Ultra-low β_y^* tuning study at ATF2

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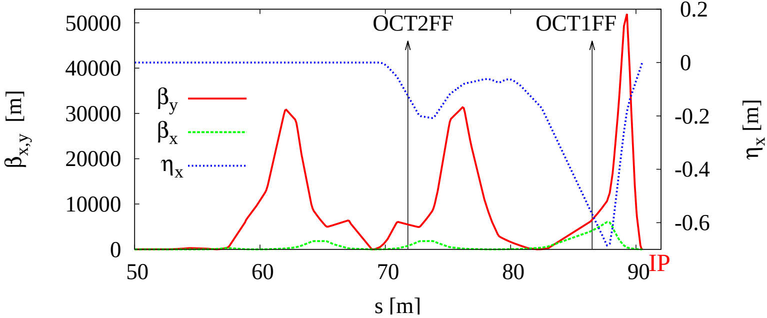
OUTLINES

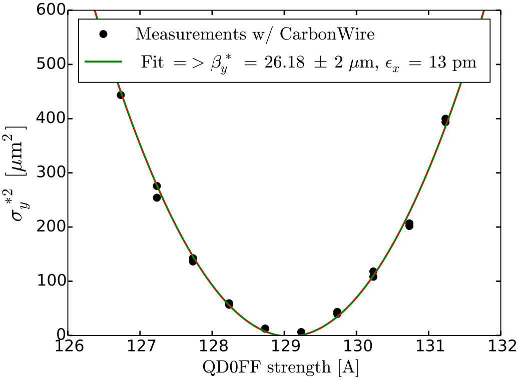
Summary of December operation tuning at ultra-low β_y^*

- The goal of the ultra-low β_y^* optics tuning at ATF2 is to demonstrate the feasibility of the Local scheme FFS at chromaticity ξ_y level comparable to CLIC
- In December 2017 operation was the first long tuning attempt using ultra-low β_y^* optics ($\beta_y^* = 25\ \mu$m) at ATF2
- The FFS was running with a target of $\beta_x^* = 100$ mm ($25\beta_x^*$x$0.25\beta_y^*$ optics) in order to reduce the impact of multipole error fields and to ease the tuning (see simulations in backup slides)
- The ultra-low β_y^* optics requires the use of octupoles to reduce σ_y^* down to 20 nm in design. The other goal of low-β study is to quantify the benefit on the beam size of using the new pair of octupoles installed at ATF2



Summary of December operation tuning at ultra-low β_y^*

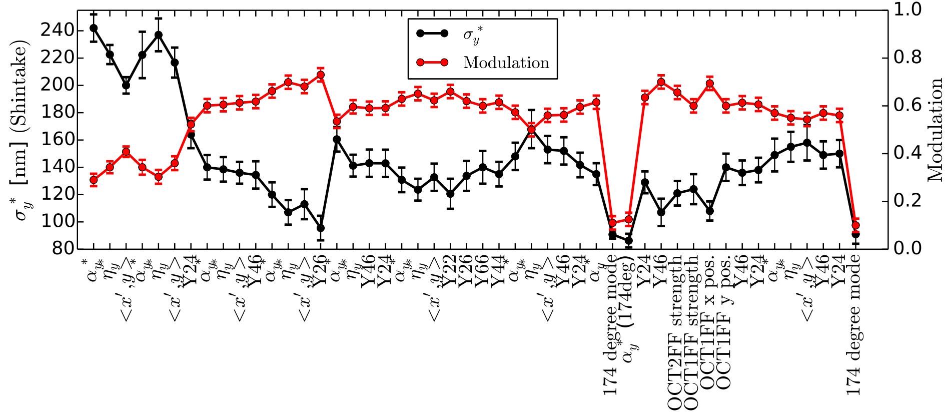
- The $25\beta_x^*$x$0.25\beta_y^*$ optics was applied by using the β matching tool in control room, that re-matched the optics by varying QF21X, QD20X (EXT line) and the matching quads (QM16FF–>QM11FF)
- As the required strength of QM14FF calculated was above the max. current of the magnet, the upstream QD19X quad had to be used and several optics change were needed before matching the desired β_y^* (measured using QD0FF scan)
- The assumed vertical emittance was ϵ_y = 13 pm as measured in the DR (no multi-OTR available)



