LHC Injectors Upgrade

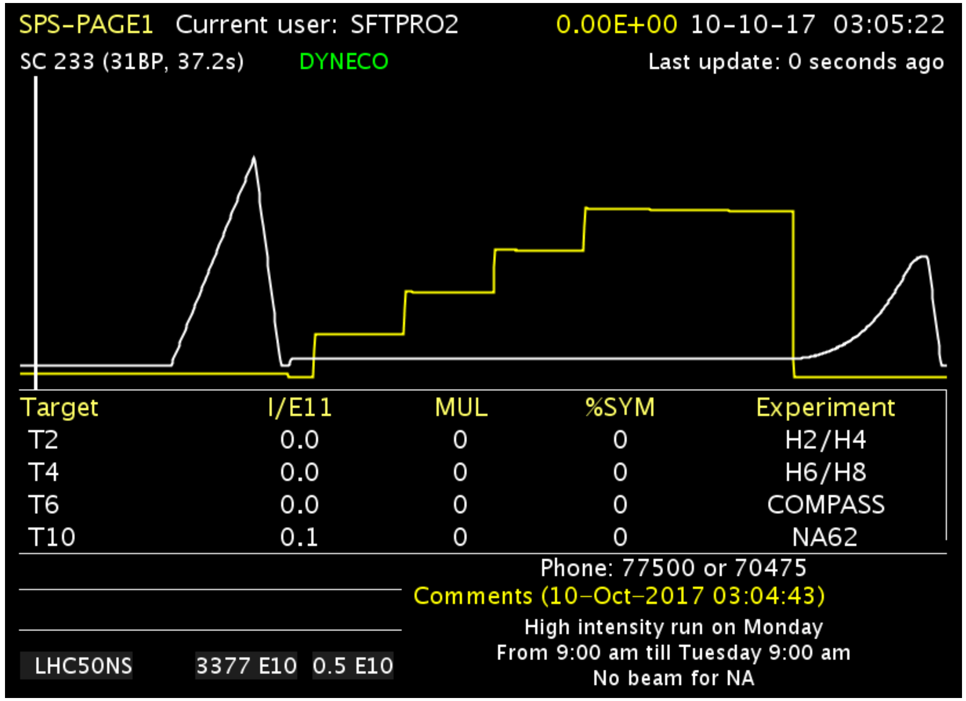
Experience with high intensity beams and space charge studies in SPS

H. Bartosik, M. Beck, T. Bohl, M. Carla’, S. Cettour Cave, K. Cornelis, H. Damerau, B. Goddard, G. Iadarola, V. Kain, A. Lasheen, K. Li, G. Papotti, J. Repond, G. Rumolo, E. Shaposhnikova, M. Schenk, M. Schwarz, F. Velotti

LIU MD day, 15 March 2018

CERN

Introduction



- **A high intensity run was performed in 2017**
  - Two days dedicated MD time
  - Aim was to study LIU beam parameter regime (as close as possible)
  - Injected up to 2.1e11 p/b (presently maximum intensity from PS with 0.35 eVs)
  - This beam cannot be accelerated yet (need LIU RF upgrade) → studies focused on flat bottom
- **Complementary space charge studies were performed with Indivs**

