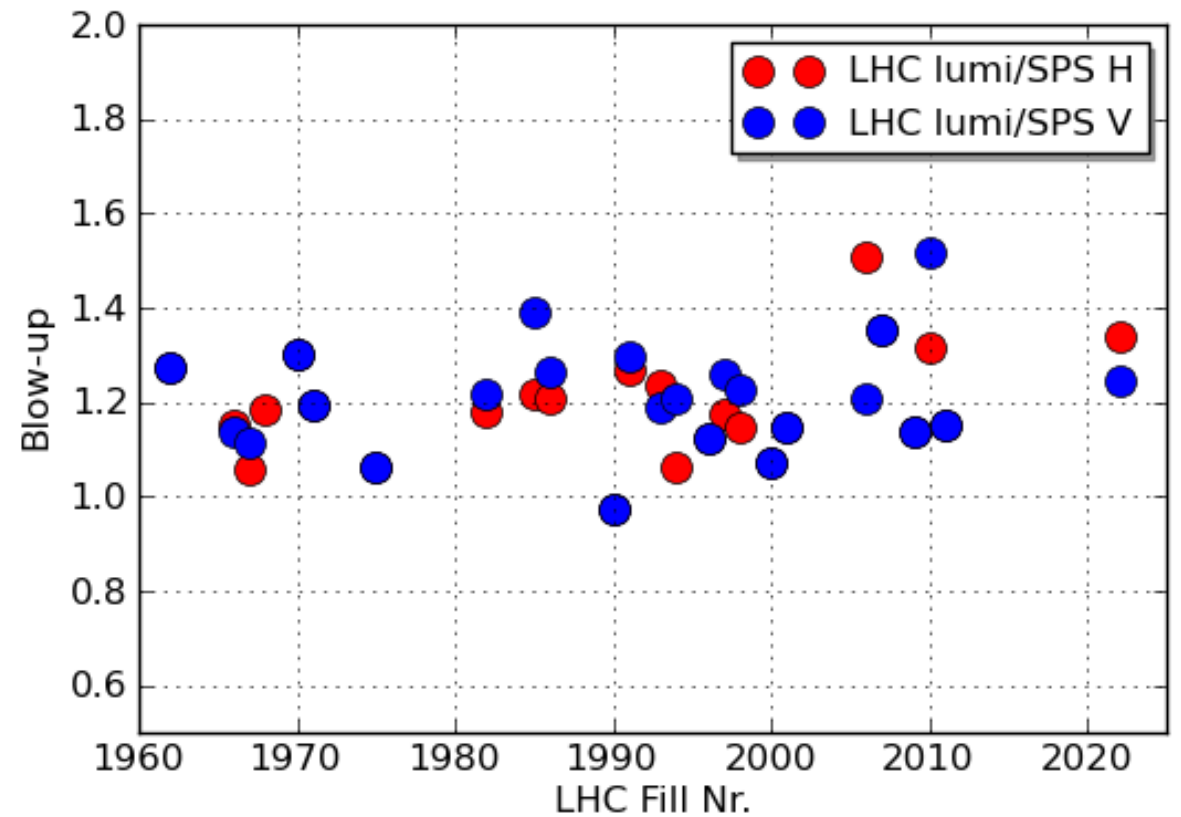
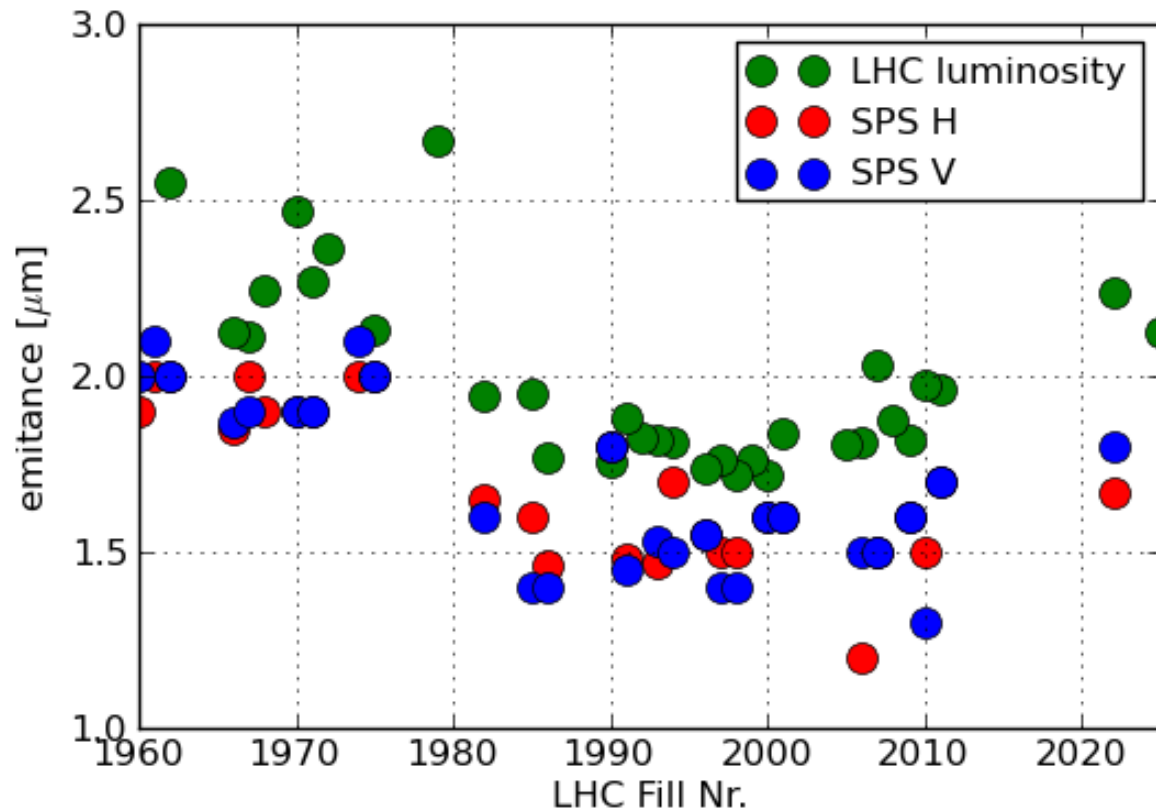


Emittance Preservation in the LHC

V. Kain, G. Arduini, B. Goddard, B. J. Holzer, J. M. Jowett, M.
Meddahi, T. Mertens, F. Roncarolo, M. Schaumann, R.
Versteegen, J. Wenninger

Analysed ~ 60 fills between mid July to mid August

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



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

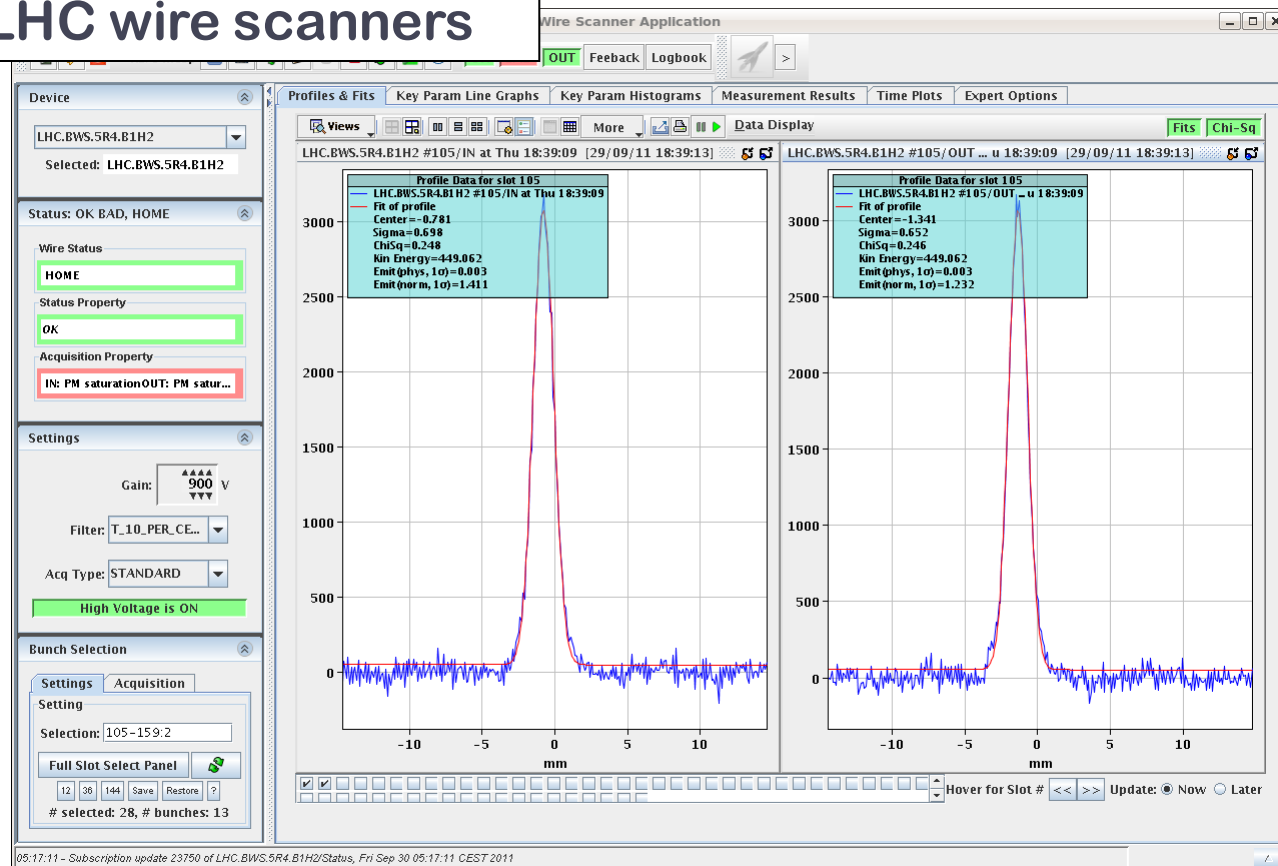
Analysed emittance preservation SPS extraction to start of LHC collisions

