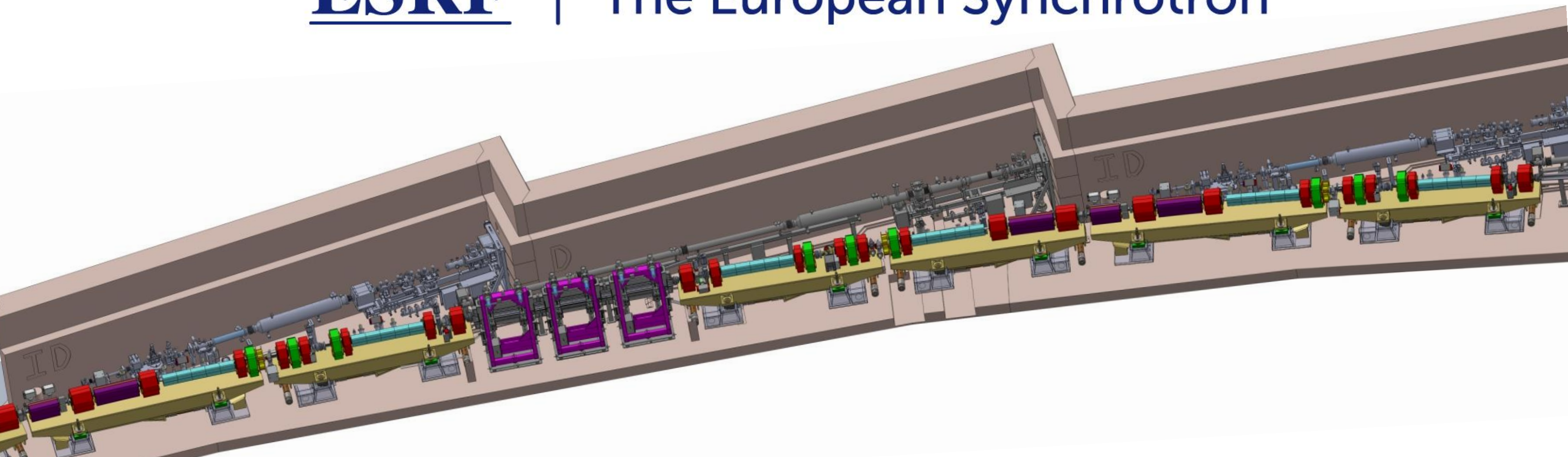
ESRF upgrade

Needs and challenges for optics control

Presented by S.M.Liuzzo
on behalf of the ESRF upgrade team

ESRF | The European Synchrotron



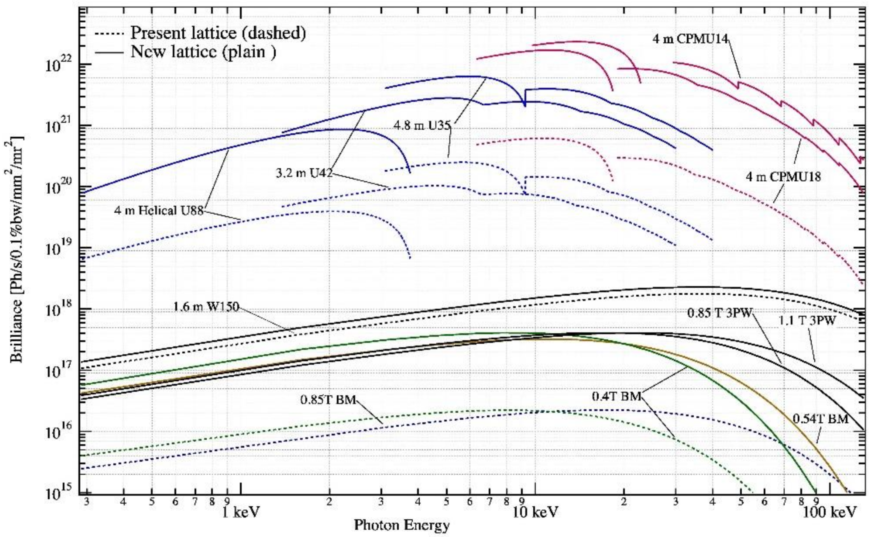
OUTLINE

- **ESRF upgrade**
- Upgrade motivations: Synchrotron radiation spectra and coherence
- Table of parameters
- **Lattice upgrade**
- Current ESRF
- Future ESRF
  - Injection cell
  - Injected beam
- Lifetime, injection efficiency, dynamic aperture
- Impact of errors
- Tuning of working point , chromaticity and optics parameters.

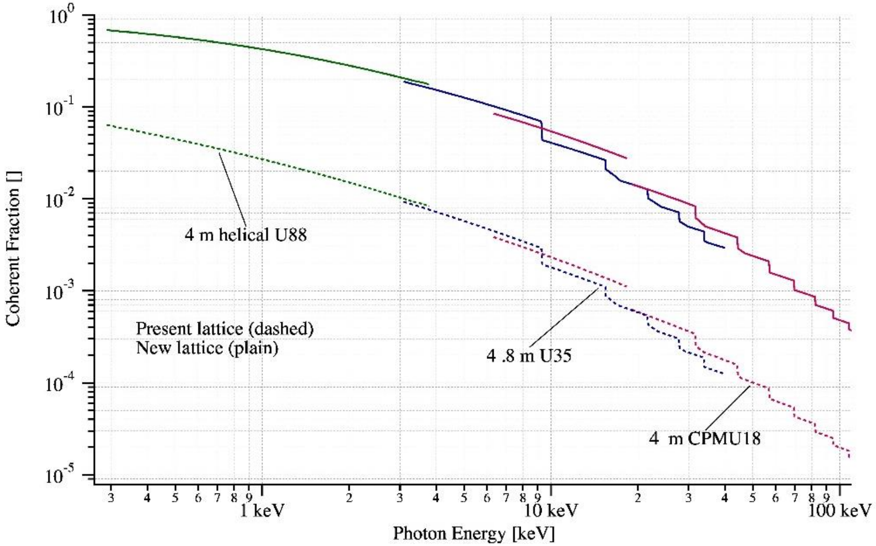
- **Needs for optics correction**
- BPM
- Correctors: steerers, quadrupoles
- Correction techniques
- **Challenges of optics correction**
- Corrector strengths
- Sextupole correction

RADIATION SPECTRA AND COHERENT FRACTION

Brilliance

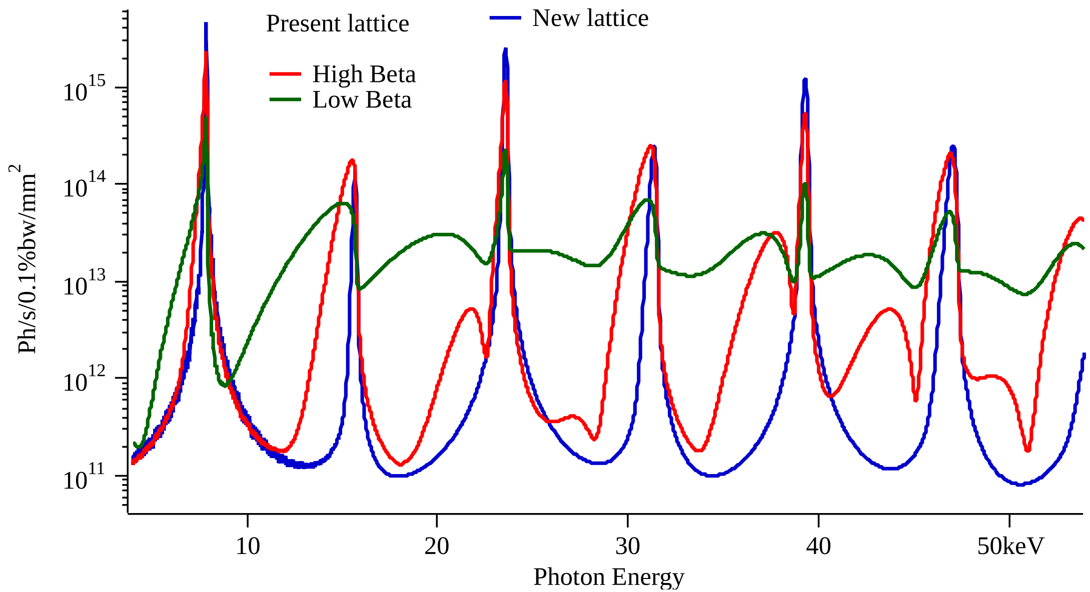


Coherence



	ESRF	upgrade
Hor. Emittance [pmrad]	**4000**	**134**
Vert. Emittance [pmrad]	**3**	**2**
Energy spread [%]	**0.1**	**0.09**
β_x[m]/β_z [m]	**37/3**	**6.9/2.6**

