Thanks to:

- EPS-AG Prizes Committee
- IPAC'14 Grant Program and all sponsors
- My PhD advisors:
  - Elena Shaposhnikova at CERN
  - Leonid Rivkin at EPFL
- Co-authors and colleagues

High-Accuracy Diagnostic Tool for Electron Cloud Observations in the LHC Based on Synchronous Phase Measurements

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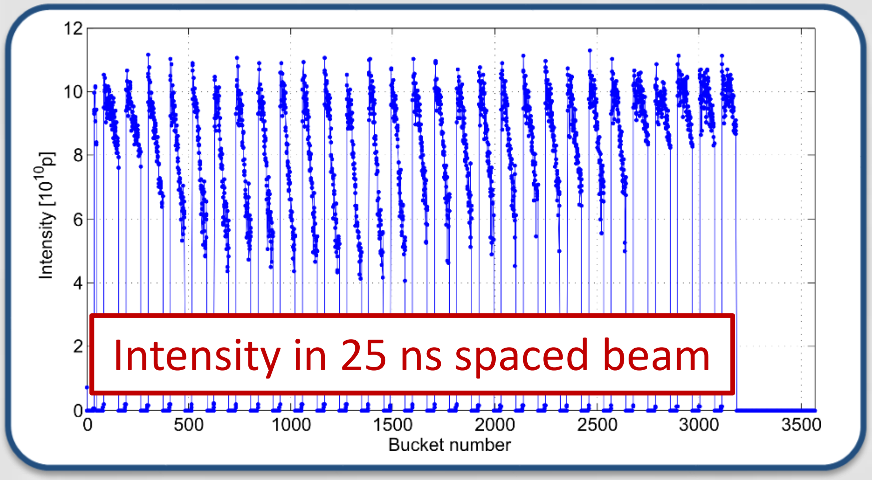
Acknowledgements:
T. Bohl, G. Iadarola, G. Rumolo, L. Tavian, LHC OP team

Outline

- E-cloud effects
- Synchronous phase shift measurements
- E-cloud observation in LHC operation
- Summary and future plans

E-cloud effects observed in the LHC

- Transverse instabilities
- Emittance growth
- Particle losses →
- Vacuum degradation
- Excessive heat load in the cryogenic system



→ Present limitation for LHC operation with 25 ns beams

→ Possible luminosity reduction

Synchronous phase shift

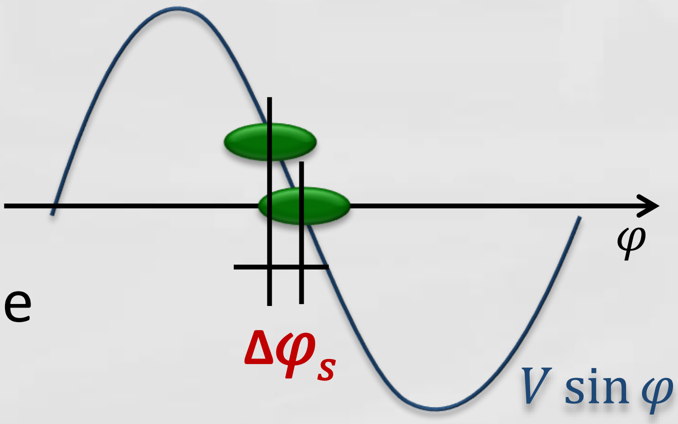
The energy loss U is compensated by the RF system through a synchronous phase shift $\Delta\varphi_s$

$$U = e\,V\,N \sin \Delta\varphi_s$$

U:= bunch energy loss per turn
V := RF voltage
N := bunch intensity

→ New method for e-cloud observation by measuring $\Delta\varphi_s$ (with a precision much better than 1 deg)

