# Optics subsystems integration studies

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# Outline

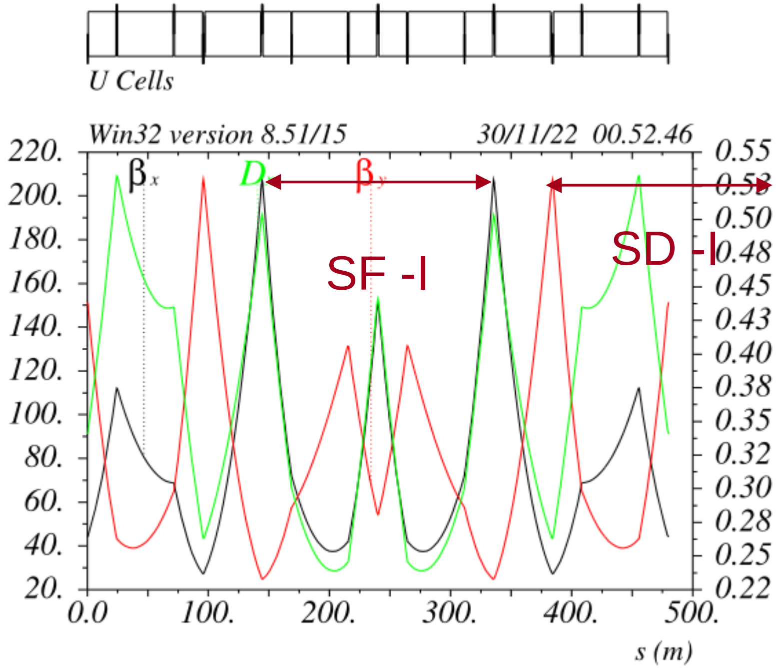
- Subsystems integration strategy
- ARC cell optimization
- Long straight section asymmetries compensation
- Integration of FFs in a ring with X-crossing angle
- HFD@LCCFF highlights
- Alignment tolerances and tuning
- Conclusions

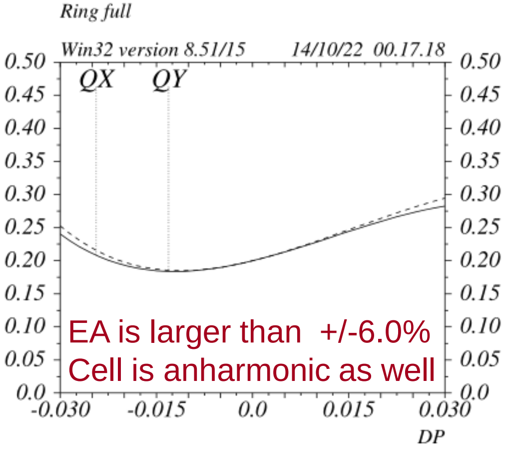
# Subsystem integration strategy

Subsystems integration made according to (as much as possible):

- Using TCs criteria
- Minimum emittance dilution
- Minimum energy loss increase
- Minimum impact on natural chromaticities
- Maintaining optics symmetries
- Develop specific solutions to compensate for asymmetries (only dipoles for now)
- Step-by-step optimization and impact evaluation on ring properties

# HFD lattice general specs  v_32a1




Octant composed of 20 cells 480m long: 9.6km total length
Total number of cells: 160
200m of the dispersion suppressor cell roll into the LongSS
A weak gradient has been added to all the dipoles: K_mad=6.1e-5
(to be checked overall benefits and feasibility)

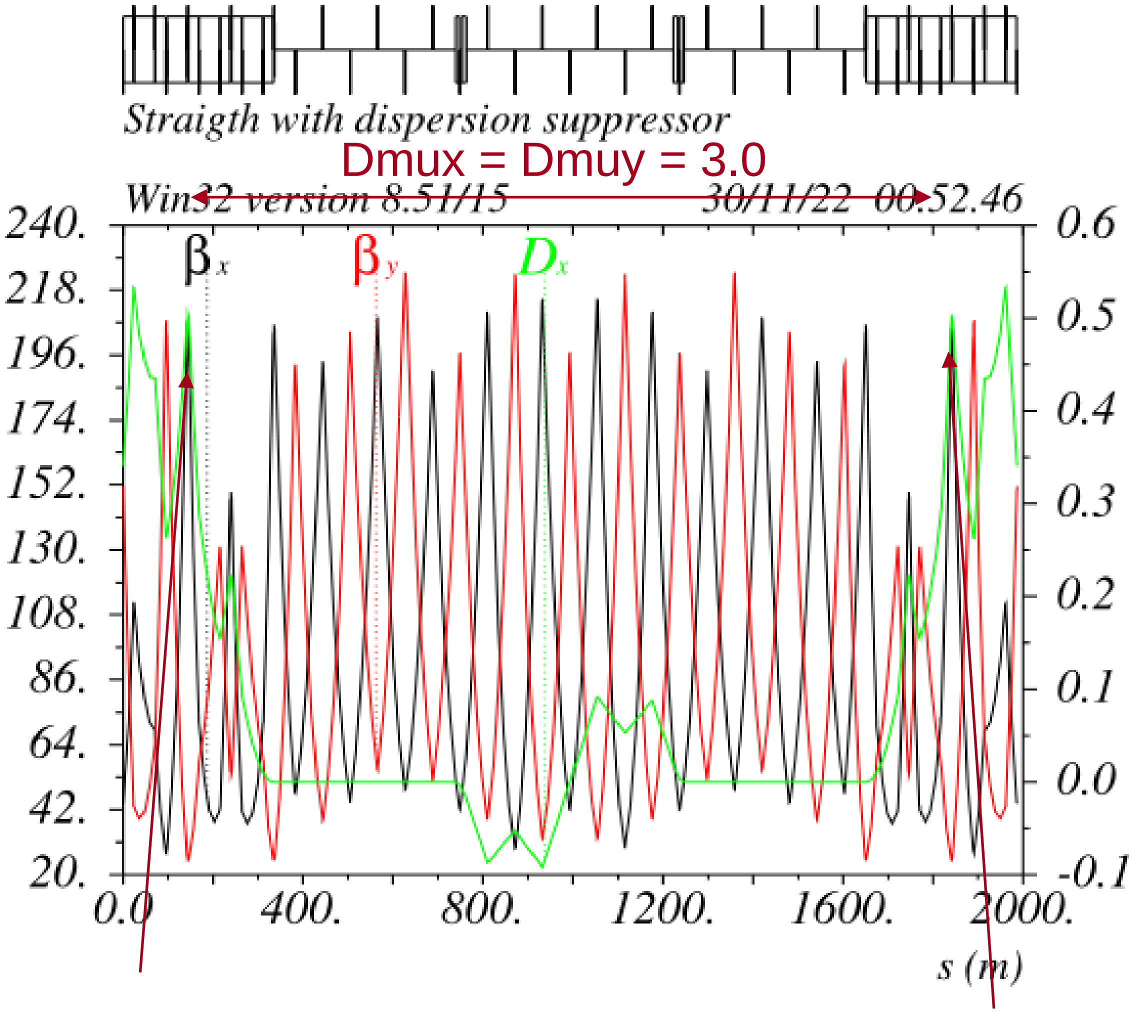
The ARC lattice can be the same for all modes
(with some readjustement of beam parameters)

Quads ~0.5-1mt long Kmad ~0.033 (20T/m@ttbar)
SF Sexts ~0.3mt long Kmadx~0.24 (145T/m^2@ttbar)
SD sexts ~0.6mt long Kmadx~0.24 (0.29T@45mm radius)

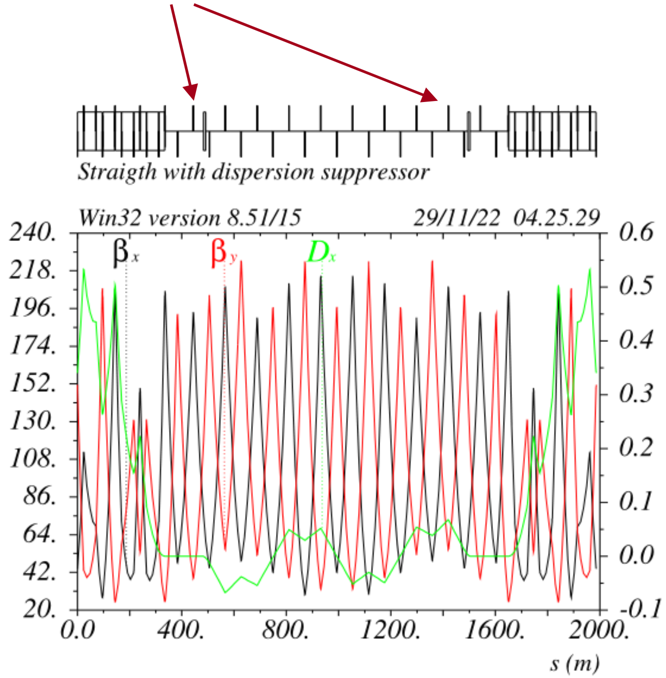
Jx = 1.5, Jy = 1.0, Jz = 1.5
Alphac = 2.57e-5
Ex = 0.34nm @ 45.5GeV  Ex = 5.44nm @ 182GeV
U0 = 31.8MeV  U0 = 8.141GeV

The Hybrid FODO (HFD) cell can be further optimized
Possibly the “breakdown” can be pushed above 200cells

# Long straight TCs with asymmetric optic (X_cross dogleg) v_32a1

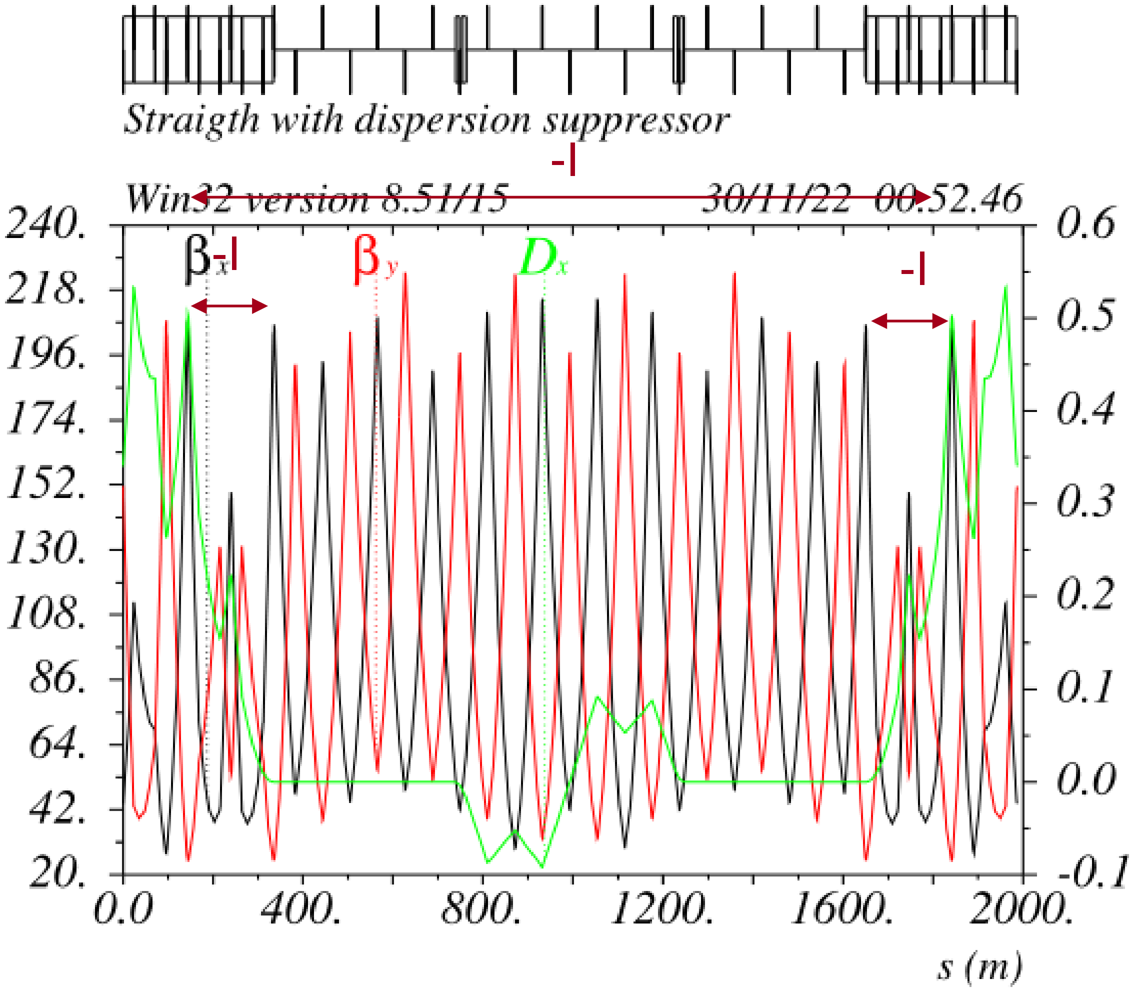



Long Straigth Section length close to
Total ring length = 88.85Km (supposing 8 identical LSS)
Overall delta_phase advance is 3 unit in both planes.
TCs conditions always respected
Example of  dipoles added for the LSS-Xcrossing
Many solutions for the dipoles are possible (see example)




The last SF of the left ARC pairs with the first SF of the right ARC as for the “standard” SFs ARC pairs

# Asymmetric Long straight insertion with TCs v_32a1



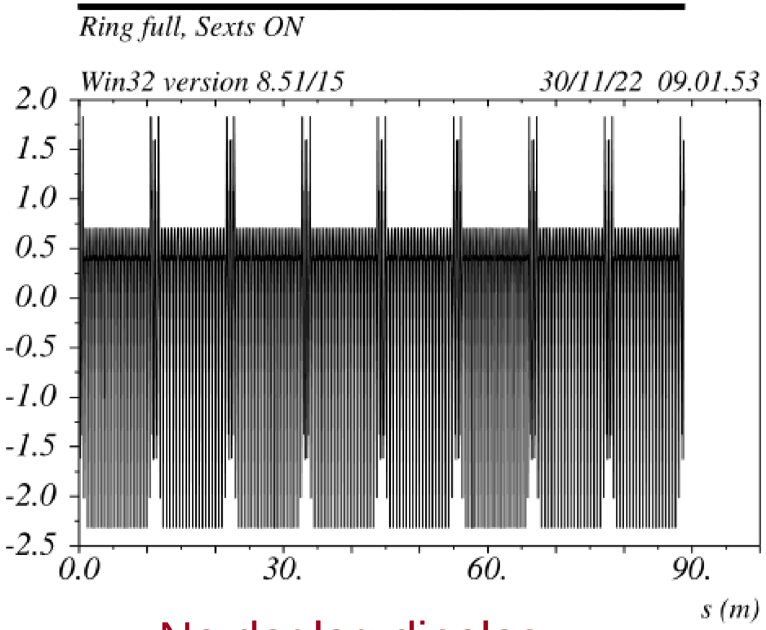

Dipoles do generate second order dispersion that affects the overall MA if not compensated
Fortunately in the DS there are 4 SF sextupoles that are all paired,
Two of them have nominal ARC dispersion and two have zero dispersion.
They have all the standard ARC value when there are no dipoles:
- they correct the properly the chromaticity and do not generate any detuning.

