Optics correction strategy, cycle optimization and implications for power converter and magnetic measurements performance

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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

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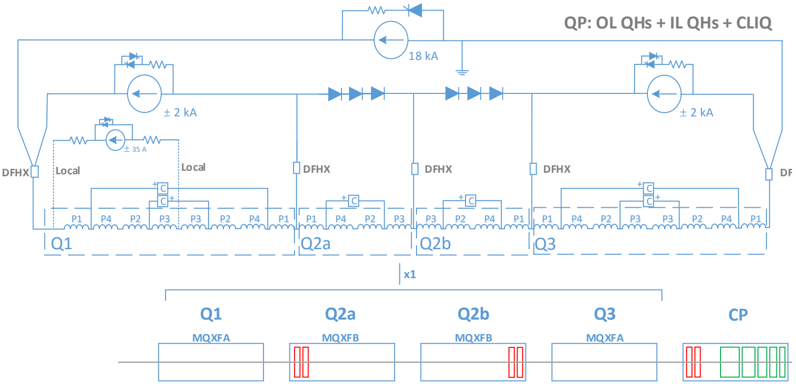
CERN, Geneva, Switzerland.

Abstract

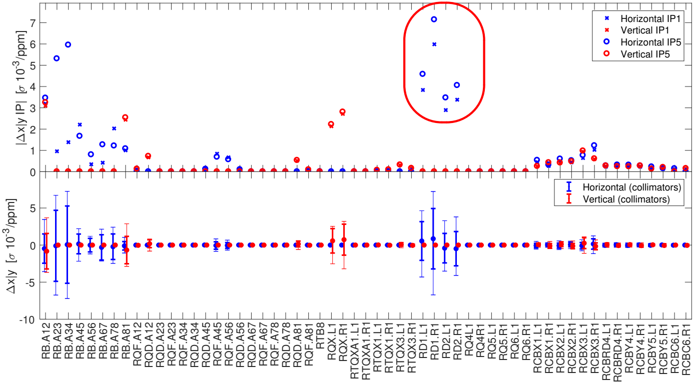
Optics control in the HL-LHC will be challenged by a very small β^* of 15 cm in the two main experiments. HL-LHC physics fills will keep a constant luminosity during several hours via β^* leveling. This will require the commissioning of a large number of optical configurations, further challenging the 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.

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.

Orbit drift from power converter noise

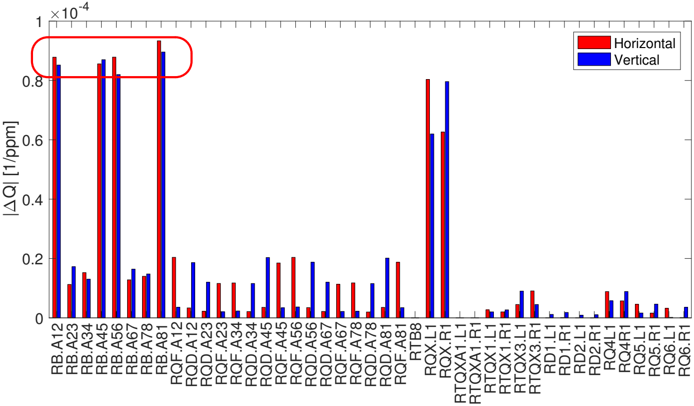


	Max |orbit drift| [σ_{beam}]	**Max $\|\Delta\beta^*/\beta^*_0\|$**
IP1/5 (x)	0.9 (0.7)	0.04 (0.02)
IP1/5 (y)	0.6 (0.5)	0.03 (0.02)