Not looking at evolution of emittance during collisions

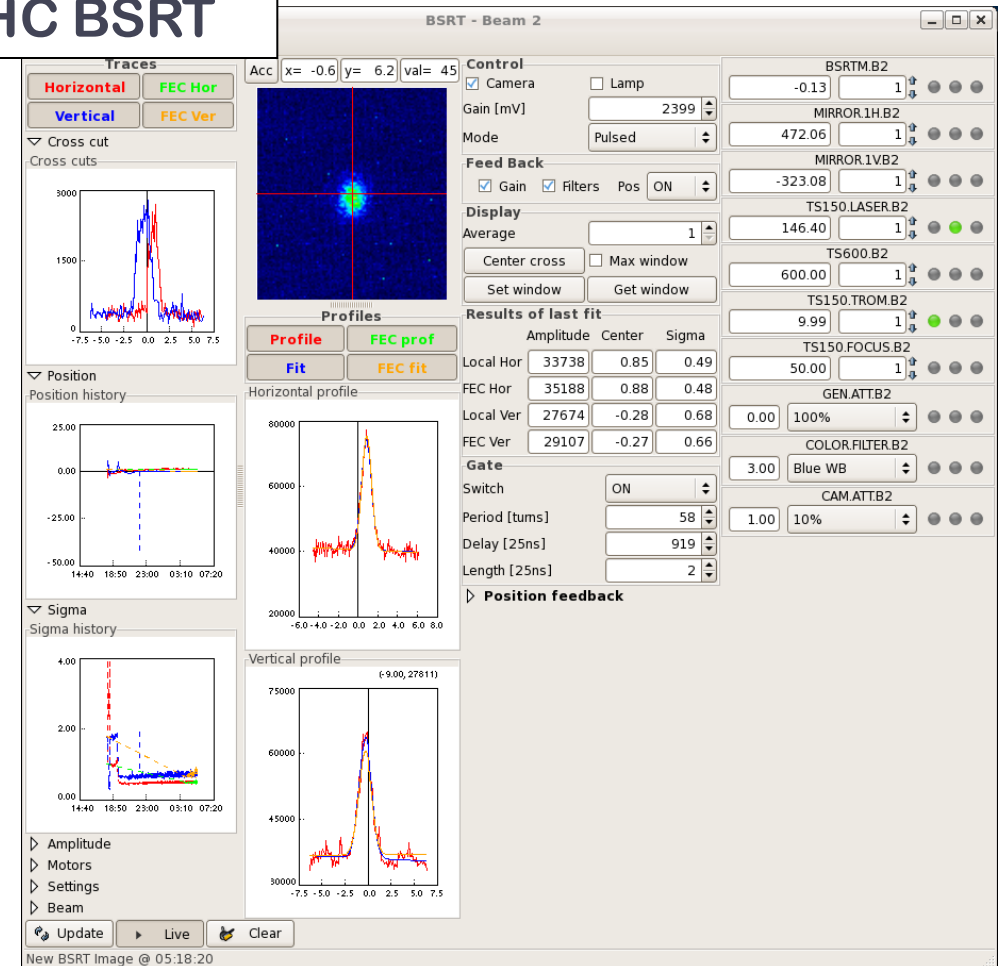
Not discussing sudden batch blow-up or 25 ns beams

Results are based on SPS/LHC wire scanners, LHC synchrotron light monitor and luminosity of ATLAS and CMS

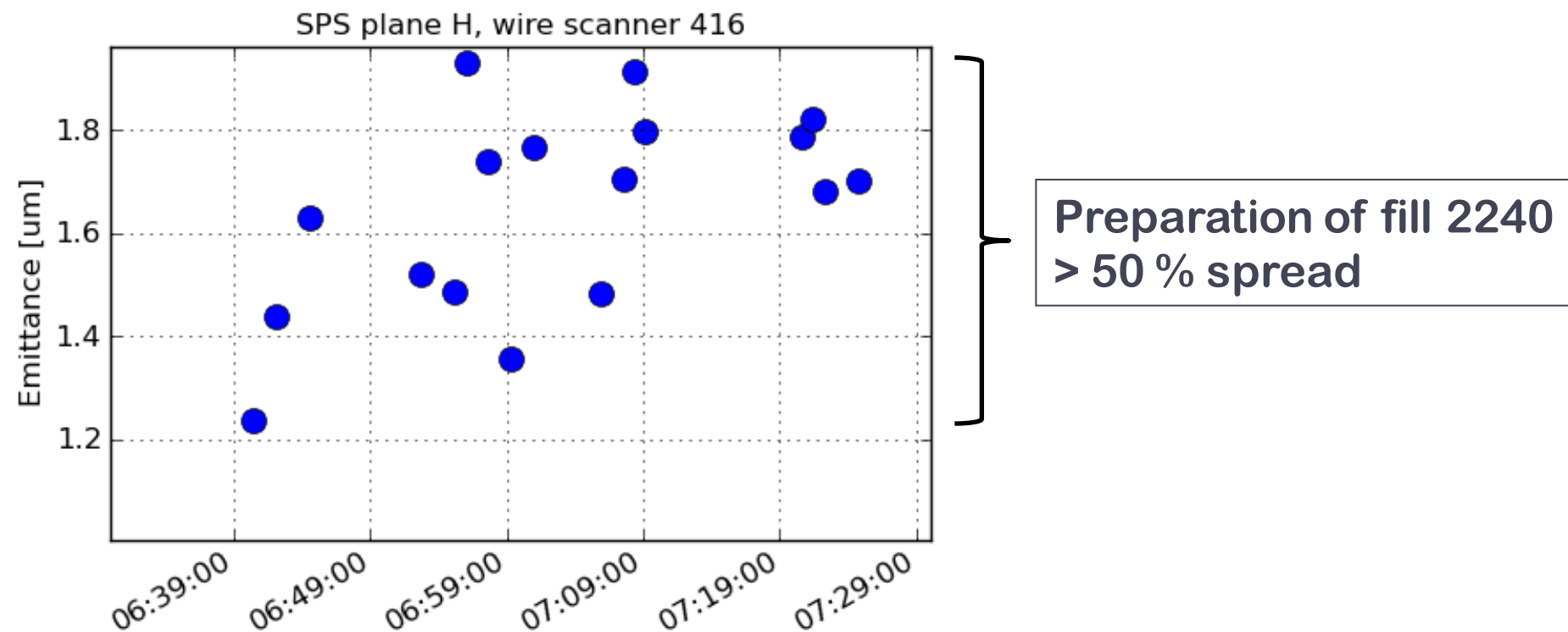
LHC wire scanners



LHC BSRT

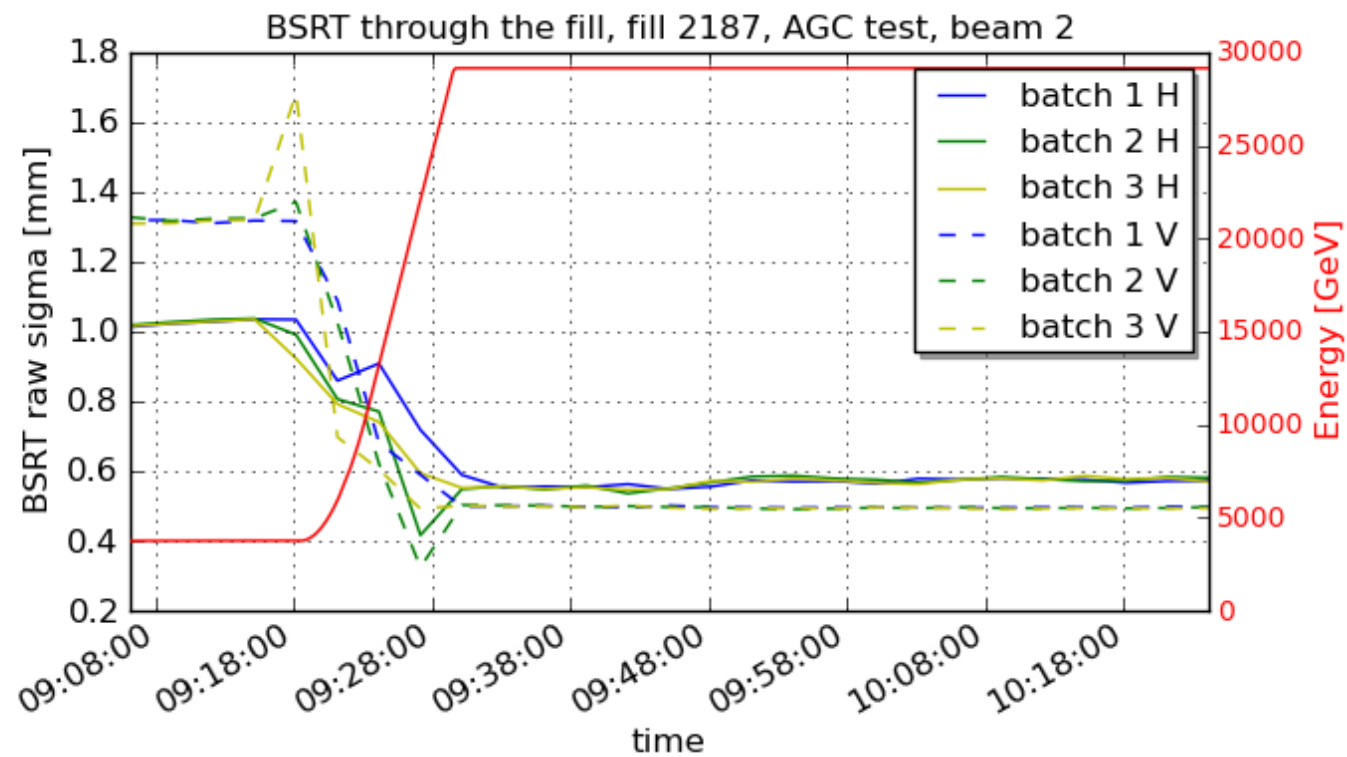


- o Wire scanners in the SPS:
 - Measure in the SPS routinely when setting up (12 + 144)
 - Not measured every cycle injected into LHC (no systematic measurement)
 - Large spread



- o Wire scanners in the LHC:
 - Measure routinely 12 bunches per beam
 - Sometimes measure first 144 bunch batch – intensity limit at 2.5×10^{13} p+
 - No measurements at 3.5 TeV for physics beam