When antisymmetric dipoles are added the first pair is unbalanced wrt to the second pair (the sum is kept):

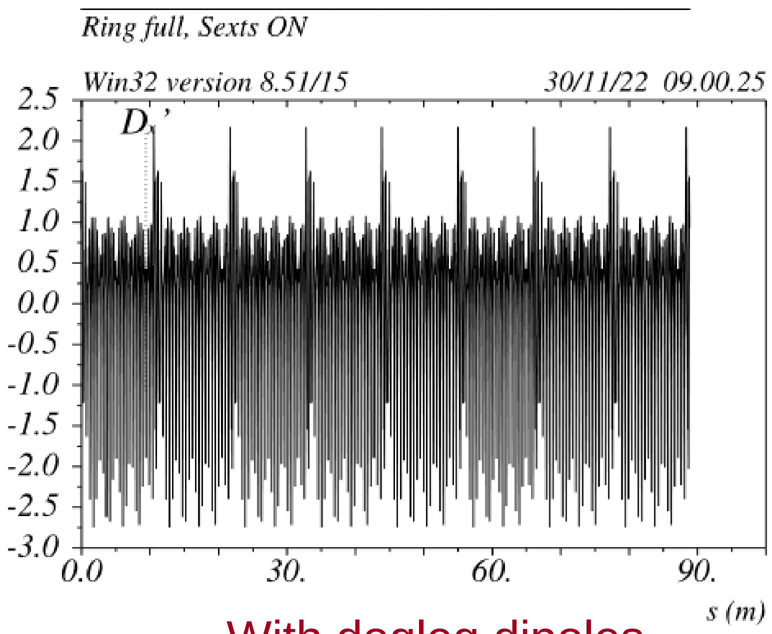
- The net effect is to generate second order dispersion that compensates the one generated by the dipoles
- Chromaticity and detuning are not affected because of the 3 “-I” conditions

The last SF of the left ARC pairs with the first SF of the right ARC as for the “standard” SFs ARC pairs

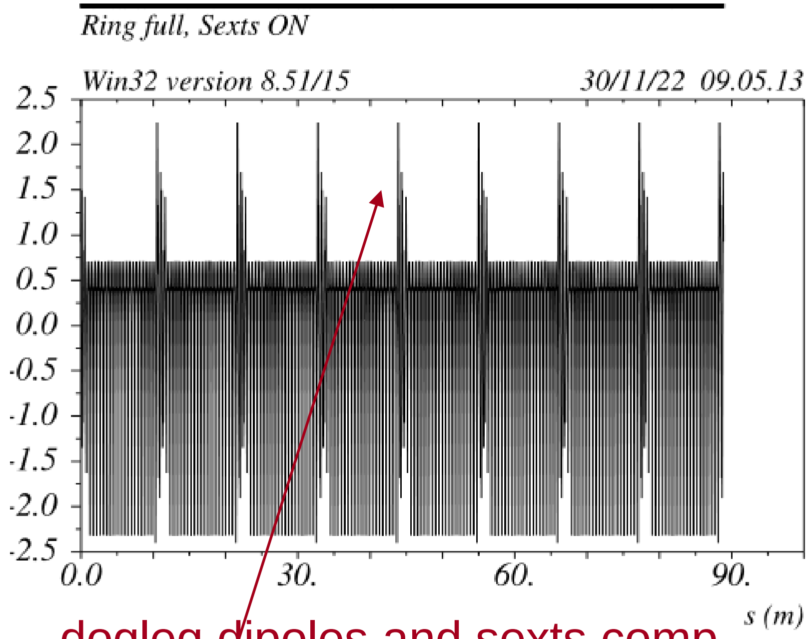
# Long straight insertion with TCs  v_32a1



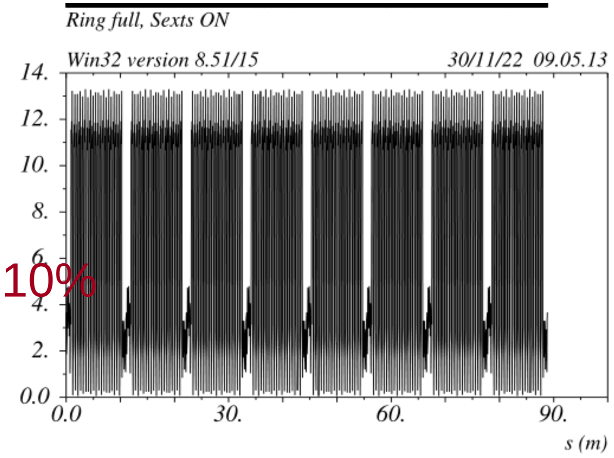

No dogleg dipoles




With dogleg dipoles

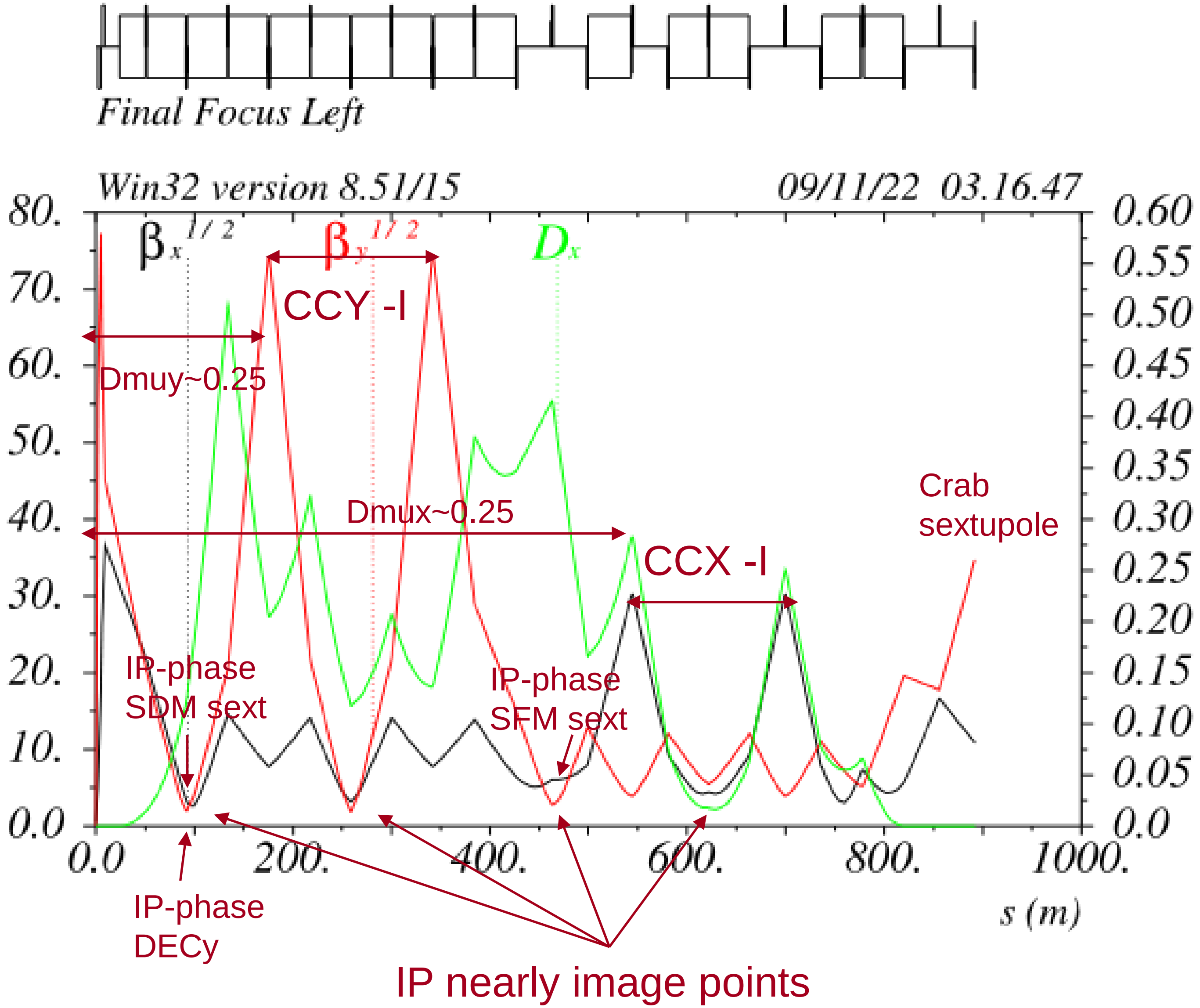



dogleg dipoles and sexts comp
ddx ripple contained in the LSS




Horizontal (and vertical) chromatic functions remain periodic and unchanged
For this case sexts pair unbalance around +/-10%
This compensation works for any antisymmetric dipole configuration
(effect of ddx mismatch on MA on backup slide)

# Final Focus with 5th order chromatic correction    v_23c



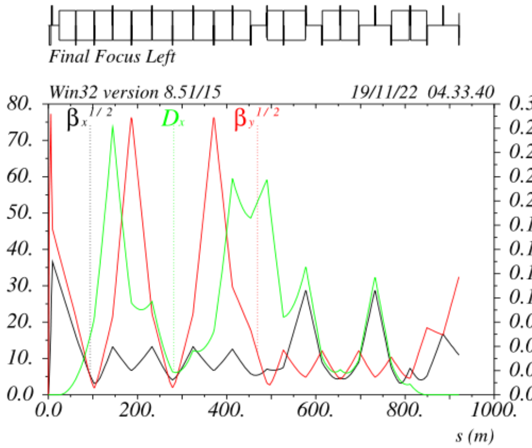

The LCCFF has a very high degree of rescalability

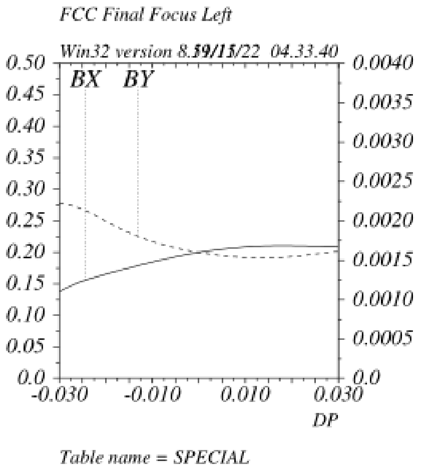
The chromatic aberrations do vanish up to the 5th order => rescaling the bends angles only higher orders do grow and their effect is negligible at least up to dE+/-3%

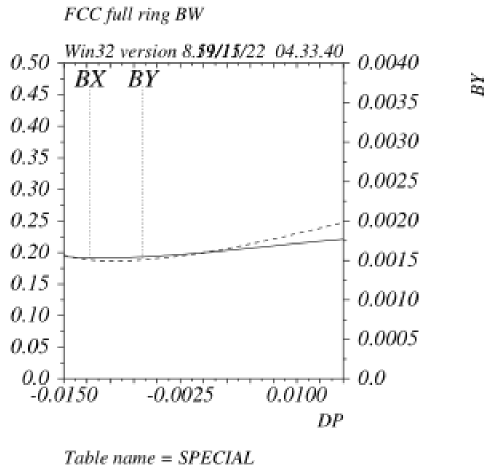
For the geometric aberrations: the long sextupole aberrations are effectively compensated by setting R12~R34~1/3*sext_length
This compensation remains valid independent while rescaling the dipoles, however the vertical DA decreases ~linearly with the dipole angle.
The horizontal does decrease as well but remains extremely large even for very weak dipoles.

