Instabilities and Beam Induced Heating in 2015

Evian 2015

Instabilities: L.R. Carver, D. Astapovych, J. Barranco, N. Biancacci, X. Buffat, W. Hofle, G. Iadarola, G. Kotzian, T. Levens, K. Li, E. Metral, T. Pieloni, G. Rumolo, B. Salvant, M. Schenk, C. Tambasco, D. Valuch, N. Wang, BI colleagues & OP colleagues.

Beam Induced Heating: All involved equipment groups.

MKI: M. Barnes, H. Day, V. Namora, L. Vega Cid, W. Weterings

Outline

- Operation in 2015
  - Instabilities at injection
  - Instabilities during the ramp and during the squeeze
  - Instabilities at stable beams
  - BCMS
- Instability threshold measurements at 6.5TeV
  - Single bunch measurements
  - 25ns vs 50ns train measurements
  - Instabilities at 40cm β*
- Beam induced rf heating
  - Overview
  - MKI heating
  - TDI heating
- Summary

Outline

- Operation in 2015
  - Instabilities at injection
  - Instabilities during the ramp and during the squeeze
  - ~~Instabilities at stable beams~~ See talk by T.Pieloni
  - BCMS
- Instability threshold measurements at 6.5TeV
  - Single bunch measurements
  - 25ns vs 50ns train measurements
  - Instabilities at 40cm β*
- Beam induced rf heating
  - Overview
  - MKI heating
  - ~~TDI heating~~ See talk by A.Lechner
- Summary

Transverse Instabilities during Operation in 2015

Injection - Timeline

Event	Date	Q' [H/V]	Joct [knob]	ADT Gain	Comments
Initial Injection Settings for 50ns Spacing	01-Jun	5/5	-0.5	0.15	Ideal settings.
Peak Settings During 50ns Scrubbing	27-Jun	15/15	-1	0.25	Coherent excitations observed, but surviving.
End of 50ns Scrubbing	02-Jul	8/8	-0.5	0.15	Validation Fill. No blowup observed.
Peak Setting During 50ns Intensity Ramp	07-Jul	10/10	-1.5	0.2	Instabilities re-appeared when using settings from 50ns validation fill. Increase in Q' and Joct mitigated this effect.
End of 50ns Intensity Ramp	19-Jul	10/10	-1.5	0.2	These parameters remained until the end of the 50ns intensity ramp.
Peak Settings During 25ns Scrubbing	28-Jul	15/15	-2	0.2	Many attempts made throughout scrubbing run to lower settings. Each time resulted in blowup.
End of 25ns Scrubbing	07-Aug	15/10	-1.5	0.25	Recommendation for 25ns Intensity Ramp.
Peak Settings During 25ns Intensity Ramp - pt1	22-Aug - 30-Sep	20/20	-1.5	0.25	Issues with ADT in B2H. Initial tunes reduced to 0.275/0.295 for improved lifetime. No issues for several weeks after ADT was fixed.
Peak Settings During 25ns Intensity Ramp - pt2	01-Oct - 02-Nov	15/15	-1.5	0.25	Large B2V blowup reappeared. Small tune separation observed (tunes shift based on intensity). When corrected, no blowup seen.
Final Settings in 2015 for 2244b w/ 25ns spacing	02-Nov	15/15	-1.5	0.25	

- 50ns bunch spacing (June – late July)
  - Scrubbing run saw blowup in both beams for low chromaticity and octupole.
  - Higher settings required to mitigate instabilities.
  - Q'=10/10, Joct=-1.5, ADT Gain=0.2 was sufficient for stability of ~500 bunches.

See LBOC Presentation 'K. Li – Summary of instability observations at injection' (1/9/15)

Injection - Timeline

Event	Date	Q' [H/V]	Joct [knob]	ADT Gain	Comments
Initial Injection Settings for 50ns Spacing	01-Jun	5/5	-0.5	0.15	Ideal settings.
Peak Settings During 50ns Scrubbing	27-Jun	15/15	-1	0.25	Coherent excitations observed, but surviving.
End of 50ns Scrubbing	02-Jul	8/8	-0.5	0.15	Validation Fill. No blowup observed.
Peak Setting During 50ns Intensity Ramp	07-Jul	10/10	-1.5	0.2	Instabilities re-appeared when using settings from 50ns validation fill. Increase in Q' and Joct mitigated this effect.
End of 50ns Intensity Ramp	19-Jul	10/10	-1.5	0.2	These parameters remained until the end of the 50ns intensity ramp.
Peak Settings During 25ns Scrubbing	28-Jul	15/15	-2	0.2	Many attempts made throughout scrubbing run to lower settings. Each time resulted in blowup.
End of 25ns Scrubbing	07-Aug	15/10	-1.5	0.25	Recommendation for 25ns Intensity Ramp.
Peak Settings During 25ns Intensity Ramp - pt1	22-Aug - 30-Sep	20/20	-1.5	0.25	Issues with ADT in B2H. Initial tunes reduced to 0.275/0.295 for improved lifetime. No issues for several weeks after ADT was fixed.
Peak Settings During 25ns Intensity Ramp - pt2	01-Oct - 02-Nov	15/15	-1.5	0.25	Large B2V blowup reappeared. Small tune separation observed (tunes shift based on intensity). When corrected, no blowup seen.
Final Settings in 2015 for 2244b w/ 25ns spacing	02-Nov	15/15	-1.5	0.25	

- 25ns bunch spacing (August-November)
  - Increased settings required throughout scrubbing run.
  - Severe blowup limited operation throughout September and early October.
  - Initially thought to be due to a problem with the ADT. This was fixed on Sept 30th and no more blowup was seen.
  - Instabilities returned in early October. Small tune separations observed. When corrected, no blowup was seen.

Injection - Timeline

Event	Date	Q' [H/V]	Joct [knob]	ADT Gain	Comments
Initial Injection Settings for 50ns Spacing	01-Jun	5/5	-0.5	0.15	Ideal settings.
Peak Settings During 50ns Scrubbing	27-Jun	15/15	-1	0.25	Coherent excitations observed, but surviving.
End of 50ns Scrubbing	02-Jul	8/8	-0.5	0.15	Validation Fill. No blowup observed.
Peak Setting During 50ns Intensity Ramp	07-Jul	10/10	-1.5	0.2	Instabilities re-appeared when using settings from 50ns validation fill. Increase in Q' and Joct mitigated this effect.
End of 50ns Intensity R	[illegible]	[illegible]	[illegible]	[illegible]	ained until the end of the 50ns nsity ramp.
Peak Settings During 25ns S	[illegible]	[illegible]	[illegible]	[illegible]	roughout scrubbing run to lower me resulted in blowup.
End of 25ns Scrubbi	[illegible]	[illegible]	[illegible]	[illegible]	for 25ns Intensity Ramp.
Peak Settings During 25ns Ramp - pt1	22-Aug - 30-Sep	20/20	-1.5	0.25	2H. Initial tunes reduced to 0.275/0.295 for improved lifetime. No issues for several weeks after ADT was fixed.
Peak Settings During 25ns Intensity Ramp - pt2	01-Oct - 02-Nov	15/15	-1.5	0.25	Large B2V blowup reappeared. Small tune separation observed (tunes shift based on intensity). When corrected, no blowup seen.
Final Settings in 2015 for 2244b w/ 25ns spacing	02-Nov	15/15	-1.5	0.25	

At injection the dominant effect is electron cloud. However, other effects in parallel i.e. unoptimised ADT, or the effect of linear coupling can also cause instabilities.

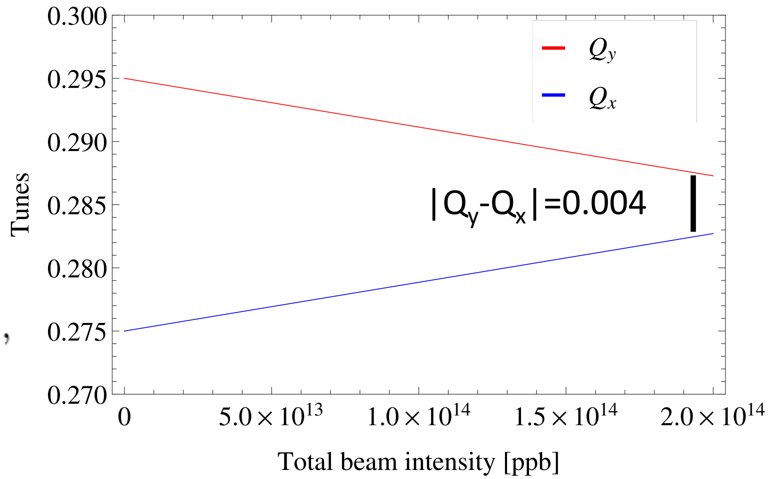
- 25ns bunch spacing (August-November)
  - Increased settings required throughout scrubbing run.
  - Severe blowup limited operation throughout September and early October.
  - Initially thought to be due to a problem with the ADT. This was fixed on Sept 30th and no more blowup was seen.
  - Instabilities returned in early October. Small tune separations observed. When corrected, no blowup was seen.