- β_y^* was well matched to approximately 25μm (assuming ϵ_y^* = 13 pm)
- However the measurement of β_x^* from QF1FF scan have shown a β_x^* of 85 mm but a fitted ϵ_x^* twice the design value indicating that the scan was biased by large horizontal dispersion at the IP
- The measured η_x^* was around 34 mm $\Rightarrow$ β_x^* was smaller than measured

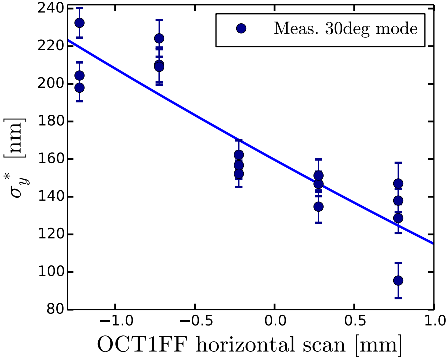
Summary of December operation tuning at ultra-low β_y^*

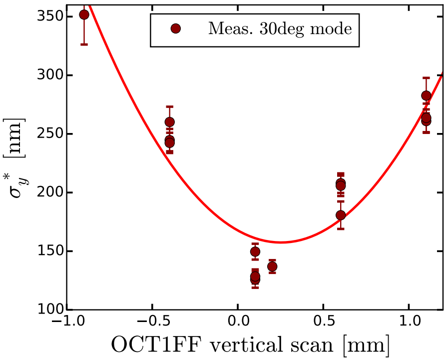
- Linear and Nonlinear knobs were applied iteratively and sextupoles strength changed according to our ultra-low β_y^* optics model
- After 5 shifts (5× 8 hours) of tuning, no clear modulation was found at 174 degree mode
- The **beam size could not be tuned below** ≈ **100 nm**
- It is difficult to observe the impact of the octupoles when tuning at 30 degree mode while it was not possible to tune the beam at 174 degree mode as the modulation was close to the noise level (M≈ 0.1).



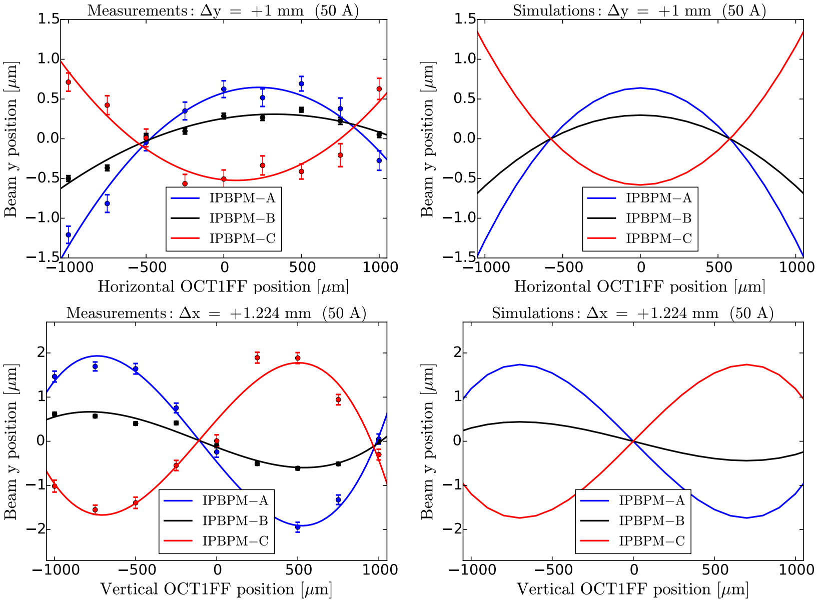
Octupoles optimization during ultra-low β_y^* tuning

- The impact of the octupoles beam size at ultra-low β_y^* is in the order of $\approx$ 9-10 nm in simulation.
- The resolution of the beam size measurement at 30 degree mode is to large to observe octupolar correction.
- However the OCT1FF position scan gave us possible useful informations about the lattice :

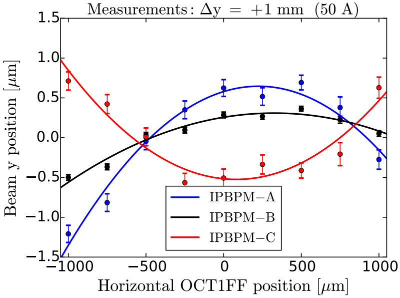




OCT1FF BBA using IPBPM (June 2017)



OCT1FF BBA using IPBPM (June 2017)