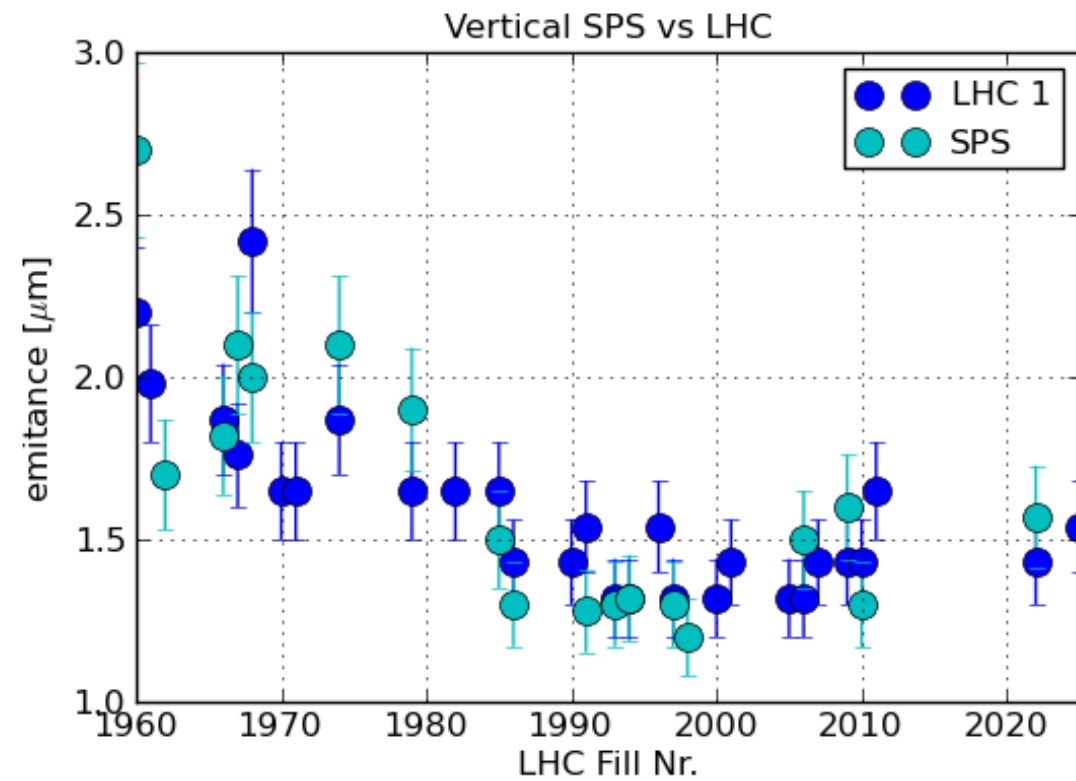
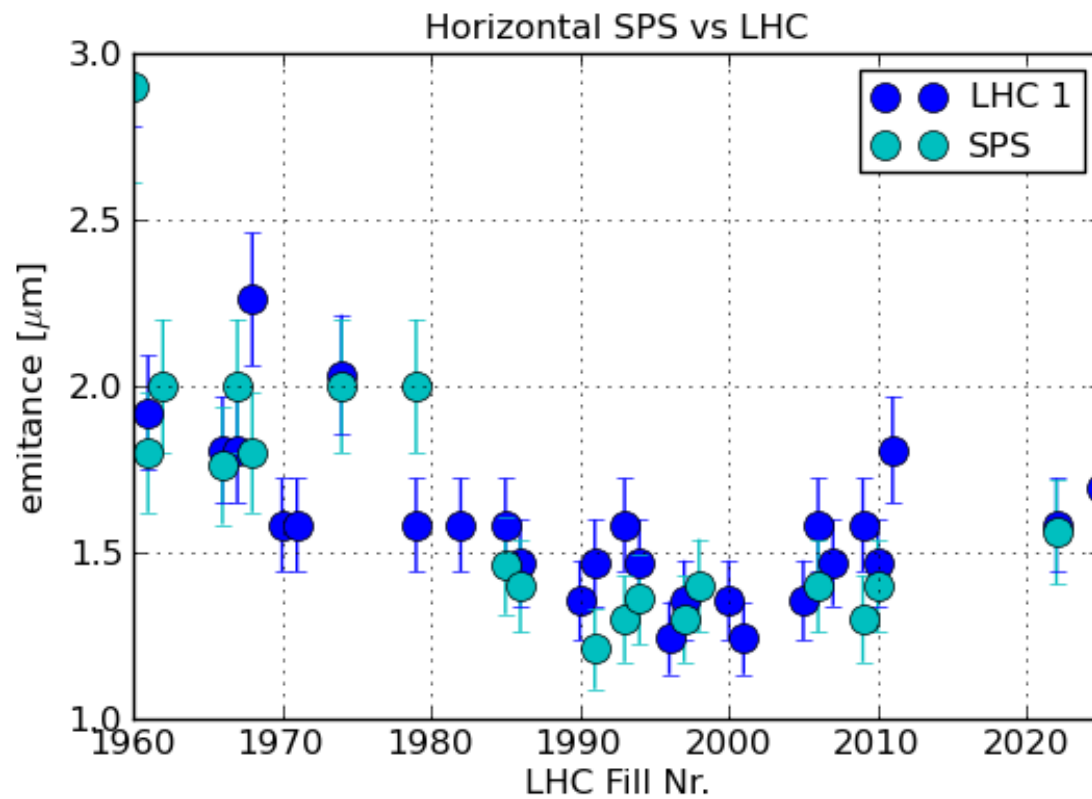
- o Continuous emittance measurement with BSRT: emittance through cycle
 - Bunch-by-bunch: 3 s per bunch → 69 min (!) per ring;
 - Good for relative measurement under same conditions
 - ❑ Absolute calibration not obvious (wire scanners are used for cross-calibration)
 - ❑ Cannot compare data at different energies – **cannot see effect of ramp**
 - ❑ Cannot compare data for different beams/planes



- o Emittance from luminosity
 - Single emittance value for different beams and planes
 - Not always fully optimized /not publishing the correct value
 - assume Gaussian beams

Used:

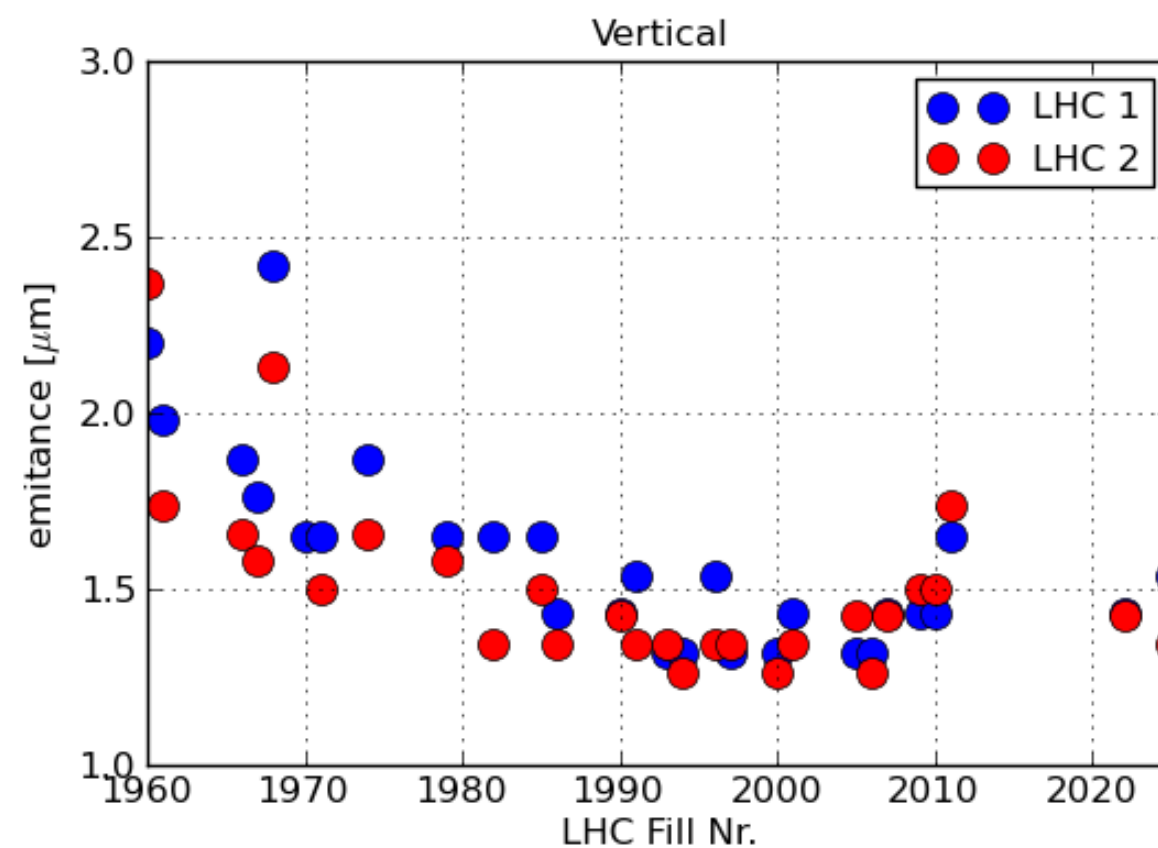
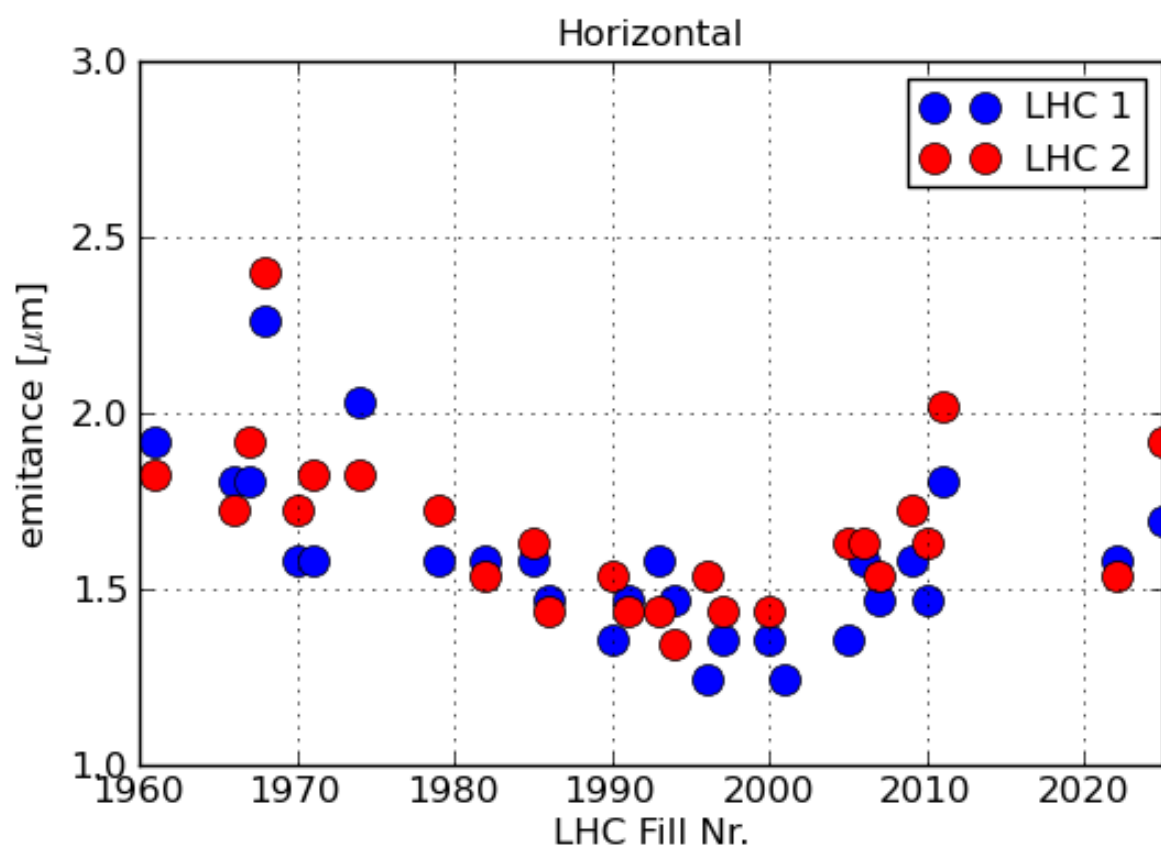
- o Wire scan data from SPS 12 bunches for fills 1960 - 2025
- o Wire scan data from LHC beam 1 12 bunches for fills 1960 - 2025



