Optics correction strategy in HL-LHC *first thoughts*

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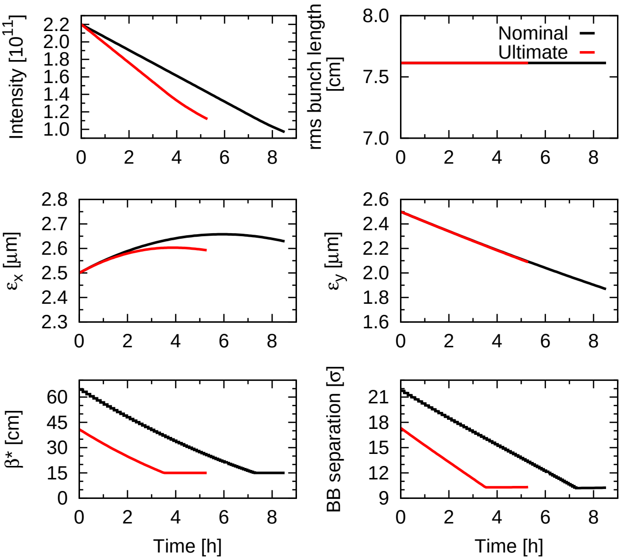
Physics fill



50% intensity drop.

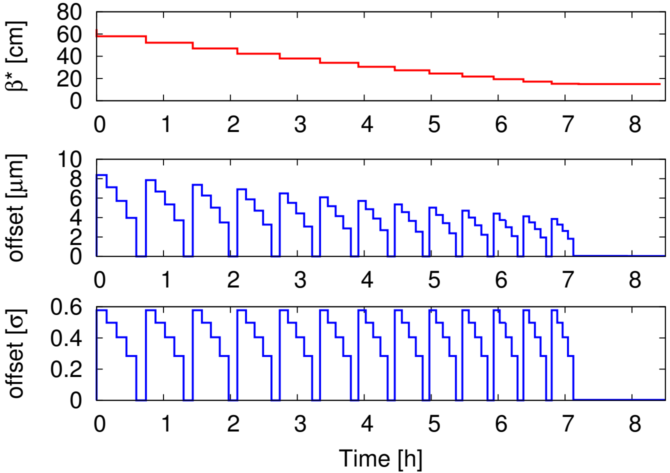
Constant bunch length.

25% drop of ϵ_y ideally.

Leveling by β^*.

Beam-beam changes.

Offset leveling too?

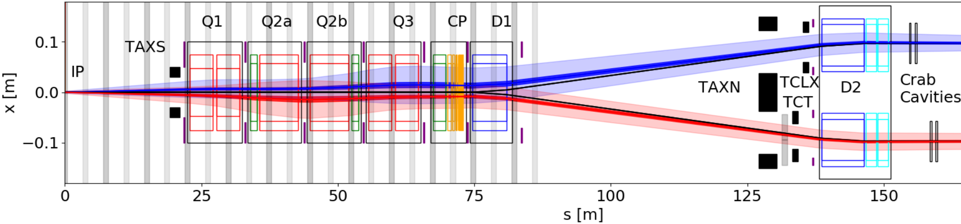


Offset leveling used to reduce number of optics or to equalize luminosities in the 2 detectors (optics errors, beam-beam, etc). Maximum offset is $\approx 1\sigma$ for stability.

Optics control goals

- ★ Global β-beating $\leq 20\%$
- ★ β^*-beating $\leq 2.5\%$ for luminosity imbalance $\leq 5\%$ between ATLAS and CMS
- ★ Global coupling: $\Delta Q_{min} \leq 10^{-3}$ for Landau damping with tune split $Q_y - Q_x \approx 5 \times 10^{-3}$.
- ★ Local coupling at IP negligible for lumi loss (working on a spec.)
- ★ Triplet non-linearities locally corrected for what Ewen presented yesterday

