What did we learn about HALO population during Long-range beam-beam studies and MDs?

Y.Papaphilippou

Thanks to
G. Arduini, F. Antoniou, M. Crouch, S. Fartoukh, S. Papadopoulou,
D. Pellegrini, T. Pieloni, B. Salvachua, A. Valishev

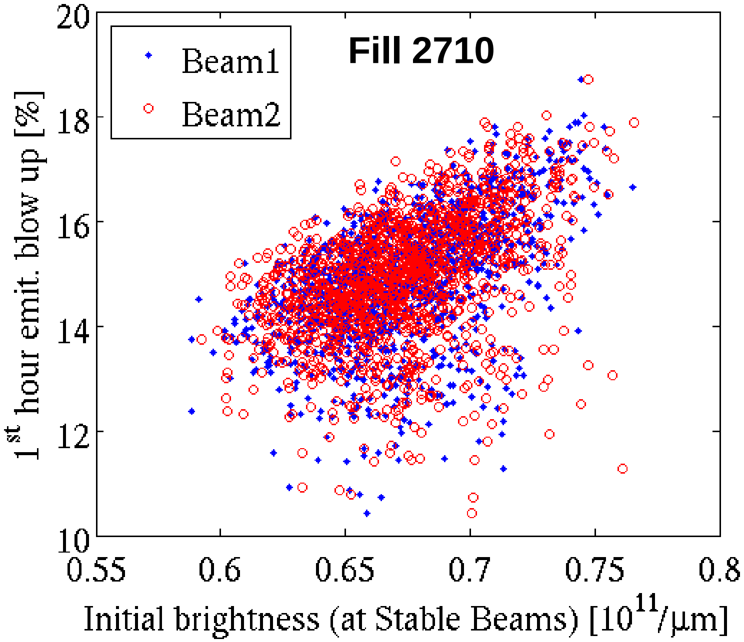
Review of the needs for a hollow e-lens for the HL-LHC, 6-7 October 2016, CERN

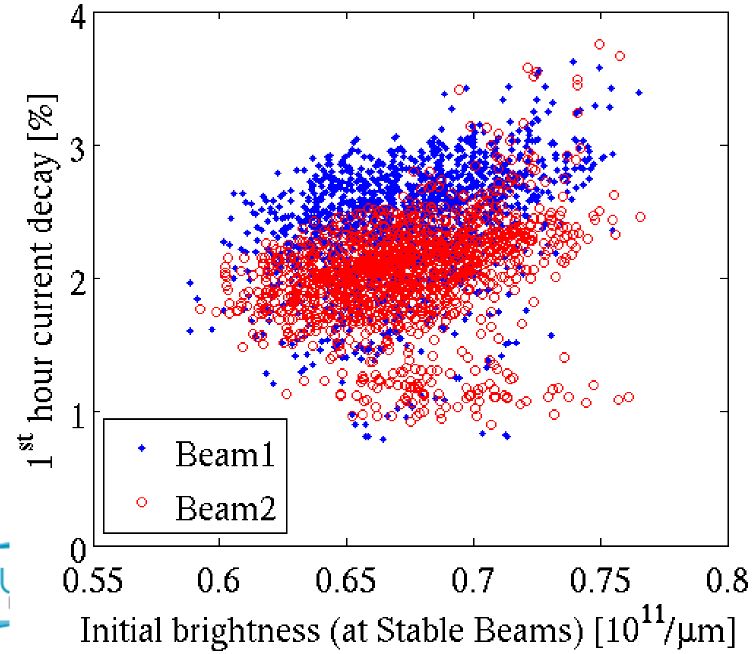
Content

- Observations during 2012 with respect to Long-range beam-beam (BBLR)
  - Emittance blow-up and losses
  - Correlation with BBLR
- Observations during 2015 BBLR experiments
  - Intensity decay versus number of LRs
  - Effect of chromaticity and octupoles
- Observations during 2015 BBLR experiments
  - Intensity decay versus number of LRs and losses
  - Emittance evolution
- Simulations
  - DA vs crossing angle and intensity
  - Simulating distributions
- Extrapolation of observations to HL-LHC

Observations during 2012 run with respect to BBLR

Emittance blow-up and beam losses



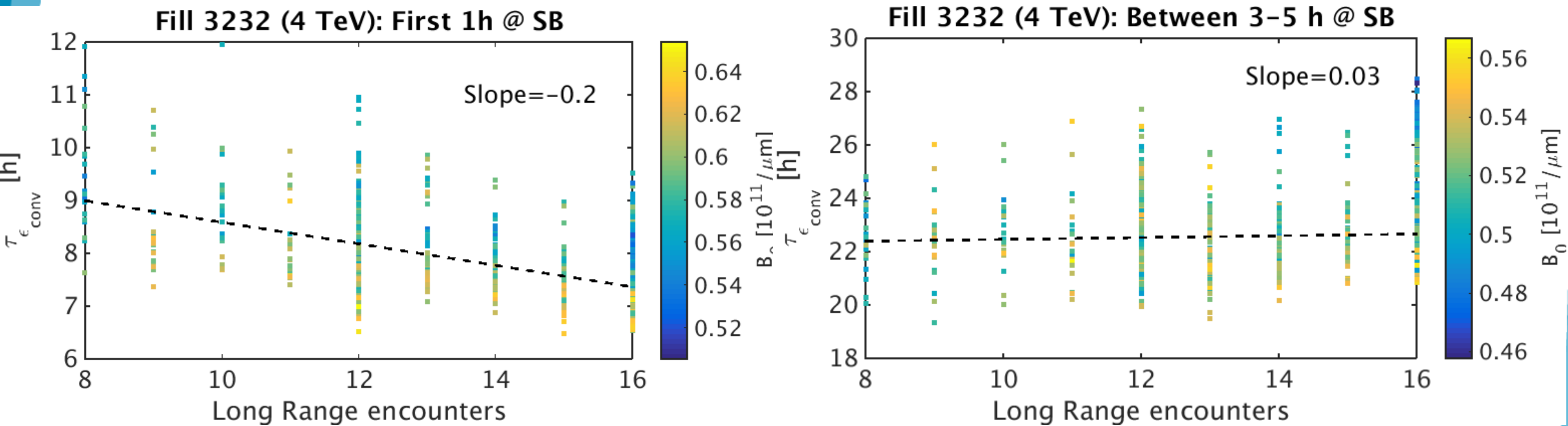


F. Antoniou

- **Convoluted emittance** inferred from luminosity
- Beam current from FBCT
- Unstable bunches are filtered out
- Relevant to HL-LHC the 1st hour of stable beams
- **Emittance blow-up** (~10-20% for this fill) **correlated** to **beam brightness**
  - Similar for both beams
- **Beam losses** (on top of burn-off ~1-4%) also correlated to brightness
  - More for B1 than B2

Effect of number of LRs on emittance growth

F. Antoniou

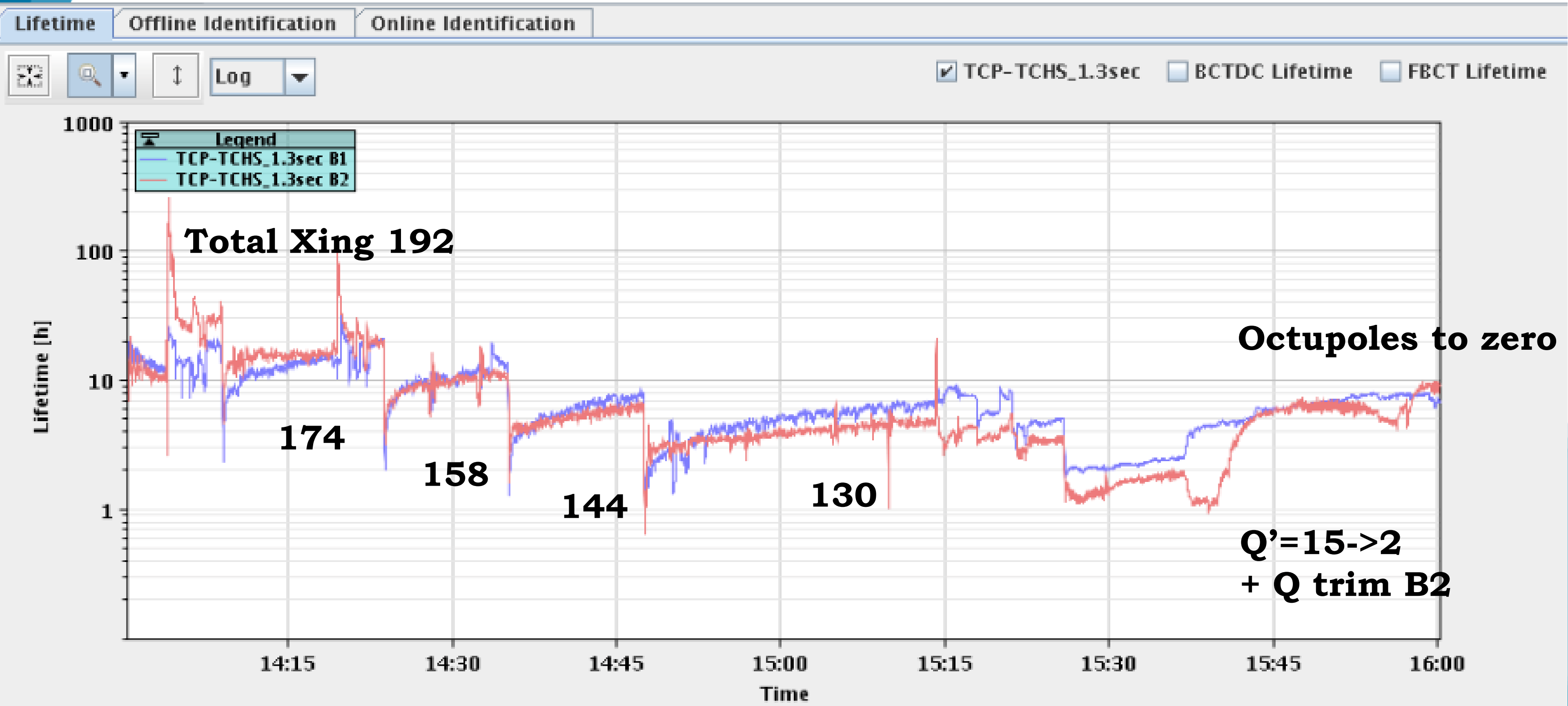


- **Convoluted emittance growth vs number of LRs** color-coded with **brightness**
- **Dependence** on both **number of LRs** and **brightness** for 1st h in SB
- **Dependence on LRs** is **lost** between **3-5 h** in SB

