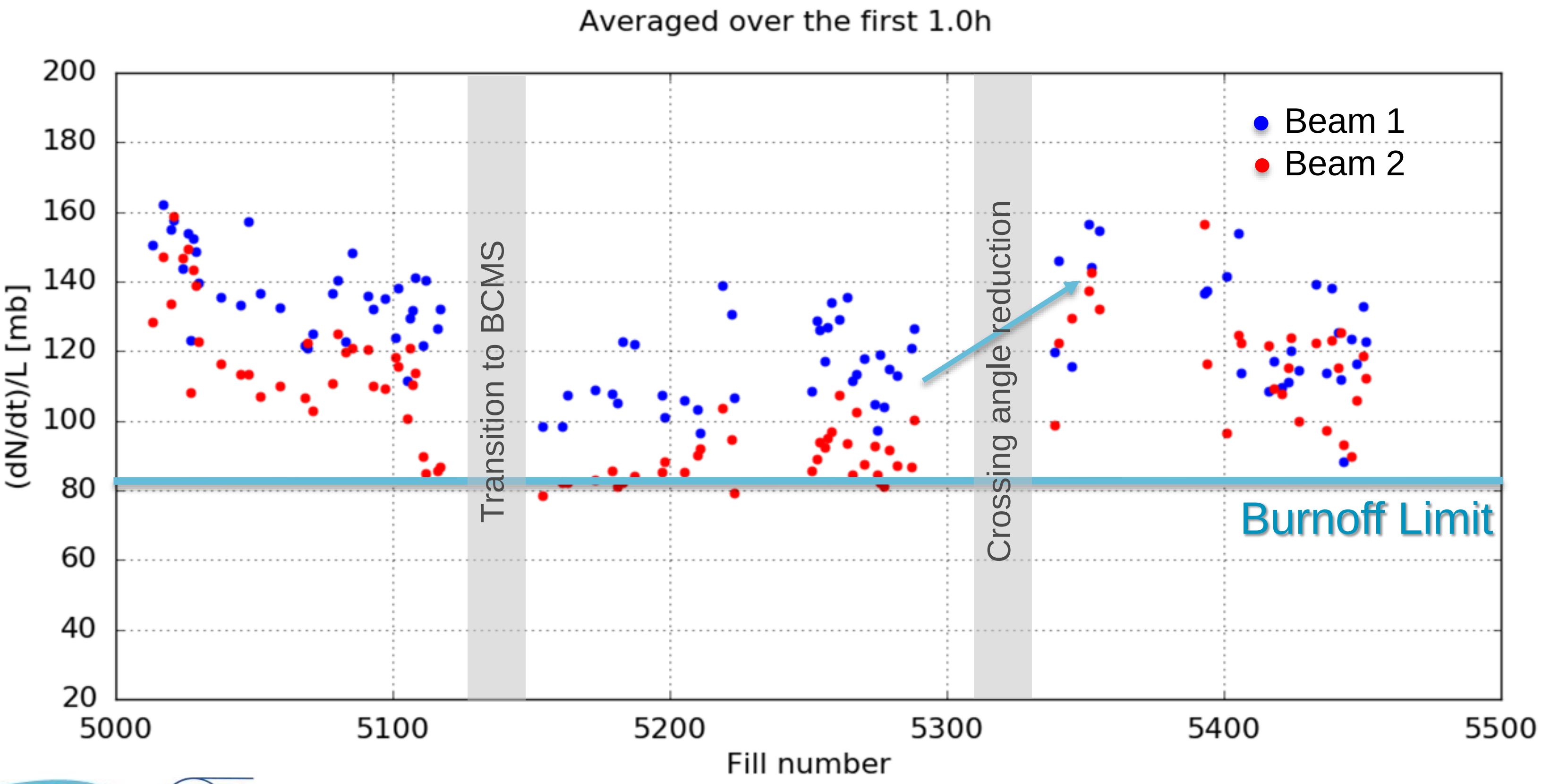
Losses calculated as % of total intensity over 10 minute windows at beginning of Stable Beam.

