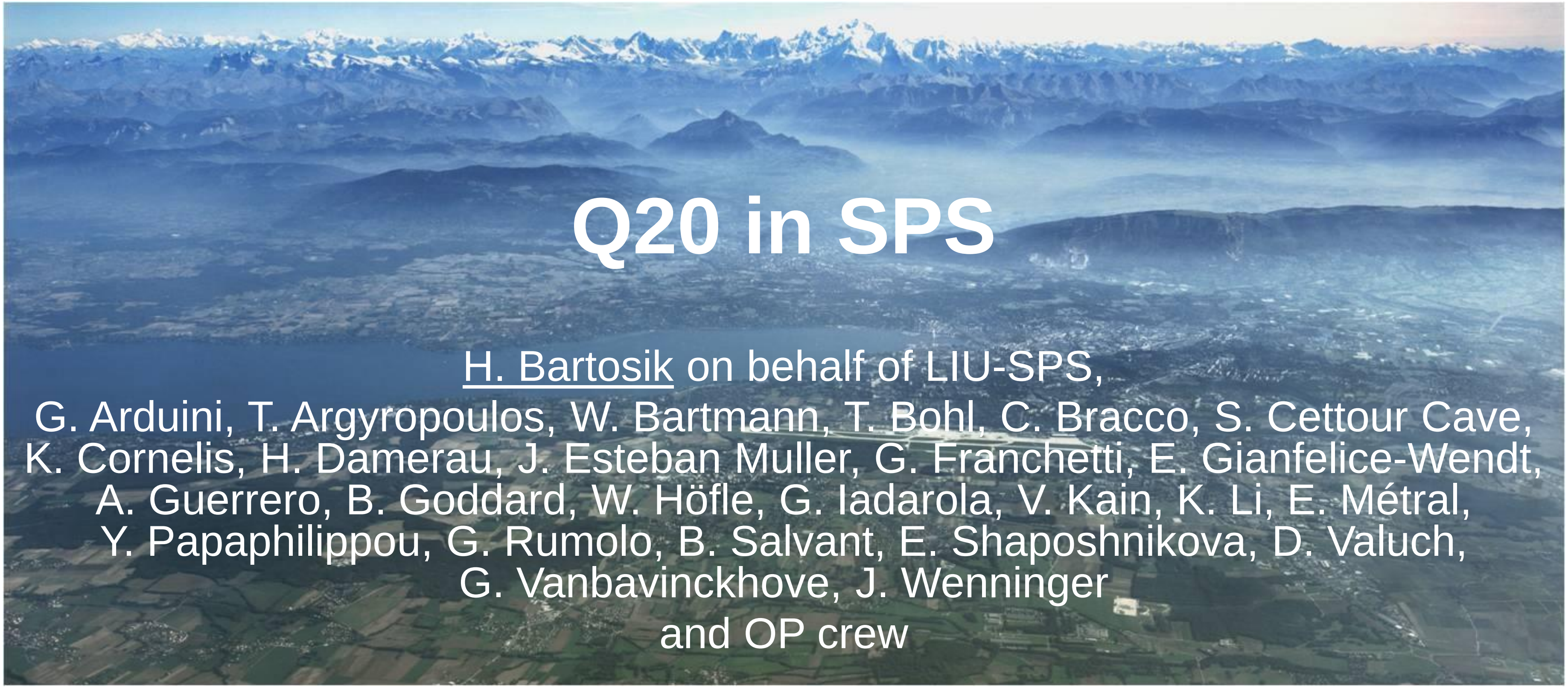
LHC Injectors Upgrade



Q20 in SPS

H. Bartosik on behalf of LIU-SPS,
G. Arduini, T. Argyropoulos, W. Bartmann, T. Bohl, C. Bracco, S. Cettour Cave, K. Cornelis, H. Damerau, J. Esteban Muller, G. Franchetti, E. Gianfelice-Wendt, A. Guerrero, B. Goddard, W. Höfle, G. Iadarola, V. Kain, K. Li, E. Métral, Y. Papaphilippou, G. Rumolo, B. Salvant, E. Shaposhnikova, D. Valuch, G. Vanbavinckhove, J. Wenninger
and OP crew

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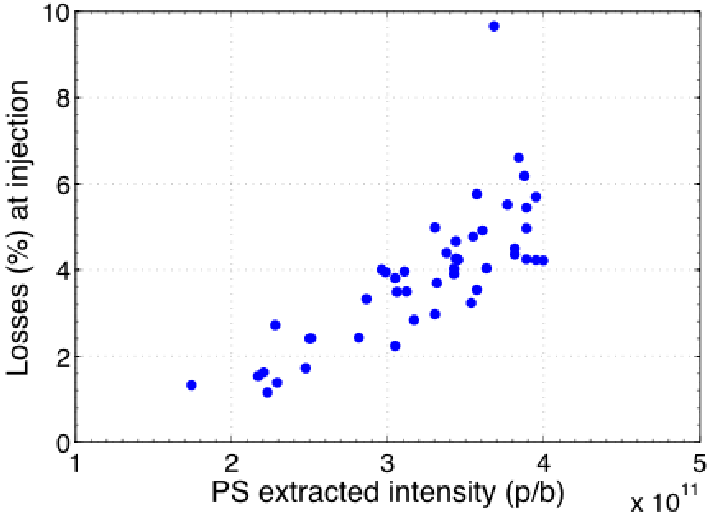
Introduction

- **Motivation for lowering transition energy in SPS (Q20 optics)**
  - Larger slip factor η (factor 3 at 26GeV, 1.6 at 450GeV) → **higher instability thresholds**
  - Transverse – TMCI at injection, electron cloud instability
  - Longitudinal – multi bunch instability, loss of Landau damping

- **High intensity single bunch**
  - TMCI threshold in Q26 at around 1.6×10^{11} p/b
  - Up to **4×10^{11} p/b without TMCI** in Q20 with low chroma

$$N_{th} \sim |\eta| \varepsilon_l / \beta_y$$



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$$N_{th} \sim |\eta| \varepsilon_l / \beta_y$$

- **Longitudinal stability (see talk of T. Argyropoulos)**
  - Longitudinal instability threshold **scales with slip factor η**
  - Clear improvement with Q20 optics wrt. Q26
    - For single and multi bunch beams
  - Less controlled longitudinal blow-up for same intensity in Q20