Observations during 2015 BBLR experiments

BBLR MD in 2015

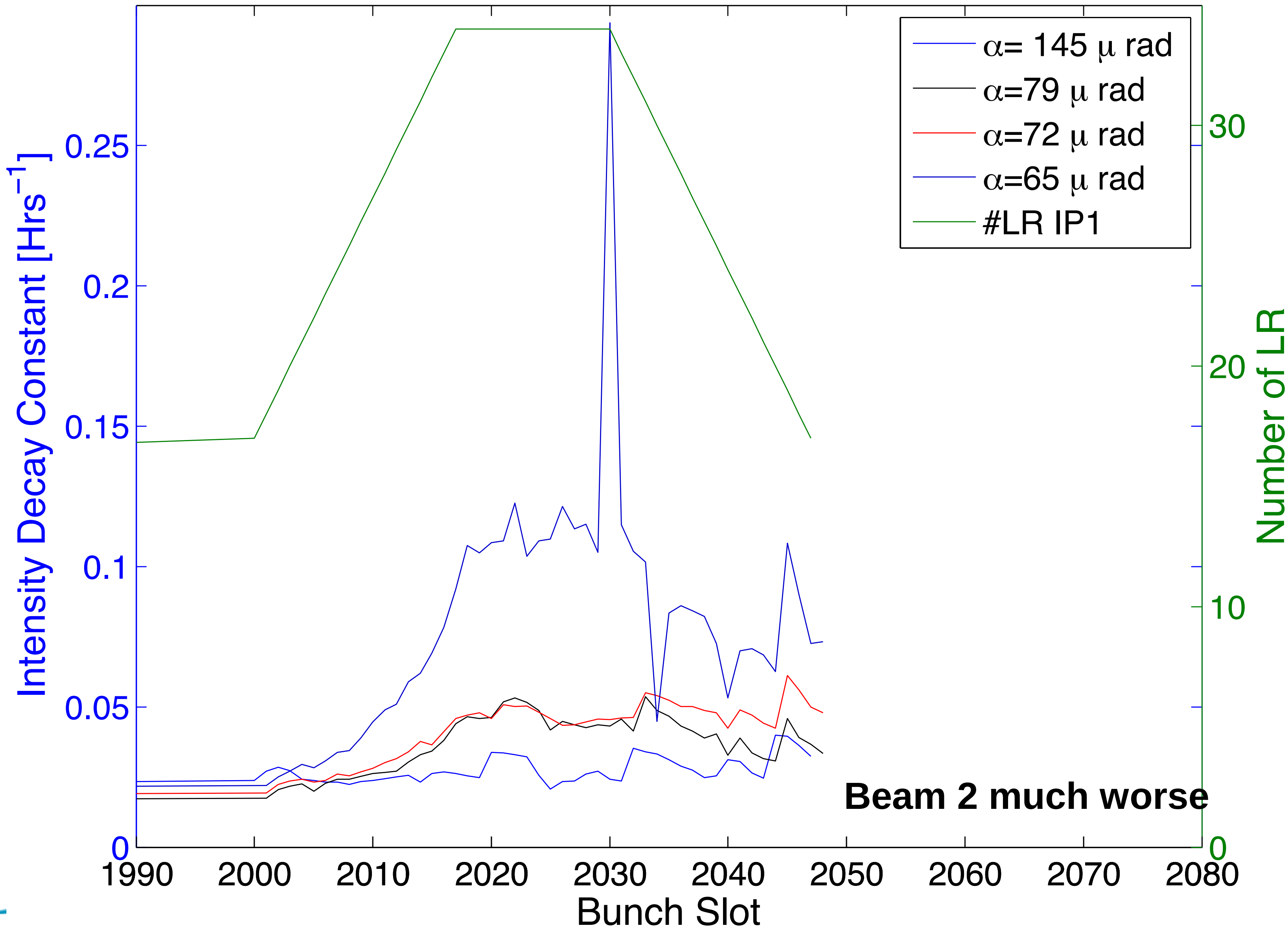
T. Pieloni et al.



- Emittances of 2.4 mm, intensities 1.1e11ppb with 48 bunches train
- Reduce crossing angle in steps from Total angle 290 to 130 mrad and quantify impact on beam intensity, emittances and luminosity lifetimes
  - Issue with large orbit drifts and collision loss
- Reduce Q' and Octupoles

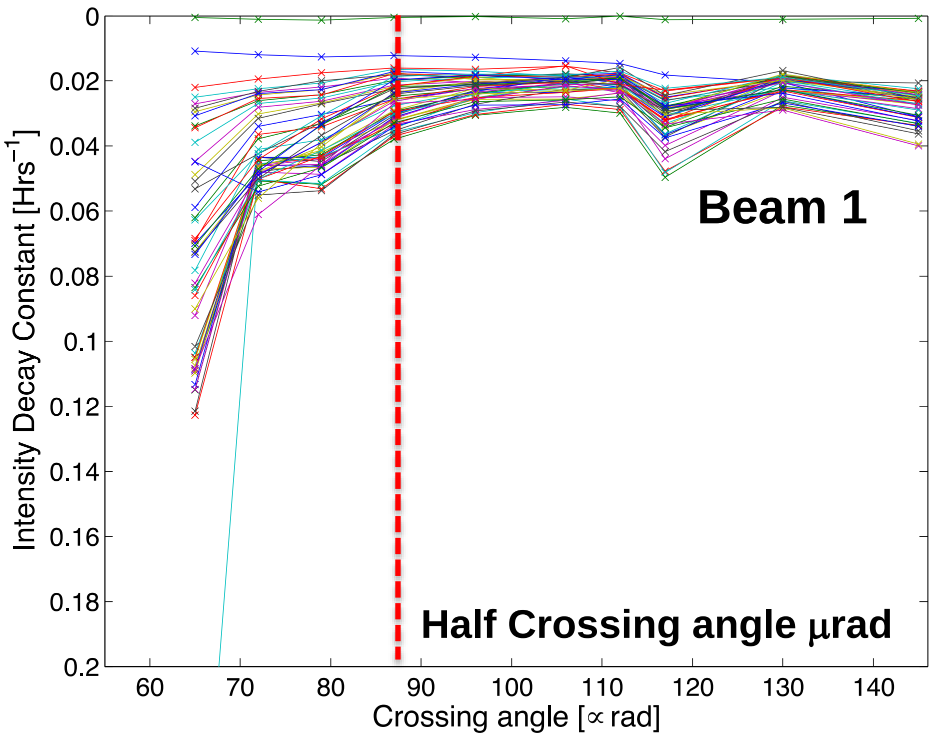
Beam 1 Intensity decay versus bunch

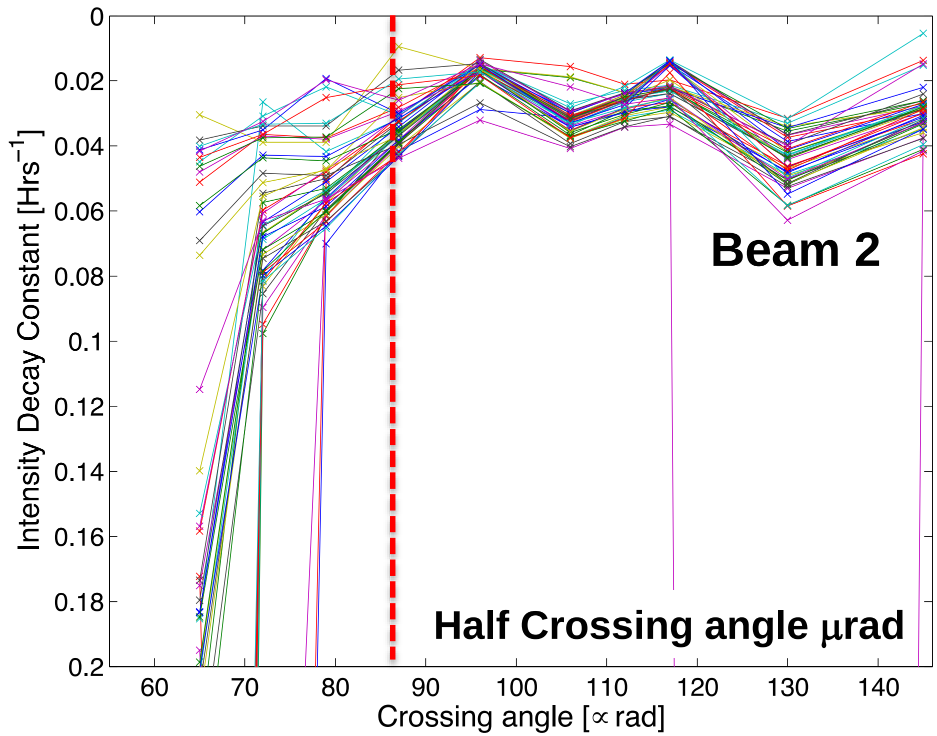
M. Crouch et al.



Intensity lifetimes versus crossing angle

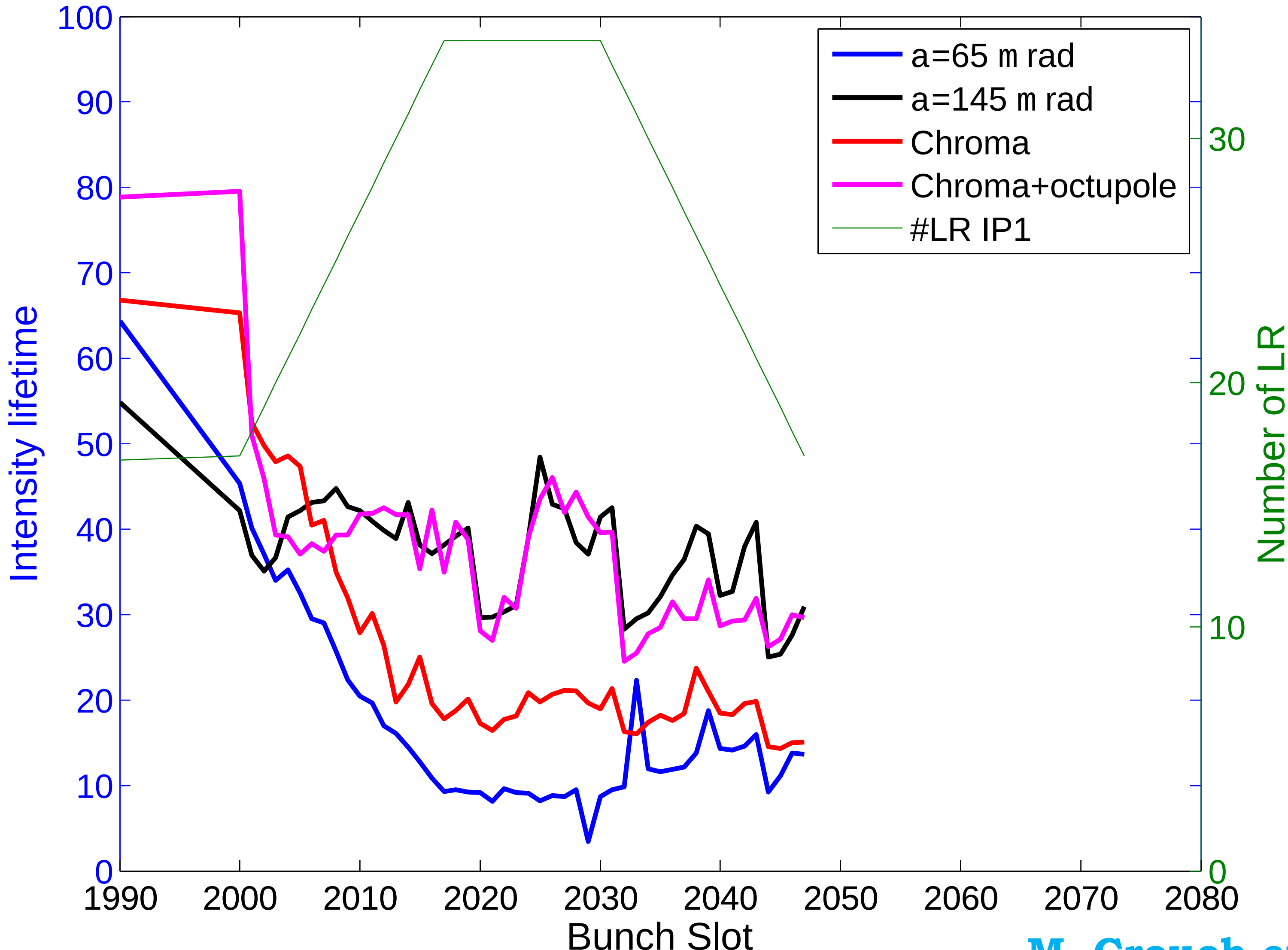
M. Crouch et al.





