Improvements to the LHC DCCT system

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Plan

- Introduction
- 2010 issues
- Solutions applied beginning 2011
- Results obtained in 2011
- Precise calibrations
- New 24 bit ADC
- Conclusions / outlook

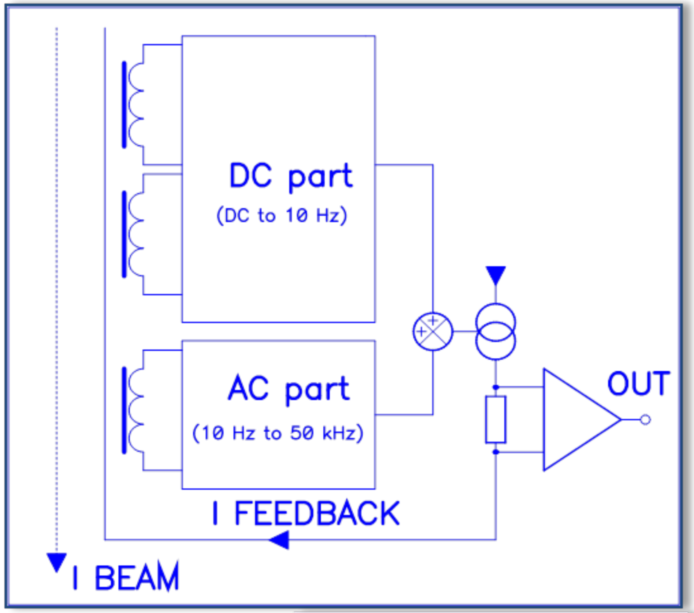
Introduction (1)

The DCCT measure the mean current of the circulating beam

(number of charges per revolution period)

Design and construction are made at CERN, principle derived from the flux gate magnetometer

- 2 modulated cores for the DC response
- 1 core for the AC response (extend the BW from 10 Hz to 50 kHz)
- Feedback current generated to cancel the magnetic field induced by the beam current