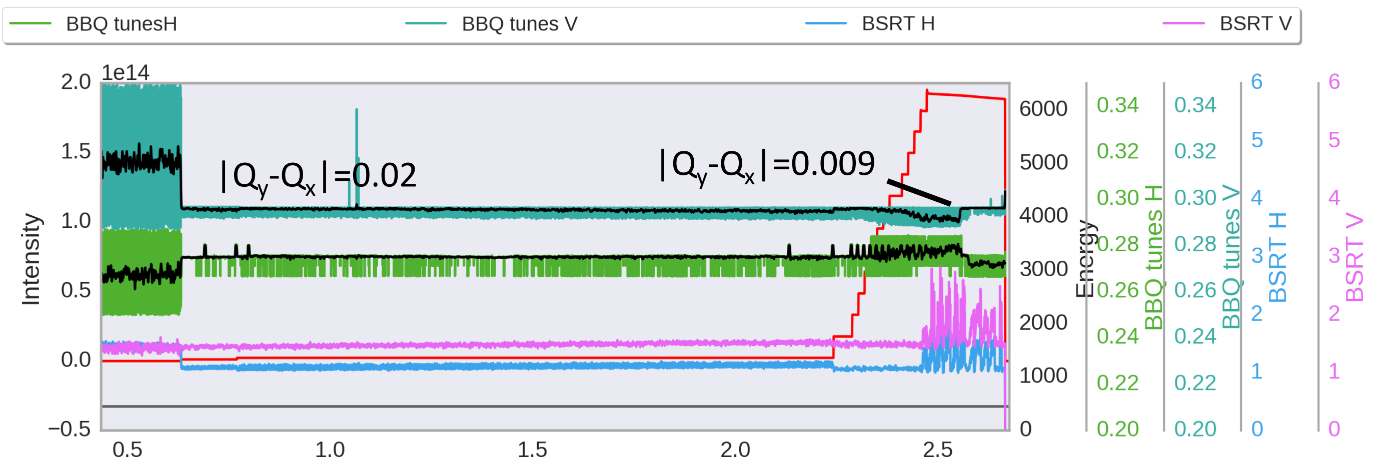
Injection – Tune Separation

- Key to preventing blowup at injection is maintaining well separated tunes.
- Laslett tune shift depends on total beam intensity.
- $N_b k_b$ = Beam intensity, β_{av}=ave. beta function, $\varepsilon_{1,2}$ depend on beam geometry with half height h and distance to ferromagnetic poles 2g.

$$\Delta Q_{\mathrm{Laslett}} = -\frac{N_b k_b r_p \beta_{av}}{\pi\gamma}\left(\frac{\varepsilon_1}{h^2}+\frac{\varepsilon_2}{g^2}\right) \simeq \begin{cases} -1.7\times 10^{-2} & \text{at 450 GeV,} \\ -1.1\times 10^{-3} & \text{at 7 TeV,} \end{cases}$$

- Tune shift measured (below) is approximately similar to analytical result (right). ε_1=0 but ε_2 and g are only approximately known.





Fill 4642, B2 (left) - tunes not separated, blowup observed.

Fill 4643, tunes separated, no blowup observed.

See 'Single Beam Collective Effects in the LHC' – F.Ruggiero
See 'Analysis of intensity dependent effects…' – T.Personn et al, IPAC15

Injection - Coupling

- Electron cloud is the dominant effect at injection. But if tunes are not well separated, and $|C^-|$ drifts to higher values, then coupling can also effect the beam dynamics.

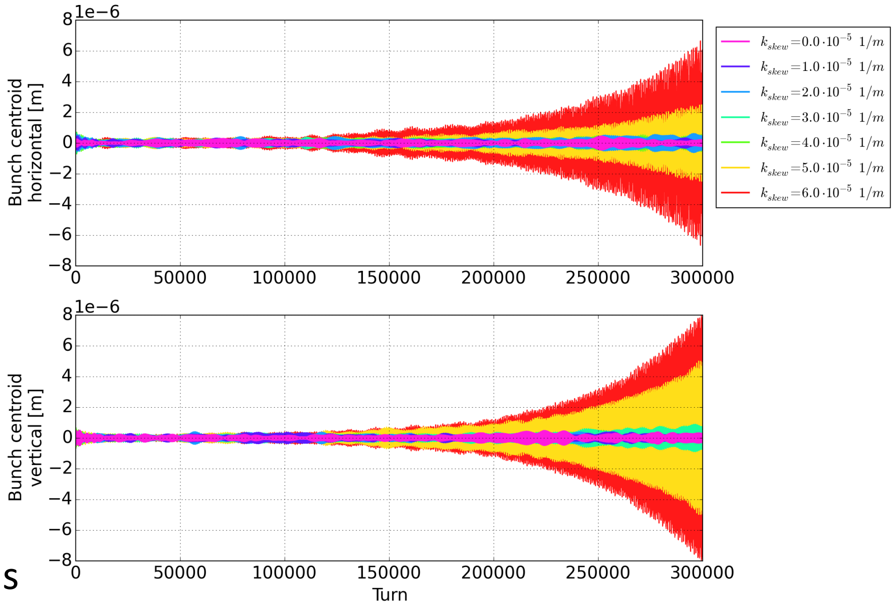
- **Preliminary** simulations in PyHEADTAIL with **simplified dynamics** show that mechanisms exist where bunches are stable without coupling and unstable when small coupling is introduced. **Additional terms may exist in formalism that are not yet considered in simulation.**

- Shown is for 3.5TeV, with adjusted tunes such that the tune separation is small.

- The strength of the skew quadrupole is increased, showing beam amplitude growth.

- A campaign of simulations is planned to determine the effect of coupling throughout the cycle.

- Ultimately, a threshold on |C-| and $|Q_x\text{-}Q_y|$ is desired.

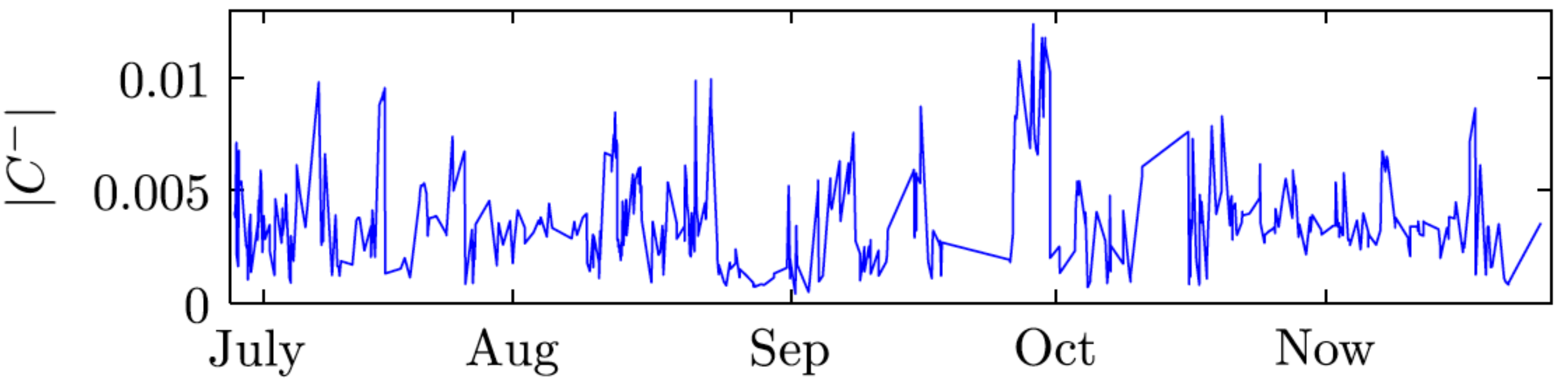


See M.Schenk, L.R.Carver, E.Métral. See HSC Section Meeting (6/12/15)
See "Chromatic coupling in the LHC and its correction" – S.Fartoukh , J.P Koutchouk.

Injection - Coupling

- In 2012, the |C-| was routinely measured at injection from the 1000 turn injection oscillations.

- This allowed accurate determinations of |C-| over the course of the year.



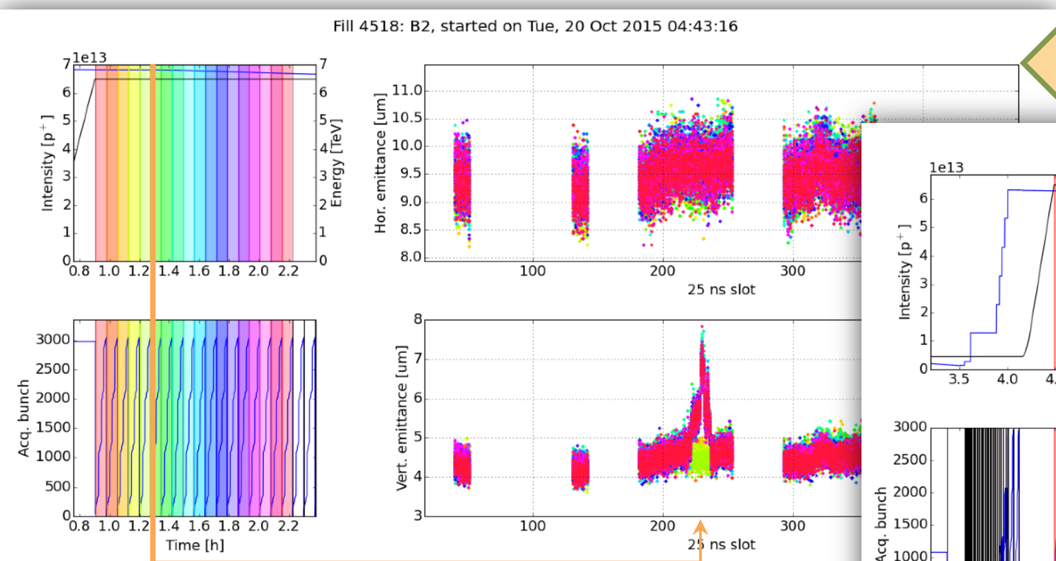
- This type of measurement was not performed in 2015. Instead we are relying on the TIMBER data, which is not always accurate.