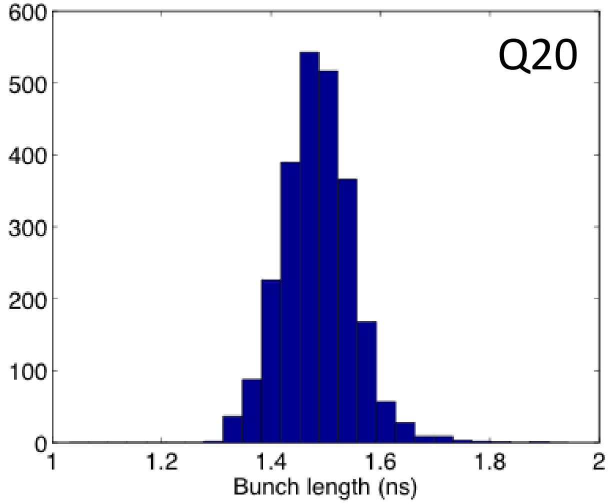
$$N_{th} \sim |\eta| \varepsilon_l^{5/2}$$

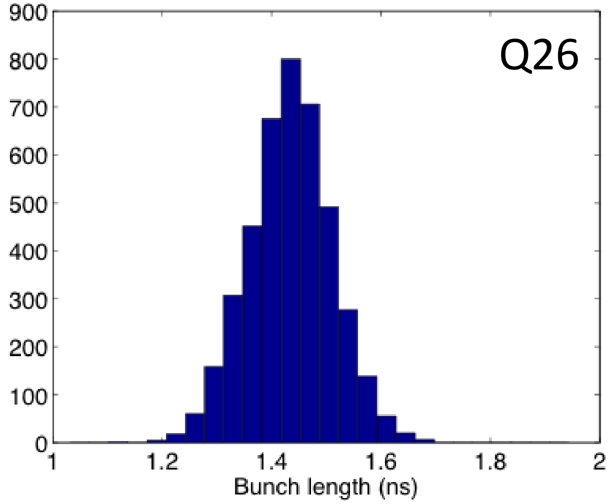
- **Important step in 2012: making Q20 operational**
  - LMC decided to switch to Q20 when longitudinal setup with Q26 became difficult

Extraction to LHC

- **At flat top maximal need to shorten bunches for transfer to LHC**
  - Maximal RF voltage already used in Q26 optics
  - Beam with same longitudinal emittance would have larger bunch length in Q20

- **Similar bunch length at flat top in both optics for same longitudinal stability**
  - With smaller longitudinal emittance in Q20 optics (due to higher threshold)
  - Demonstrated in MD studies and in preparation for testing injection into LHC
    - Smaller rms spread in bunch length at extraction with Q20