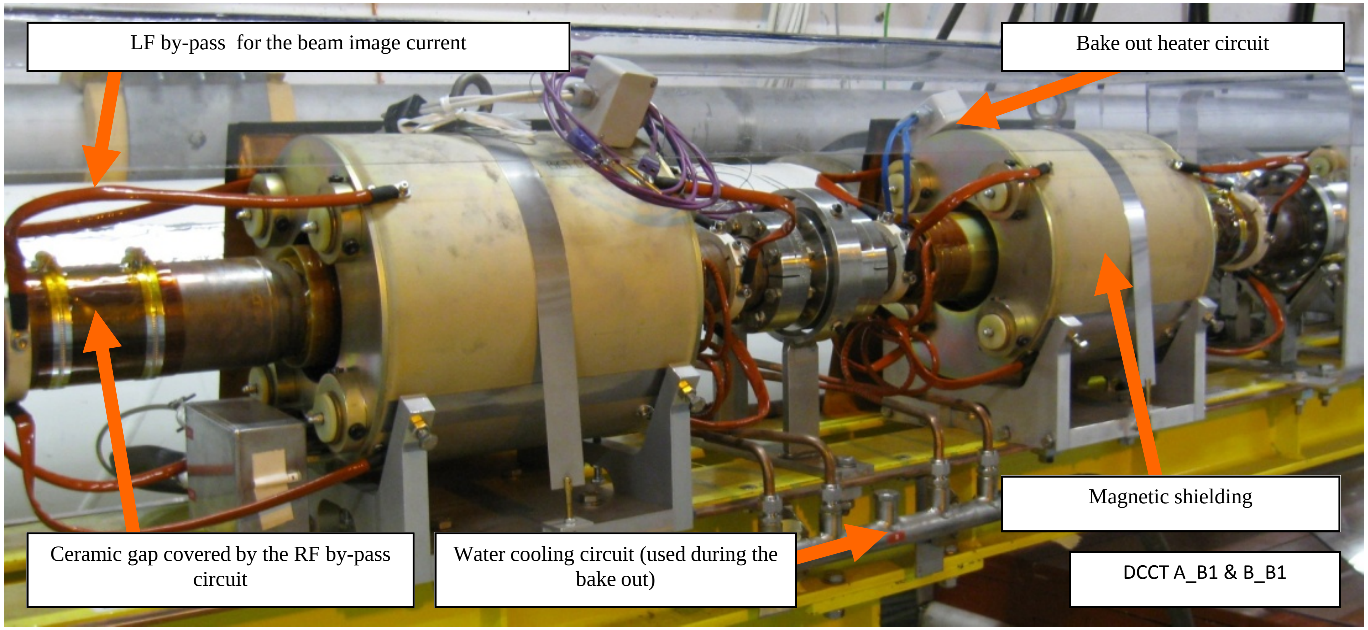
(very) simplified DCCT block diagram

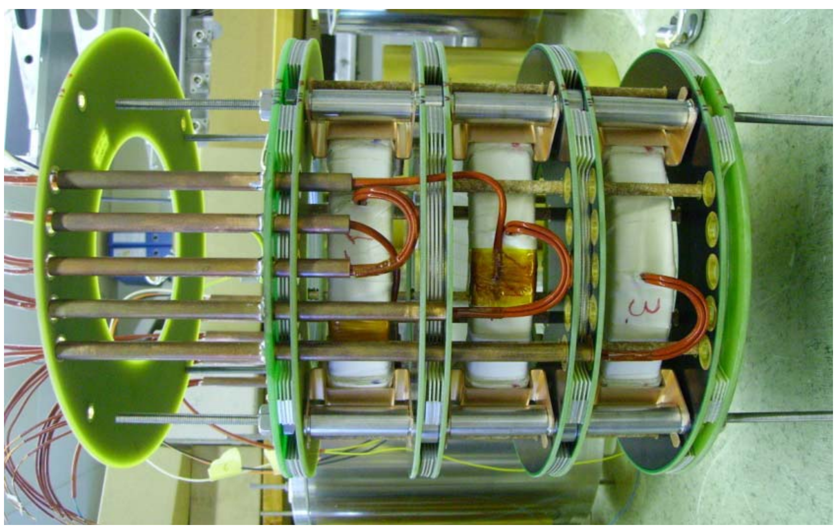
The DCCTs are the reference for the cross calibration with Fast BCTs used to calibrated the experiment detectors (luminosity measurement)

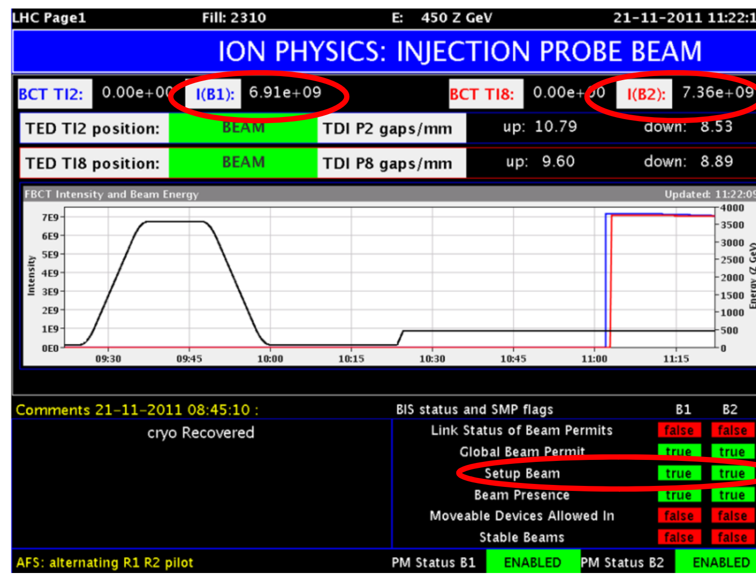
4 DCCT (2 per beam) are installed in LHC point 4

- monitors and front end electronics in RA47
- back end electronics and DSC in SX4

Introduction (2)

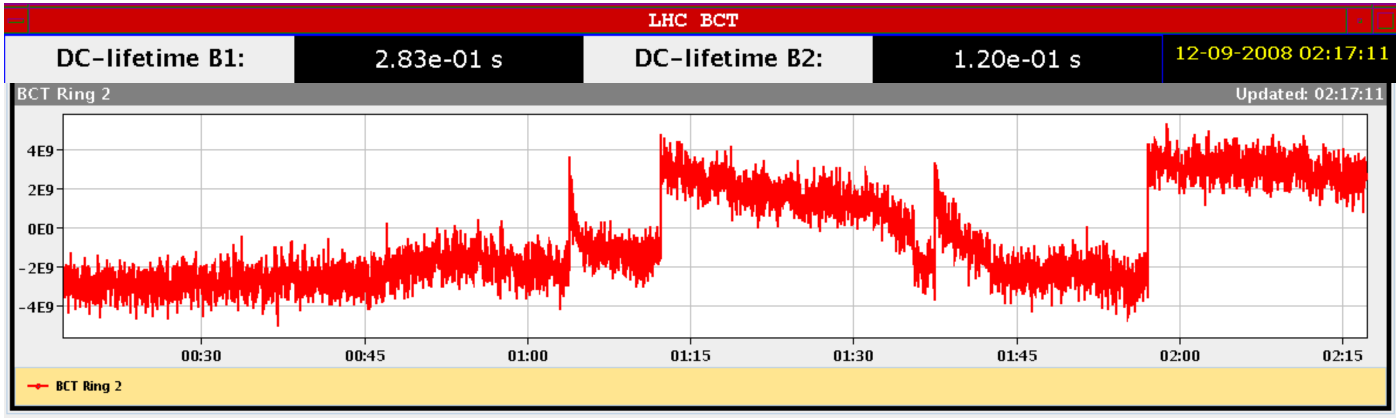






From the commissioning to mid-2010

The DCCTs performed well since the commissioning and fulfilled the specs for low intensity beams



First beams on December 2009, probe and pilot beams in ring 2

But some issues appeared mid 2010 with new beam parameters

(bunch intensity increase from 2E10 to 1.3E11 charges/bunch and new filling pattern from a few bunches to 600 bunches) appealed for improvements….

