Report on the status of ATF2 ultra-low β_y^* optics

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Outline

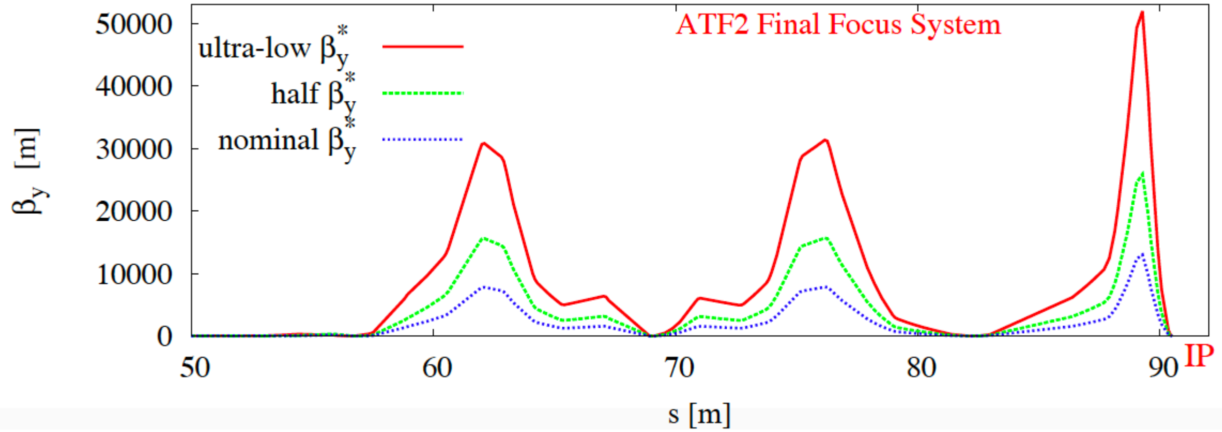
- Motivation
- December 2017 Machine Tuning with ultra-low β_y^* optics
- February 2018 Machine Tuning with ultra-low β_y^* optics
- Summary of May 2018 run
- Summary of November 2018 run
- Conclusions

Motivation

- 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.

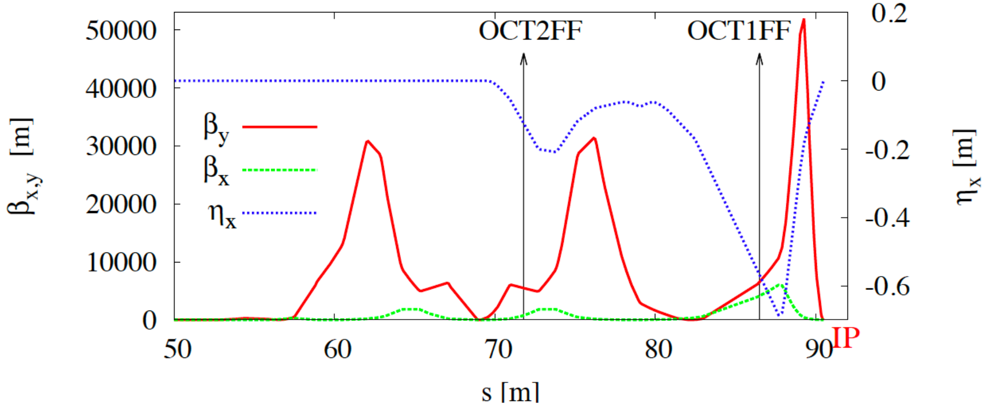
	β_y^* [μm]	$\sigma_{y,design}^*$ [nm]	L^*[m]	ξ_y (L^*/β_y^*)
ILC	480	5.9	3.5/4.5	7300/9400
CLIC	70	1	3.5	50000
ATF2 nominal	100	37	1	10000
ATF2 half β_y^* (w/ oct.)	50	25	1	20000
ATF2 ultra-low β_y^* (w/ oct.)	25	20	1	40000

- Decreasing β_y^* makes the FFS more sensitive to beam line imperfections, amplify contributions from higher order aberrations and wakefields.

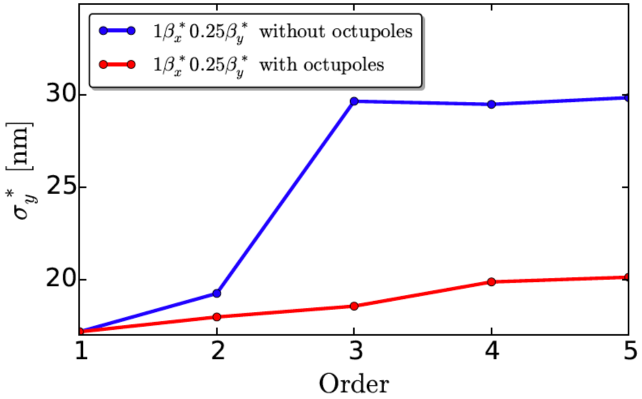


Motivation

- The other goal of the ultra-low β_y^* study is to quantify the benefit on the beam size of using the pair of octupoles installed at ATF2 in November 2016.



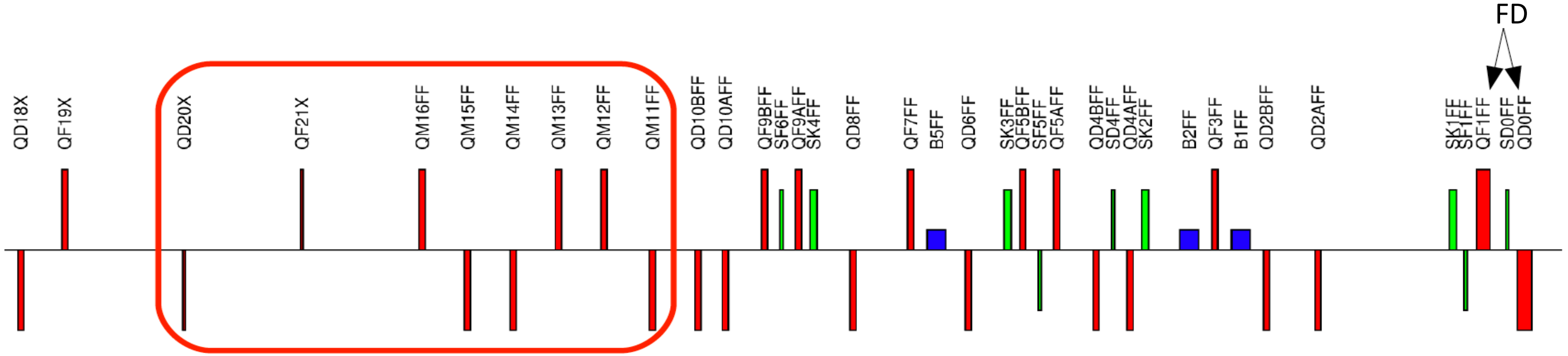
- The ultra-low β_y^* optics requires the use of octupoles to reduce σ_y^* down to 20 nm in design.



- December 2017 operation was the first long tuning attempt using ultra-low β_y^* optics at ATF2 (64 hours of continuos tuning).

December 2017 Machine Tuning with ultra-low β_y^* optics

- Matching of the $\beta_{x,y}^*$

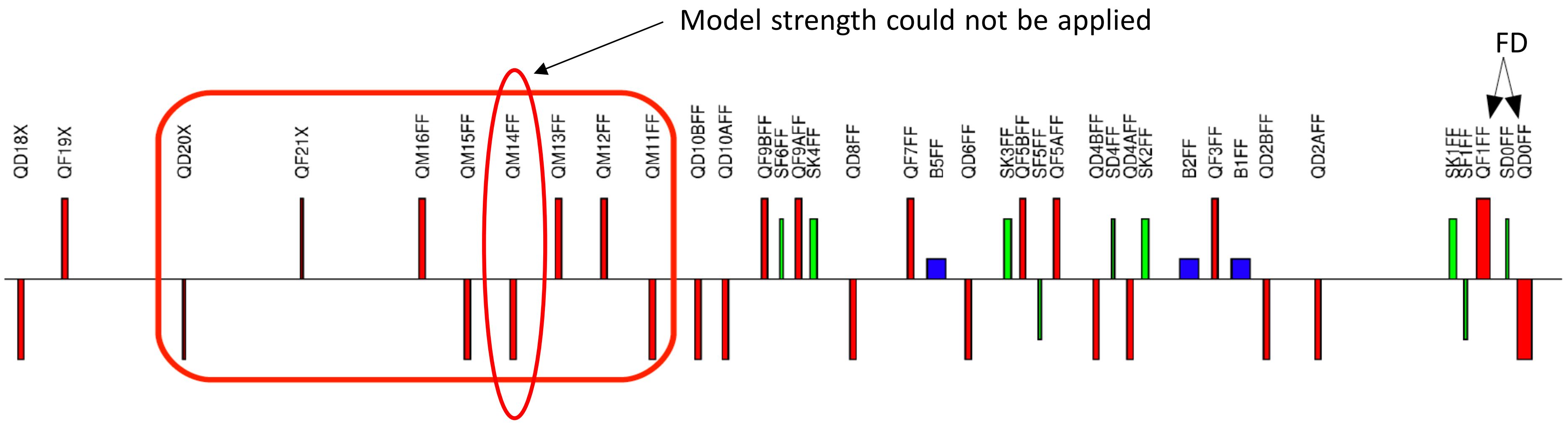


- Optics matching by means of 2 quads in the EXT line (QD20X and QF21X), the 5 matching quads (QM16FF→QM11FF) and the FD (QF1FF and QD0FF).

