Emittance Preservation and Transmission through the LHC Cycle

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LHC Parameters 2011

- LHC Physics Parameters 2011

Parameter	
Bunch spacing [ns]	50
Energy [TeV]	3.5
β* (IP1/IP2/IP5/IP8)	1.5/10/1.5/3 → 1/10/1/3
Bunch intensity	1.5×10^{11}
Norm. emittance @ collision [μm]	~ 2.5
Total number bunches per ring	1380
Maximum injected batch [# bunches]	144
Minimum injected batch [# bunches]	12
Crossing angle (IP1,IP5) [μrad]	120
Long. emittance @ injection [eVs]	0.38-0.53

- Collimators

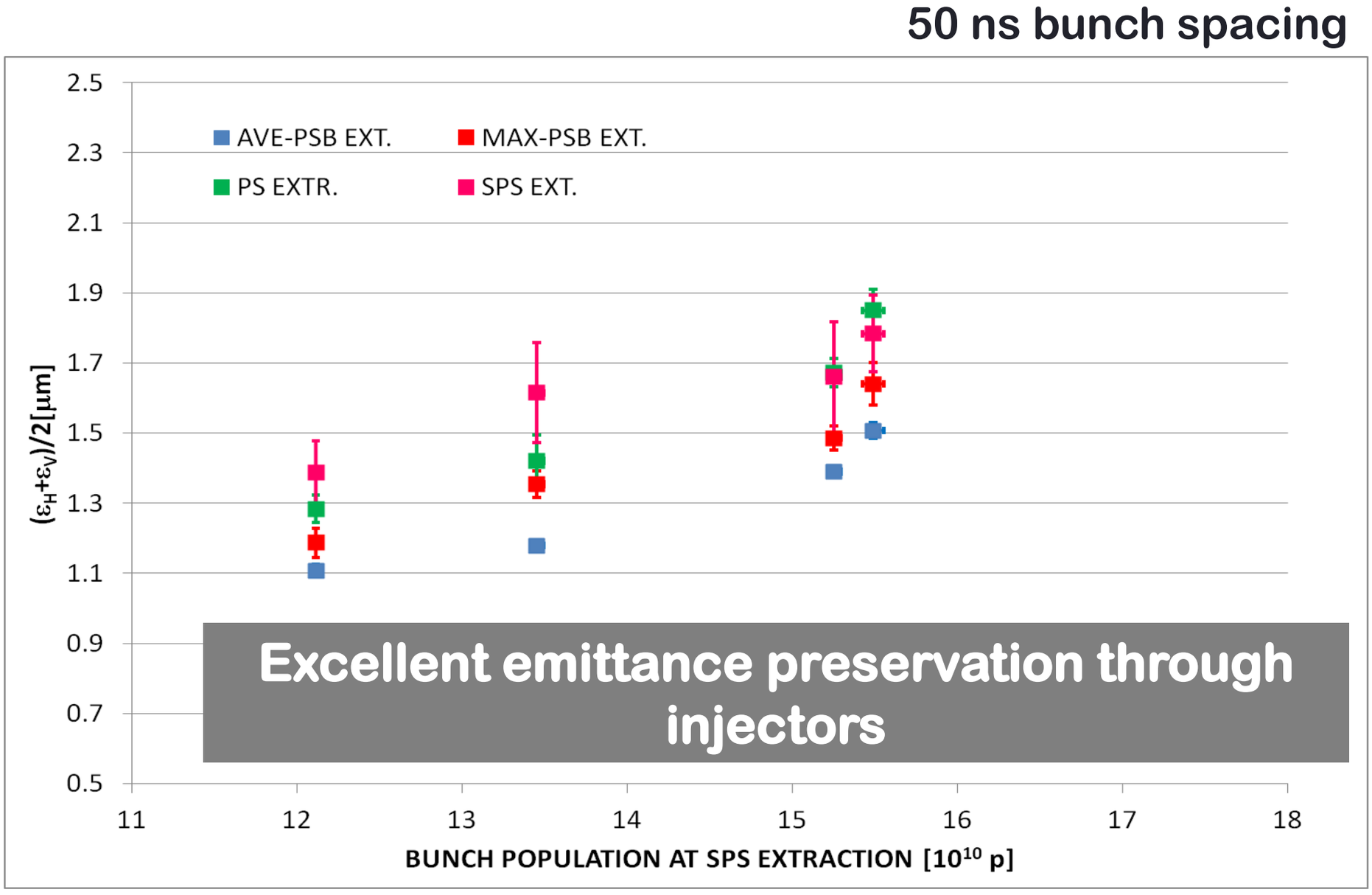
	2011	Tight (2012)
TCP IR7 [σ]	5.7	4
TCSG IR7 [σ]	8.5	6
TCLA IR7 [σ]	17.7	8
TCT IR1/5 [σ]	11.8	9.3
TCSG IR6 [σ]	9.3	6.8
TCDQ IR6 [σ]	9.8	7.3

2011 parameters not extreme:

bunch spacing
β*
collimators

From the Injectors

- Remarkable 2011 performance:
  - 50 ns: 1.5 x 10^{11} p^+/bunch, 1.9 μm norm. emittance at the exit of the SPS
  - 25 ns: 0.98 x 10^{11} , 2.5 μm

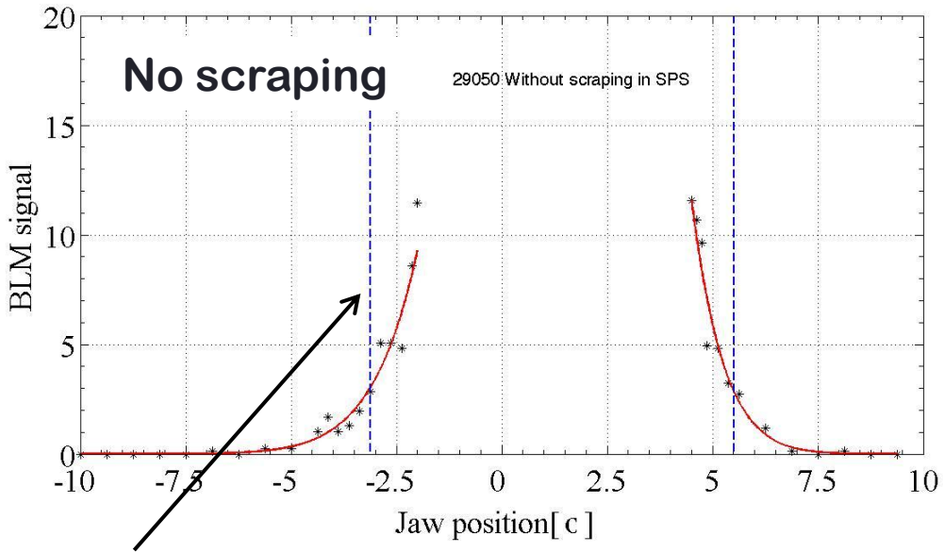


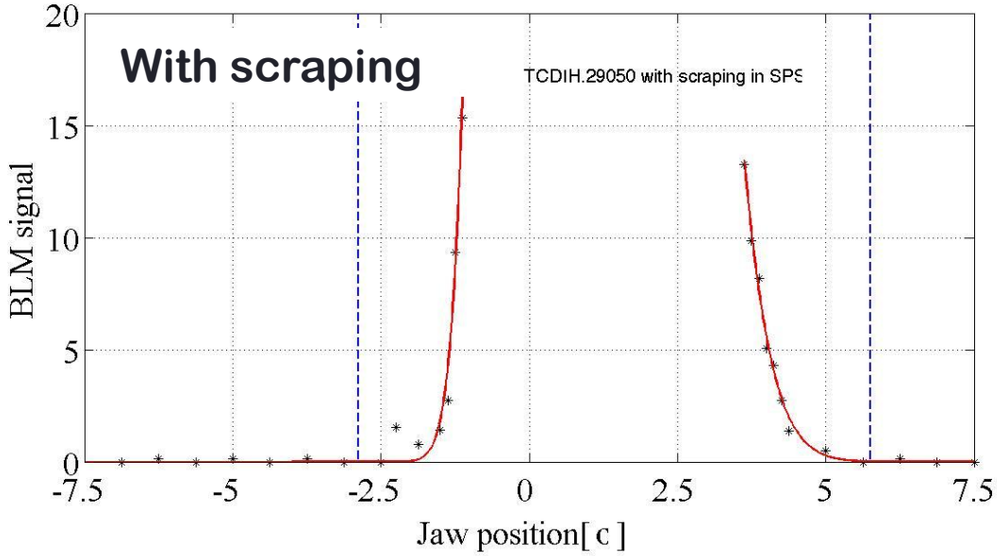
SPS scraping

- Not all the intensity that is produced by the injectors can be used by the LHC

- The long tails of the bunch distributions have to be scraped off to avoid high losses at the moment of injection into the LHC

