HL-LHC operational scenarii and machine performance

November, 2017. Madrid

HiLumi HL-LHC PROJECT

"The report" is almost ready!

UPDATE OF THE HL-LHC OPERATIONAL SCENARIOS FOR PROTON OPERATION

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The main aim of this document is to have a clearly identified set of beam and machine parameters to be used for numerical simulations and performance assessment. Two scenarios are discussed:

i) Nominal scenario (levelling at a luminosity of 5×10^{34} cm^{-2}s^{-1}).
ii) Ultimate scenario (levelling at a luminosity of 7.5×10^{34} cm^{-2}s^{-1}).

Two related HiLumi reports

CERN-ACC-REPORT-2017-xxx

November 3, 2017

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Beam dynamics requirements for HL–LHC electrical circuits

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Abstract
A certain number of LHC magnets and relative electrical circuits will be replaced for the HL-LHC upgrade. The performance of the new circuits will need to be compatible with the current installation, and to provide the necessary improvements to meet the tight requirements of the new operational scenario. This document summarises the present knowledge of the performance and use of the LHC circuits and, based on this and on the new optics requirements, provides the necessary specifications for the new HL-LHC electrical circuits.

Keywords
LHC, HL–LHC, circuit specifications, power converters.

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Optics Measurement and Correction Challenges for the HL-LHC

F. Carlier, J. Coello, S. Fartoukh, E. Fol, D. Gamba, A. García-Tabares, M. Giovannozzi, M. Hofer, A. Langner, E.H. Maclean, L. Malina, L. Medina, T.H.B. Persson, P. Skowronski, R. Tomás, F. Van der Veken and A. Wegscheider.
CERN, Geneva, Switzerland.

Abstract

Optics control in the HL-LHC will be challenged by a very small β^* of 15 cm in the two main experiments. HL-LHC physics fills will keep a constant luminosity during several hours via β^* leveling. This will require the commissioning of a large number of optical configurations, further challenging the efficiency of the optics measurement and correction tools. We report on the achieved level of optics control in the LHC with simulations and extrapolations for the HL-LHC.

… and one ECR under preparation

EDMS NO.	REV.	VALIDITY
0000000	**0.0**	**DRAFT**

REFERENCE : NOT REQUIRED

HL – LHC Engineering Change Request
OPTICS CONFIGURATION CHANGE

ECR DESCRIPTION

WP Originator	WP2, WP5	***Process***	Process concerned
Equipment	N/A	***Baseline affected***	Scope
Drawing	N/A	***Date of Issue***	2017-10-28
Document	TDR	***CI responsible***	G. Arduini, S. Redaelli
WPs Affected		***Reference Document***	TDR Version 0.1

Detailed Description

This ECR describe the upate in optics and layout since the TDR V0.1 [1] as well as the resulting collimator settings. This document complement the information on the TDR.

Reasons for change

This update concerns the optics configuration for the baseline running scenario of HL-LHC. The optics data in MAD-X format is publsihed [2].

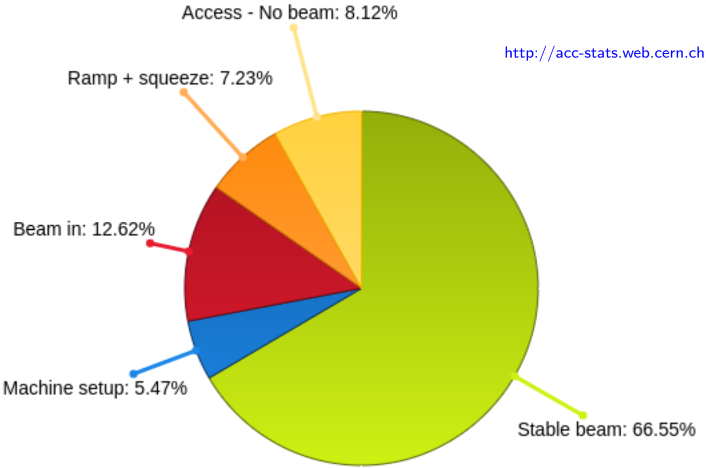
1) The layout used in optics model is conform to the drawings LHCLSXH_0001/AA, LHCLSXH_0002/AA, LHCLSXH_0009/AB , LHCLSXH_0010/AF.
2) The normalized strengths of the main magnets (MB, MQ*, MCB*, MS) from injection to the of the levelling (β^*=15 cm in IP1/5, 3m in IP8, 10m in IP2) in high luminosity operations and to high beta (β^*=30 m in IP1/5/2/8) are provided.
3) The phase advance between MKD and TCT has been optimized and allows tighter tertiary collimator settings and increase aperture margins in Point 1 and 5.