- The target β_x^* is 100 mm → final optics $25\beta_x^*$ x $0.25\beta_y^*$ to relax FD multipolar tolerances (comparable w/ CLIC).

December 2017 Machine Tuning with ultra-low β_y^* optics

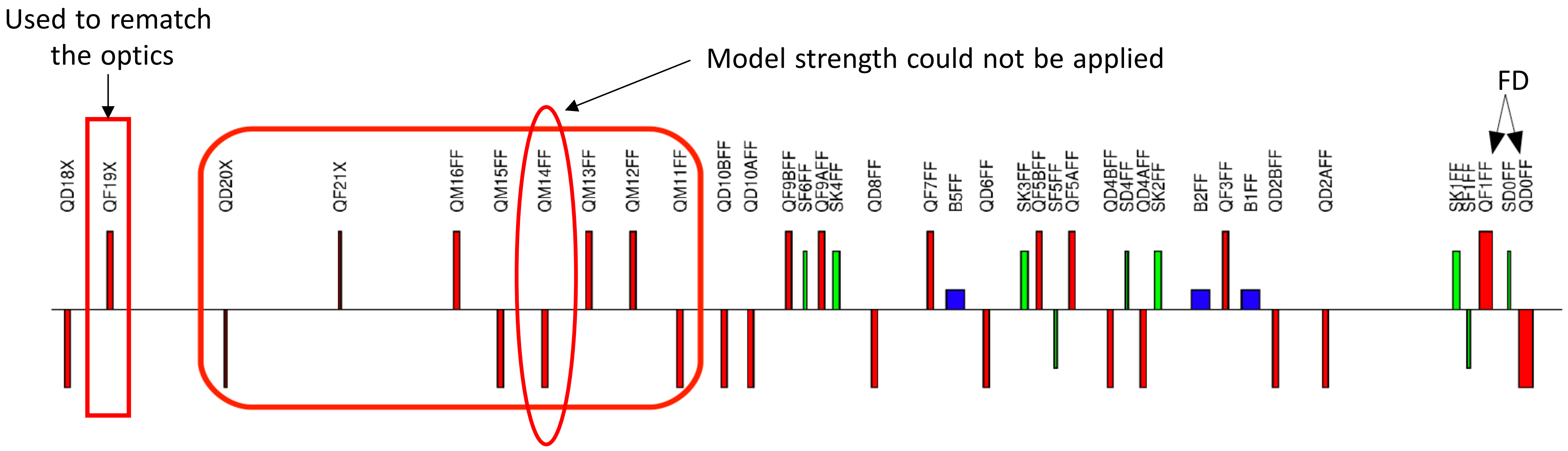
- Matching of the $\beta_{x,y}^*$



- The initial optics from simulation model could not be implemented due to the strength of the QM14FF that was slightly above the power supply window of the magnet.

December 2017 Machine Tuning with ultra-low β_y^* optics

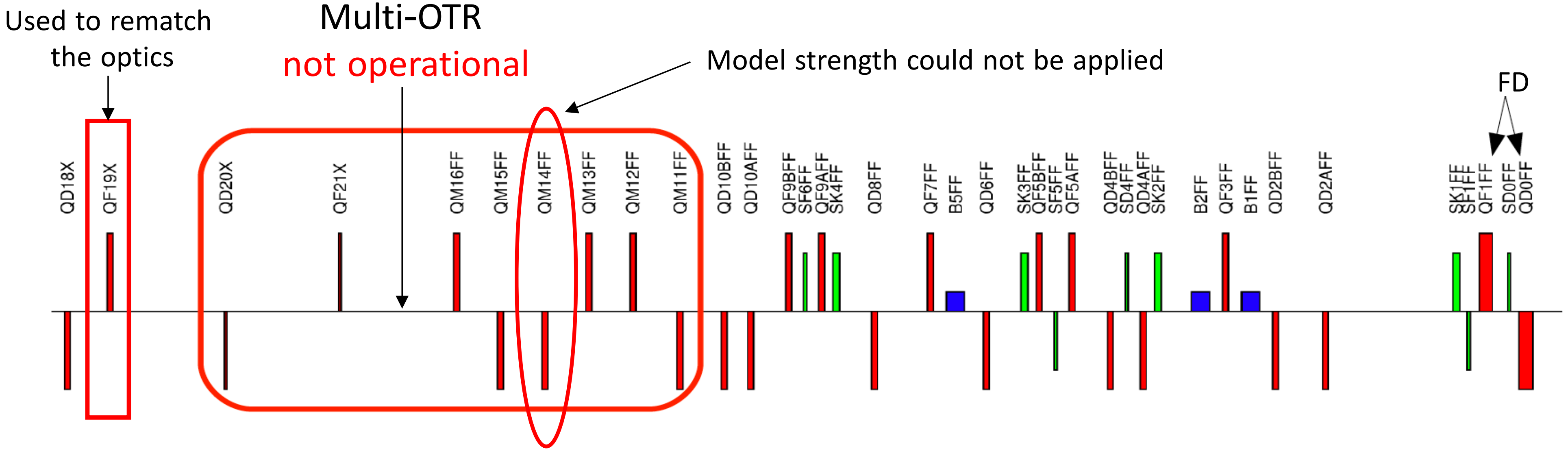
- Matching of the $\beta_{x,y}^*$



- The ultra-low β_y^* optics was rematched → several matching attemps needed and adjustement of the strength of the QF19X extraction quadrupole.