no remote cal
remote cal

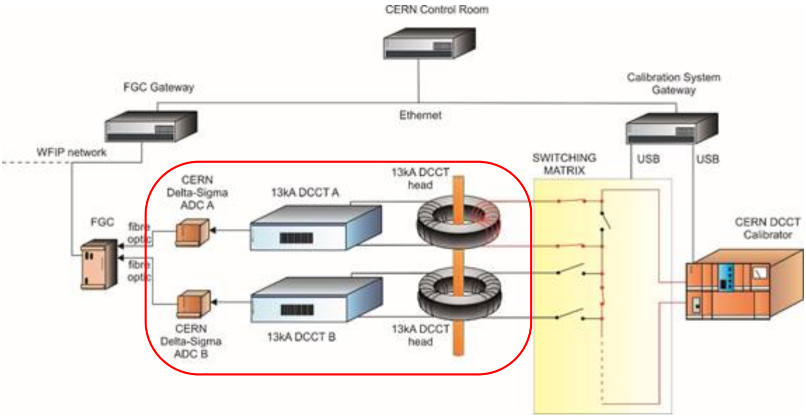
Remote calibration systems for D1&D2 PCs cost 200 kchf but it is judged unnecessary

Tune ripple from power converter noise



- ★ Increased β-functions in the ATS arcs magnifies power converter noise, increasing tune ripple.
- ★ The 4 ATS dipole PCs are proposed to be upgraded to *class 0* to reduce tune jitter from 4.1×10^{-5} to 2.7×10^{-5}.

Upgrade of 4 dipole PCs to class 0



Cost: 600 kchf

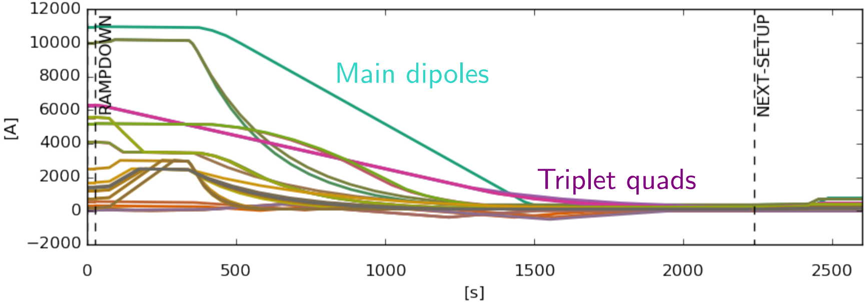
Turn-around-Time

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



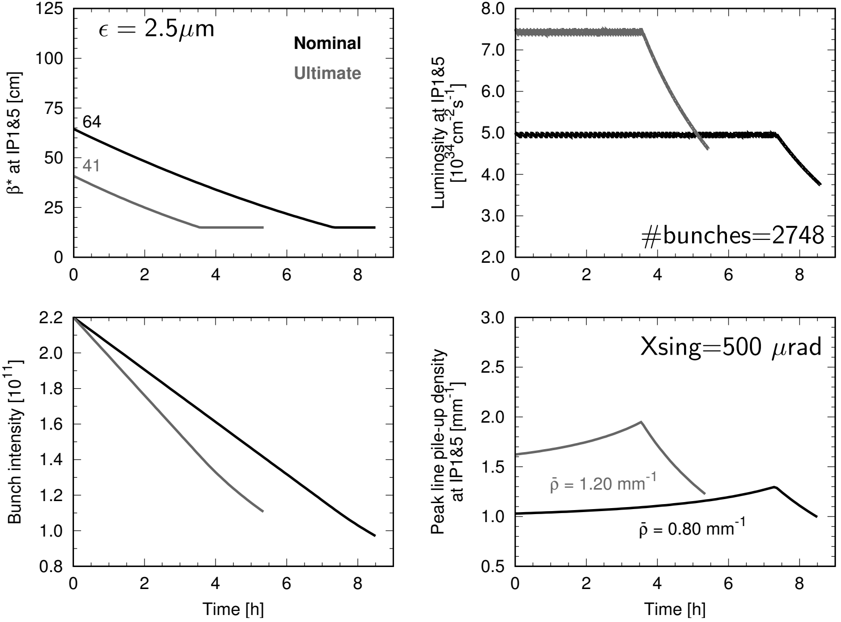
In HL-LHC upgrading IR2 and IR8 triplet PCs could reduce TaT by 15 minutes, increasing integrated lumi by 2-3%.

cost? diode option cheap: 80 kchf?