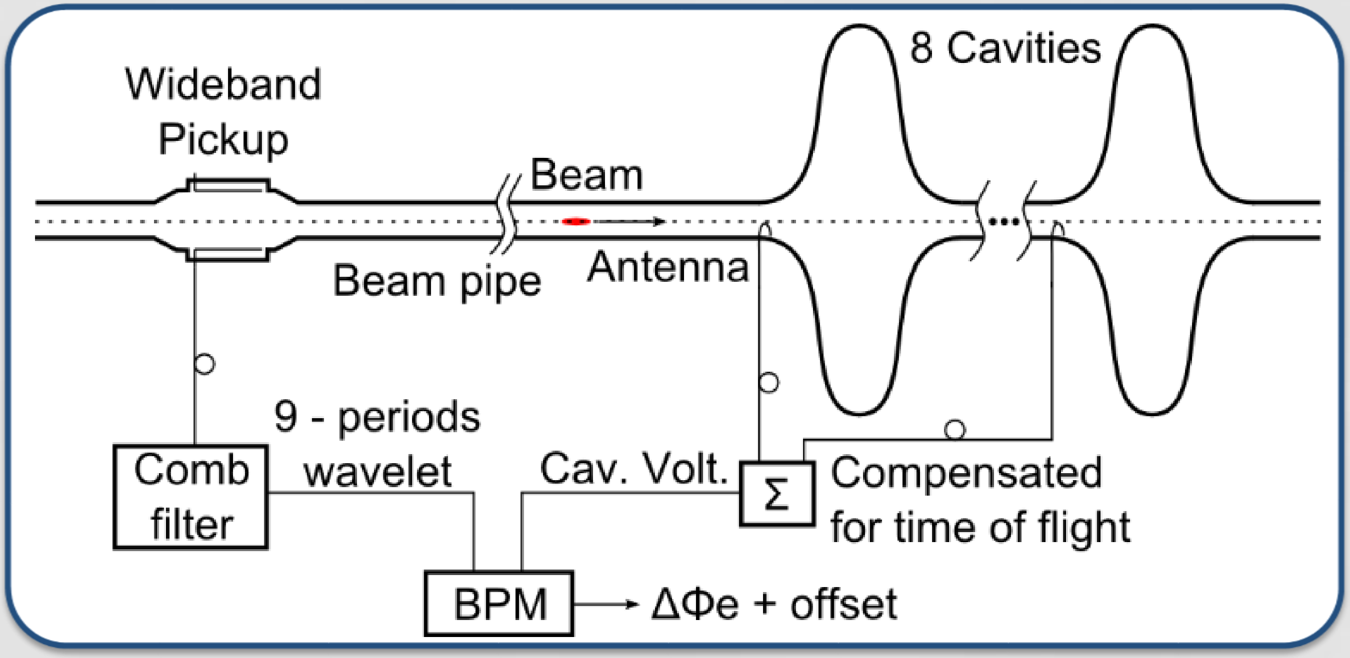
- $\Delta\varphi_s$ includes also energy loss due to:
  - resistive impedance
  - synchrotron radiation
  - → Use the first bunches as a reference



Synchronous phase shift

- Bunch positions from longitudinal profiles? But…
  - Include the phase shift due to beam loading, comparable to e-cloud effect (~ 1 deg)

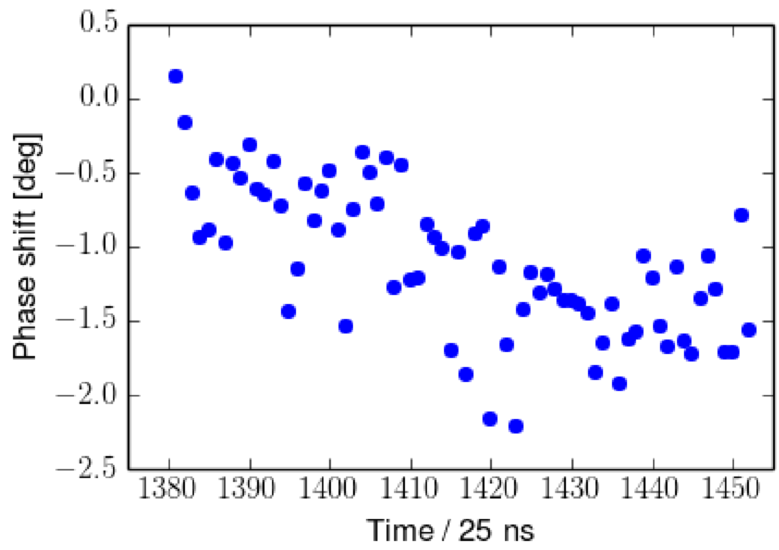
→ **Beam phase module** from the RF phase loop