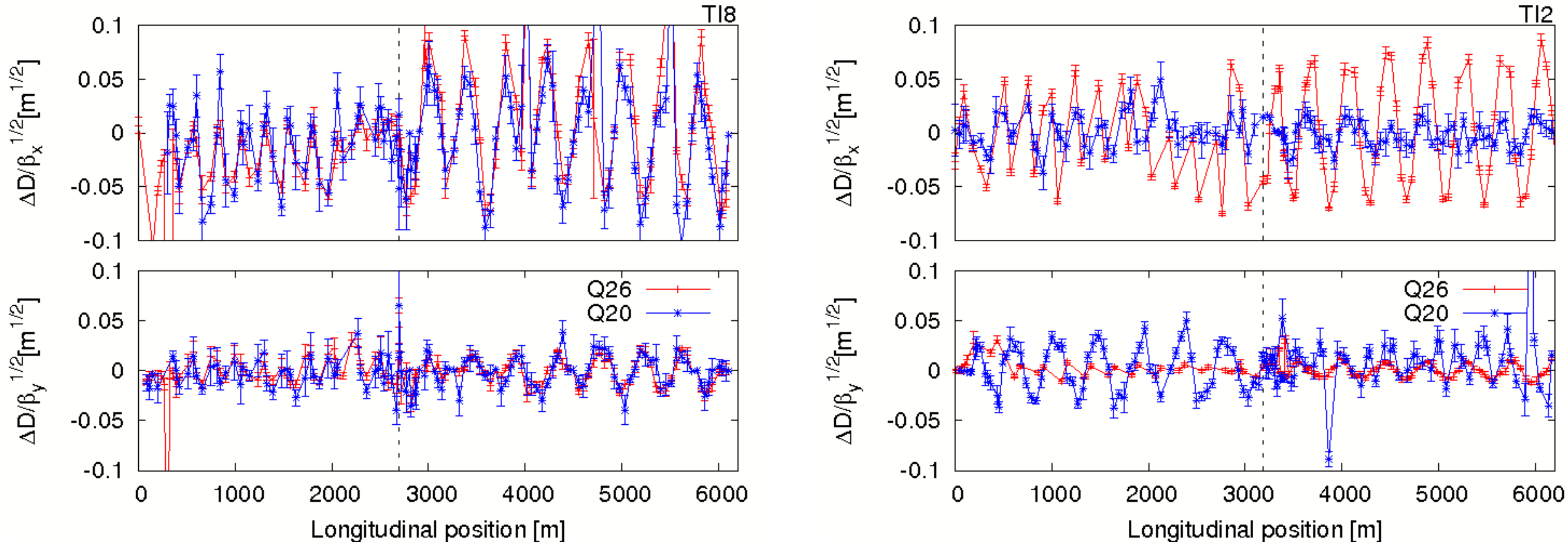
⇒ **SPS Q20 ready to deliver to LHC**

Preparation of injection into LHC

- **Series of MDs for setting up extraction bumps and transfer lines**

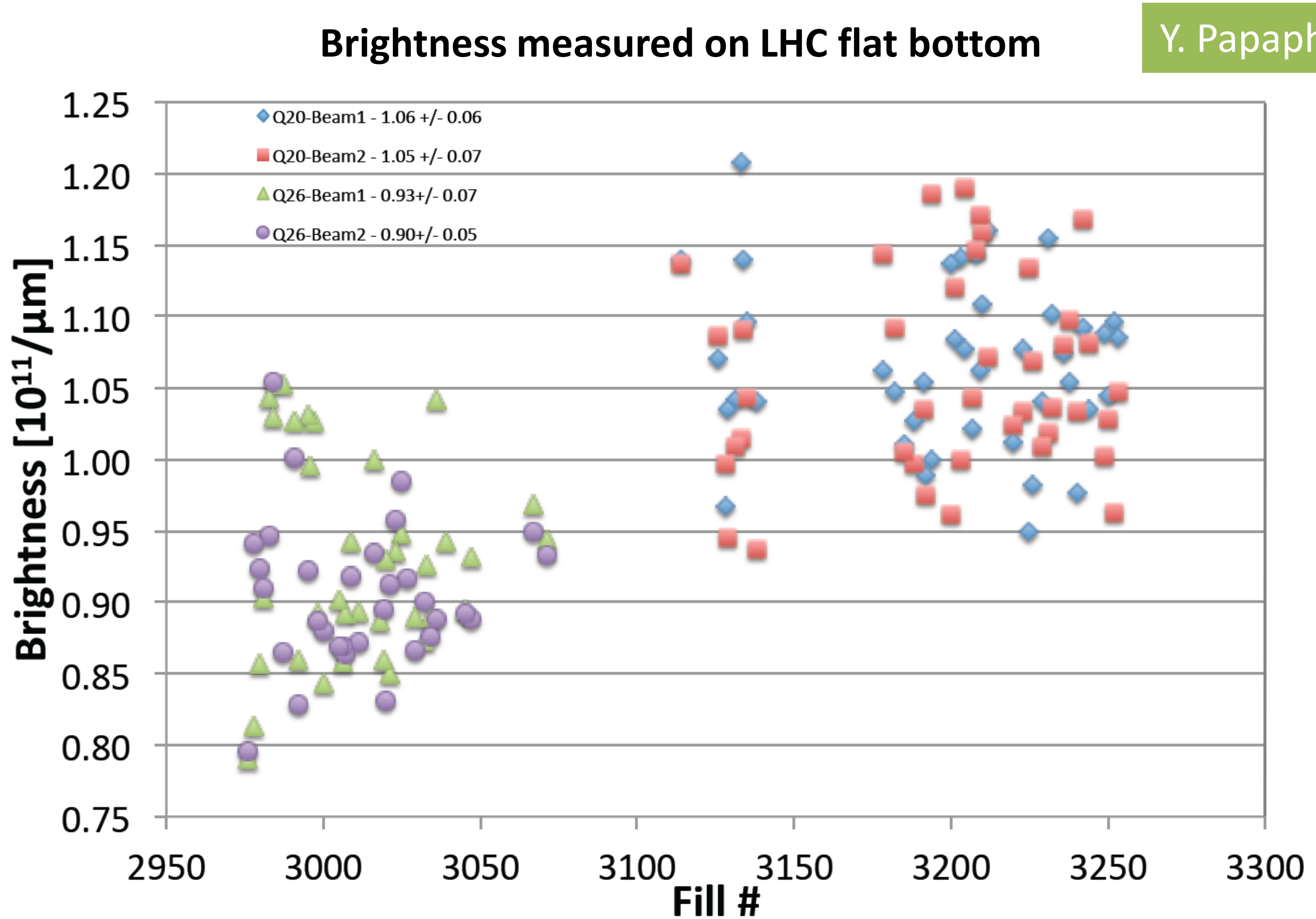
- **Transfer line matching (ABT and collaborators)**
  - Dispersion measurements
    - Similar errors for both optics for Beam 1
    - Small differences between two optics for Beam 2