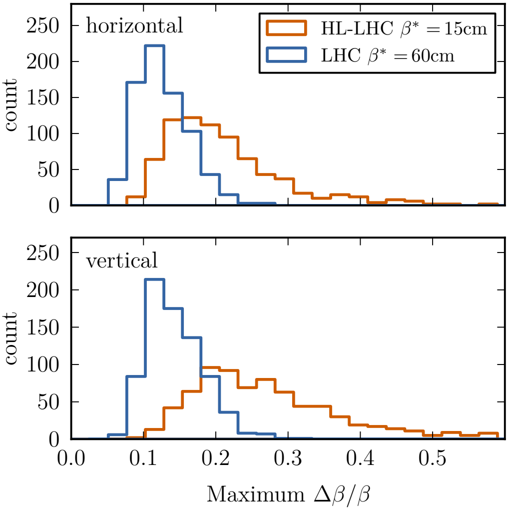
Challenges for optics control in HL

- β^* leveling: $\approx$50 optics need fine commissioning
- Arc errors enhanced without local quads for correction.
- β^* accuracy with k-modulation challenged by tune jitter
- HL-LHC non-linear magnetic errors affect: DA, Landau damping, β^* and coupling. All changing Vs crossing angle. Beam-based measurements are mandatory.
- We have no experience in correcting b_5, b_6 and a_6.

β^* leveling

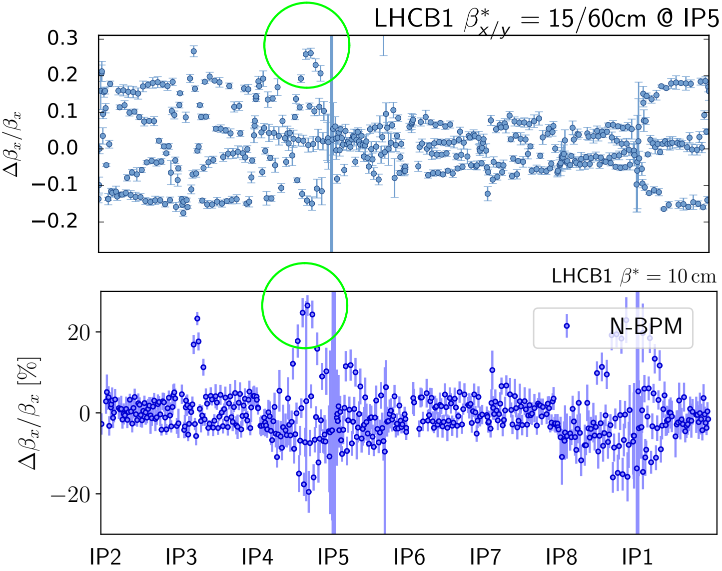


HL-LHC arc errors correction simulation



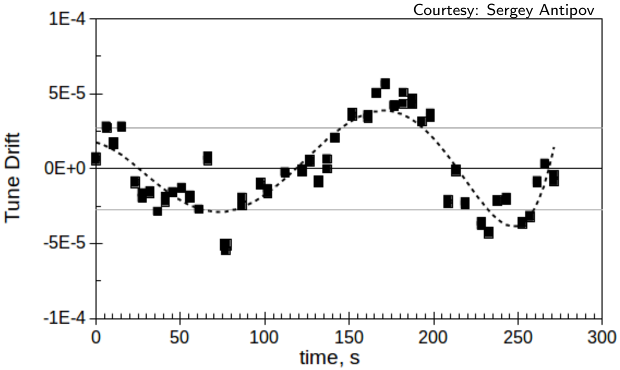
With current tools we expect 10-20% β-beating in HL-LHC.
Collimation & β^*-reach request 5% (as LHC).