- Beam **lifetimes** reduced from **30** to **8** (beam 1) or **5 h** (beam 2)
- For full crossing angles below **180 μrad** limit lifetimes drop to **20 h**
- Onset of losses with LR patterns occurs at a beam-beam separation of 8.5 σ

Beam 1 Intensity versus Q’ and Octupoles



M. Crouch et al.

Reducing Q’ 15→ 2 units

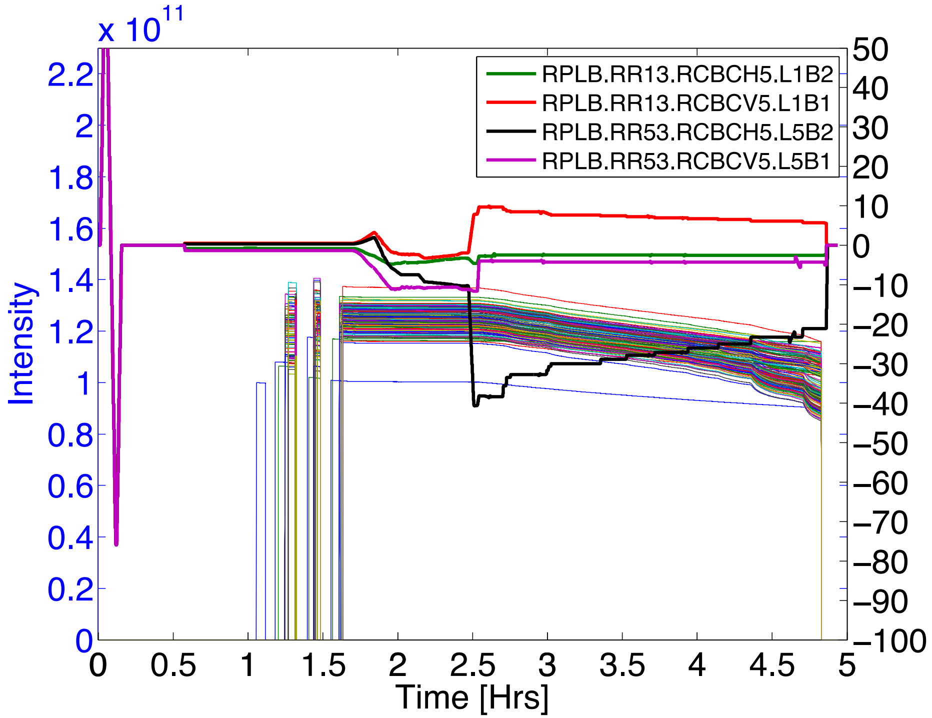
Landau Octupoles from 476 → 0 A

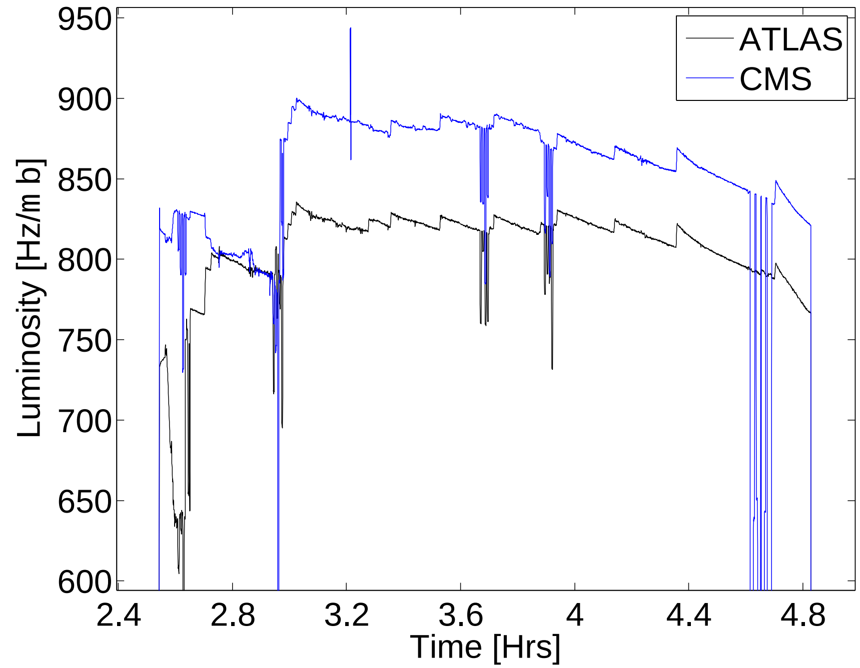
Lifetimes improves going back to 30 hours

Observations during 2016 BBLR experiments

Beam-Beam Long-range experiment in 2016

T. Pieloni et al.

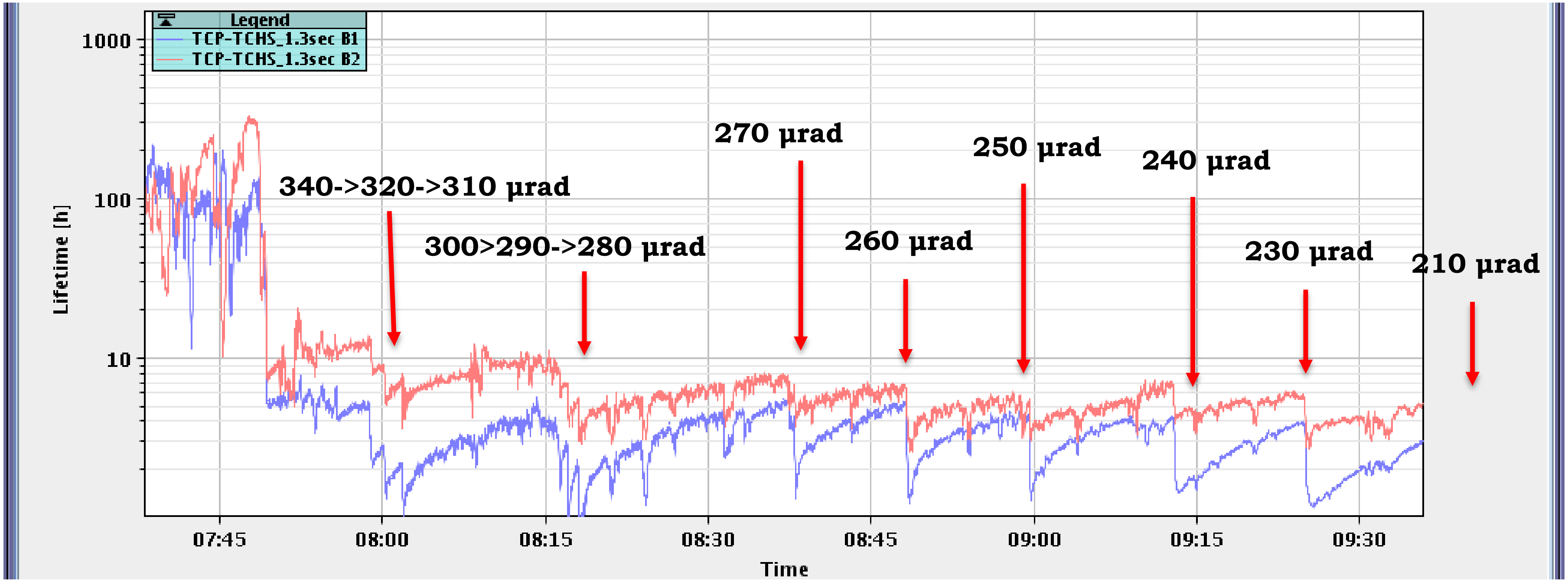




- Bunch intensities of ~1.3e11 with emittances of ~2.5μm @ collision
- Three trains of 48 bunches colliding in IP1/IP5 and one also in IP2 and IP8

Beam-Beam Long-range experiment in 2016

T. Pieloni et al.

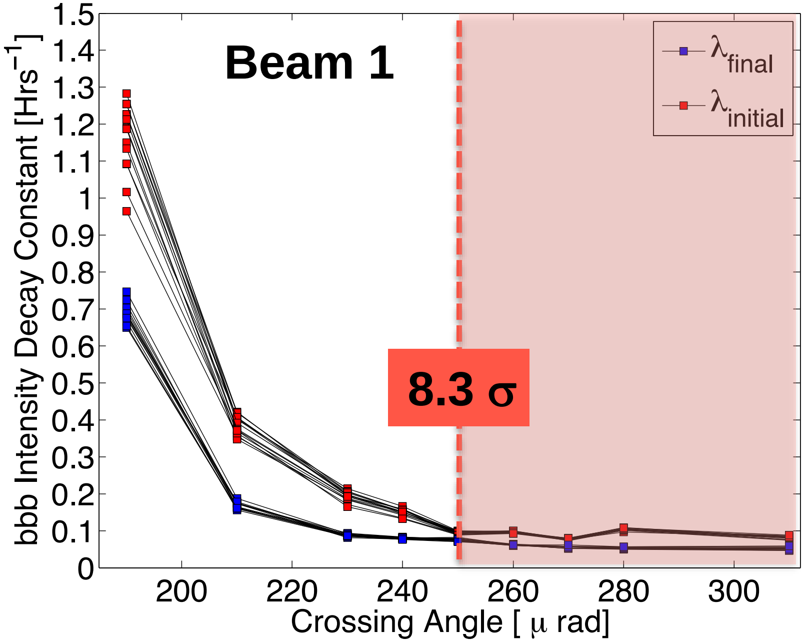


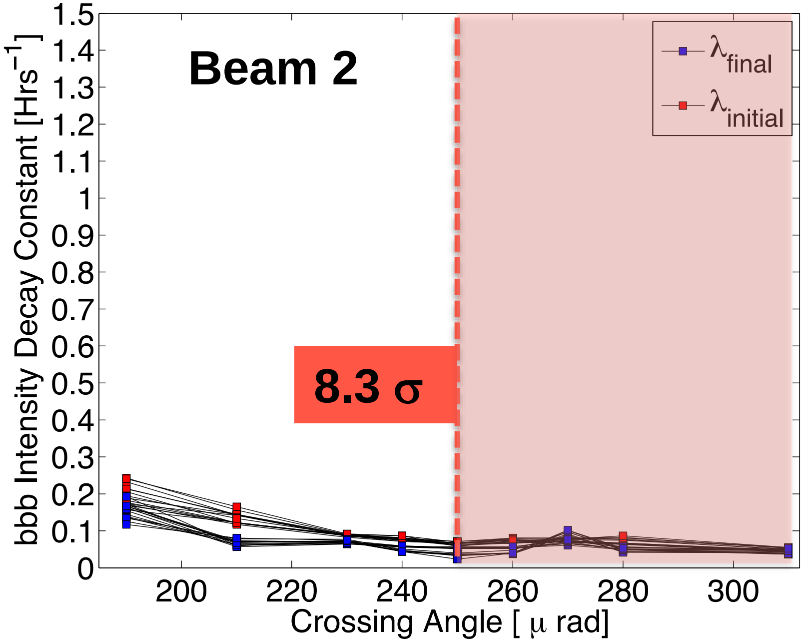
- Crossing angle scan in both IP1 and IP5: reduce in steps and monitor effect on beam lifetime (~20 minutes)
- Test chromaticity and Landau octupoles impact
- Issue with orbit drifts at higher crossing angles (370-310µrad)
- Fast lifetime drop at first time 5 min followed by slow recovery for 15 minutes at new angle