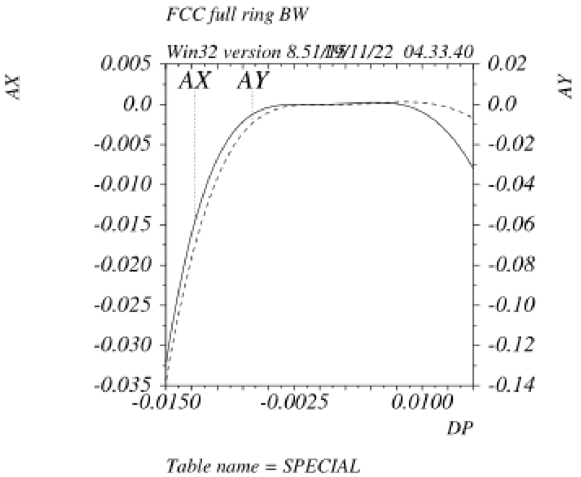
There is a lot of flexibility in the FF to meet the IP crossing angle requirements and the overall ring layout

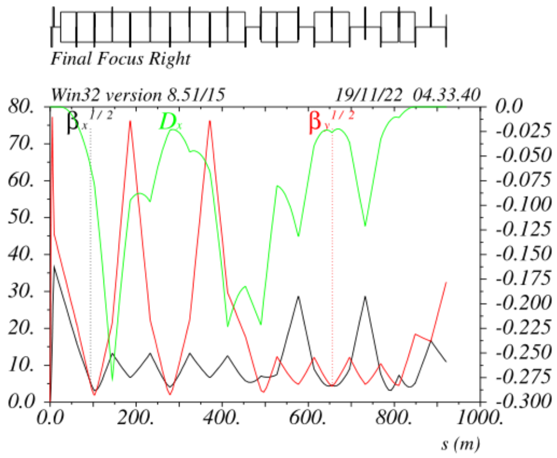
# Tests of ring performances with opposite bend angles
# Left-Right Final Focus

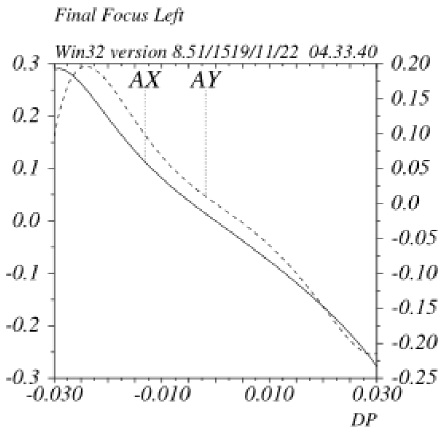


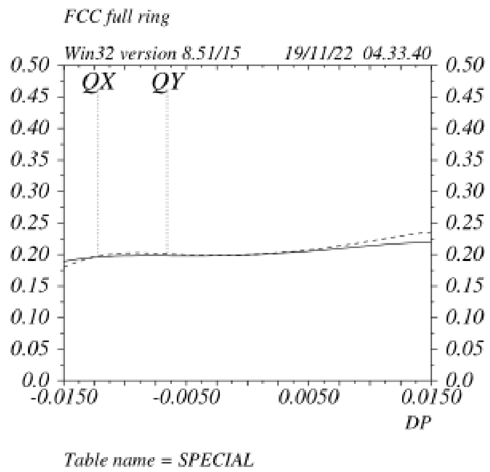



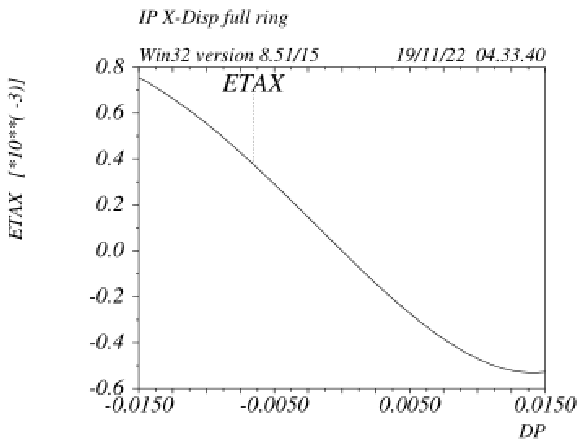



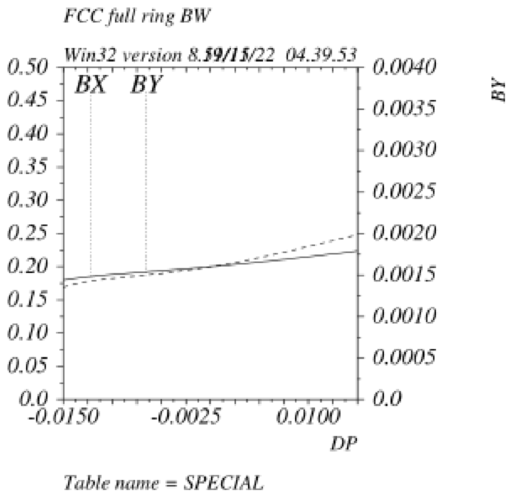



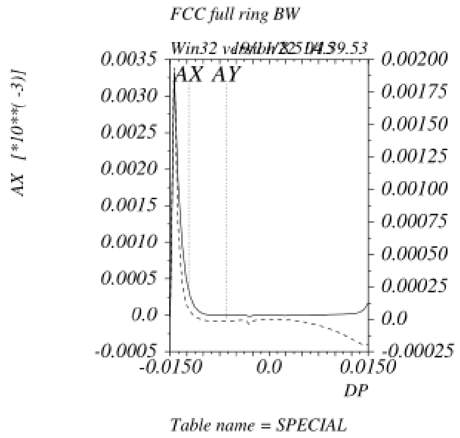



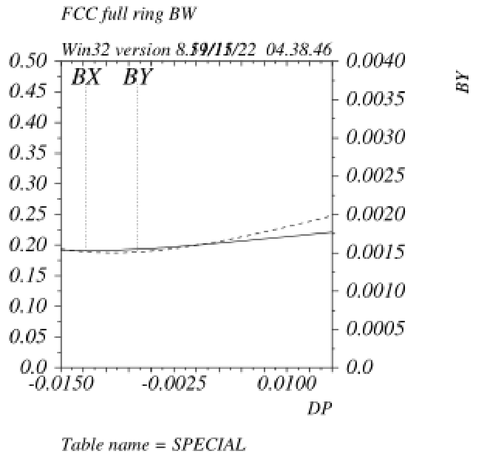



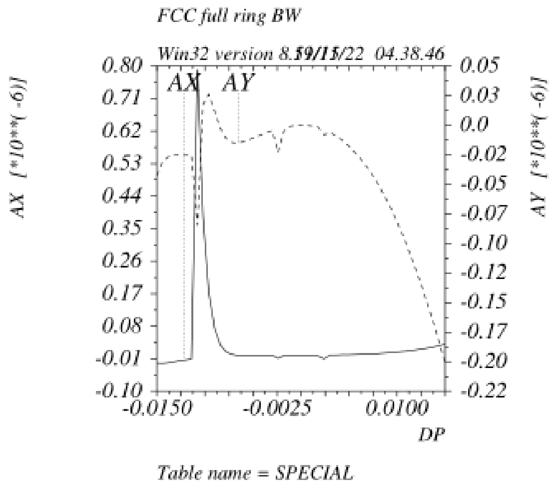

Total FF bend angle +/-20mrad, half wrt to v_23c

# Tests of ring performances with same bend angles Left-Right Final Focus, both positive or negative



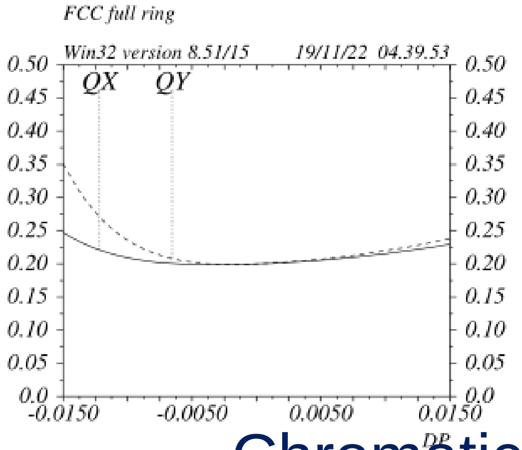



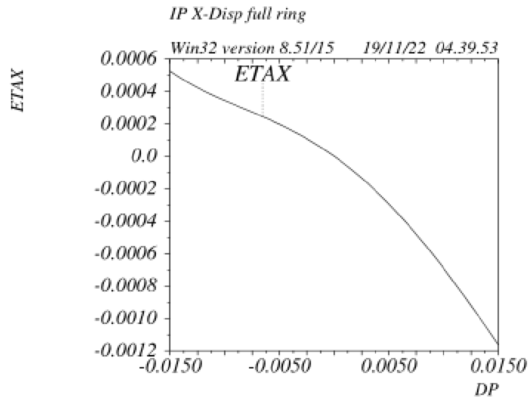



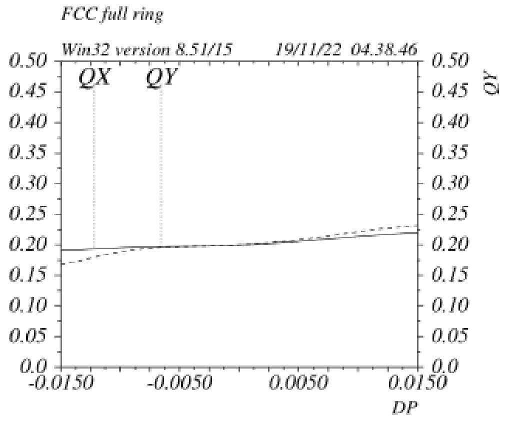



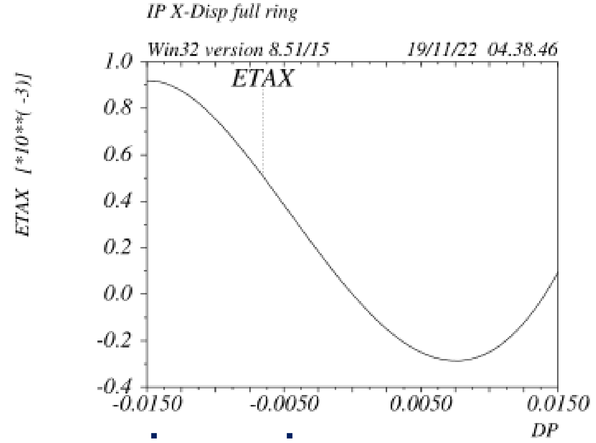

Both FF bend angles positive

Both FF bend angles negative



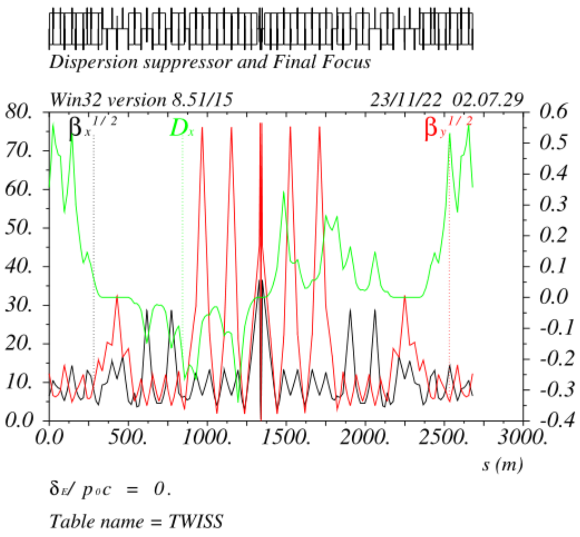



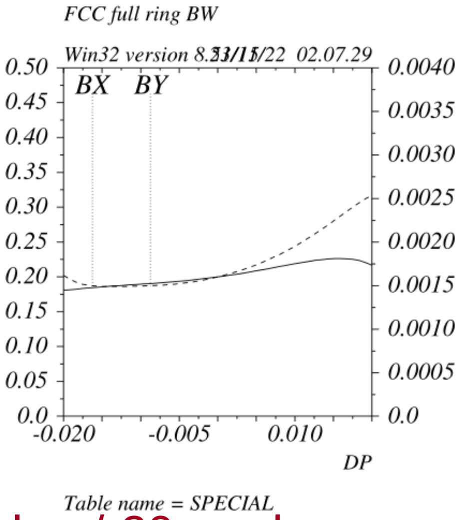



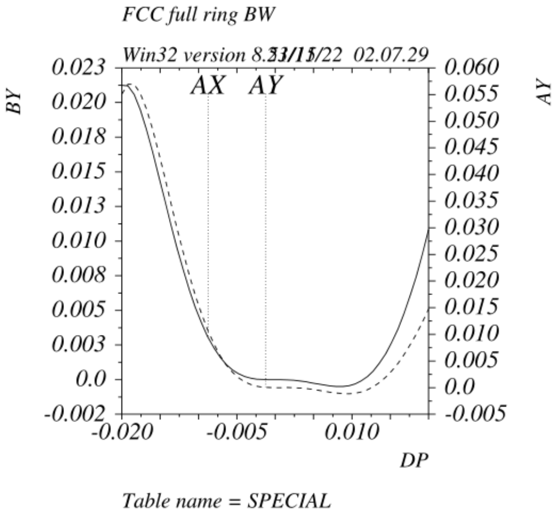




Chromatic properties almost independent from FF L/R dispersion signs

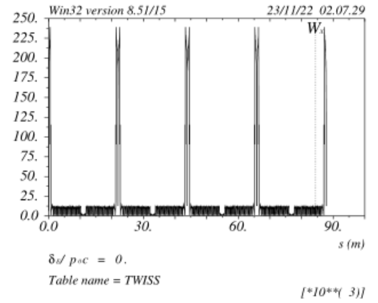
# Ring optics and chromatic properties with opposite sign FF dipoles v_30a2