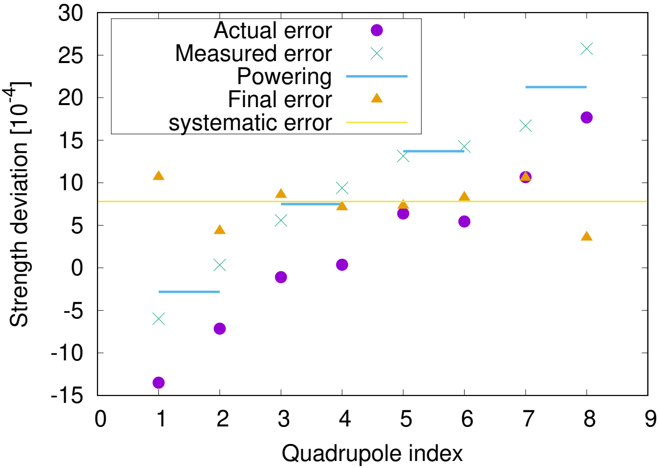
HL-LHC IR layout



Triplet quadrupoles' specs

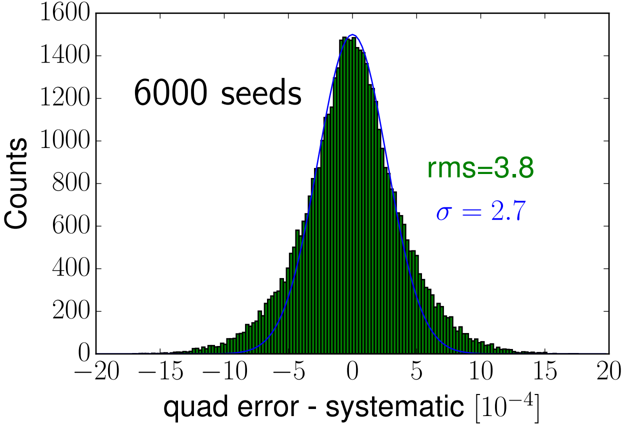
- MQXFA magnet must provide an integrated gradient between 554 T and 560 T when powered with current of 16.470 kA. The difference between the integrated gradient of any pair of series magnets with the same cross-section shall be smaller than 3 T (**50 units)**
- TF is measured with a systematic uncertainty of ±10 units* and a precision of ±2 units
- Q2 magnets will be sorted and paired from a pool of 8 quadrupoles.
- Ideal sorting yields deviation $<$13 units between pairs with 90% probability

Illustration of Q2 sorting



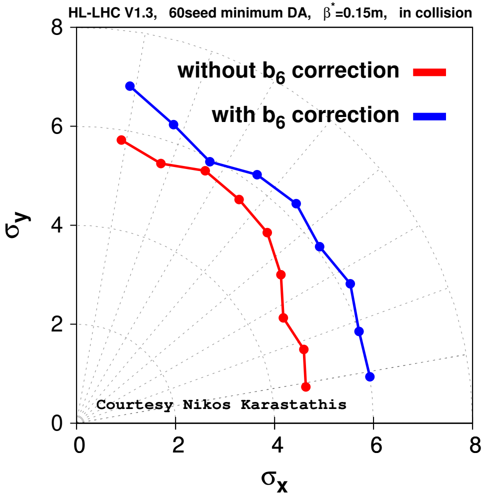
For illustration, 1 unit strength error in triplet quads generates $\Delta\beta/\beta = 7\%$ at β^*=15 cm.

Final error w.r.t. systematic



The full process can be approximated by assigning a systematic error of ±10 units plus a Gaussian error with σ between 2.7 and 3.8 units.

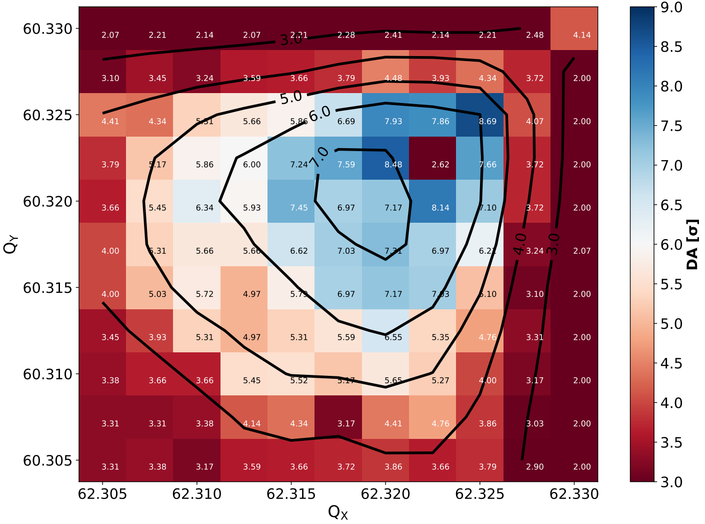
No b_6 correction, $\beta^* = 15$ cm



Without b_6 correction in the first year $\beta^* = 15$ cm seems not possible.