December 2017 Machine Tuning with ultra-low β_y^* optics

- Matching of the $\beta_{x,y}^*$

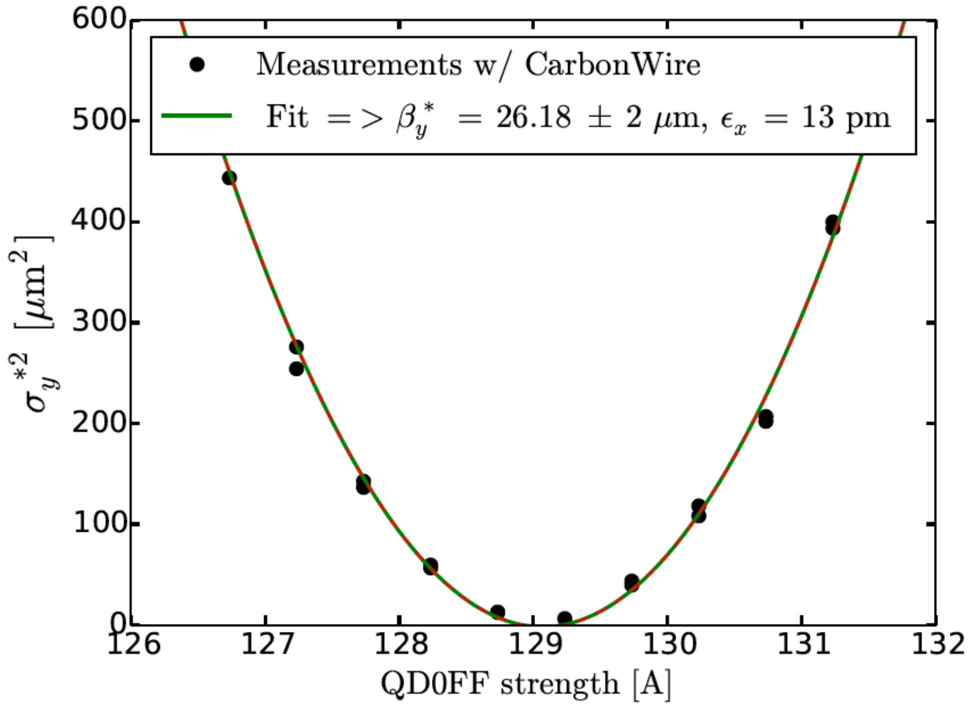


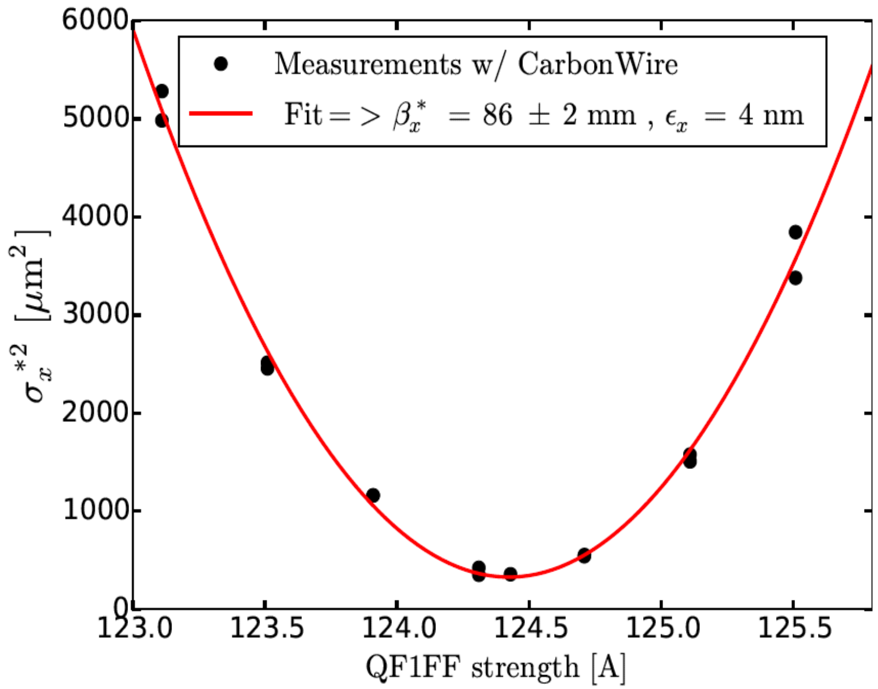
- Without the multi-OTR we could not measure and correct the vertical emittance and the <x,y> coupling at the entrance of the FF line and could not obtain emittances and Twiss parameter at OTR0X, difficult for optics rematching → **important limitation for tuning.**

- The measurement of the vertical emittance was done in the DR → ϵ_y = 12.9 pm.

December 2017 Machine Tuning with ultra-low β_y^* optics

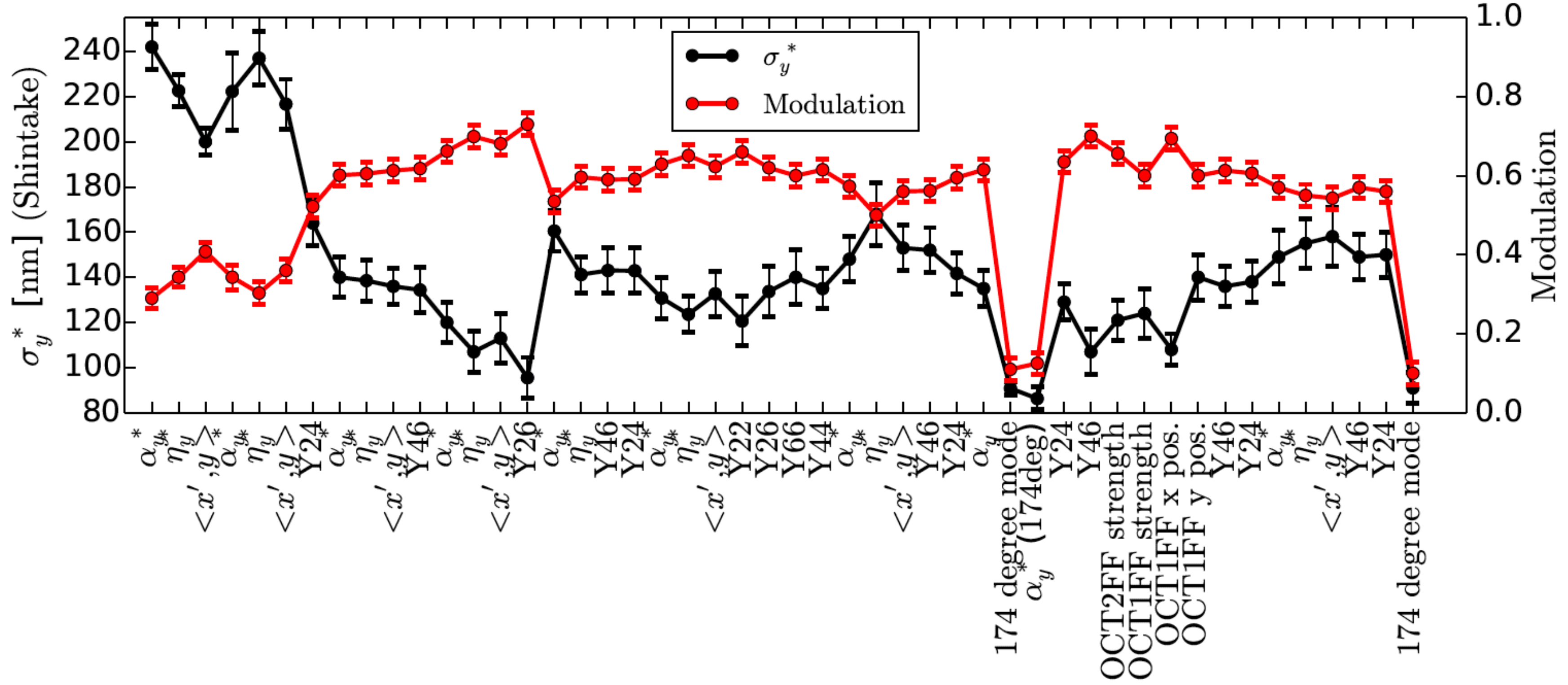
- β_y^* was well matched to $\approx$ 25 µm (assuming the vertical emittance measured in the DR).
- β_x^* was measured of $\approx$ 85 mm but a fitted ϵ_x^* twice the design value indicating that the scan was biased by large horizontal dispersion at the IP.
- The measured η_x^* was around 34 mm → β_x^* was smaller than measured.





December 2017 Machine Tuning with ultra-low β_y^* optics

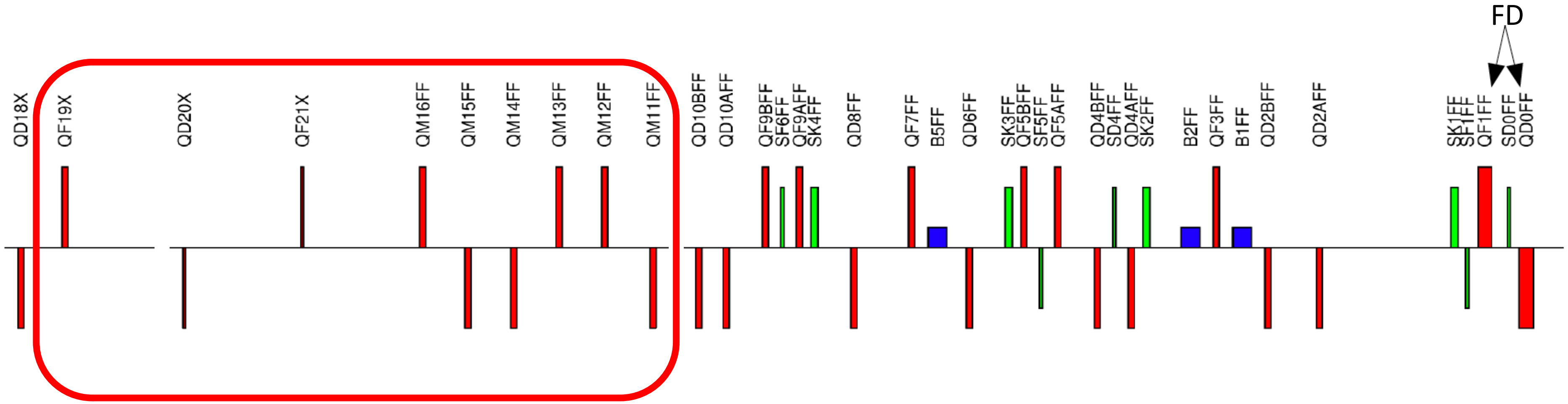
- Linear and Nonlinear knobs were applied iteratively and sextupoles strength changed according to the ultra-low β_y^* optics model.
- After 5 shifts (5 x 8 hours) of tuning, no clear modulation was found at 174 degree mode.
- The beam size could not be tuned below ≈ **97 nm.**
- It is difficult to observe the impact of the octupoles at 30 degree mode.