Outline

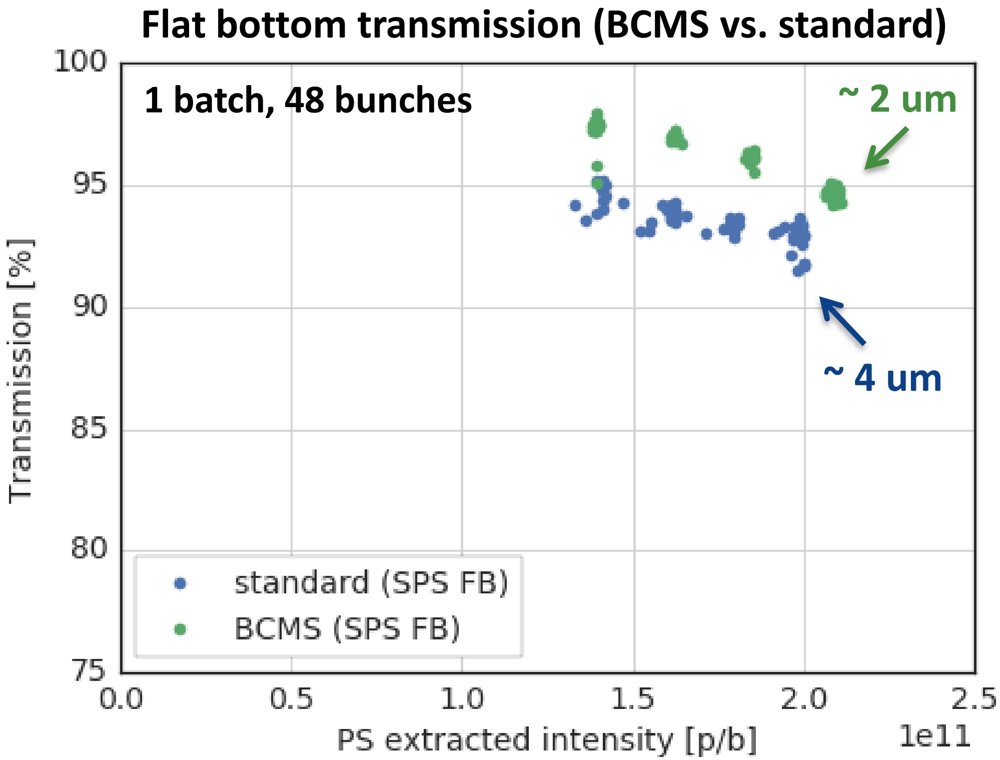
- **Studies with 25 ns beams**
  - 25 ns standard vs. BCMS
  - Tune scan
  - Transverse emittance blow-up
  - Horizontal instability studies
  - Tune shift along the bunch train
- **Single bunch space charge studies**
- **Plans for 2018**

Outline

- **Studies with 25 ns beams**
  - 25 ns standard vs. BCMS
  - Tune scan
  - Transverse emittance blow-up
  - Horizontal instability studies
  - Tune shift along the bunch train
- **Single bunch space charge studies**
- **Plans for 2018**

25 ns standard vs. BCMS beam

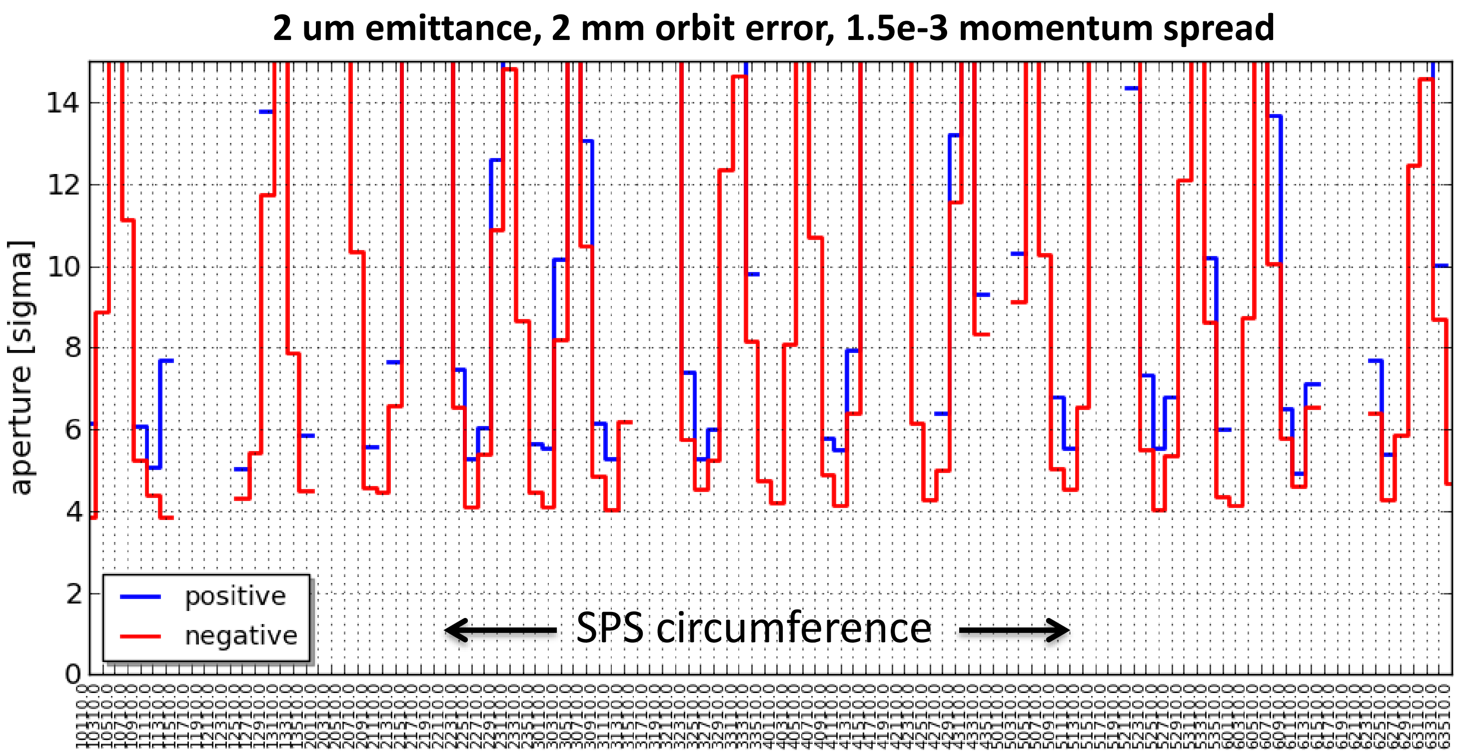
- **Better transmission for BCMS beam**
  - Flat bottom transmission improves for smaller emittance, despite enhanced space charge!
  - Losses are concentrated in high dispersive regions of the machine
  - Related to asymmetric momentum acceptance (see next slide)