Horizontal Transfer Line Collimator scan





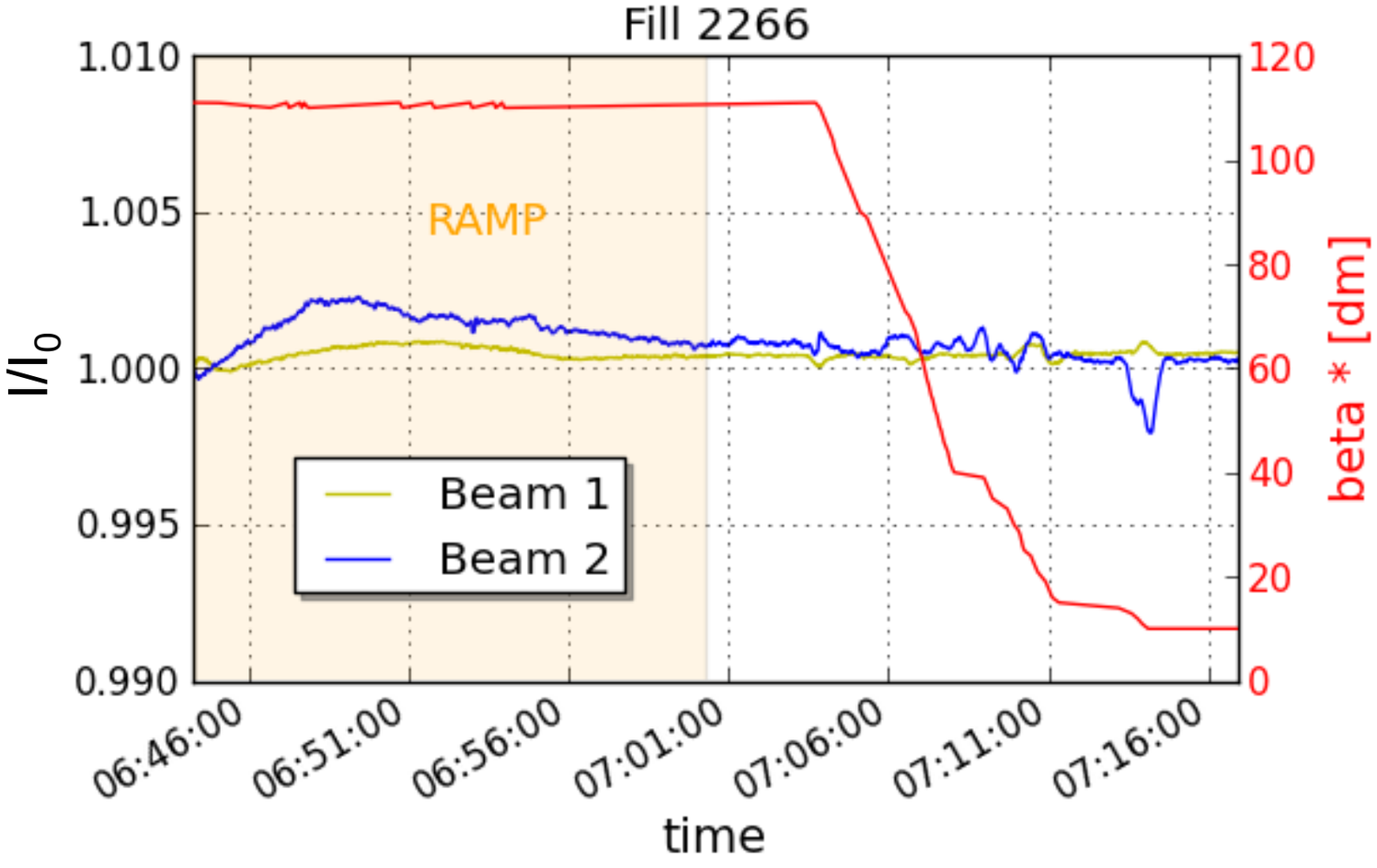
Nominal setting of transfer line collimator

- Injected nominal emittances (3.5 μm) with scraping: no problem

- Scrape **< 5 % of beam before extraction in the SPS**

2011 LHC Transmission

- **Excellent transmission: < 0.1 % loss**
- Collimators close to beam at all times
- Run through ramp and squeeze with
  - Orbit feedback
  - Tune feedback
  - Transverse feedback
- LHC very reproducible – correct optics once !!