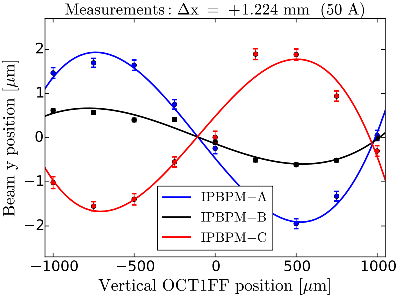


Table – Horizontal OCT1FF magnetic center measured by the IPBPMs

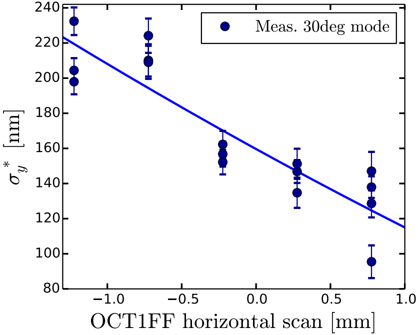
Cavity	OCT1FF x position [μm]
IPBPM-A	224 $\pm$ 19
IPBPM-B	325 $\pm$ 67
IPBPM-C	81 $\pm$ 26

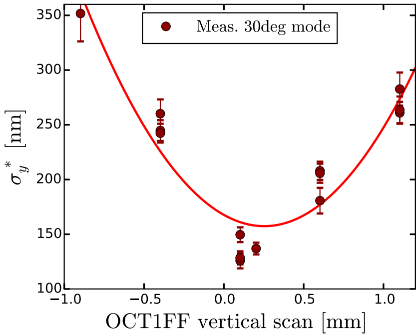
Table – Vertical OCT1FF magnetic center measured by the IPBPMs

Cavity	OCT1FF y position [μm]
IPBPM-A	-105 $\pm$ 14
IPBPM-B	-120 $\pm$ 52
IPBPM-C	-101 $\pm$ 13

Octupoles optimization during ultra-low β_y^* tuning

- Horizontal offset of a normal octupole generates normal sextupolar field (can generate Y24 and Y46 aberrations)
- Vertical offset generates skew sextupolar field (can generate Y22, Y26, Y44 and Y66 aberrations)

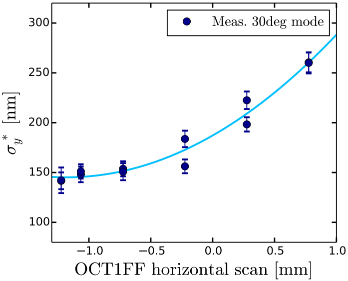


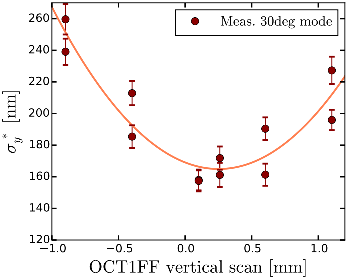


- **Possible mismatch of the linear optics with the normal sextupole strength applied for ultra-low β_y^***
- Same observations for the nominal optics ($10\beta_x^* 1\beta_y^*$) between June and December 2017 operations.

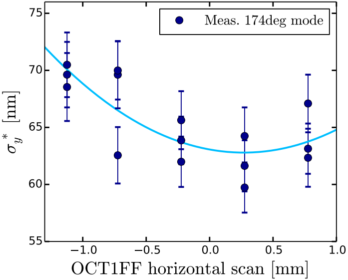
Octupoles optimization during 10x1 optics tuning (June & December 2017)

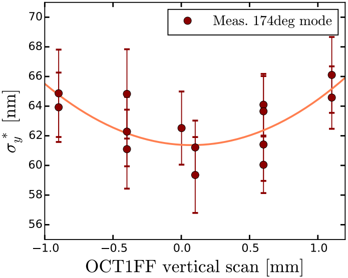
June 2017 :





December 2017 (modification in the 10x1 optics) :

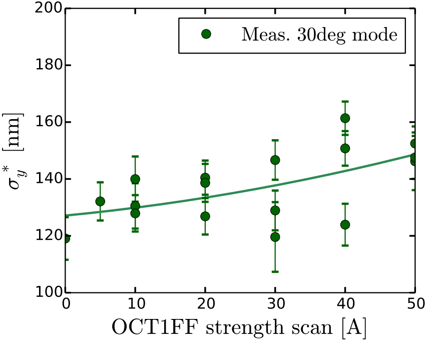




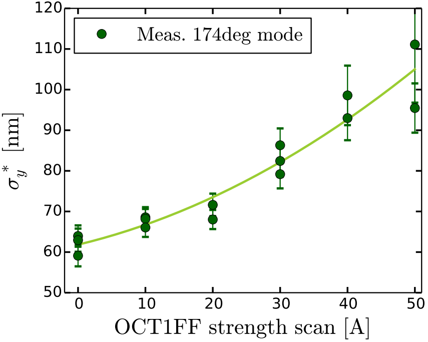
Octupoles optimization during 10x1 optics tuning (December 2017)