Issues in 2010

- **Incomplete saturation** of the highest sensitivity ranges

  Cause: a strong AC component superimposed to the DC signal prevented the foreseen saturation to be reached, consequently the automatic range selection by SW was distorted

  Cures:

  - lowering the range threshold
  - filtering the range amplifiers

- **Offset reduction not sufficient** after the Digital Offset Suppressor

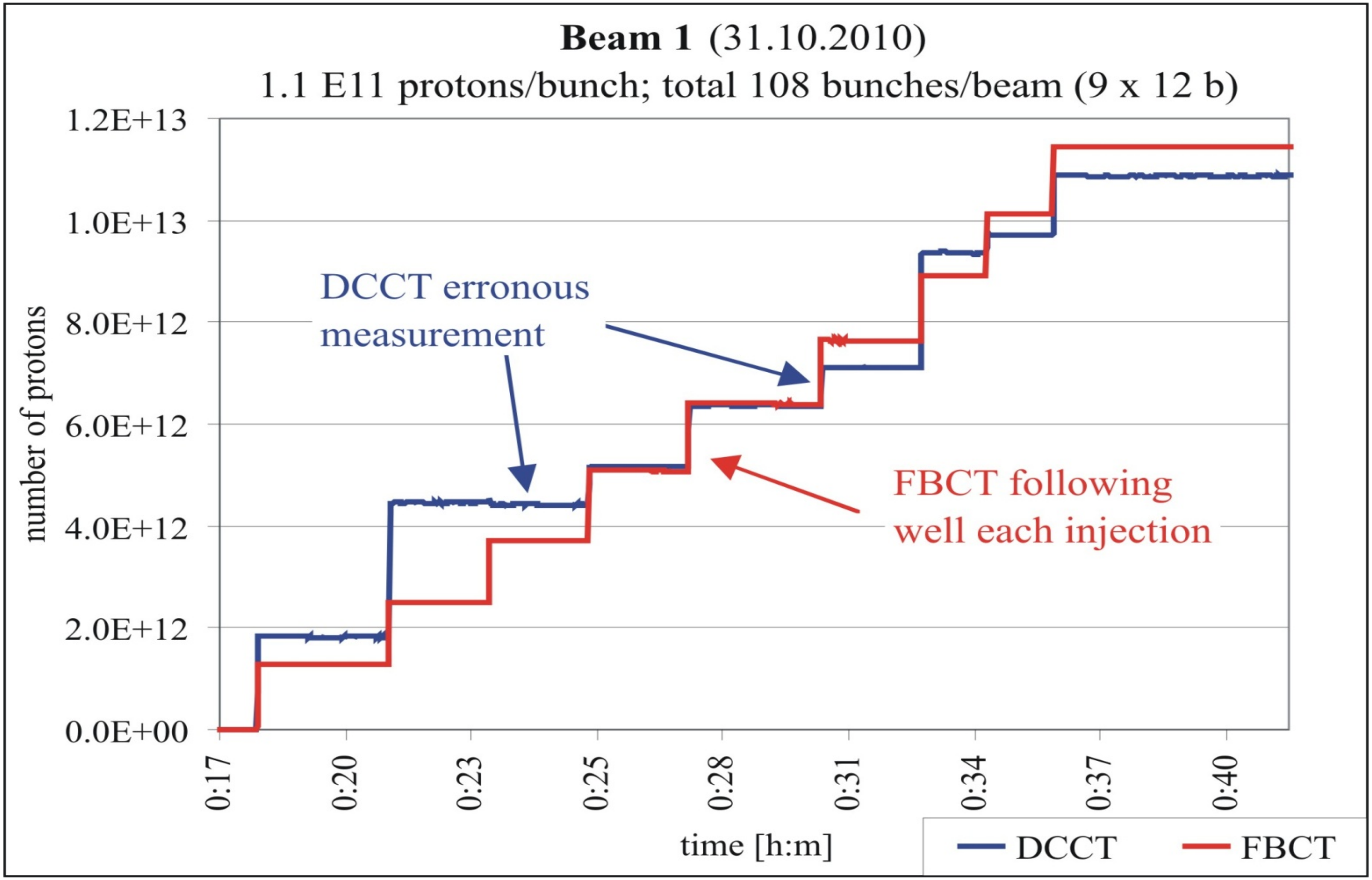
  Cure:

  the HW offset suppression (integration time 80ms) has been complemented by a SW solution consisting of offset acquisition (triggered by the sequencer) and averaging over 60 s before subtraction

- **Filling pattern dependence**

  More tricky to understand and to solve…

Filling pattern dependence (1)