SPECTRA OF ONE UNDULATOR



lattice	Rms source size [mm]		Rms source size [mm]	
	H	V	H	V
Present low beta	49.8	6.2	105.6	5.1
Present high beta	411.6	6.2	11.5	5.1
New lattice	28.2	6.1	7.2	5.1

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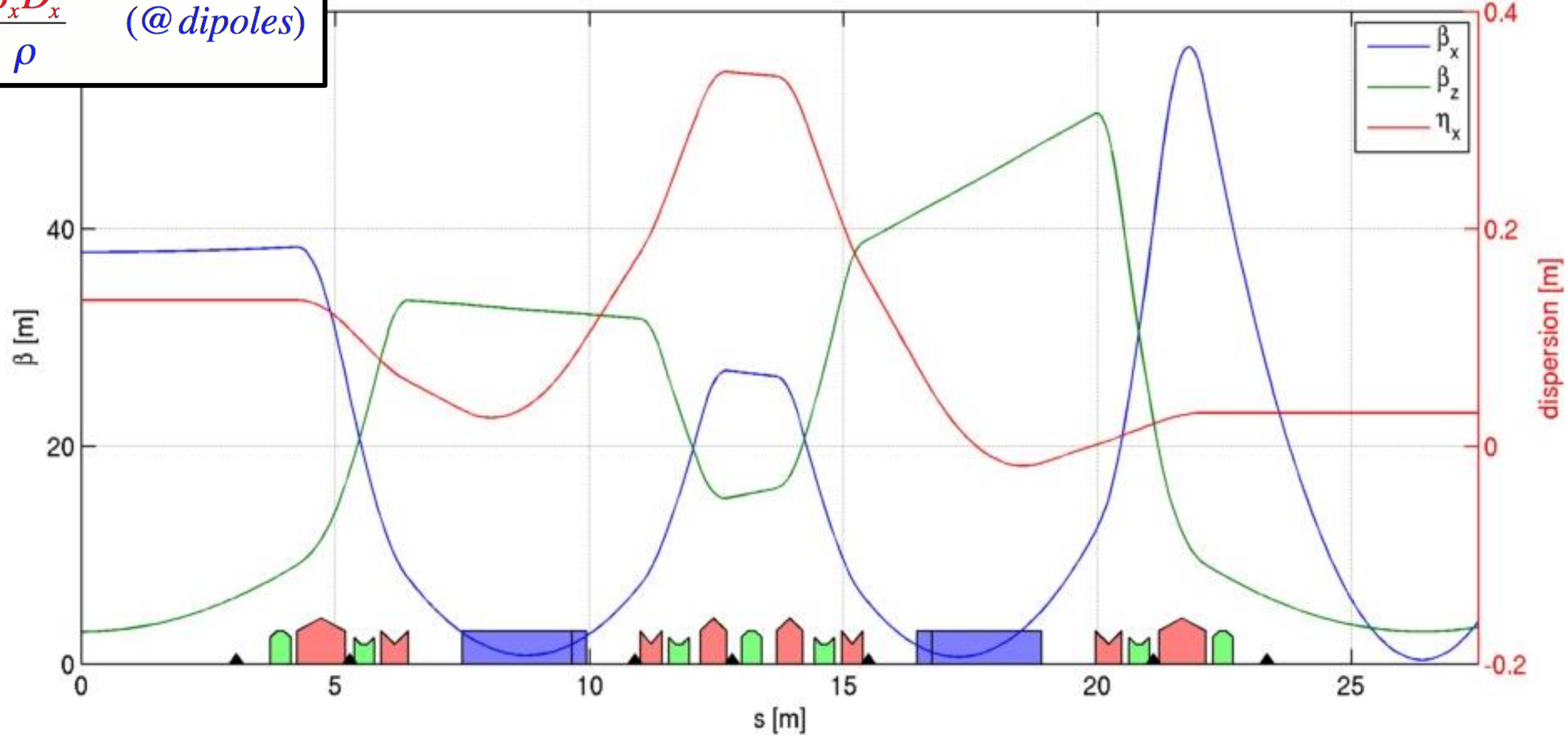
CURRENT ESRF

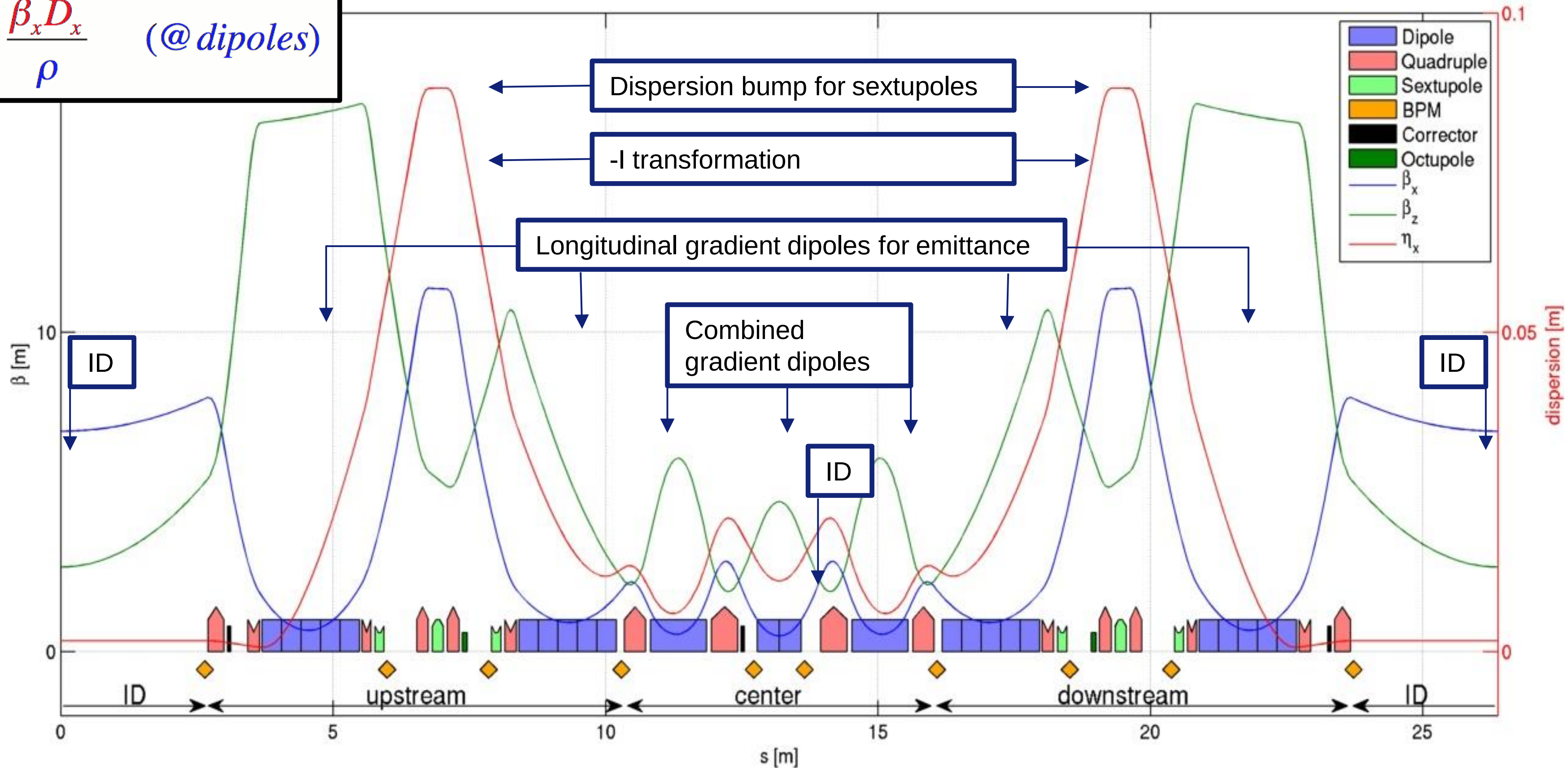
$$E_x \propto \frac{\beta_x D_x}{\rho} \qquad (@\,dipoles)$$



16 superperiods (mirrored cell aboce, 32 cells in total).
Achromatic condition broken for lower emittance (ε_x from 7 nmrad to 4 nmrad).