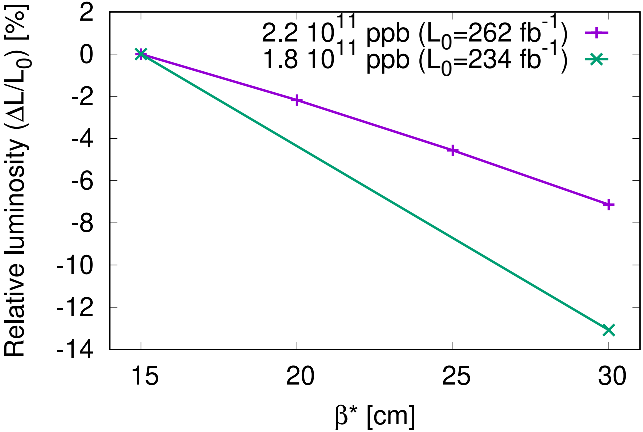
No b_6 correction, $\beta^* = 30$ cm OK

Min DA HL-LHC v1.3, b_4=-4, No IT b_4 Correctors Fail, $N_b = 1.6 \times 10^{11}$ ppb
$\beta^*_{IP1/5}$=30 cm, $\phi/2$=250 μrad, ε=2.5μm, Q'=15, I_{MO}=-300 A



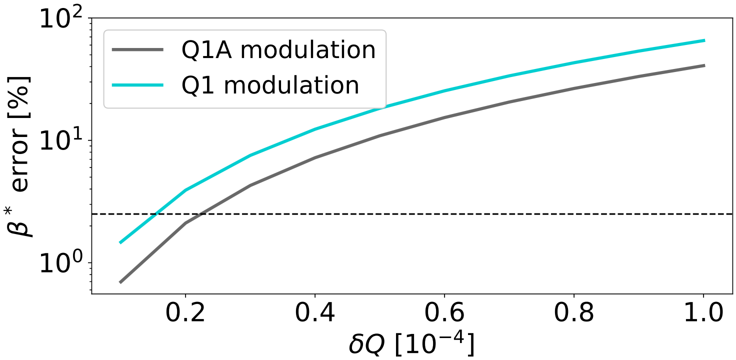
2.07	2.21	2.14	2.07	2.21	2.28	2.41	2.14	2.21	2.48	4.14
3.10	3.45	3.24	3.59	3.66	3.79	4.48	3.93	4.34	3.72	2.00
4.41	4.34	5.31	5.66	5.86	6.69	7.93	7.86	8.69	4.07	2.00
3.79	5.17	5.86	6.00	7.24	7.59	8.48	2.62	7.66	3.72	2.00
3.66	5.45	6.34	5.93	7.45	6.97	7.17	8.14	7.10	3.72	2.00
4.00	5.31	5.66	5.66	6.62	7.03	7.31	6.97	6.21	3.24	2.07
4.00	5.03	5.72	4.97	5.79	6.97	7.17	7.03	5.10	3.10	2.00
3.45	3.93	5.31	4.97	5.31	5.59	6.55	5.35	4.76	3.31	2.00
3.38	3.66	3.66	5.45	5.52	5.17	5.65	5.27	4.00	3.17	2.00
3.31	3.31	3.38	4.14	4.34	3.17	4.41	4.76	3.86	3.03	2.00
3.31	3.38	3.17	3.59	3.66	3.72	3.86	3.66	3.79	2.90	2.00

Luminosity loss versus β^*



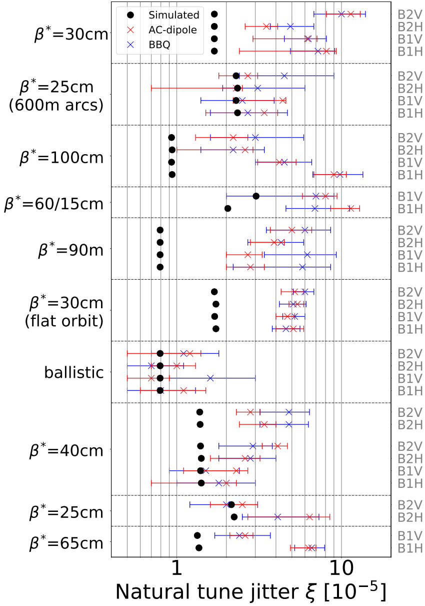
$\beta^* = 25$ or 30 cm seem reasonable goals for the first year with a penalty of about 10% in integrated luminosity.