G. Vanbavinckhove



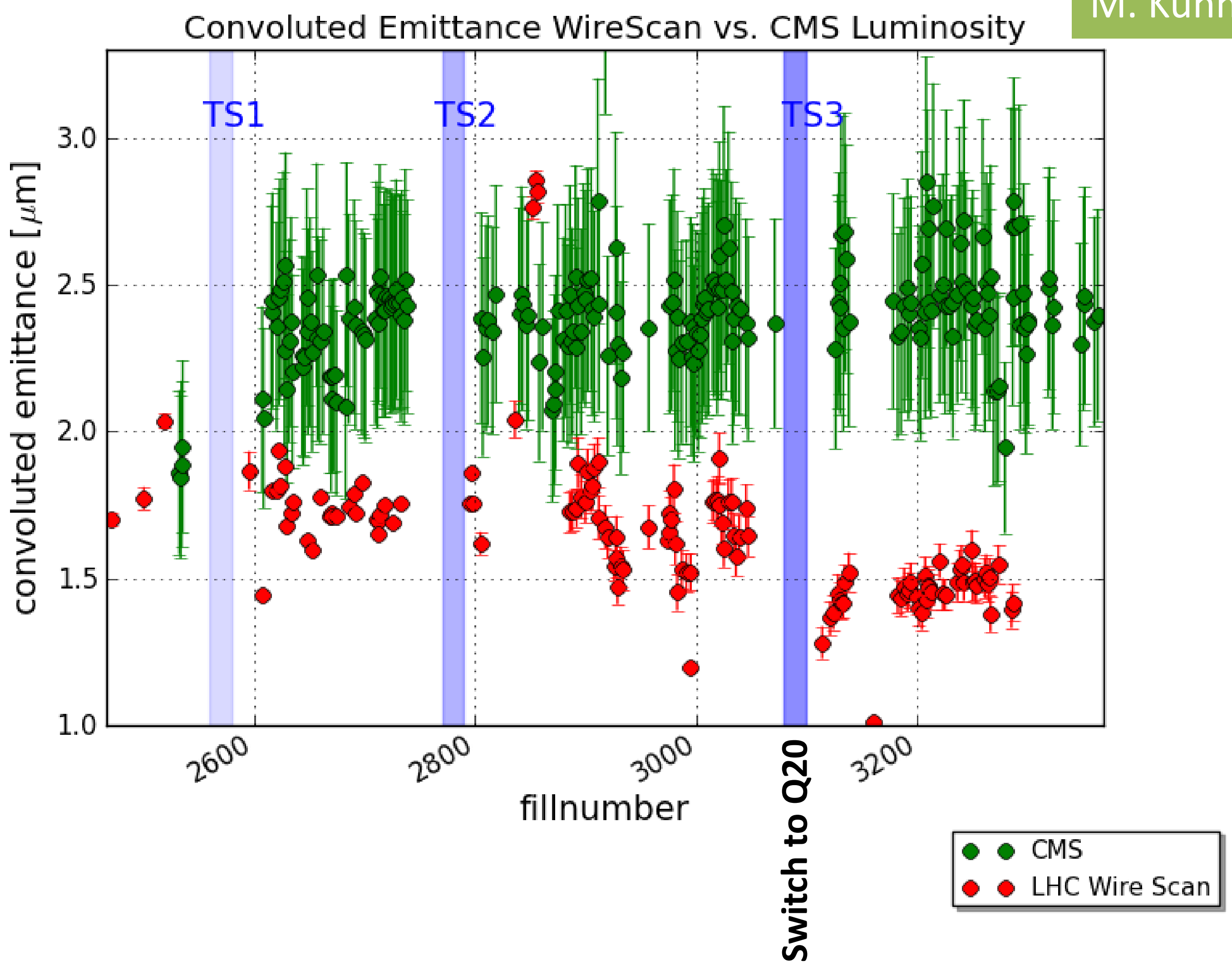
Operational performance

Y. Papaphilippou



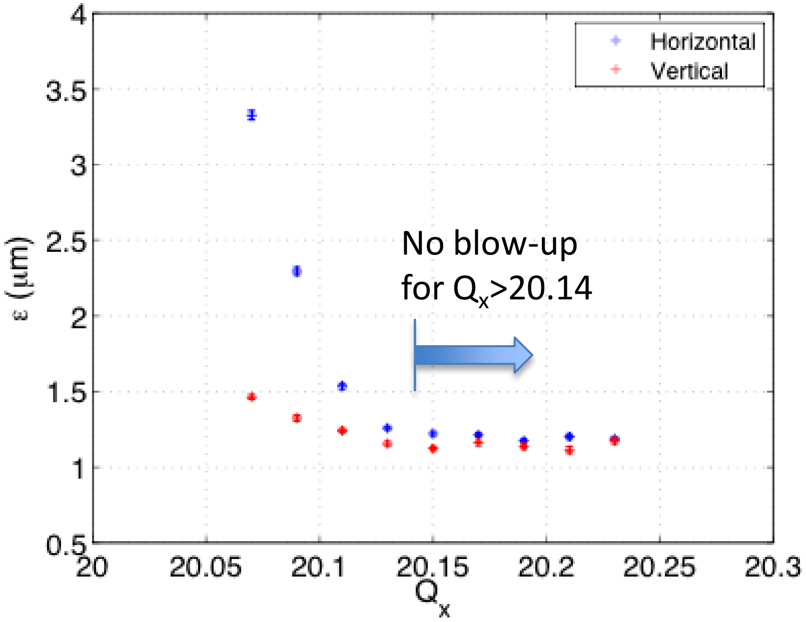
Operational performance

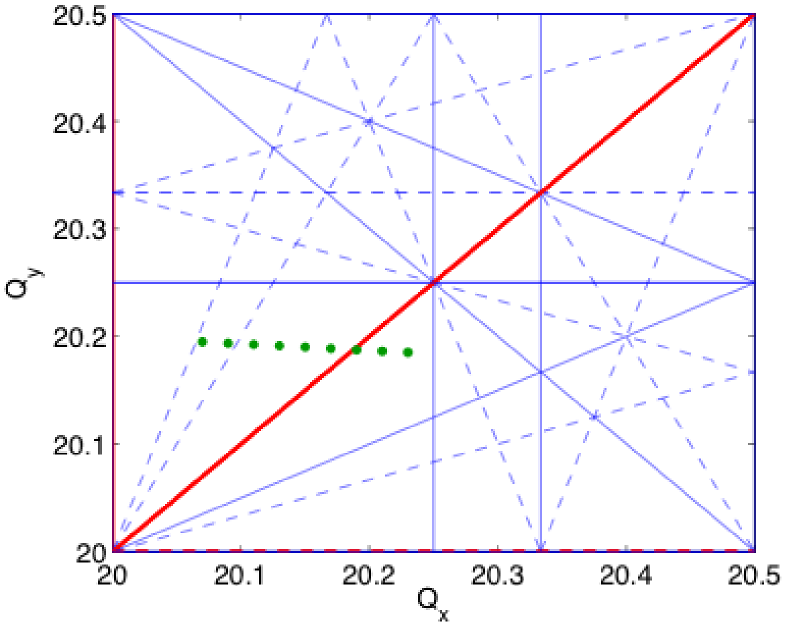
M. Kuhn



Space charge tune spread

- **High brightness 50ns BCMS beam** (see talk of S. Hancock)
  - N = 1.95x10^{11} p/b (at injection)
  - ε ~ 1.15μm
  - **$\Delta Q_x/\Delta Q_y$ ~ 0.10/0.18** expected from Laslett formula
  - Transmission up to flat top around 94% (without scraping)