- At 30 degree mode the resolution of the beam size measurement is too large to observe the impact of the octupoles
- Octupolar correction on the vertical beam size will observed only at 174 degree mode

Measured at 30 degree mode (10x1 optics)

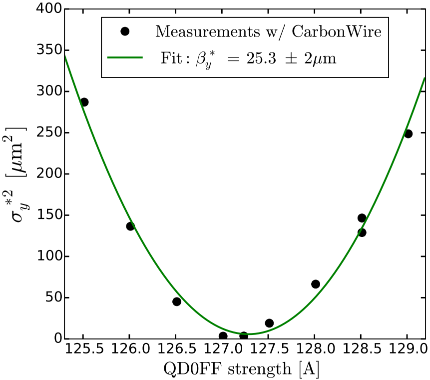


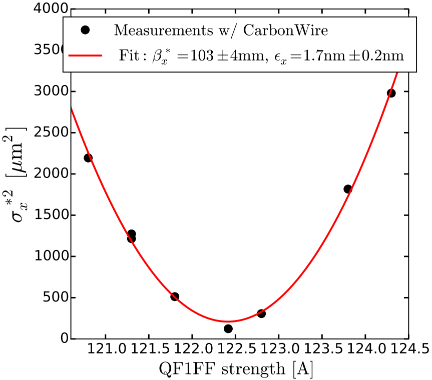
Measured at 174 degree mode (10x1 optics)



February 2018 : tuning at ultra-low β_y^*

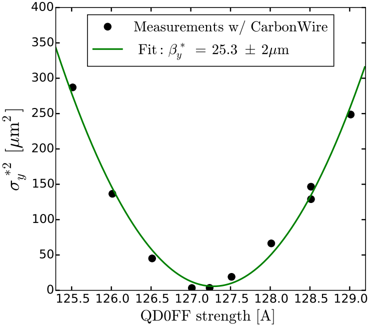
- For the second attempt the 25x0.25 optics was re-matched in simulation before the run and by taking into account the constraints of the FF optics.
- The sextupoles were re-optimized for the new optics
- Smaller β_y^* target (15μm) was needed to measure β_y^* of $\sim$25μm but β_x^* was very consistent with the optics model and matched directly $\sim$100 mm
- Residual dispersion was corrected from the fit of the quad scans. The measured η_x^* was around 3 mm.

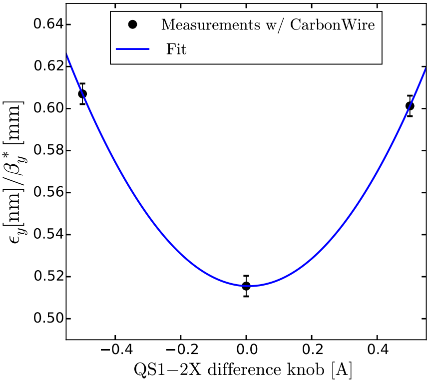




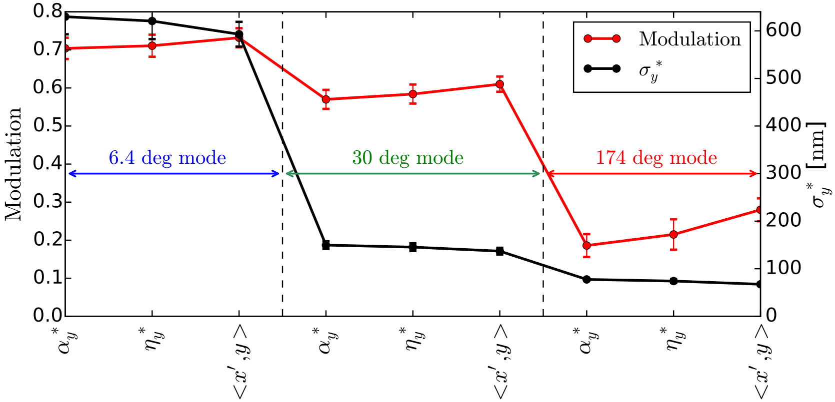
February 2018 : tuning at ultra-low β_y^*

- In order to check that the QD0FF scan was not bias by $< x, y >$ coupling which would lead to an over-estimation of the measured divergence, a quick scan of the QS1X-QS2X difference knob was performed.