- We would like to set up the systematic measurements for 2016.

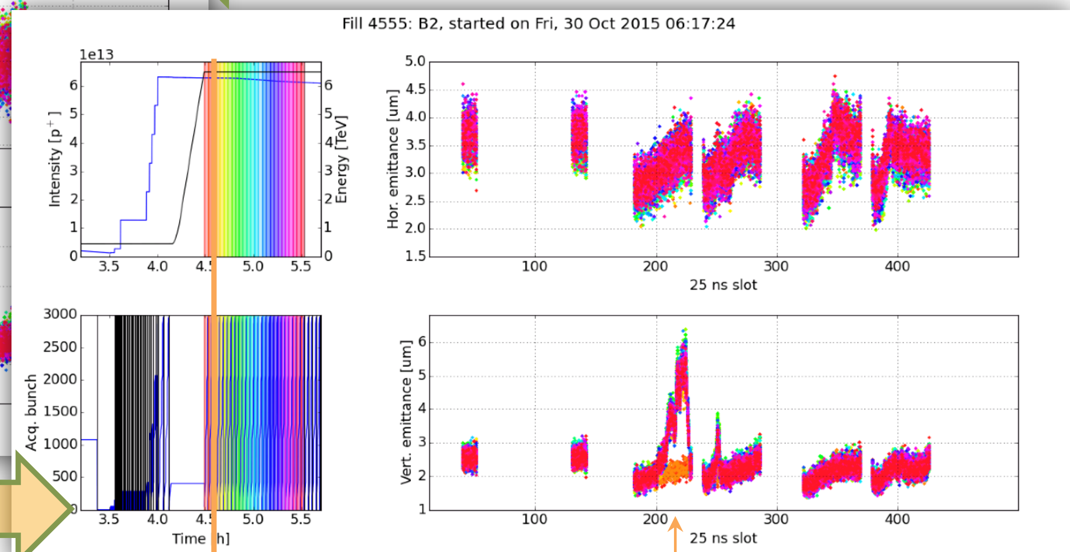
See T.Persson, R.Tomas "Improved control of the betatron coupling in the LHC"PRST:AB **051004** (2014)

Ramp / Squeeze

- Losses observed in B1H at beginning of ramp for Q'<10.
- Emittance blowup in B2V occurred routinely at ~9m during squeeze
- Squeeze instability is very reproducible – always about 30 bunches in the first batch of 144 bunches.
- Both instabilities cured for the 25ns beam by increasing chromaticity from 10 → 15
- Both ramp and squeeze instability returned for the BCMS fill. On threshold of stability during operation.
- OBSBOX to be used in 2016 to gain better understanding of the nature of these instabilities



25ns beam – chromaticity at 10 units



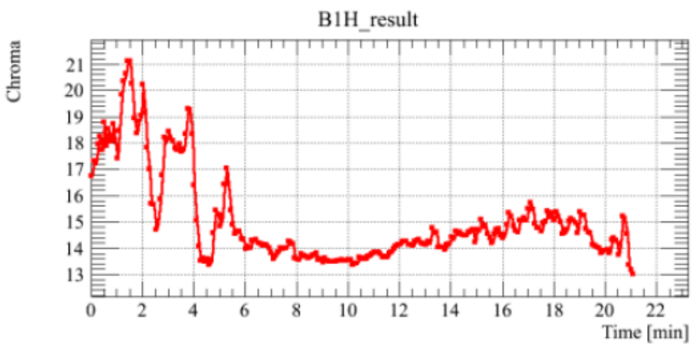
BCMS beam – chromaticity at 15 units

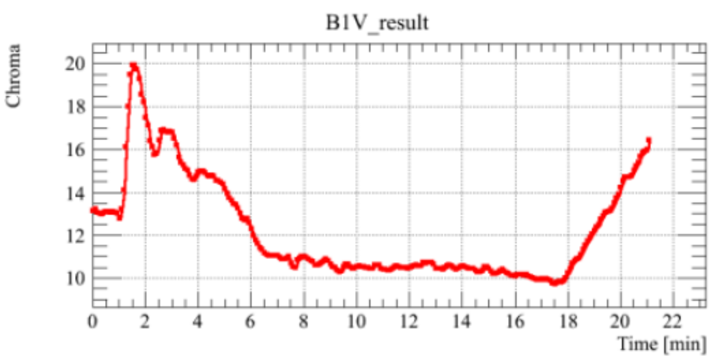
See LBOC 'Instabilities at FT and EOS – L.R.Carver 1/9/15'

Possible Causes

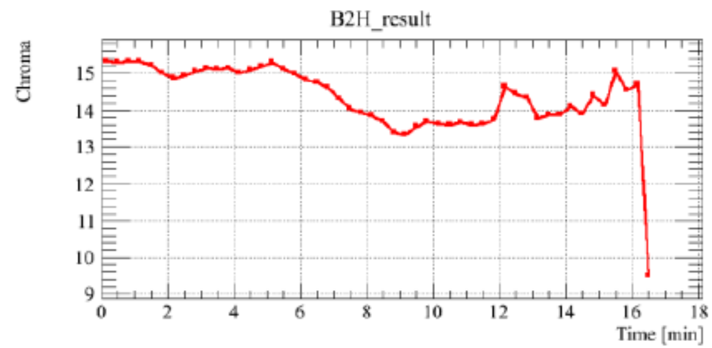
- During the ramp and during the squeeze, the chromaticity can fluctuate.
- Studies have been performed by M. Solfaroli that show the chromaticity variation for different stages of the machine cycle.

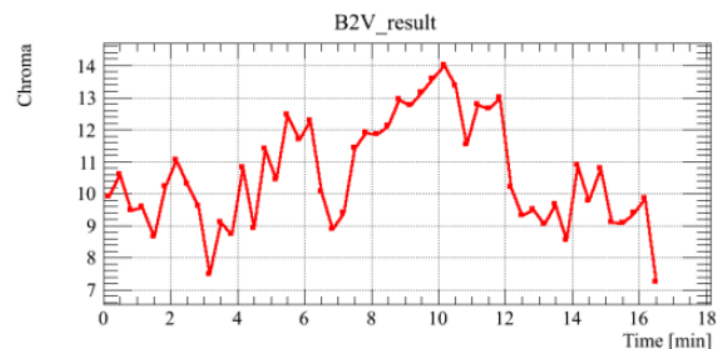
Ramp





Squeeze





See HL-LHC-LARP Annual Meeting ‘How precisely can we control our magnets? – M. Solfaroli 30/10/15’

BCMS

- Fill before BCMS with 2244b was stable.
- Fill after BCMS with 2244b was stable.
- Instabilities were caused by brighter beams.

- Beams were blown up by the time of injection.
- Pre-ramp instability in B1H, fluctuation in chromaticity could have caused losses.
- Recurrence of squeeze instability at 9m beta*. During normal operation we may be at the threshold of stability during squeeze. ObsBox will allow further study into this effect as it is very reproducible.
- Bunch activity in stable beams but no blowup.

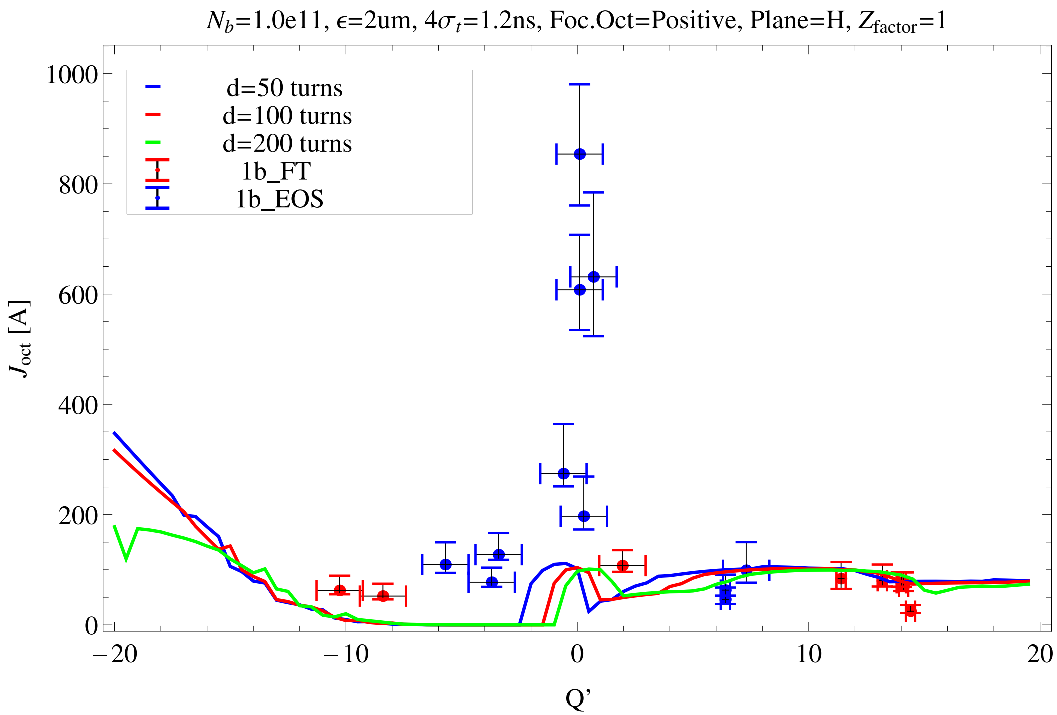
- **Instabilities during this fill had the same characteristics as those seen with nominal bunch parameters.**