Emittances conserved within measurement accuracy

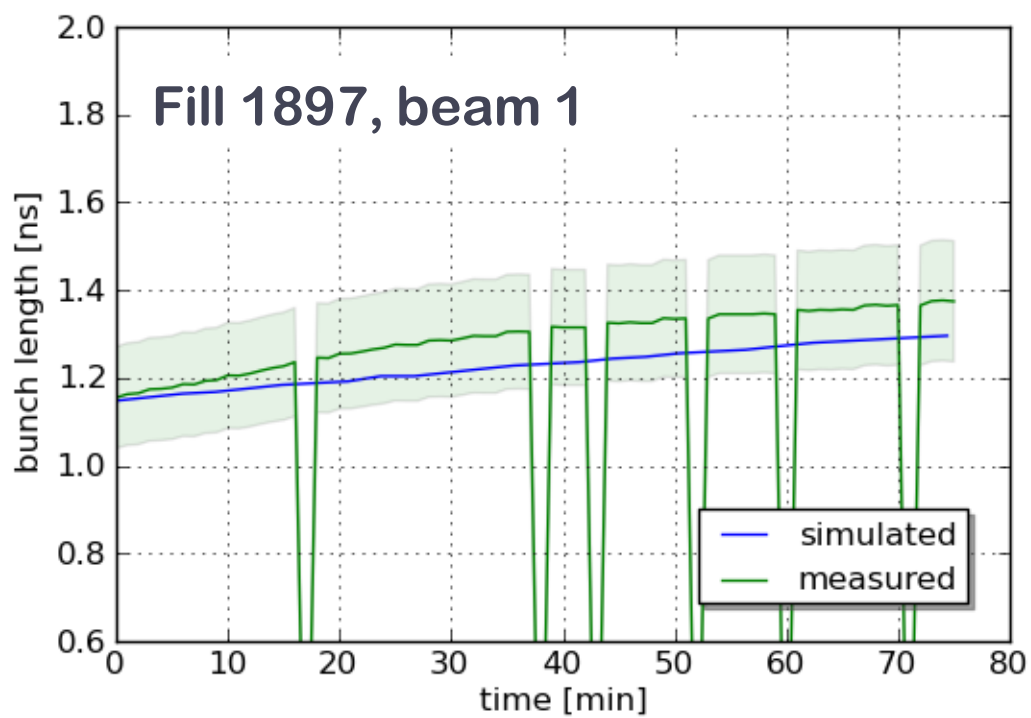
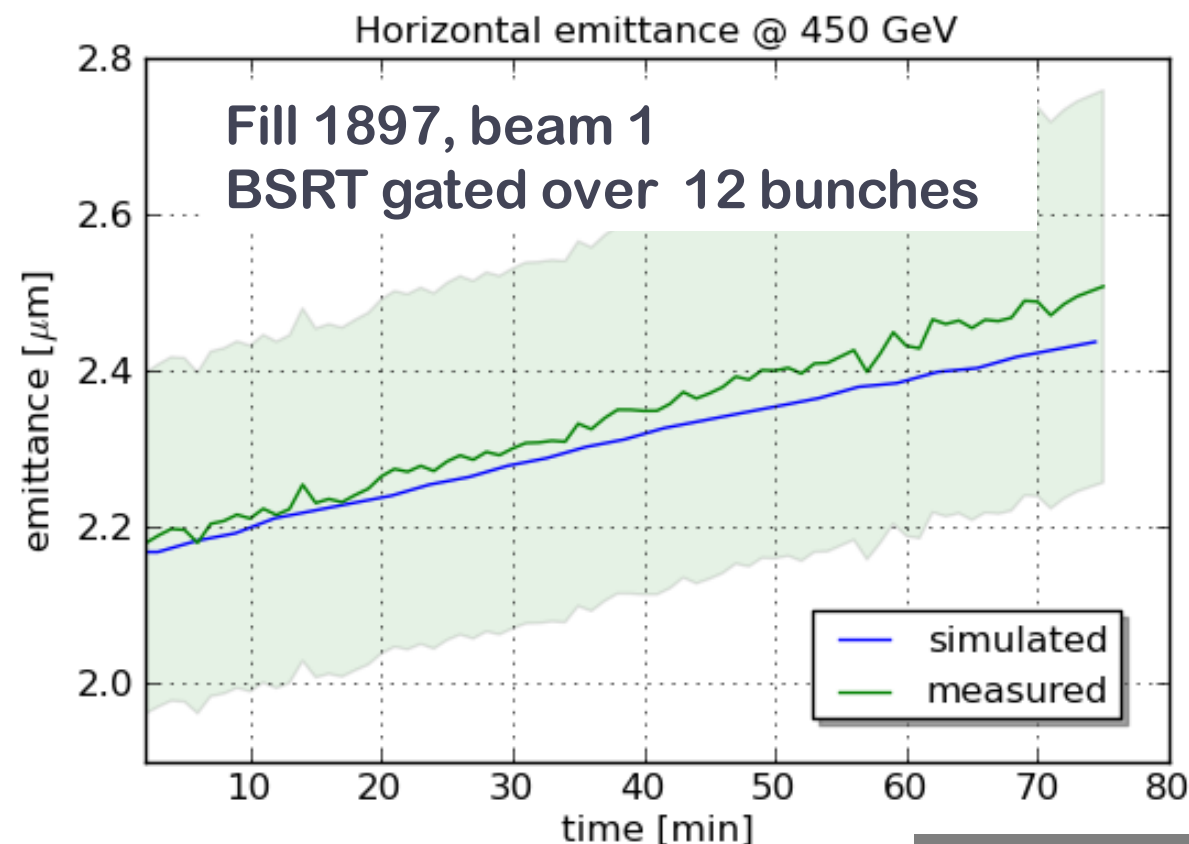
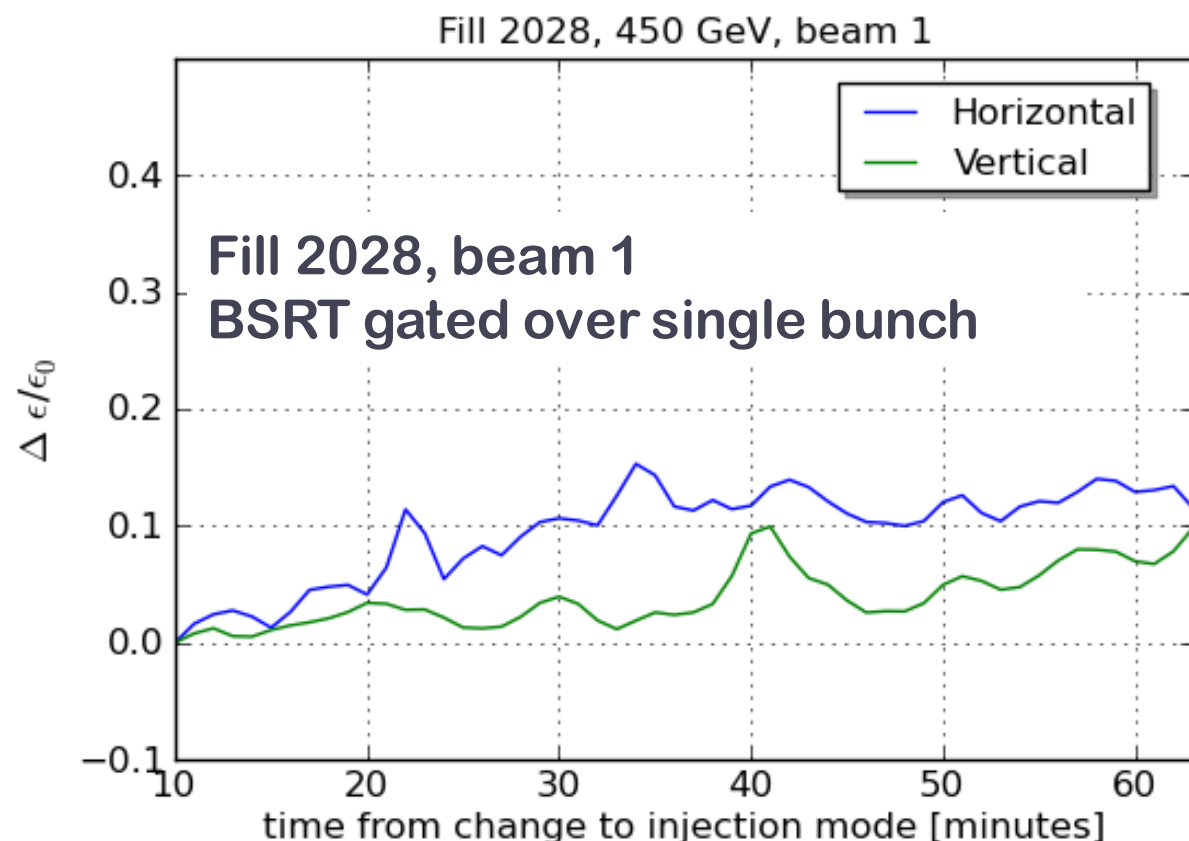
Beam 1 versus Beam 2

- o Comparing beam 1 with beam 2 wire scans of 12 bunches



Using the measured beta functions at wire scanners:
Beam 1 and beam 2 emittances are consistent