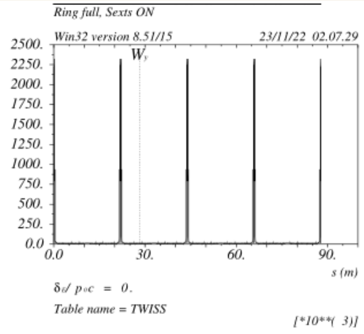


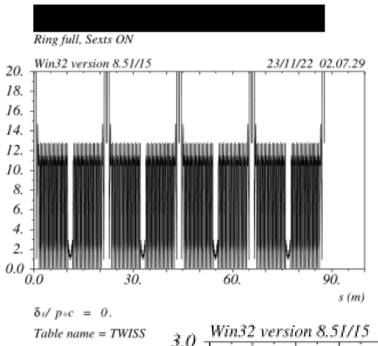



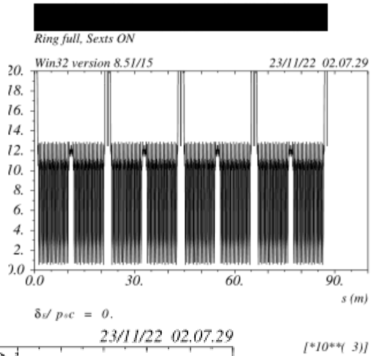



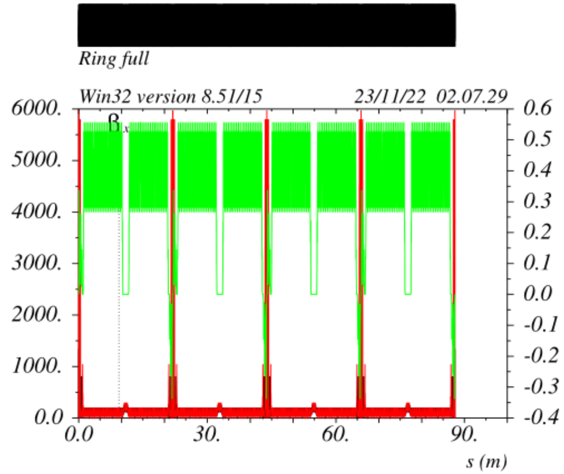

Total FF bend angle +/-20mrad

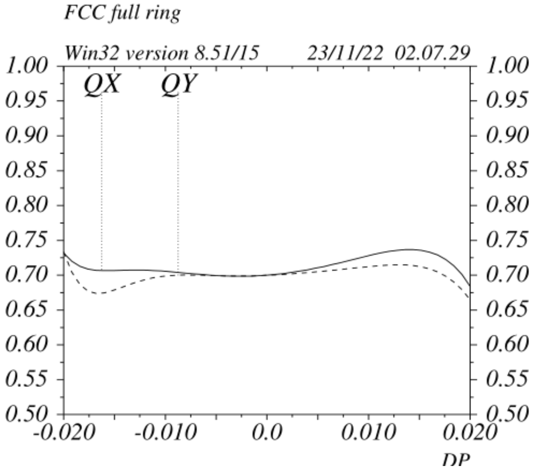


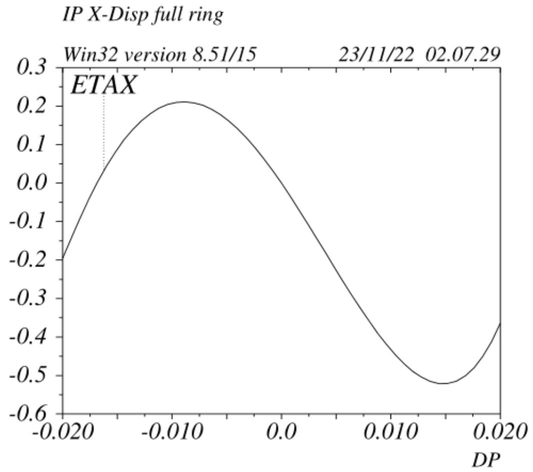



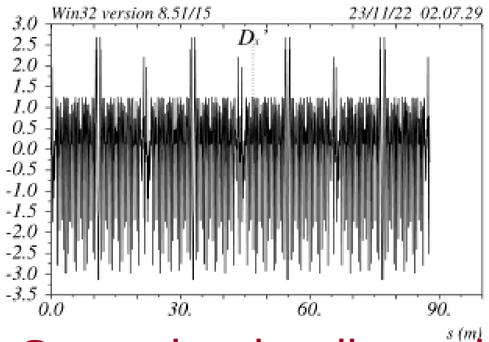



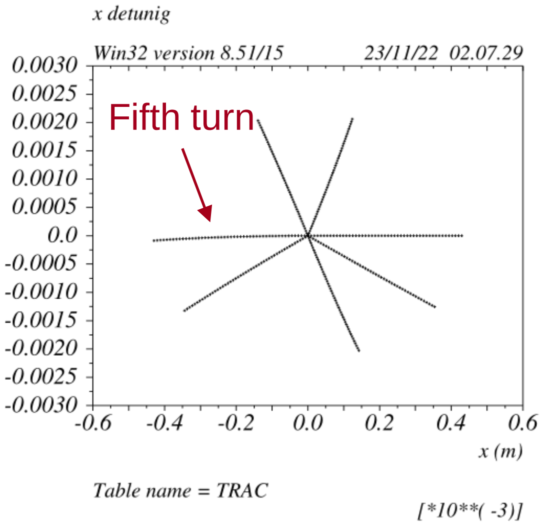



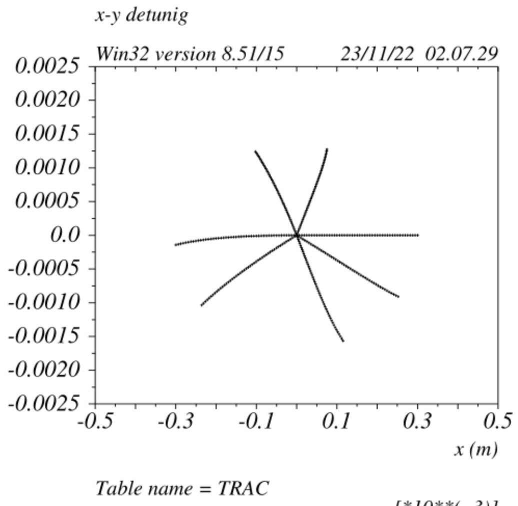



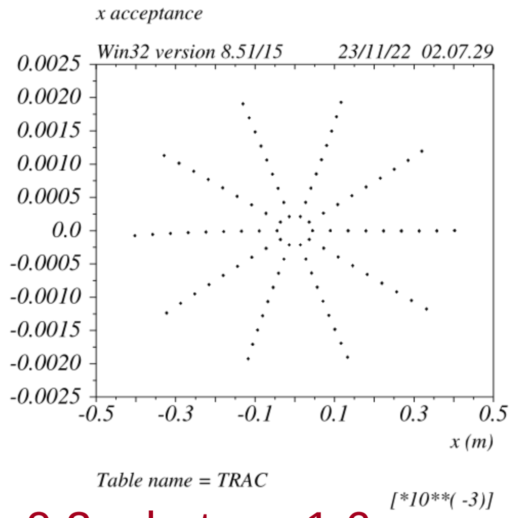



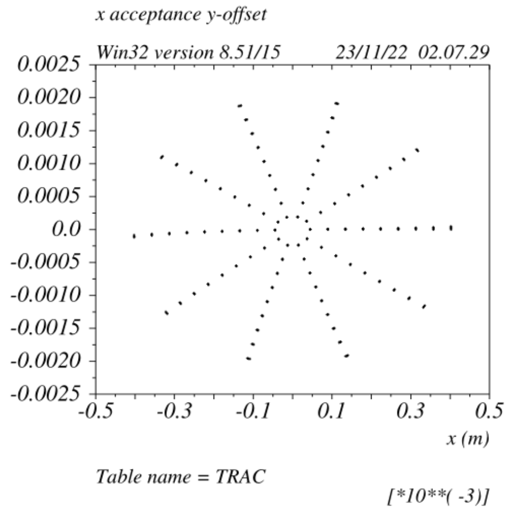

Second order dispersion not matched

# Transverse beam dynamics with opposite sign FF dipoles  v_30a2



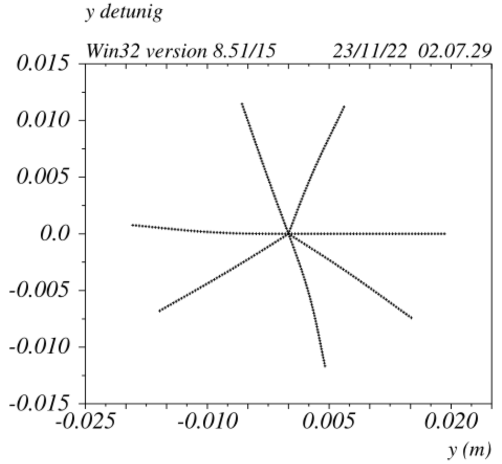



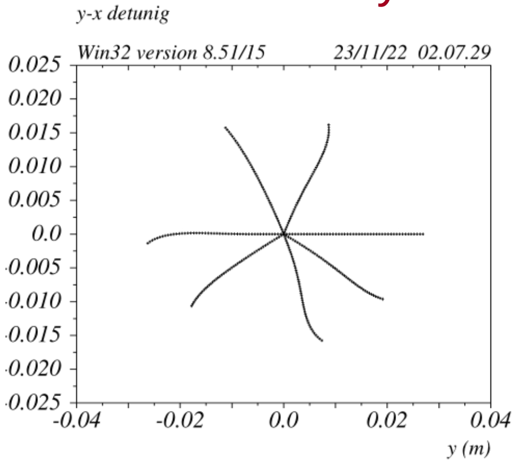



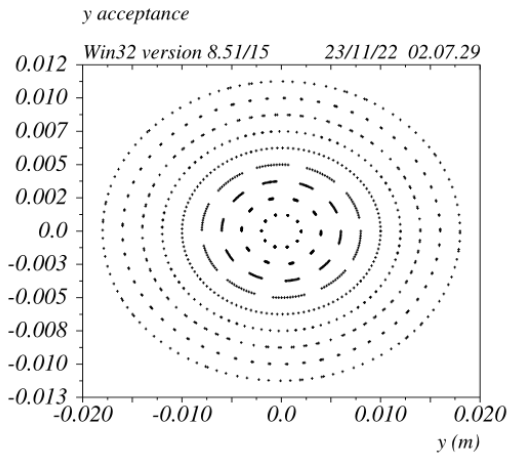



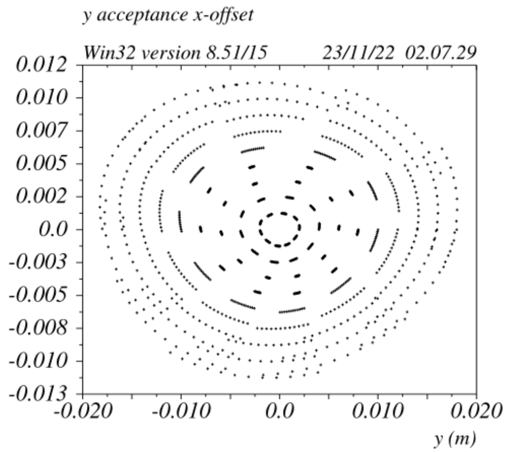

Tracking at the IP betax= 0.2m betay =1.6mm

mux = 0.7  muy = 0.7



# Ring with opposite sign FF dipoles

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The beam dynamics properties are very good

However the two rings must come back (at~30-40cm distance) in the ARCs

This requires:

- larger total FF bend angle, this can pratically be done only in the downstream FF
- last ARC cells become highly asymmetric
- asymmetrizing the FF-Left-Right lengths helps to recover geometry and minimize dilutions
- Lengthening the system helps as well

All the differences do generate asymmetric second order dispersion that is detrimental to MA, and should be dealt with.

In general the emittance increases (from stronger FFR ARC-DSL dipoles)

The energy loss increases as well.