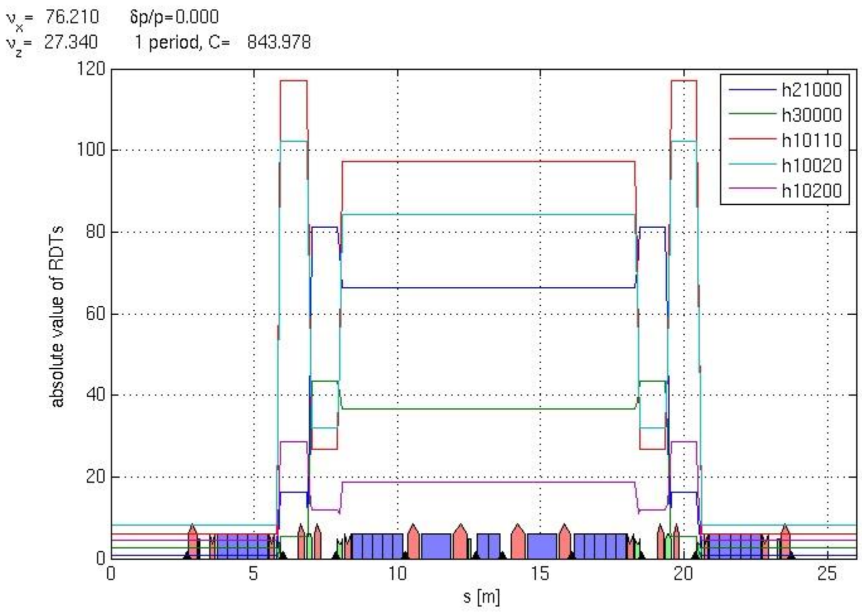
UPGRADE ESRF

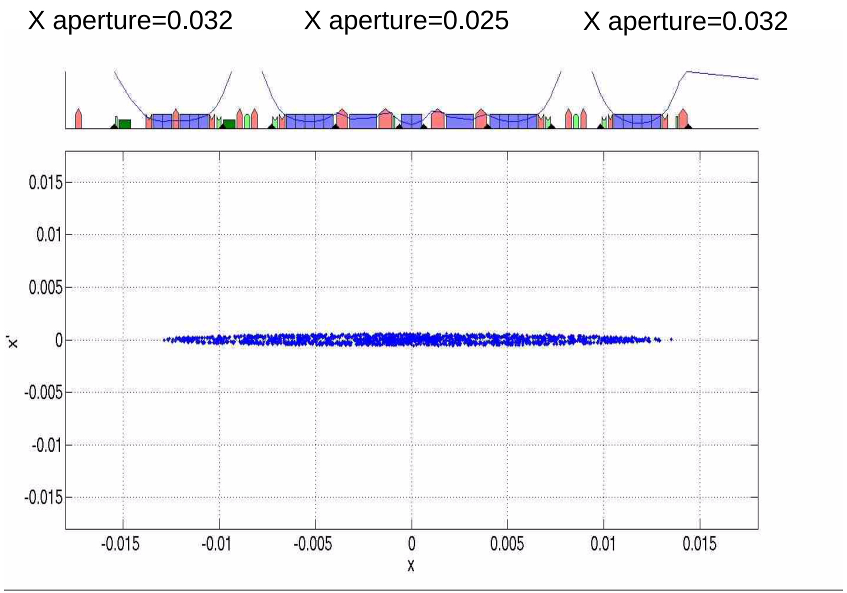
$$E_x \propto \frac{\beta_x D_x}{\rho} \qquad (@\,dipoles)$$



32 superperiods. 7 bend achromatic lattice (ε_x=135 pm, 110 pm including undulator radiation).

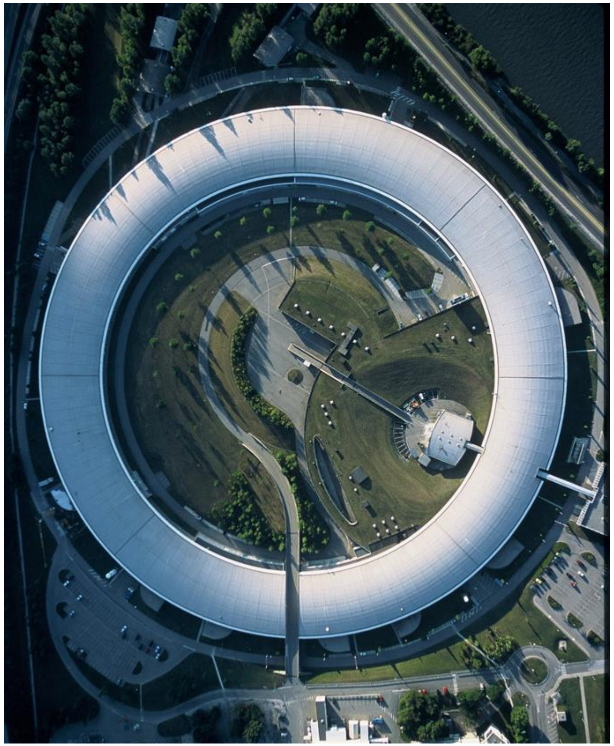
UPGRADE ESRF: SEXTUPOLE RDT





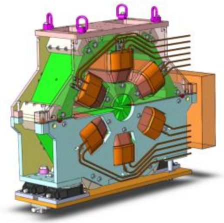
Sextupole RDTs cancel within the cell thanks to appropriate phase advance choices. Phase space is locally distorted.

MAIN LATTICE PARAMETERS

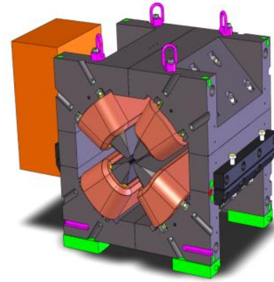


	Upgrade	ESRF
Energy [GeV]	6.00	6.04
Tunes	75.21, 26.34	36.44, 13.39
Emittance x [pmrad]	135	4000
Emittance y (target) [pmrad]	5	5
Energy loss per turn [MeV]	2.6	4.9
RF voltage (acceptance) [MV]	6 (5.6%)	9 (4%)
Chromaticity	6, 4	4, 7
Circumference [m]	843.98	844.39
Energy spread [%]	0.095	0.106
Beam current [mA]	200	200
Lattice type	HMBA	DBA
Touschek lifetime [h]	~20	~80