- o Emittances are growing at injection – reasonably consistent with IBS



T. Mertens

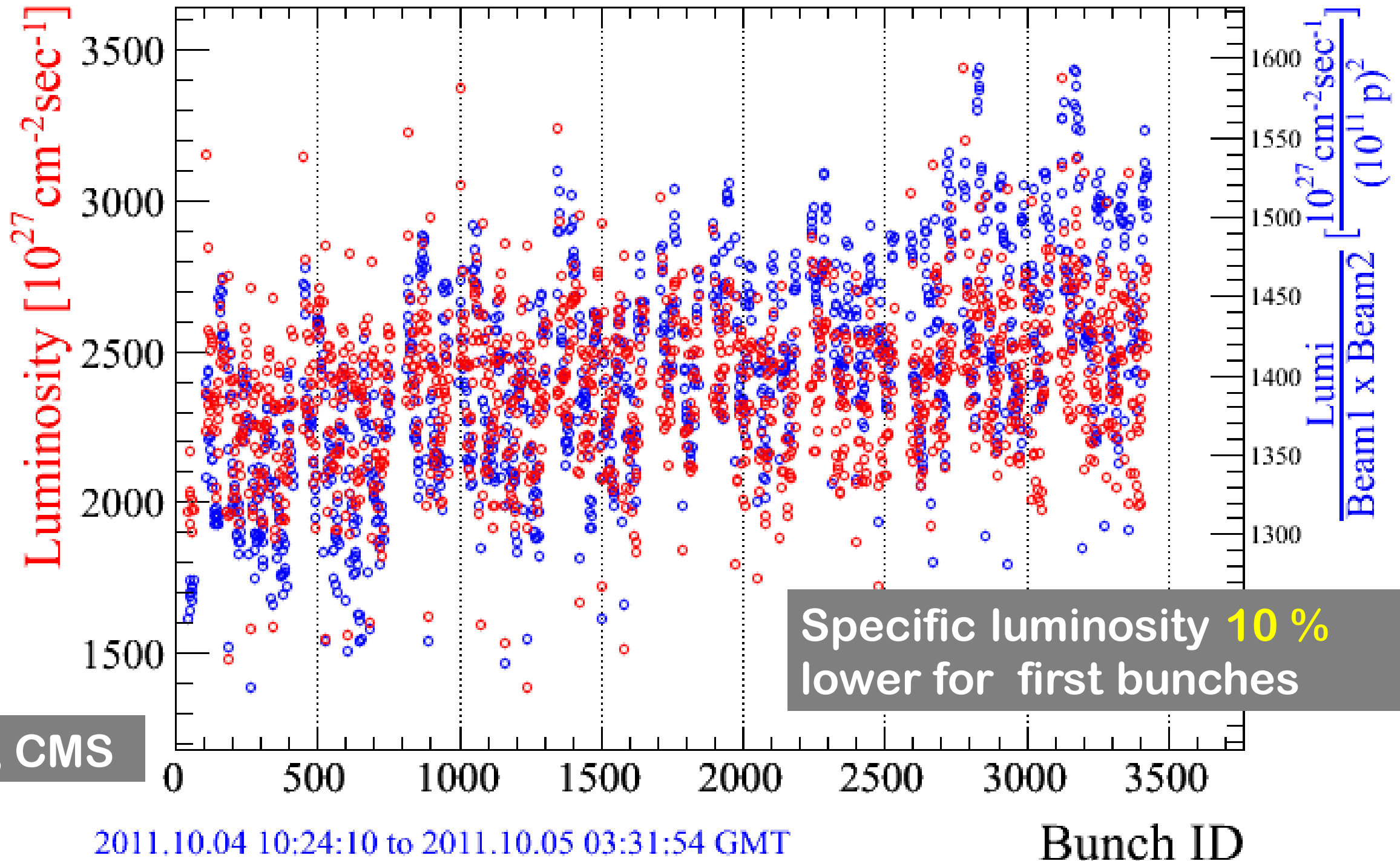
Simulations of IBS, uncoupled

Transverse emittances fit
Bunch length seems to grow faster than simple IBS ?

Filling about 30 minutes, $d\varepsilon/\varepsilon$ 0 – 10% in H

Fill 2182 Lumi per Crossing

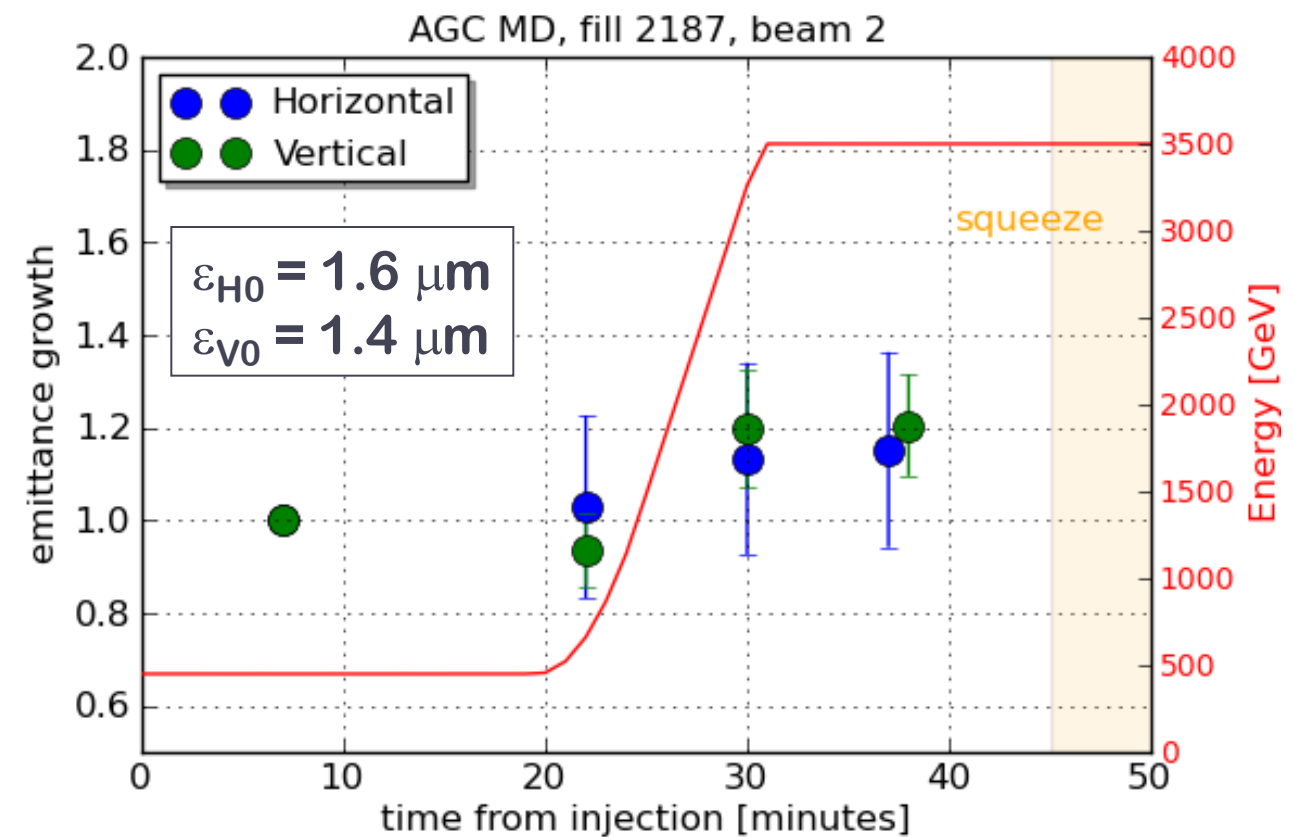
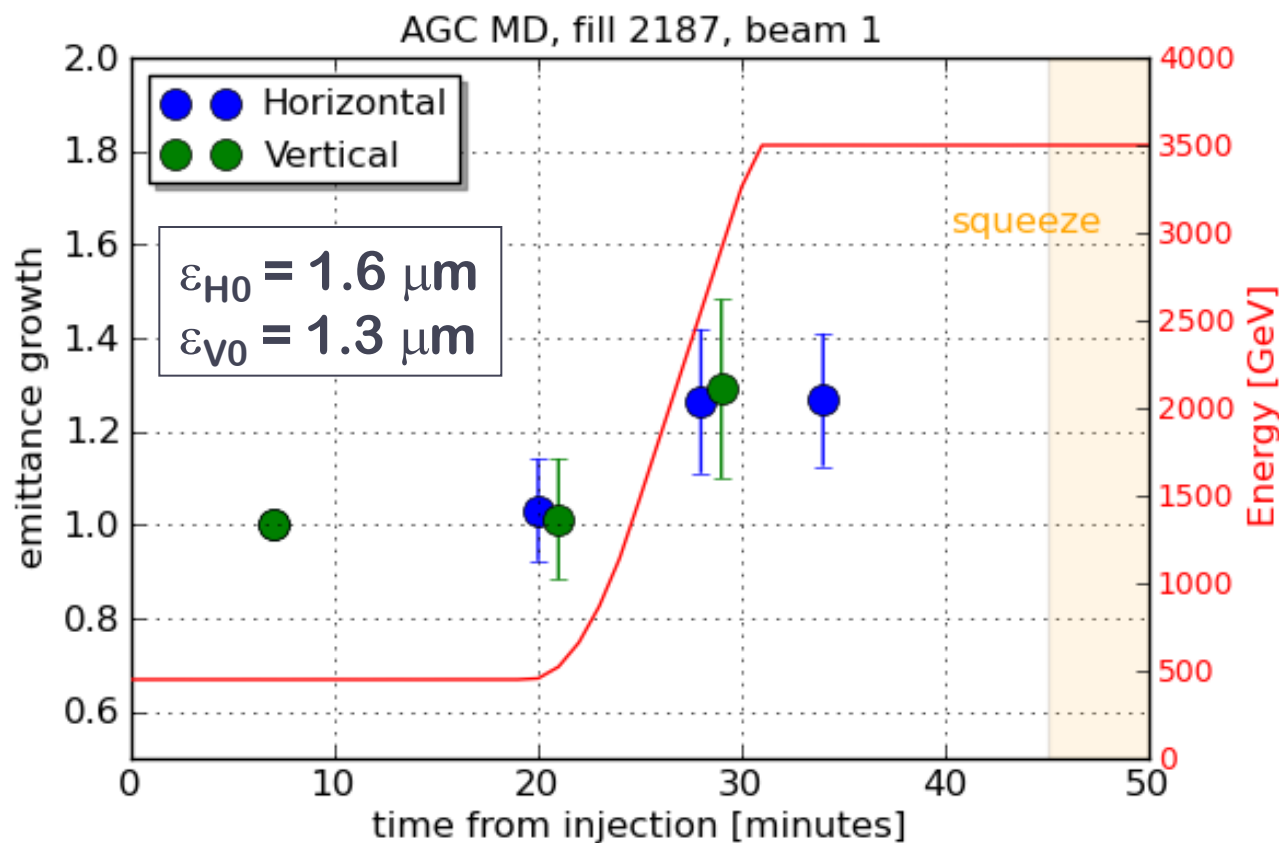
- Lumi per bx
- Spec Lumi per bx



A. Ryd, CMS

- o Cannot use BSRT data, BGI was not commissioned
- o Dedicated fills are necessary: low number of bunches to do wire scans through the ramp

First indication: Abort gap cleaning test fill (12+12+12 bunches, 50 ns)