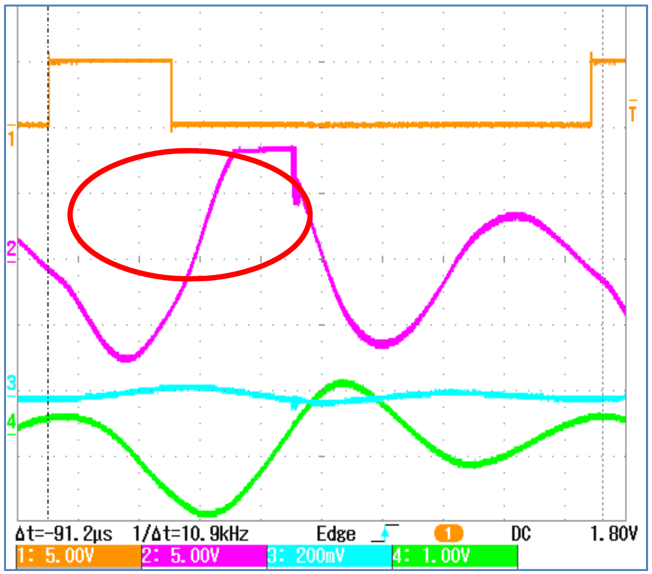


Over or under estimated measurement according to the filling pattern

Filling pattern dependence (2)

Tools to analyze the source of the anomaly

- SW simulation
  - Matlab/Simulink model (thanks to Steve Smith)
  - Spice
- Measurement on the test bench

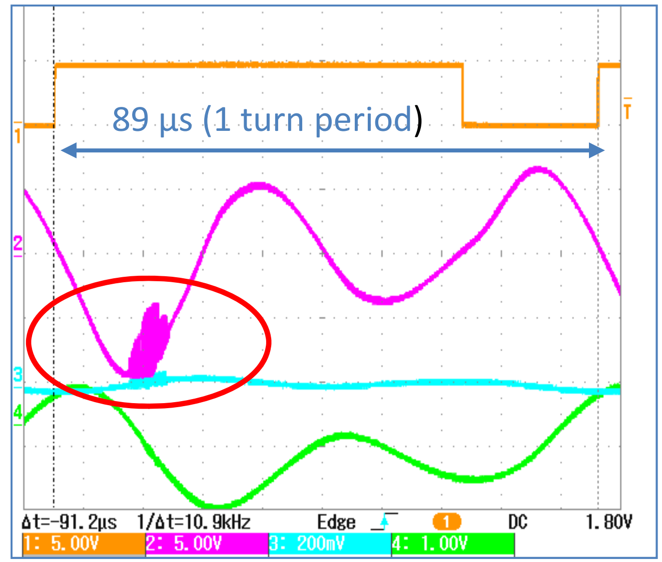


Simulation of the beam (filling percentage)

Signal within the AC loop

Output A

Output B



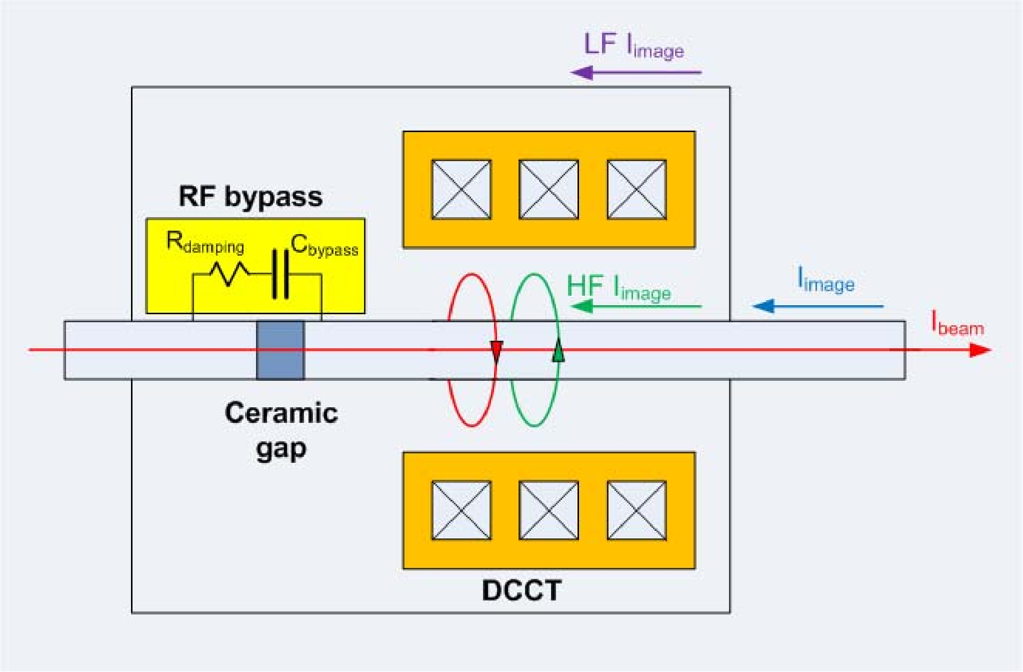
Positive or negative saturation depending on the filling percentage!