MAGNETS

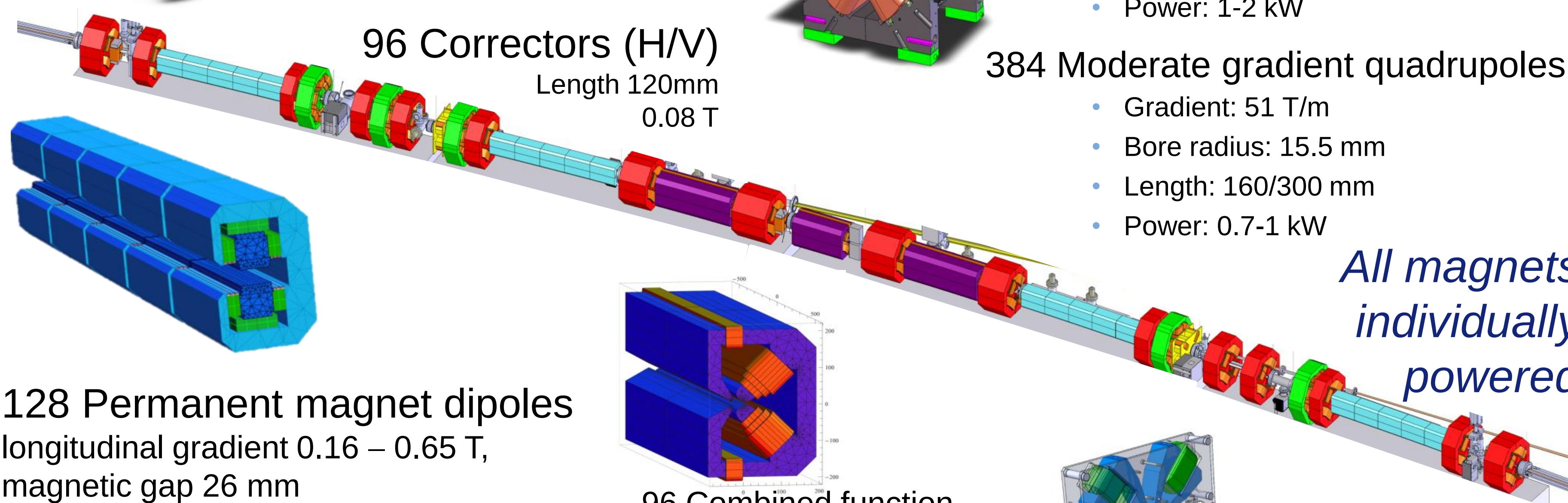


192 Sextupoles
Length 200mm
900-2200 Tm^{-2}
Also used as dipole and skew quad correctors



128 High gradient Quadrupoles

- Gradient: 85 T/m
- Bore radius: 12.5 mm
- Length: 390/490 mm
- Power: 1-2 kW



96 Correctors (H/V)
Length 120mm
0.08 T

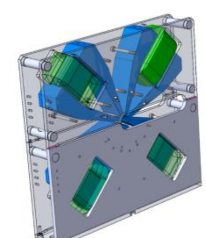
384 Moderate gradient quadrupoles

- Gradient: 51 T/m
- Bore radius: 15.5 mm
- Length: 160/300 mm
- Power: 0.7-1 kW

All magnets individually powered

128 Permanent magnet dipoles
longitudinal gradient 0.16 – 0.65 T,
magnetic gap 26 mm
1.8 meters long, 5 modules
Hybrid Sm2Co17 / Strontium Ferrite

96 Combined function Dipole-Quadrupoles
0.54 T / 34 Tm^{-1}
& 0.43 T / 34 Tm^{-1}



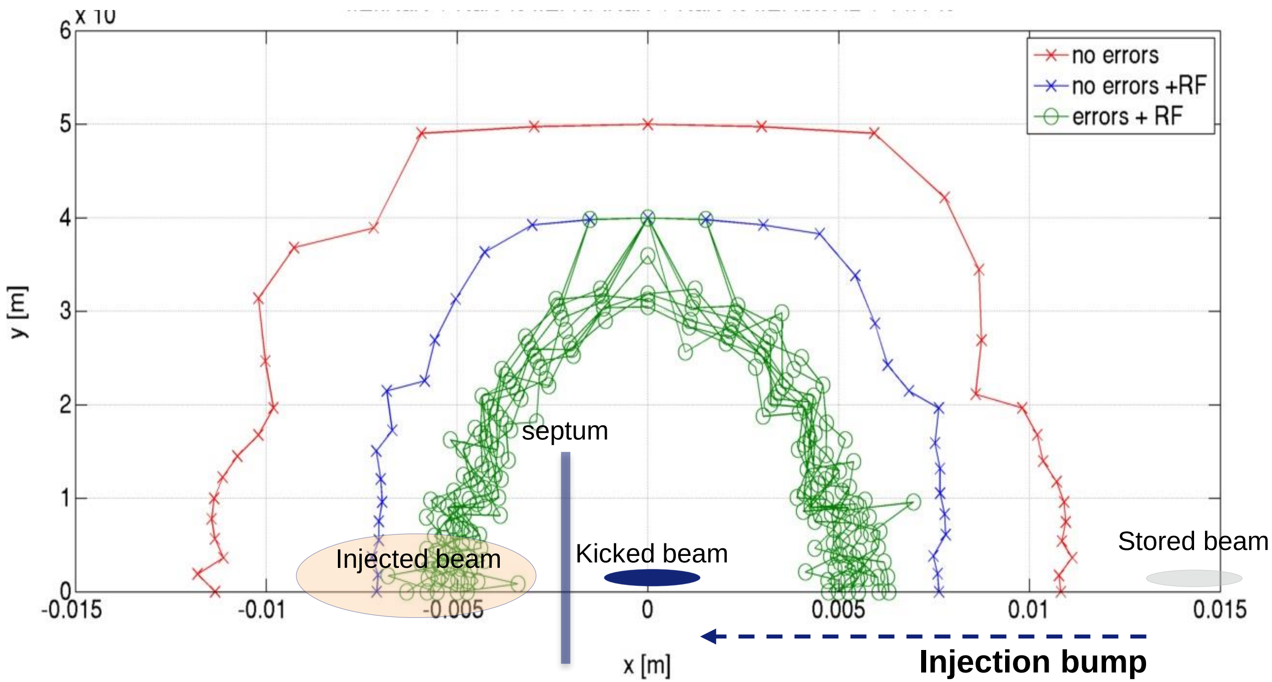
64 Octupoles
51.2 10^3 T/m^{-3}

Courtesy of G. Le Bec, J.Revol

DYNAMIC APERTURE OF UPGRADE LATTICE CELL, WITHOUT INJECTION SECTION

Off-axis injection requires large dynamic aperture at injection

Injection in a standard straight section has an efficiency of <50% (average of 10 seeds),

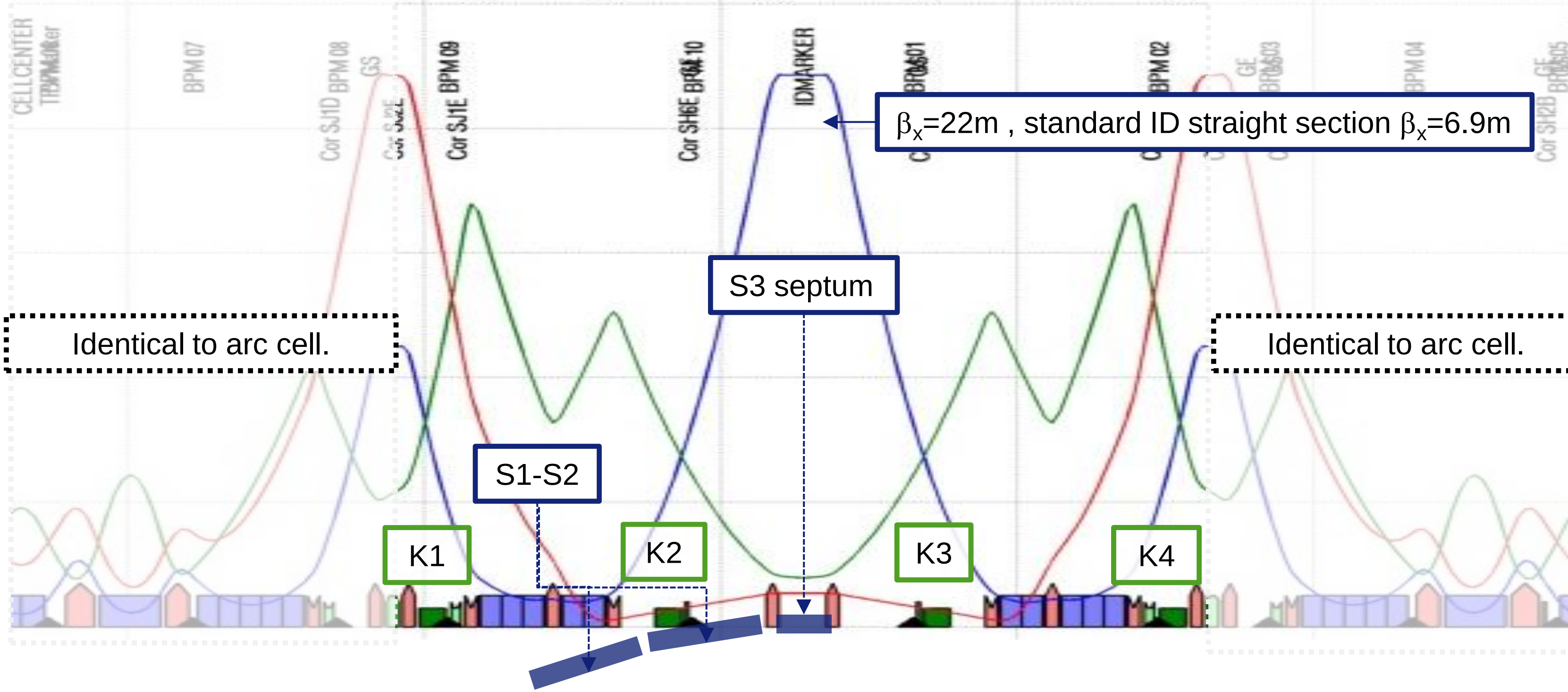


Two solutions are adopted:

1) An ad-hoc injection cell with high beta

2) Optimized injected beam shape and emittance

INJECTION CELL ESRF UPGRADE



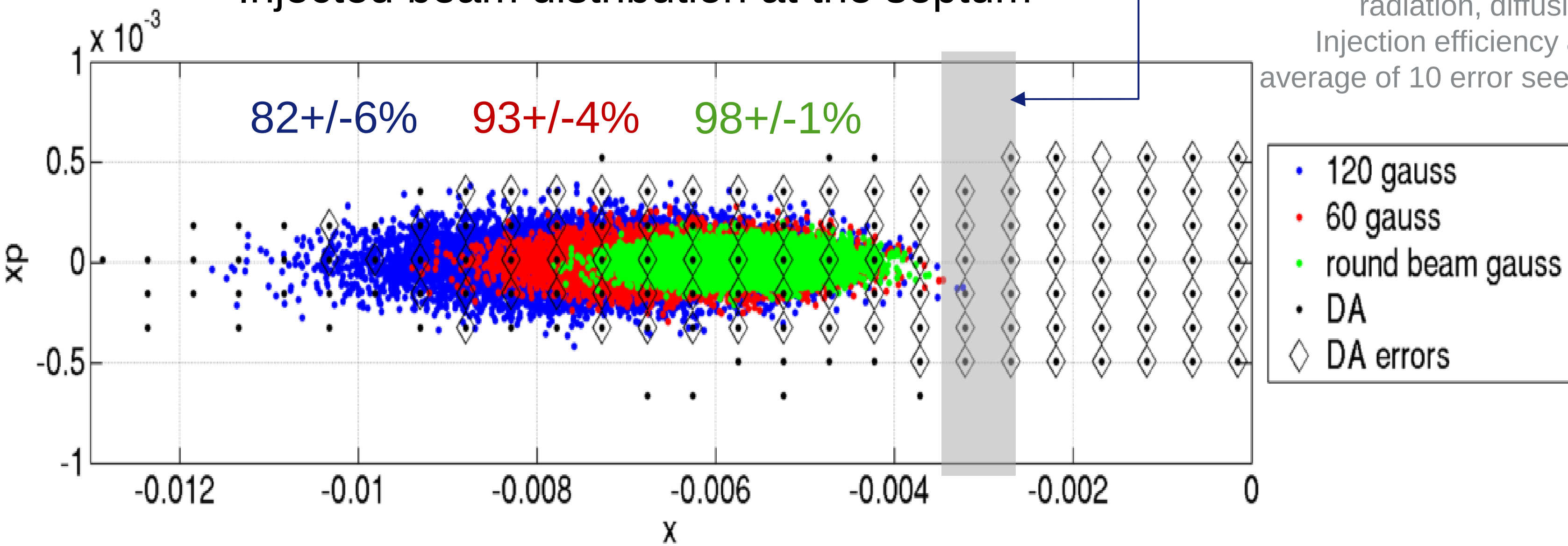
Retuning of the sextupoles in the injection cell is crucial

Touschek Lifetime	With errors	Without errors
Without injection	24.5 h	55.6 h
With injection	21.3 h	43.1 h

INJECTION EFFICIENCY BOOSTER-SR

Injected beam distribution at the septum

10^4 particles for 1000 turns, radiation, diffusion. Injection efficiency are average of 10 error seeds.



The colors correspond to:

- the actual booster beam (ε_x=120nm),
- reduced emittance by injecting with the booster off-energy (ε_x=60nm),
- round beam (ε_x=ε_y=30nm) obtained exciting the coupling resonance in the booster.

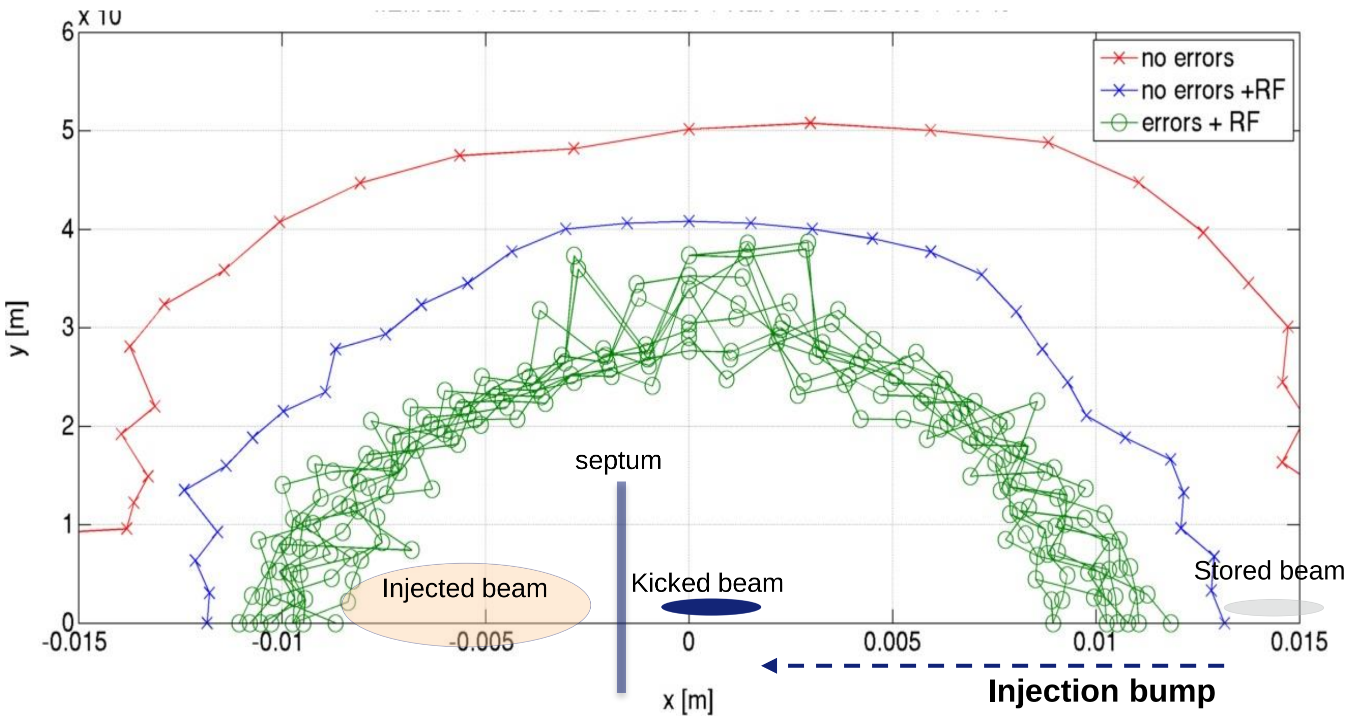
The beta function at end of the transfer line are optimized for each beam

LIFETIME, DYNAMIC APERTURE AND INJECTION EFFICIENCY

With the dedicated injection section and the modified injected beam

the upgrade lattice has injection efficiency of 98+/-1% (average of 10 seeds),

With a lifetime of 21+/-1 h (average of 10 seeds), 43 h without errors.



There is a strong impact introduced by the RF cavity, due to large path lengthening with amplitude