- **Proposal to explore blown up BCMS beams and then reduce emittance over several fills is ideal way forward.**

See HSC Section Meeting 'Analysis of BCMS beam in the LHC… – L.R.Carver 23/11/15'

Instability Measurements at Flat Top & End of Squeeze in 2015

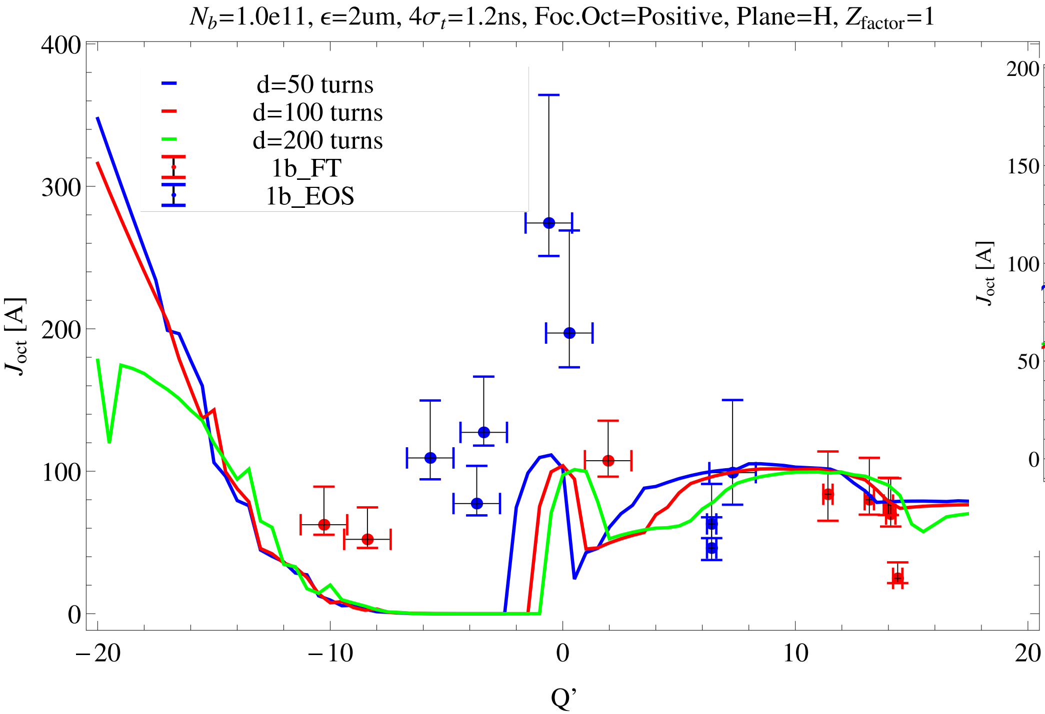
Single Bunch Measurements at 6.5TeV

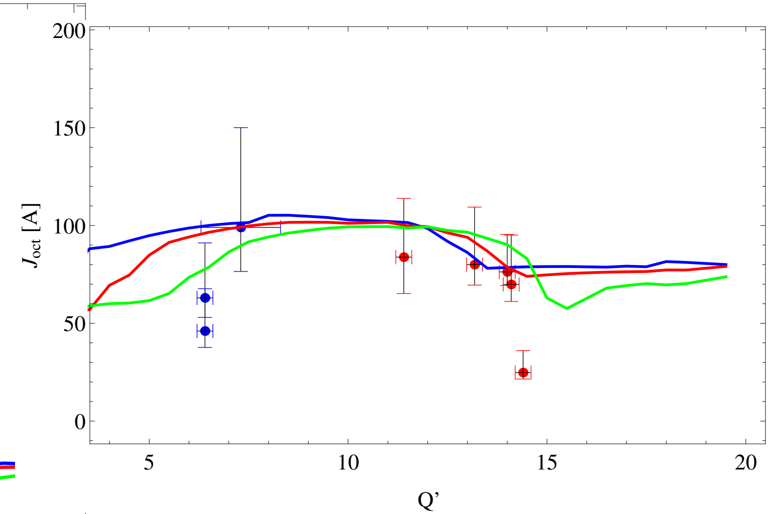


- Many single bunch instability threshold measurements made throughout 2015.
- Incrementally lower current in Landau Octupoles until instability develops.
- Re-scale measured octupole current for nominal bunch parameters, ε=2um and N_b=1e11
- Measurements are compared with predictions from DELPHI, also made with nominal bunch parameters.
- These measurements would not have been possible in 2012. Improvements to chromaticity tool (K. Fuchsberger, M.Solfaroli, L.Carver) made it possible.

See LBOC 'Chromaticity correction without RCS –M. Solfaroli 18/08/15'

Single Bunch Measurements at 6.5TeV

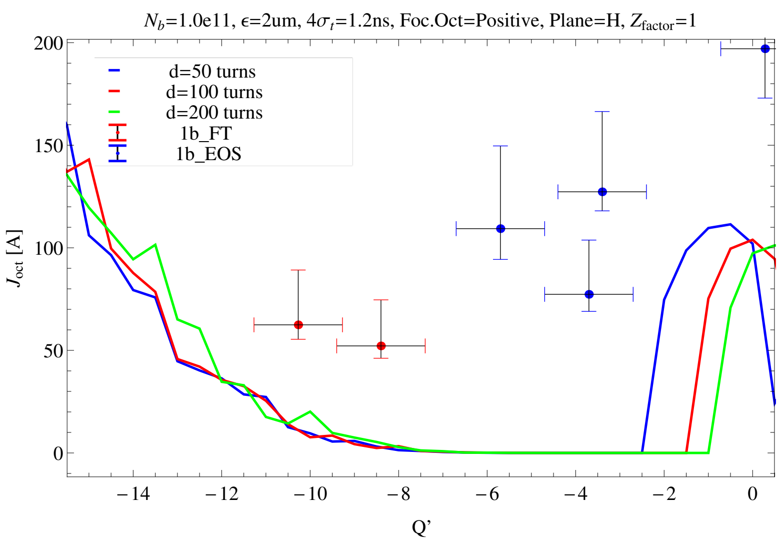




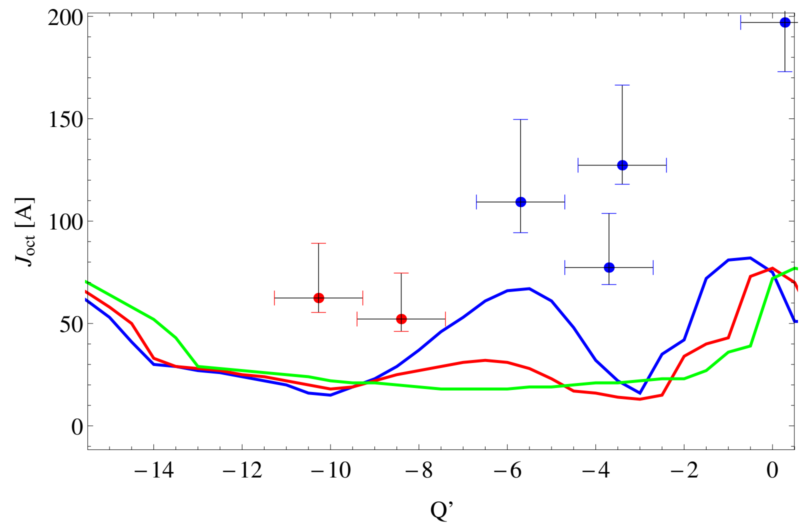
- Three different chromaticity regimes exist.
- **For Q'>2 (Operational regime)**
- Good agreement is seen between measurements and DELPHI predictions.
- Prediction does not change much for varying damping time -> less uncertainty due to ADT.