Note: FBCT measurement dependence on beam position and bunch length

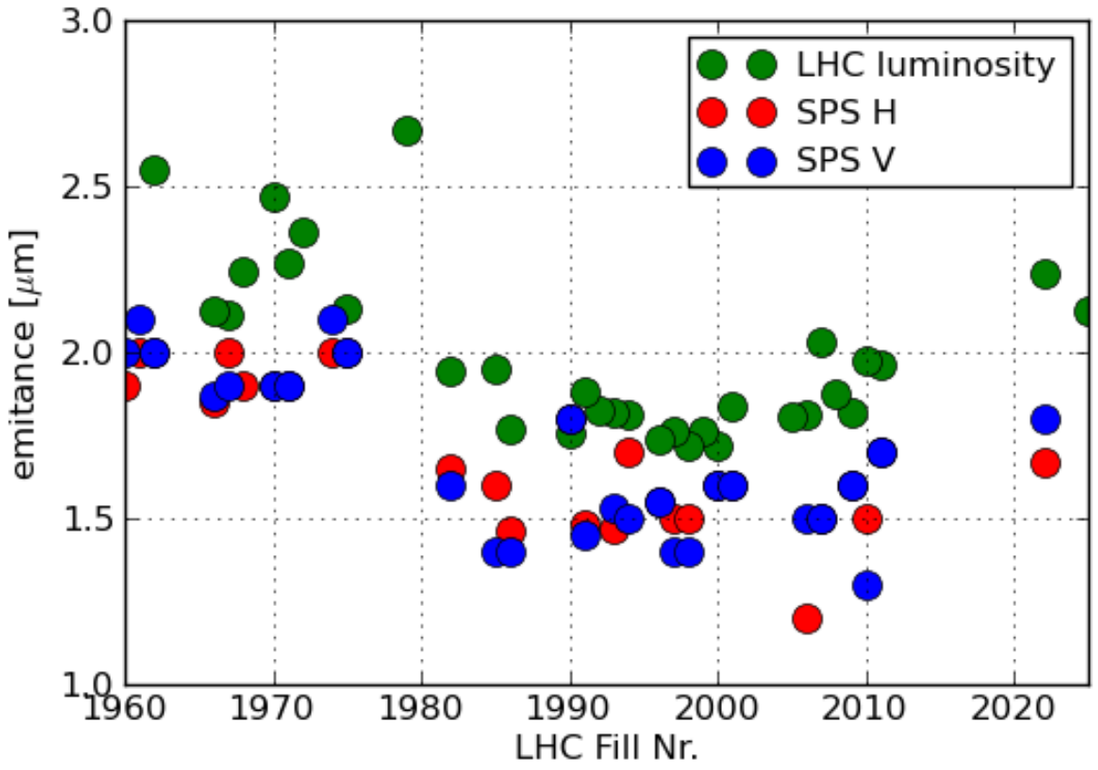
Emittance Preservation

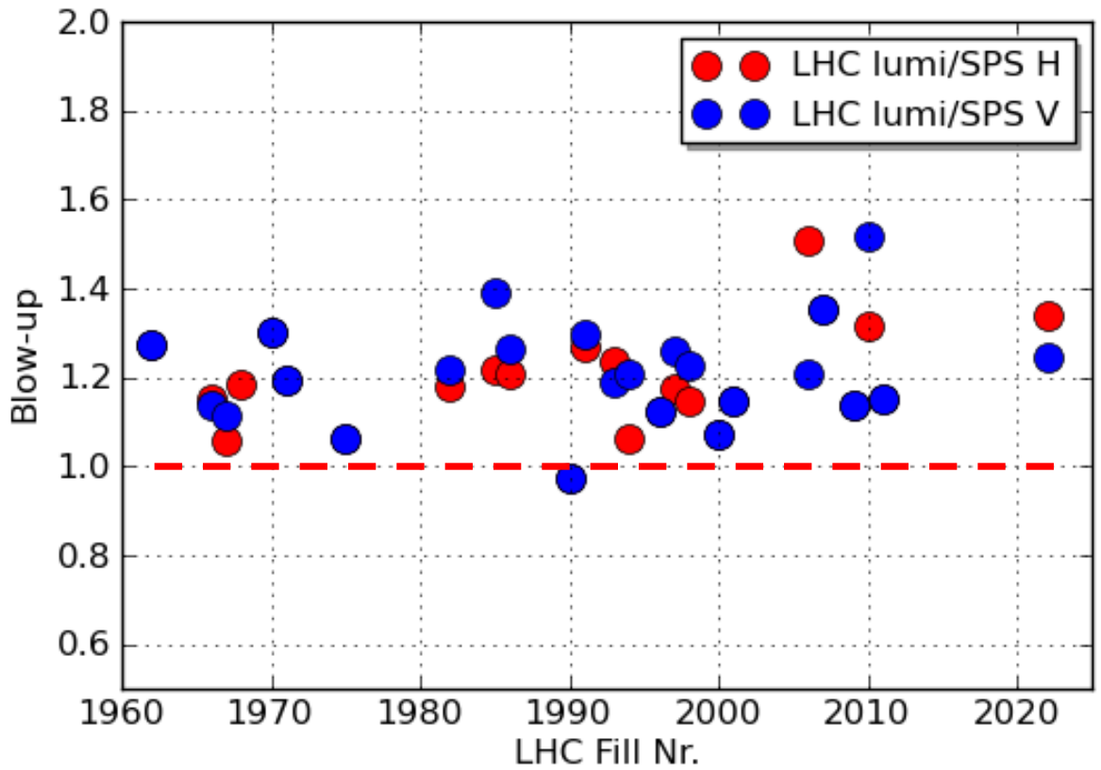
- Only started middle of 2011 to seriously investigate emittance preservation
- Main limitation: instrumentation – no system fully adapted to measure physics beams through cycle
- Several different profile measurement systems in the LHC
  - Wire scanners, low intensity only
  - Synchrotron Light Monitors (BSRT): continuous, bunch-by-bunch, not during energy ramp, calibration difficult
  - Beam-Gas Ionization Profile Monitor (BGI): continuous, not commissioned in 2011
  - (Luminosity)
- Lessons learnt:
  - Importance of fast and well-calibrated continuous emittance measurement – emittance evolution needs to be available online: BSRT and BGI
  - Importance of using measured optics
- Checked emittance preservation through different phases of cycle – presented results at Evian, Chamonix

Significant Blow-up through Cycle

Analysed ~ 60 fills between mid July to mid August (50 ns, 1.2 ×10^{11}, β*=1.5 m)

Comparison of **convoluted emittance from LHC luminosity** with **SPS wire scan** for 144 bunches:





On average ~ 20 - 30 % growth between SPS flattop and collisions

Summary of Blow-up Investigations

1. No measureable blow-up from injection process
   - **Sensitivity: ± 10 %**

2. Blow-up during injection plateau → bunch-by-bunch differences, smallest effect on total emittance blow-up
   - **0 – 10 %, different for different batches**

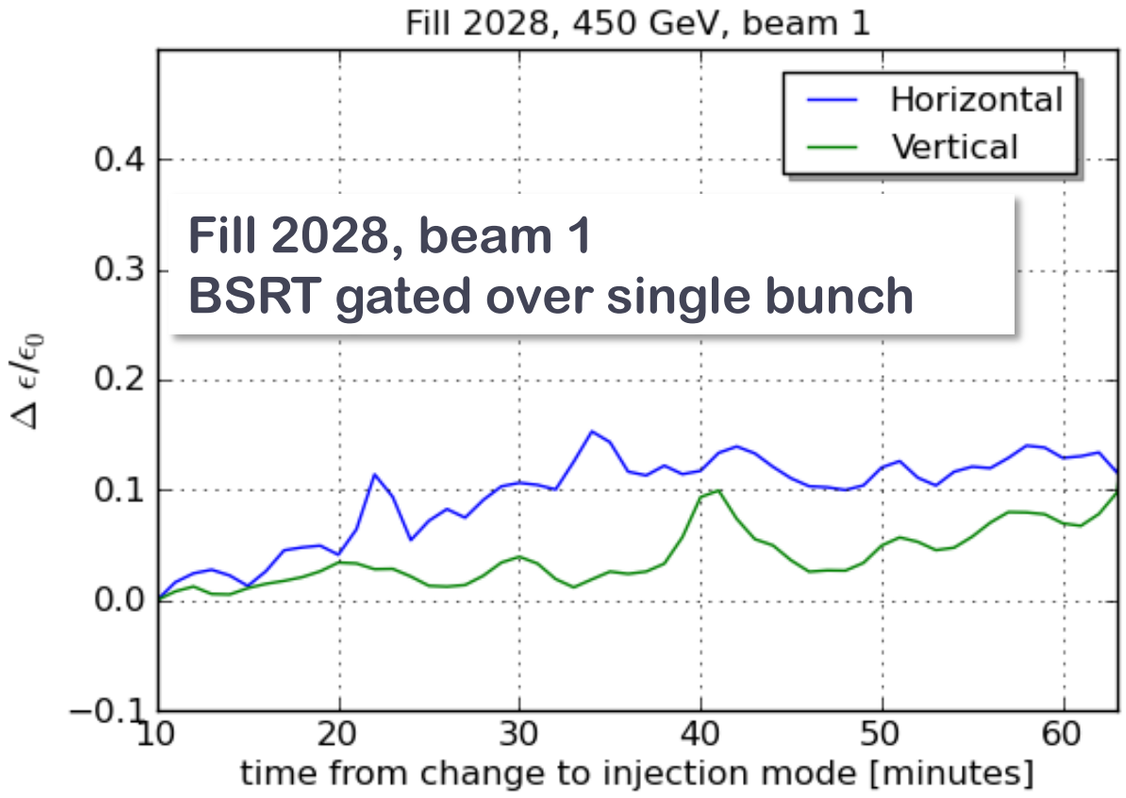
3. Significant blow-up during the ramp
   - **> 20 % for 1.6 μm**

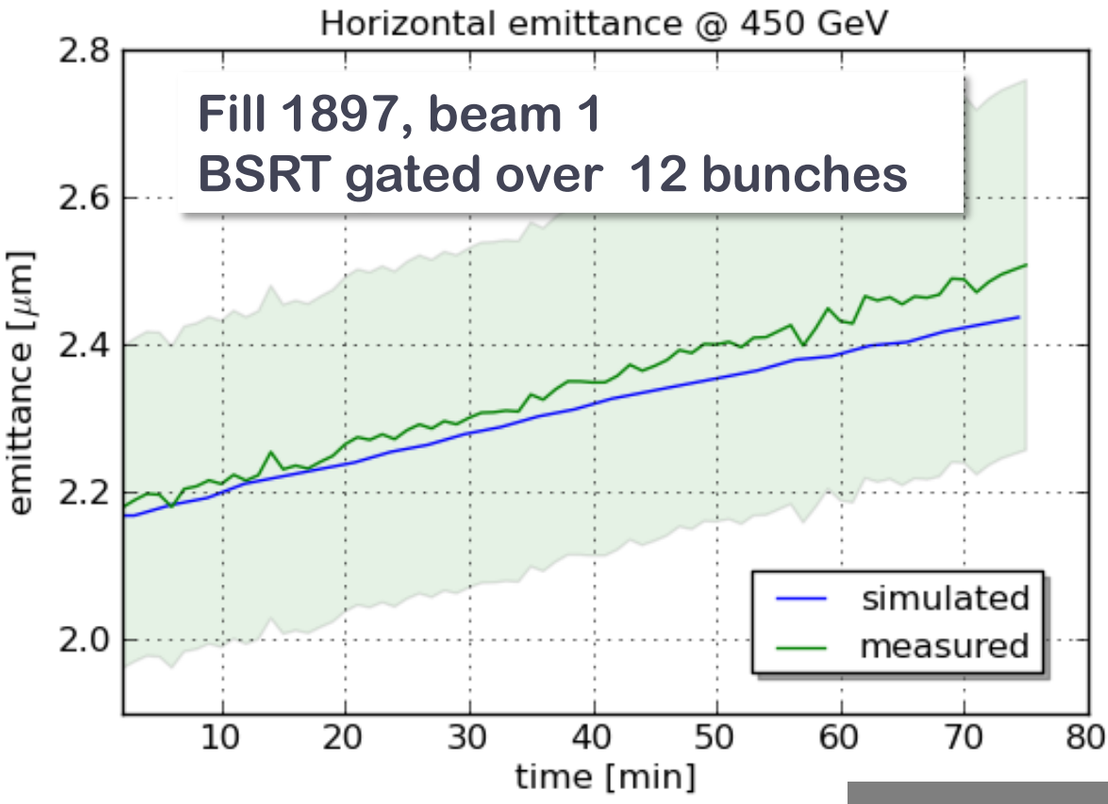
4. Blow-up during the squeeze for beam 1, horizontal plane
   - **> 20 %**