Optics	TCT6 IR1 B1	TCT6 IR5 B1	TCT6 IR1 B2	TCT6 IR5 B2
HL-LHC v1.2 15cm	106	285	137	101
HL-LHC v1.3 15cm	180	155	154	152

Table above shows the difference betweem the MKD to TCT phase for Verion 1.2 and 1.3. The configuration improve both Point 1 and Point 5 to be compatible with equal setting of the TCTH and TCTV as the nominal LHC and, automatically, the

LHC efficiency with 8b4e BCS beams

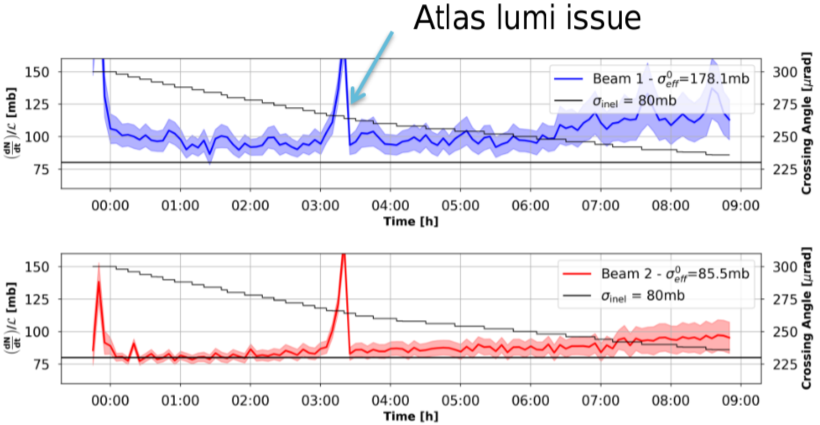
http://acc-stats.web.cern.ch/acc-stats



HL-LHC: we assume **50%** performance efficiency (stable beam: 39%)

LHC effective σ_{bo} for burn-off

Effective σ_{bo} for burn-off is close to 81 mb for beam 2 but higher for beam 1,



HL-LHC: Baseline $\sigma_{bo} = 111$ mb but exploring 81 mb. No extra emittance blow-up beyond IBS considered. Keep DA$\geq 6\sigma$.

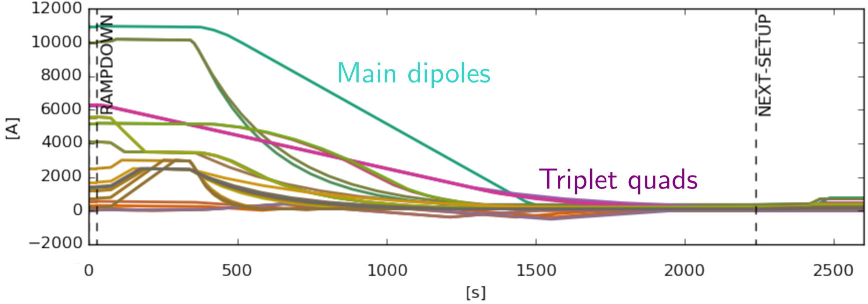
Turn-around-Time

Phase	Time [minutes]	
	Old baseline	New baseline Nominal (Ultimate)
Ramp-down	60	**40**
Set-up, injection	55	65
Ramp & Squeeze	25	25
Flat-top, Squeeze	30	**5 (10)**
Adjust/collide	10	10
TOTAL	**180**	**145 (150)**

Faster ramp-down and Ramp & Squeeze have considerably reduced turn-around-time.