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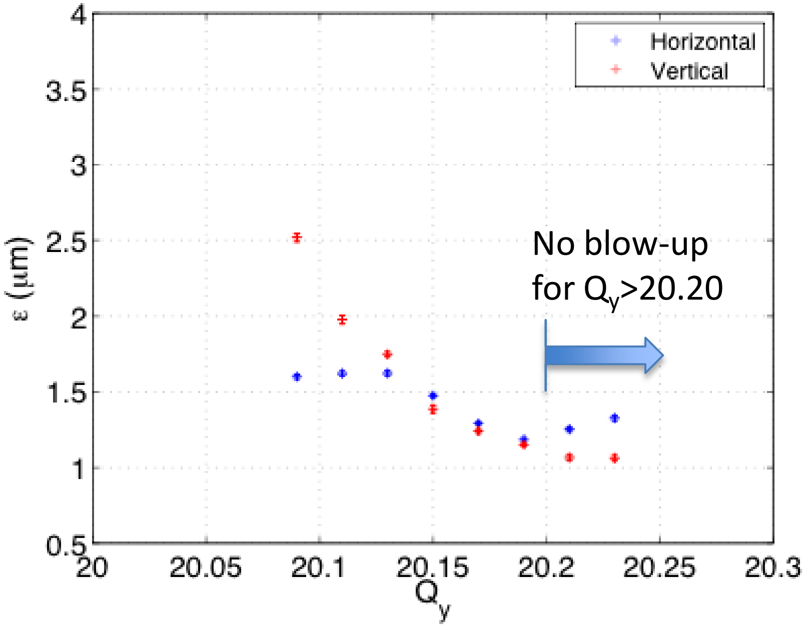
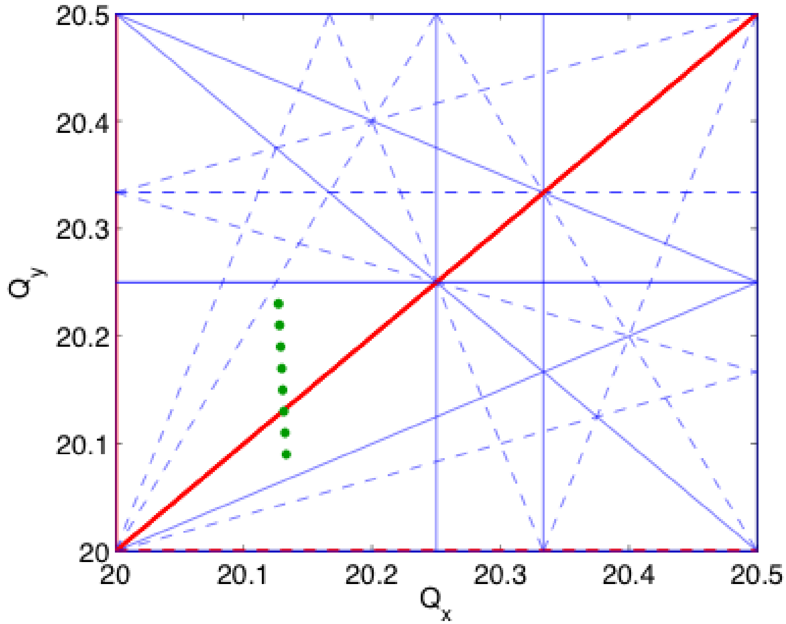
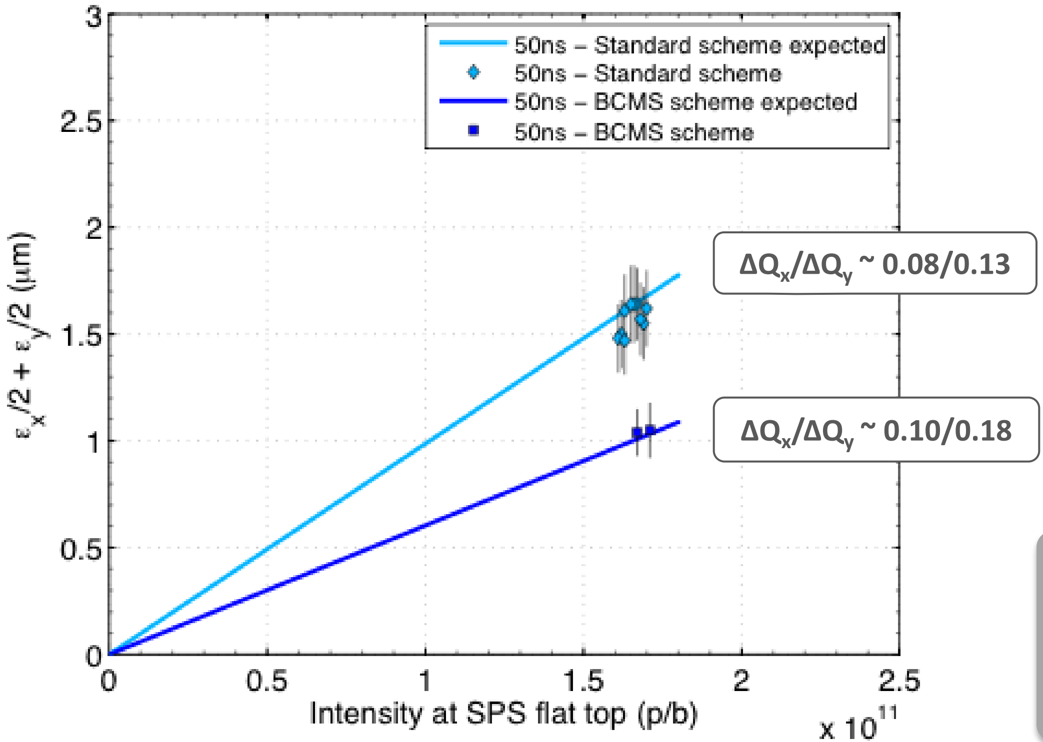




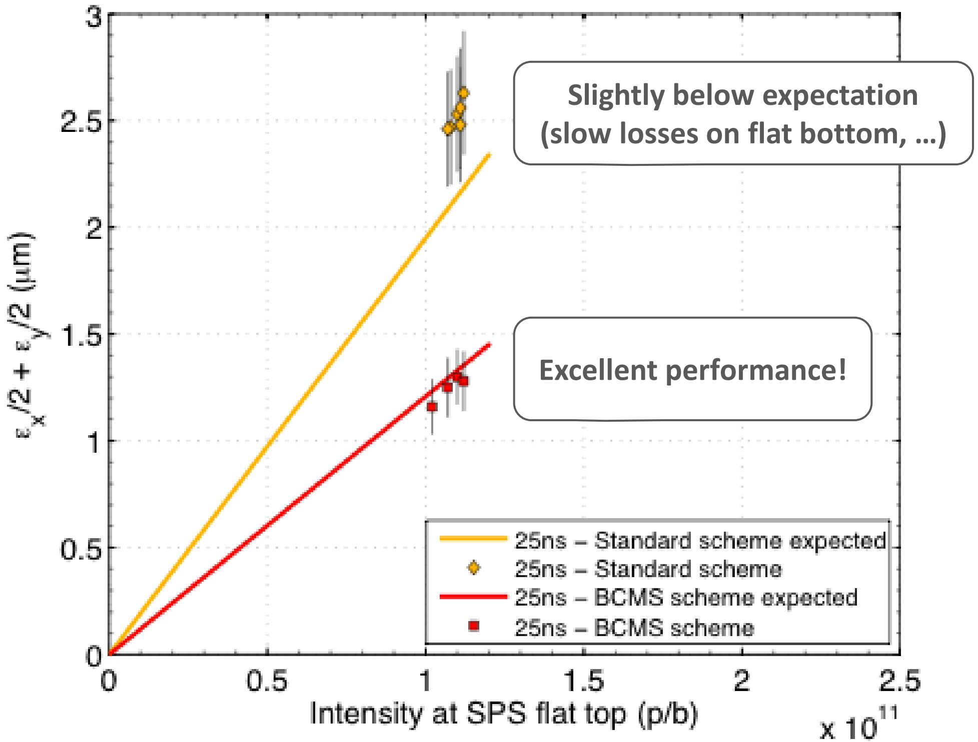
2012 achieved beam parameters – 50ns



Expected performance: Scaling PSB measurement with LIU budget for blow-up and losses