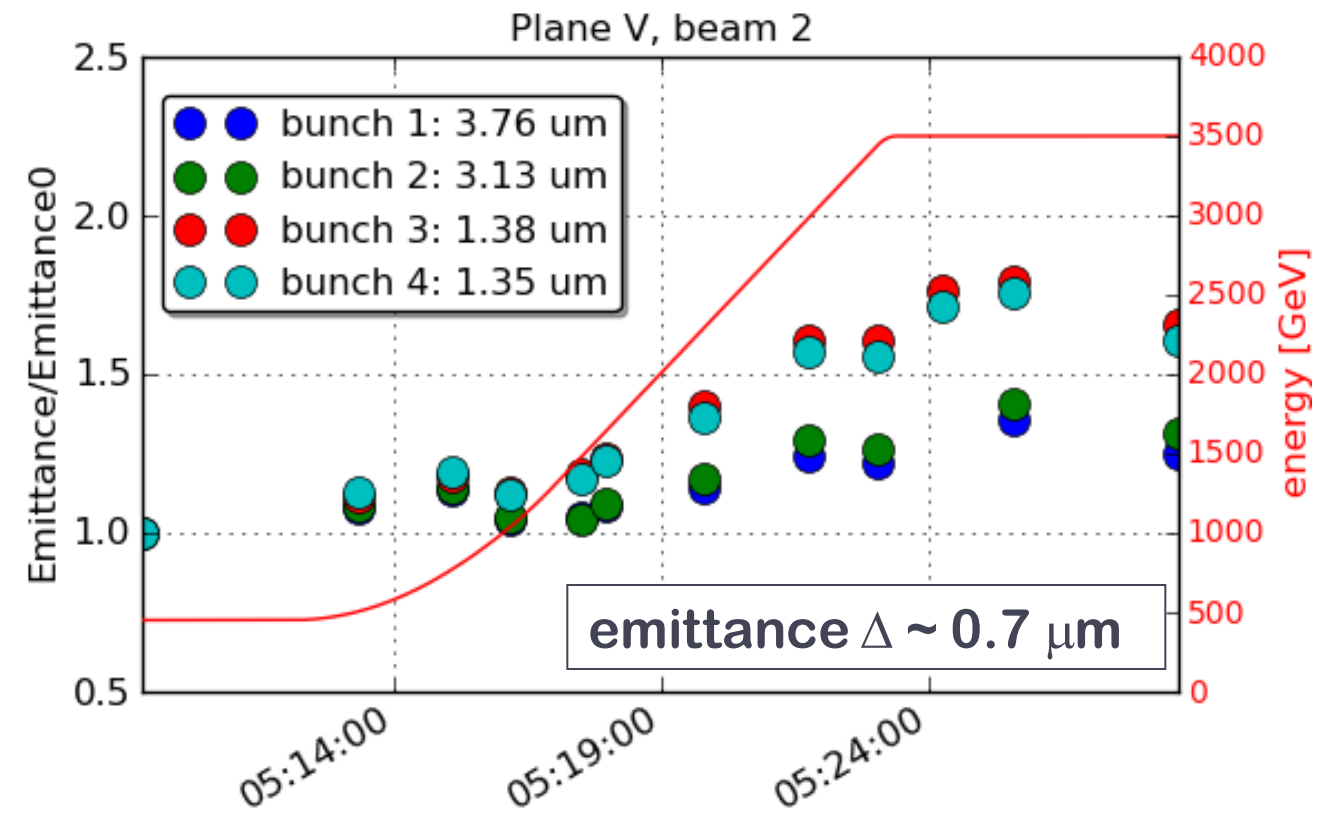
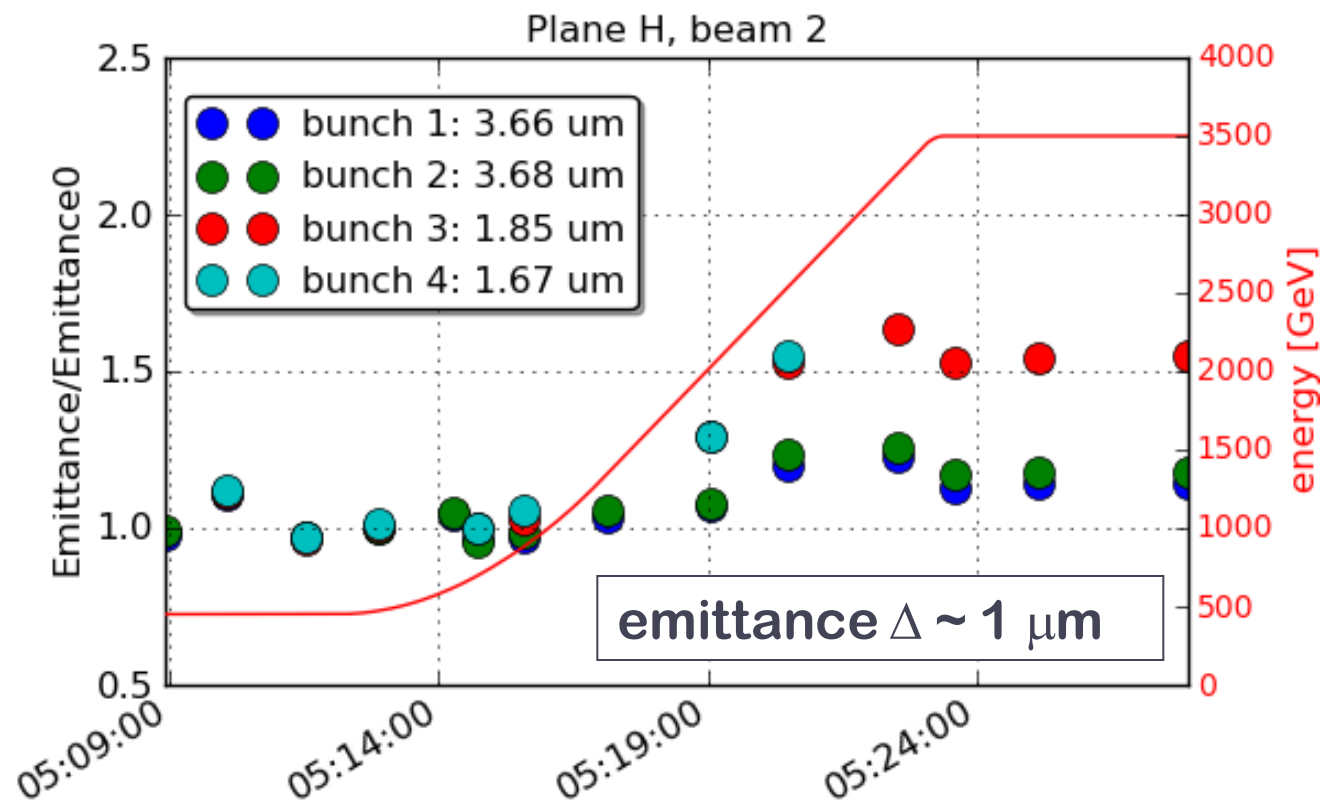
Used measured β at injection and flattop and linear interpolation between

Blow-up during the ramp: measurement indicates $> 20\%$

Last BI MD in 2011:

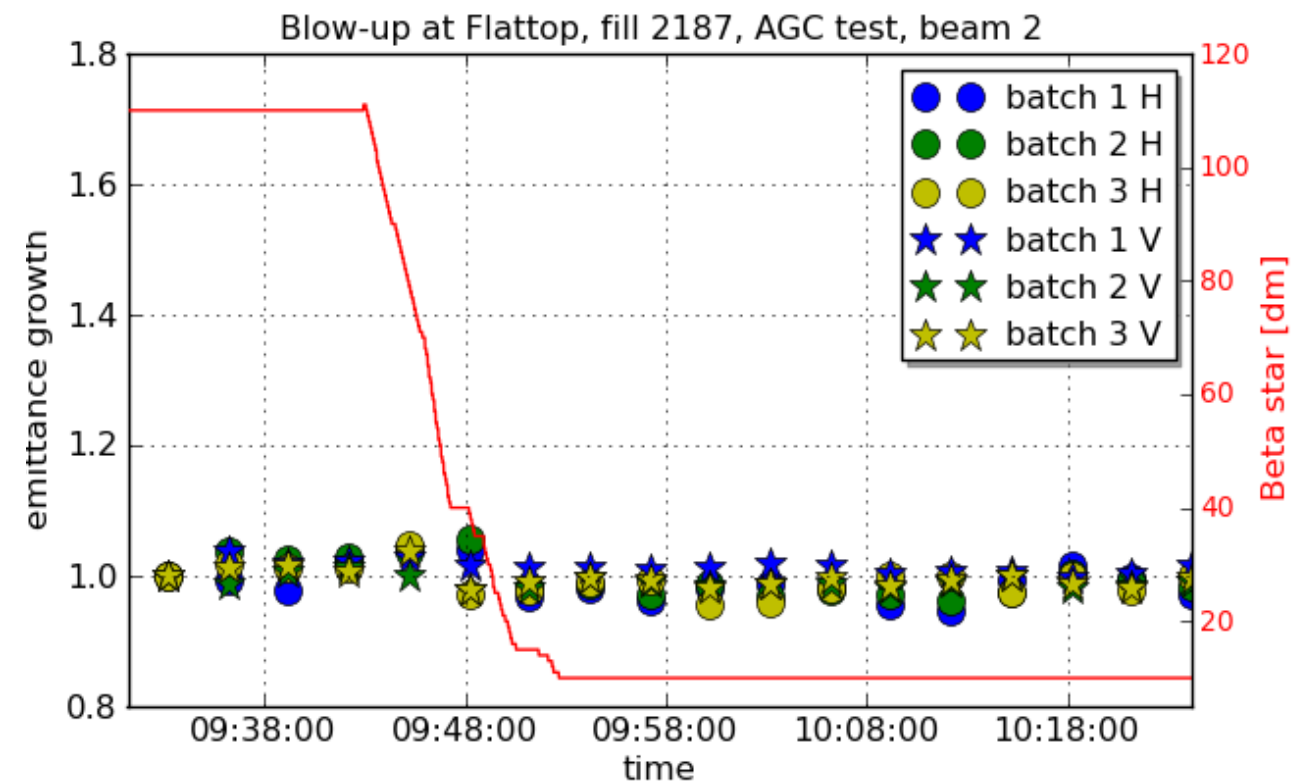
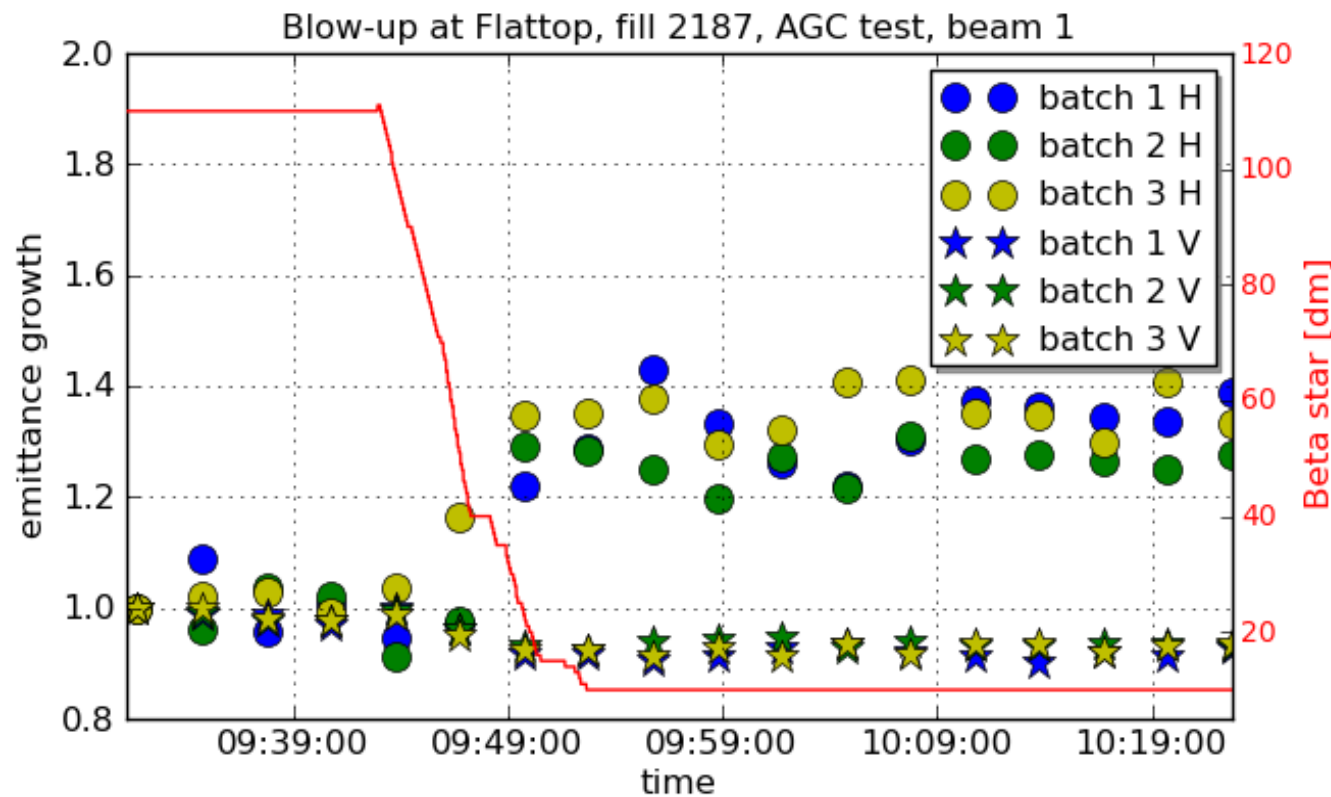
Ramp of 4 bunches per ring – different emittances