Therefore studies in the second half of 2017 were performed with BCMS beam (similar brightness as LIU beam post-LS2)

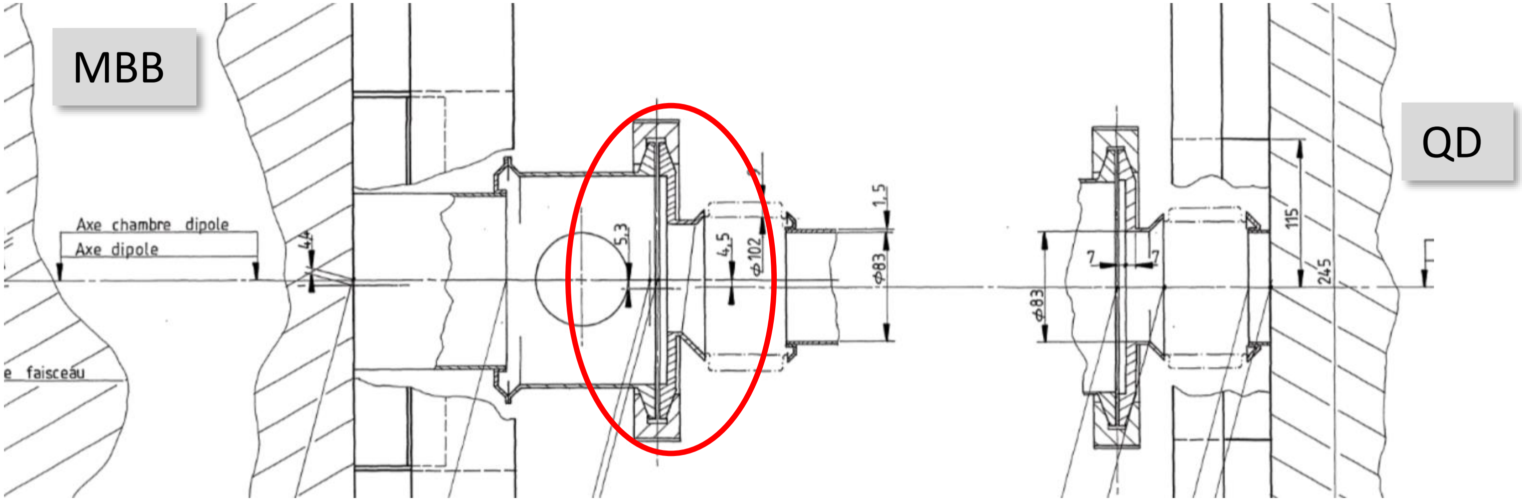
Momentum acceptance

- **Radial steering revealed asymmetric momentum acceptance**
- **Detailed measurement of horizontal aperture**
  - Aperture close to QDs systematically smaller towards machine center