Average over several fills with Xing=140urad



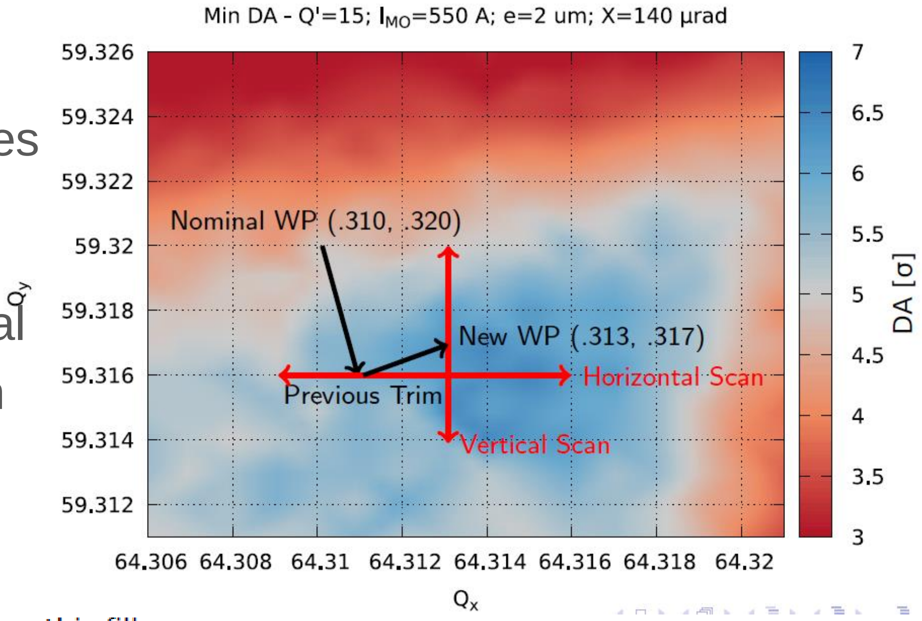
Traces of e-cloud and of LRs are visible.