Unfortunately no useful wire scan data for beam 1



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

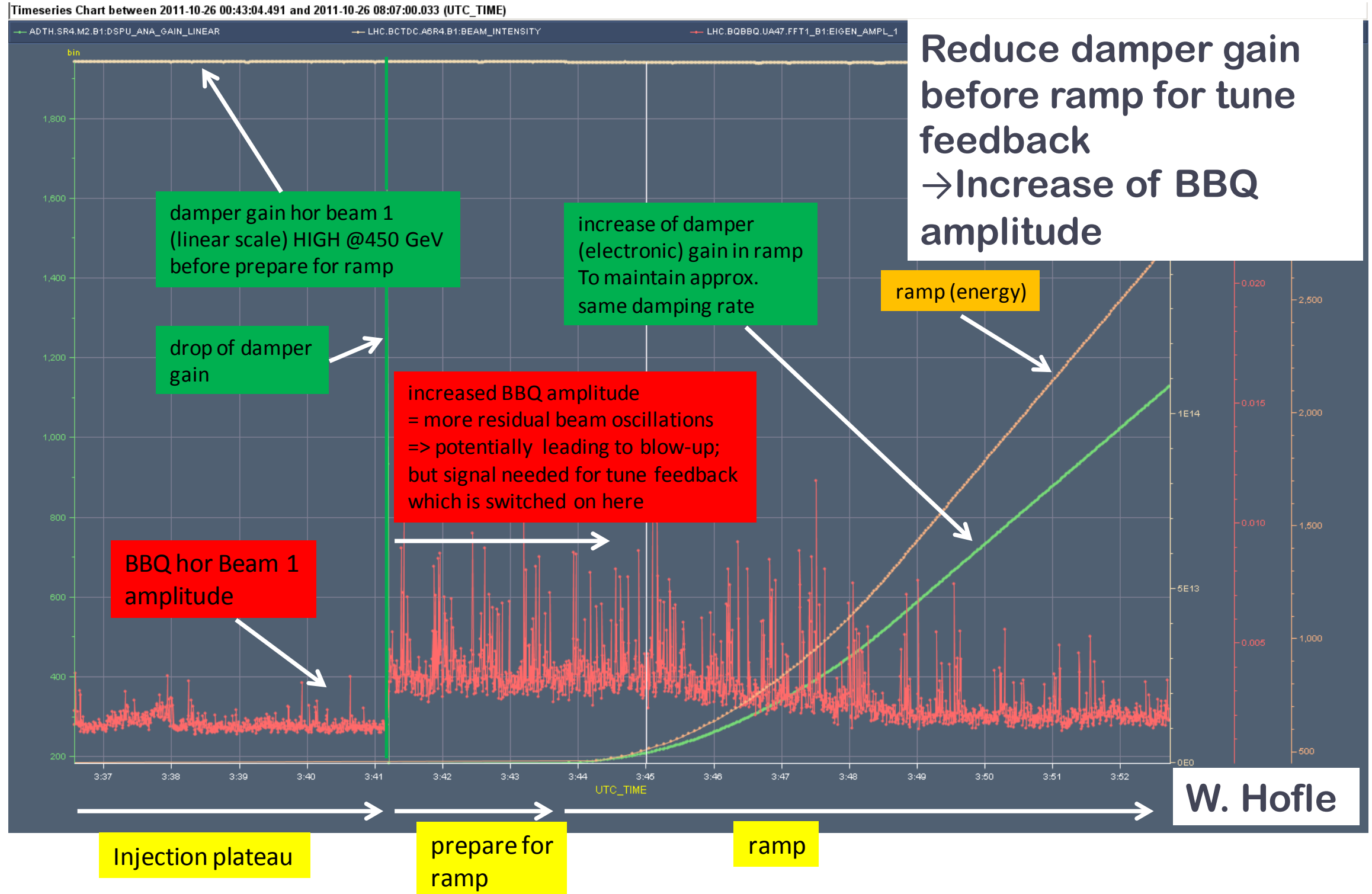
- o Use BSRT to study emittance evolution through the rest of the cycle
- o Looked at the Abort Gap Cleaning Test Fill (12 + 12 + 12 bunches per ring)
 - Integration: 3 s per bunch; averaged over 12 bunches → good resolution



- o **Blow-up during squeeze @ about 3 m for beam 1? Or optics change at point 4 due to optics correction?**
 - Took measured beta at 3.5 m and 1 m from optics team into account.
 - Needs to be further investigated

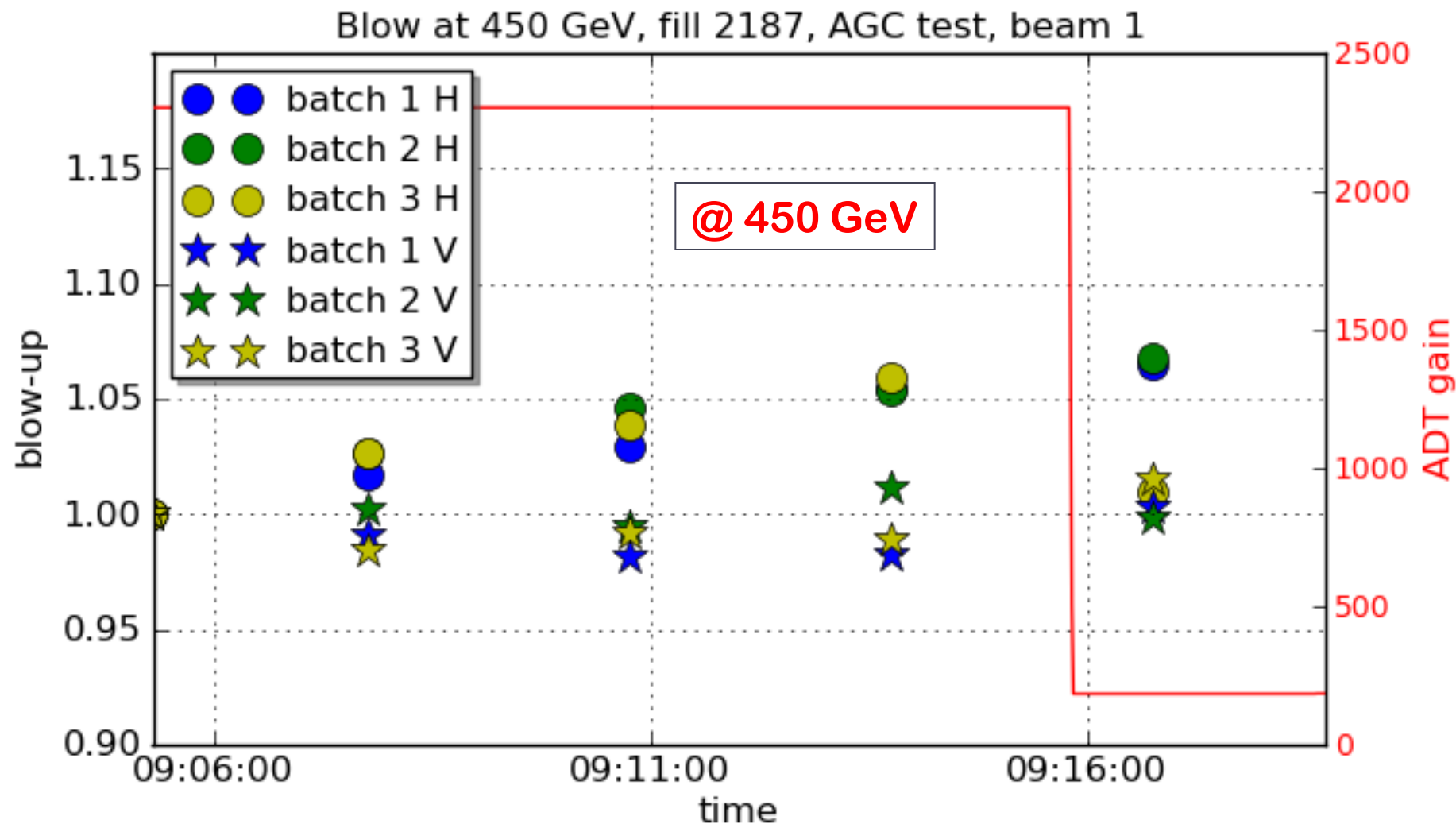
Possible sources for growth @ ramp

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



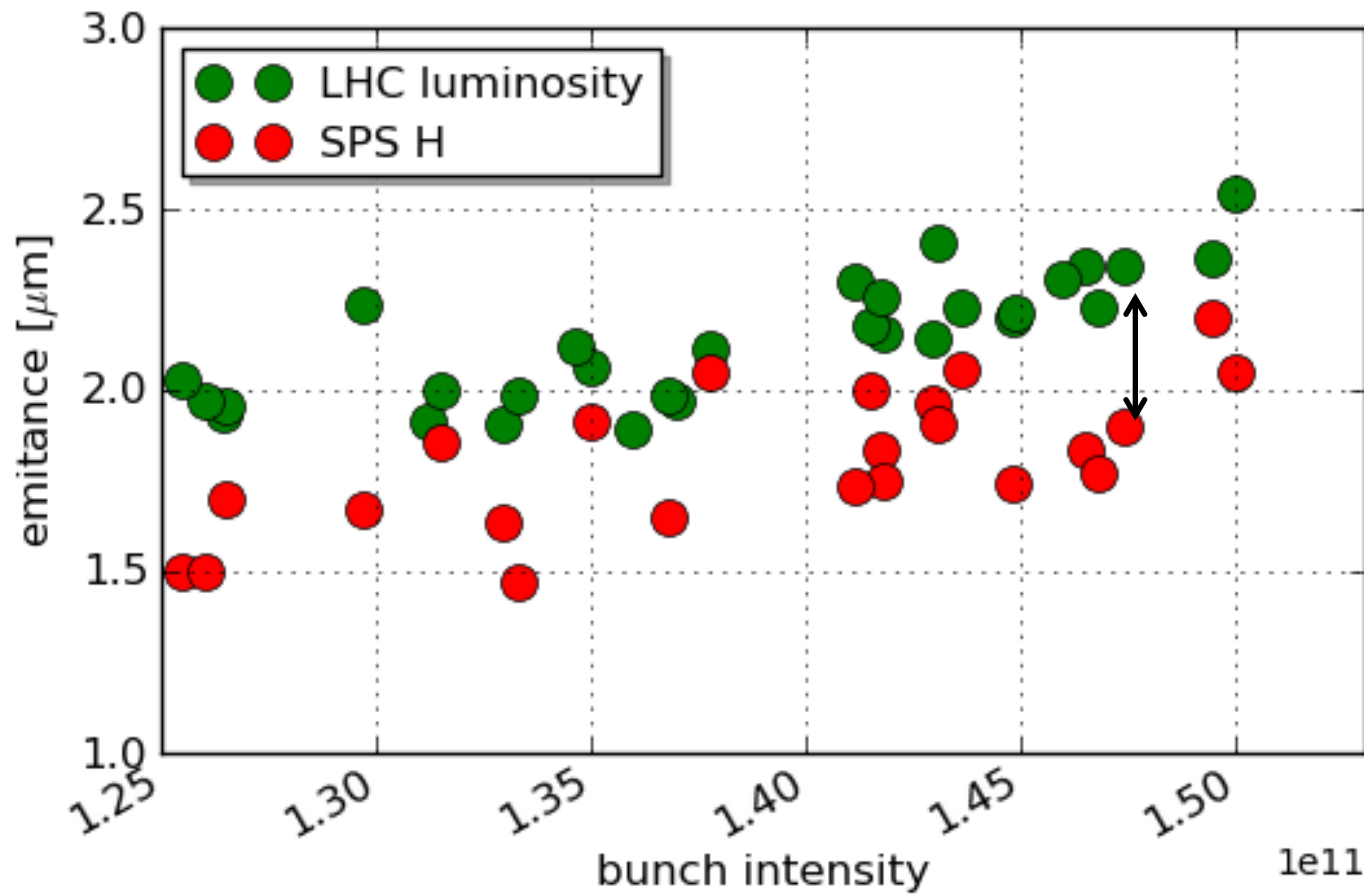
Again Abort gap cleaning test fill 2187.