Explains the over or under estimated measurement

Filling pattern dependence (3)

Cause #1 of the excessive amplitudes observed within the AC Loop:

RF bypass not effective enough



The RF bypass is a low pass filter for the magnetic field induced by the beam and seen by the DCCT.
It avoids non linear behavior of the LF amplifiers in presence of HF

General principle:
RF bypass fc < DCCT feedback fc

Many attempts made in 2010 to improve its efficiency before understanding the importance of the **vacuum pipe grounding** (explains why the DCCT behaved differently in the machine than on the bench test)

Modifications:

increase the value of the bypass capacitor and suppression of the damping resistor

Filling pattern dependence

Cause #2 of the excessive amplitudes observed within the AC Loop:
the AC loop itself

- Inappropriate gain partition in the AC loop (responsible for the generation of the HF feedback current)
- BW not sufficient
- Op amp limitations (current, voltage swing, slew-rate) induce non linearity before saturation

+ monitoring points BW (available in surface) not sufficient to discover the saturation of the AC loop located in the front end electronics

Modifications made beginning of 2011:

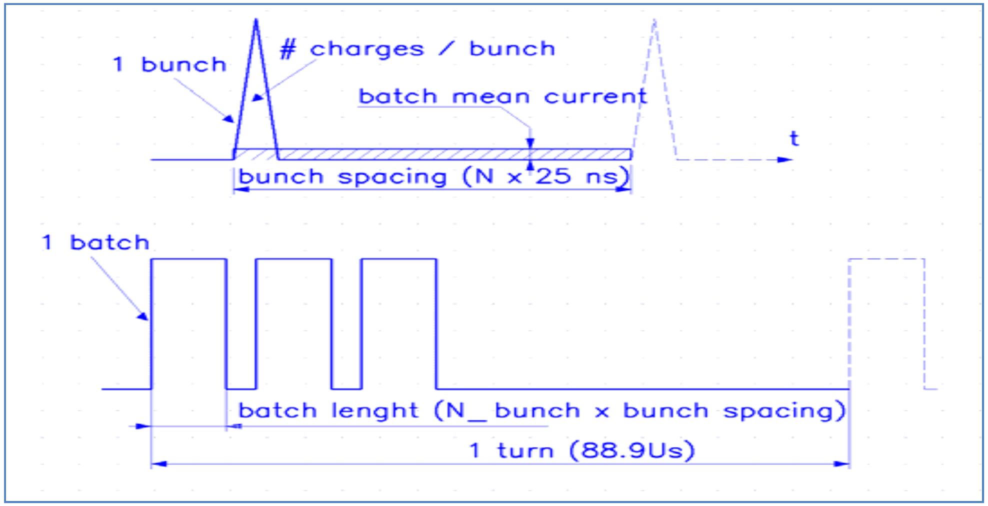
- Change of the AC loop gain partition before and after the dominant pole (compensation for loops stability)
- Use of higher speed op amp in the AC loop
- Increase the BW of the monitoring points available from the surface