February 2018 Machine Tuning with ultra-low β_y^* optics

- Matching of the $\beta_{x,y}^*$

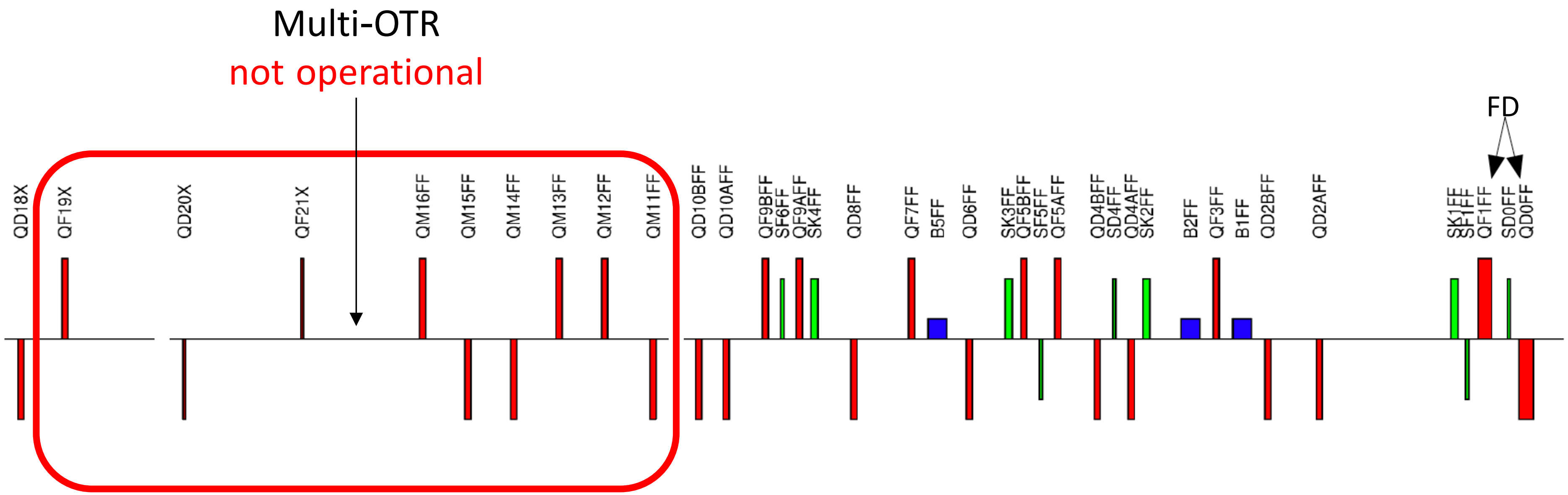
  - For the second attempt the $25\beta_x^*$ x $0.25\beta_y^*$ optics was re-optimized in simulation before the run to take into account the constraints from the matching quads. The quads changed are QF19X→QF21X in the extraction line, the matching quads (QM16FF→QM11FF) and the FD (QF1FF and QD0FF).



  - The sextupoles were re-optimized for the new optics.

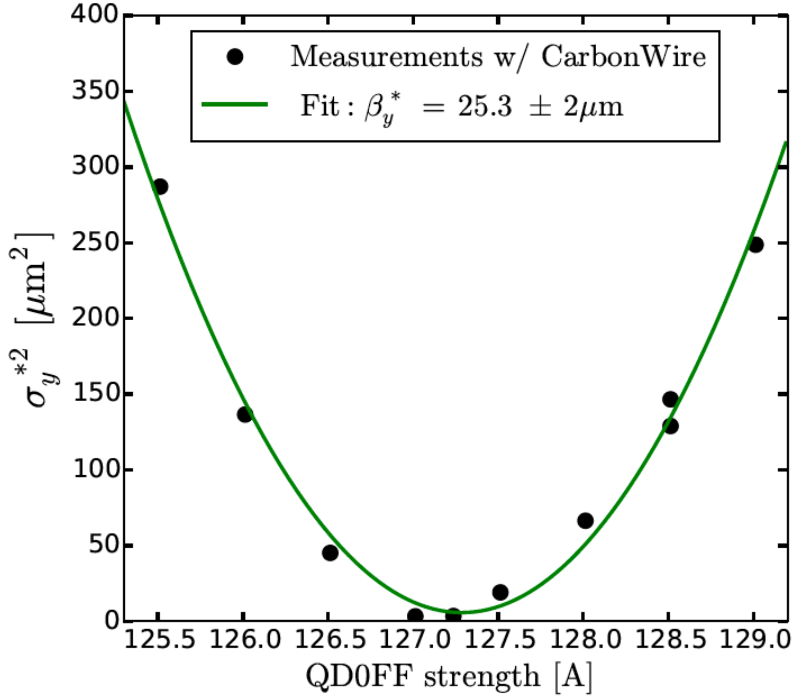
February 2018 Machine Tuning with ultra-low β_y^* optics

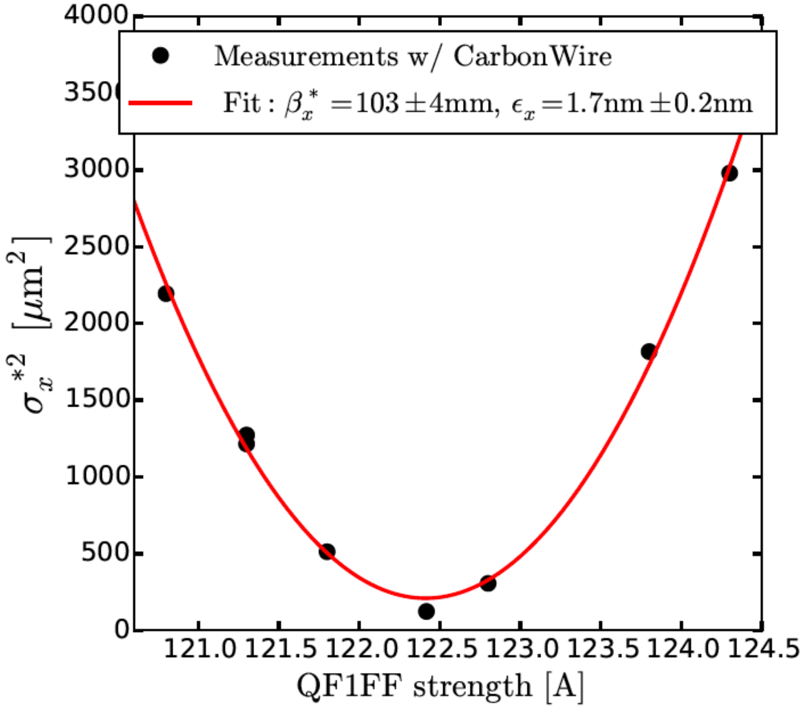
- Matching of the $\beta_{x,y}^*$



- The multi-OTR was still not available in February run.
- The measurement of the vertical emittance was done in the DR → ϵ_y = 12.5 pm.