Required accuracy:
< 0.1 deg
at 400 MHz

Synchronous phase shift measurements: raw data

- LHC at 450 GeV, scrubbing run Dec of 2012



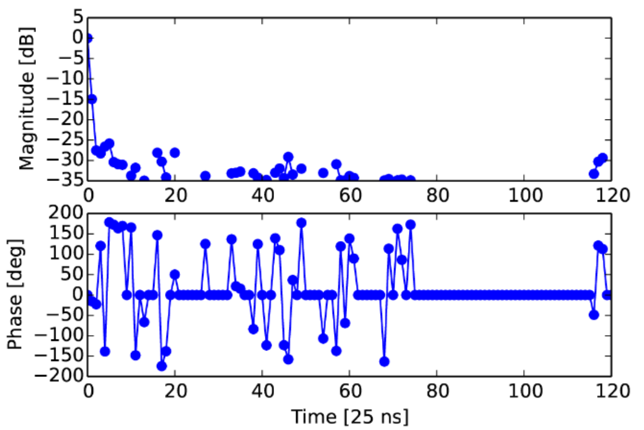
Train of 72 bunches spaced by 25 ns

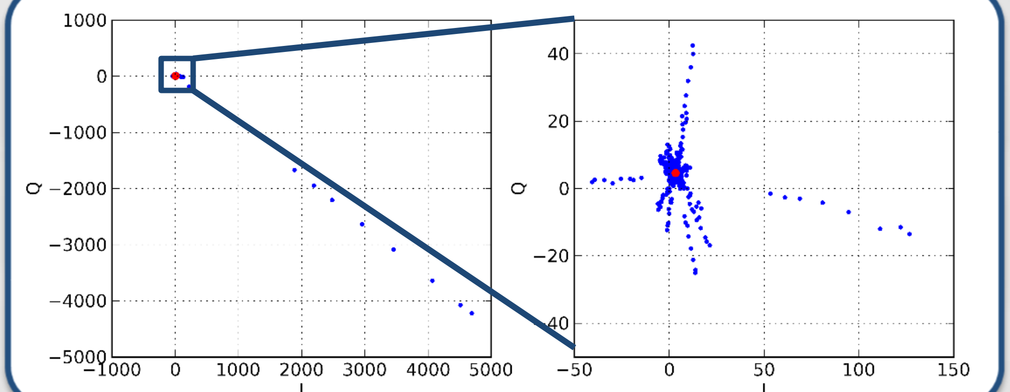
Synchronous phase shift measurements: corrections

Systematic errors

(1) Reflections in the cables: affect subsequent bunches

(2) Offset in the IQ plane (vector representation): affects single bunch





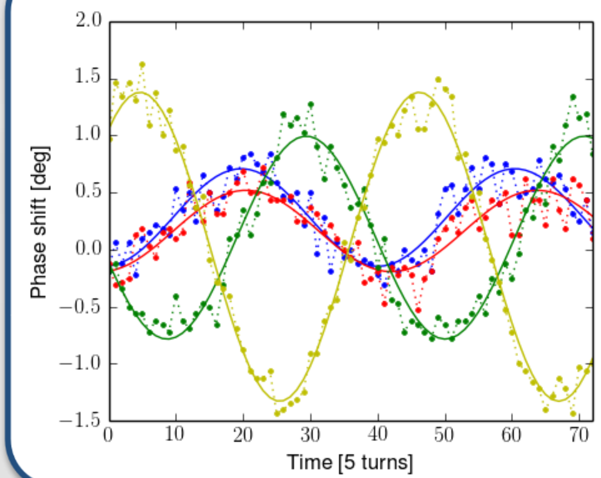
→ **Transfer function measured with a single bunch and used for correction**

→ **Measured from the noise in the empty buckets to correct the origin displacement**

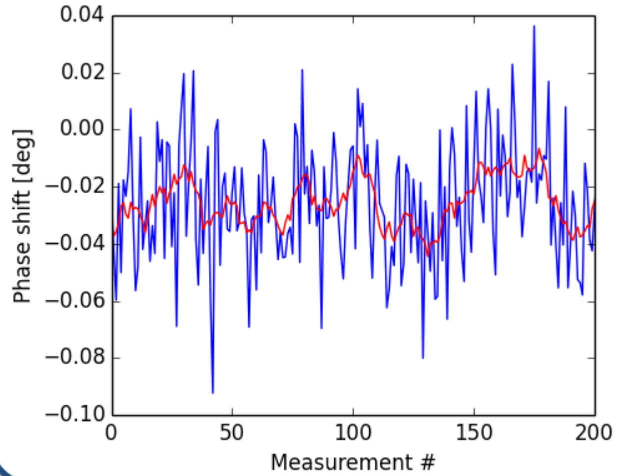
Synchronous phase shift measurements: corrections