Further improving turn-around-time?

LHC current ramp-down



In HL-LHC upgrading IR2 and IR8 triplet PCs could reduce TaT by 15 minutes, increasing integrated lumi by 2-3%.

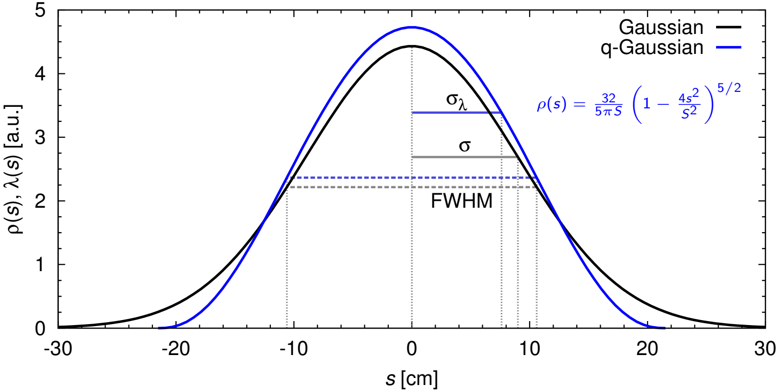
Protected aperture & β^*

	Old baseline $[\sigma]$	New baseline $[\sigma]$
TCP IR7	6.7	6.7
TCS IR7	9.1	9.1
TCSP IR6	10.1	10.1
TCDQ IR6	10.6	**10.1**
TCT IR1/5	12.9	**10.4**
Protected ap.	14.6	**11.9**

Thanks to improved phase advance MKD→TCT the tighter collimation β^* is reduced to **15 cm**.
Crossing angle is also reduced to **10.5**σ (old 12.5σ).
See Roderik's and Riccardo's talks.

q-Gaussian longitudinal bunch profile

q-Gaussian density is now considered instead of Gaussian

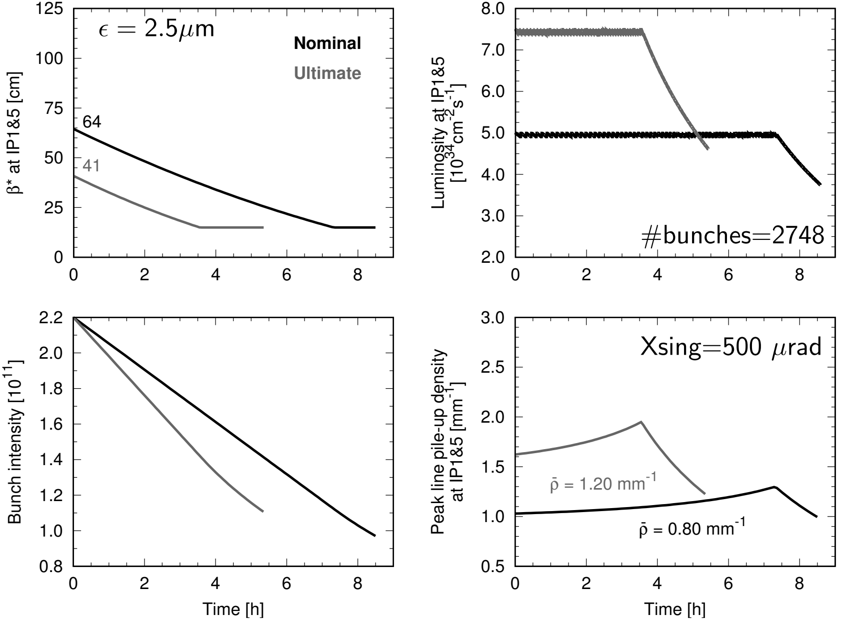


- For $\sigma = 9\text{cm}$ ($4\sigma = 1.2\text{ns}$): rms $\sigma_\lambda = 7.6\text{cm}$, FWHM $= 21.2\text{cm}$.
- Using q-Gaussian increases virtual luminosity by 10.3%.