February 2018 Machine Tuning with ultra-low β_y^* optics

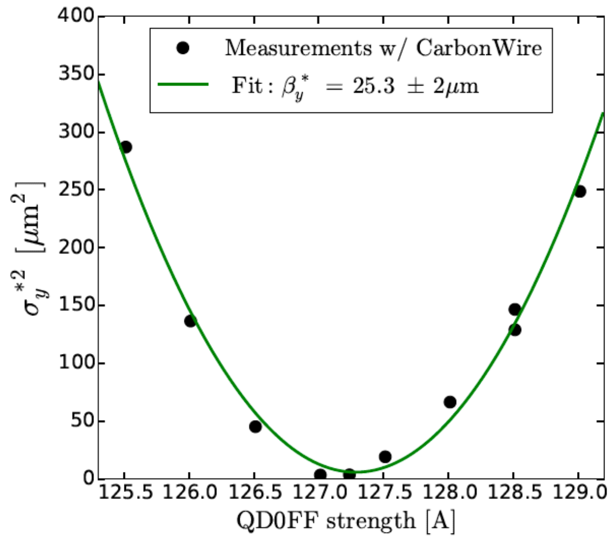


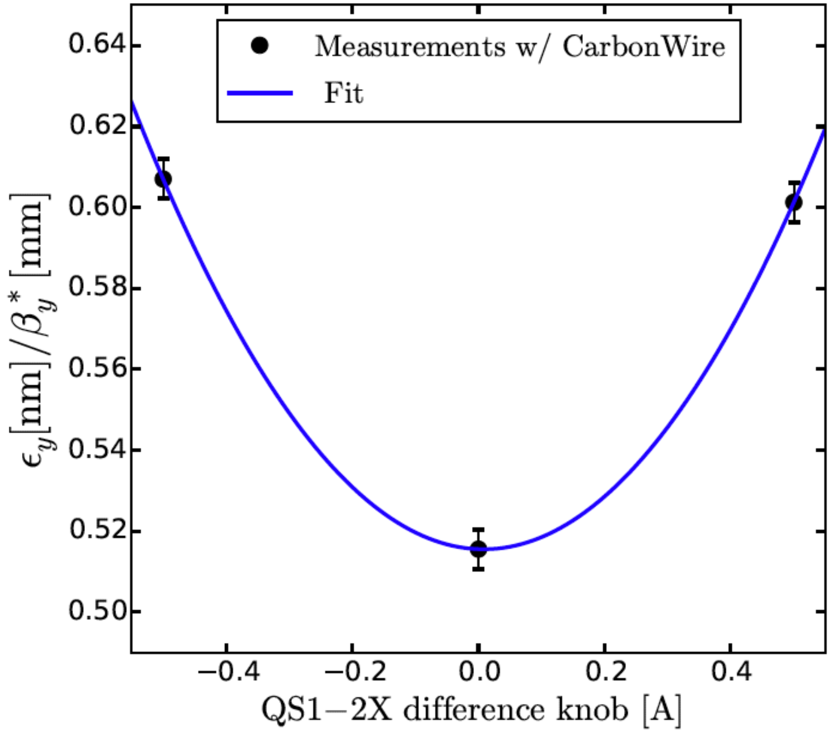


- Smaller β_y^* target (15µm) was needed to measure β_y^* of $\sim$ 25µm but β_x^* was very consistent with the optics model and matched directly $\sim$ 100 mm.
- Residual dispersion was corrected from the fit of the quad scans → the measured η_x^* was around 3 mm.

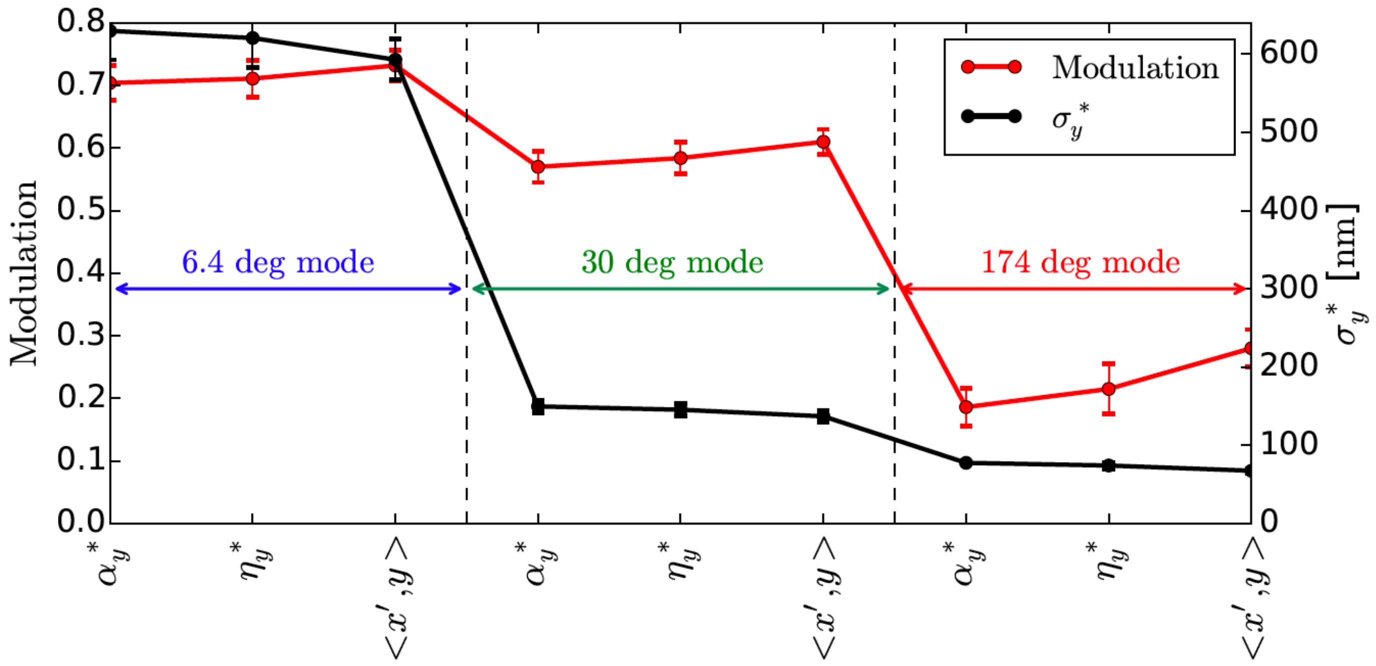
February 2018 Machine Tuning with ultra-low β_y^* optics

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



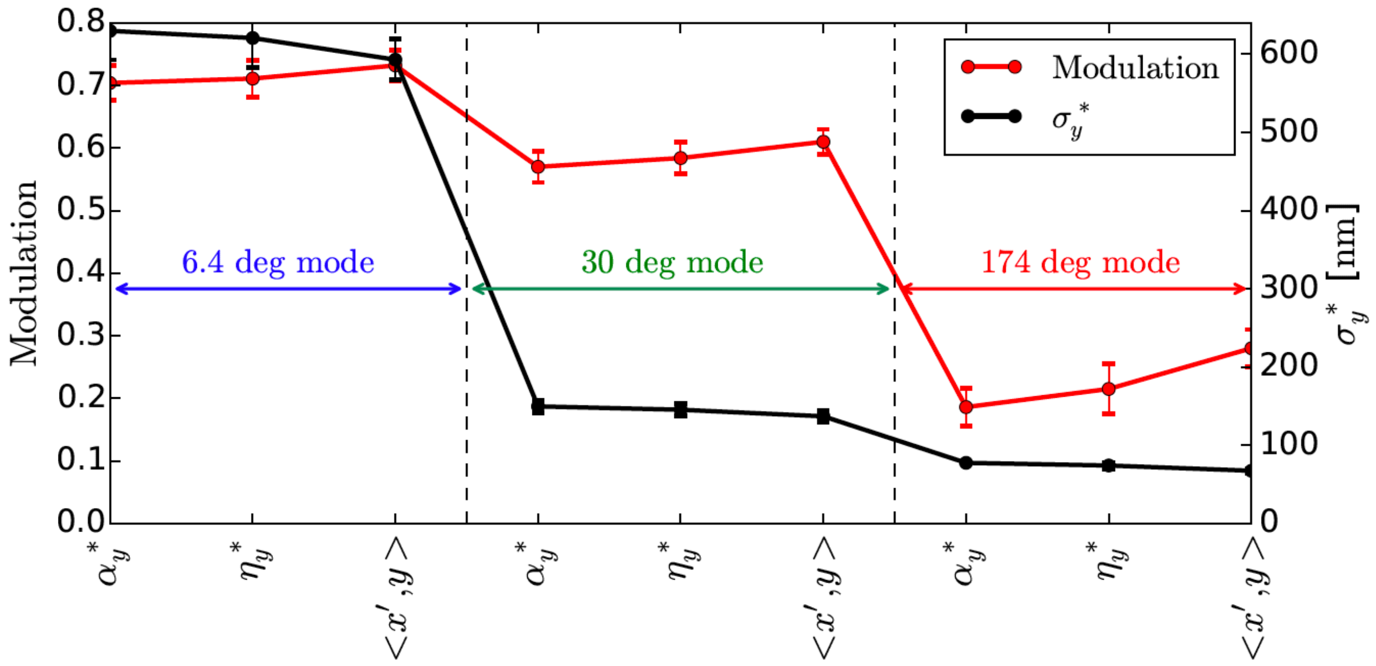


February 2018 Machine Tuning with ultra-low β_y^* optics



- Tuning time reduced compared to Dec17 run due to multiple reasons: long correction of the very large background generated from the larger beam size along the FF; rematch of the Shintake laser tuning and retune of the optics after 4 shifts → QF1FF strength was not reset to its original value leading to a large increase of β_x^*.

February 2018 Machine Tuning with ultra-low β_y^* optics



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

Summary of May 2018 run

- Load the same optics used in February 2018 but with the advantage of measuring the emittance (multi-OTR was recovered) → the time allocated for the ultra-low β_y^* study was too little to perform a complete machine tuning.

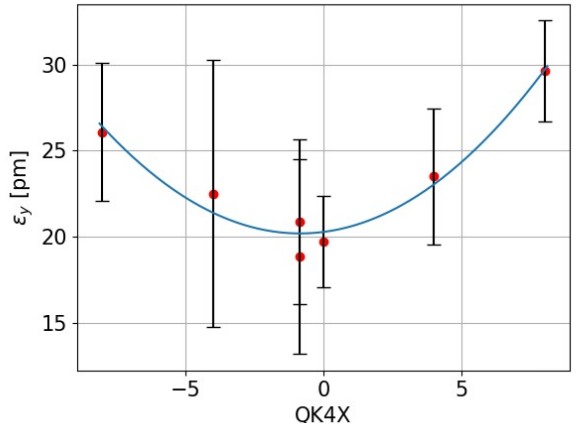
- The results only include the emittance measurements with multi-OTR and the twiss function evaluation at the IP (carbon wire) → preparation for next winter beam operations.