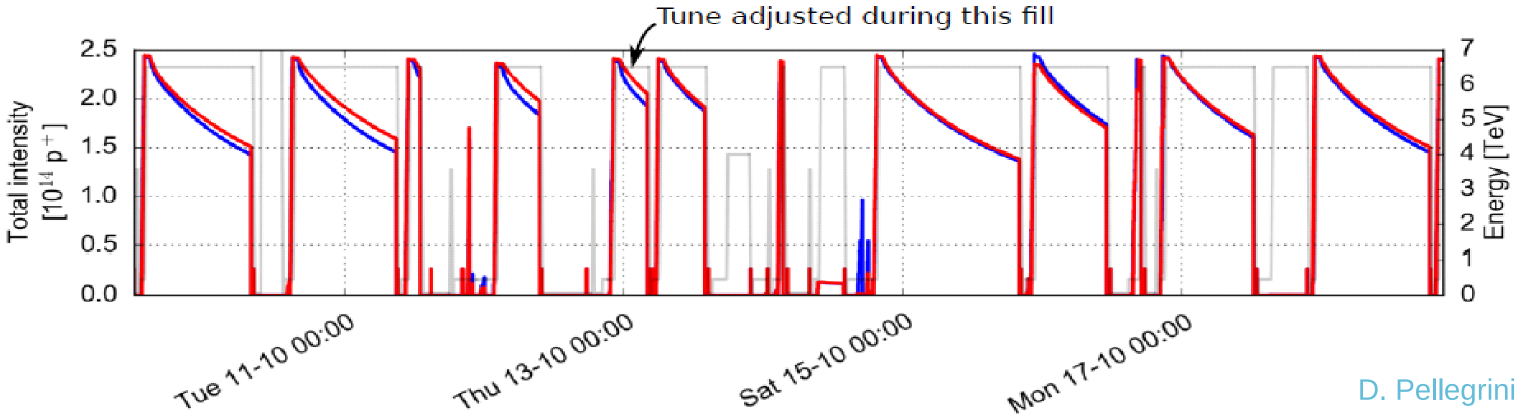
Reduction of Crossing Angle



Tune Adjustment

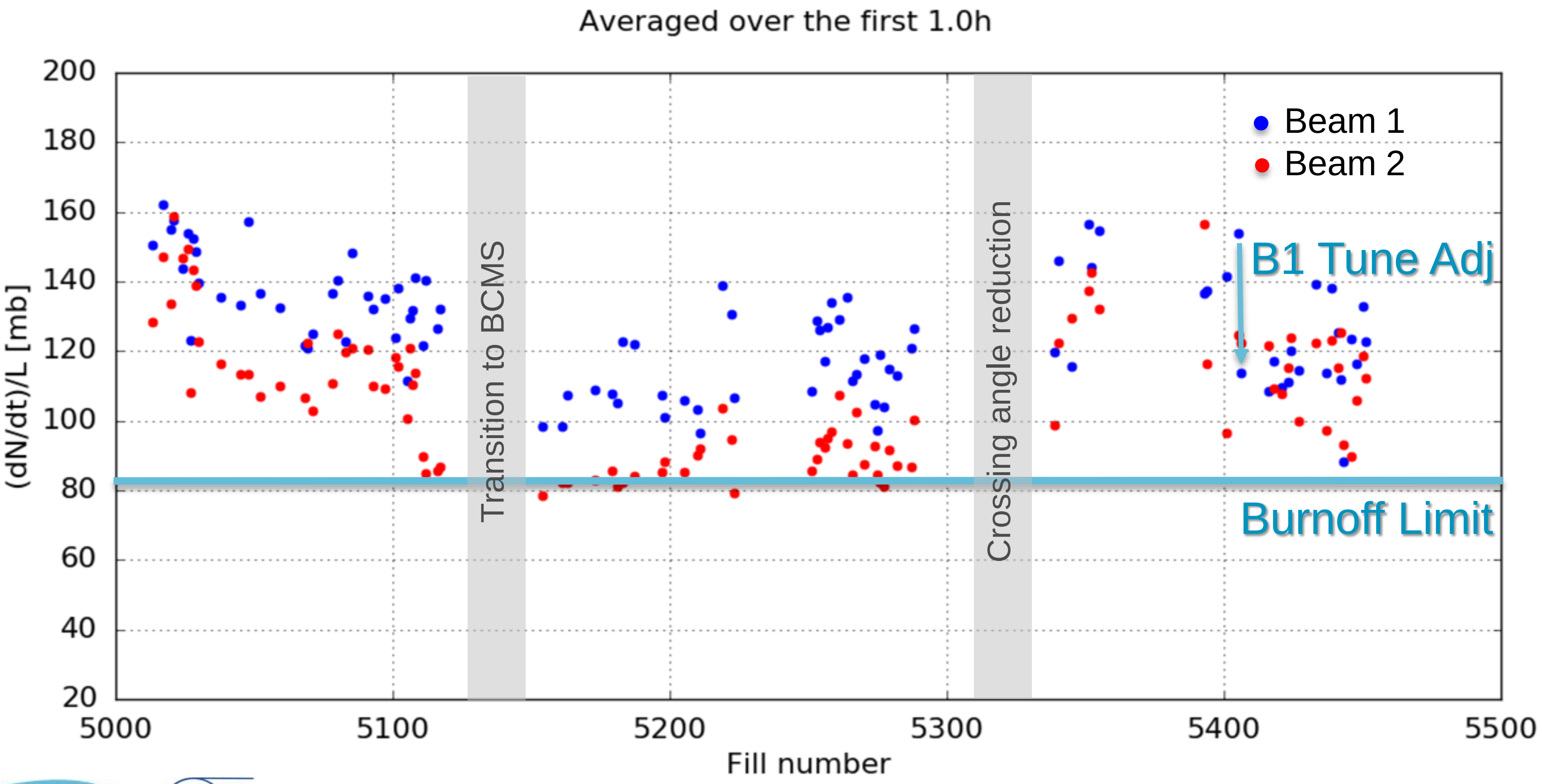
- Beam1 typically showed more losses than Beam2
- DA Tune scans pointed out that the nominal WP (.31, .32) is sub-optimal
- The tune of Beam1 was adjusted in operation according to predictions
- Beam1 lifetime was recovered