Long Range experiment 2016: intensity decay

T. Pieloni et al.

$$d_{sep} = \sqrt{\frac{\beta^*}{\epsilon_{x,y}/\gamma}}\phi$$



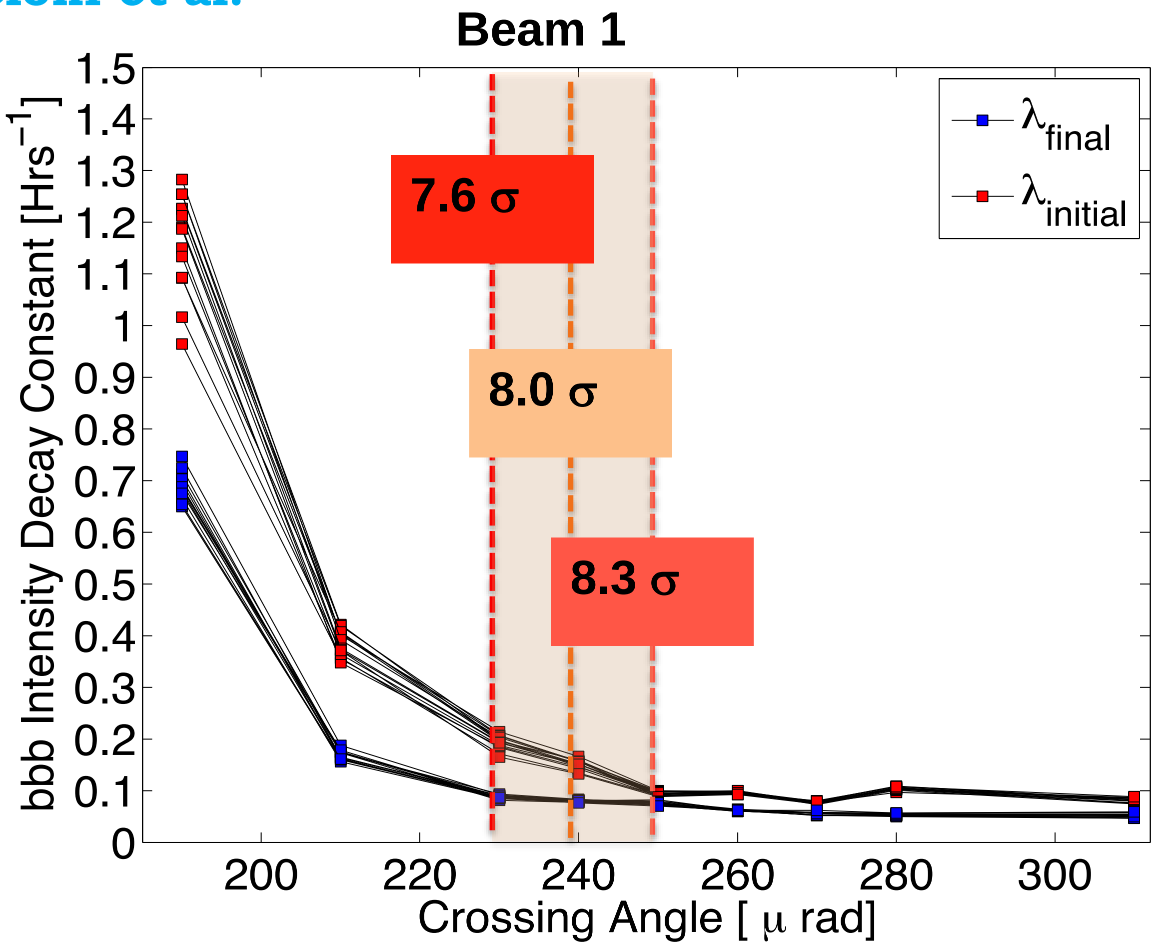


ϕ
310
280
270
260
250
240
230
210
190

- Plotting initial and final intensity decay versus crossing angle
- Only **Beam 1** visibly affected by crossing angle reduction
- For angles in range 310-250 μrad, losses do not follow crossing angle reduction

Long Range experiment 2016: intensity decay

T. Pieloni et al.



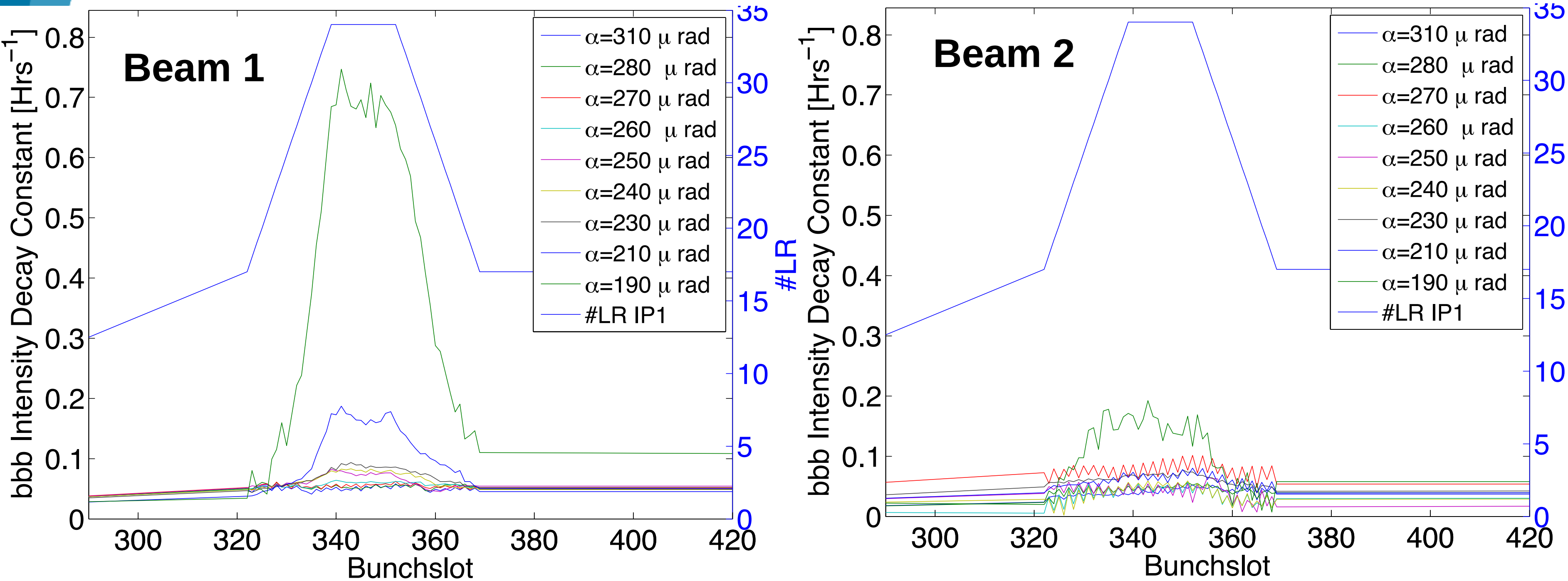
$$d_{sep} = \sqrt{\frac{\beta^*}{\epsilon_{x,y}/\gamma}}\phi$$

ϕ
310
280
270
260
250
240
230
210
190

- For 250-230 μrad, start observing beam-beam long range pattern in losses
- Below 230 μrad, BBLR becoming dominant

Long Range experiment 2016: intensity decay

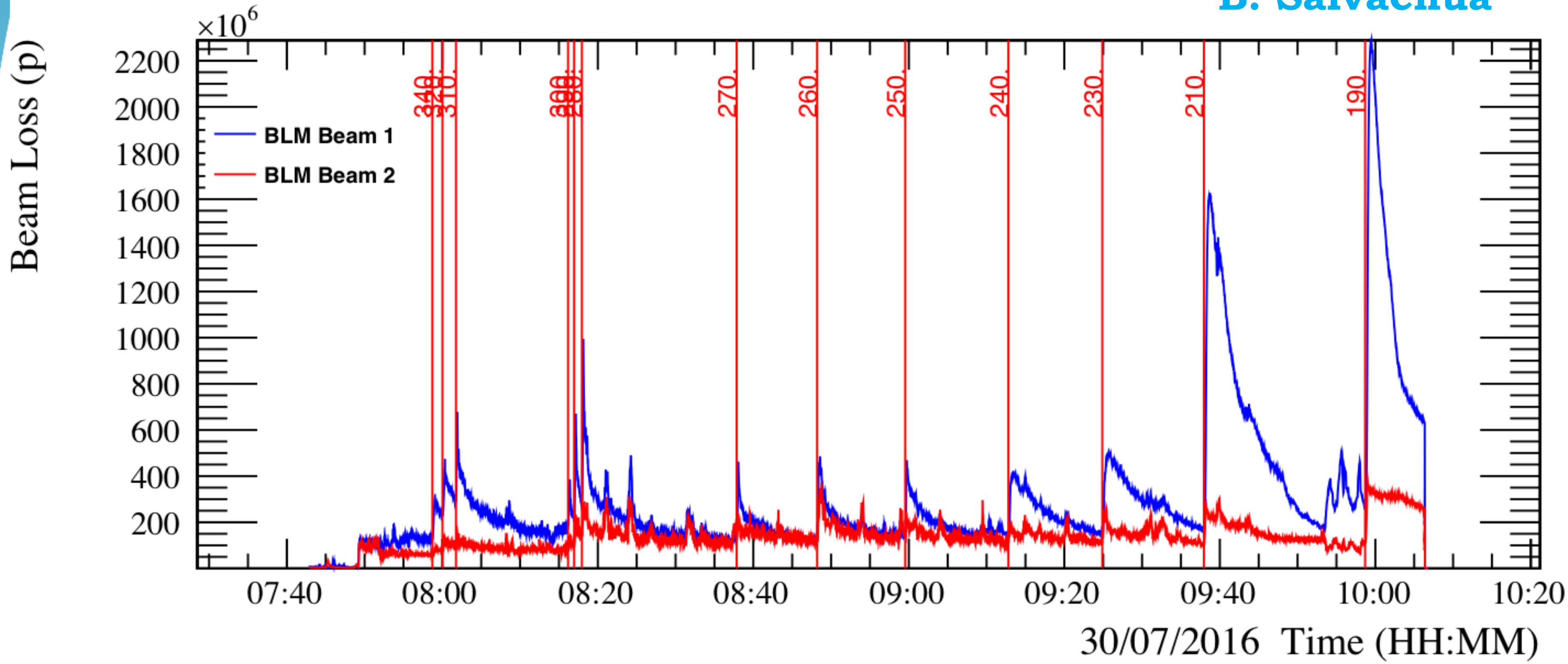
T. Pieloni et al.