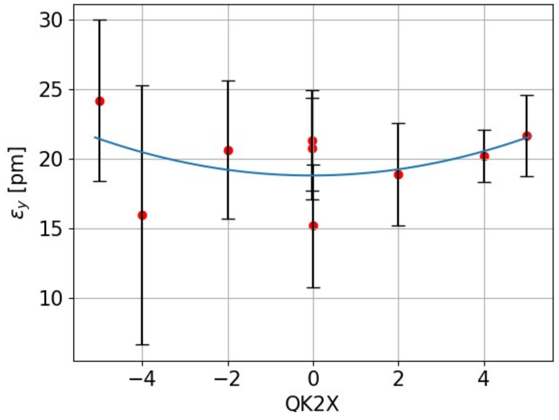
- Before moving to the multi-OTR emittance measurements, the orbit was corrected and the dispersion was reduced in the OTRs region to $\pm$ 10mm in the vertical plane.

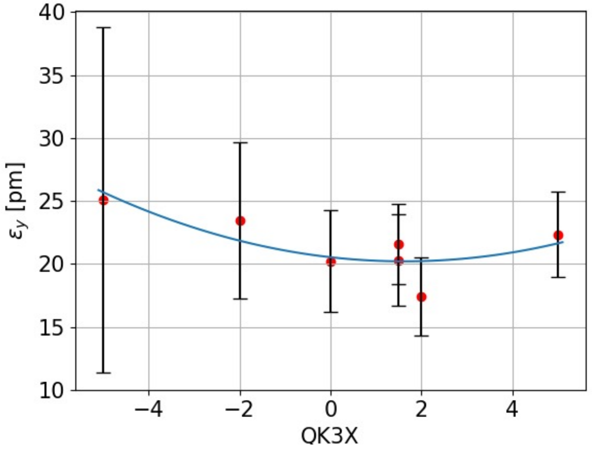
- The emittance measured was 23 $\pm$ 4 pm → <x,y> coupling correction to reduce this value.

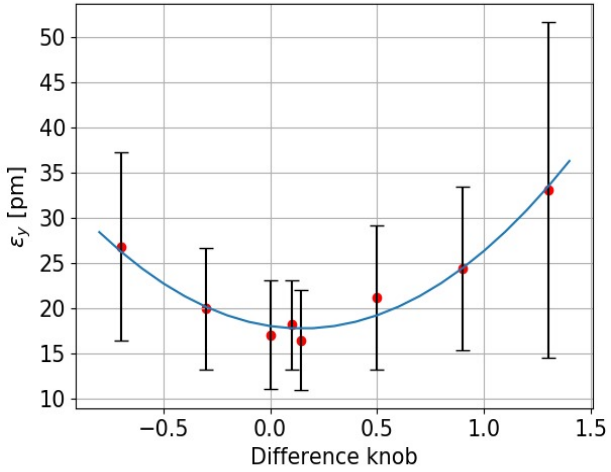
Summary of May 2018 run

- The <x,y> coupling correction is performed by scanning the strength of four skew quadrupoles (QK1X, QK2X, QK3X and QK4X) in the extraction line and by applying the Δ-knob with the vertical emittance measured by the multi-OTR system being a figure of merit.



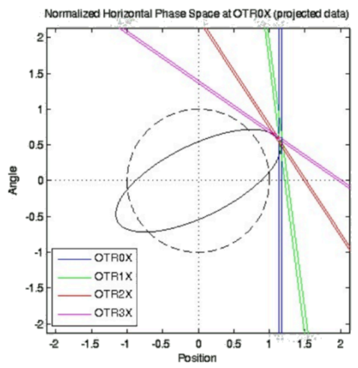


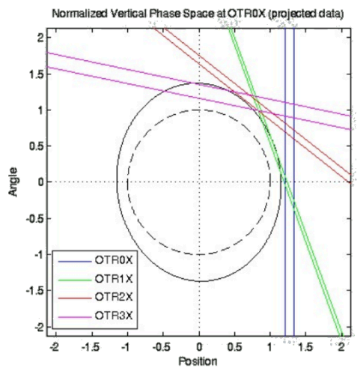


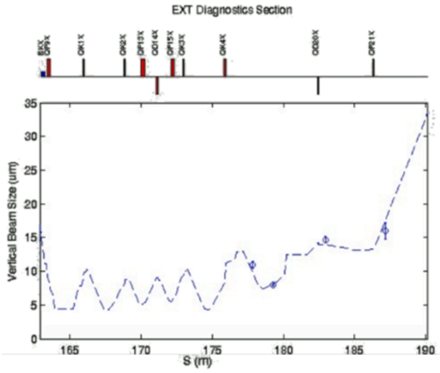


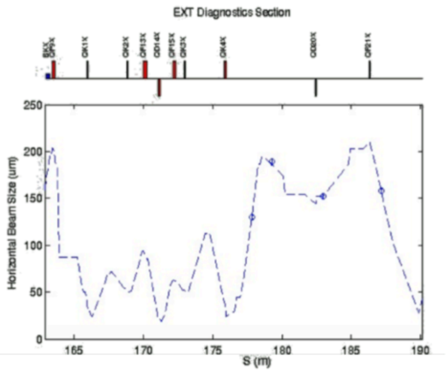
Summary of May 2018 run

- The value of the emittance at the entrance of the FFS after the <x,y> coupling correction was **19 ± 6 pm.**