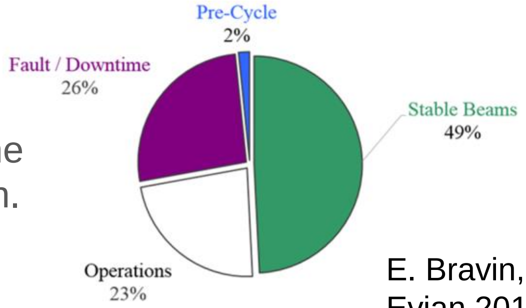
D. Pellegrini et al.
LMC, 19 Oct 2016

Tune Adjustment

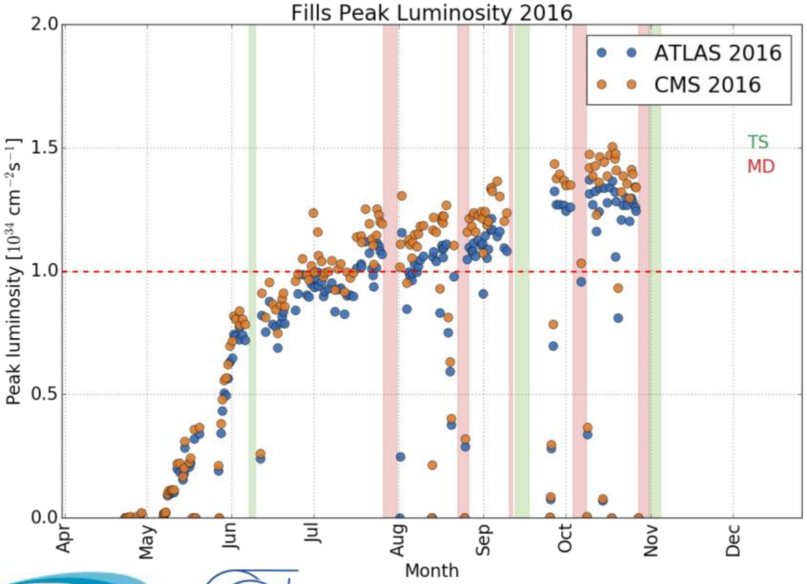


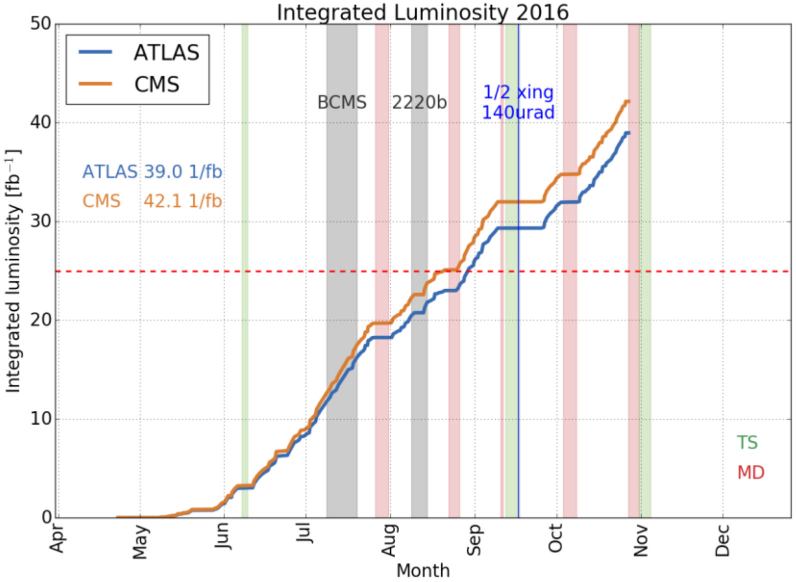
2016 Outcome

- 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



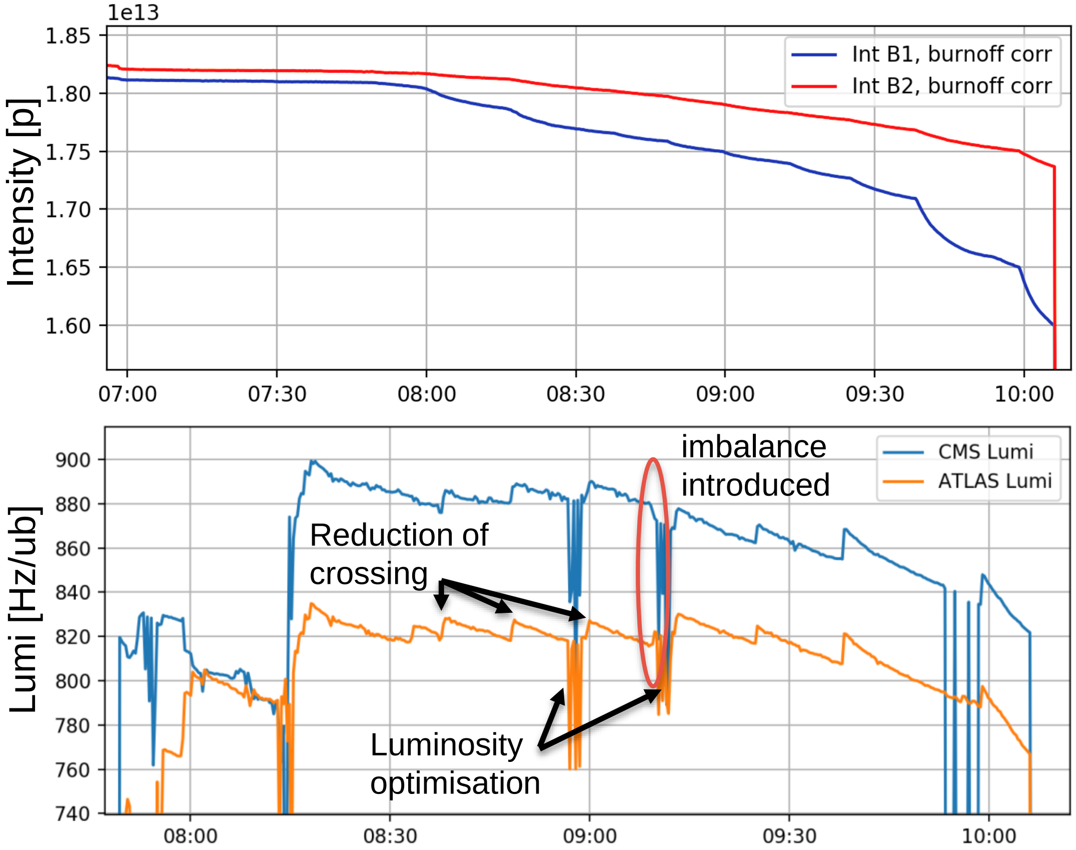


MD on LR Separation

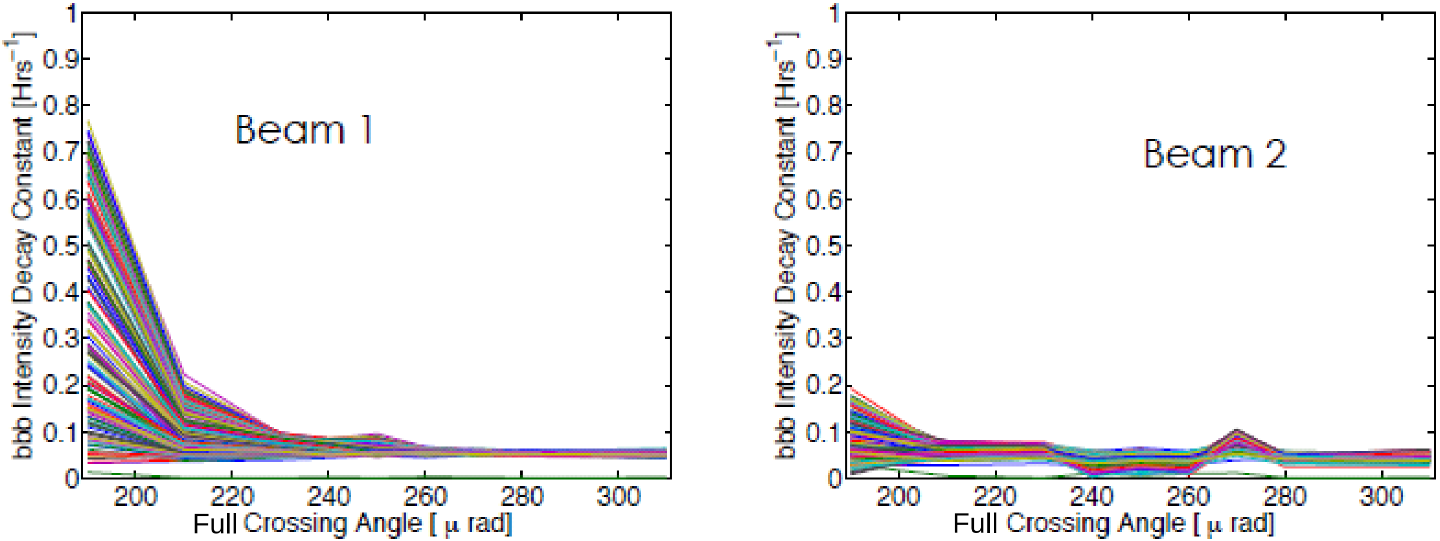
- Test performed during MD on fill 5137 by T. Pieloni et al. with symmetric trains in conditions similar to SB (strong-strong scenario).
- The crossing angle was reduced in steps during collision, lifetime was closely monitored.