Impact of changes on integrated luminosity

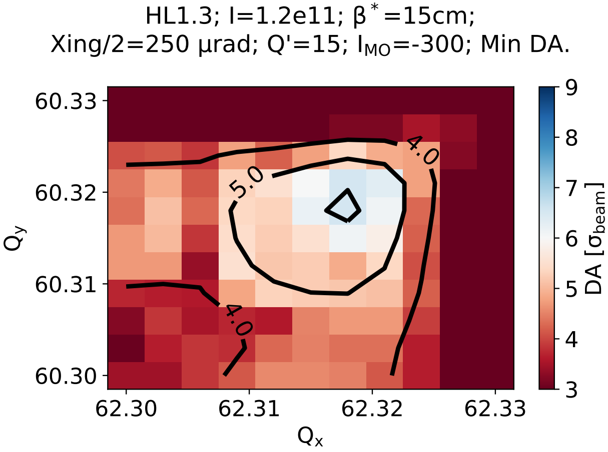
Change	ΔL_{int} [%]	
	Nominal	Ultimate
Shorter turn-around time	$+6.0$	$+7.2$
Smaller β^* and crossing angle	$+3.1$	$+6.4$
q-Gaussian longitudinal bunch profile	$+1.1$	$+2.3$

Baseline



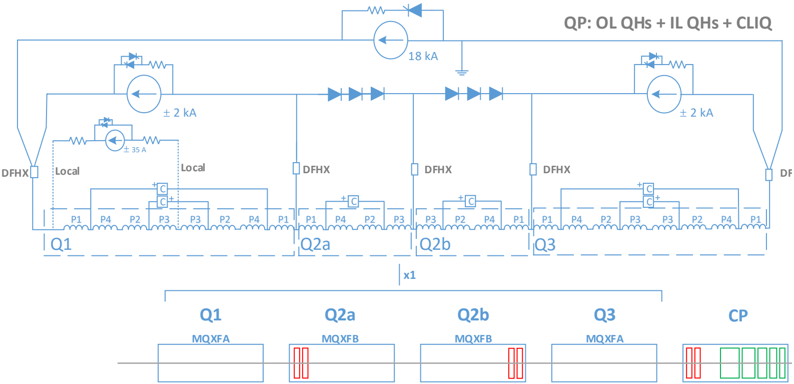
$\epsilon = 2.5\mu$m
Nominal
Ultimate
64
41
β* at IP1&5 [cm]
#bunches=2748
Luminosity at IP1&5 [10^{34}cm^{-2}s^{-1}]
Bunch intensity [10^{11}]
Time [h]
Xsing=500 μrad
$\bar{\rho}$ = 1.20 mm^{-1}
$\bar{\rho}$ = 0.80 mm^{-1}
Peak line pile-up density at IP1&5 [mm^{-1}]
Time [h]

Baseline: DA validation



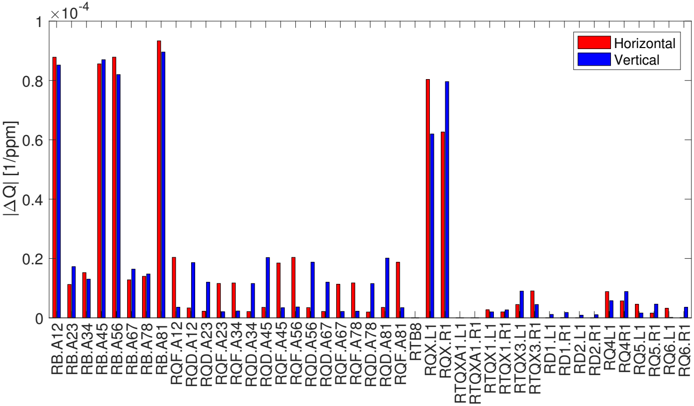
DA $= 6\sigma$ in a small region close to $Q_x = Q_y$. Tune and coupling control become critical. Further details in Nikos' presentation.