Single Bunch Measurements at 6.5TeV

DELPHI – Perfect Damper

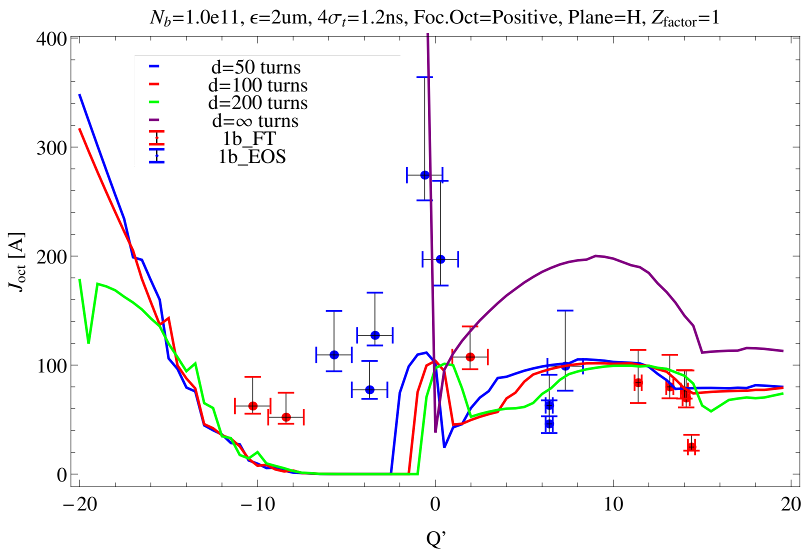


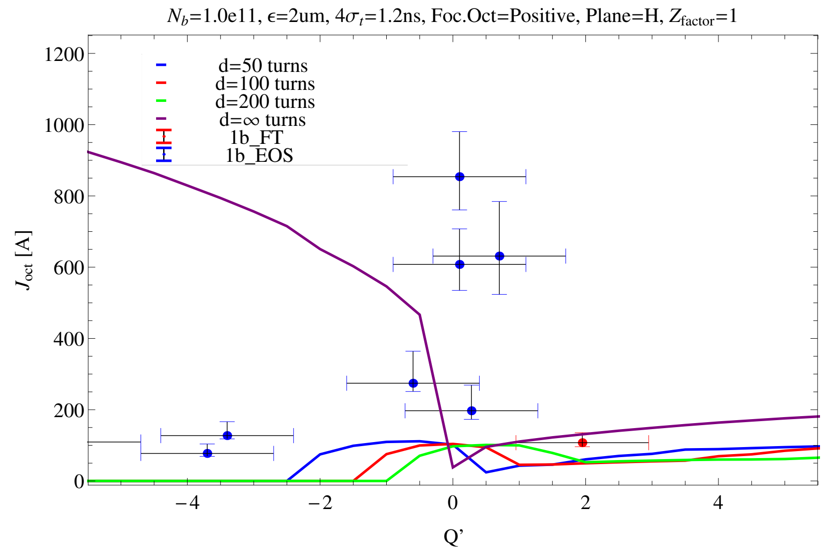
COMBI– Imperfect Damper



- **For Q'<-2**
- DELPHI predicts zero current required for stability because in this regime a mode 0 is dominant -> should be damped by ADT.
- Simulations from X.Buffat have shown that an imperfect damper model creates an offset in this region of ~30A.

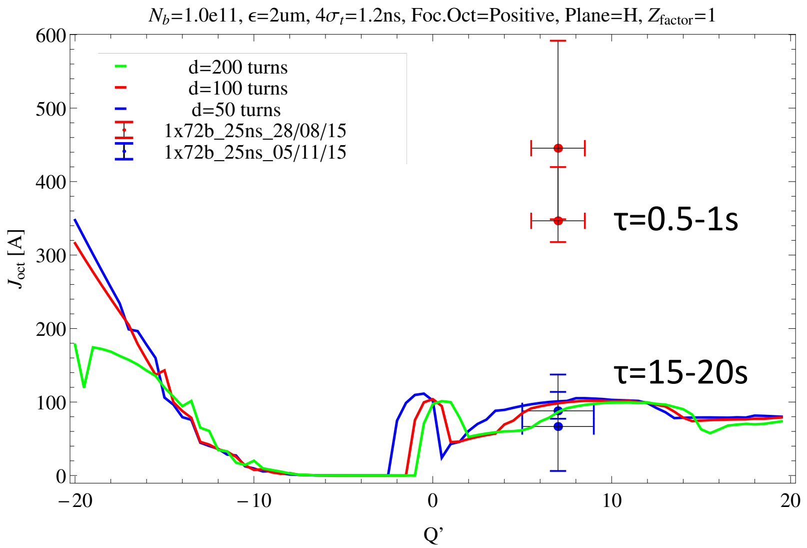
Single Bunch Measurements at 6.5TeV





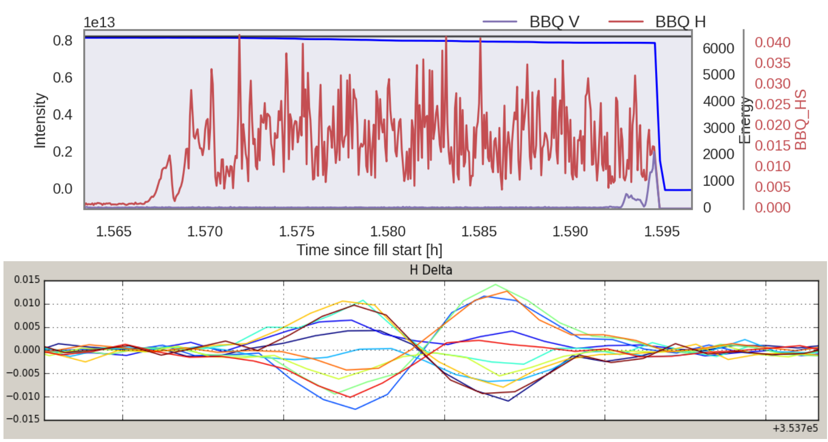
- **For Q'≈0**
- Very large discrepancy seen when comparing DELPHI with single bunch measurements.
- Observation is repeatable, measurements occurred over period of ~3 months. Not machine issue.
- Possible explanations are dominance of Q'' compared to Q', or ADT not performing as expected for this regime. Both of these will be explored further in 2016.

Train Measurements at 6.5TeV

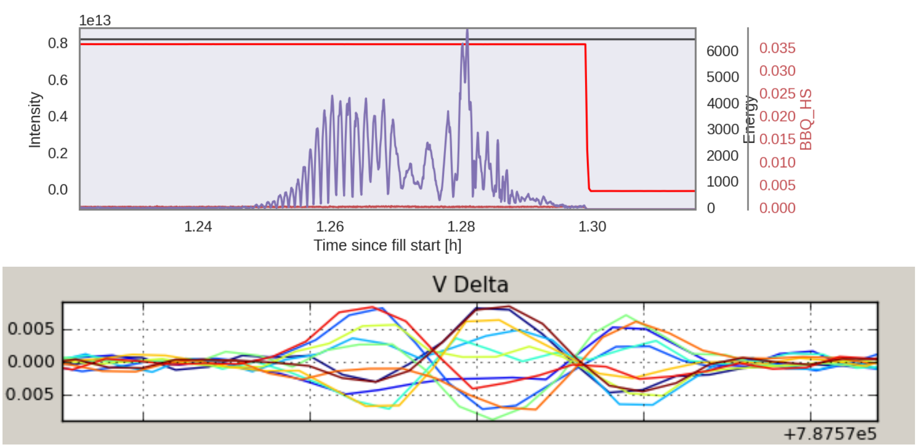


- 72b w/25ns became unstable at 350A (unscaled) with presence of e-cloud (≈0.8deg sync. phase shift) on 28/08.
- 72b w/25ns became unstable at currents consistent with single bunch measurements on 05/11. Sync. phase shift observed of ≈0.3deg.
- Difference due to effect of scrubbing at FT.
- Different kind of instability observed between two cases. 2 nodes expected from simulation for H or V single bunch instabilities.

B1, 1x72b, 28/08

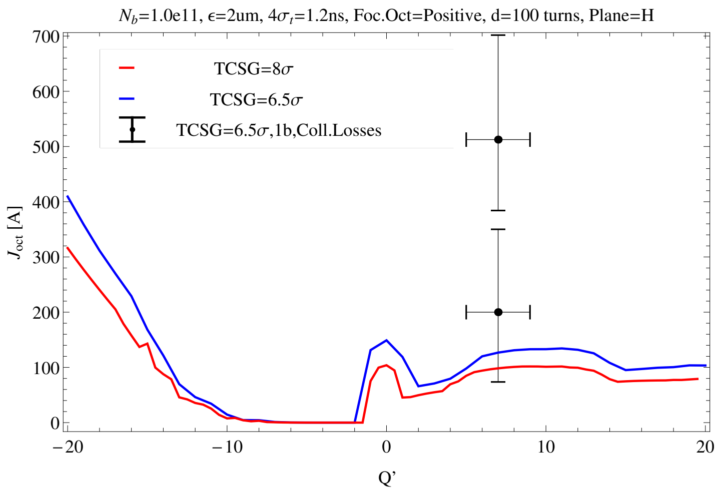


B2, 1x72b, 05/11

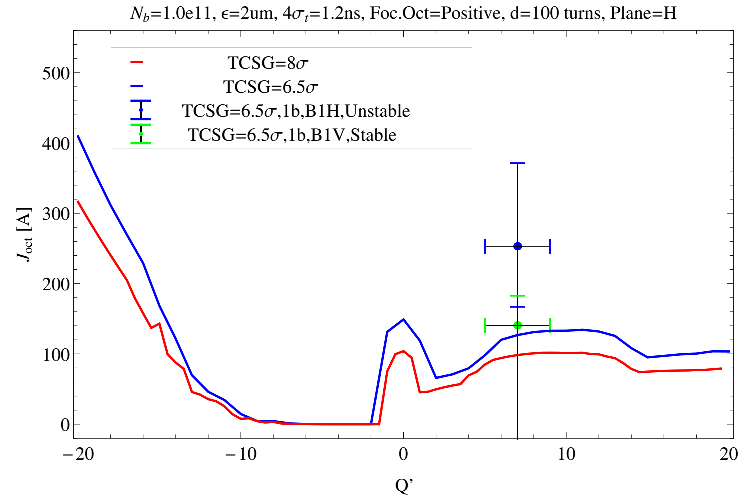


MD2 – Instabilities at 40cm

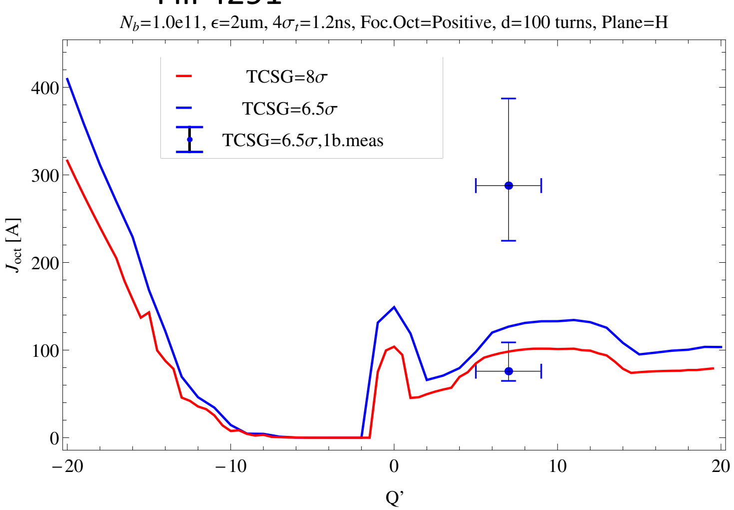
Fill 4290



Fill 4290



Fill 4291



- Measure instability threshold with TCSG at tighter setting of 6.5σ.
- Large losses on the collimator occurred for B2 nominal during the first ramp.
- Despite going unstable, could not trust measurements due to transverse distribution
- B1H became unstable at higher than expected values. Surprising as B1H emittance was greater than B1V.
- Repeat fill was equally unreliable and a repeat MD needed.