5. Absolute emittance growth independent of bunch intensity through cycle
   - $\Delta\varepsilon/\varepsilon$ **~ 0.5 – 0.6 μm for convoluted, averaged emittance from luminosity**

Growth @ 450 GeV

- Emittances are growing at injection – reasonably consistent with IBS although slighty faster





Simulations of IBS, uncoupled T. Mertens

Horizontal emittance: ~ 10 % in 20 minutes

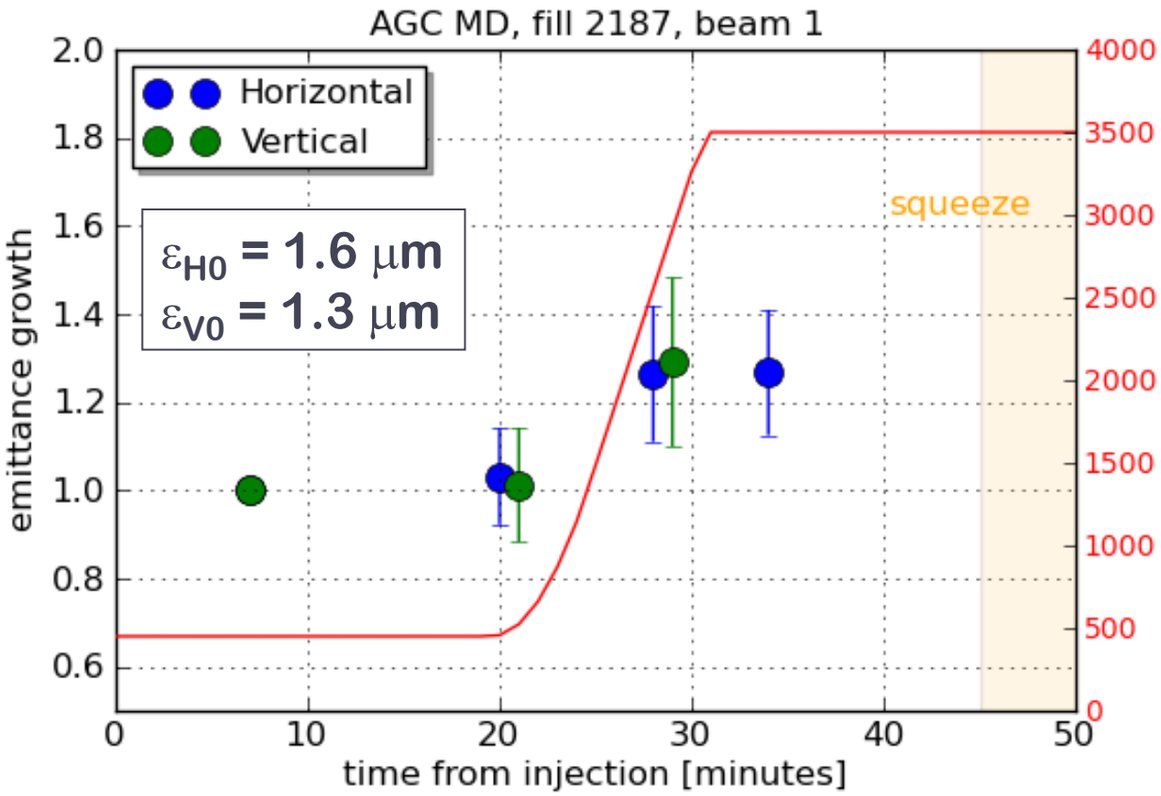
Filling about 30 minutes → $\Delta\varepsilon/\varepsilon$ 0 – 10% in H

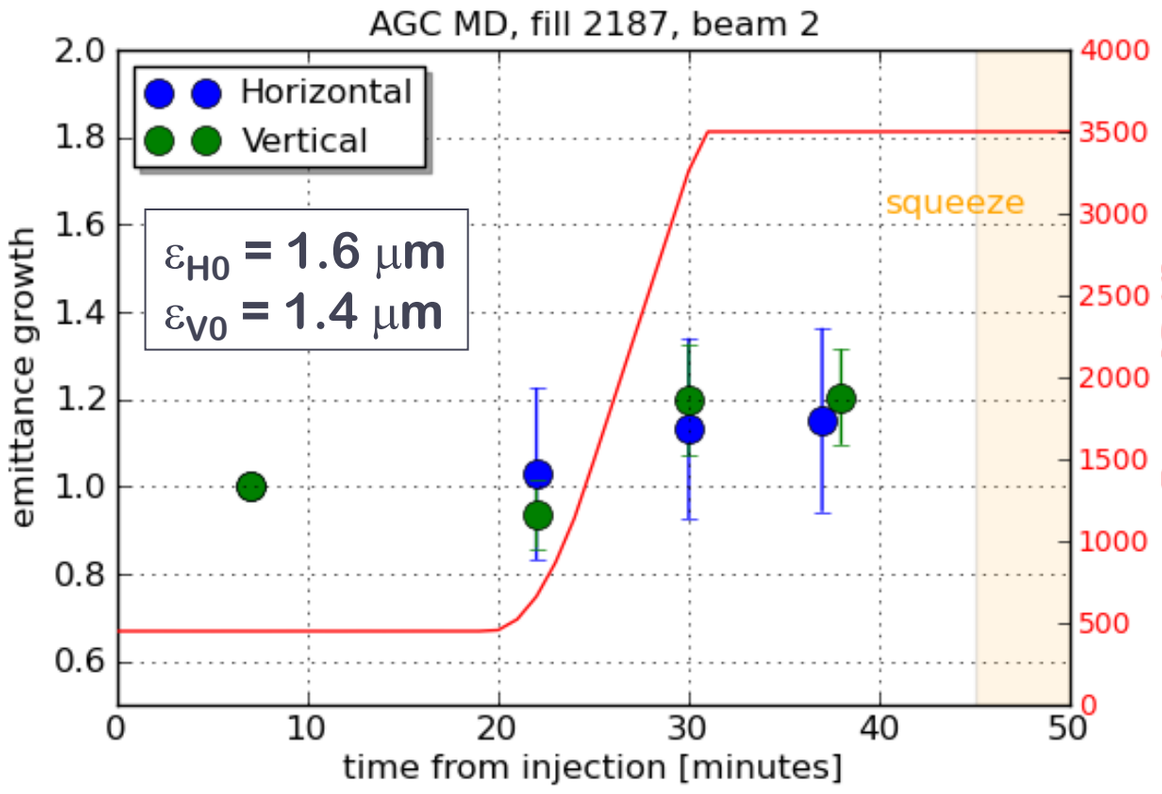
More studies and IBS simulations to come in 2012

Batch-by-batch longitudinal blow-up to possibly reduce effect

The Ramp

Wire scans through the ramp, low intensity (3 12 bunch batches, 50 ns)