- From 370 to 250 μrad no long-range pattern with long lifetimes of 20-30 h
- From 250 to 230 μrad, long-range effects appear, reducing lifetimes to 15-10 h
- Below 230 μrad, strong long-range effects and lifetimes drop to below 10 h
- All trains show similar behavior (no apparent effect of IP2 and IP8)
- Beam 2 does not follow the same pattern

Losses for Beam 1 versus Beam 2

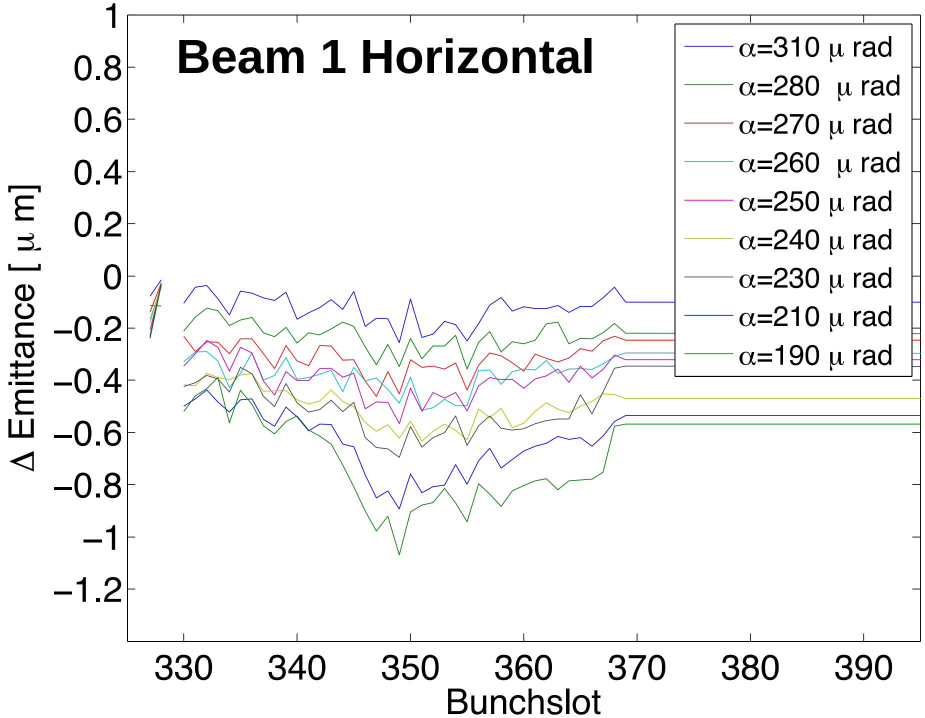
B. Salvachua

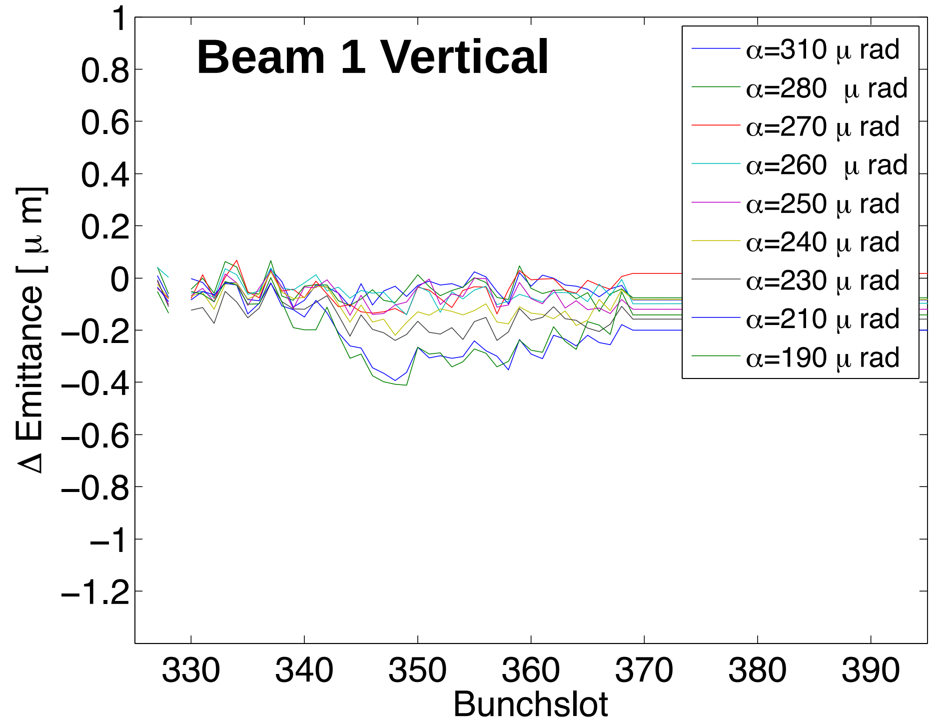


- Loss patterns confirm the previous observations, with strong losses below 230 μrad (but only in Beam 1)

Emittances observations

M. Crouch

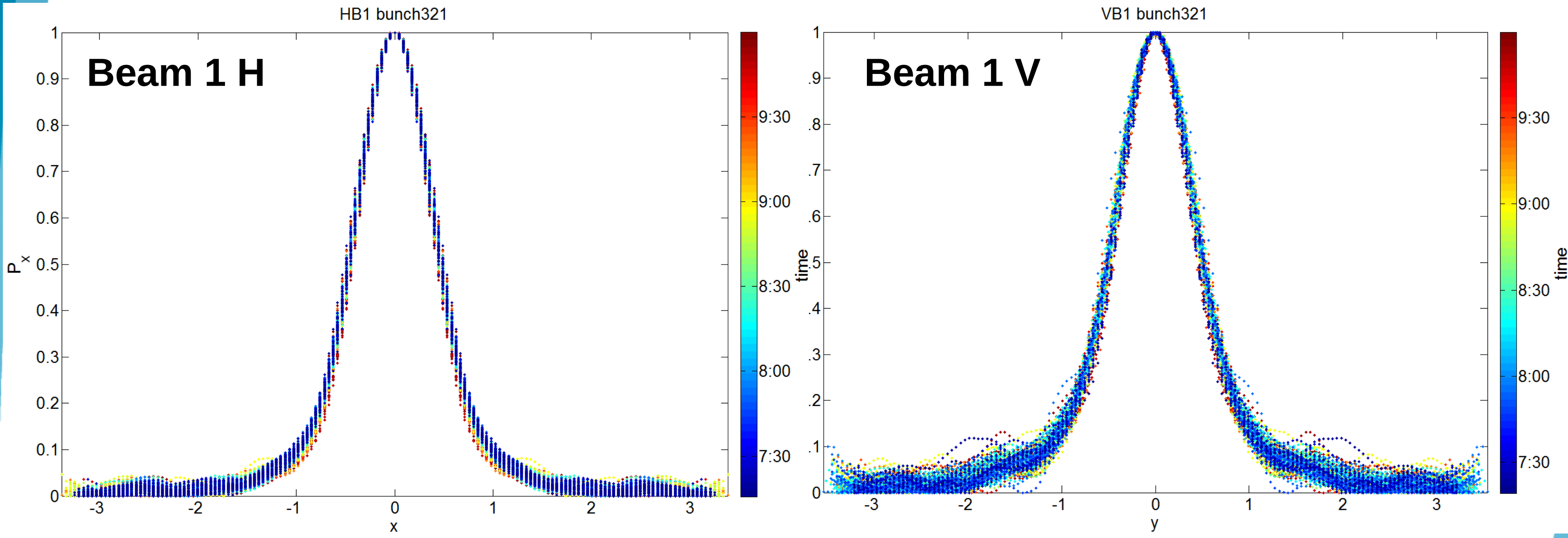




- Emittance of B1 is damping especially in the horizontal plane
- Following a long range pattern for reduced crossing angles (scraping?)

Beam Profiles

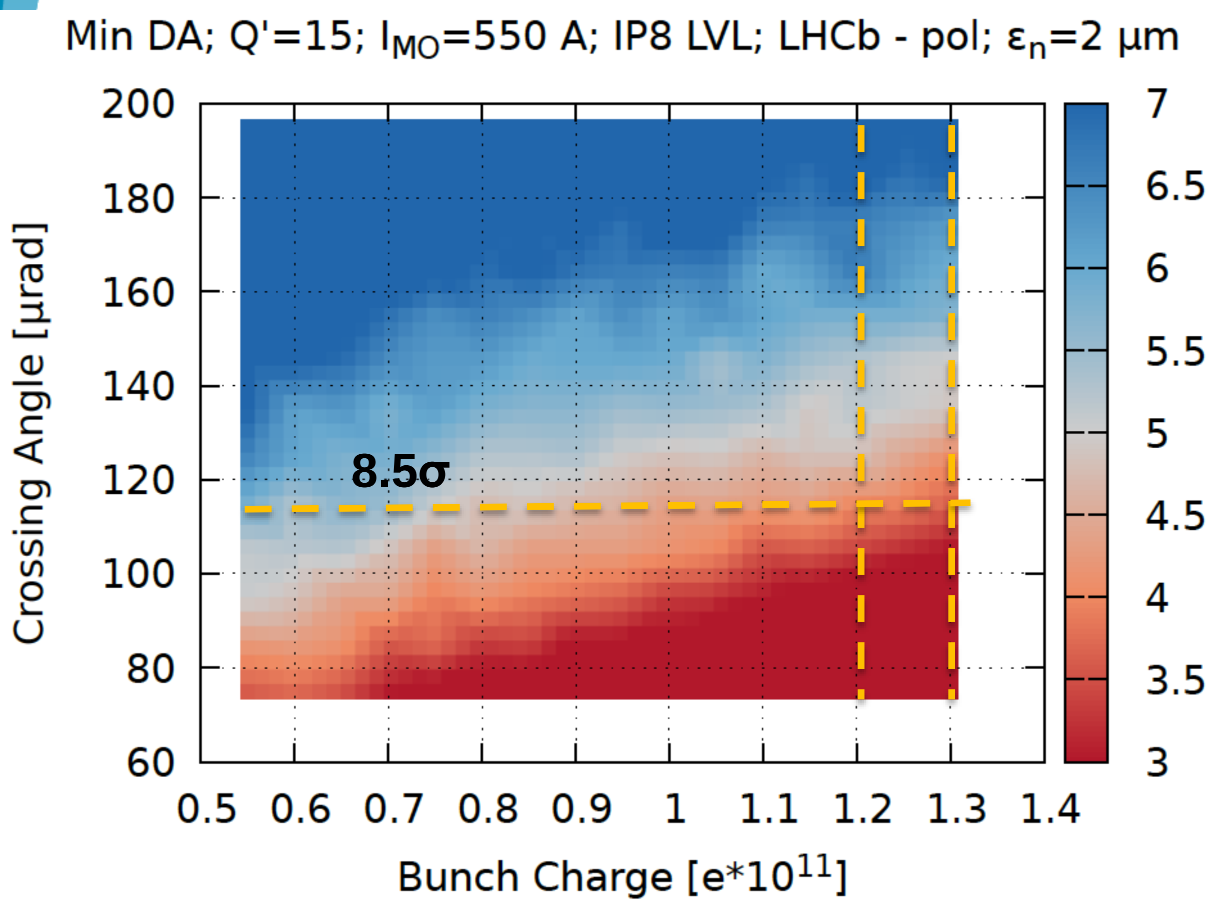
S. Papadopoulou



- Profiles significantly non-Gaussian especially for beam 1 and in the vertical plane
- Analysis for evaluation and evolution of tails is on-going