Data post-processing

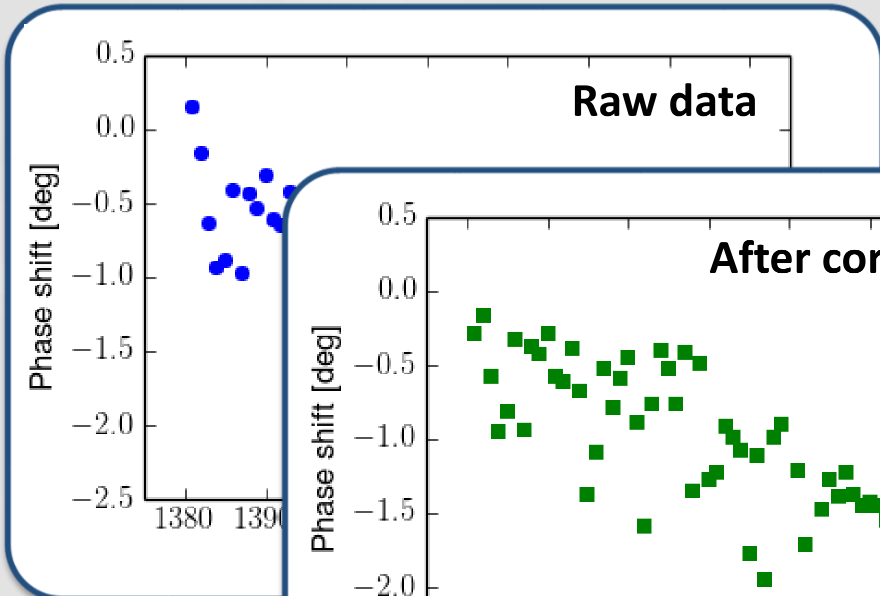
(1) Sine-wave fit of the synchrotron oscillations