- The impact of LR was observed especially in B1, while B2 was not so sensitive.

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



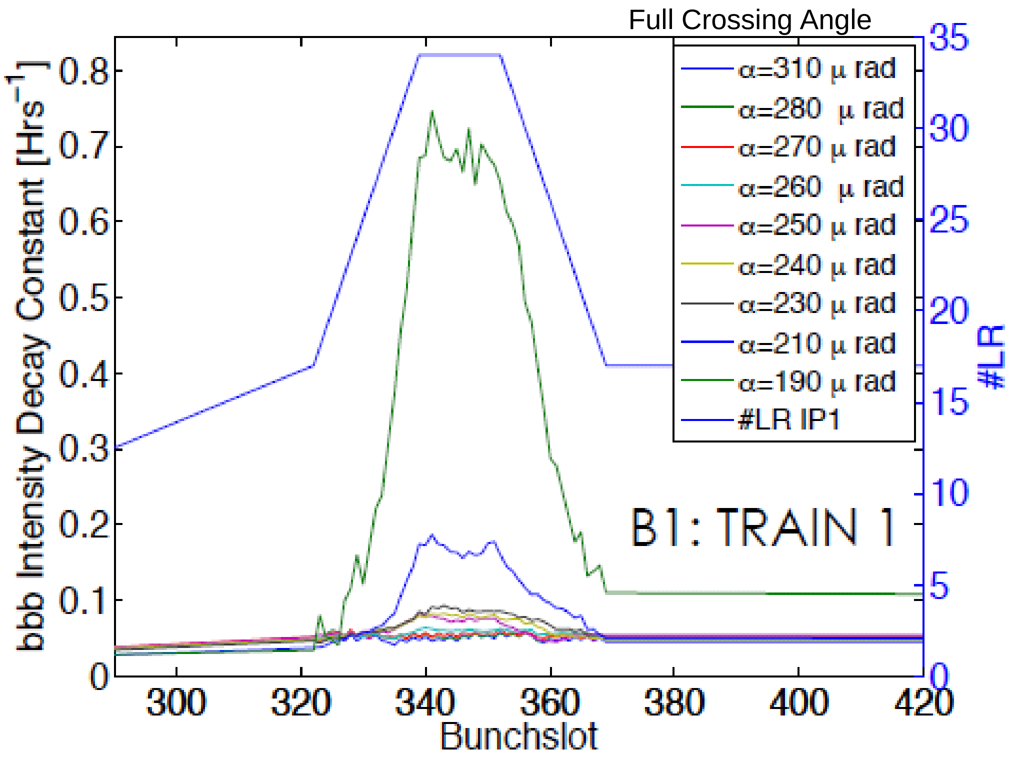
Outcome of MD on LR Separation



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

- Tune shift from crossing and asymmetry see talk of Belen.
- The encounters at minimum separation can possible have an impact on the symmetry due to different Left and Right beta functions (S. Fartoukh)
- The faster intensity decay of B1 steers towards a week-strong scenario: B2 is less and less perturbed by beam-beam.