β^* control with K-modulation



A good β^* control requires excellent tune measurement uncertainty of about 2.5×10^{-5} at $\beta^* = 15$ cm. Tune jitter is the main limitation.

Tune jitter in LHC



Simulation includes latest power converter (PC) estimates with 2 DCCTs (frequencies below 0.1 Hz).

In general simulation underestimates measurements.

The contribution from PC noise in frequencies 0.1-10 Hz needs to be studied.

Noise in 0.1-500 Hz (preliminary)

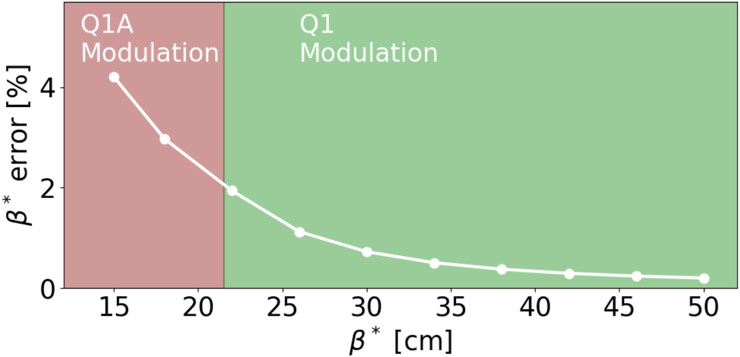
Table: Pessimistic HL–LHC rms stability figures corresponding to the noise in the 0.1-500 Hz region (15 cm β^* nominal optics HLLHCV1.3).

Tune stability	Orbit stability	β-beating
5×10^{-4}	$3\% \ \sigma_{\mathrm{beam}}$	3×10^{-3}

This possible noise is of concern for k-modulation, but also for beam-dynamics in general and will be further studied.

K-modulation in HL-LHC

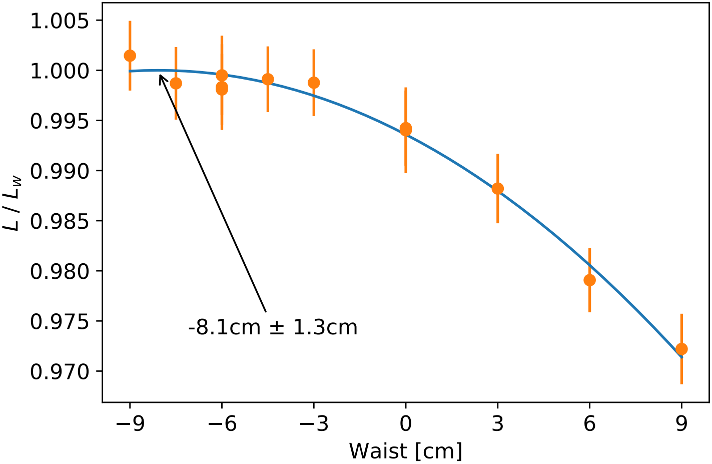
Considering only noise below 0.1 Hz with 2 DCCTs:



Even in this optimistic scenario target is not met at $\beta^* =$15 cm. K-mod improvements in Hector's talk. Experience with waist scans follows.

β-waist from luminosity scan

Experiments in LHC with $\beta^* = 30$ cm:



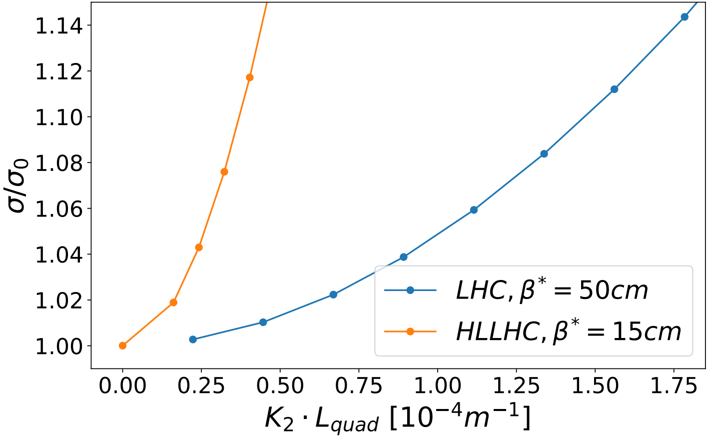
Waist scan vs k-modulation

	Measured vertical waist [cm]	
	K-mod	lumi scan
Beam 1	-5±3	-8.2±1.4
Beam 2	4±2	0.4±0.1

Luminosity waist scans are clearly more accurate than K-modulation to measure the β-waist position.