Tests

The important parameter for the DCCT is the **mean batch current**

$$I_{mean\_batch} = \frac{N_{charges/bunch} \times e}{T_{bunch\_spacing}}$$

with e = elementary charge

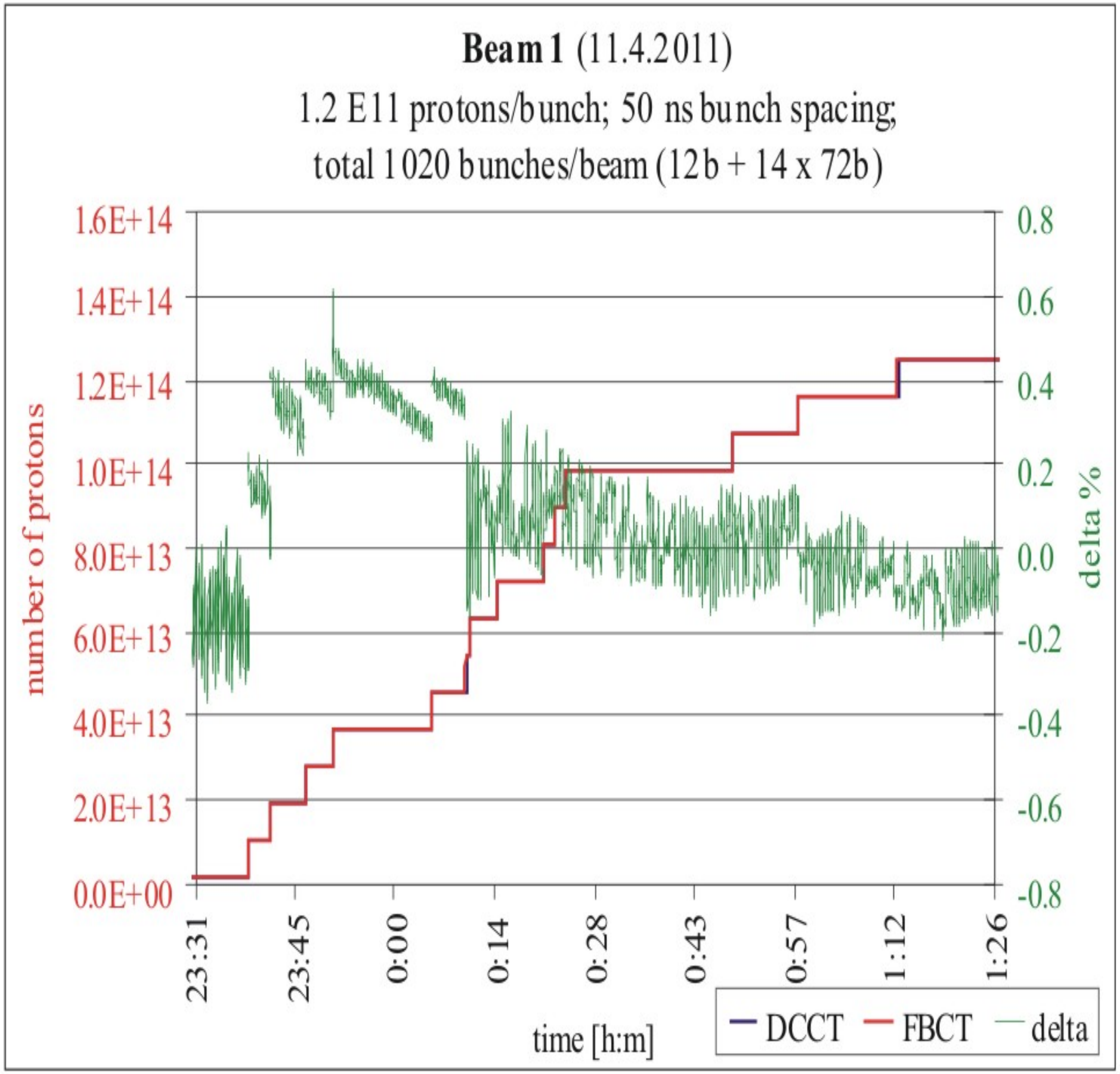


After the modifications different filling patterns were measured on the test bench

Green: successfully tested (OK for beam expected in 2011/12)
Red: still to be tested (current set-up is not powerful enough to simulate such patterns)

$I_{mean\ batch}$ [mA]		$T_{bunch\ spacing}$ [ns]				
beam	$N_{charges/bunch}$	25	50	75	150	300
lead ion min	5.60E+08	3.6	1.8	1.2	0.6	0.3
lead ion max	5.60E+09	35.9	17.9	12.0	6.0	3.0
proton nominal	1.15E+11	736.9	368.5	245.6	122.8	61.4
proton ultimate	1.67E+11	1070.1	535.1	356.7	178.4	89.2

Results



Scrubbing run in April 2011 (368 mA average current per batch)

Very good agreement
Delta DCCT / FBCT < ±0.5 %(FBCT previously cross-calibrated with the DCCT)

Confirmation of the good results obtained in laboratory!
With these conditions the **voltage swing** within the AC loop **< 30%** of the dynamic range