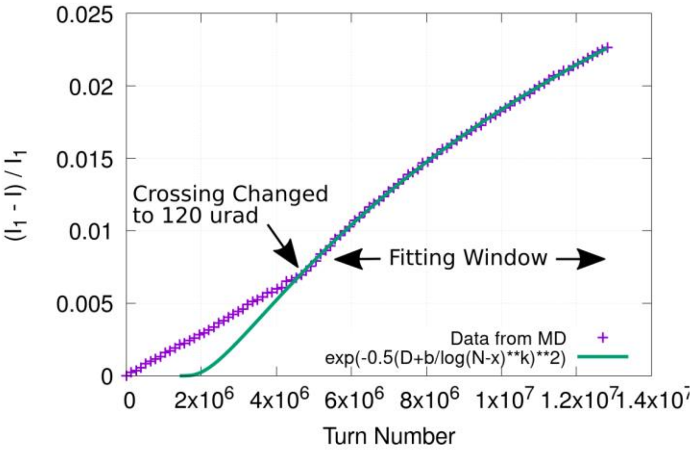
Losses VS Bunch Slot



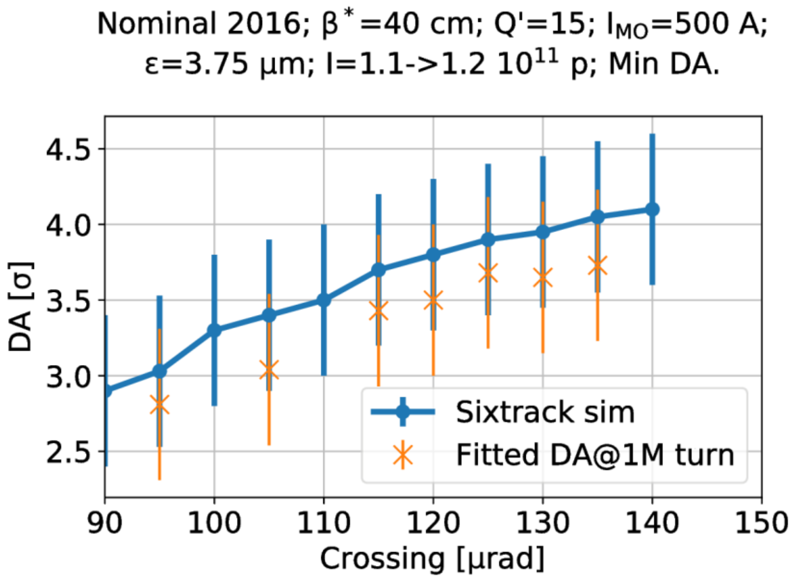
M. Crouch, Beam-Beam and Luminosity Meeting, 14 Oct 2016

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

Fitting with DA and Intensity Scaling Laws



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



- 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 for time being: pacman bunches are (erroneously) equally threated
- Some agreement with simulations although the many uncertainties present