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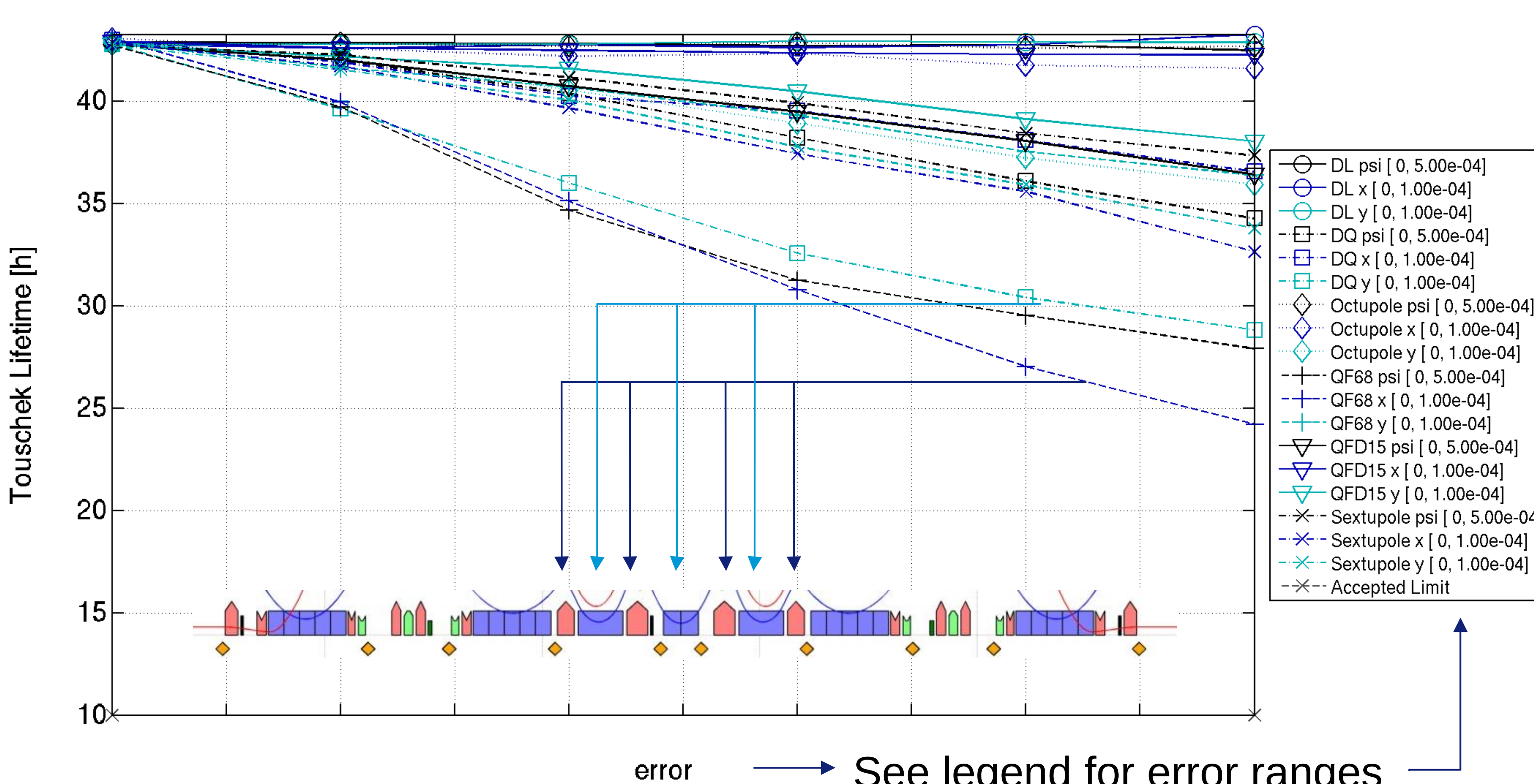
LIFETIME VS ERRORS

Each point is average of 10 seeds.



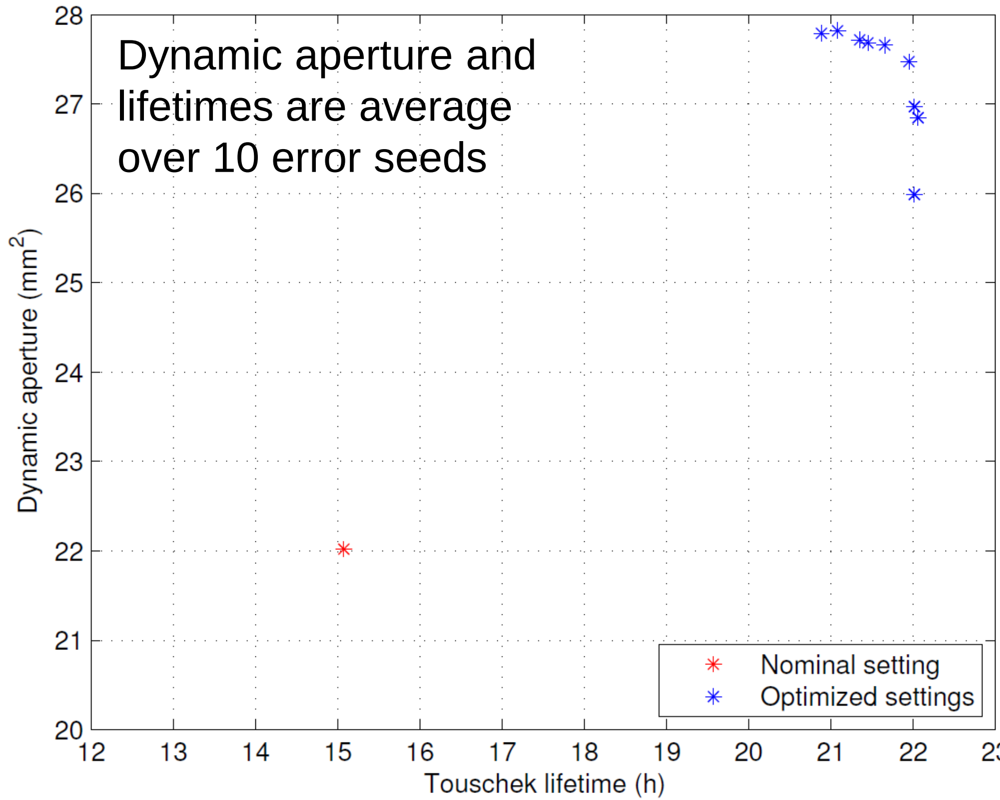
See legend for error ranges

TUNE WORKING POINT AND NON LINEARITY OPTIMIZATION

The optimization of the working point, chromaticity, optics (matching parameters), sextupole and octupoles is performed with a genetic algorithm to **maximize Touschek lifetime and dynamic aperture**.

Also discrete scans of tune and chromaticity are performed in wide regions.

High chromaticity improves lifetime and D.A.



Courtesy of N.Carmignani

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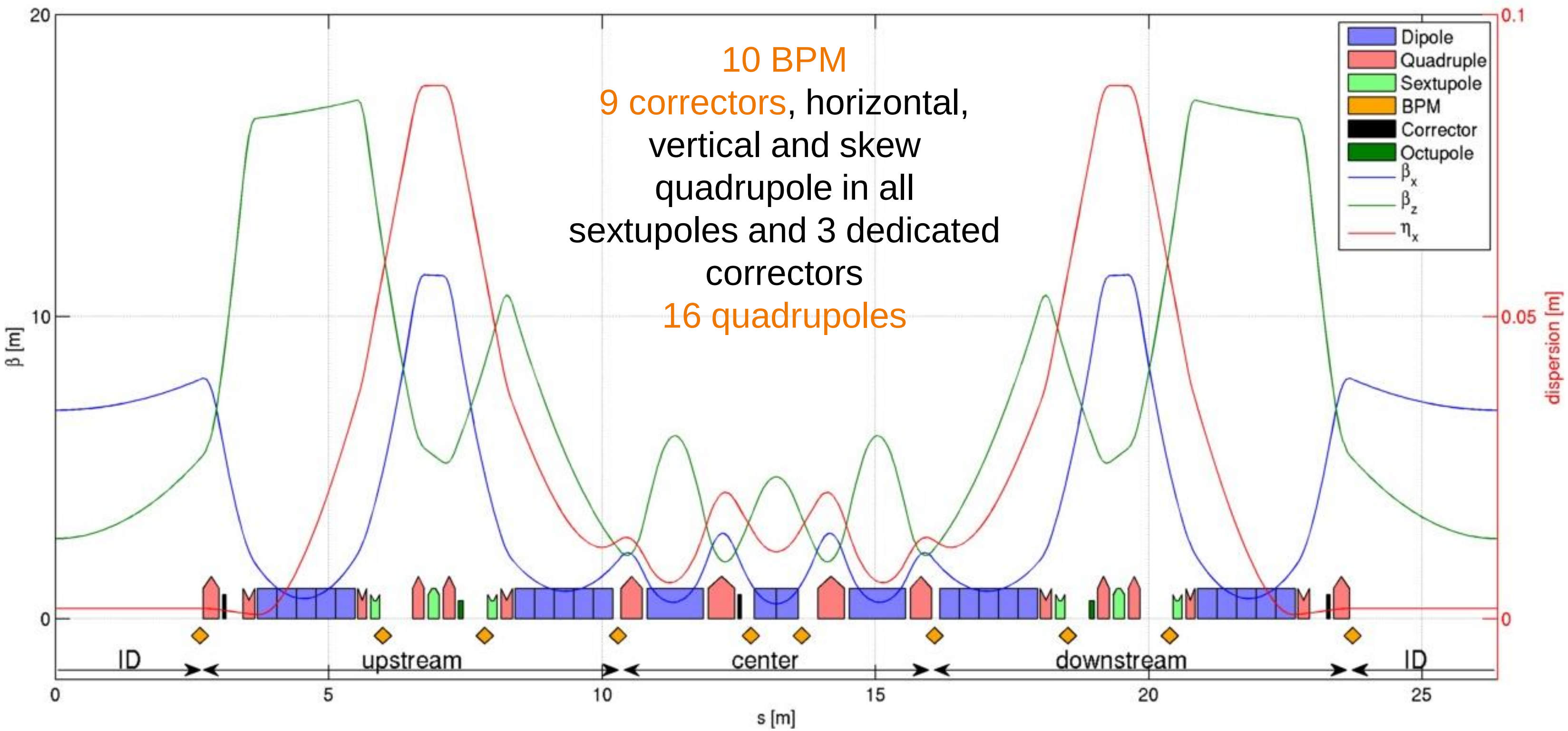
NEEDS AND CHALLENGES FOR OPTICS CORRECTION: CORRECTORS AND BPM

Correctors in all sextupoles plus 3 separated correctors

All magnets have independent power supplies



EXAMPLE OF CORRECTION OF RANDOM ERRORS

Simulation of the whole correction sequence, from transfer line to ORM* fit.