Flat and round ATS optics MDs ($\beta_{arc} \times 4$)



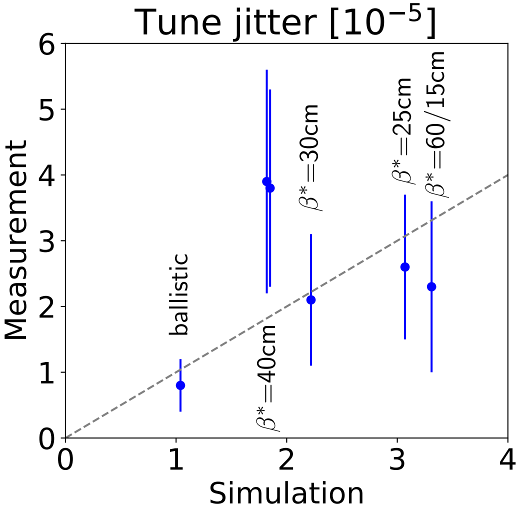
$\Delta\beta/\beta$ not under control for ATS large β_{arc}

Measured tune jitter in MDs



What is this 100s oscillation? How large will it be in HL-LHC? It could impair β^* measurements with K-modulation.

Measured tune jitter in MDs



β^* accuracy, K-modulation and tune jitter

- ★ ATLAS/CMS Lumi imbalance should be below 5%
- ★ From power supply ripple in current baseline we expect:

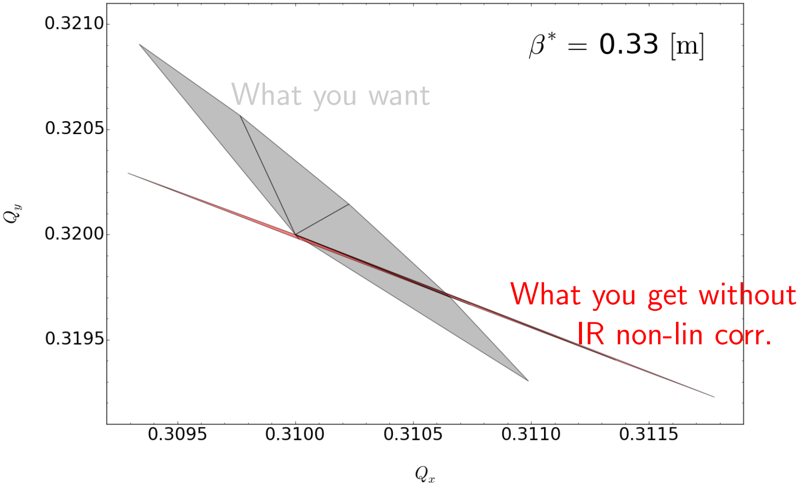
tune jitter=4.1×10^{-5} $\rightarrow$ β^* accuracy=10% $\rightarrow$ Lumi imb.$\approx$20%

- ★ **If we upgrade 4 arc dipole PCs to class 0:**

tune jitter=2.7×10^{-5} $\rightarrow$ β^* accuracy=6% $\rightarrow$ Lumi imb.$\approx$12%

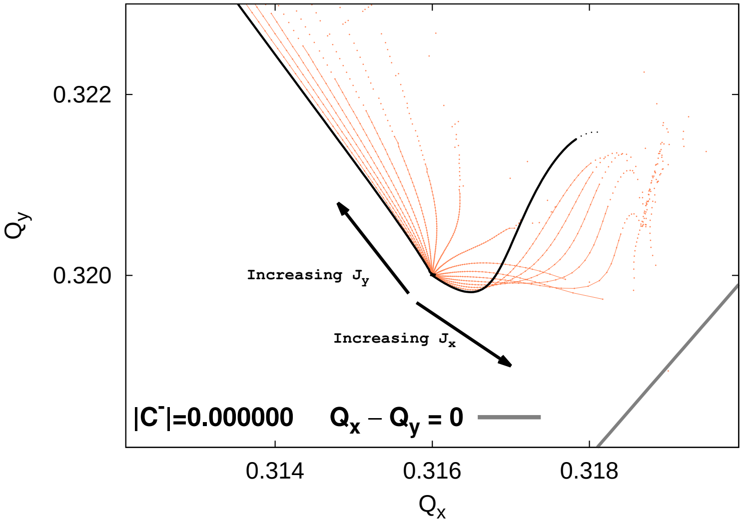
- ★ Further noise reduction techniques, statistics would still be required to achieve the 5% goal in lumi.