Simulations

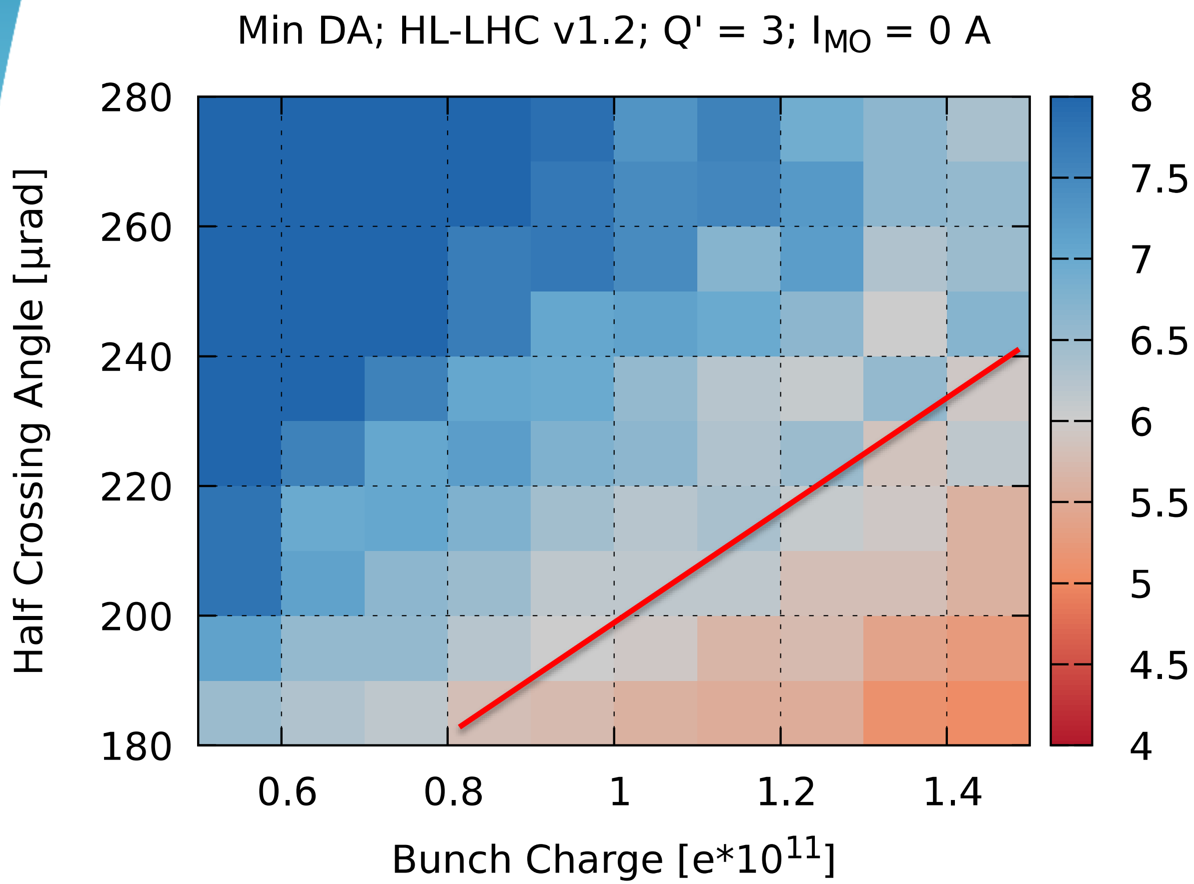
Dynamic aperture for present LHC



- **DA** while scanning (half) **crossing angle versus intensity** for β^* = 40cm and 2μm emittances
  - Chromaticity of 15, Maximum octupole, IP8 on
- Onset of long range losses from experimental data correspond to DA of around **4 σ**

HiLumi HL-LHC PROJECT

Dynamic aperture for HL-LHC

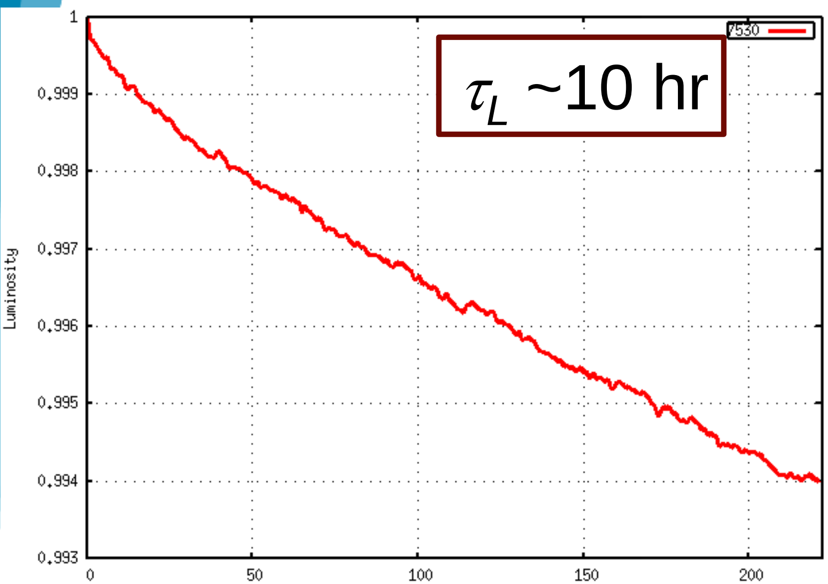


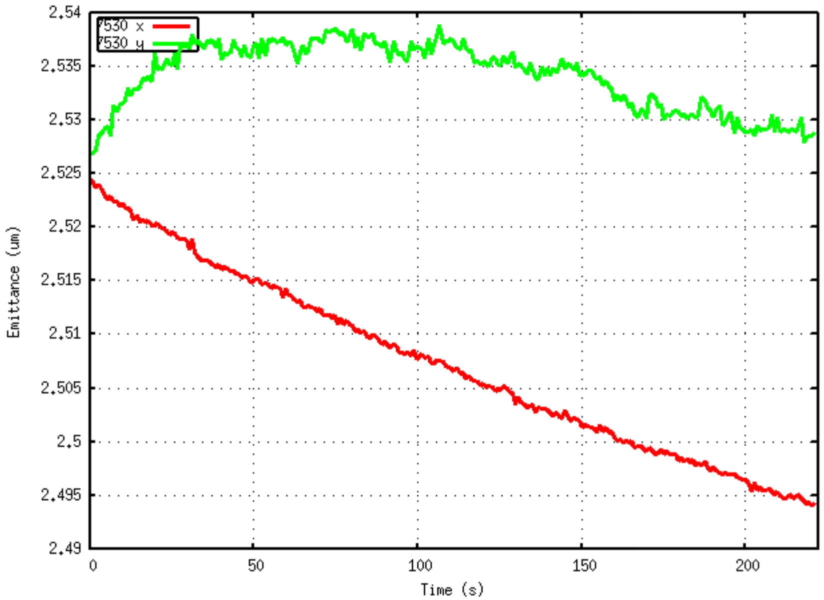
- DA while scanning (half) crossing angle versus intensity for $\beta^* = 20$cm
  - CC with half voltage, IP8 on
- Always quite comfortable, but:
  - No errors, low chromaticity, zero octupoles

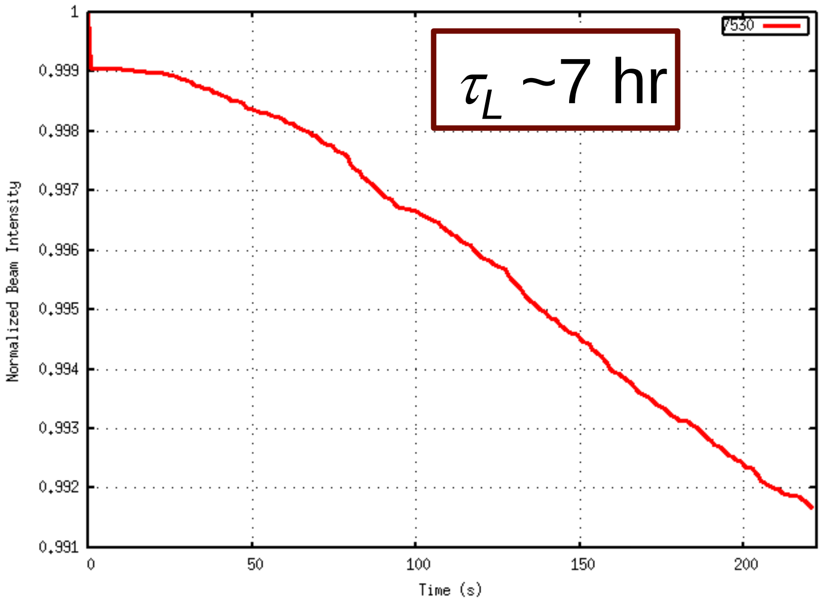
D. Pellegrini

Simulating distributions

S. Valishev







- Flat beam configuration with β^* = 30/7.5cm, x=320 μrad, IP8=on, CC=off
- Significant beam and luminosity lifetime degradation