- **Find a closed orbit correcting open trajectories**
- **Correct orbit**
- **Create lattice error model fitting 'measured' RM (partial, 14/288 cor.)**

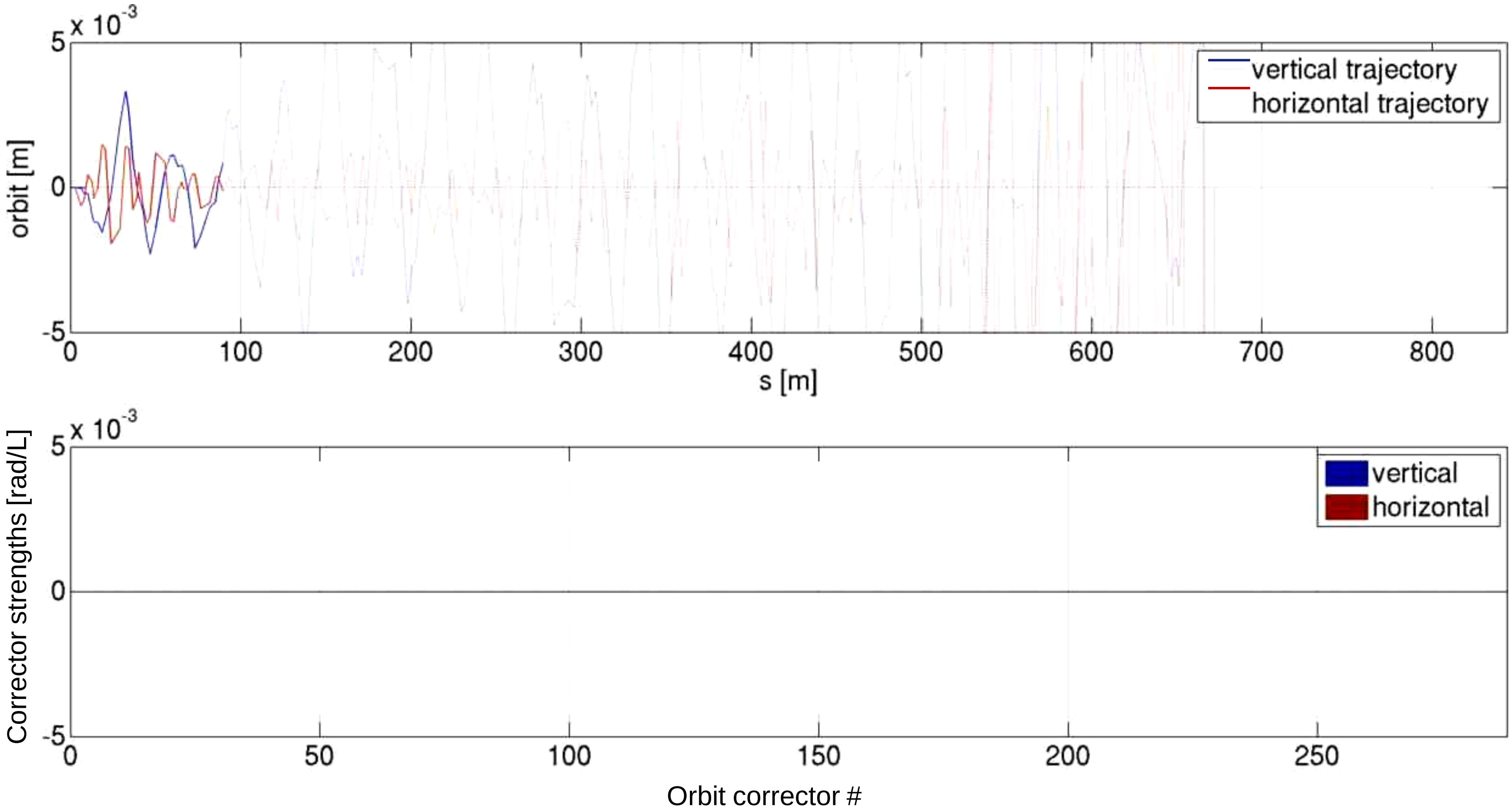
  $$ORM_{err} = [\Delta ORM/\Delta K] * \Delta K_{fit}$$

- **Compute Resonance Driving Terms and correct simultaneously normal and skew quadrupole RDT and dispersion**
- **Fix tune and chromaticity**
- **Iterate a few times**

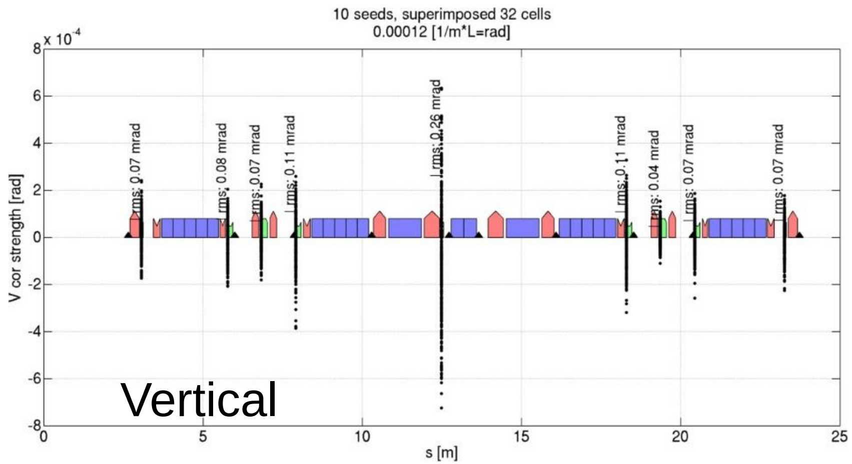
	Closed orbit only	After tuning	Current ESRF
X [μm]	160(675)	116	61
Y [μm]	111(250)	58	70
$Dx-Dx_0$ [m]	0.017	0.001	0.028
Dy [m]	0.002	0.0002	0.002
β–beating x [%]	26.2	0.7	4.9
β–beating y [%]	26.5	0.8	3.3
Tune x [.21]	0.208	0.21	0.44
Tune y [.34]	0.336	0.34	0.39
Q'_x [6]	6.328	6.00	3.89
Q'_y [4]	3.971	4.00	6.92
ε_x [134.7 pmrad]	250.4	134.7	4099
ε_y [0.04 pmrad]	2.2	0.18	3.123