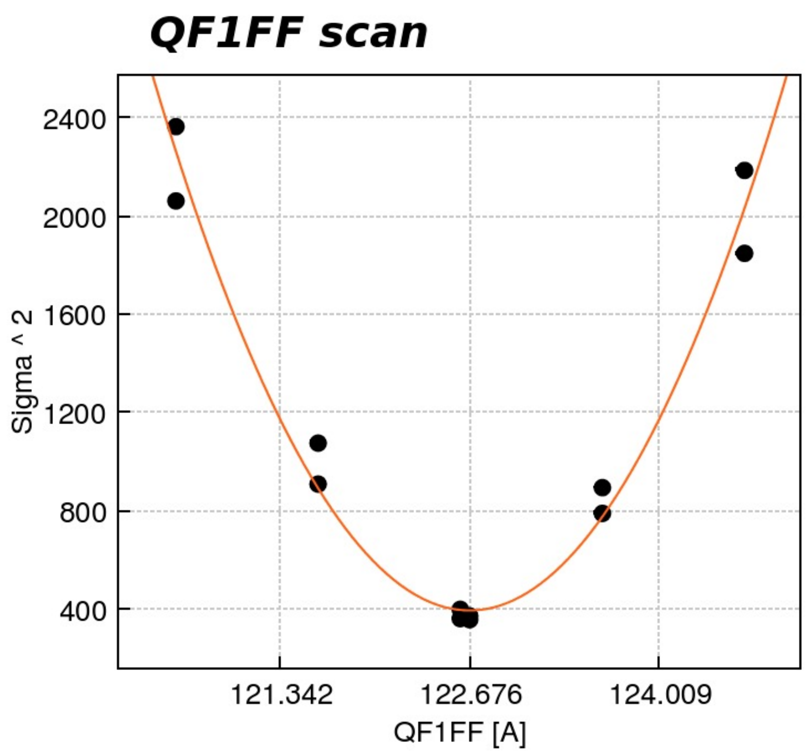


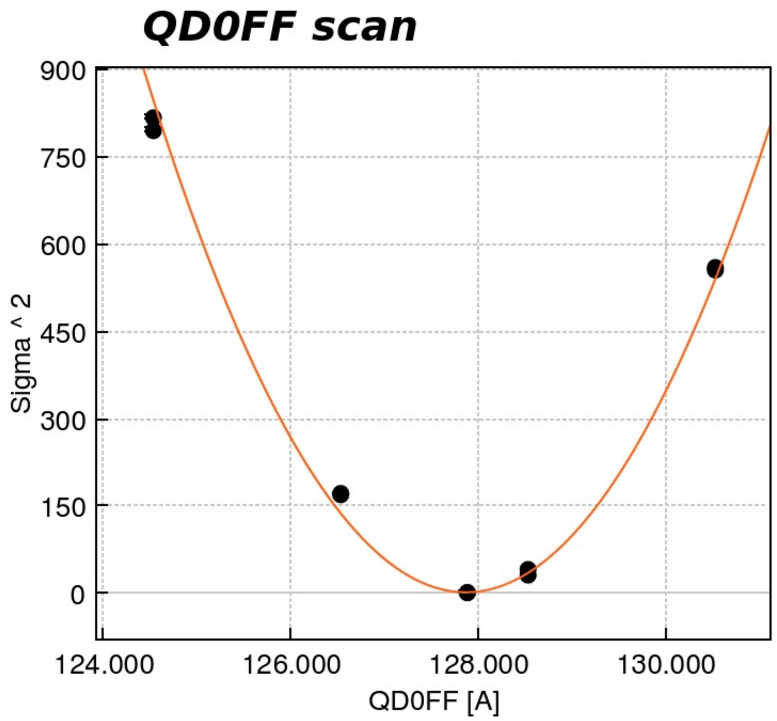



```
Horizontal projected emittance parameters at first OTR
------------------------------------------------------
energy    =   1.2820         GeV
emit      =   1.2850 +-   0.4690 nm
emitn     = 3223.8110 +- 1176.6395 nm
emit*bmag =   1.8785 +-   0.1657 nm
bmag      =   1.4619 +-   0.4058    (  1.0000)
bmag_cos  =   0.4462 +-   0.0000    (  0.0000)
bmag_sin  =  -0.5771 +-   0.0000    (  0.0000)
beta      =  13.3298 +-   4.7160 m  (  6.3052)
alpha     = -10.3450 +-   3.7993    ( -4.4943)
chisq/N   =   0.9841

Horizontal projected emittance parameters at IP
------------------------------------------------------
sig       =  18.0492 +-   0.1702 um (  7.1600)
sigp      =  71.1946 +-  26.0663 ur ( 179.5204)
beta      = 253.5226 +-  93.3960 mm ( 39.8952)
alpha     =   0.0046 +-   0.1085    ( -0.0238)

Horizontal projected emittance parameters at waist
------------------------------------------------------
L         =   0.0012 +-   0.0279 m
beta      = 253.5172 +-  93.1706 mm
sig       =  18.0491 +-   0.1715 um

Vertical projected emittance parameters at first OTR
------------------------------------------------------
energy    =   1.2820         GeV
emit      =  18.8733 +-   5.6629 pm
emitn     =  47.3495 +-  14.2072 nm
emit*bmag =  19.1648 +-   6.1750 pm
bmag      =   1.0154 +-   0.0323    (  1.0000)
bmag_cos  =  -0.1705 +-   0.0000    (  0.0000)
bmag_sin  =   0.0336 +-   0.0000    (  0.0000)
beta      =   5.2144 +-   0.8104 m  (  6.1903)
alpha     =   2.2042 +-   0.5053    (  2.5763)
chisq/N   =   6.1925

Vertical projected emittance parameters at IP
------------------------------------------------------
sig       =  11.9851 +-   2.1605 um (  0.0436)
sigp      = 1151.7620 +-  9.9411 ur ( 433.0907)
beta      = 7610.9045 +- 1178.8637 mm (  0.1006)
alpha     = 731.4027 +- 113.2781    (  0.0019)

Vertical projected emittance parameters at waist
------------------------------------------------------
L         =   0.0104 +-   0.0000 m
beta      =   0.0142 +-   0.0022 mm
sig       =   0.0164 +-   0.0026 um
```

Summary of May 2018 run

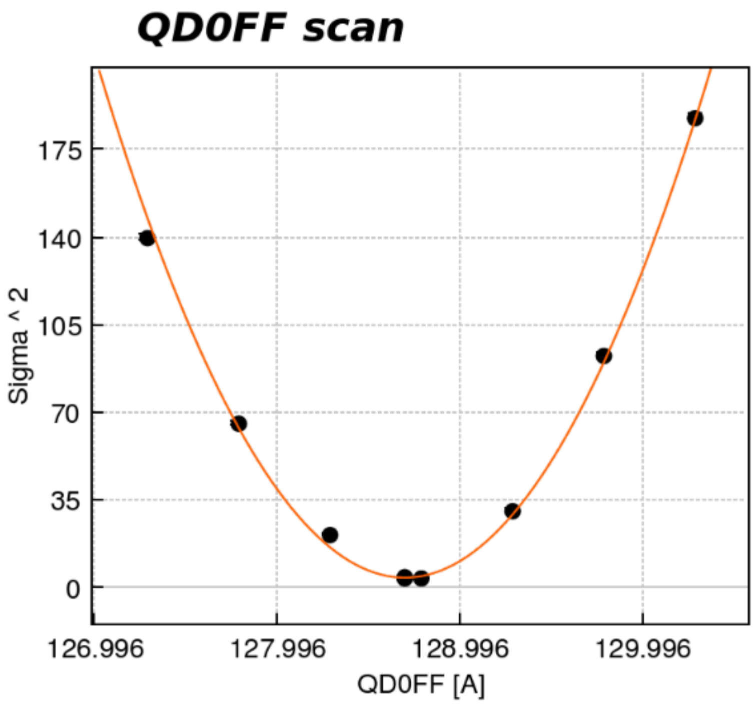
- Dispersion correction in the FFS region with the Σ-knob QS1X-QS2X.
- The values of the β_x^* and β_y^* measured with the carbon wire scans were: 229 mm and 40 μm (for an emittance of 18 pm) or 27 μm (for an emittance of 12.5 pm → measured in the DR).

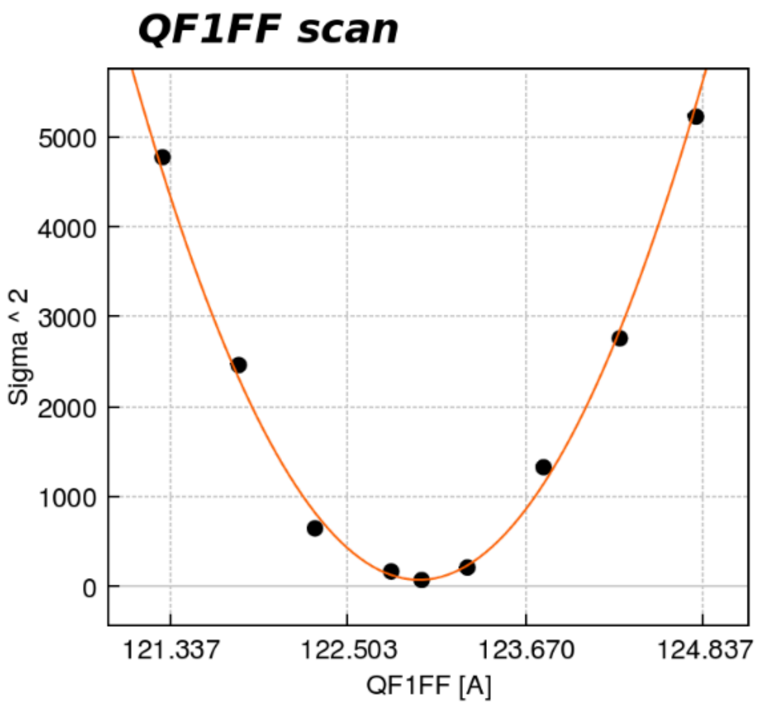




Summary of November 2018 run

- The goal of these first two shifts in November run was to match the optics used in February 2018.
- At the beginning of the owl shift the multi-OTR screens were not working → they were recovered only for the day shift.
- The emittance measurements were inconsistent → the emittance values were too large.
- The evaluation of the twiss parameters at the IP with the carbon wire scanner showed a β_x^* value smaller than the design (55 mm) and a divergence of 0.43 (β_y^* value of $\approx 25\ \mu$m → the vertical emittance measured in the DR was 9.1 pm).





Summary of November 2018 run

- Summary of the optics matching

	Measured β_x^*	Measured β_y^*
December 2017	86 mm	$(\epsilon_y/\beta_y^*$ = 0.48) ϵ_y= 12.9 pm 26.2 μm
February 2018	103 mm	$(\epsilon_y/\beta_y^*$ = 0.43) ϵ_y= 12.5 pm 25.3 μm
May 2018	229 mm	$(\epsilon_y/\beta_y^*$ = 0.45) ϵ_y= 12.5 pm 27.7 μm
November 2018	55 mm	$(\epsilon_y/\beta_y^*$ = 0.43) ϵ_y= 9.1 pm 21.2 μm

Conclusions

- During the second long tuning attempt of the $25\beta_x^*$ x $0.25\beta_y^*$ 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 2018 run could be further improved with the use of all the 2^{nd} order sextupole knobs and to use the octupoles for 3^{rd} order correction to further reduce the σ_y^*.