Instability Measurements in 2016

- Verify impedance model without ADT.
- Increase beam intensity for instability threshold measurements. We have shown that 1x72b w/ 25ns now goes unstable at single bunch thresholds. What if we increase the number of bunches?
- Greater understanding of $-2<Q'<2$ and $Q'<-2$. Further measurements and simulation required.
- Initially measure stability threshold for TCSG=7.5σ for β*=40cm. Repeat MD for TCSG=6.5σ.
- Measurements of coupling at injection – will be able to compare with simulation results.

Summary

- Transverse instabilities regularly observed during operation.
- ADT gain, Chromaticity and Octupole current increased to mitigate blowup. By the end of November, instabilities were able to be suppressed routinely.
- BCMS fill showed that at injection and during the squeeze, we are quite close to the limit of stability.
- ADT ObsBox will be able to provide more detailed bunch-by-bunch information which will allow us to understand some of the instabilities better.

- Instability measurements show good agreement for operational chromaticities. Further studies required for small and negative chromaticities.
- Threshold was increased by a factor of 5 for bunch train in strong presence of e-cloud. High intensity physics scrubbed the machine at flat top, thereby reducing e-cloud levels and reverting to single bunch instability thresholds.

Beam Induced Heating

Summary table of LHC issues

equipment	Problem	2011	2012	2015	2016
VMTSA	Damage			removed	removed
TDI	Damage			Beam screen reinforced, ~~copper coating on the jaw~~	New spares to be followed up, should be much better
MKI	Delay			Beam screen upgrade and non conformity solved	
Collimators	Few dumps			Non conformity solved. TCTVB removed	TCLIA issue believed to be an artefact
Beam screen Q6R5 and TOTEM	Regulation at the limit			Upgrade of the valves + TOTEM check	
ALFA	Risk of damage			New design + cooling	
BSRT	Deformation suspected			New design + cooling	
BGI	vacuum increase			To be followed up	Temperature probes installed

- 2015 went much better!
- Other devices may show up in the list

Damage
Limits operation
Worry that can limit operation
Should be fine

Summary table of LHC issues

equipment	Problem	2011	2012	2015	2016
VMTSA	Damage			removed	removed
TDI	Damage			Beam screen reinforced, ~~copper coating on the jaw~~	New spares to be followed up, should be much better
MKI	Delay			n d	
Collimators	Few dumps			Non conformity solved. TCTVB removed	TCLIA issue believed to be an artefact
Beam screen Q6R5 and TOTEM	Regulation at the limit			Upgrade of the valves + TOTEM check	
ALFA	Risk of damage			New design + cooling	
BSRT	Deformation suspected			New design + cooling	
BGI	vacuum increase			To be followed up	Temperature probes installed

Most problems observed in 2012 were seriously and efficiently addressed.

- 2015 went much better!
- Other devices may show up in the list

Damage
Limits operation
Worry that can limit operation
Should be fine

Summary table of LHC issues

equipment	Problem	2011	2012	2015	2016
VMTSA	Damage			removed	removed
TDI	Damage			Beam screen reinforced, ~~copper coating on the jaw~~	New spares to be followed up, should be much better
MKI	Delay			Beam screen upgrade and non conformity solved	
Collimators	Few dum			removed	TCLIA issue believed to be an artefact
Beam screen Q6R5 and TOTEM	Regulation at the limit			Upgrade of the valves + TOTEM check	
ALFA	Risk of damage			New design + cooling	
BSRT	Deformation suspected			New design + cooling	
BGI	vacuum increase			To be followed up	Temperature probes installed

TDI heating should be followed up closely after the exchange during the YETS (see talk of A.Lechner).

- 2015 went much better!
- Other devices may show up in the list

Damage
Limits operation
Worry that can limit operation
Should be fine

Summary table of LHC issues

equipment	Problem	2011	2012	2015	2016
VMTSA	Damage			removed	removed
TDI	Damage			Beam screen reinforced, ~~copper coating on the jaw~~	New spares to be followed up, should be much better
MKI	Delay			Beam screen upgrade and non conformity solved	
Collimators	Few dumps			Non conformity solved. TCTVB removed	TCLIA issue believed to be an artefact
Beam screen Q6R5 and TOTEM	Regulatio limit				
ALFA	Risk of d				
BSRT	Deforma suspected			cooling	
BGI	vacuum increase			To be followed up	Temperature probes installed

A collimator cooling non-conformity was identified and solved during the run.

Issues with non-physical temperature reading are being investigated.

- 2015 went much better!
- Other devices may show up in the list

Damage
Limits operation
Worry that can limit operation
Should be fine

Summary table of LHC issues

equipment	Problem	2011	2012	2015	2016
VMTSA	Damage			removed	removed
TDI	Damage			Beam screen reinforced, ~~copper coating on the jaw~~	New spares to be followed up, should be much better
MKI	Delay			Beam screen upgrade and non conformity solved	
Collimators	Few dumps			Non conformity solved. TCTVB removed	TCLIA issue believed to be an artefact
Beam screen Q6R5 and TOTEM	Regulation at the limit			Upgrade of the valves + TOTEM check	
ALFA	Risk of damage			New design +	
BSRT	Deforma suspecte				
BGI	vacuum increase			To be followed up	Temperature probes to be connected

The BGI pressure increase will be followed up with the connection of temperature probes.

- 2015 went much better!
- Other devices may show up in the list

Damage
Limits operation
Worry that can limit operation
Should be fine

Summary table of LHC issues

equipment	Problem	2011	2012	2015	2016
VMTSA	Damage			removed	removed
TDI	Damage			Beam screen reinforced, ~~copper coating on the jaw~~	New spares to be followed up, should be much better
MKI	Delay			Beam screen upgrade and non conformity solved	
Collimators	Few dumps			Non conformity [illegible]	TCLIA issue believed to be an artefact
Beam screen Q6R5 and TOTEM	Regulation at the limit			Upgrade of the valves + TOTEM check	
ALFA	Risk of damage			New design + cooling	
BSRT	Deformation suspected			New design + cooling	
BGI	vacuum increase			To be followed up	Temperature probes installed

Focus of this section.

- 2015 went much better!
- Other devices may show up in the list

16/12/15

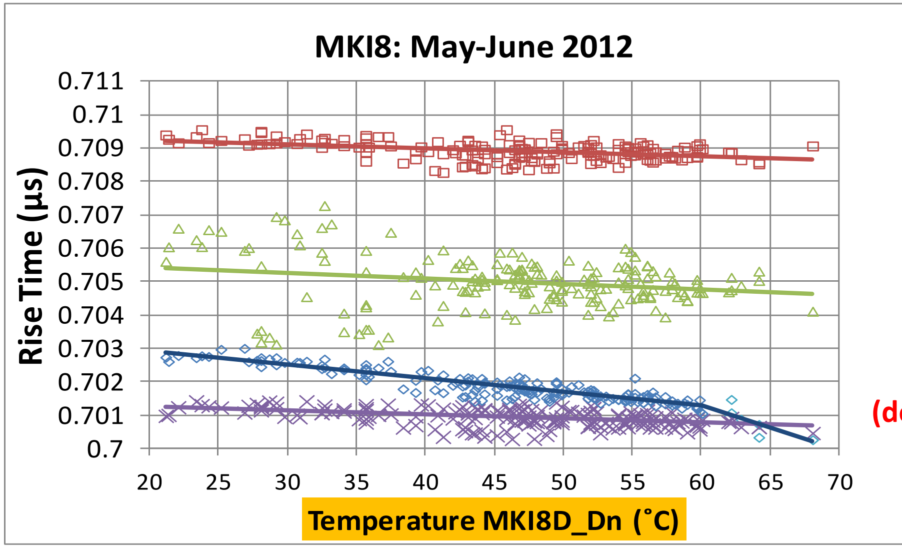
Damage
Limits operation
Worry that can limit operation
Should be fine

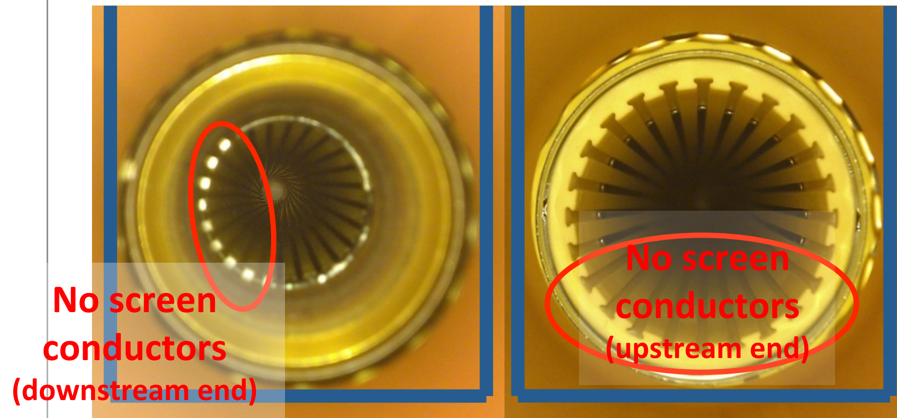
MKI Introduction

- Before LS1, there were 15 conducting screens in the aperture of each magnet.
- Until TS3 2012, MKI8D had 90 degree twist in conducting screens. Ferrite was exposed to wakefields, causing ~160W/m of heating, occasionally limiting LHC operation.
  - All other MKIs had maximum ferrite heating of ~70W/m and did NOT limit LHC operation.
- Temporary loss of magnetic properties of ferrite with prolonged periods of high intensity fills with power deposition of ~160W/m, motivated intense study into heating into all MKI's.
- After LS1, all MKI's have a full complement of 24 conducting screens. From measurements, maximum power deposition during run 2 is expected to be ~50W/m for all MKI's, i.e. less than MKI's that did not limit operation before LS1.
- Position of PT100 moved from end plates to side plates.