- **50ns standard scheme**
  - Regularly used to fill LHC since September 2012 using Q20 optics, at present PS intensity limit
  - Measurements done with 4 batches
- **50ns BCMS scheme**
  - Beam sent to the LHC once to check emittance preservation and luminosity gain in LHC
  - Measurements done with 3 batches

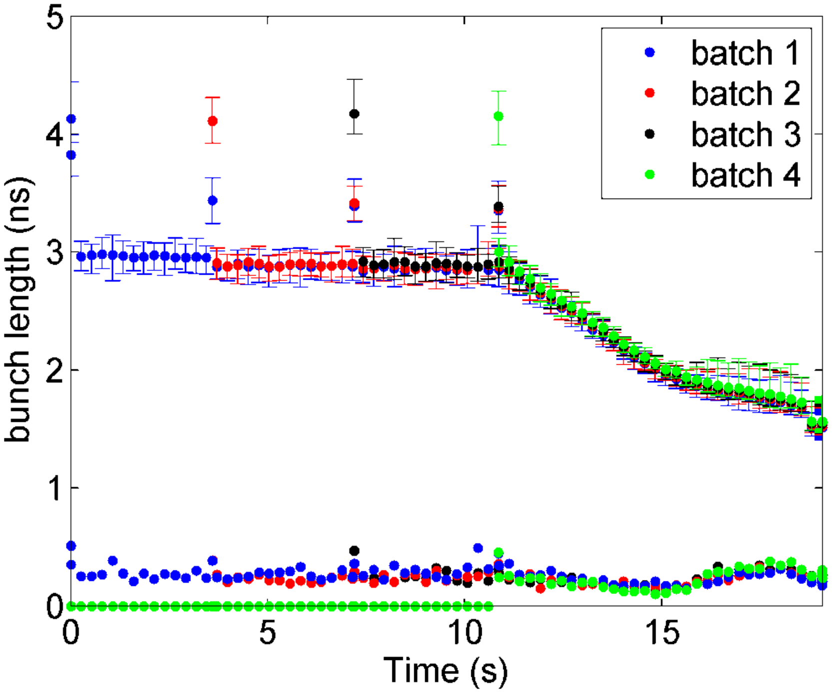
2012 achieved beam parameters – 25ns



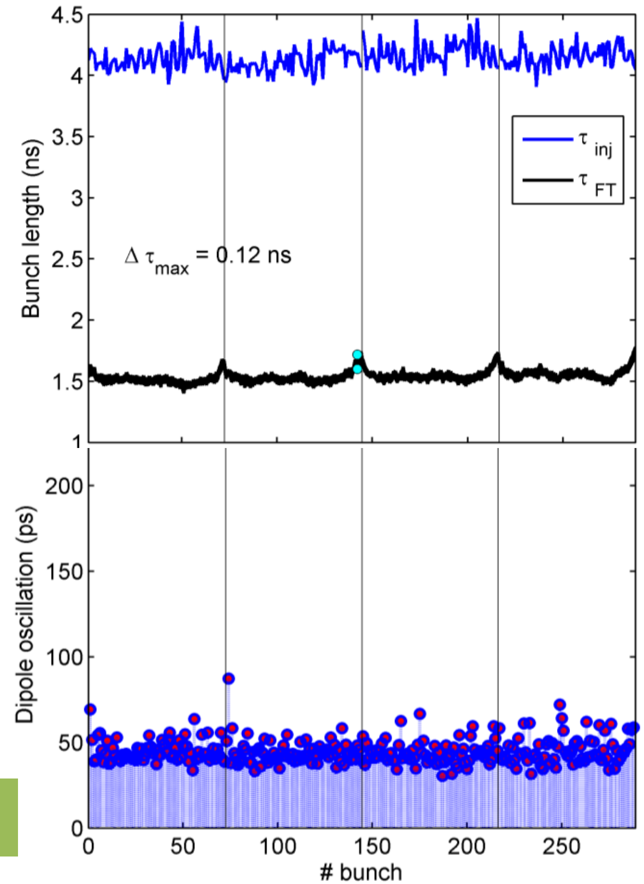
Expected performance: Scaling PSB measurement with LIU budget for blow-up and losses

- **25ns standard scheme**
  - Regularly used during the LHC scrubbing run
  - Measurements done with 4 batches
- **25ns BCMS scheme**
  - Used for the LHC 25ns pilot physics run at the end of 2012
  - Measurements done with 3 batches

