Linear coupling in 2012 and 2016
Outline

• How do we measure coupling?
• What is/was limiting the measurements?
• In 2012:
  – What was the coupling?
  – What was the reason for the high coupling in October?
• In 2016:
  – What happened after the technical stop in September?
  – What was the coupling throughout the year?
Ways to measure coupling

• 1. Exciting the beam and recording the response with BPMs
  – Needs the ability to excite the beam (or injection oscillations)

• 2. Rely on the residual oscillations in combination with the BBQ
  – Gives an indication of the coupling, but the results must be interpreted

• 3. Push the tunes as close as possible
  – Used a few times, a direct measurement but time consuming and does not provide a way to correct
BBQ acquisition problem with vertical spectra shifted by 1 bin was fixed at 2016-04-21

Before an underestimation of the coupling from the BBQ (around $3 \times 10^{-3}$ in this case)
Noisy spectra increases the value of the measured coupling

Depending on the day and configurations: different noise levels → Different amplitude of the coupling

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So what was the coupling?
Will try to give our best estimates..
2012 (beam 1, 60 cm)

• Good after the commissioning but changed...
2012 (beam 1, 60 cm)

- So what happened?

Change of coupling knob $(3 \times 10^{-3})$
observing the BBQ
(30th April)
Was this correction reducing the coupling?
Other sources than change of coupling knobs?

- Orbit changes, drifts, movements, *etc*...

- Below is a plot of the C- we expect to get from the measured tilt of the triplet quads (measured once every hour)

  - Note that the assumption is zero coupling after the commissioning!

  - Depending on the distribution of error it could actually improve the situation.

*Triplet data from: Dominique Missiaen via Massimo Giovannozzi*
Corrected during MD but never incorporated into operation

BBQ went from $0.007 \rightarrow 0.002$
More or less consistent with the AC-dipole
Change of coupling knob $(3 \times 10^{-3})$
obscpace observing the BBQ (30$^{th}$ April)

2012 (beam 1, 60 cm)

Triplet movement (worst possible scenario)

Triplet movement (best possible scenario)
2016
After Technical stop september-2016

Good corrections from the BBQ data down to about 60 cm
Beam 1 correction in the order of $5 \times 10^{-3}$

Basically cancelled the first correction at 40cm
What did the BBQ show?

• Nothing really...
Coupling in 2016
(40cm beam 1)

Many changes to coupling in this region

The correction implemented from the BBQ

After the correction it should have gone down to around here
Coupling in 2016
(40cm beam 2)

Many changes to coupling in this region
Triplet movements in 2016

• Potentially explains the small drift between June and October

*Triplet data from: Dominique Missiaen via Massimo Giovannozzi
What about injection?

• Normally well corrected since:
  – Injection oscillations
  – BBQ is more reliable there
• Most fills are corrected to a few $10^{-3}$
However, a coupling decay has also been observed.

Beam 2

Measured during MD 1850 and will be presented today at the LSWG.
Summary/outlook

• The large coupling in 2012 was likely due to
  – Non-optimal change of the knobs
  – Tilts of the triplets or other movements/drift
• Few measurements of coupling in 2016
  – Stable between June and October for 40 cm
• The mechanisms behind the coupling decay at injection is under investigation
• A tool to easily measure and correct coupling is under development
  – Uses the ADT and also works with nominal bunches
  – Could be a part of the quality check after each technical stop
Backup slides
Before and after local coupling corrections

The 1 BPM system needs good local correction to work
The normal FFT

The spectrum is mirrored in the 0.5 line.

\[ |f_{1001}| = \frac{1}{2} \sqrt{\frac{H(0,1)V(1,0)}{V(0,1)H(1,0)}} \]

An approximation under the assumption that the sum resonance is negligible.

Which is not completely valid in particular for injection tunes.
Using the complex variable

We use two BPMs to construct a complex variable:

\[ h_x = x - ip \]

\[
|f_{1001}| = \frac{1}{2} \sqrt{\frac{H(0,1)V(1,0)}{V(0,1)H(1,0)}}
\]

\[
|f_{1010}| = \frac{1}{2} \sqrt{\frac{H(0, -1)V(0, -1)}{V(0,1),H(1,0)}}
\]

\[
|C^-| \approx 4|(Q_x - Q_y)| |f_{1001}|
\]

(b) Complex spectra normalized to V(0,1).
1 vs 2 BPMs

The data is from a free kick (no Ac-dipole)
Removing the $f_{1010}$ from the two BPM method
From one location to the next (f_{1001})

\[ S_0 \quad \longrightarrow \quad S_1 \quad (\phi_x - \phi_y) \]

Assuming no local sources of coupling
From one location to the next ($f_{1010}$)

$S_0 \quad \rightarrow \quad (\phi_x + \phi_y) \quad \rightarrow \quad S_1$

Assuming no local sources of coupling
What we measure in 1 BPM

\[ S_0 \rightarrow S_1 \]
We have reached $\text{abs}(C \cdot) = 0.0002$

- [https://cds.cern.ch/record/2210530?ln=en](https://cds.cern.ch/record/2210530?ln=en)
Comparison between BBQ at injection

We changed the imaginary knob in the control room

- 3 time for beam 1
- 2 time for beam 2
Comparison knob and AC-dipole

We changed the imaginary knob in the control room
● 3 time for beam 1
● 2 time for beam 2

Beam 1

Beam 2
Same observation in 2012

BBQ

Ac-dipole

Normal octupoles do not feed down to coupling.

Ewen Maclean's thesis
Known limitations with the BBQ system

• Relies on well corrected local sources
• Only 1 location
  – Local variations
  – Not able to separate between the $f_{1001}$ and $f_{1010}$
• No measurement of the phase
• In general not reliable when octupoles are on
Change of BBQ due to octupoles powering

2016 (BOFSU) LHCb1, 450[GeV]

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Comparison during ramp and de-squeeze (VdM)

Beam 1

Beam 2
Before and after Corrections

Beam 1

Nominal bunches and octupoles were on!

Beam 2
Change of coupling knobs

J. Wenninger

29/11/16