FF section becomes longer and is detrimental to the overall layout

# Ring with same sign FF dipoles

A solution has been studied starting from the symmetric FFLR case where the total FF bend angle (one side) is equal to one ARC cell (one ARC cell is removed from each side) ~39mrad

This layout is very effective:

- The FF is lengthened "for free" by about the removed ARC cell length (480mt)
- The emittance and energy loss are very close to the full periodic ring (because one ARC cell dipoles have been replaced by the longer and weaker FF dipoles)
- The IP shifts horizontally (as standard) by a few meters wrt the "straight line" case

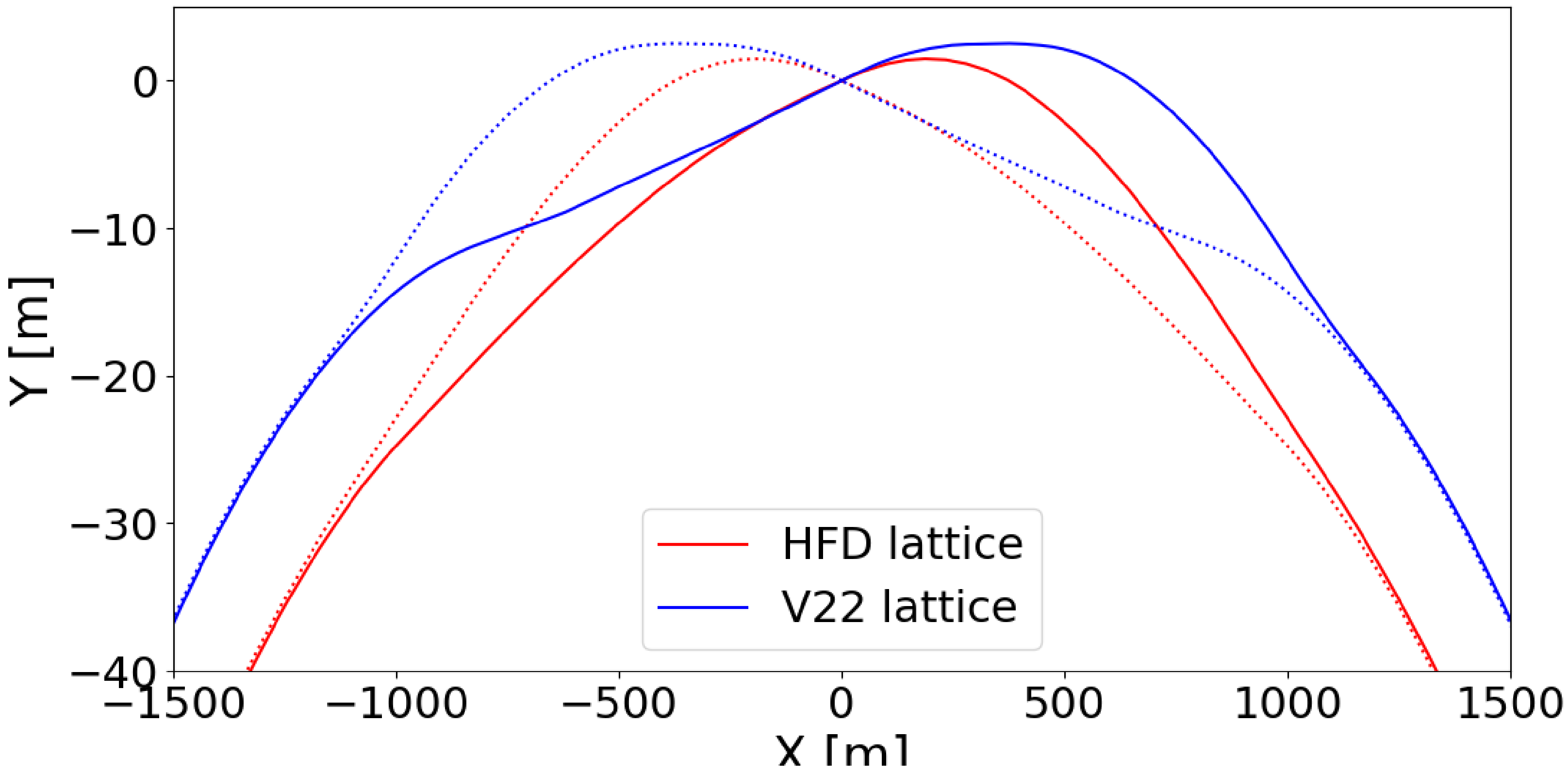
To make up for the **crossing angle set to 30mrad** and recover the two rings distance in the ARCs:

- the FFL total bend angle decreases (~19mrad) and the FFR increases (~59mrad)
- FFLDS angle increases and the FFRDS decrease (~+/-5mrad)

Given the large DA&MA of the FF it is not needed to change the length of the FFL vs FFR.

The maximum distance between the two rings is about 7mt (at ~450mt from the IP)

# Interaction region survey with same sign FF dipoles



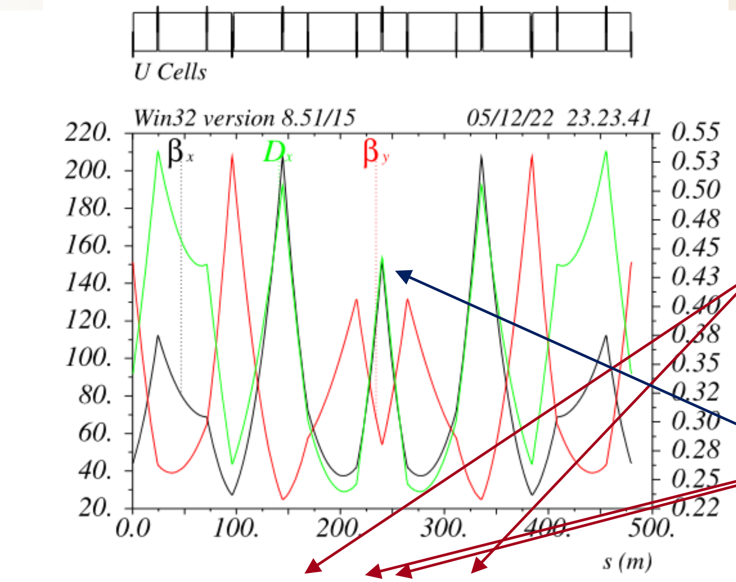

Example of the survey with same lengths and same dipoles sign FFs

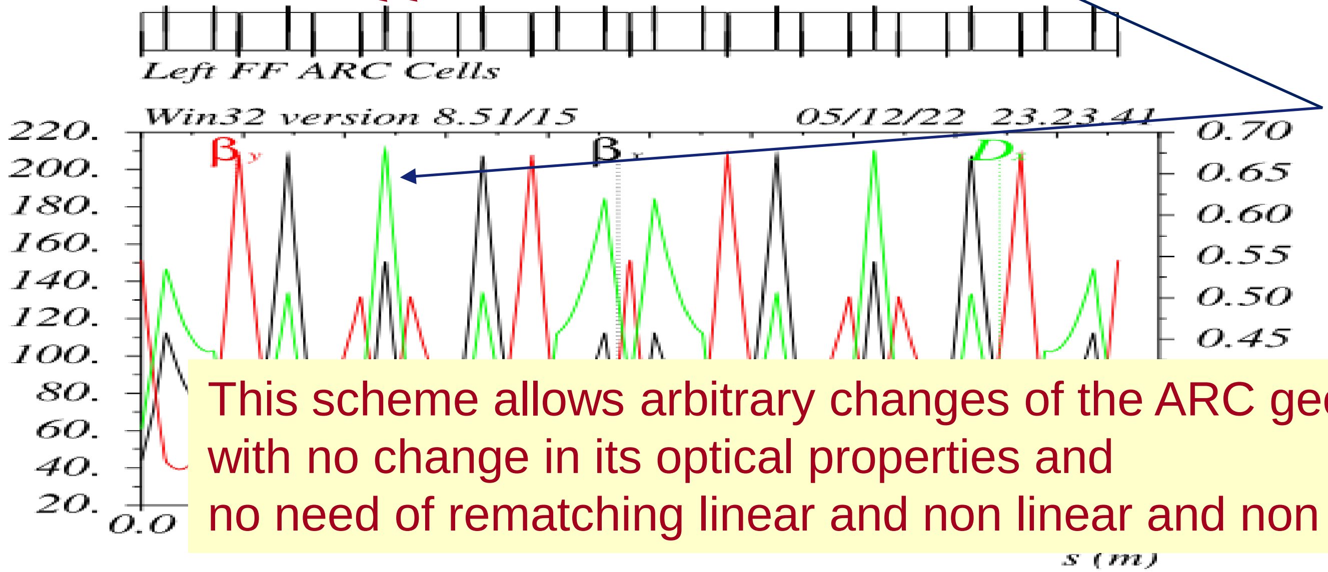
In this example (an early version) the crossing angle is 26.6mrad and the FF is shorter wrt V22

# ARC geometry change: modification of a single Cell dipoles

It is not trivial to change the ARC geometry, in particular bend angles in a limited area while maintaining the periodic properties (betas, chromatic functions etc)

For HFD a very effective solution is found by using the fact that 2 (pairs) of dipoles are almost at –I and can be increased or decreased with a minor compensation of the two inner dipoles (to recover the dispersion)



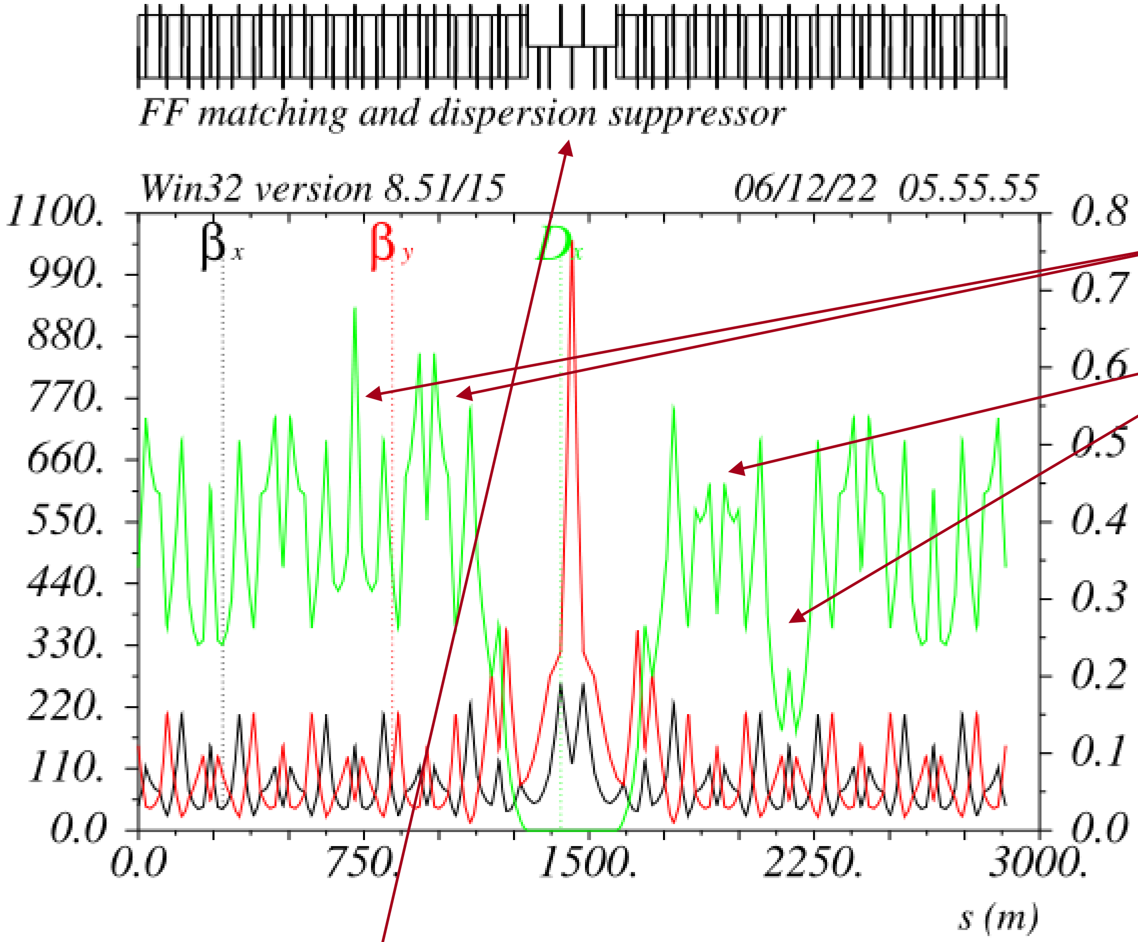




- Betas in the cell are unchanged
- Dispersion bump is limited inside the cell
- Betas and dispersion at the sextupole are unchanged
- Only change is the emittance and energy loss

ific cell

This scheme allows arbitrary changes of the ARC geometry
with no change in its optical properties and
no need of rematching linear and non linear and non linear optics/elements