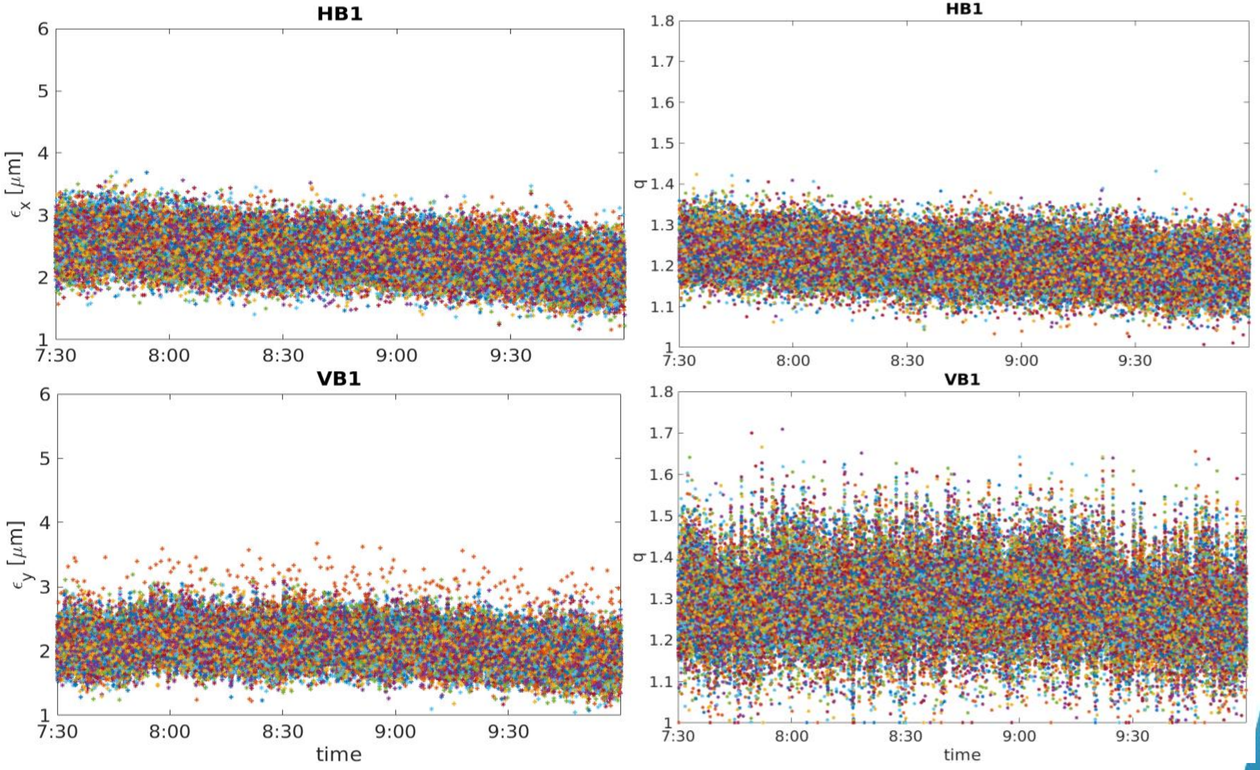
Work in progress also by M. Crouch

Transverse Profile analysis with q-Gaussian

- Need to disentangle IBS, SR and tail cleaning
- Filtering and spectral cleaning, but poor sensitivity to tails from BSRT
- Hard to draw conclusions
- Tails appear to shrink together with the emittance but…

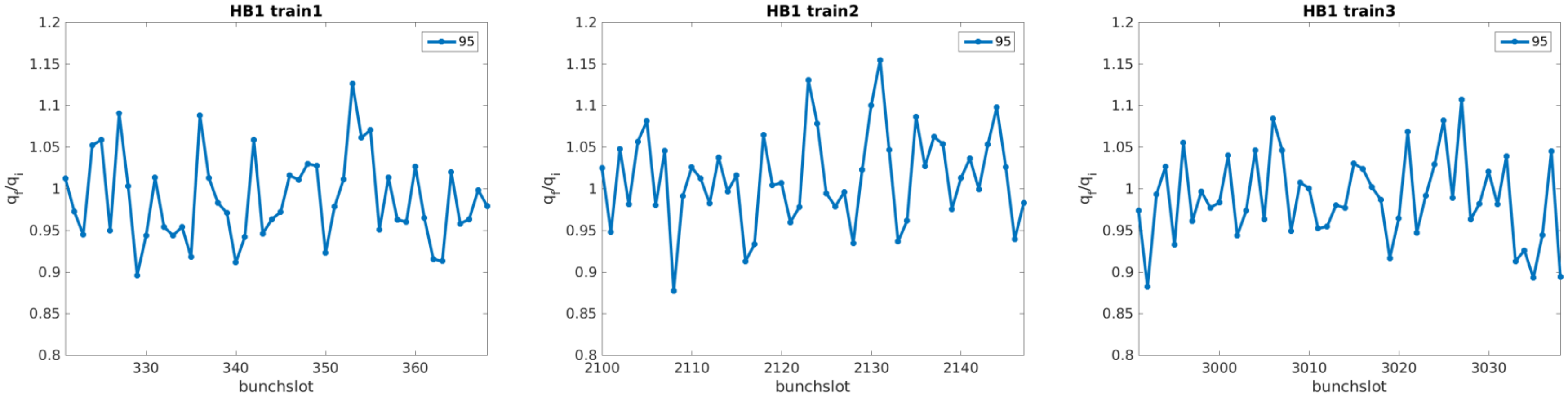
Emittance evolution

Tails evolution



S. Papadopoulou

Transverse Profile analysis with q-Gaussian



S. Papadopoulou

- All the bunch slots behave in comparable manners: no LR signatures.
- Diffraction, noise and sensitivity to fit range.
- Input for experiments of halo cleaning with wire: other monitoring techniques may be required!