Momentum acceptance

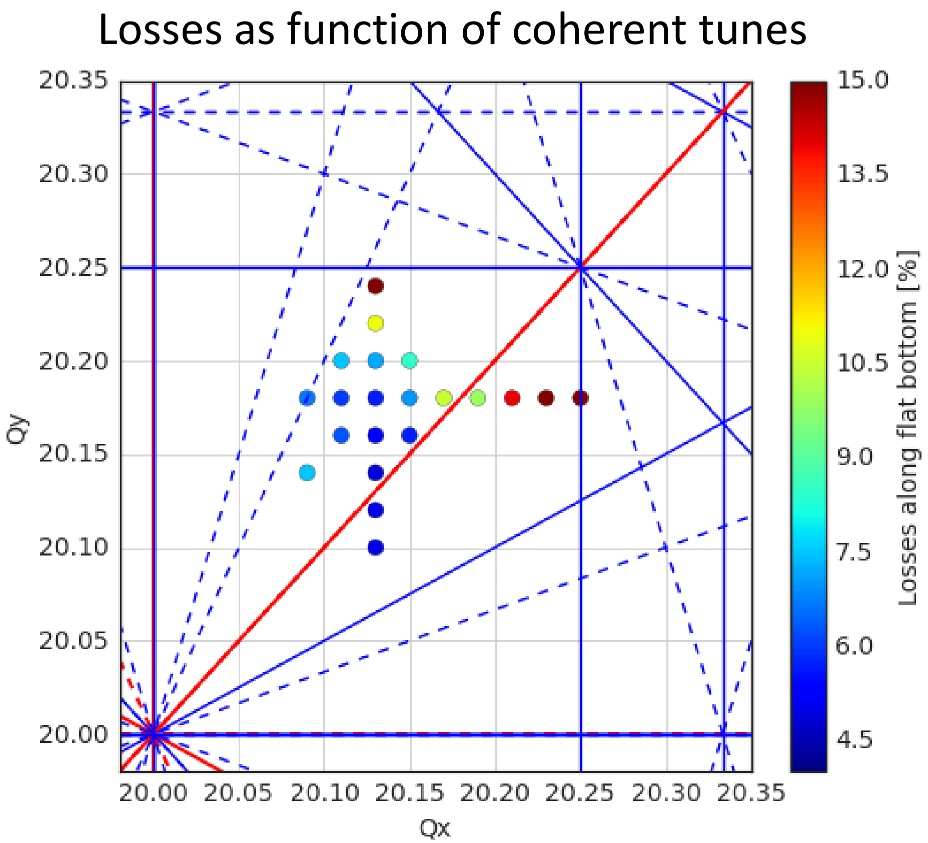
- **Radial steering revealed asymmetric momentum acceptance**
- **Detailed measurement of horizontal aperture**
  - Aperture close to QDs systematically smaller towards machine center
- **Design flaw of MBB-QD transitions identified**
  - Modified vacuum transitions with enlarged aperture installed in 3 positions during the YETS for testing impact on losses



Tune scan

- **Studied dependence of flat bottom losses on working point**
  - Usual working point (20.13/20.18) already close to optimum – losses can be higher for other working points (in particular towards higher tunes…)
  - To be further investigated which resonances are the detrimental ones taking into account the coherent and incoherent tune shifts

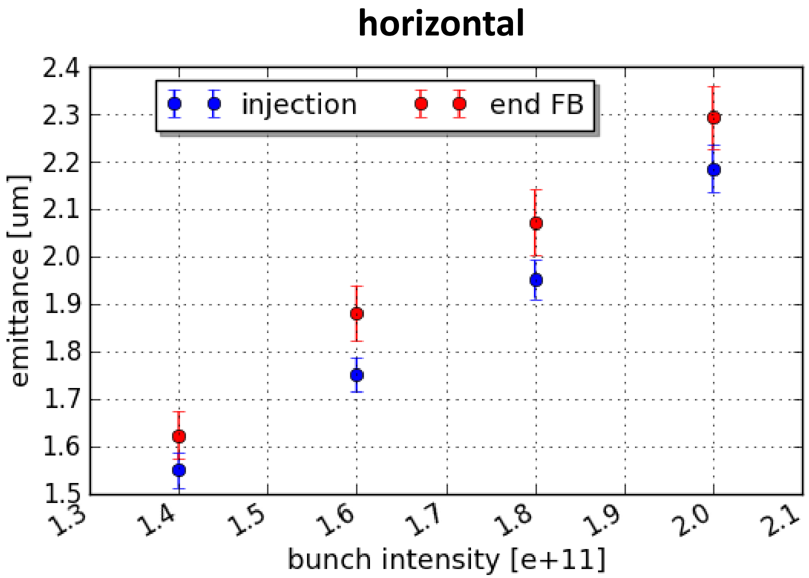
bare tunes are shifted compared to measured coherent tunes like this:

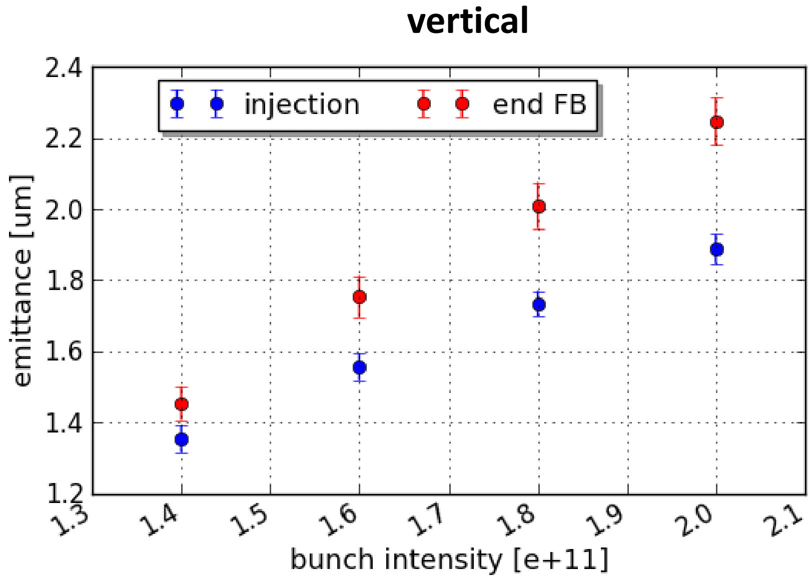


Transverse emittance studies

- **Measured emittance as function of intensity**
  - Single batch BCMS beam
  - End flat bottom corresponds to 10.8 s

- **Vertical emittance growth increases with intensity, not observed in horizontal**
  - **To be studied in more detail in 2018**



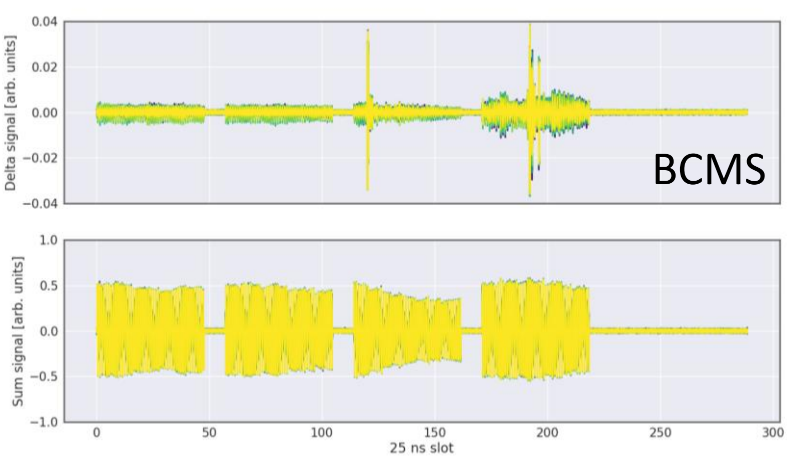


Horizontal instability

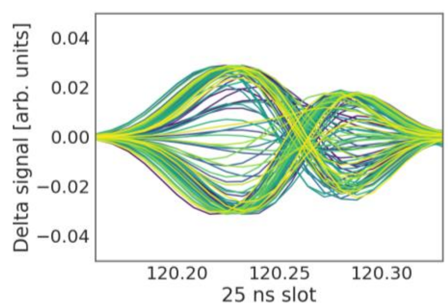
- **The 20 MHz horizontal coupled bunch instability from 2015 was not observed**
  - Now the transverse damper has higher gain at 20 MHz, but only 4 x 48 bunches (4 x 72 in 2015)

- **In 2017 the 4 x 48 bunches suffered from single bunch instabilities (some bunches in 3rd and 4th batch)**
  - Single bunch instability mode changes and can be cured with chromaticity
  - $\xi_H \sim 0.1 - 0.2 \rightarrow$ mode 1
  - $\xi_H \sim 0.3 - 0.5 \rightarrow$ mode 2
  - $\xi_H > 0.5 \rightarrow$ instability mostly suppressed

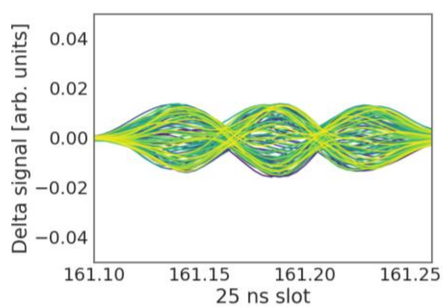
- **To be studied more systematically in 2018**