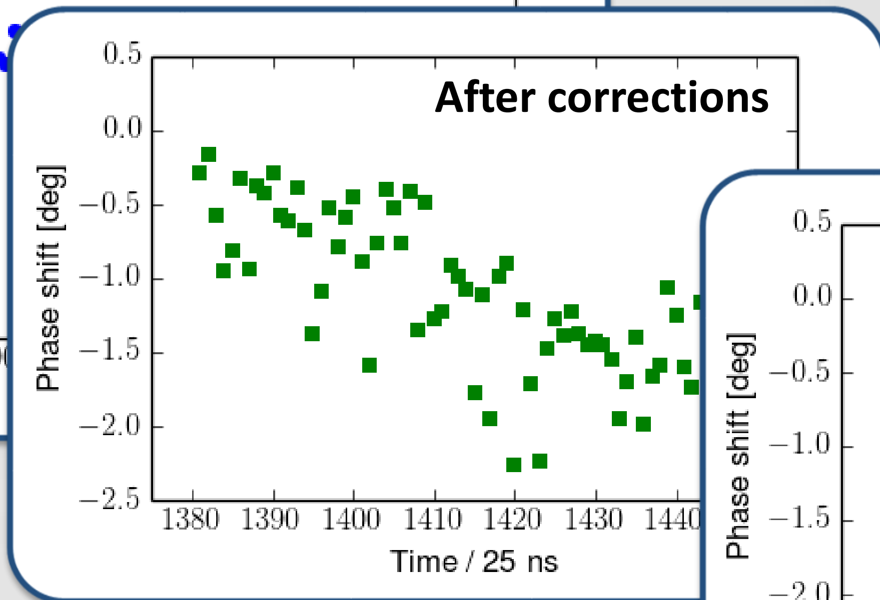


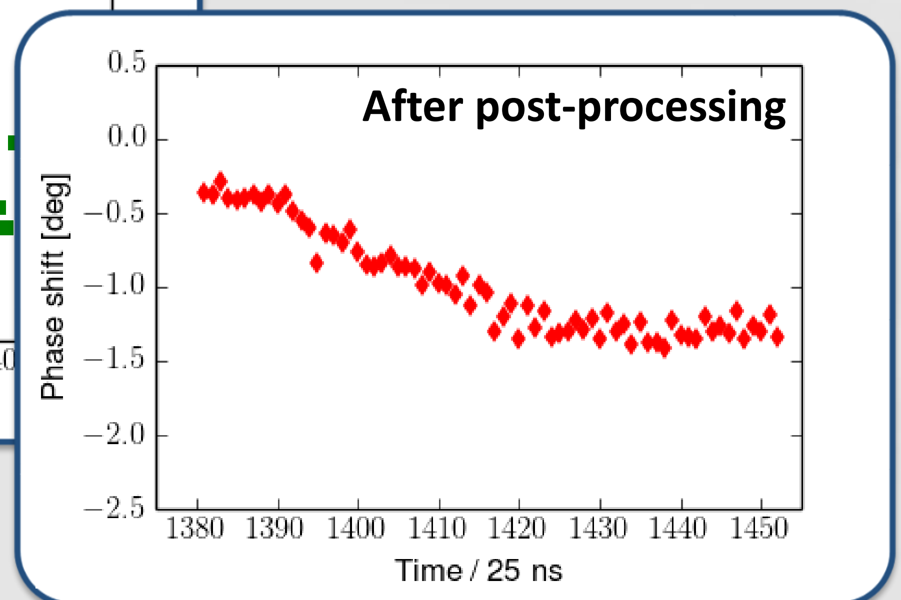
(2) Smoothing each bunch phase over time