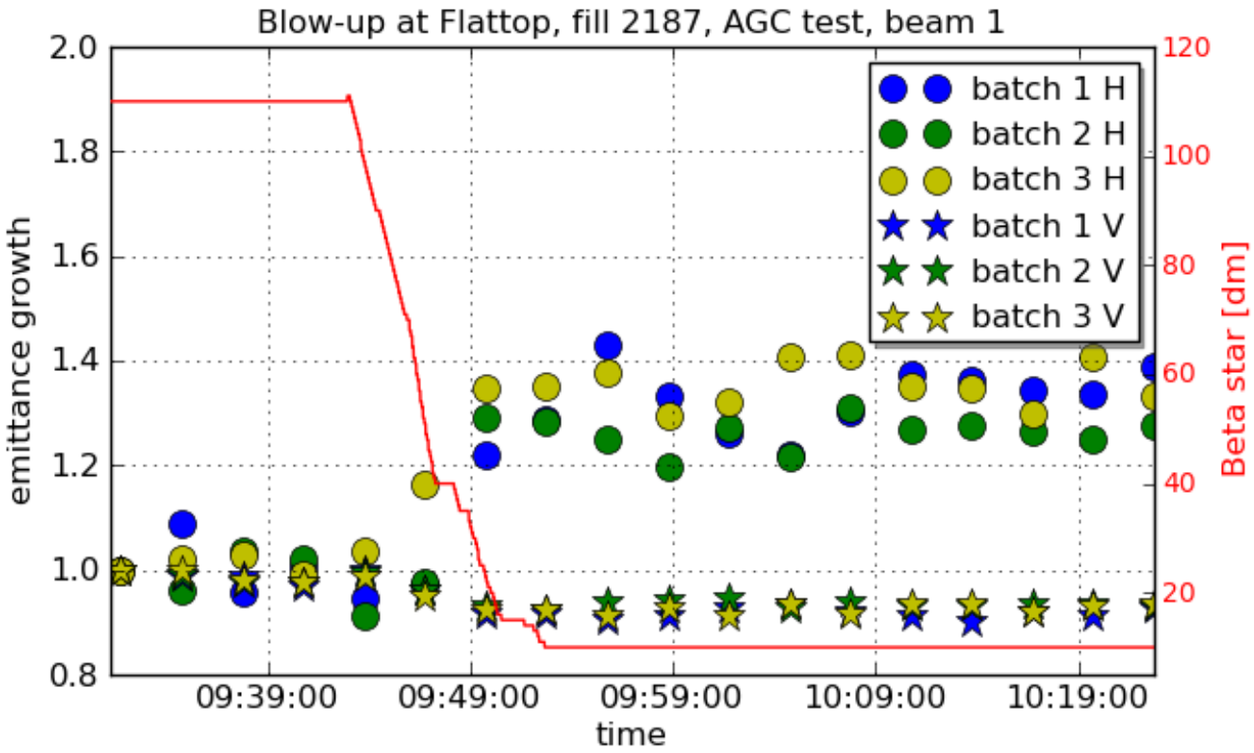
Used measured β at injection and flattop and linear interpolation between

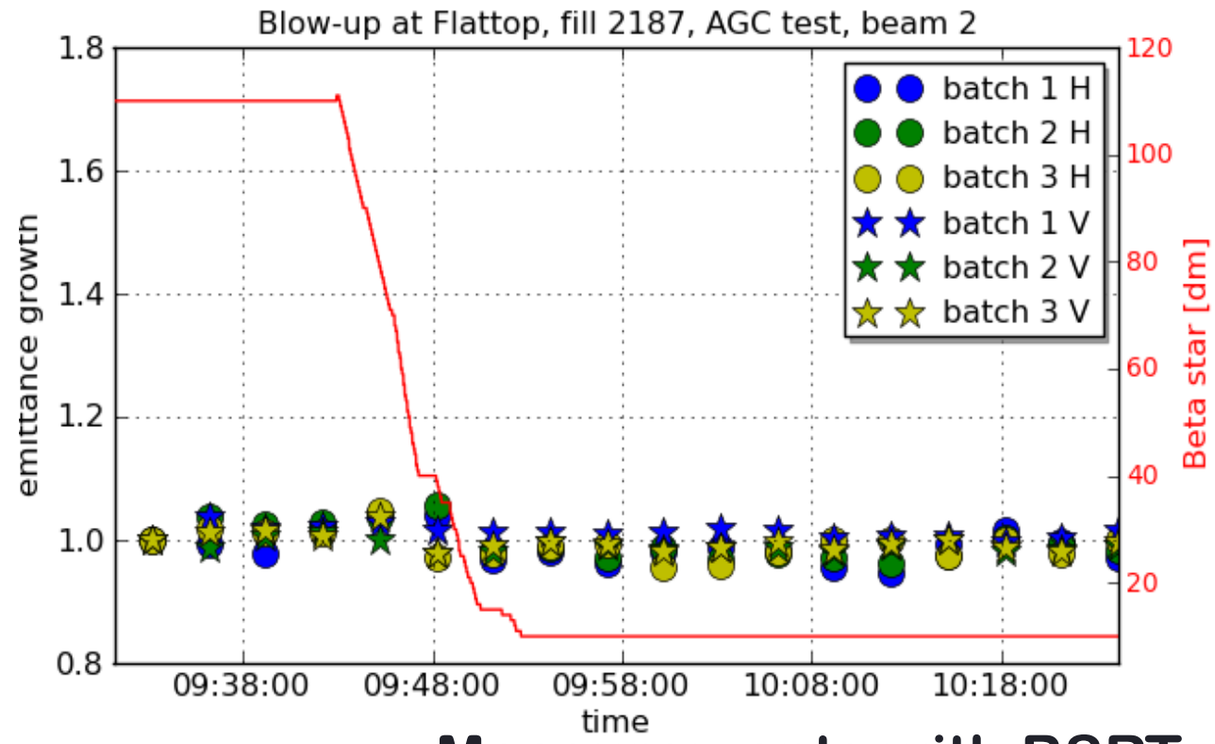
Blow-up during the ramp: measurement indicates > 20 % all planes

Effect was reproduced in other test fills

Emittance blow-up at 3.5 TeV

- Evolution of the emittance through the squeeze for same fill as before

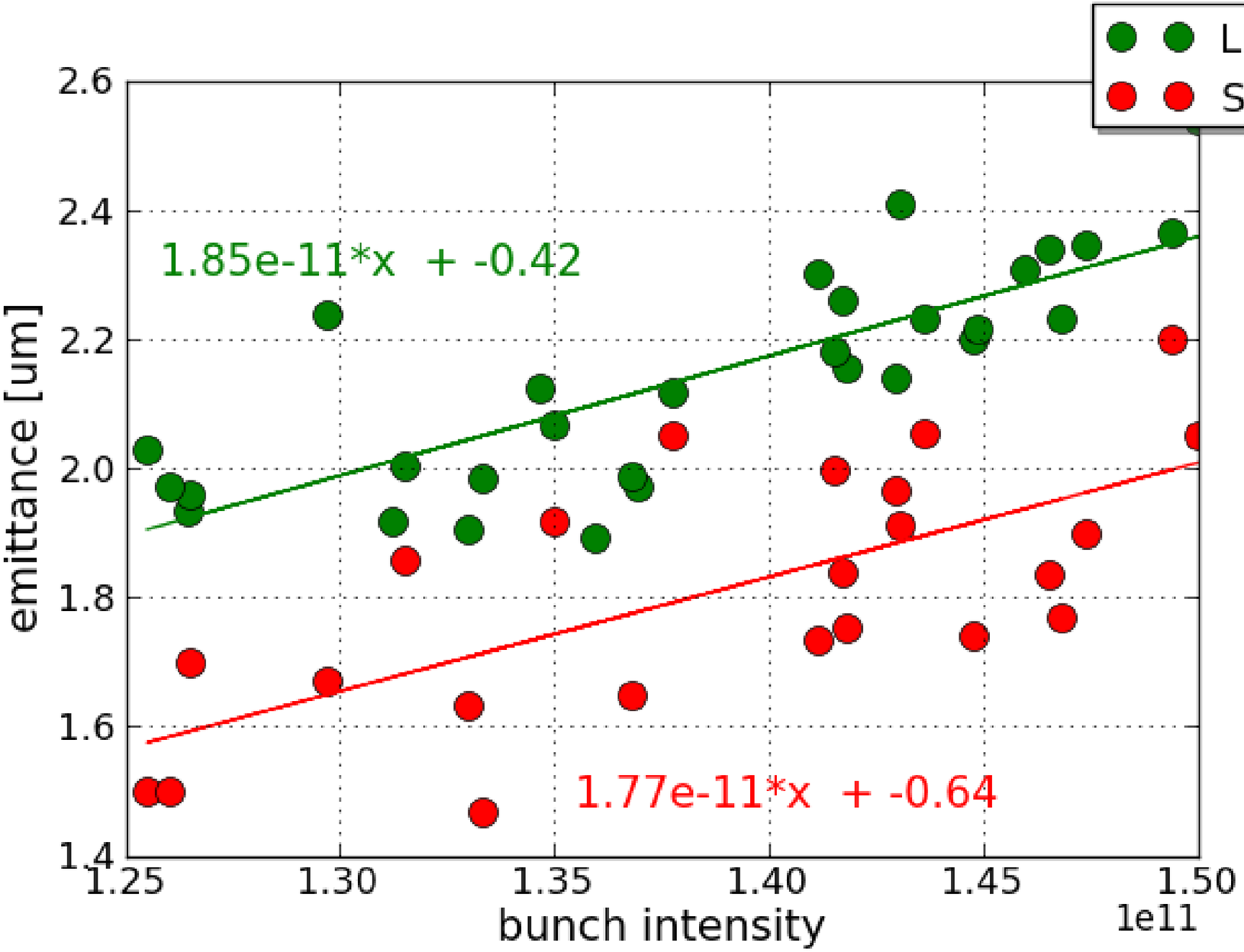




Measurements with BSRT

- **Blow-up during squeeze for beam 1 H**
  - Took measured beta at 3.5 m and 1 m from optics team into account
  - Looked at BSRT from several physics fills, always blow-up of beam 1H
  - Blow-up of beam 1 H between 5 and 1.5 m β^*