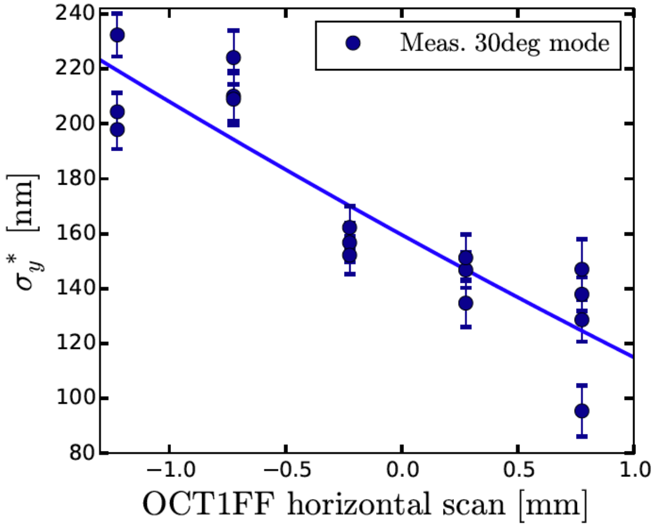
- The abscence of multi-OTR was an important limitation because it is very important for optics rematching and <x,y> coupling correction.

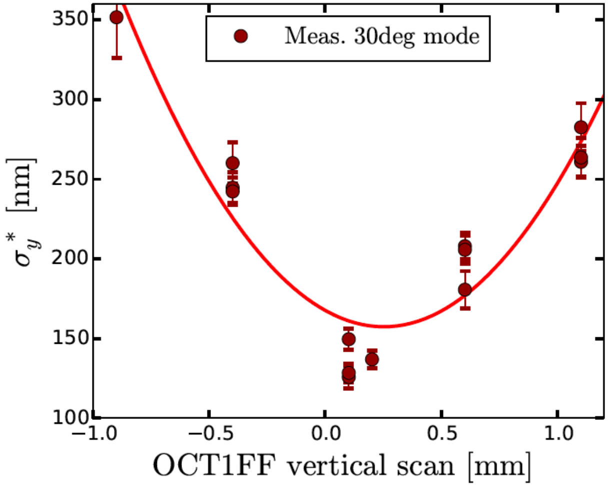
- The last tuning session ends on an incomplete tuning study for the exploration of the ultra-low β_y^* performance
  → **a whole week will be allocated to the study in December 2018 beam operation.**

Thanks for the attention!

Back-up Slides

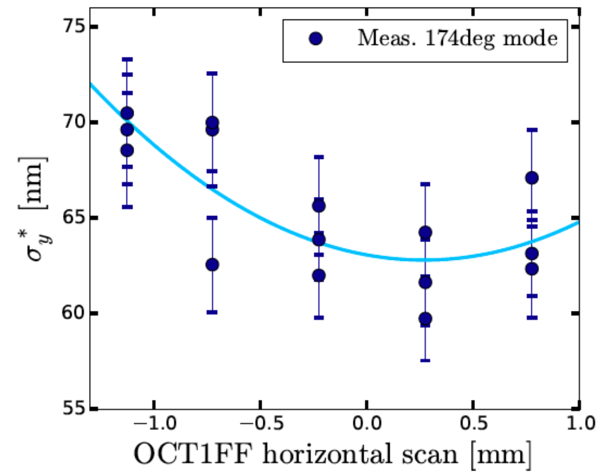
- The impact of the octupoles beam size at ultra-low β_y^* is in the order of ≈9-10 nm in simulation.
- The resolution of the beam size measurement at 30 degree mode is to large to observe octupolar correction.
- However the OCT1FF position scan gave us possible useful informations about the lattice:

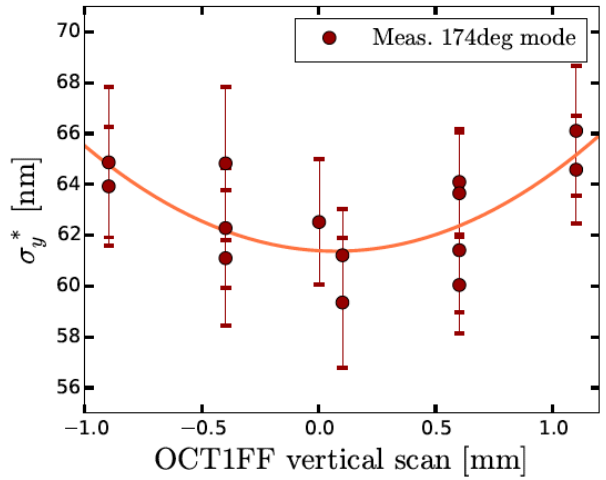


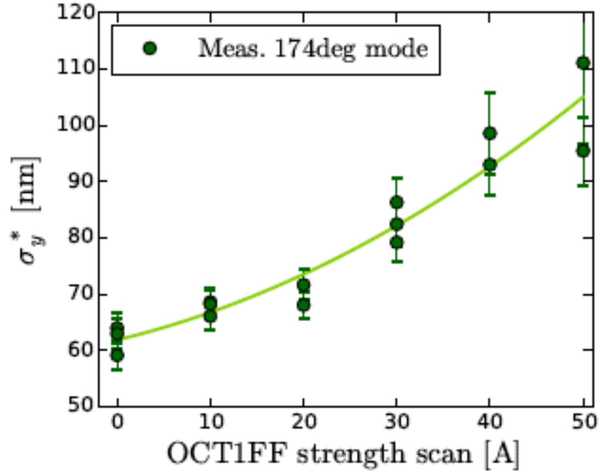


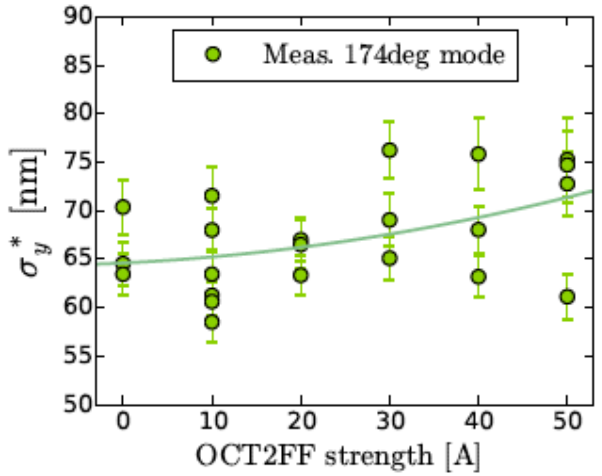
- Horizontal offset of a normal octupole generates normal sextupolar field (can generate Y24 and Y46 aberrations).
- Vertical offset generates skew sextupolar field (can generate Y22, Y26, Y44 and Y66 aberrations).
- **Possible mismatch of the linear optics with the normal sextupole strength applied for ultra-low β_y^*.**
- Same observations for the nominal optics (10β_x^* x 1β_y^*) for December 2017 operations.

December 2017 (modification in the 10x1 optics):



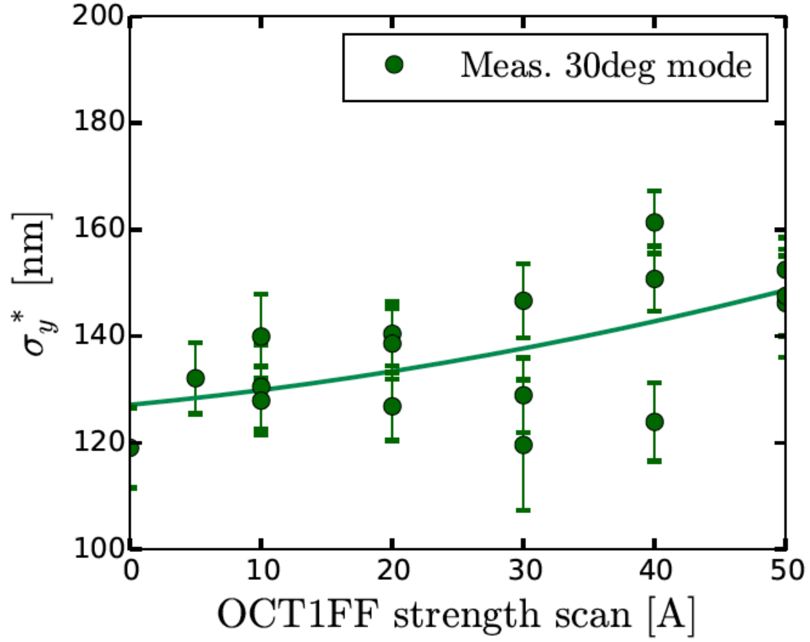






- At 30 degree mode the resolution of the beam size measurement is too large to observe the impact of the octupoles.
- Octupolar correction on the vertical beam size will observed only at 174 degree mode.

Measured at 30 degree mode (10x1 optics)



Measured at 174 degree mode (10x1 optics)