Evolution of profiles

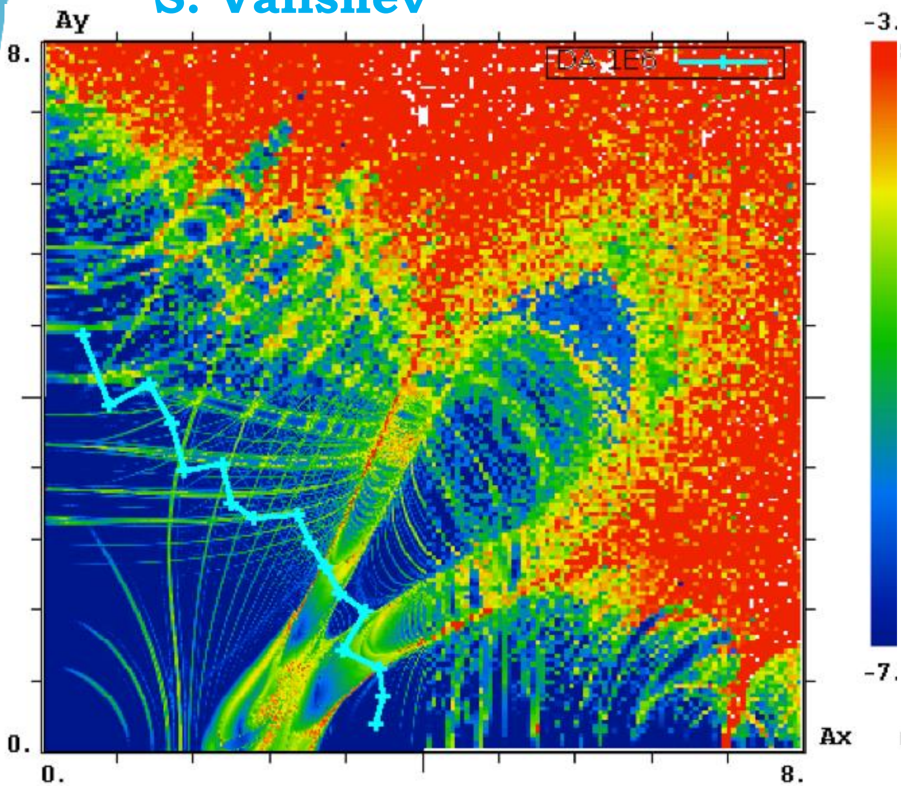
S. Valishev

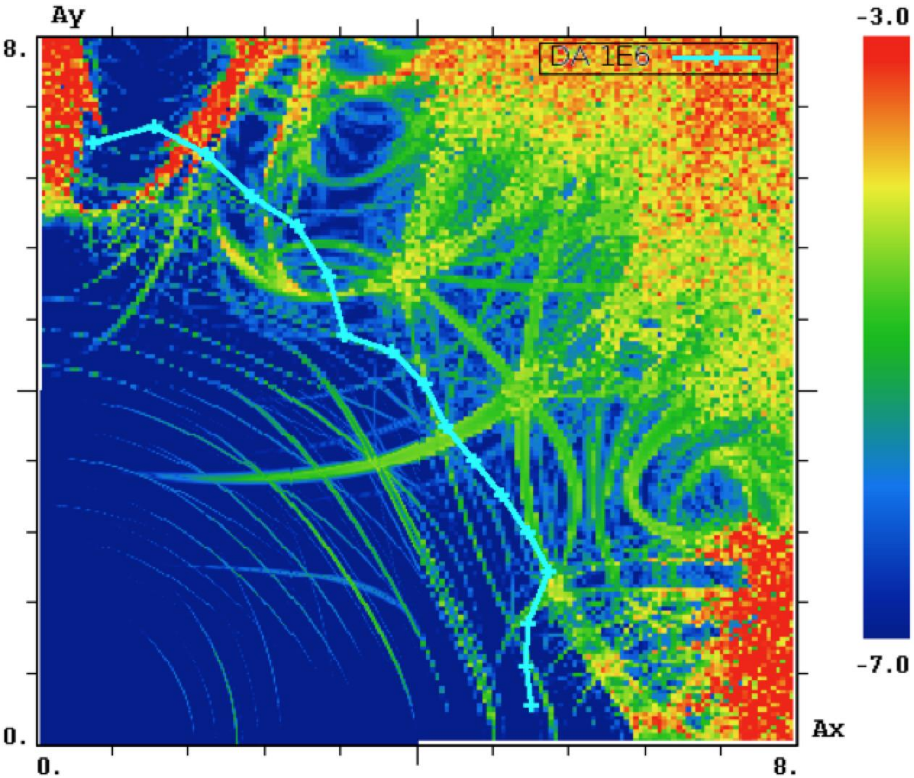
- Significant evolution of tails but also core blow-up

BBLR Compensation with wire

BBLR=off, DA=3.2 BBLR=on, DA=5.4

S. Valishev



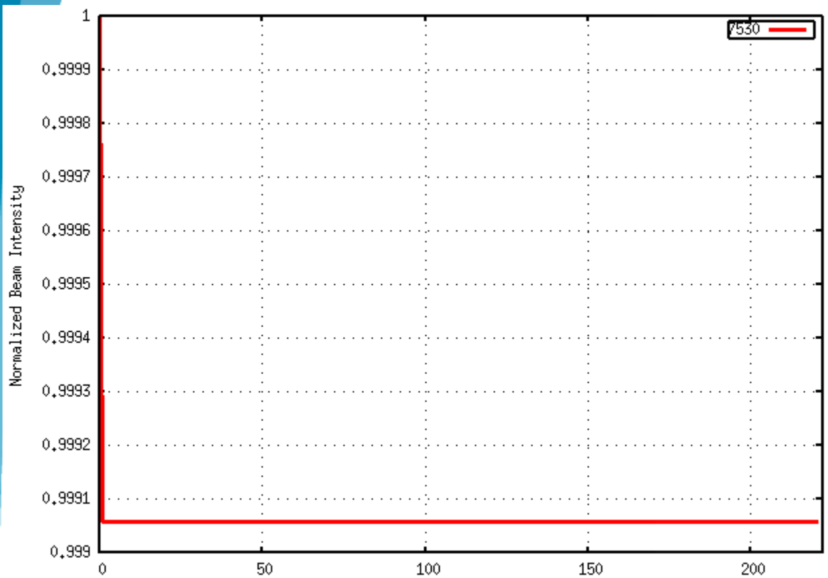


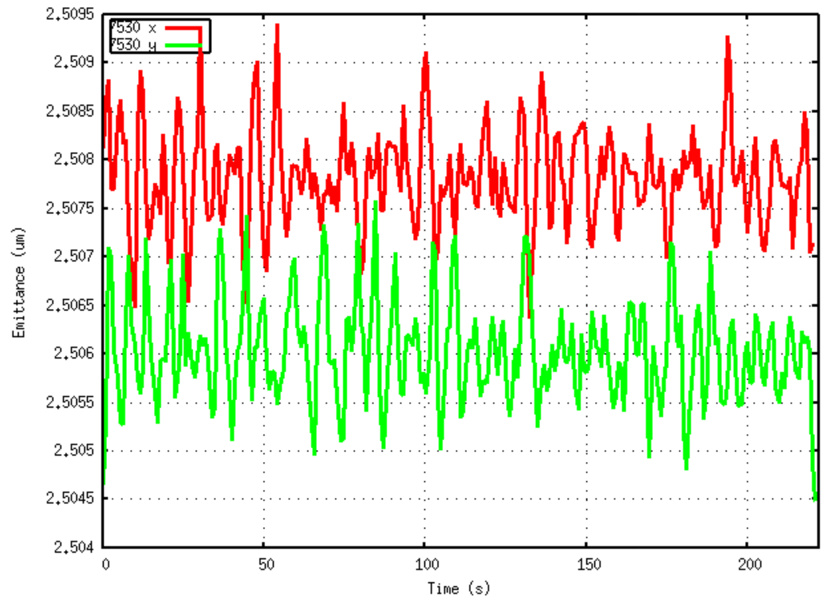
- Initial DA around 3σ, increased to above 5 σ with wire

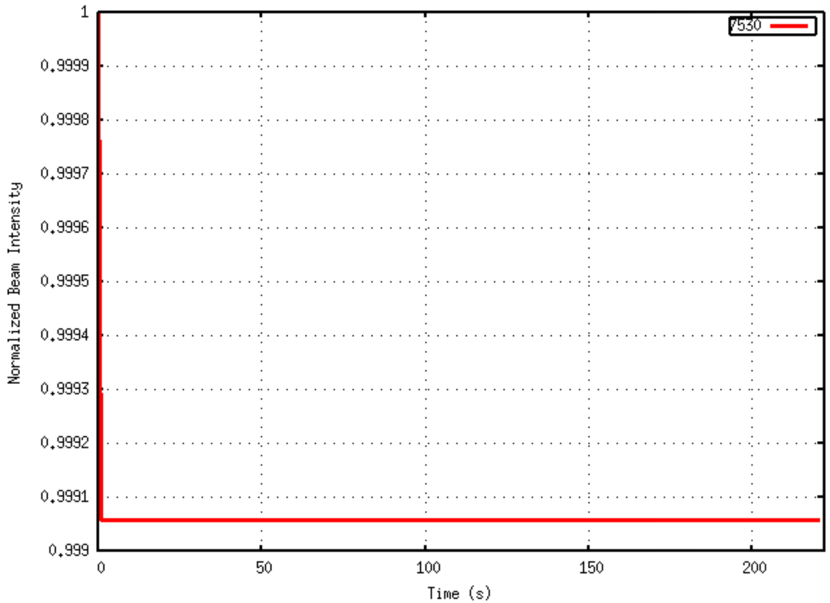
Simulating distributions

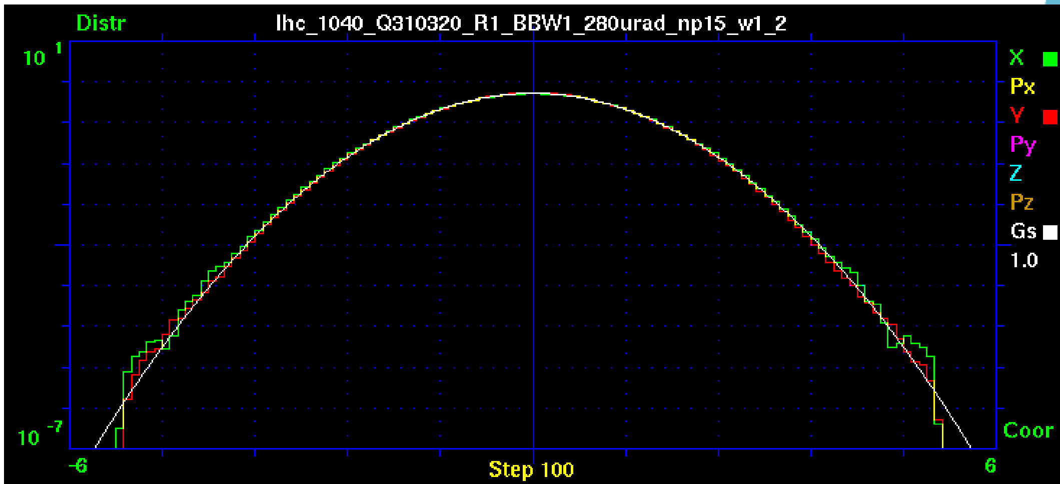
- Lifetime recovery, no blow-up and tails

S. Valishev









Extrapolation to HL-LHC

- **Pessimistic scenario** : Running the HL-LHC in conditions of **DA** of around **3 σ** through the beginning of leveling process (quite **aggressive**)
- Losses of ~**20%** for 1st hour for bunches with 16 long ranges (around 80%) corresponding to **9.6e13 p**
- For the rest of the bunches, linear drop of losses with number of long ranges down to 0 for 8 long ranges. In that case, losses correspond to extra **2.7e13p**
- The total losses are estimated to **12.3e13p/h** (**20%** of the beam besides burn-off)
- This corresponds to a lifetime of around ~**10h** (without burn-off)

Extrapolation to HL-LHC

- **Relaxed scenario** : Running the HL-LHC in 2016 conditions (**DA** of around **5 σ**) through the beginning of leveling process (quite **realistic**)
- Losses of ~**5%** for 1st hour for bunches with 16 long ranges (around 80%) corresponding to **2.4e13 p**
- For the rest of the bunches, the losses correspond to an extra **0.6e13p**
- The total losses are estimated to **3e13p/h** (**5%** of the beam besides burn-off)
- This corresponds to a lifetime of around **45h** (without burn-off)