Dependence on bunch intensity

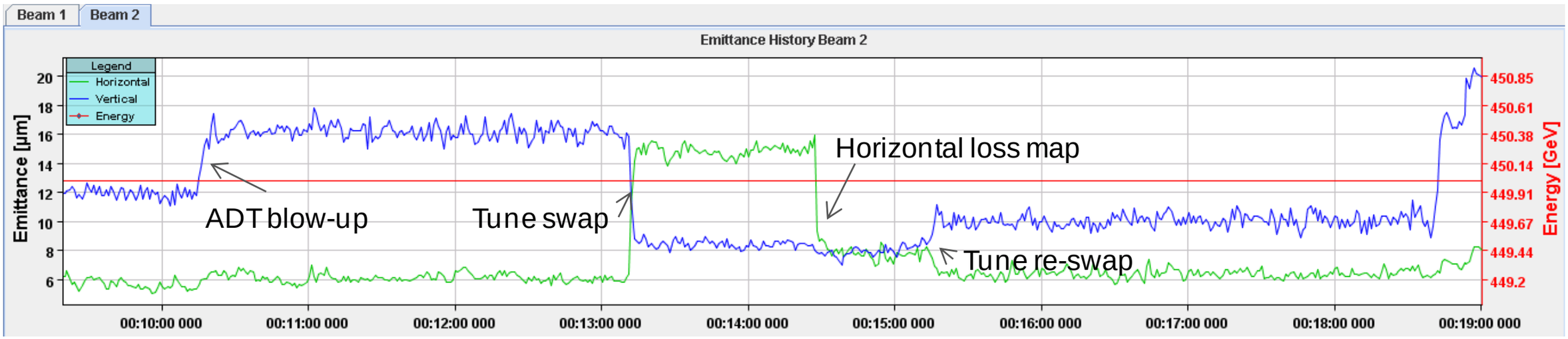


Constant blow-up of $\Delta\varepsilon/\varepsilon \sim 0.5\ \mu m$

Approximately constant absolute growth between SPS extraction and LHC collisions for different bunch intensities

Plans for 2012

- Many, many improvements for instrumentation and MDs planned

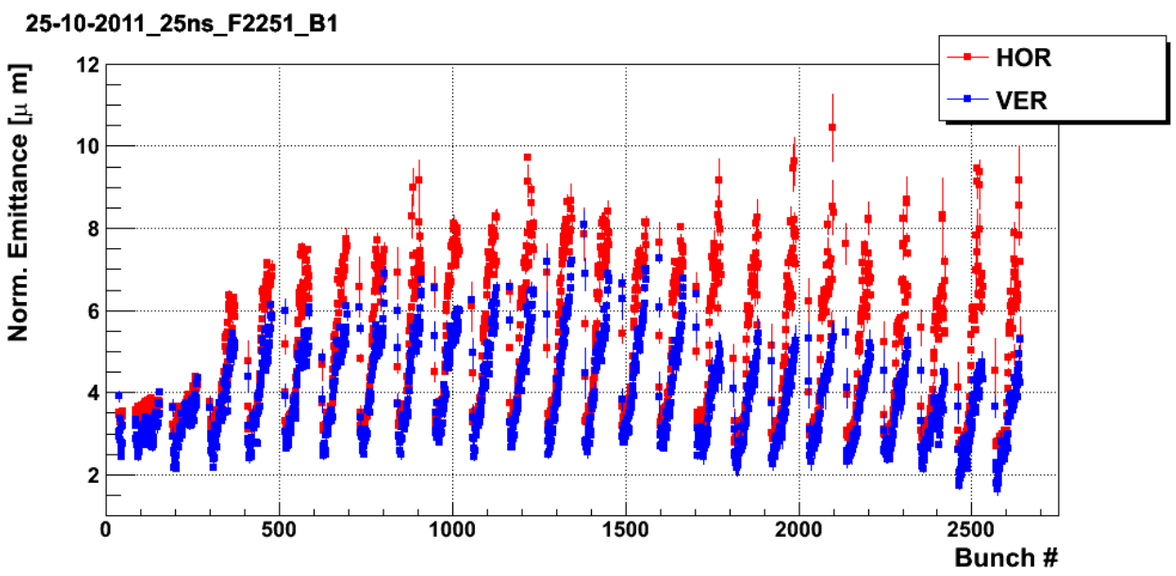


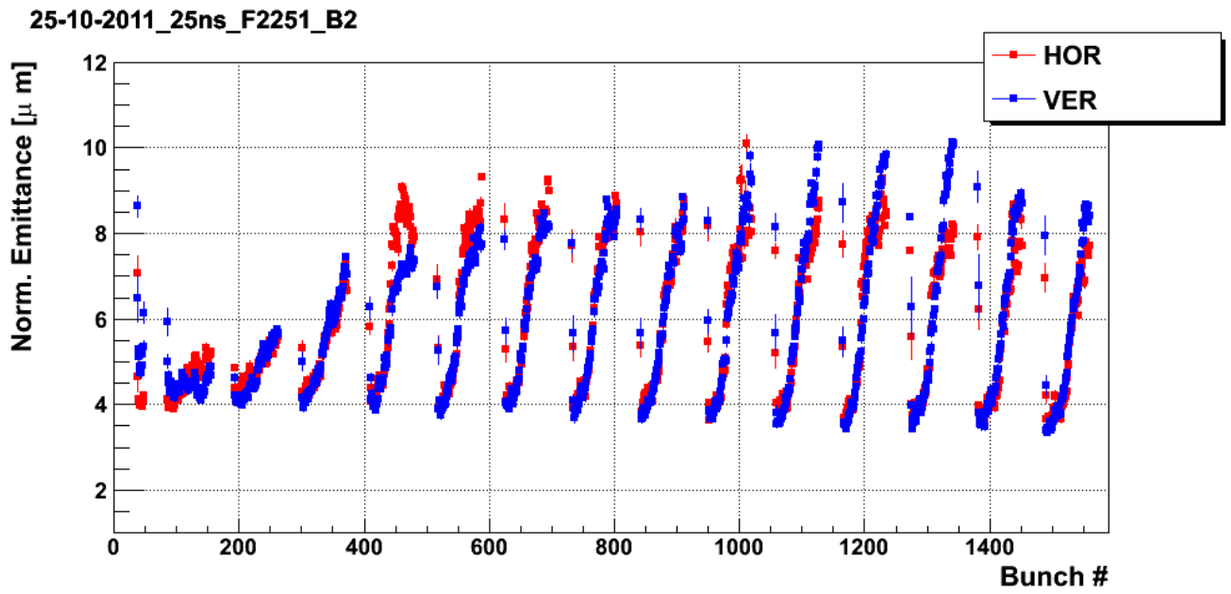
2012 BSRT: online emittance evolution measurement

- Injection plateau:
  - Batch-by-batch long. blow-up to be tested.
  - Shorten filling cycle
- Ramp:
  - Source of blow-up not clear. Will test dependence on damper gain. Will be hardest to continuously observe. BGI needed.
- Squeeze:
  - Only affected one beam and plane in 2011. Will check during commissioning with nominal intensity. Should be able to correct this in 2012
- Goals: find sources of blow-up and/or dependence on ε and I_b

25 ns

- Status after last scrubbing test, 24th of October 2011
  - Batches of 72 bunches, spaced by 1 us, circulating
  - E-cloud instability: emittances still far from being useful for physics





- Fill 2186 – 25 ns physics fill 12 + 24 + 24 bunches
  - Injected emittances: 2.6 μm convoluted
  - Into collision: 3.2 μm – 0.6 μm blow-up through cycle consistent with 50 ns observation
- Transmission excellent – lifetimes never below 25 h.