→ comfortable margin for the beams expected in 2011/12

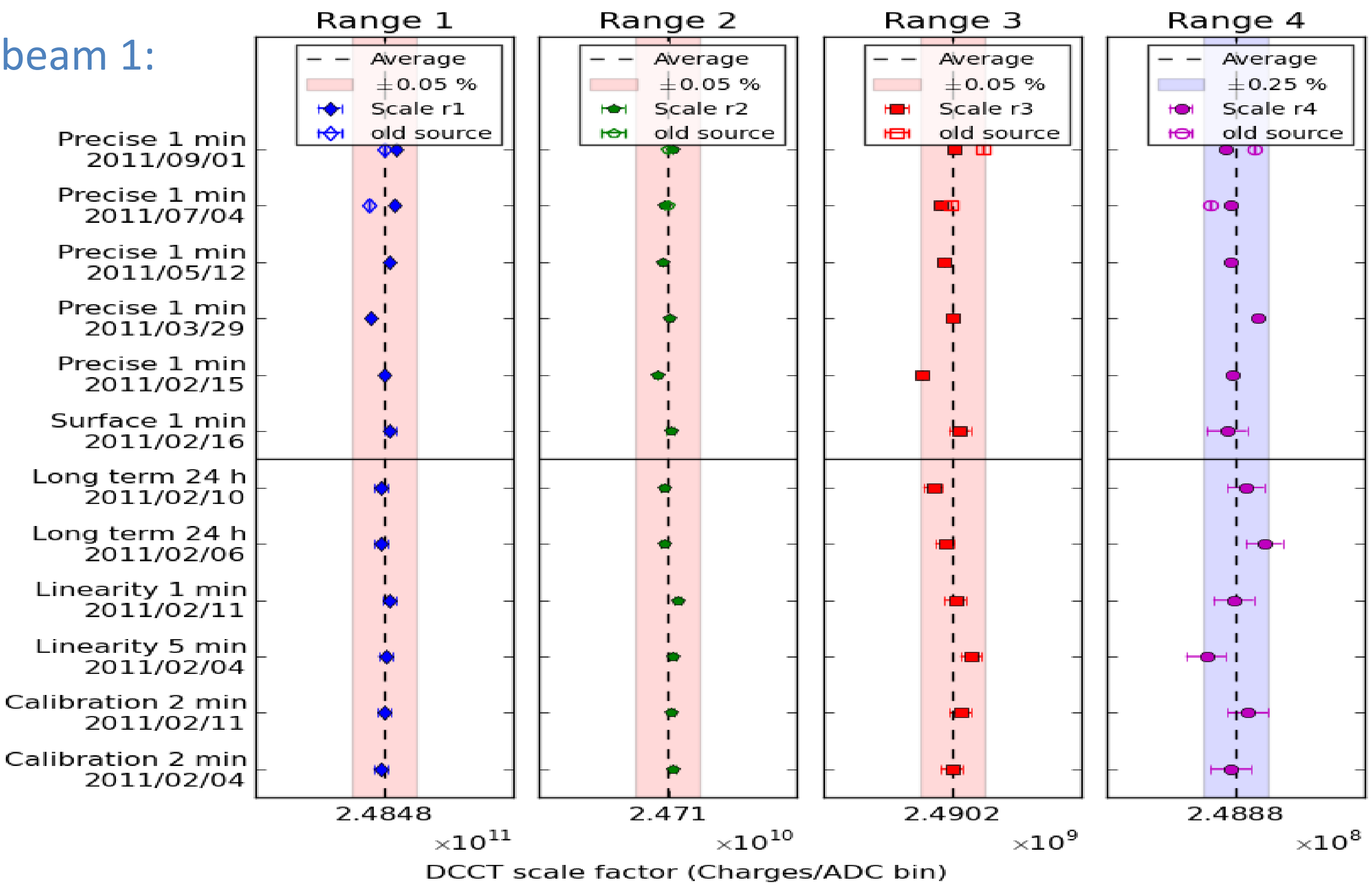
Precise calibration

The DCCTs have been precisely calibrated at each TS in 2011

The stability of the calibration is excellent

- better than **±0.05 %** on range 1, 2 and 3
- better than **±0.25 %** on range 4

Example DCCT A beam 1:

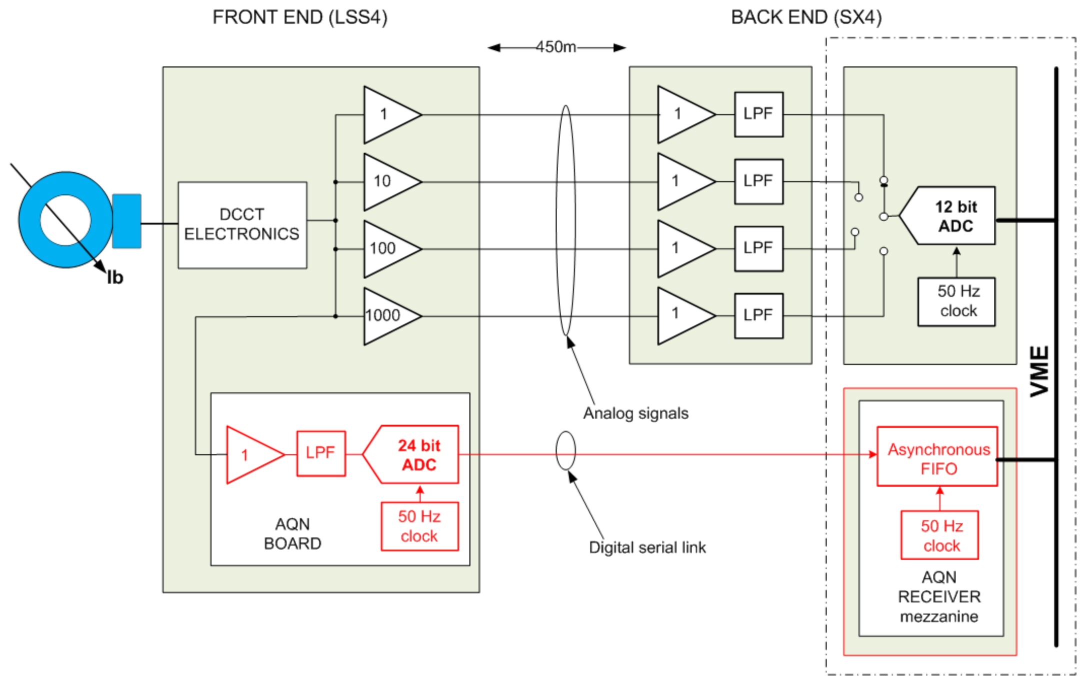


New 24 bit ADC

Short specs
Number of bits: 24
Effective number of bits: 20
Sampling rate: 50 Samples/s

Implementation (S.Thoulet)
•ADC on a board located in the FRONT END (~5 m apart the monitor)
•Digital serial link
•Asynchronous FIFO on a VME board located in SX4