ξ_H ~ 0.1 – 0.2

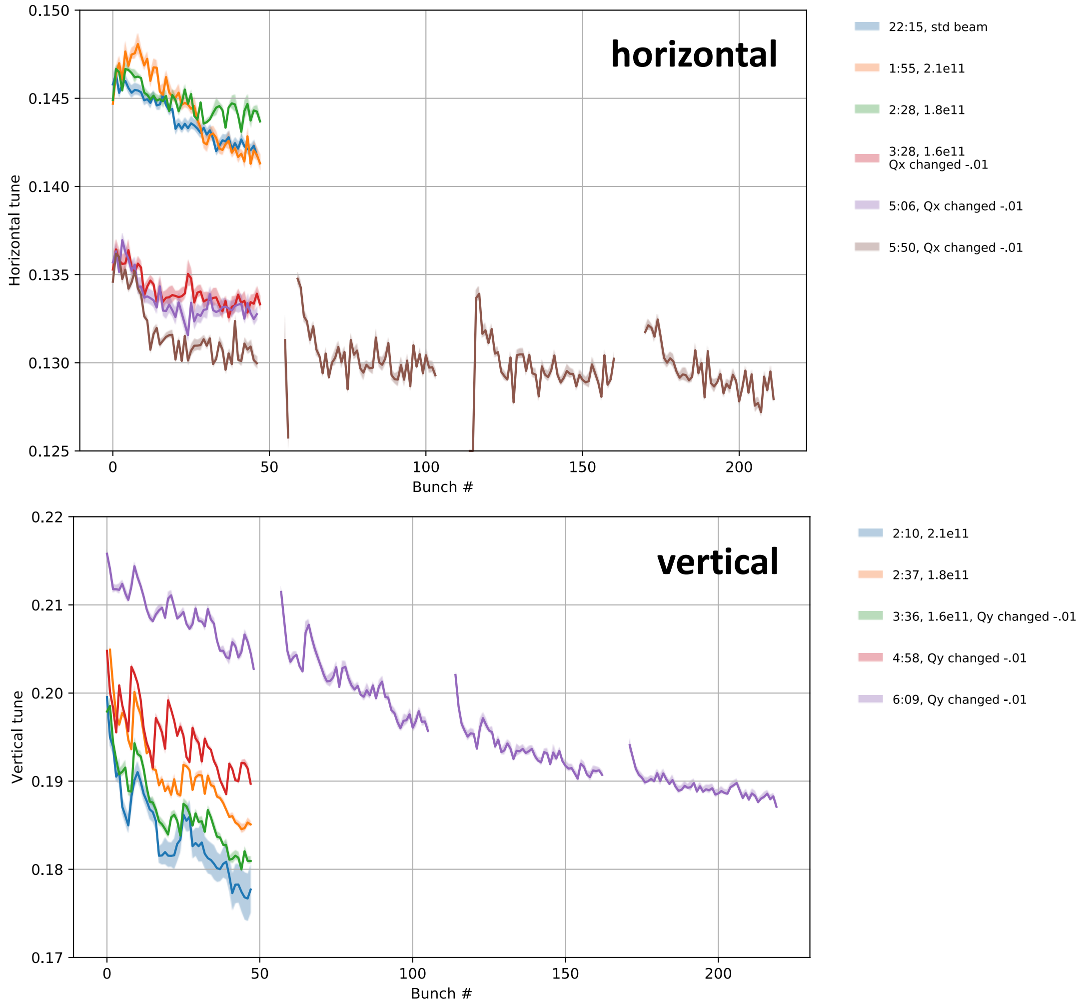


ξ_H ~ 0.3 – 0.5



High intensity 25 ns beam studies

- **Coherent tune shift bunch-by-bunch**
  - **Large vertical tune shift accumulating along the train**