Triplet trim circuits news



- ★ New Q1A trim circuit of ±35A added for k-modulation: critical for accurate β^* control.
- ★ Q2A trim removed: Q2A/Q2B TF relative difference minimized via magnetic measurements and sorting.

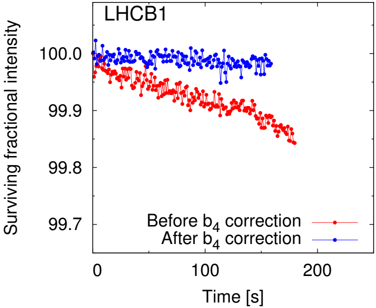
Power converter noise

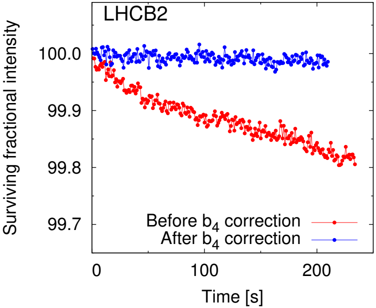


- ★ Increased β-functions in the ATS arcs magnifies power converter noise, challenging β^* control.
- ★ A new power converter *class 0* is being proposed to reduce tune jitter, improving β^* accuracy from 8% to 4%.

IR non-linear correction

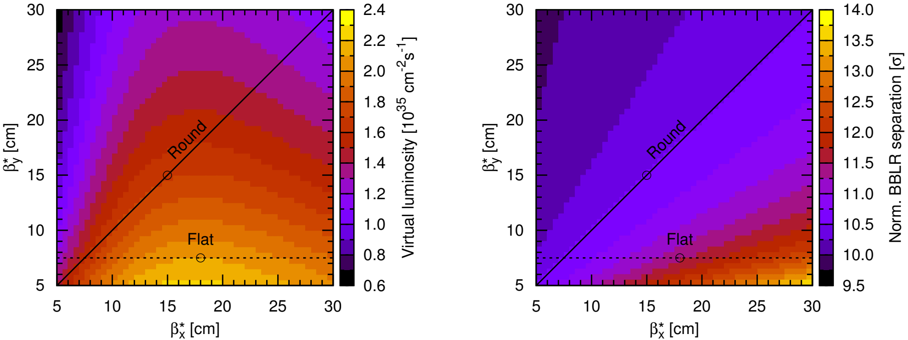
LHC IR non-linear correction at $\beta^* = 14$ cm in ATS MD:





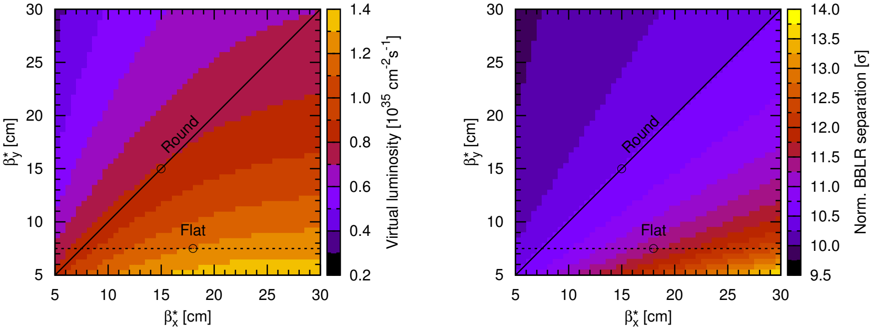
- ★ Losses without IR correction of 4%/h at $\beta^* = 14$ cm.
- ★ Lifetime recovered thanks to beam-based corrections
- ★ HL-LHC has larger IR non-linear errors $\rightarrow$ *Challenge ahead!*

Flat optics (with CCs)



- ★ Optimum values for luminosity are $\beta_x^*/\beta_y^* = 18$ / 7.5 cm and crossing angle of 11.3σ
- ★ IR remote alignment is needed for aperture at $\beta^* = 7.5$ cm
- ★ DA validation of this configuration is still required,
- ★ Operation with flat optics is a new regime$\rightarrow$ MDs