25ns beam – longitudinal



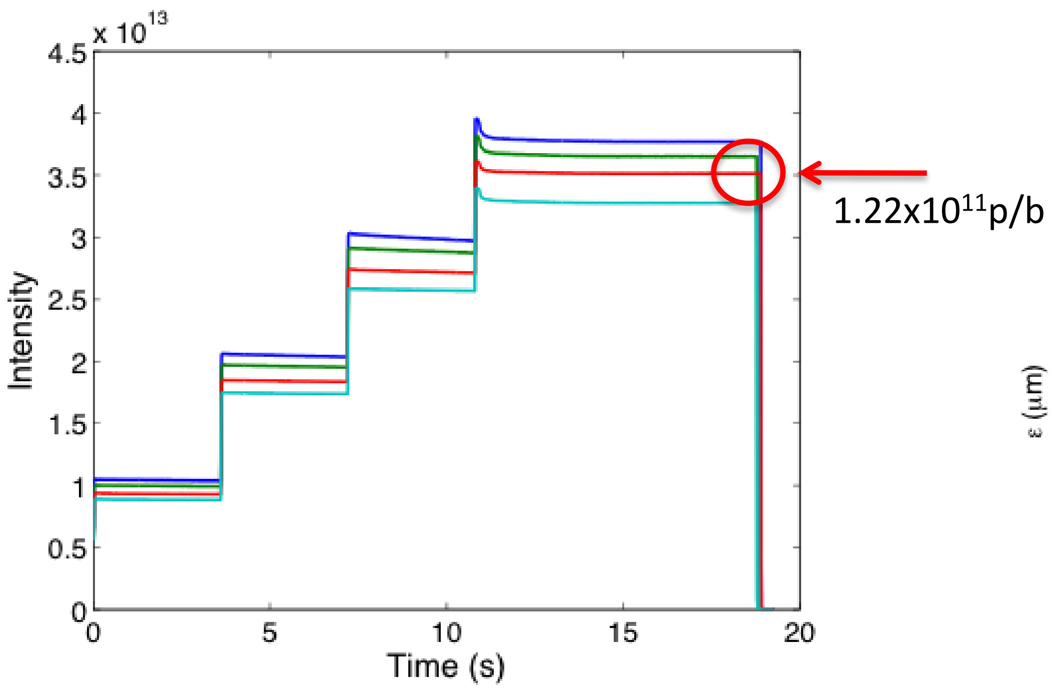
T. Argyropulos, J. Esteban



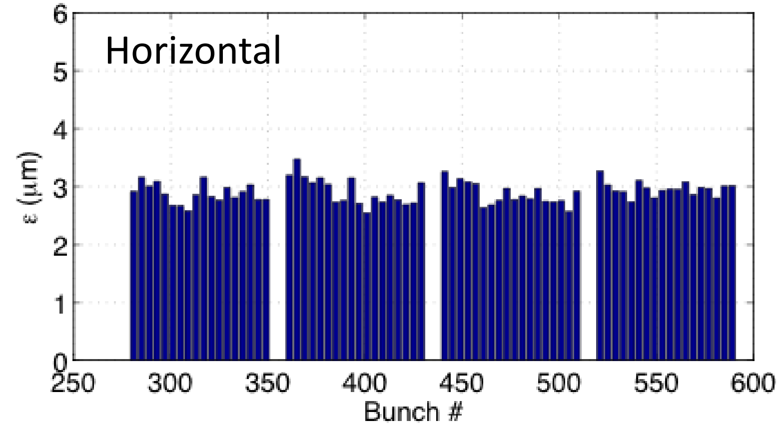
- **Classical 25ns beam**
  - 4 batches with up to 1.25x10^{11} p/b at flat top ready to be injected into LHC
  - Longitudinal setup becomes difficult for higher intensity **(see talk of T. Argyropoulos)**

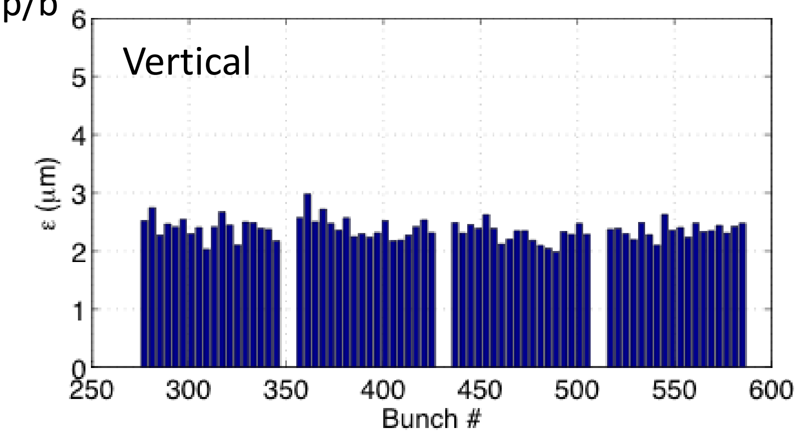
25ns beam – transverse

- **$1.3x10^{11}$ p/b injected**
  - No emittance blow-up along bunch train



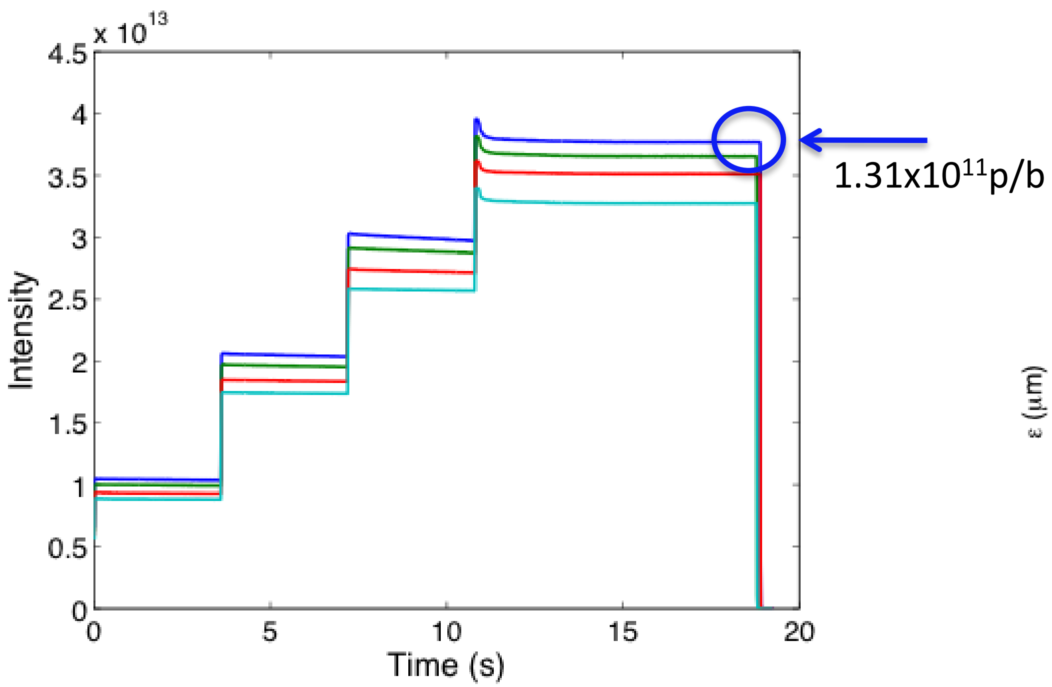
measured at flat top …





25ns beam – transverse

- 1.3×10^{11} p/b injected
  - No emittance blow-up along bunch train
- **1.45×10^{11} p/b injected**
  - Blow-up and losses end of 3rd and 4th batch …
  - Electron cloud? **(see talk of G. Iadarola)**