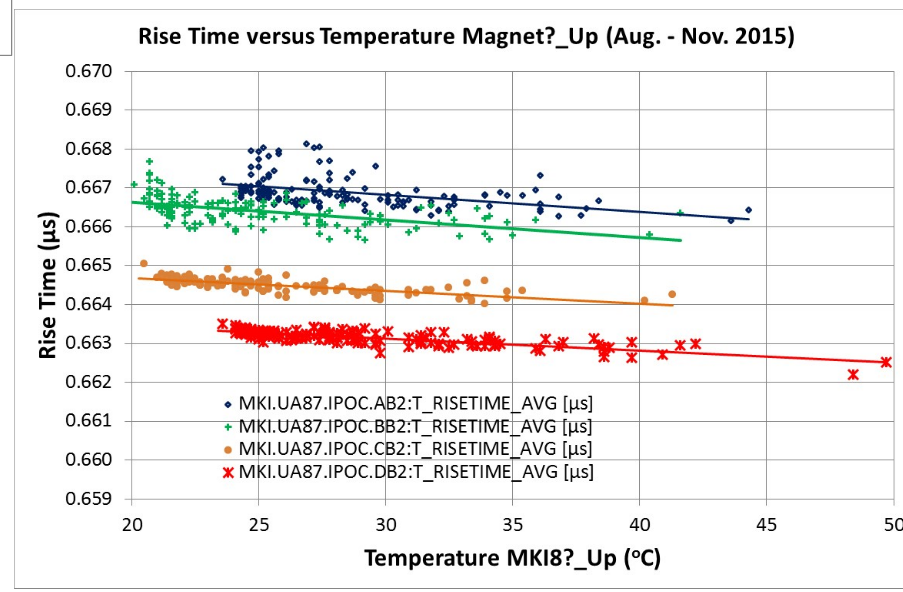
See 29th MKI Strategy Meeting 'Current status of LS1 work…–M. Barnes 17/12/14'

Check for non-linearity of Ferrite





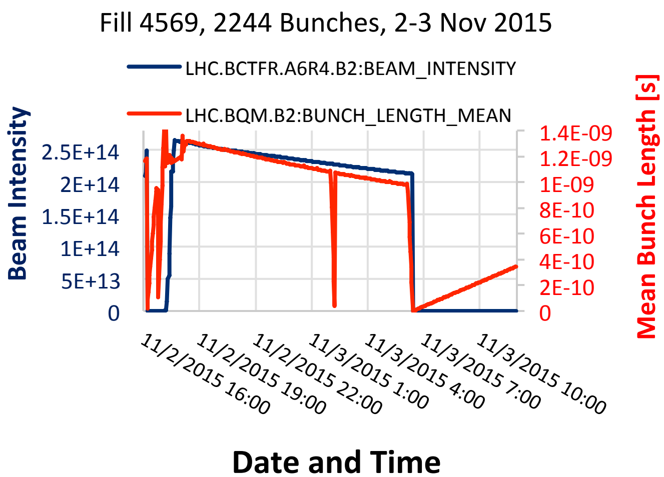
- Above: Until TS3 2012, MKI8D had "twisted" ceramic tube – causing high heating of ferrite yoke at <u>down</u>stream end ⇨ started to exceed Curie temperature and hence non-linearity in current rise-time above ~60˚C measured.

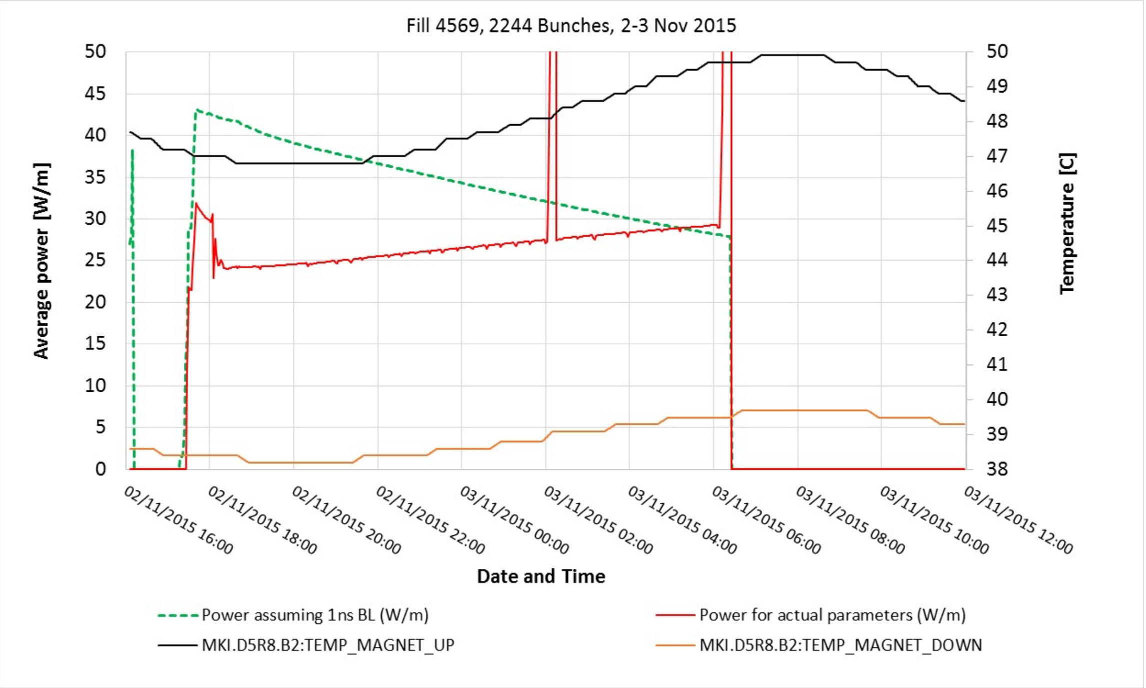


- Right: MKIs now have full complement of screen conductors. As expected, ferrite yoke is below Curie temperature i.e. no non-linearity seen.

- SIS interlock level gradually increased with experience, to avoid risk of mis-injection due to high ferrite temperature.

MKI Temperature During Long Fills





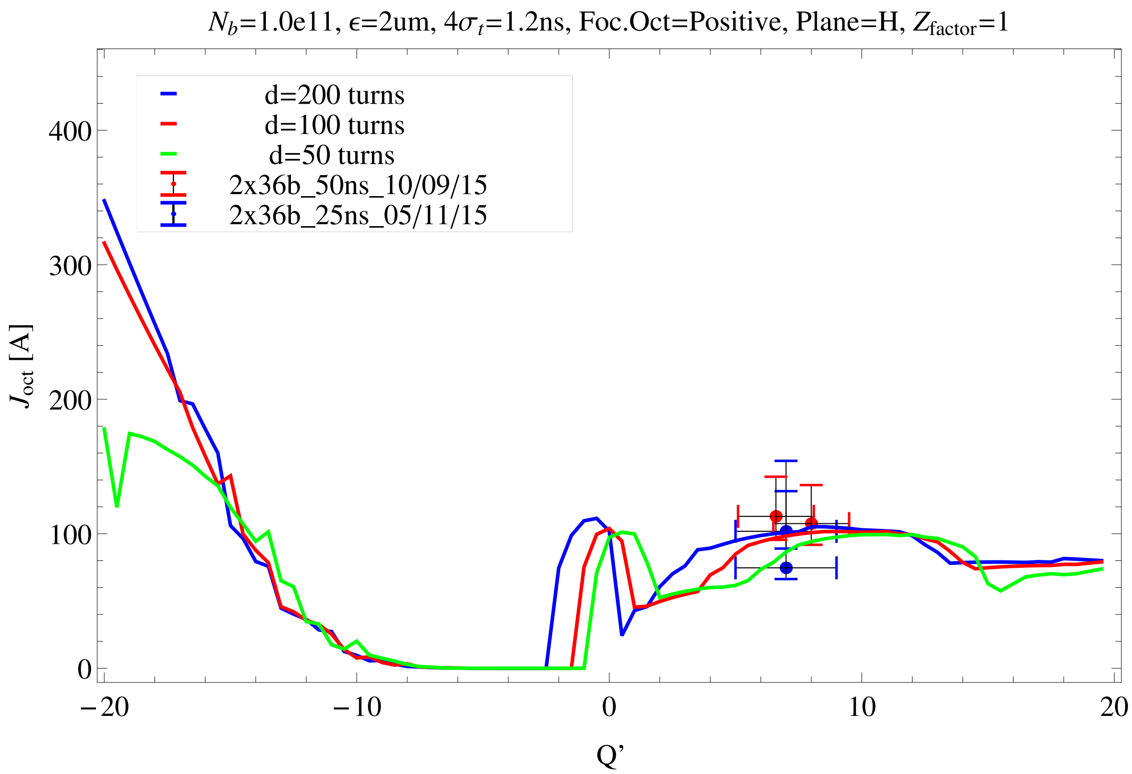
- Post LS1: upstream temperature readings, for all MKIs, are higher than downstream end.
- MKI8D Magnet_Up, as expected, has the highest PT100 reading.
- For MKI8D, average power loss estimated for above fill is ~26W/m [scaled from 52W/m for $1.15\text{x}10^{11}$ ppb, 2808 bunches, 1ns beam by ppb^2 and $(1/BL)^2$ to $1.16\text{x}10^{11}$ ppb, 2244 bunches].
- 40˚C measured at downstream end corresponds to ~26W/m power deposition.
- ~50˚C measured at upstream end corresponds to ~43W/m (and max. ferrite temp. of ~75˚C)