# Left and right FF Dispersion suppressor for optic with crossing angle v_34a1



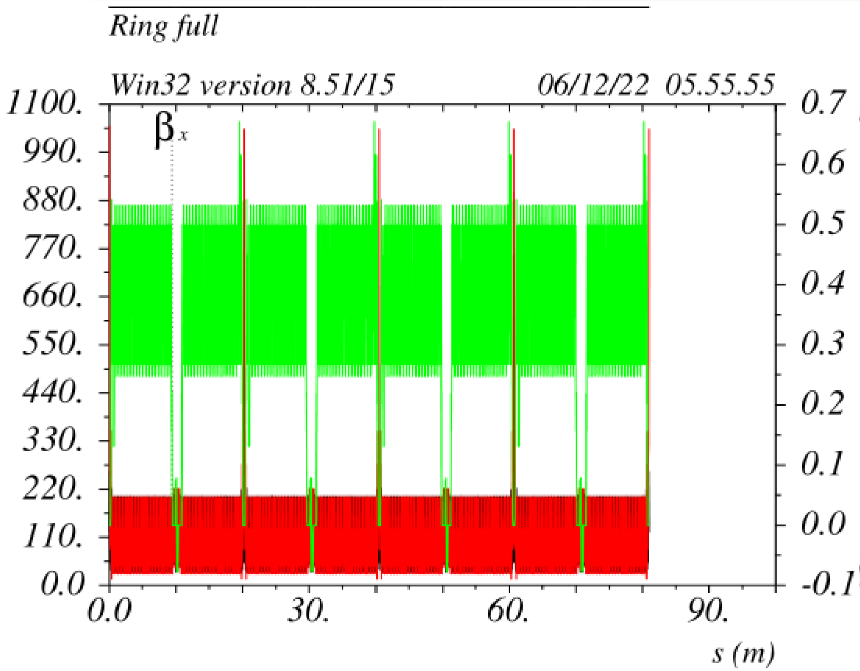

Left side last arc cell bends ~6mrad more

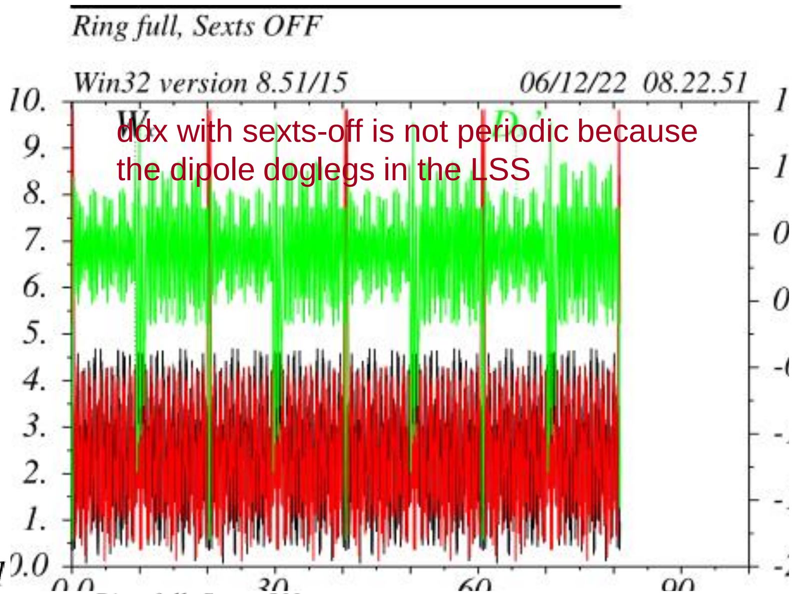
Right side first arc cell bends ~6mrad less

Optics (longitudinal elements coordinates, quads and sextupoles strengths) is left-right symmetric

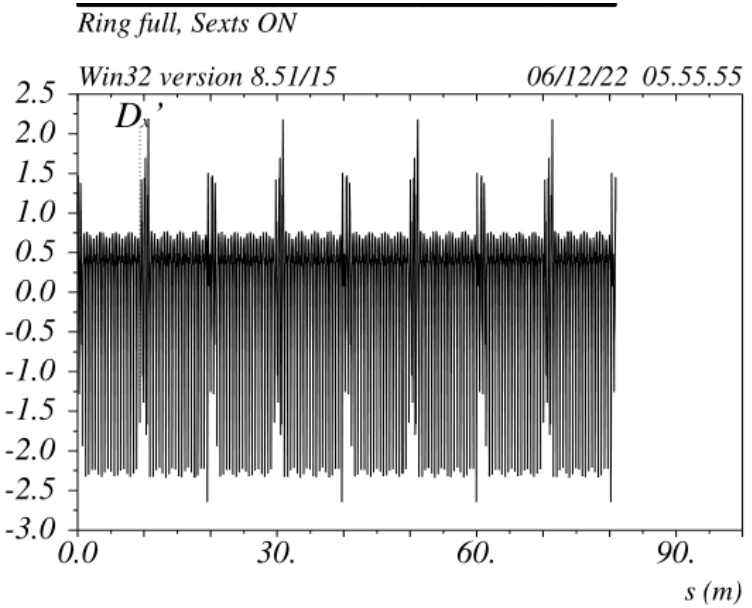
Left and right Final Focus are inserted in the middle

# TCs for the ARC+LSS+FFDS (FF not inserted yet) v_34a1

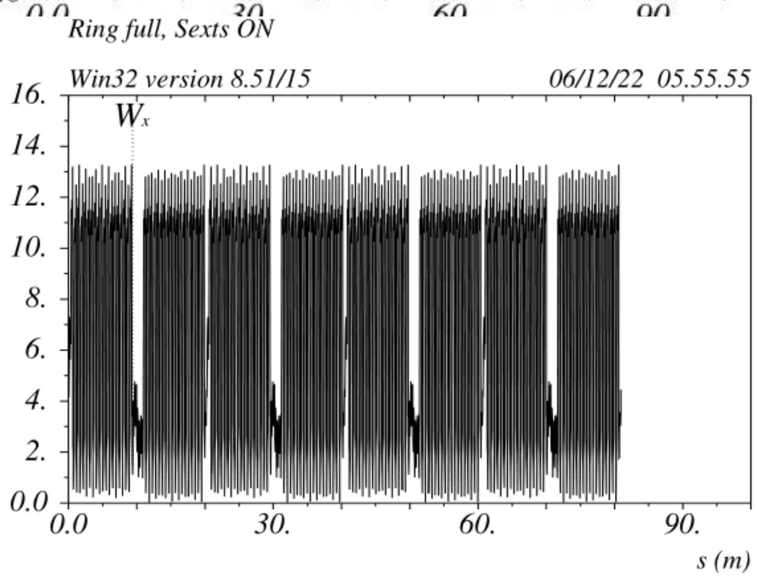


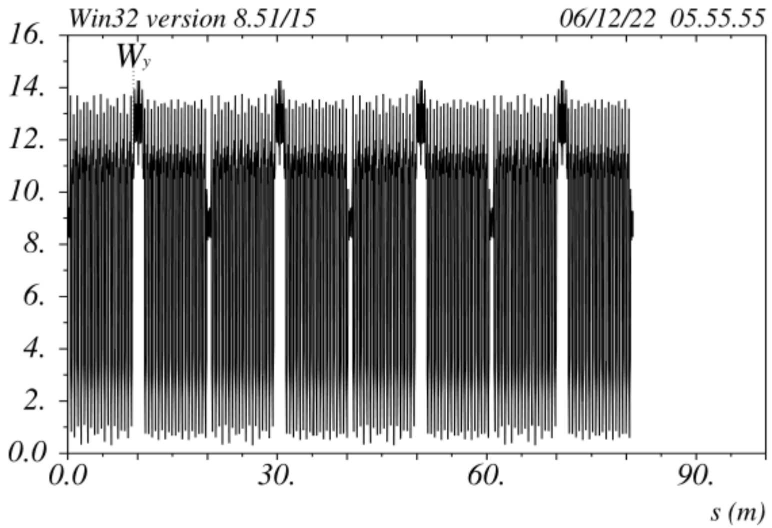




ddx with sexts-off is not periodic because the dipole doglegs in the LSS



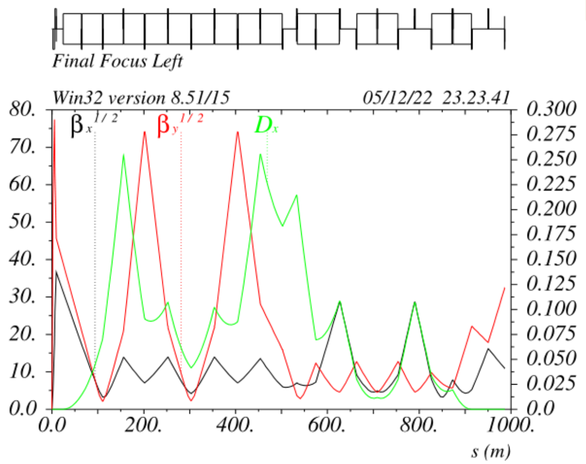

Ring with LSS and
Final Focus Dispersion suppressor
(without FF)

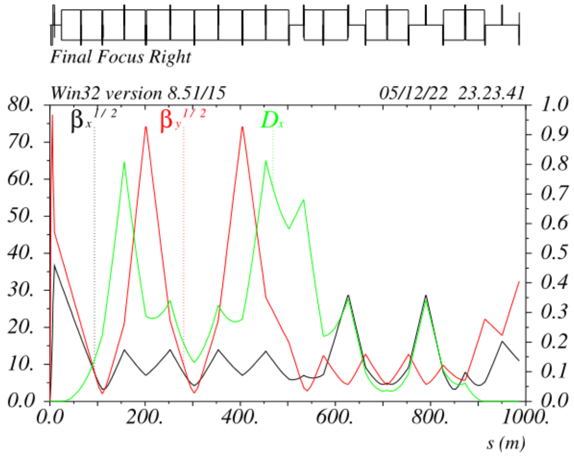


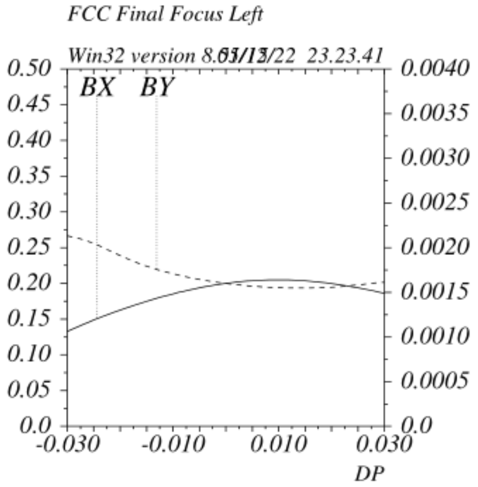



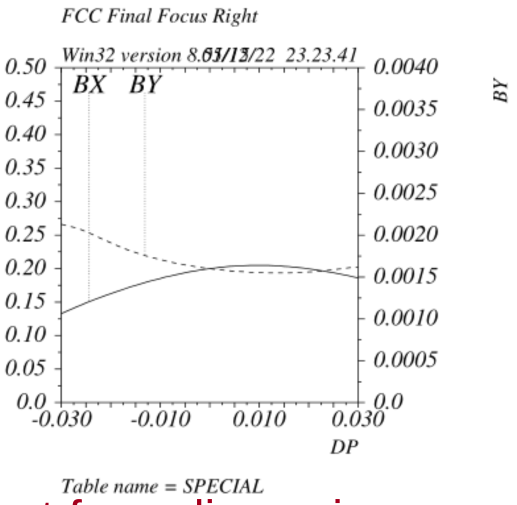

Transparency conditions are
met for all subsystems

# Single pass optics and chromatic properties for left&right FFs v_34a1

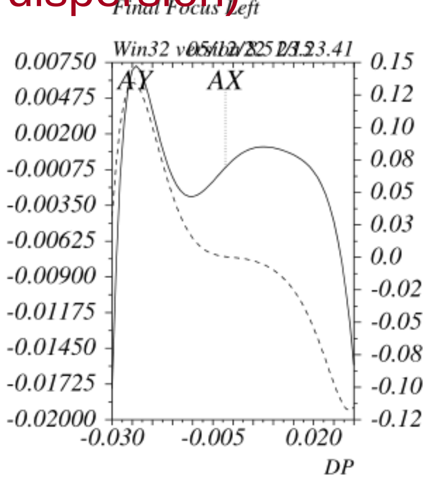


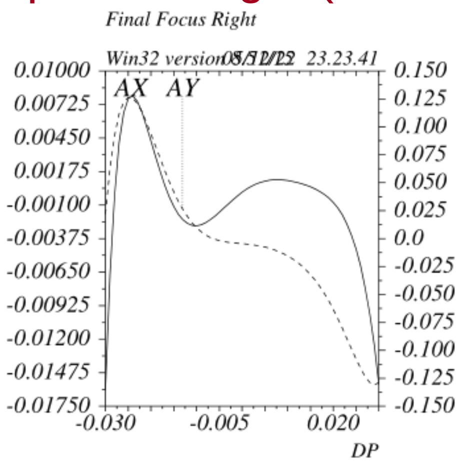



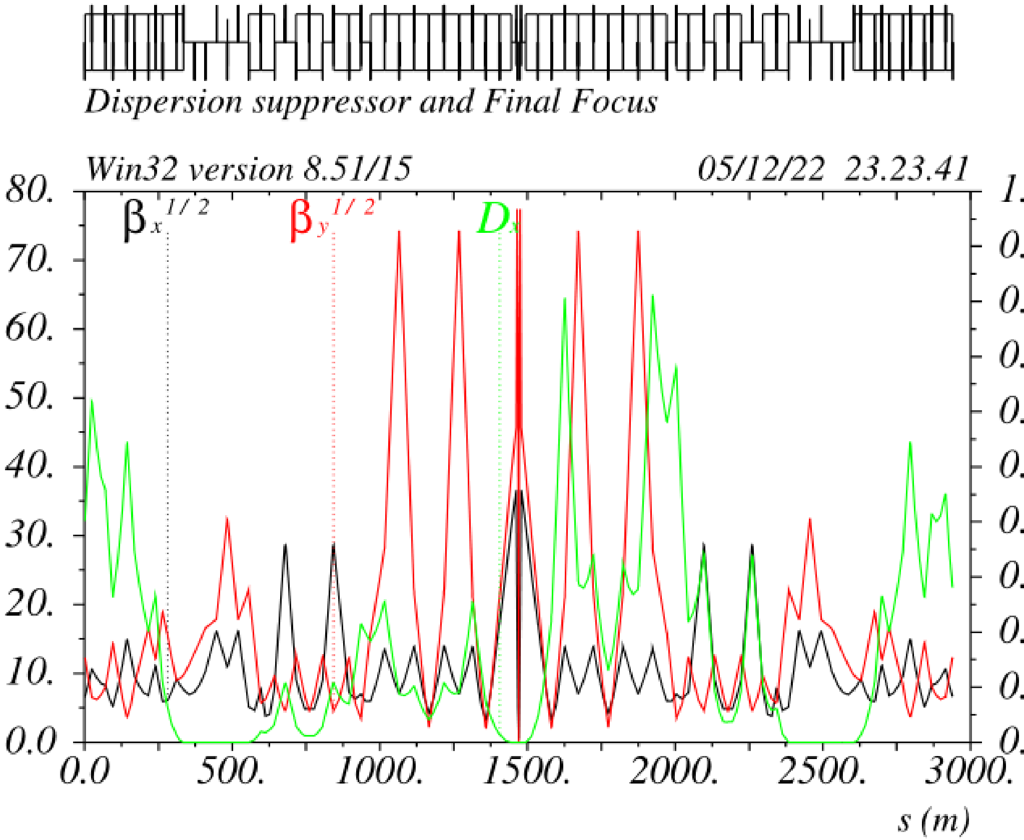

Chromatic properties nearly independent from dispersion.
Ultimately the DA is linked to the FF sextupole strength (or directly to dispersion).