Summary

- Experience from **2012** shows that **long range effects** had **significant impact** on 1st h losses and emittance blow-up
- Both **losses** and **blow-up** in 1 h were **brightness dependant**
- Long range experiments in 2015 and 2016 showed a **limit of 8.5 σ separation** for triggering significant losses correlated to long-ranges
- **Heavy tails** and **larger emittances** may be more sensitive to LR effects
- **DA simulations** show **margin** for **crossing angle reduction** in HL-LHC (if stability is ensured for keeping low chromaticity and octupoles and impact of errors is small)
- In order to have a significant **impact** in **lifetime** (<10h) and emittance blow-up, **DA** has to drop to **3σ**
- For DA larger then **5σ**, and in the absence of other implications, lifetime should be comfortable (~40h)

Thanks for your attention

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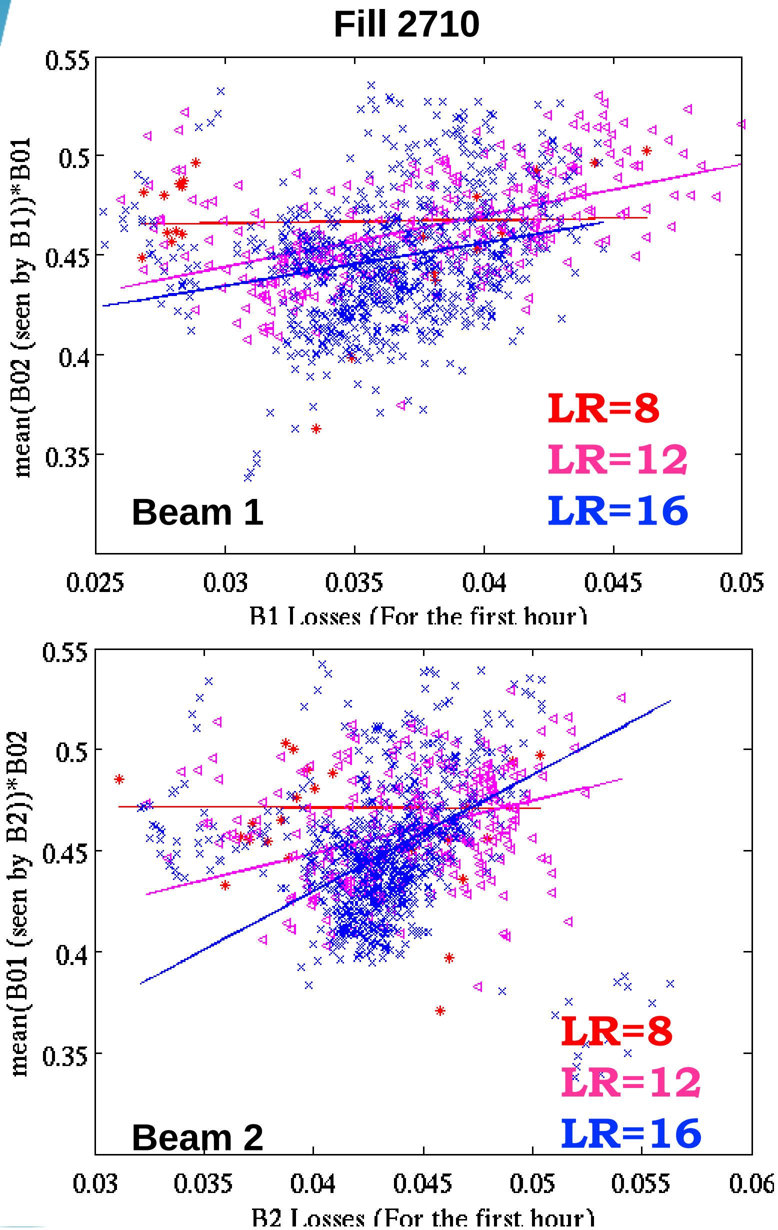
HL-LHC PROJECT

Additional slides

CERN

Correlation with BBLR

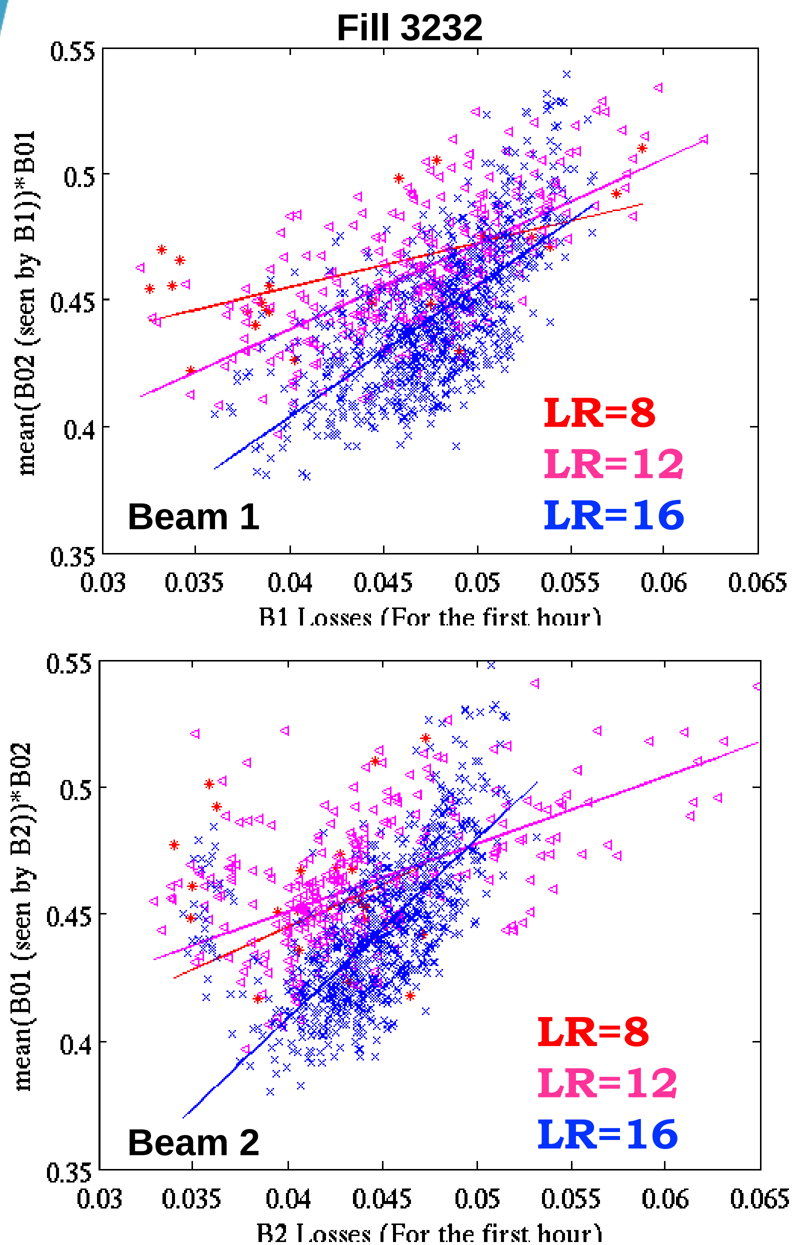


F. Antoniou

- Observable: **mean brightness** of **long-range** encounters of **strong beam times brightness** of **weak beam** vs **losses** of **weak beam** after 1h in SB
- The bunches with **8**, **12** and **16** long-range encounters are plotted
- Correlation is observed for **Fill 2710** (early in the run) with different **slope** for different number of long-range encounters
- The **slope** is **steeper** for larger long-range encounters
  - More for B2 than B1

Correlation with BBLR

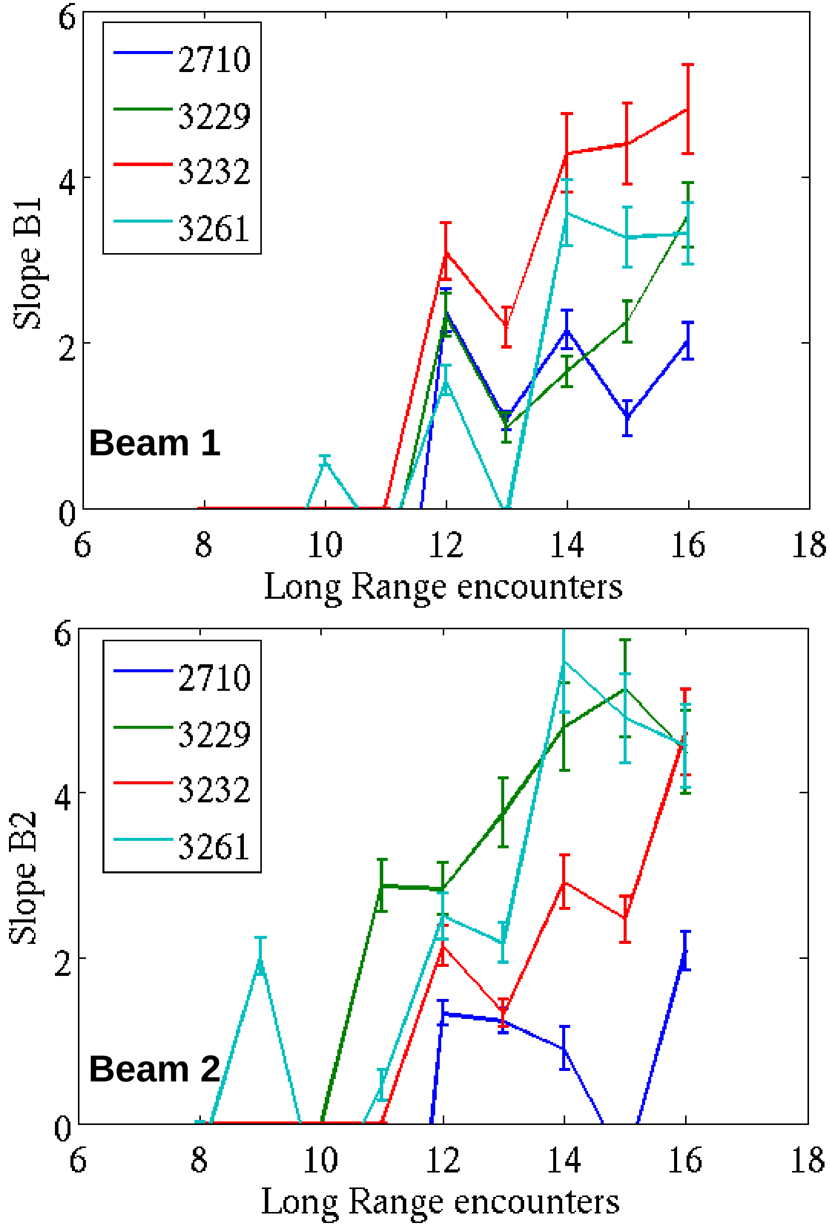
F. Antoniou



- Similar trend is observed for **fill 3232** (late in the run)
- Steeper slopes are observed, indicating stronger effect of BBLR for the later part of the run

Correlation with BBLR

F. Antoniou



- Dependence of slope on number of LR encounters for 4 different fills
- Clear trend of **slope increase with** the **number of long range encounters** observed.
- For **fill 2710** (lower brightness), weaker correlation observed
- **Intuitive interpretation**: towards and during collisions, brightness dependent mechanism (head-on + noise?) blows-up beam core, creating tails, leading to losses due to BBLR
- Work in progress to obtain scaling taking into account variations of bunch-by-bunch conditions (orbit, tunes, collisions in other IPs, etc.)