Summary

- Beam induced heating has not shown any significant surprises throughout 2015 (excluding TDI). Similar performance is anticipated for 2016 (barring any new non-conformities).
- Heating monitoring will be pursued in 2016 with all the tools put in place in 2015.
- SIS interlock threshold for MKI's is still deliberately set quite low. Threshold is incrementally increased upon verification that there are no non-linearities in the ferrite yoke behaviour.
- Decrease in bunch length to 1ns (throughout the fill) should not cause excessive heating in the MKI's.
- No problems with MKI's expected during run 2.

Backup

2x36b – 25ns vs 50ns



Summary of Expected Power Depositions in MKI

MKI Magnet	Installed	Pre-LS1* (W/m)	Post-LS1 (W/m)	HL-LHC, 25ns (W/m)
MKI11-T13-MC03 (24 screen conds.)	**MKI8D**	35	**52**	**191**
MKI02-T10-HC14 (24 screen conds.)	MKI8C	30	48	177
MKI07-T08-MC08 (24 screen conds.)	MIK2A	27	45	163
MKI01-T05-HC16 (24 screen conds.)	Spare	28	45	167
MKI09-T03-HC18 (24 screen conds.)	Spare	26	44	162
MKI08-T11-MC09 (24 screen conds.)	MKI2D	26	43	158
MKI10-T06-HC13 (24 screen conds.)	MKI2C	25	41	150
MKI03-T01-HC17 (24 screen conds.)	Spare	25	39	145
MKI06-T07-HC12 (24 screen conds.)	MKI2B	23	37	138
MKI05-T02-HC15 (24 screen conds.)	MKI8B	21	36	130
MKI12-T12-MC01 (24 screen conds.)	**MKI8A**	20	**34**	**125**
Average:		**26**	**42**	**155**
Standard deviation:		**4.2**	**5.4**	**20.0**
MKI2A **pre-LS1**: 15 screen conds.		**68**[a]	117	432
MKI8D **pre-TS3, 2012**: 15 (90 twist) screen conds.		**161**[b]	N/A	N/A

Expected Post-LS1 power deposition in MKI8A is ~65% of MKI8D.

Expected "steady-state" post-LS1 temperatures (with bake-out jackets installed, 22˚C ambient):

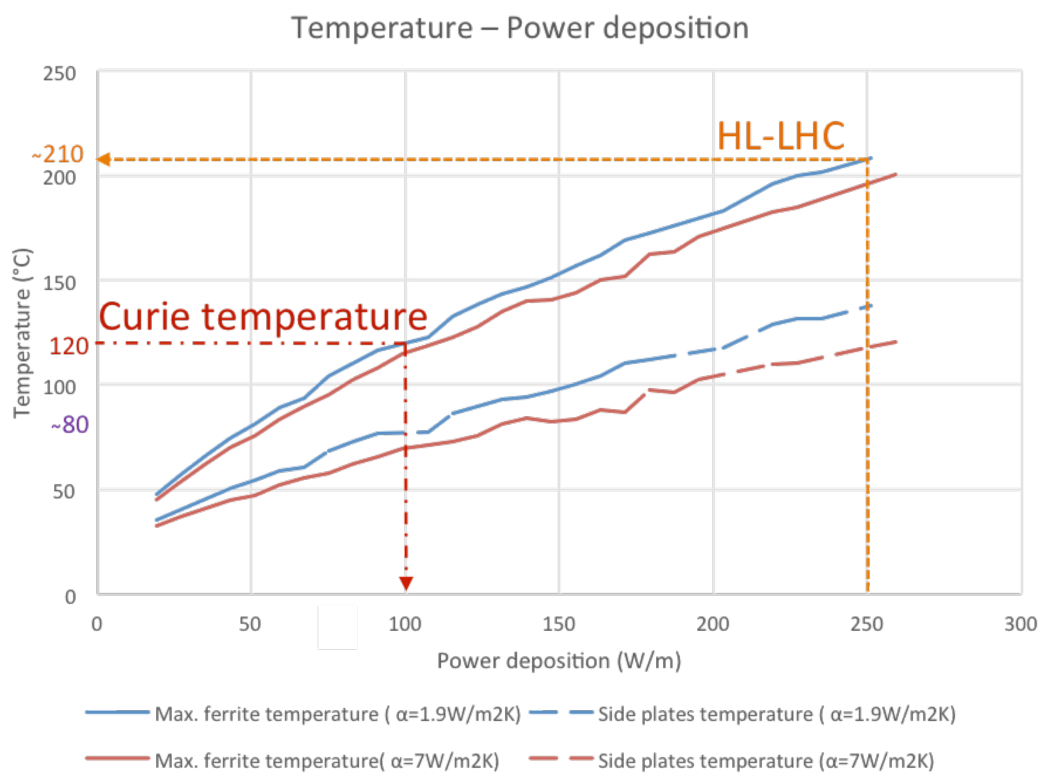
Power Deposition (W/m)	Max. ferrite temperature [˚C]	Side plate temperature [˚C]
52 (100%)	**82**	**55**
43 (83%)	74	50
34 (65%)	65	45
26 (50%)	56	40
18 (35%)	46	34

Estimate for fill #4381, 17/9/2015, 1033 bunches, 1.06×10^{11} ppb. → 26 (50%)

6˚C

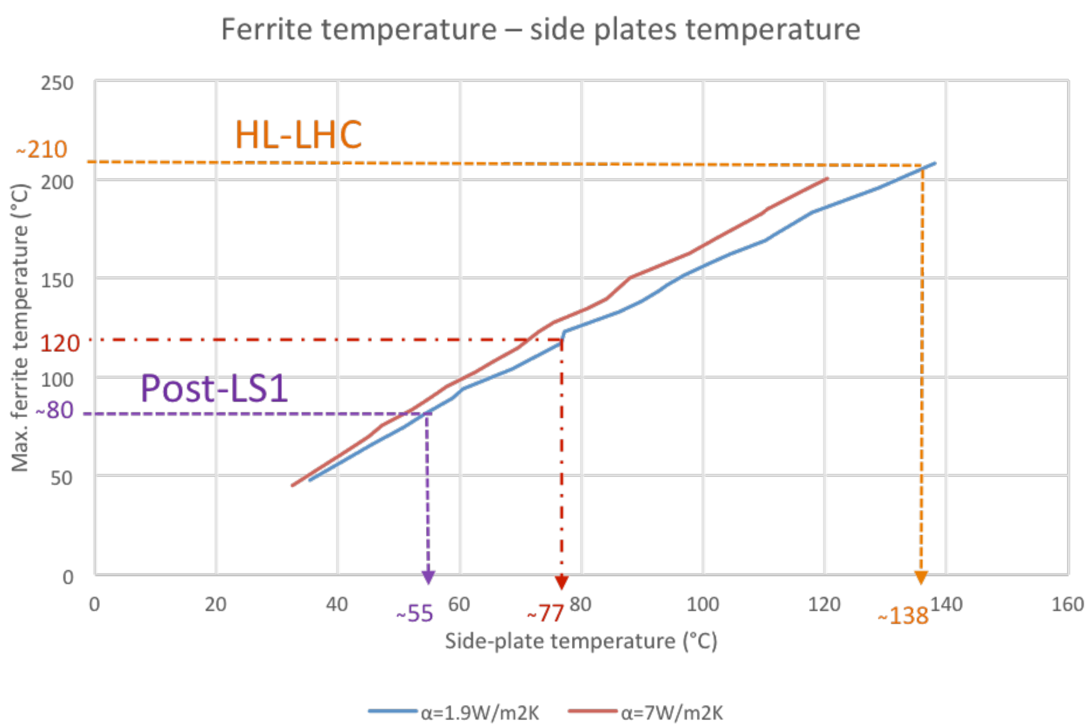
New design of capacitively coupled end (in manufacture) is expected to reduce power deposition by ~20%.

New location of the PT100 sensors



- Plot showing the relevant calibration between measured power deposition and magnet temperature for the new PT100 location.
- Non-linearities observed at temperatures still far from that anticipated for HL-LHC.

New location of the PT100 sensors



- Plot showing the relevant calibration between measured power deposition and magnet temperature for the new PT100 location.
- Non-linearities observed at temperatures still far from that anticipated for HL-LHC.