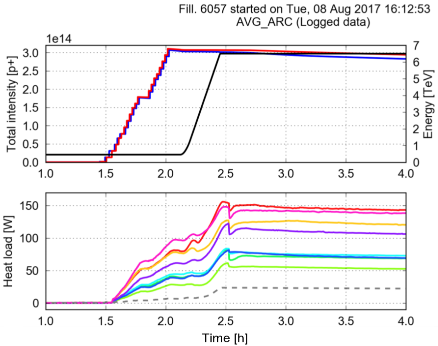
No CCs (flat optics)



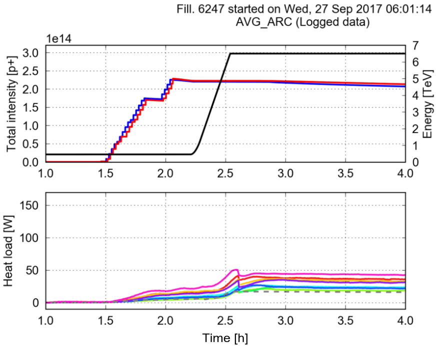
The optimum values for luminosity are $\beta_x^*/\beta_y^* = 31.5$ / 7.5 cm and crossing angle of 12.5σ. Again counting on remote alignment. DA and operation validation of this configuration are required.

Heat load: 25ns Vs 8b+4e

25 ns (2556b)



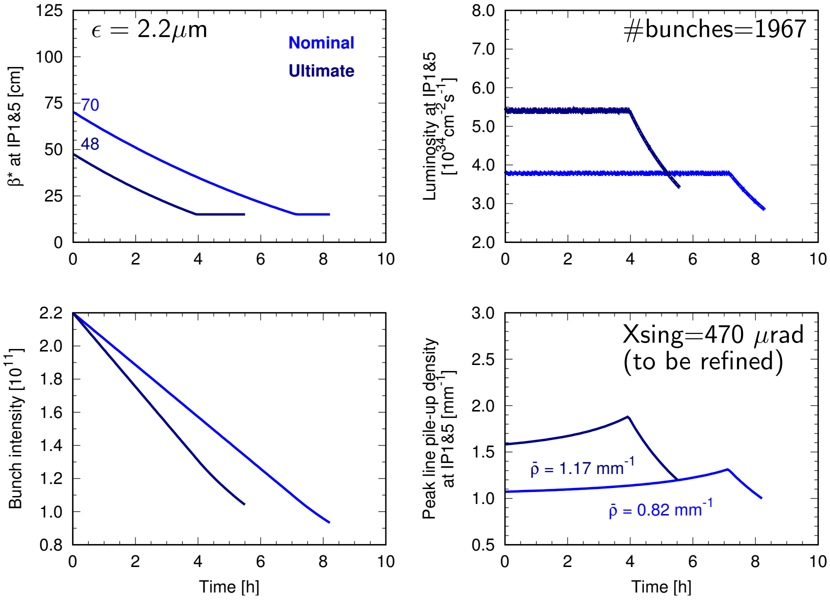
8b+4e (1916b)



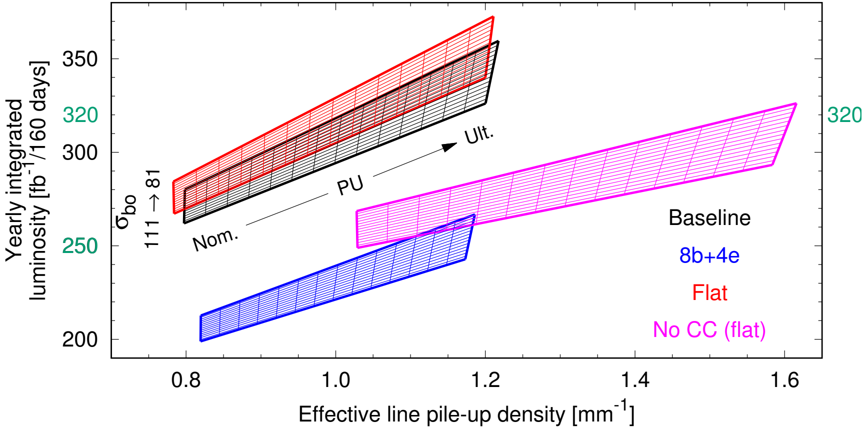
- Need to understand differences among arcs and
- gain from coating IR2 & IR8 triplets and matching sections

See Giovanni Iadarola's talk for further details.