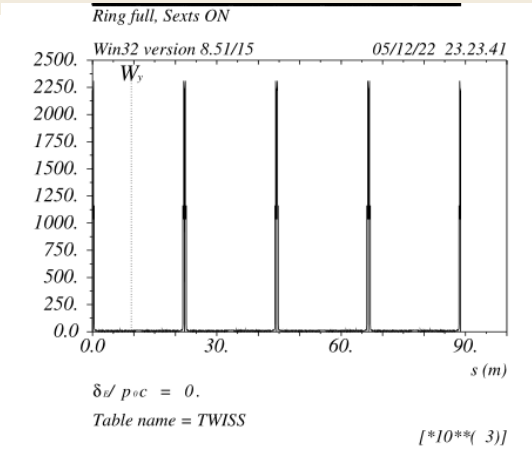



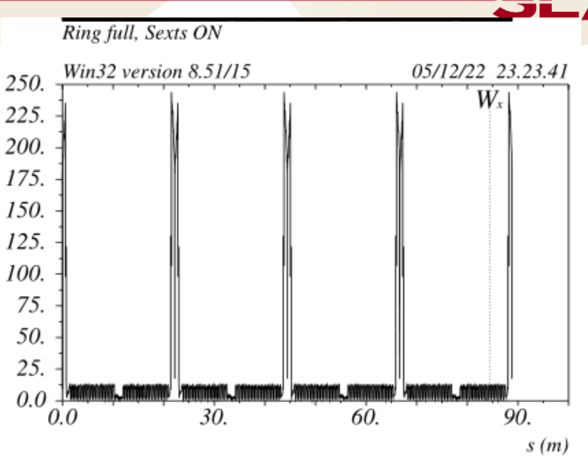

FF left & FF right optics
All quads are symmetric
Dipoles FFL/FFR are uniformily rescaled
Sextupoles are inversely rescaled

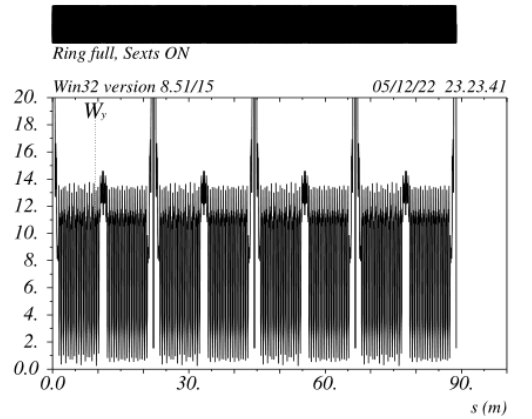
# FFLR optics and chromatic properties of the complete ring v_34a1

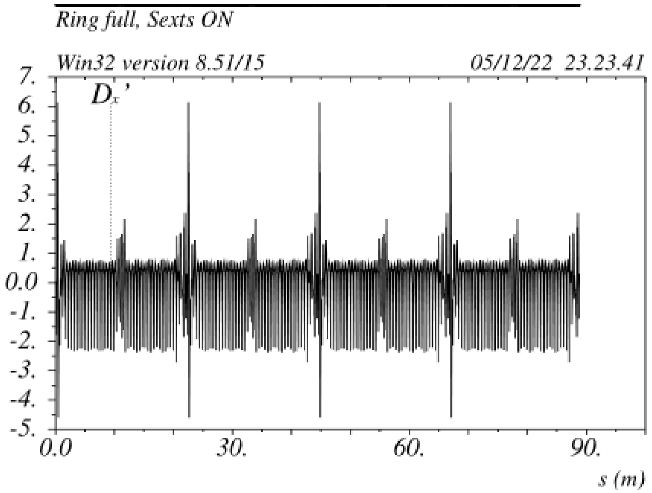



Matching sections optics is left-right symmetric as well



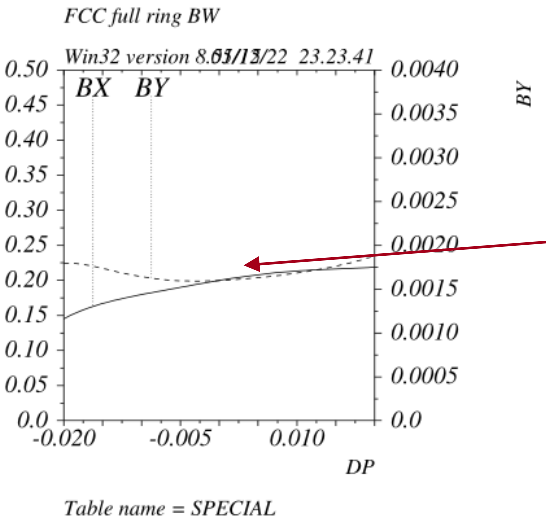



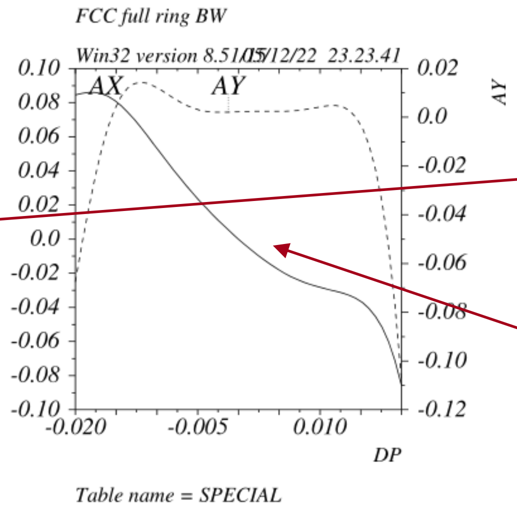




Ring chromatic functions are unaffected by inserting the FFs
ARC sextupoles are not changed as well

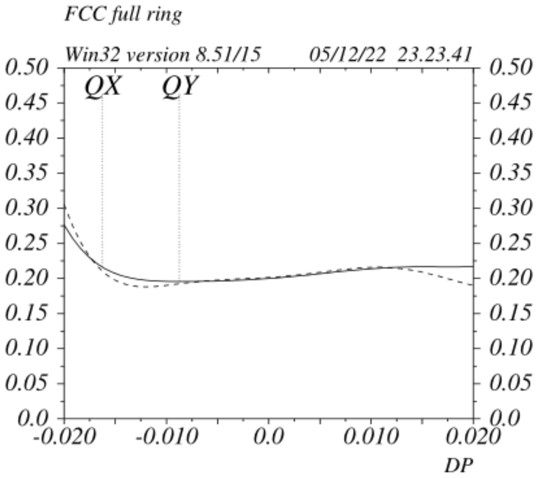
# Full ring chromaticities with same sign FF dipoles v_34a1

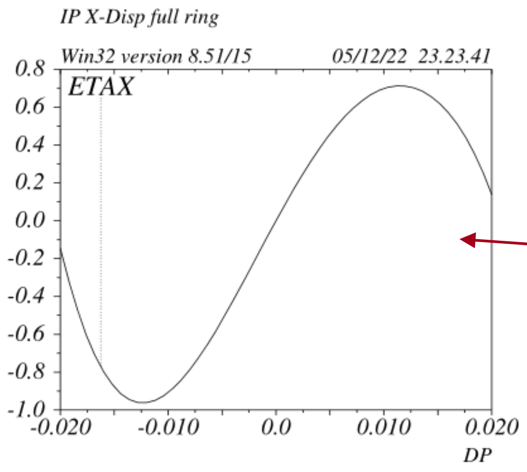



Betas at the IP are
almost the same as the ones produced by the single pass FF

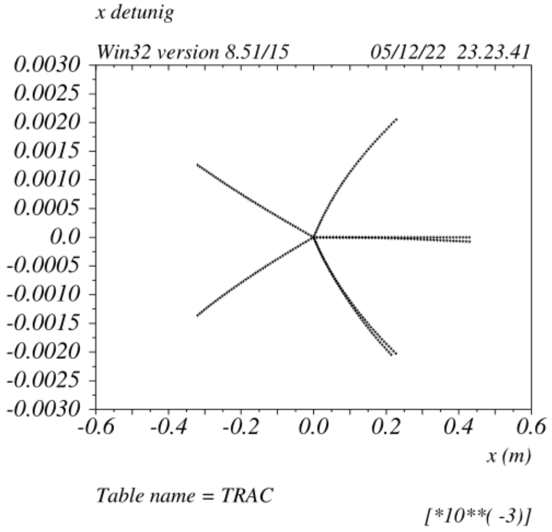
The linear slope on alphax is because the asymmetries induced by the different values of left-right dipoles

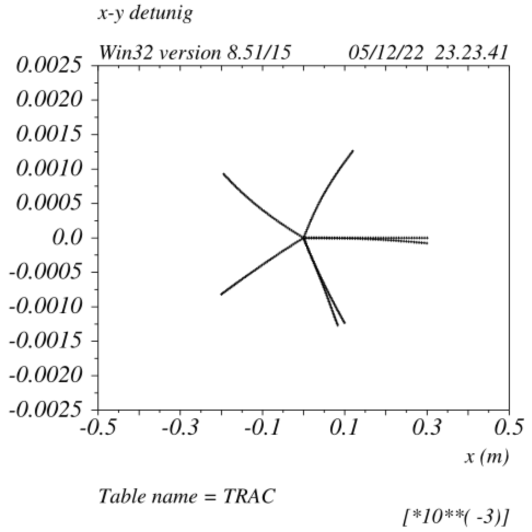


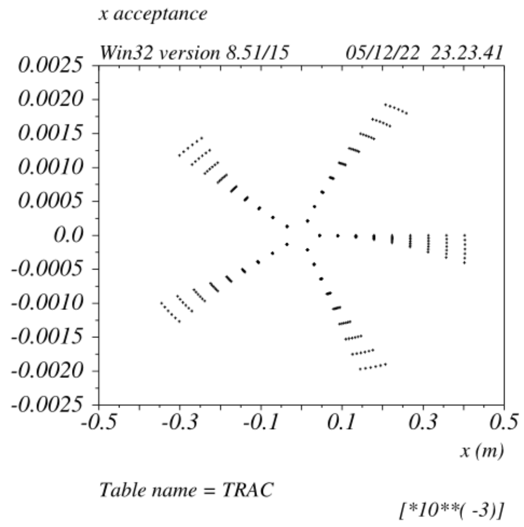



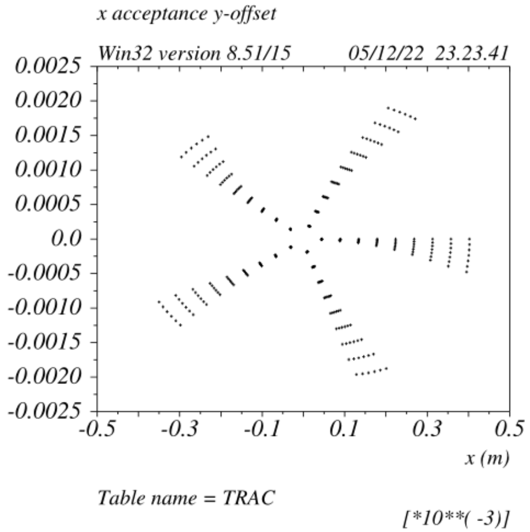

Since the second order dispersion is matched, only third (and higher) order dispersion remains at the IP