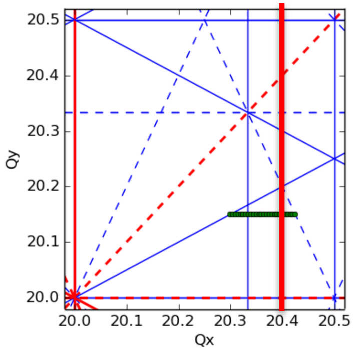


Outline

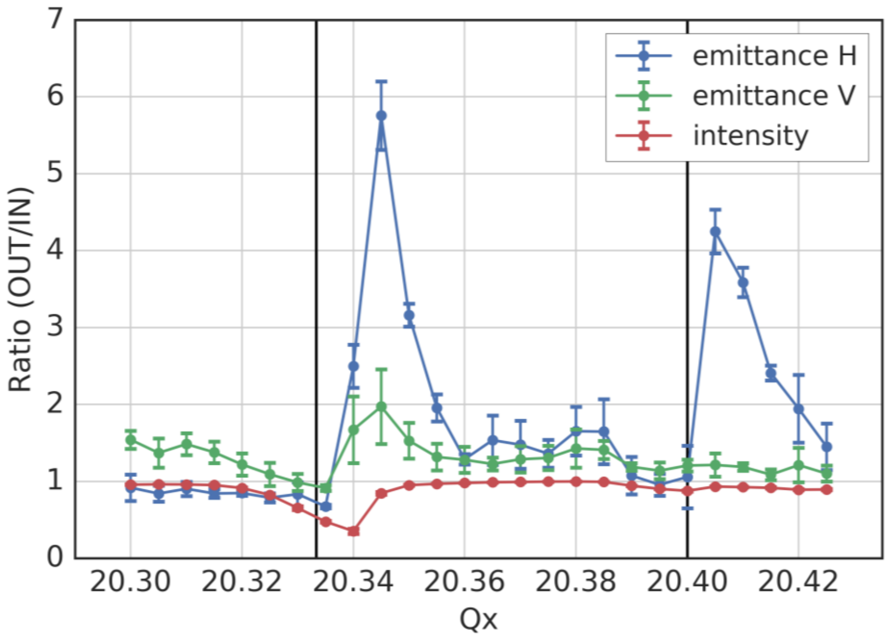
- **Studies with 25 ns beams**
  - 25 ns standard vs. BCMS
  - Tune scan
  - Transverse emittance blow-up
  - Horizontal instability studies
  - Tune shift along the bunch train
- **Single bunch space charge studies**
- **Plans for 2018**

High brightness and space charge studies

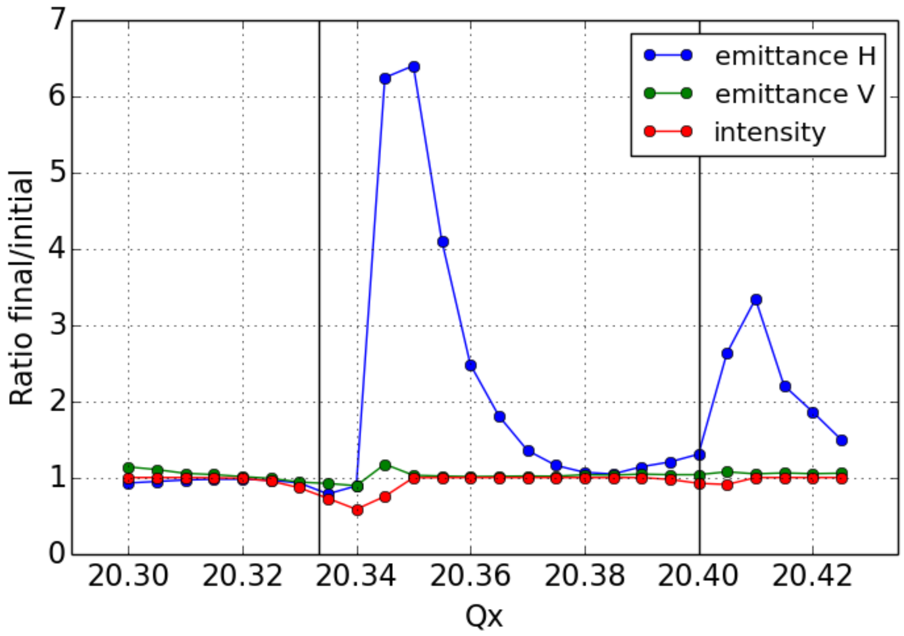
- **Benchmarking of beam response close to betatron resonances**
  - **Qx = 20.33 resonance excited by sextupole**
  - **Identified space charge driven resonance at Qx = 20.4**
  - **Observed beam response not reproduced by space charge itself**
  - **Blow-up and losses enhanced by quadrupole ripple**