Luminosity loss versus IP coupling

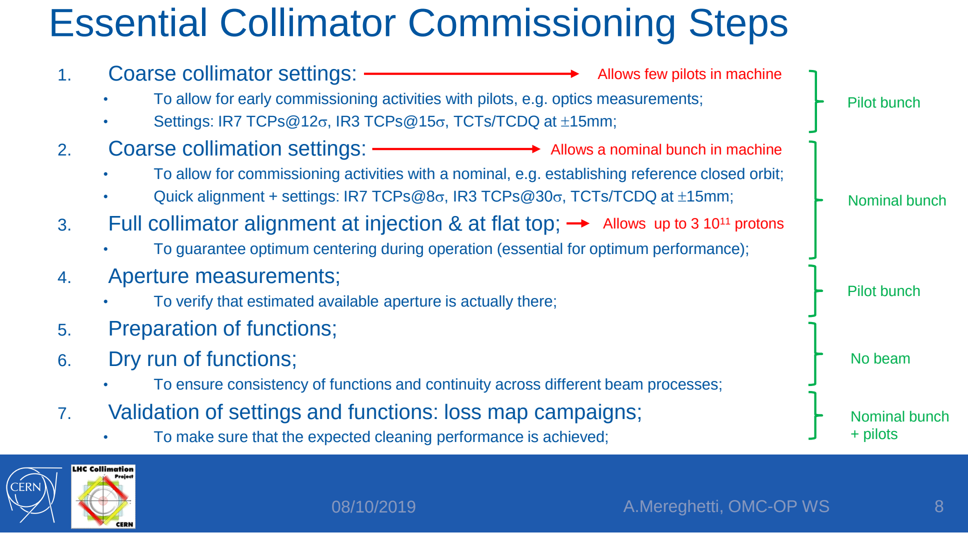
Powering skew quads next to IP to generate a local coupling bump:



This will need luminosity scans for fine tuning.

When can we fit luminosity scans?

Luminosity scans after point 2 or 3?:



Essential Collimator Commissioning Steps

1. Coarse collimator settings: → Allows few pilots in machine
   - To allow for early commissioning activities with pilots, e.g. optics measurements;
   - Settings: IR7 TCPs@12σ, IR3 TCPs@15σ, TCTs/TCDQ at ±15mm;

Pilot bunch

2. Coarse collimation settings: → Allows a nominal bunch in machine
   - To allow for commissioning activities with a nominal, e.g. establishing reference closed orbit;
   - Quick alignment + settings: IR7 TCPs@8σ, IR3 TCPs@30σ, TCTs/TCDQ at ±15mm;
3. Full collimator alignment at injection & at flat top; → Allows up to 3 10^{11} protons
   - To guarantee optimum centering during operation (essential for optimum performance);

Nominal bunch

4. Aperture measurements;
   - To verify that estimated available aperture is actually there;

Pilot bunch

5. Preparation of functions;
6. Dry run of functions;
   - To ensure consistency of functions and continuity across different beam processes;

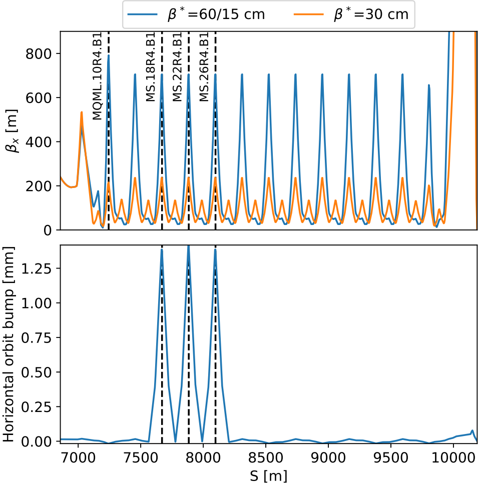
No beam

7. Validation of settings and functions: loss map campaigns;
   - To make sure that the expected cleaning performance is achieved;

Nominal bunch
+ pilots

08/10/2019 A.Mereghetti, OMC-OP WS 8

Local correction in the arcs



ATS optics experiments with large β in the arcs revealed the need for local correction with orbit bumps at sextpoles during experiments in 2018.