Synchronous phase shift measurements: before and after corrections





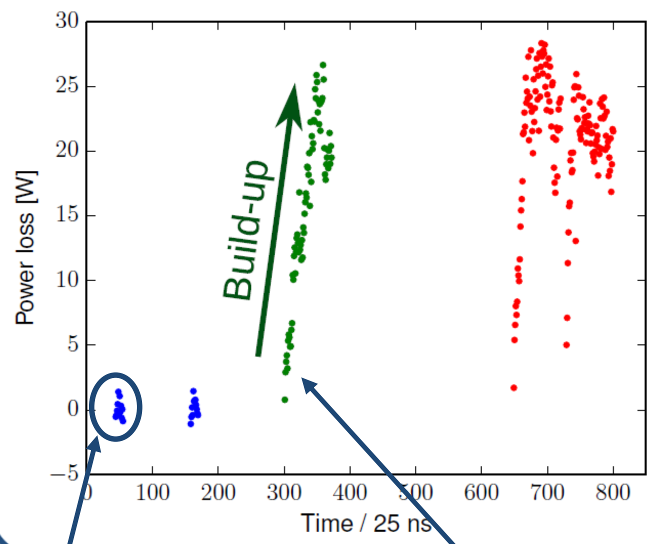


Train of 72 bunches spaced by 25 ns

Bunch-by-bunch e-cloud observation via $\Delta\varphi_s$

E-cloud build-up leads to an increasing energy loss along the bunch trains

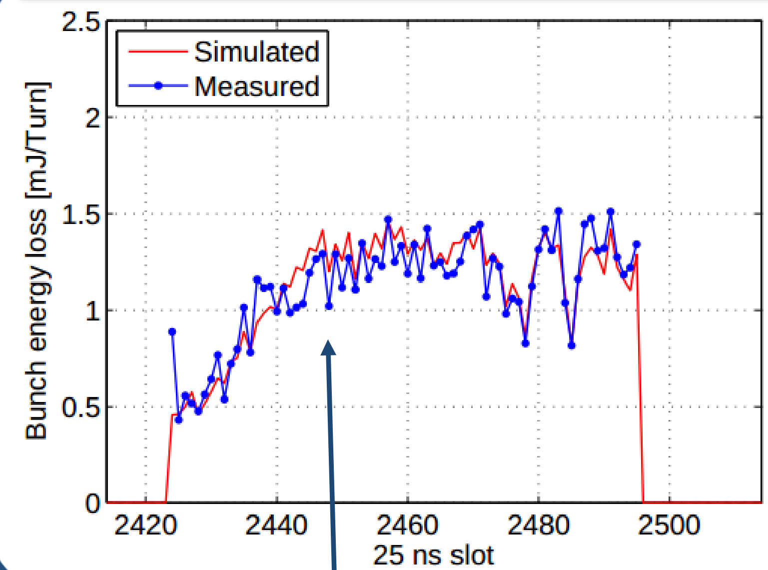
Power loss along a few LHC batches



Reference

1st batch of 72 bunches

Measurements & simulations

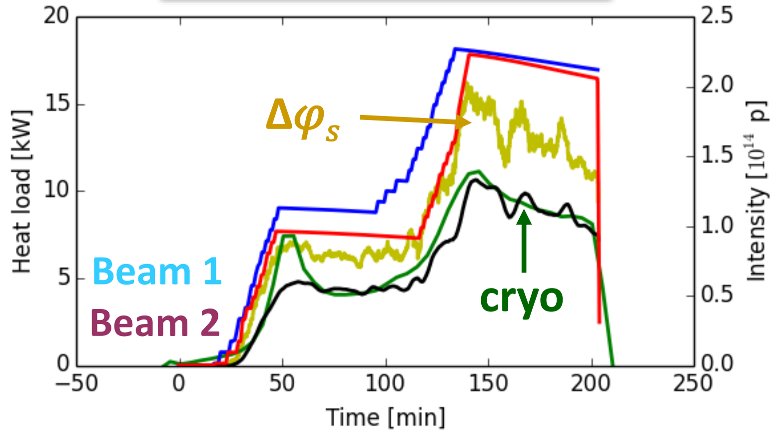


→ Very good agreement with simulations (by G. Iadarola et al. [5])

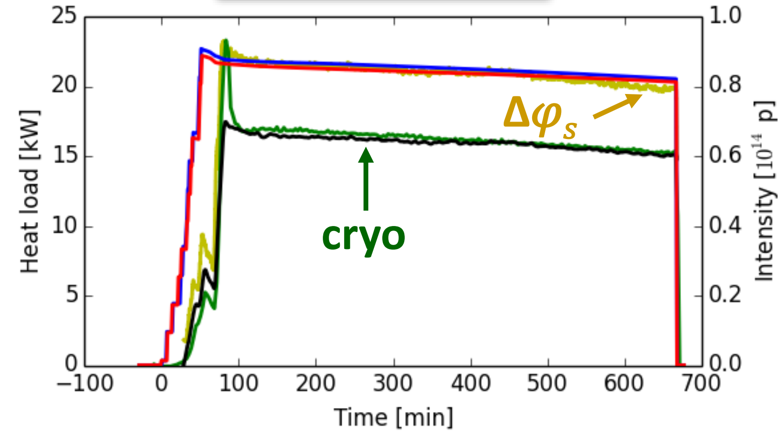
E-cloud during LHC cycle

E-cloud density evolution in the ring can be estimated from the sum of the power loss over all bunches

450 GeV flat bottom



Ramp to 4 TeV



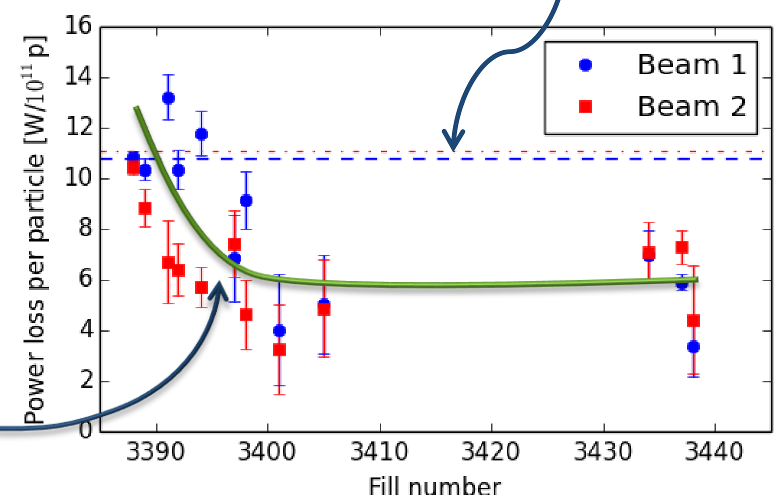
The heat load in the cryo system [9,10] can be **estimated from $\Delta\varphi_s$** taking into account:

1) Slow response time of the cryogenic system → Moving average filter applied
2) Only the superconducting magnets are measured by cryo → Scale factor (0.7/0.79)

E-cloud evolution during the LHC scrubbing run (end of 2012)