Non-linear errors: Landau damping (in LHC)

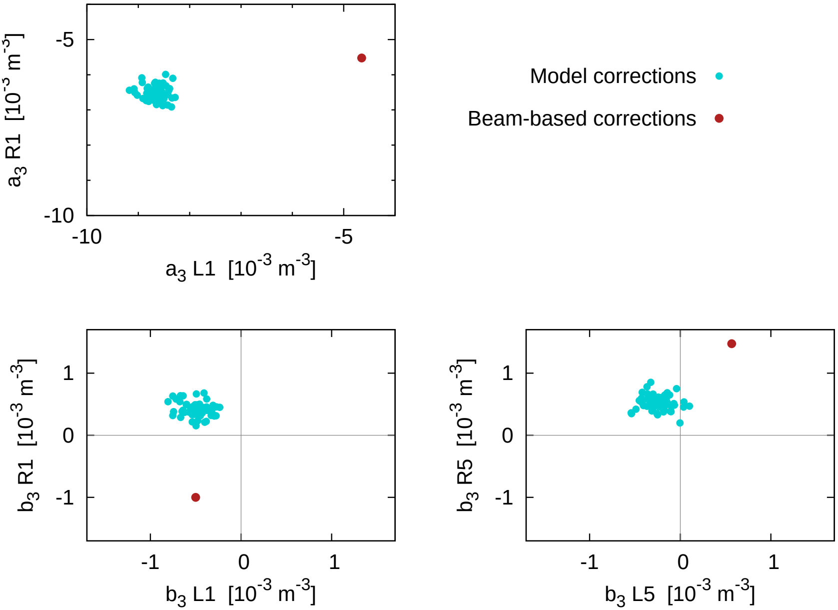


Non-linear correction is critical for Landau damping.

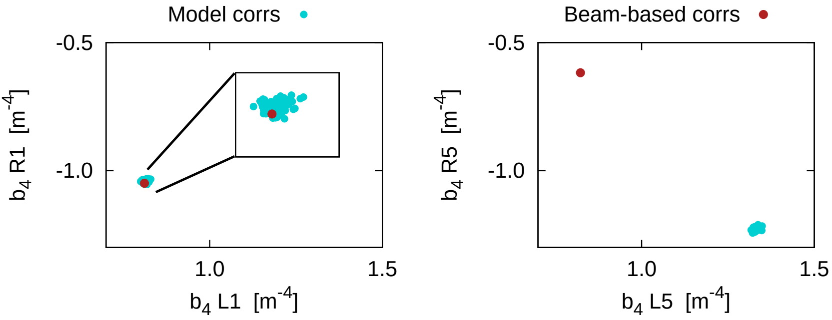
Non-linear errors: Landau damping and skew octupoles (a_4)



IR errors: model vs measurements a_3 & b_3



IR errors: model vs measurements b_4

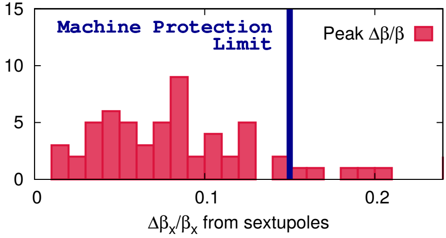


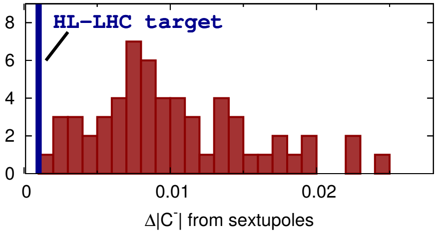
In LHC discrepancies between corrections from magnetic measurements and from beam measurements can be very significant. Sources are: meas. uncertainties, orbit errors and magnet misalignments.