Summary

- Optics correction will likely need about 2 years
- Start with β^*=25 or 30cm?
- β^* control will need luminosity scans early in the commissioning
- Good magnetic and alignment measurements will be fundamental for an efficient commissioning
- Run 3 commissioning to be used to test as many aspects of strategy as possible

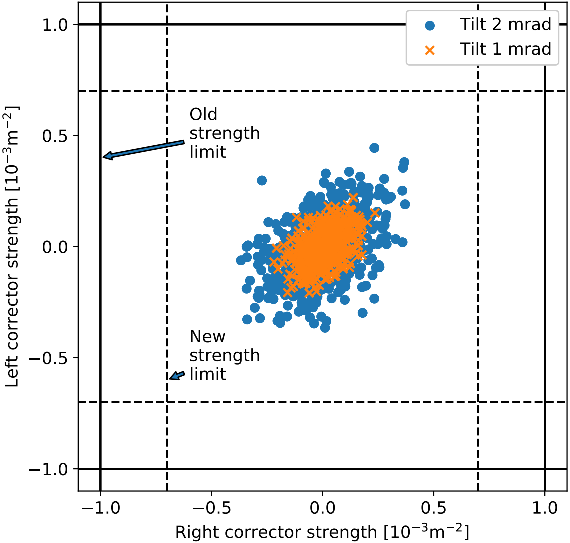
Back-up slides

Power converter stability

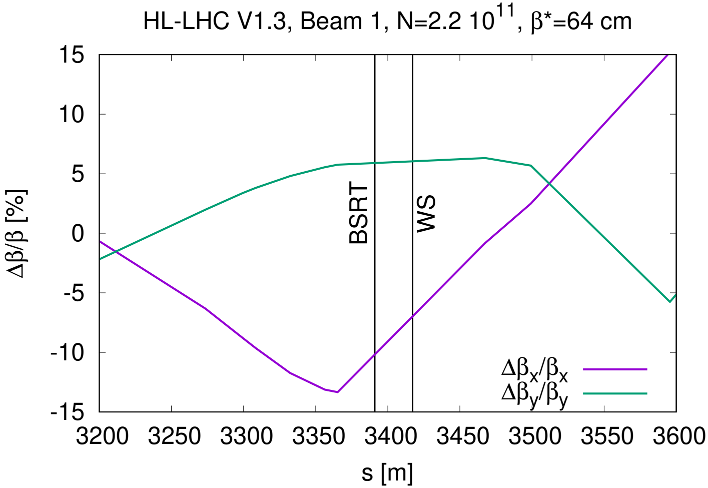
Table: Power converter stability specifications for HL–LHC circuits with 1 DCCT (for 2, scale by $1/\sqrt{2}$). All uncertainties are 2σ in units of $10^{-6} I_{rated}$, where σ is the rms.

Circuit name	I_{rated} **[A]**	**PC class**	**Stability 20 min**	**Stability 12 h**
RB[a], RQ(D/F)[a]	13000	1	0.4	2
RQX	18000	0	0.2	1
RTQX(1/3), RCBX	2000	2	1.2	15.5
RTQXA1[b]	60	4	5	40
RQSX[d], RCBRD, RTB9[c]	600	3	2	34
RC(S/O/D/T)X, RCB(C/Y)[a]	120	4	5	40
RD(1/2)	14000	0	0.2	1
RQ4[a]	4000	2	1.2	15.5
RQ(5/6)[a]	5000	2	1.2	15.5

IR skew quadrupole corrector



β-beating from beam-beam



Beam-beam changes β within ±15% in the beginning of the fill.

Sensitivity (@ Ultimate)

Deviations that cause **2% int. luminosity** change:

Parameter	Δ	*unit*
Turn-around-time	10	min
ppb (constant brightness)	0.09	10^{11}
ϵ (constant ppb)	0.2	μm
β^*	4	cm
Efficiency	1	%

10% change in emittance causes a 2% loss on integrated luminosity.