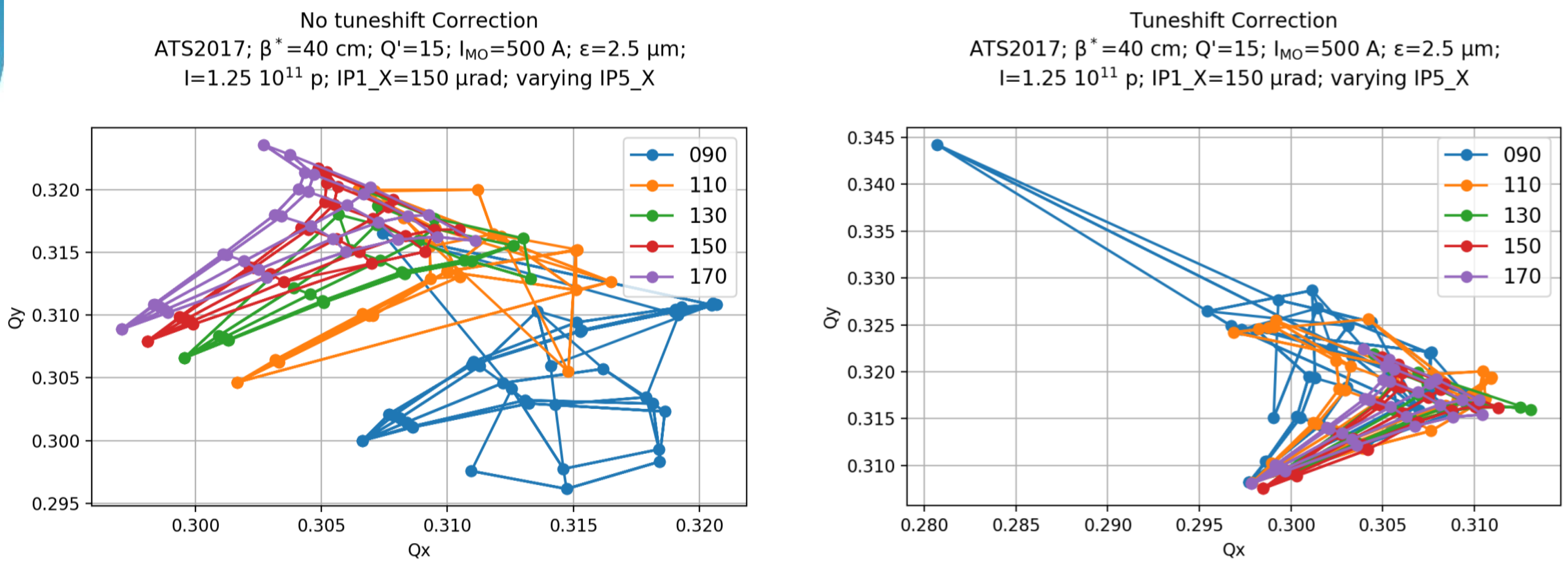
Perturbation of Single IP: scenario

- 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

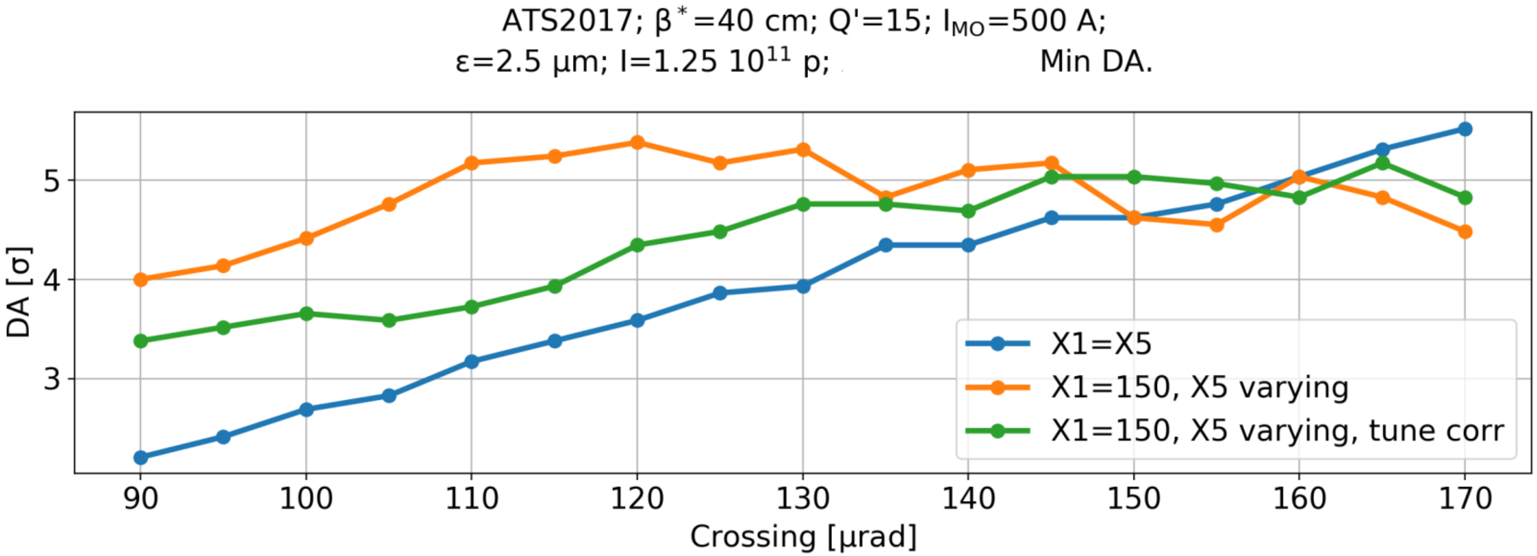
- Moving from small to large DA may require long time before DA losses appear again
  - one could use the data immediately after the change to evaluate non-DA losses (Burnoff, Beam-Gas, …)
  - the transition point may not be clear
- Operate the crossing and the wire (almost) simultaneously trying to 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 earlier).
- 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 multi-parametric 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 remain unknown
- Breaking the IP1/5 symmetry appears tricky:
  - Detailed knowledge of the dynamics is required
  - Optics (orbit, tune, chroma) has to be adjusted to compensate for masking effects

Thank you!