8b+4e: back-up for unbearable e-cloud

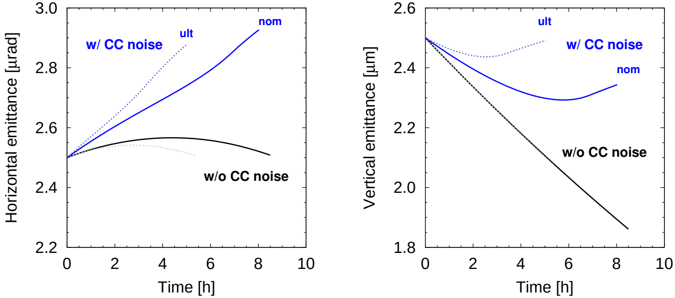


Performance and effect of σ_{bo}



First estimates of CC noise & tolerance

Estimated CC emittance growth by RF is 0.12 μm/h at β^*=15cm



$$\left(\frac{d\epsilon}{dt}\right)_{\mathrm{CC}} \approx 0.12\mu\mathrm{m/h}\frac{V_{\mathrm{CC}}^2}{(6.8\mathrm{MV})^2}\frac{15\mathrm{cm}}{\beta^*}$$

For lumi loss below 1%, CC emittance growth must be below 0.04 μm/h at β^* =15 cm.

For general emittance growth and instabilities see Xavier's talk.

Concluding remarks

- ★ New baseline scenario meets goals at 50% efficiency
  - Pushed: optics, collimation, impedance, beam-beam, DA, etc.
  - New: Ramp & Squeeze, Q1A trim, remote alignment, PC class 0, etc.
- ★ A slightly flat optics increases performance by 2-4%
- ★ The largest threat is e-cloud, 8b4e reduces performance by 25%
  - A mixed filling scheme 25ns/8b4e could mitigate loss
- ★ Not having CCs would result in 7-10% lower luminosity with 25% larger $\overline{\rho}$
- ★ Emittance growth and instabilities (including non-colliding bunches) need to be watched out.

Back-up slides

Optics control: LHC Vs HL-LHC

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	unit	LHC $\beta^* = 40$ cm	HL-LHC $\beta^* = 15$ cm
CMS/ATLAS luminosity imbalance tolerance	[%]	5	5
Tune jitter (rms)	$[10^{-5}]$	2-4	4.1
Assumed tune measurement uncertainty	$[10^{-5}]$	1.5	2.5
β^* accuracy:			
rms tolerance for lumi imbalance	[%]	2	2
rms achieved or expected	[%]	1	4
Peak β-beating after correction	[%]	5	10-20
β-beating from crossing angle (without non-linear IR correction)	[%]	2	20
$\lvert C^- \rvert$:			
Tolerance for instabilities	$[10^{-3}]$	1	1.0
Tolerance for K-modulation	$[10^{-3}]$	1	0.6
7 month drift	$[10^{-3}]$	3	12
$\Delta \lvert C^- \rvert$ from crossing angle (without non-linear IR correction)	$[10^{-3}]$	2	20
Dynamic aperture:			
Before IR correction	$[\sigma]$	10	5
After IR correction	$[\sigma]$	12	9

Table 6: Tolerances and achieved or expected values for LHC and HL-LHC optics control related parameters. Tune jitter values come from [16]. The assumed tune jitter of 2.5×10^{-5} requires upgraded power supplies for the telescopic arc dipoles. LHC DA values are taken from [84] and rescaled to the HL-LHC emittance of 2.5 μm.

200MHz suppresses e-cloud in dipoles, perf.?