measurements

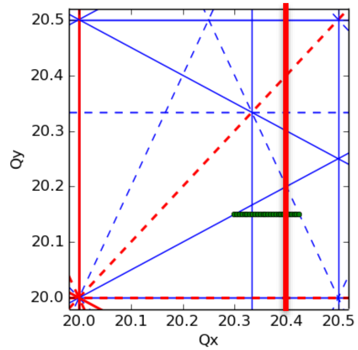


simulations with Q-ripple

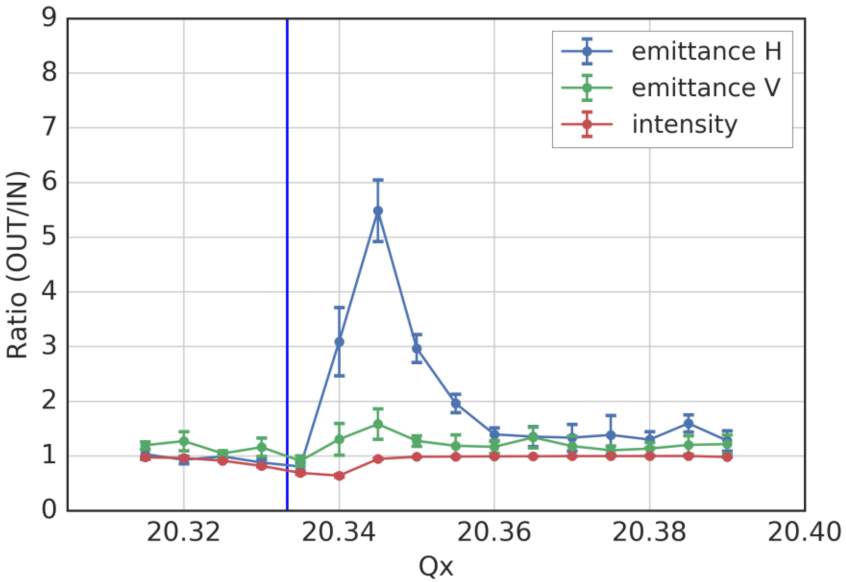


High brightness and space charge studies

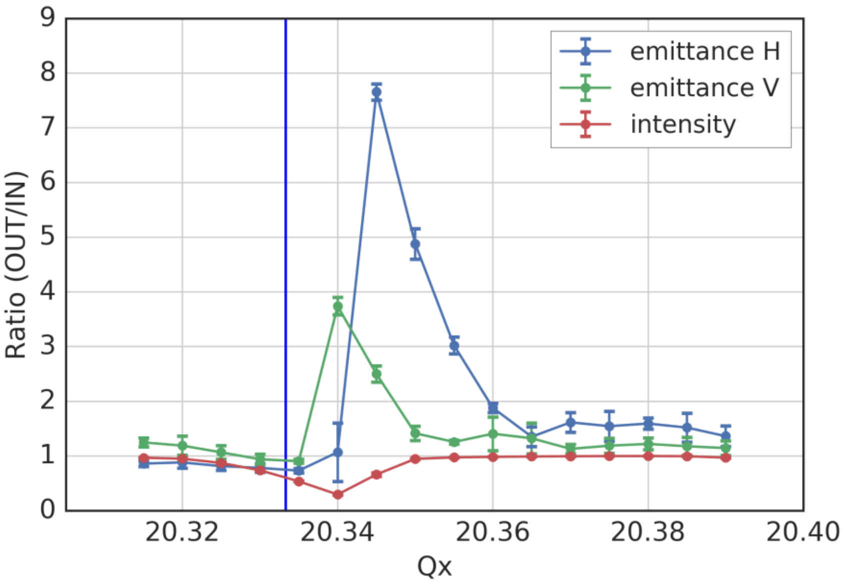
- **Benchmarking of beam response close to betatron resonances**
  - **Qx = 20.33 resonance excited by sextupole**
  - **Identified space charge driven resonance at Qx = 20.4**
  - **Observed beam response not reproduced by space charge itself**
  - **Blow-up and losses enhanced by quadrupole ripple**
  - **Clear enhancement of beam response with voluntary QF ripple**



Measurement with natural ripple



… with voluntary Qx ripple: ±6e-3 @ 90 Hz



Outline

- **Studies with 25 ns beams**
  - 25 ns standard vs. BCMS
  - Tune scan
  - Transverse emittance blow-up
  - Horizontal instability studies
  - Tune shift along the bunch train
- **Single bunch space charge studies**
- **Plans for 2018**

Plans for 2018

- **Verify reduced losses in locations with enlarged QD-SSS aperture**
- **Further characterize the horizontal single bunch instability**
  - Determine growth rates and mode numbers
  - Stabilization with octupoles (including configuration without Q'')
  - Measurement of detuning with amplitude to determine Landau damping
- **Study vertical emittance growth on flat bottom for high intensity beams**
  - Check dependence on chromaticity and working point
  - Study bunch-to-bunch behavior
  - Try to identify source for emittance growth
- **Continue benchmark measurements with single bunches close to resonances**

LHC Injectors Upgrade

Thank you for your attention!