Scrubbing effect from the maximum power loss per particle for a given fill

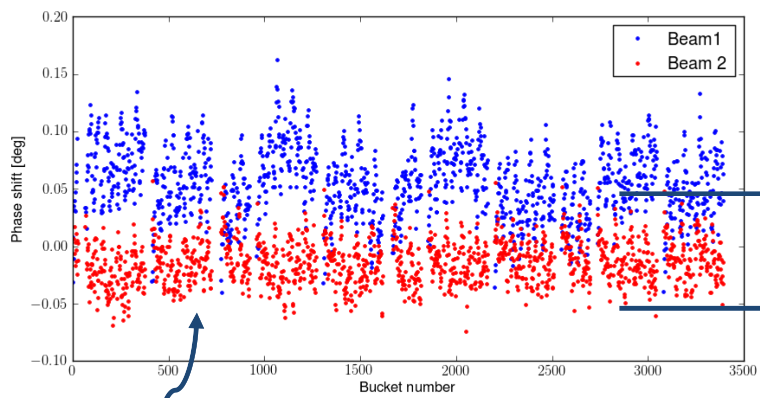
E-cloud activity at the end of 2011



SEY reduction

E-cloud evolution in 2012 in LHC

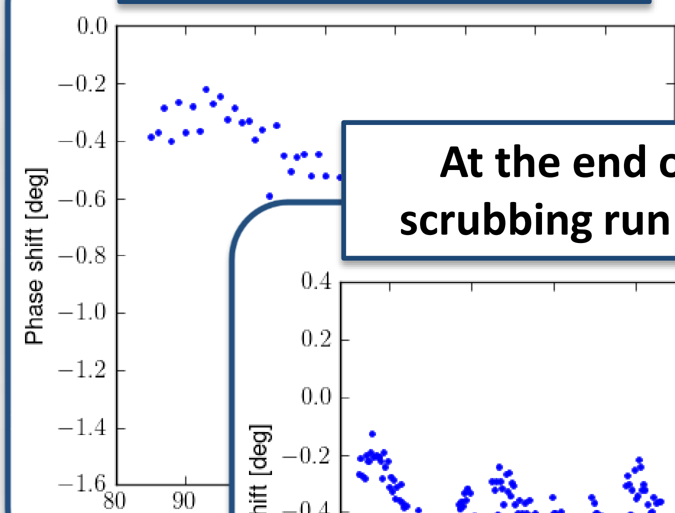
No e-cloud for 50 ns beams



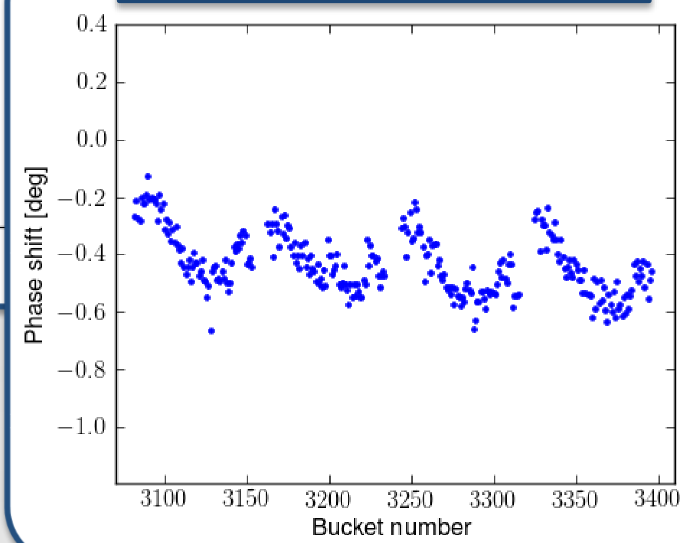
Scattering from the remaining errors

0.1 deg

At the beginning of the scrubbing run (25 ns)



At the end of the scrubbing run (25 ns)



Summary and future plans

- A new method for e-cloud observation was developed using synchronous phase measurements
  - E-cloud build-up along the bunch trains can be observed
  - Total beam power loss due to e-cloud can be calculated
- Measurements were reproduced in simulations with a very good agreement
- The heat load in the cryogenic system can be estimated from these measurements
- The implementation of this method in the LHC Control Room (together with the Operation group) is in progress
  - Real-time e-cloud observation
  - Scrubbing run optimization
  - An input for the cryogenic system feedback

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Thank you!

The poster will be presented again today in the Messi area (THPME174)