Future LHC Operation

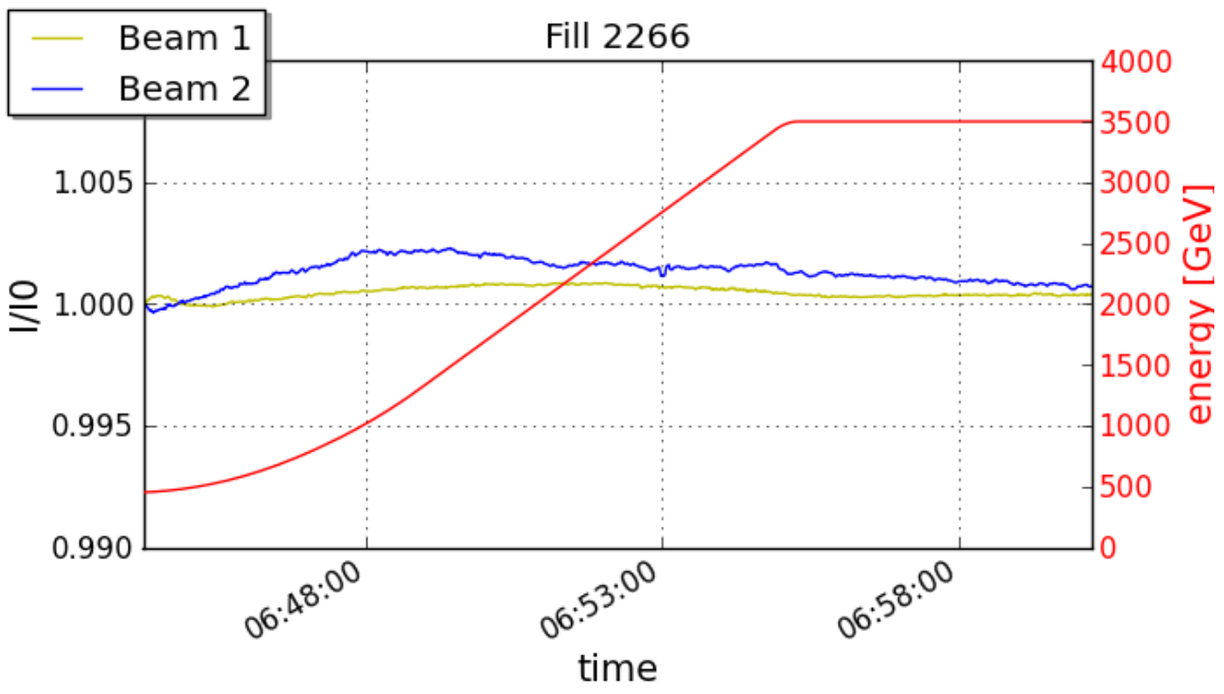
- Difficult to say how representative 2011 operation is for nominal or HL LHC operation

- Need 2012 for further experience
  - Smaller β^*
  - Tight collimator settings and impedance
  - 25 ns and long-range beam-beam interaction

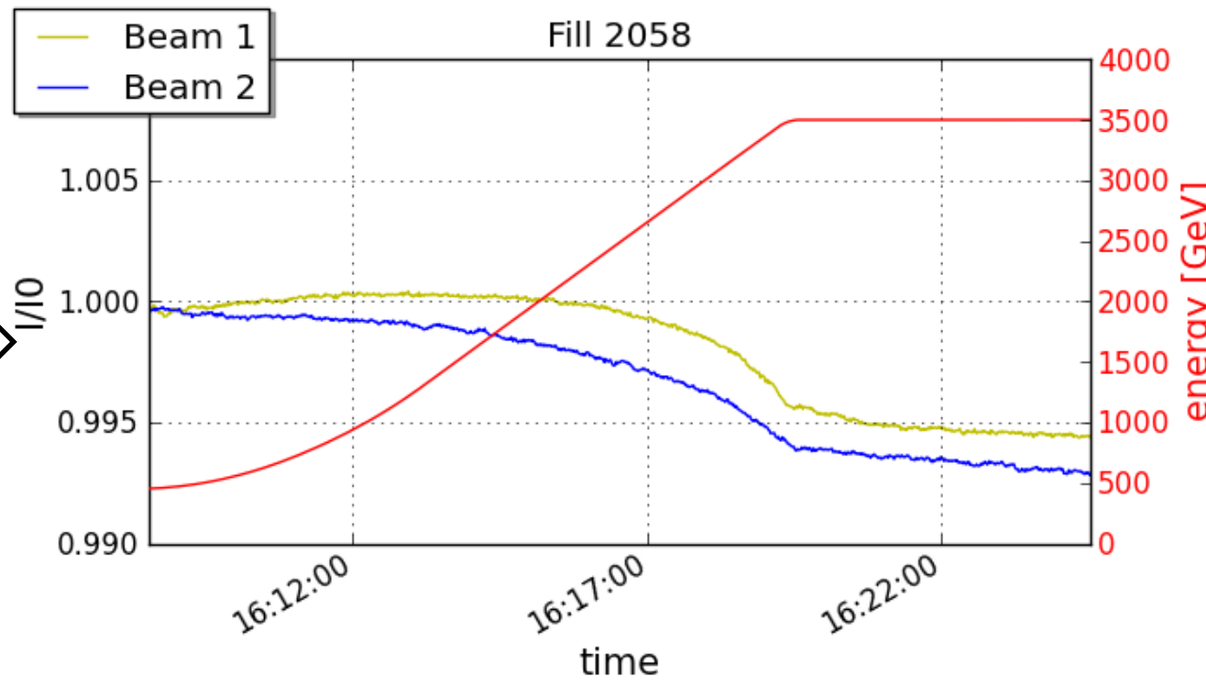
Tight collimator settings

- Transmission through the ramp degrades with tight collimator settings

Ramp loss < 0.1 %
Standard collimator settings 2011



Ramp loss >0.5 %,
Tight collimator settings 2011



- Lost several % during squeeze due to orbit movements – scraping tails
  - **Seems understood: leakage of crossing and separation bumps in the IRs.**

Conclusion

- Transmission through the LHC cycle 2011 was excellent.
  - Loss < 0.1 %
- Significant emittance blow-up through the LHC cycle
  - $\Delta\varepsilon/\varepsilon \sim 0.5 - 0.6$ μm convoluted
  - Goal of 10 % blow-up through cycle is challenging
- Need 2012 experience to get full(er) picture for transmission and emittance preservation
  - Smaller β^*
  - Tight collimators
  - More powerful emittance diagnostics
  - MDs : emittance preservation, impedance, chromatic effects with smaller β^*, long-range,…