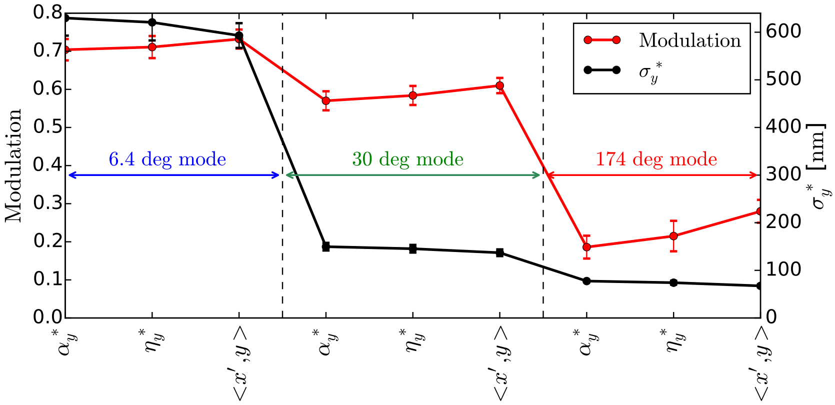


February 2018 : tuning at ultra-low β_y^*



- **Tuning time reduced compared to Dec17 run** due to multiple reasons : long correction of the very large background generated due to the larger beam size along the FF, Shintake laser tuning and also the optics had to be rematched and re-tuned after 4 shifts (QF1FF strength was not reset to its original value leading to a large increase of σ_x^*) $\Rightarrow$ 1.5 shifts left for tuning with the Shintake monitor

February 2018 : tuning at ultra-low β_y^*



- Despite the shorter tuning time and without applying 2^{nd} order sextupole knobs or octupoles, the beam size could be squeezed rapidly and modulation could be observed at 174 deg mode
- The minimum beam size measured at 174 degree mode was $\sigma_y^* = 64 \pm 2$ nm by applying only linear knobs ⇒ **improved optics and performance compared to Dec17 operation**

Summary and future Plan for low-β_y^* study at ATF2

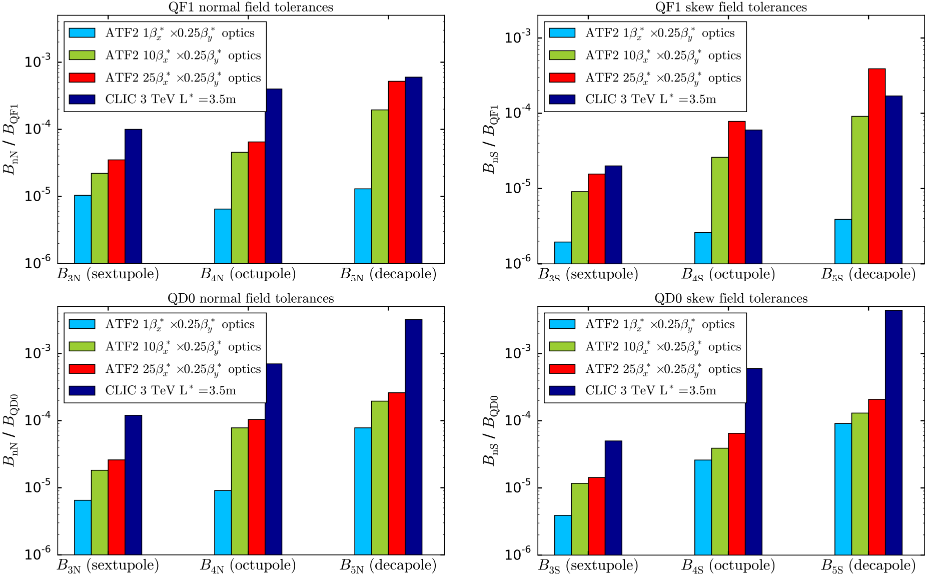
- During the second tuning attempt of the $25\beta_x^* \times 0.25\beta_y^*$ FF lattice, **the performance of the system in terms of beam size achieved was improved despite the shorter tuning time** and the fact that nonlinear knobs were applied.
- These results highlight the supicions raised during the Dec17 operation about the applied optics.
- The tuning performance of the updated lattice optimized for the February run could be further improved if more tuning time is allocated on this optics. **The use of all the 2^{nd} order sextupole knobs are needed to achieve beam sizes below 30 nm** (simulation)
- The abscence of **multi-OTR was an important limitation for tuning** the optics (corrections of the emittance and couplings and the matching of the Twiss at the entrance of the FFS)
- modulation can be observed at 174 degree mode with this optics, it will be possible during future operations, to use and optimize the octupoles for 3^{rd} order correction on the IP beam size
- The last tuning session ends on an incomplete tuning study for the exploration of the ultra-low β_y^* performance. **More tuning time is required to be able to adress and quantify precisely the beam size limitations for this optics.**