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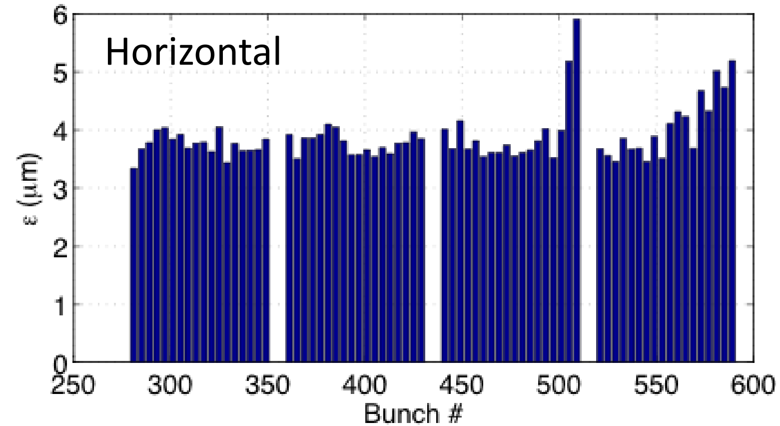
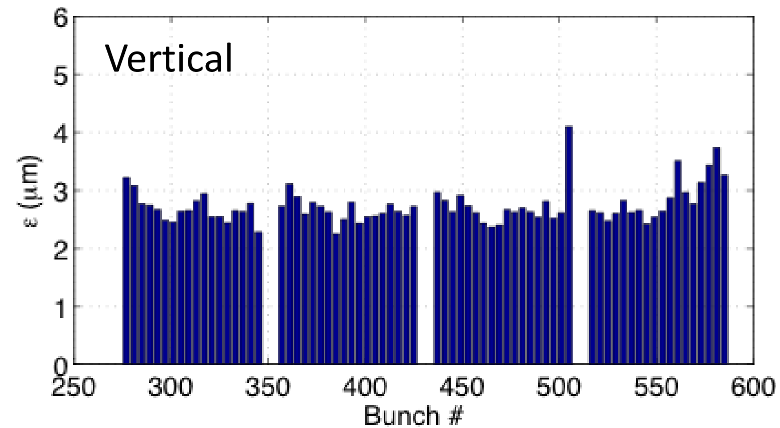
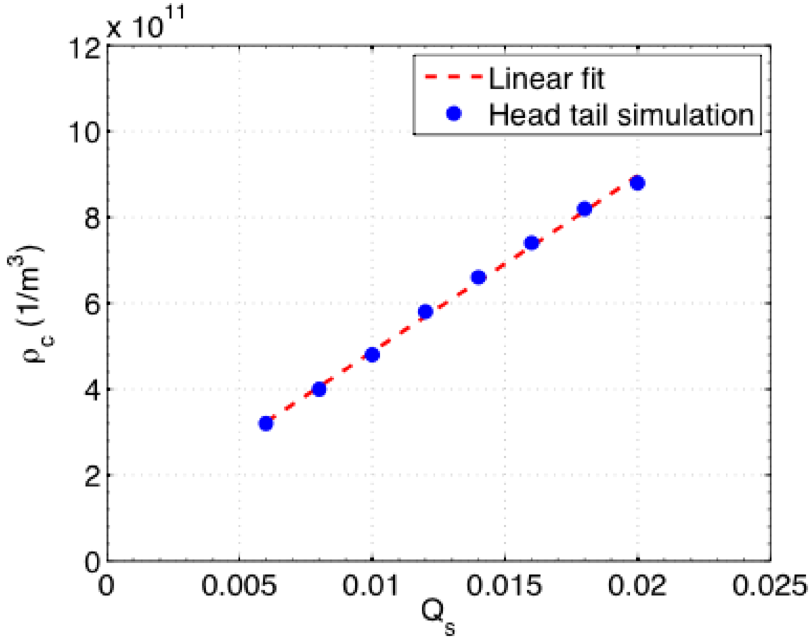
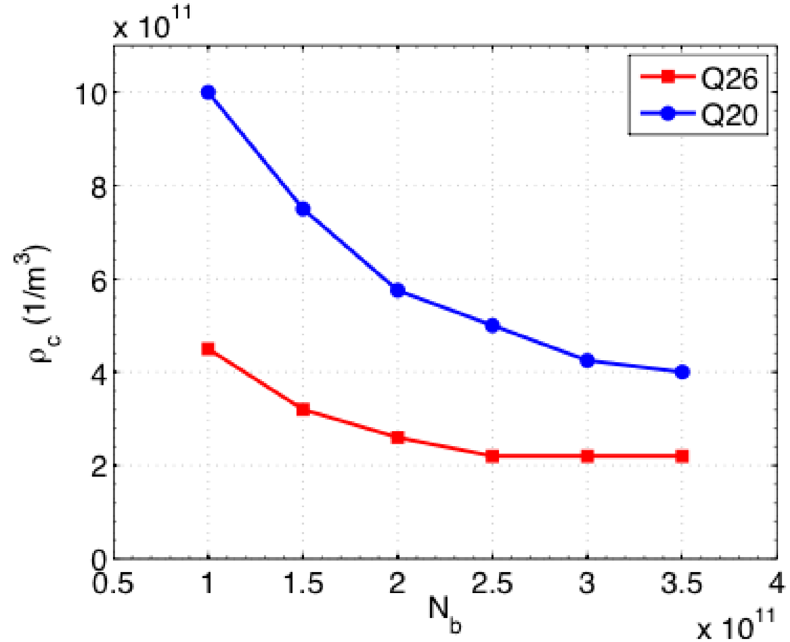




Electron cloud instability - simulations





- **Head tail simulations**
  - Uniform electron cloud distribution
  - Injection energy
  - Electron cloud is located in dipole regions

Presently the nominal 25ns beam does not suffer from e-cloud effects, but more margin with Q20 …

- **Instability threshold scales with Q_s (~η for matched RF-voltage)**

⇒ **Clearly higher instability threshold with Q20!**

Summary and conclusions

- **Successful implementation of Q20 as operational optics**
  - Continuation of successful MD studies since the end of 2010
  - No fundamental problems during 5 months of successful operation
  - Higher brightness measured in the LHC at injection energy after switching to Q20
- **No intensity limitation from transverse for single bunches within LIU target parameters**
  - Up to $4x10^{11}$ p/b injected with small chromaticity without instability for nominal long. emittance
- **High brightness multi-bunch beams**
  - Good brightness preservation of BCMS beam from the PS up to SPS flat top
  - Operation with large space charge tune spread ($\Delta Qy \sim 0.18$) is feasible
  - Confirmation of results from single bunch measurements
- **25ns beam**
  - Ready for LHC with 4 batches up to $1.25x10^{11}$ p/b
  - Transverse instabilities for higher intensities need to be understood and cured (e-cloud?)
  - Longitudinal studies to be continued for optimizing and stabilizing beam at high energy
- **First operational experience with Q20 with ion beams**
  - Further studies and data analysis ongoing

LHC Injectors Upgrade

Thank you for your attention!

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