# Transverse beam dynamics with same sign FF dipoles  v_34a1

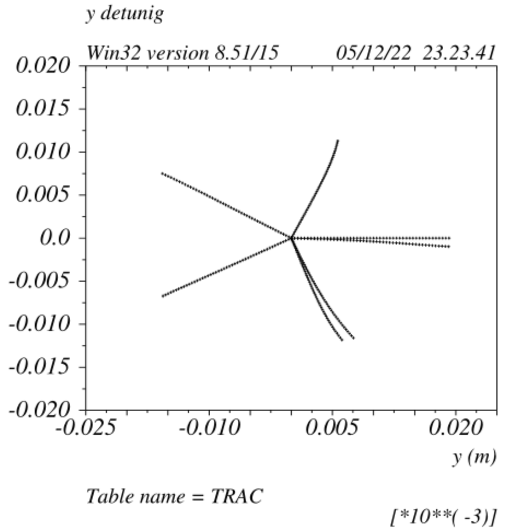


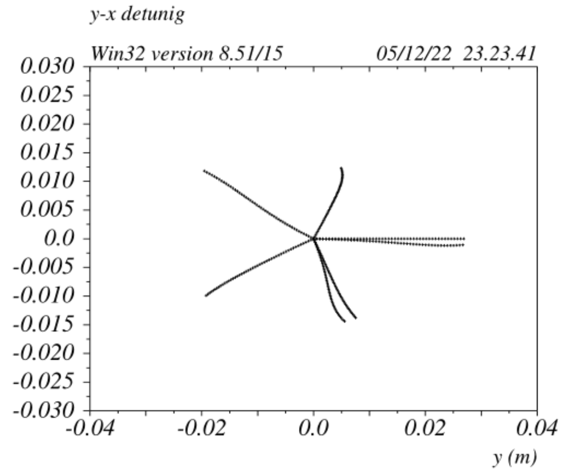



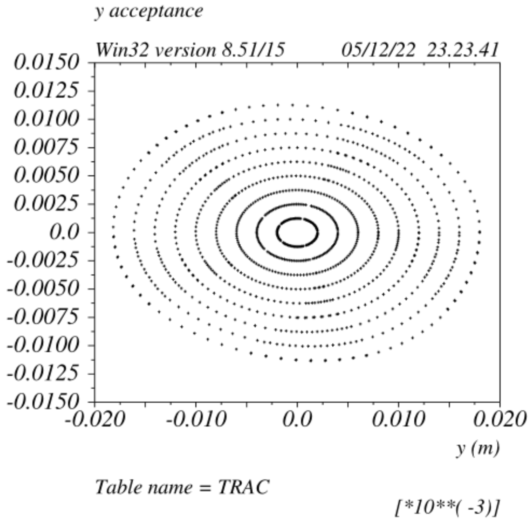



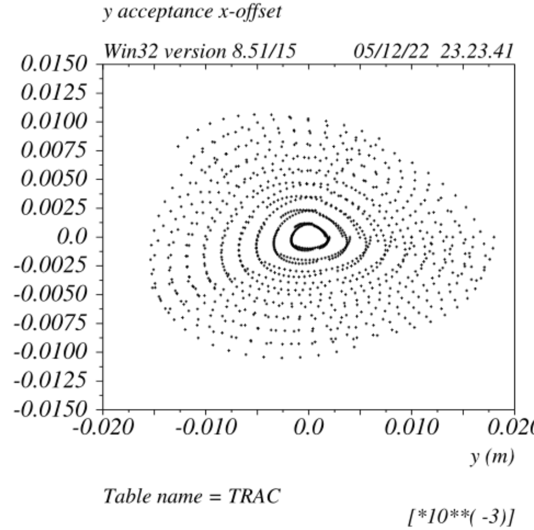




## Tracking at the IP betax= 0.2m betay =1.6mm, mux = 0.2 muy = 0.2

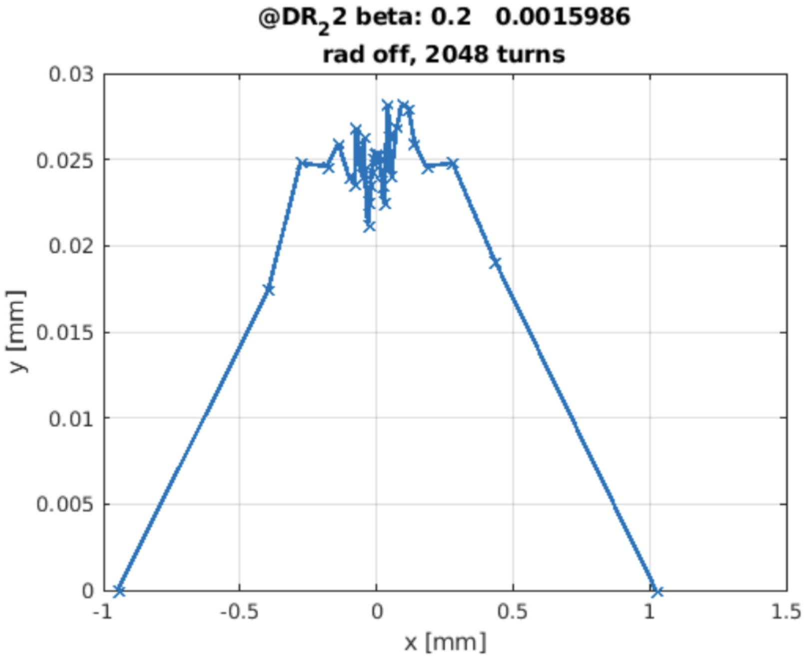


# Transverse beam dynamics with same sign FF dipoles  v_34a1




**S Liuzzo**

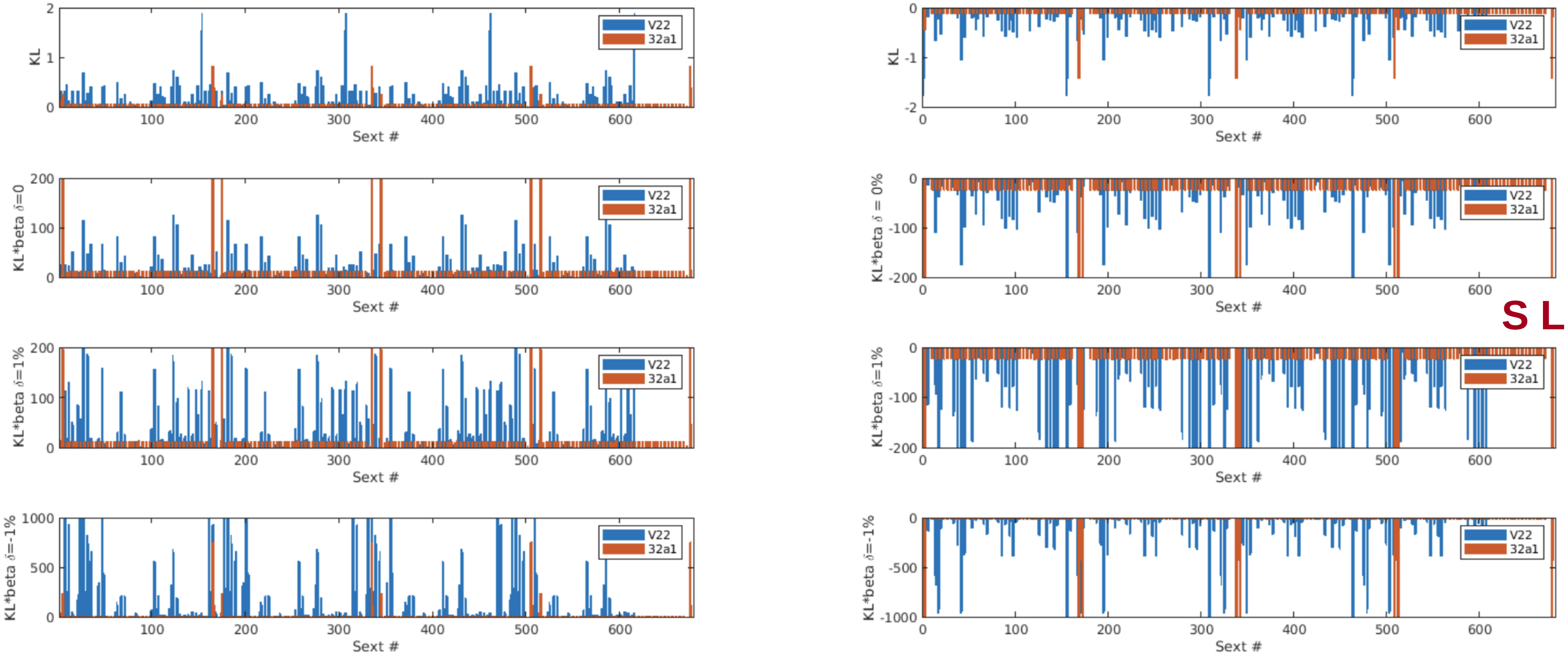
Transverse acceptance transported to the ARC with betax_max~betay_max~200m is about:

30mm/9mm x/y respectively (tracking with AT/PTC)

# HFD and LCCFF highlights

- HFD has very large DA, MA and LMA=~MA (because high order chromatic correction is achieved in a single cell)
- Same lattice should be apt for all energies (to be verified)
- @ttbar quads are about 60% in number and 60% in strength (e.g. length) wrt to Short-FODO9090
- @ttbar sexts are about 60% in number and 15% in strength (e.g. length) wrt to Short-FODO9090
- LCCFF has very large DA&MA
- LCCFF has a very effective setup for minimum impact of CRAB sextupoles on DA&MA
- LCCFF with same length and dipoles_angle_sign for left&right ensures almost negligible emittance and energy loss increase due to this insertions. Layout distorsions are also minimal
- LCCFF reduces (or makes it not necessary) the ARCs sextupoles modulation to improve DA&MA to a few% (to be verified)
- LCCFF is a "quasi-perfect" achromat, IP betas* are changed with the beta-matching quads in the DS and at first order no sextupoles in the ARC and in the FF need to be retuned
- Main ARC functions consist primarily into bending the beam and generate the minimum horizontal (and vertical) emittance with minimum energy loss.
- HFD+LCCFF results in ARCs sextupoles maximum strength ~7% wrt to current design
- Vertical emittance dilution in the ARCs should be significantly reduced as well

# Feed down on ARC sextupole alignment tolerances




S Liuzzo

Sextupole integrated strengths for v22@z and v32a1 (HFD&LCCFF)
Sextupoles more directly related to IP CC are clearly visible in both planes
KsL*betas are about constant as function of de for v32a1
v22@ttbar has KsL*betas about 4 times larger (not shown)

# ARC sextupoles alignment tolerances

- ARC sextupole alignment tolerances are relaxed at least proportionally to the reduction in their strength.

  This is effectively true for the Long-FODO9090 case that has similar betas and dispersion across the sextupoles..

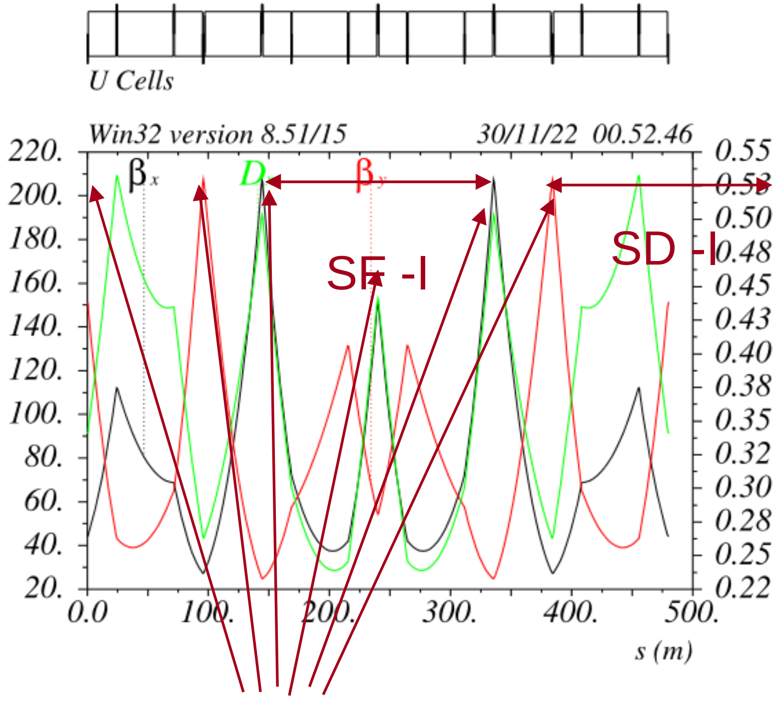
  Tolerances should be further relaxed because the non-linear dynamics across the sextupoles is improved: dynamic betas are nearly identical to on-energy&on-axis ones. The fact that ARC sextupoles do not contribute (significatively) to the FF chromatic correction helps as well.

- Supposing that the present lattice requires 10um alignment tolerances (on both ends), HFD+LCCFF would most likely require 100-200um (on both ends) tolerances

  Alignment requirements on relative quad-nearby_sext positioning can be of the order of 50-100um.

  BBA can be performed (as for current machines) on the nearby quad, this will ensure that the absolute orbit on the sextupoles will not exceed the quad-sext positioning error and tolerances will be kept.

# ARC orbit and betabeating/dispersion/emittance control




ARCs betabeating, dispersion and coupling correction can be performed as with current machines, eg EBS:

- the reconstructed errors (quads and skews) are supposed to be originated only at the sextupole locations,
- the correction applied is = -errors.
- The correction can be applied just by changing the reference orbit on the sextupole BPMs (that will generate the required quads and skew components) as for the LEP-DFS case

…to be checked

In principle BPMs and correctors could be placed only on the high-beta locations:
6 BPMs and correctors(x&y) per ARC cell => ~960 total for the ARCs
Orbit will be controlled at the sextupoles (angle at the sextupole will not be controlled, but sexts are ~0.3-0.6m long)
A "small" orbit distorsion will remain across the "low-beta" quads, the distorsion is of the order of the quad rms-misalignment (~100-200um) and should have negligible consequences on machine performances
Sextupoles are weak and trimming coils on the sextupoles could provide the maximum corrector strength required, resulting in saving in number of components and increasing the main dipoles filling factor

# Conclusions

The exploitation of novel methods to insert specific optical segments in a periodic ARC lattice with minimum impact of optical properties leads to:

- Improvements in overall machine performances
- Simplifications of the overall optic
- Better understanding of the beam dynamics of specific subsystems and the resulting machine as a whole
- Relaxed requirements on accelerator components, in particular magnets gradients and tolerances
- Simplification of tuning procedures
- Increase the likelihood of reaching “close to ideal” machine parameters

FCC case has been used just as an example to demonstrate the effectivness of this method.

Very generally it could be applied for the design of a large variety of new accelerators, further extending their ultimate performances.

The possibility to effectively implement it for FCCee will require a much more careful and detailed study.