Thank you for attention
and
many thanks to all ATF2 collaborators for the help !

BACKUP SLIDES

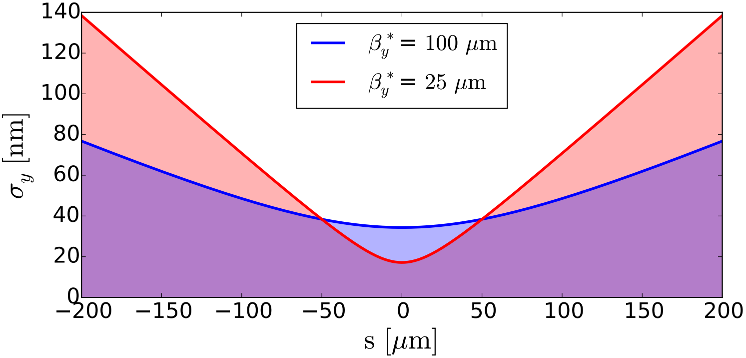
FD multipole fields tolerances : CLIC vs ATF2 ultra-low β_y^*

- FD multipole tolerances comparison between ultra-low β_y^* optics and CLIC 3 TeV



Shintake monitor systematic error : beam size growth within the fringe pattern

Crossing angle θ [deg]	6.4	30	174
Fringe pitch d [μm]	4.77	1.028	0.266
Measurable σ_y [nm]	$424 \sim 1700$	$90 \sim 400$	$25 \sim 100$



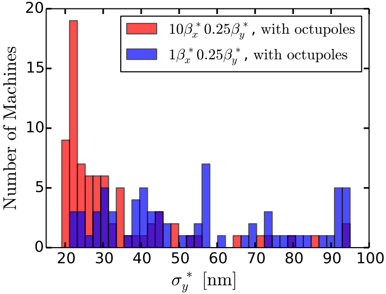
$$M_{\text{meas.}} = \left(1 + 4k_y^2\sigma_{z,\text{laser}}^2 \frac{\epsilon_y}{\beta_y^*}\right)^{-\frac{1}{2}} M_{\text{ideal}}. \quad (1)$$

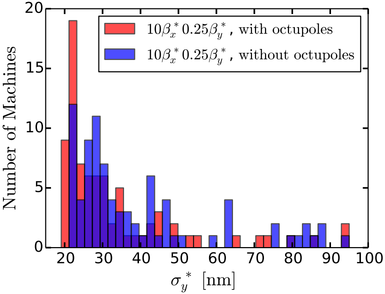
(2)

For $\beta_y^* = 25\ \mu$m and $\epsilon = 12$ pm, $C_{\sigma_y \text{growth}} = 97.1$ % at 174 deg mode while for the nominal optics ($\beta_y^* = 100\ \mu$m) $C_{\sigma_y \text{growth}}$ =99.7 %.

Ultra-low β_y^* tuning simulations

σ_{offset}	100μm
σ_{roll}	200μrad
Strength error	0.1%
Tuning time	≈12 shifts





- $1\beta_x^* 0.25\beta_y^*$ tuning : average beam size is **75 nm ± 20 nm** ; 10% of the machines reach $\sigma_y^* \leq 30$ nm
- $10\beta_x^* 0.25\beta_y^*$ tuning without octupoles : average beam size is **44.2 nm ± 13 nm** ; 41% of the machines reach $\sigma_y^* \leq 30$ nm
- $10\beta_x^* 0.25\beta_y^*$ tuning with octupoles : average beam size is **35 nm ± 11 nm** ; 63% of the machines reach $\sigma_y^* \leq 30$ nm