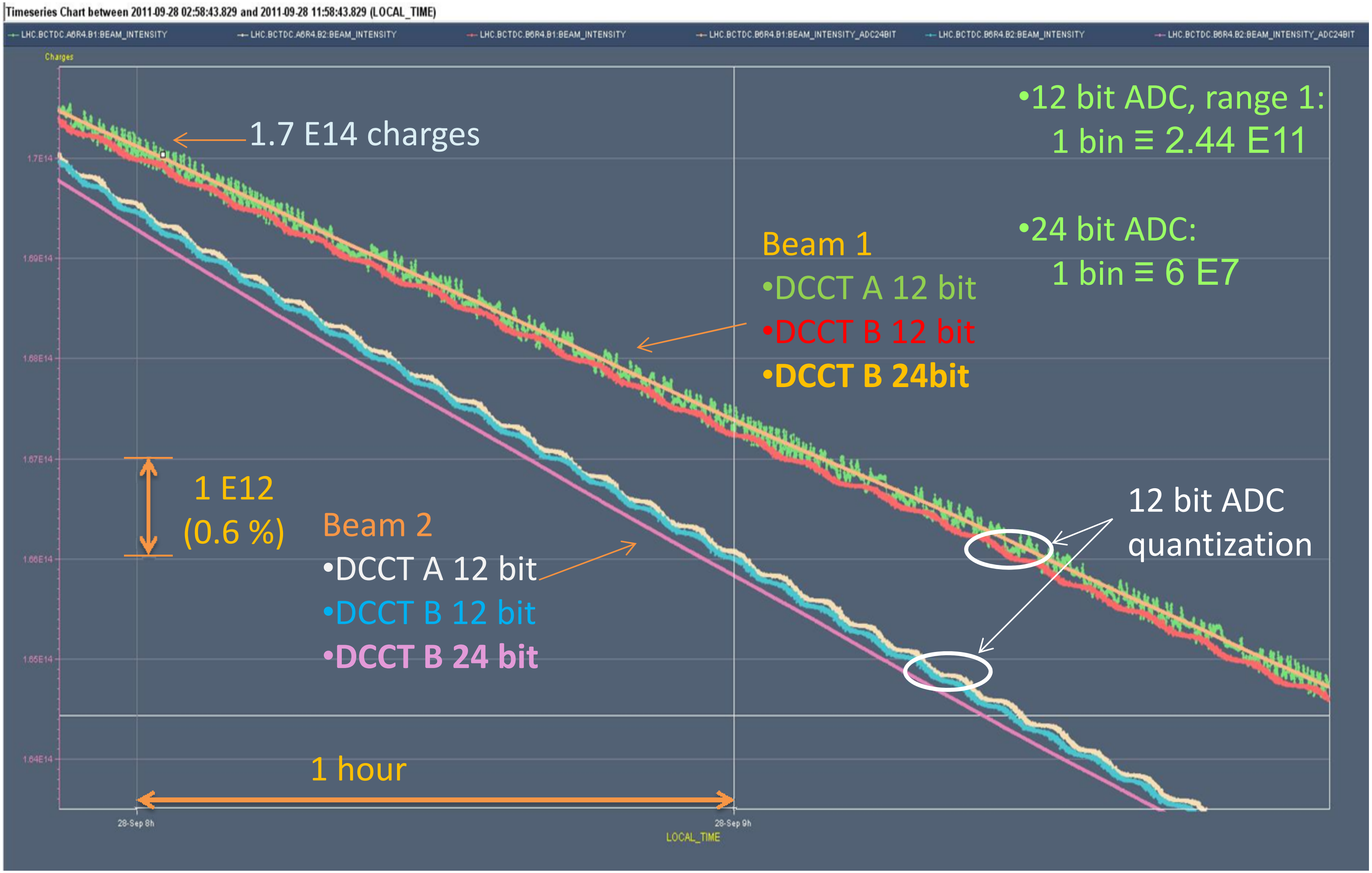
Advantages
•Resolution significantly improved (obvious at high intensity)
•One single range to cover the whole dynamic (make simpler the calibration, no range selection)
•Improve the S/N, avoid the transmission of the analog signal over 450m



Status
•System B (DCCT B_Beam 1 and B_beam 2) equipped in August 2011
•A new FESA class created, data logged in TIMBER
•System A equipped in November 2011

Still to do
•Comparison systems A and B
•Studies:
- •ADC linearity
- •Long term offset variation
- •Long term Scaling factor variation

New 24 bit ADC - Result with beam



Conclusions and outlook

A lot a work done to improve, calibrate and characterize the DCCT and … the results are there!

No more filling pattern dependant but still to be tested on the test bench with the equivalent of 25ns spaced bunch.

Different things we have learnt (bypass, AC loop, monitoring BW) can be applied on the injectors even though the revolution frequencies are much higher.

The first results obtained with the 24 bit ADC are excellent, still some studies needed (linearity, long term offset and scaling factor variation).

The HW developed for LHC (new electronics, 24 bit ADC) will be use, with some adaptation, for the injectors consolidation.

Thanks for your attention

....Time for questions...

DCCT BLOCK DIAGRAM