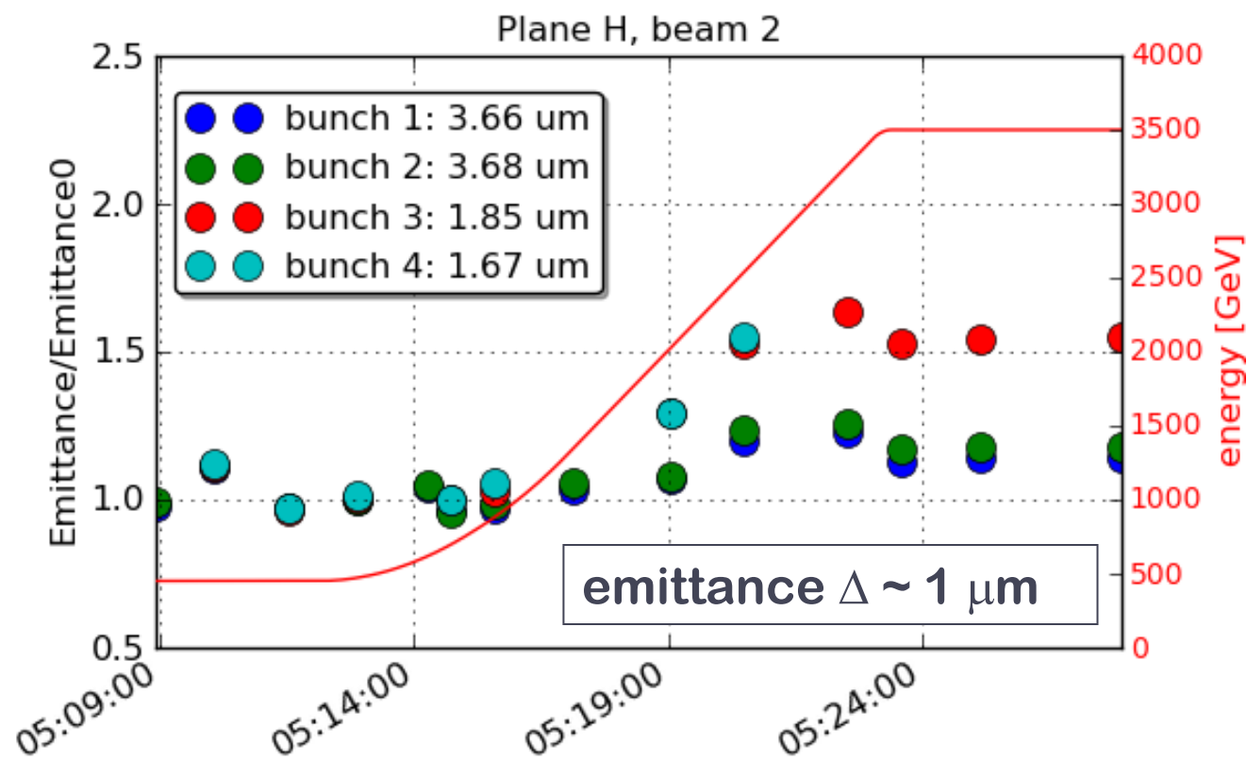
EXTRA SLIDES

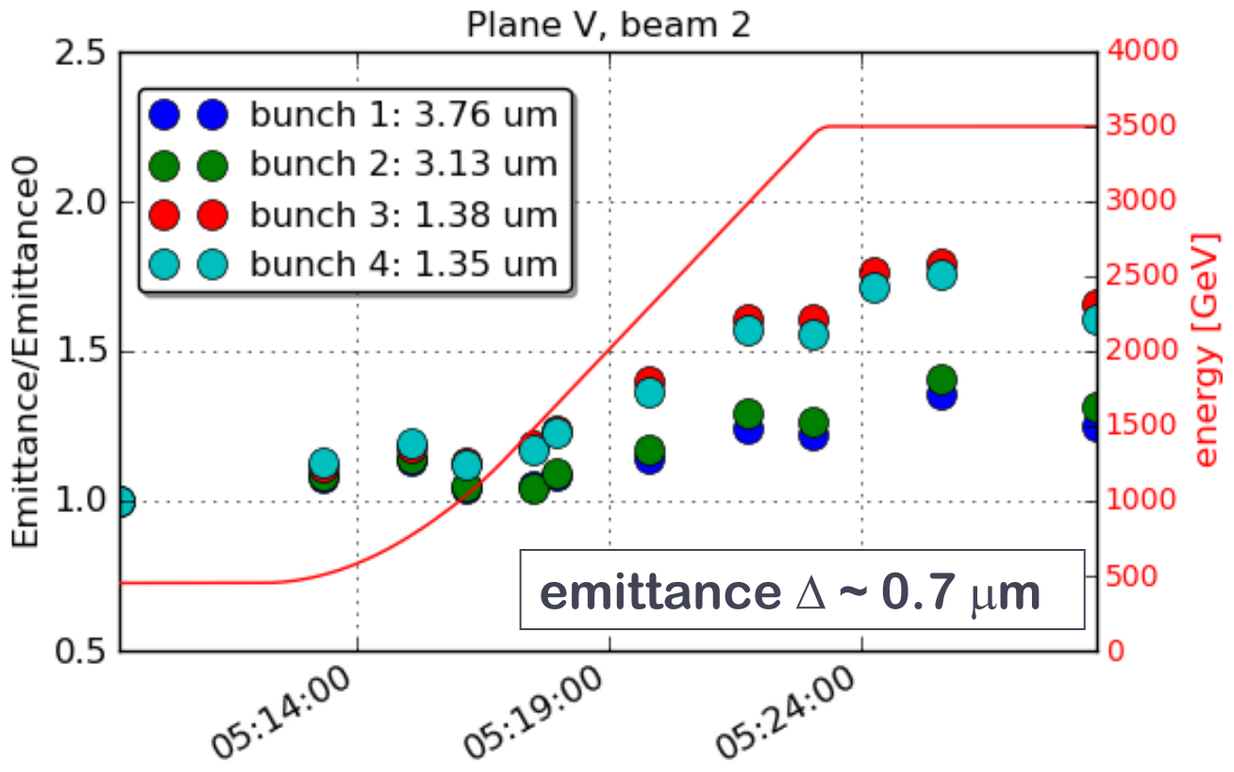
The Ramp - continued

Last BI MD in 2011:

Ramp of 4 bunches per ring – different emittances

Unfortunately no useful wire scan data for beam 1



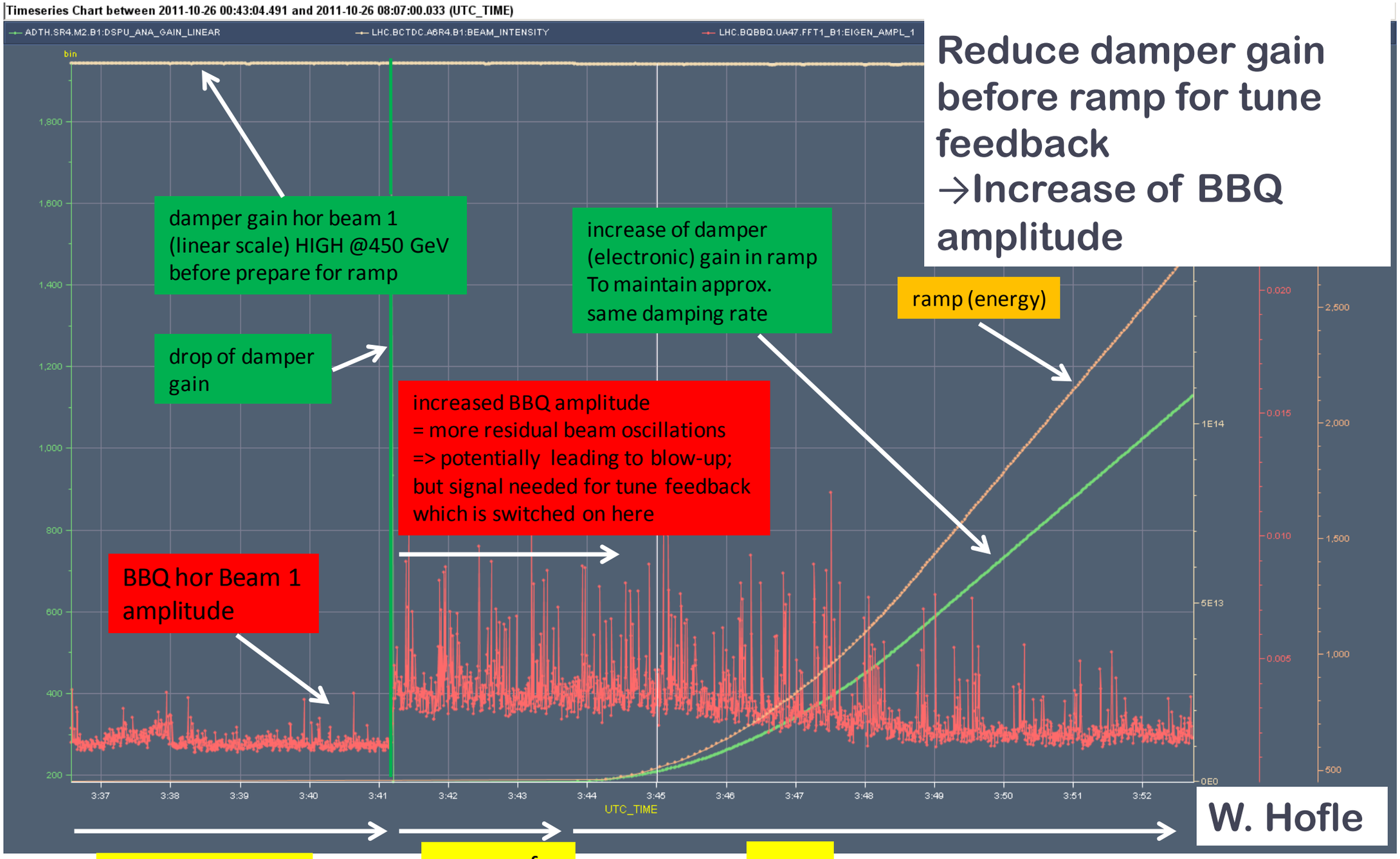


Relative growth different,
but…different emittances grow by the same amount

Although larger than for 12 bunch trains

Possible sources for growth @ ramp

- Ramp still needs to be further optimized
  - Chromaticity,…
- Effect of reduced damper gain during ramp?



Batch-by-batch emittance differences