(I have asked E. Todesco for uncertainties in magnetic multipole measurements).

Non-linear errors: Feeddown

e.g. simulation studies of HL-LHC (15cm, 295μrad)





Non-linear errors plus crossing angle heavily affect linear optics.
It might be more important to correct for feeddown than for DA!
Strategy to be defined.

Non-linear errors: DA

- DA without non-linear correction is **5**σ at β^*=15cm
- This challenges optics measurements which use $\approx 2\sigma$ oscillation
- Iterative corrections linear$\leftrightarrow$non-linear together with
- 1^{st} guess from magnetic measurements will be critical
  - Accurate magnetic and alignment measurements are fundamental
- Ideal correction for DA gives **9**σ
- What will be the DA value when correcting for feed-down?

cost / benefit

- ★
- ★
- ★
- ★
- ★

Possible AC dipole review in 2018

- AC dipole is fundamental for linear and non-linear optics commissioning
- It is limited to 1 measurement per minute to allow for cool-down
- Tunes away injection/collision tunes requires intervention
- AC dip. amplifier breaks about once per year
- Review in 2018 to check possible improvements or upgrades

Back-up

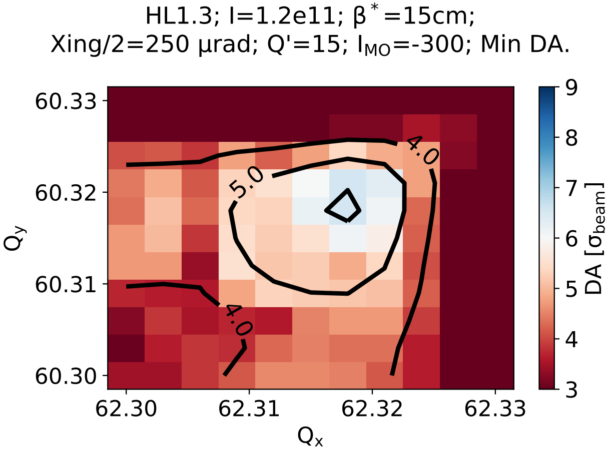
Optics control: LHC Vs HL-LHC

HiLumi HL-LHC PROJECT

	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
$\|C^-\|$:			
Tolerance for instabilities	$[10^{-3}]$	1	1.0
Tolerance for K-modulation	$[10^{-3}]$	1	0.6
7 month drift	$[10^{-3}]$	3	12
$\Delta\|C^-\|$ 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.

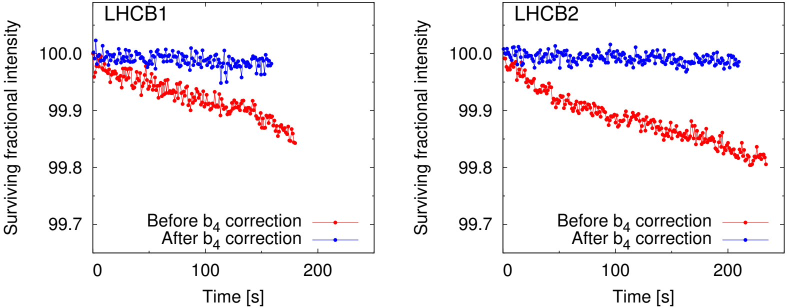
Baseline: DA validation



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

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!*

Concluding remarks

- New baseline scenario meets goals at 50% efficiency
  - Pushed: optics, collimation, impedance, beam-beam, DA, etc.
  - New: 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 $\overline{\rho}$