Evolution during injection and switch of damper gain during prepare ramp:



No clear indication of immediate blow-up when reducing gain.

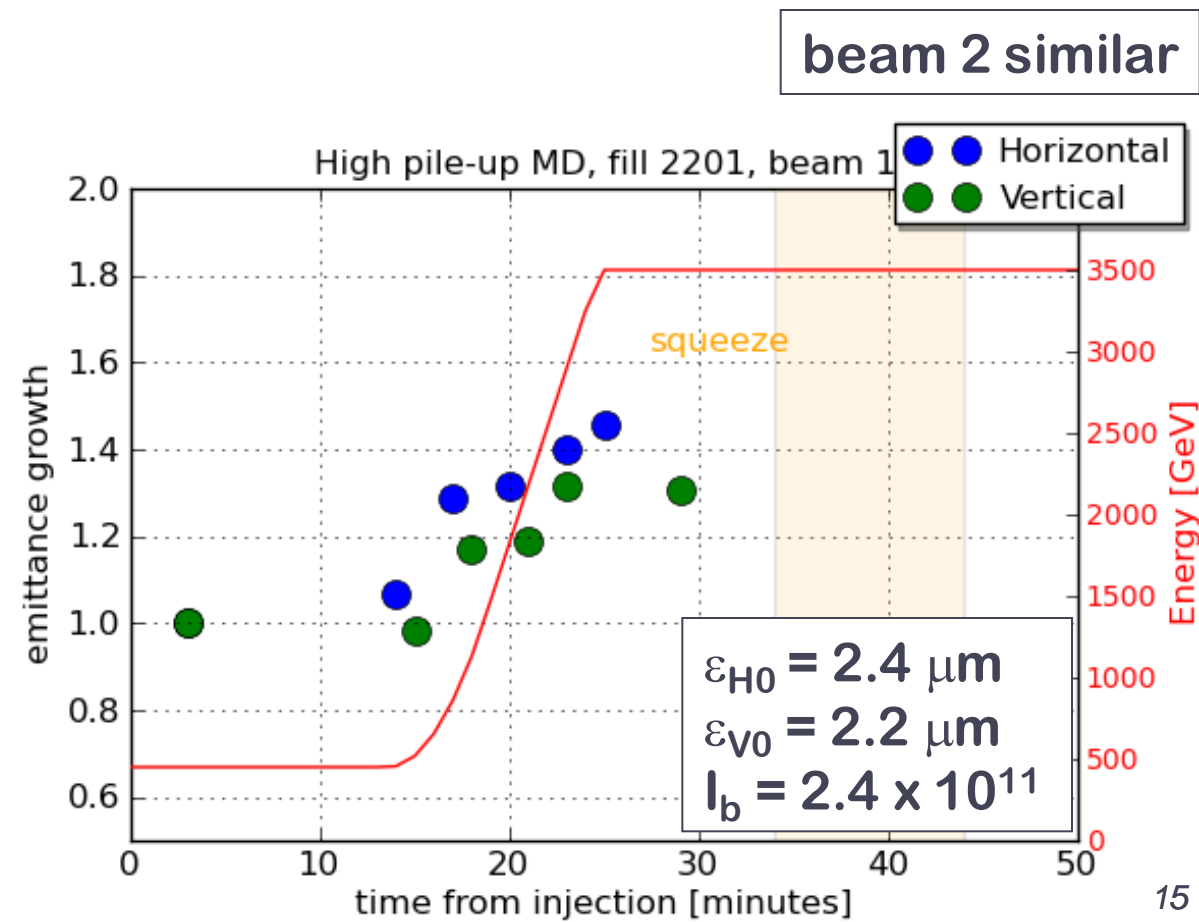
Dependence on bunch intensity?



Growth from SPS to collision vs bunch intensity:
Constant absolute growth

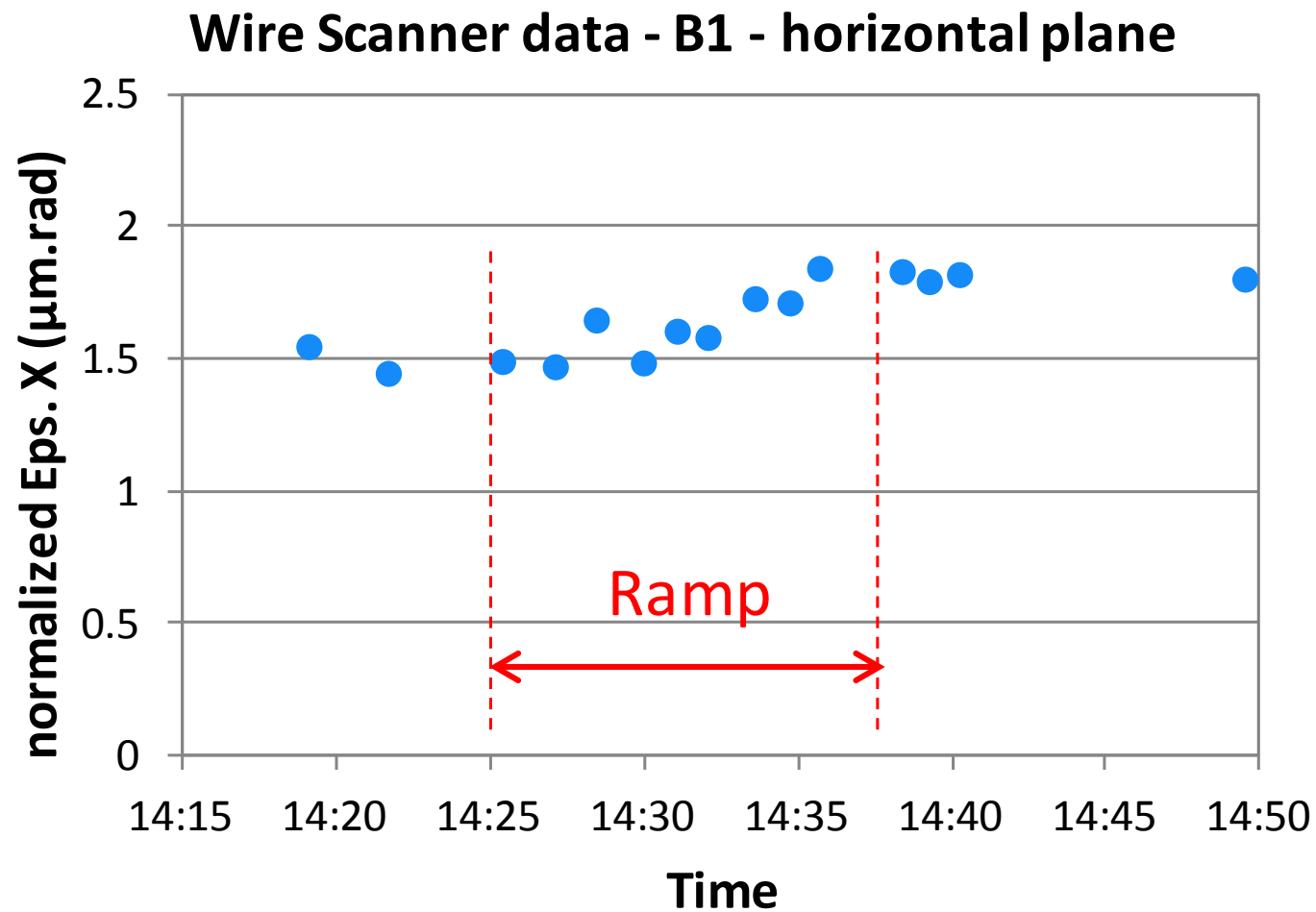
High pile-up MD, fill 2201:
Delta **similar to BI MD**,
but more than with 12 bunch trains

Delta of $\sim 1 \mu\text{m}$ in H
Delta of $\sim 0.6 \mu\text{m}$ in V



- o Ions also experience blow-up during the ramp
- o Wire scans during the ramp not possible with physics beam

Data taken during quench test on 7th of December, single bunch analyzed



Blow-up of ~ 20 %

Many more studies required

Planned MDs:

- o Will study bunches with different intensities (same emittances) and different emittances
 - Effect on IBS during injection
 - Effect on emittance blow-up during ramp
- o Effect of damper gain and working point (50 Hz lines,...)

Need

- o Beta-beat change over time?
- o BGI commissioned
- o Faster, better calibrated BSRT – will come
- o Wire scans during ramp more automated – timing tables,...
- o Measured betas more easily available – working on it
- o More reliable wire scans + bunch-by-bunch in the SPS
 - Automated settings for given intensity,...
- o Emittance measurement for each LHC transfer in the SPS

- o Emittances grow **20 % - 30 %** from SPS extraction to LHC collisions
- o Data consistent with **NO emittance** growth from injection into LHC
- o **Emittance growth during injection plateau** is apparent (~ 10 % in 20 minutes for horizontal plane)
 - Continue to minimise time at injection
 - Dedicated filling cycle? Reduce time in “prepare ramp”...
- o Wire scanner data indicates **blow-up during ramp**
 - Measurements so far: > 20 % (50 ns) in H and V, even more for single bunches - additive source of blow-up?
- o More data required for emittance evolution during squeeze
 - Indication of from fill 2187: Beam 1 H growth > 20 %
- o **More data and analysis needed to improve accuracy and understanding**
 - Faster and better calibrated BSRTs next year, BGI operational, better settings for Wire scanners, reliable fits
 - Dedicated MD and physics fill data will be combined to get the full picture