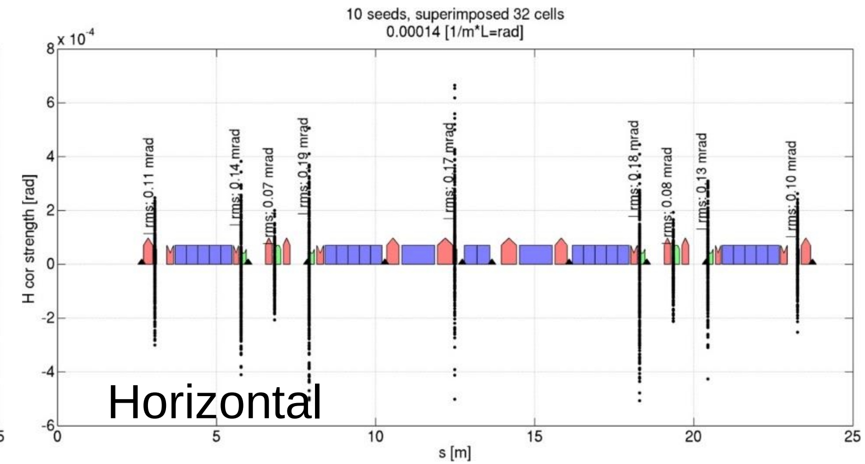
***Orbit Response Matrix**

INITIAL OPEN TRAJECTORY CORRECTION



ORBIT CORRECTOR STRENGTHS DISTRIBUTION

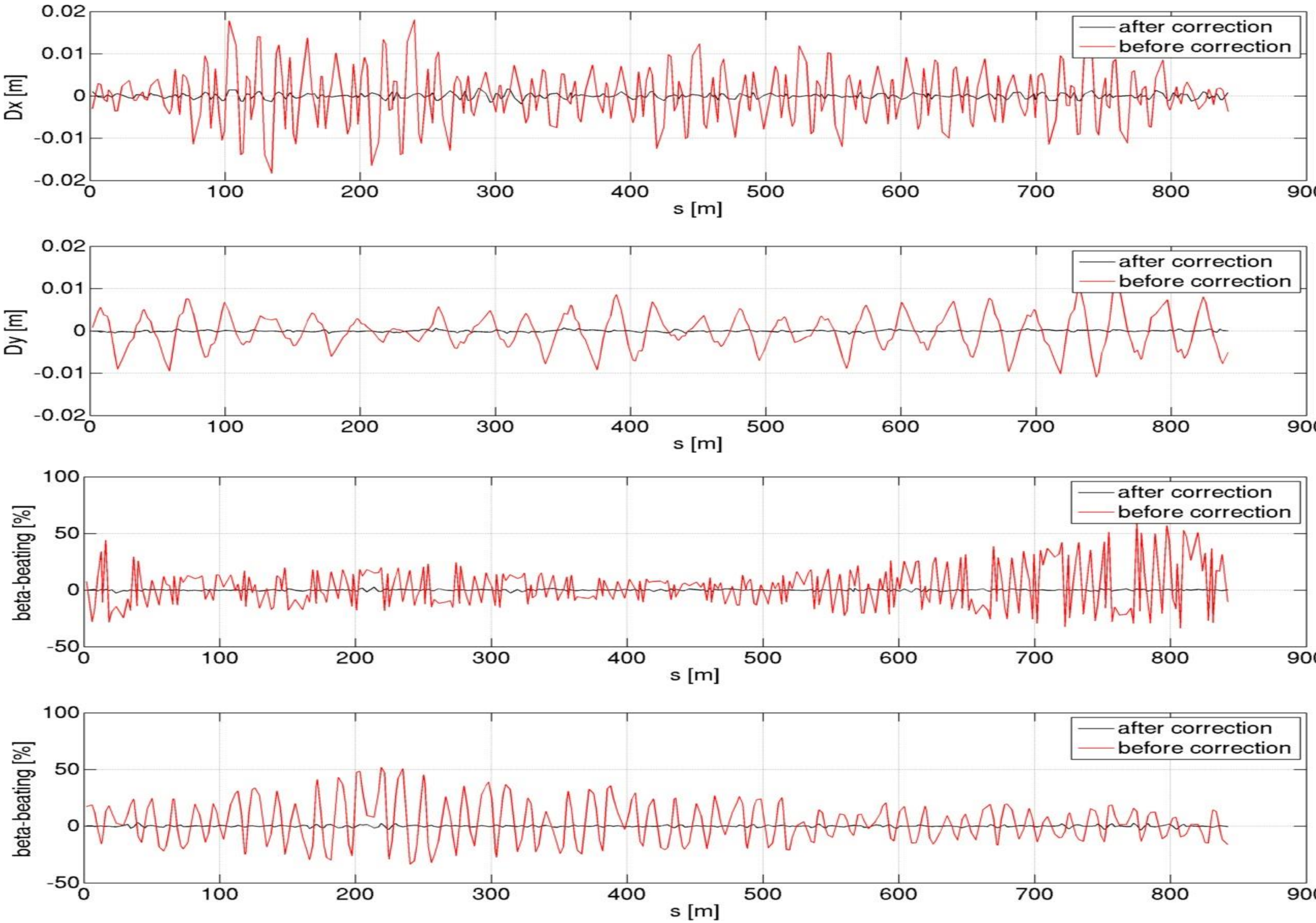




The central vertical corrector is the strongest. Solutions are under study to reduce its force. This may require a larger corrector, only H-V, or tighter error tolerances.

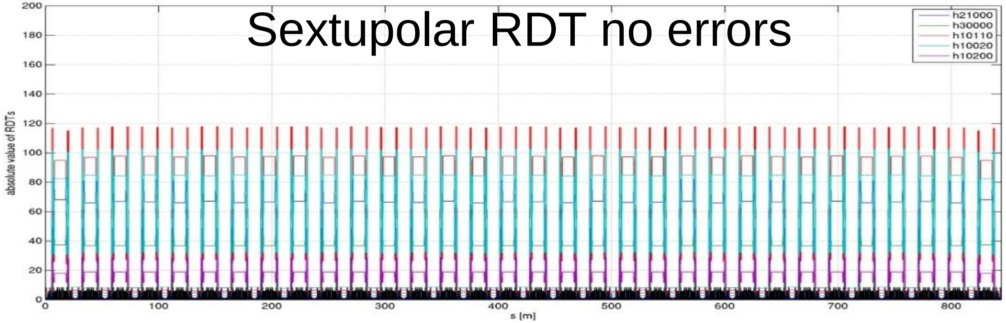
	H corrector	V corrector	Skew quadrupole
Required	0.6 mrad	0.78 mrad (SH2 only!)	0.2 T
Magnet design	0.6 mrad	0.3 mrad	0.43 T

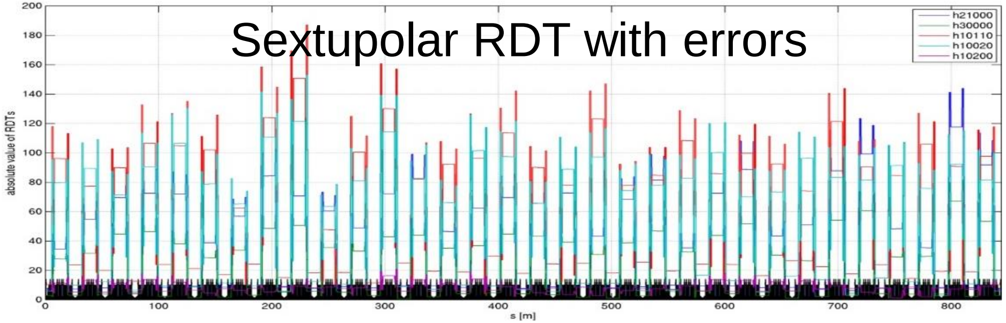
DISPERSION AND BETA BEATING CORRECTION (NORMAL AND SKEW QUAD.)

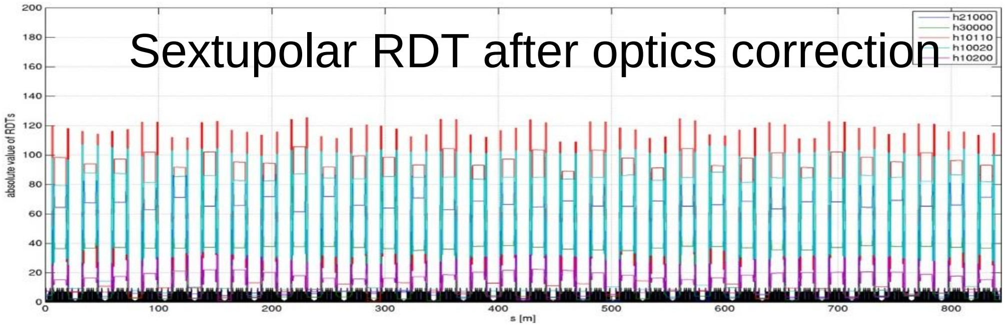


The European Synchrotron | ESRF

SEXTUPOLAR RESONANT DRIVING TERMS AFTER CORRECTION







The use of sextupole independent power supplies will allow to recover also the residual distortion. Work is in progress (N.Carmignani, A.Franchi). More details in Andrea Franchi's Talk.

Many other techniques will be applied and are under study to improve the optics correction, in particular focusing on the correction of off energy beam dynamics and resonant driving terms.

CONCLUSIONS

The ESRF upgrade lattice will provide higher brilliance and coherent X-ray beams to the users.

The lattice cell allows a large dynamic aperture.

98+/-1% injection efficiency is granted by a dedicate injection section and an improved injected beam.

Lifetime is optimized and is currently about 20h (most common filling pattern).

The correction scheme presented is used daily at ESRF and allows to correct the upgrade lattice optics to values similar or better compared to the current lattice.

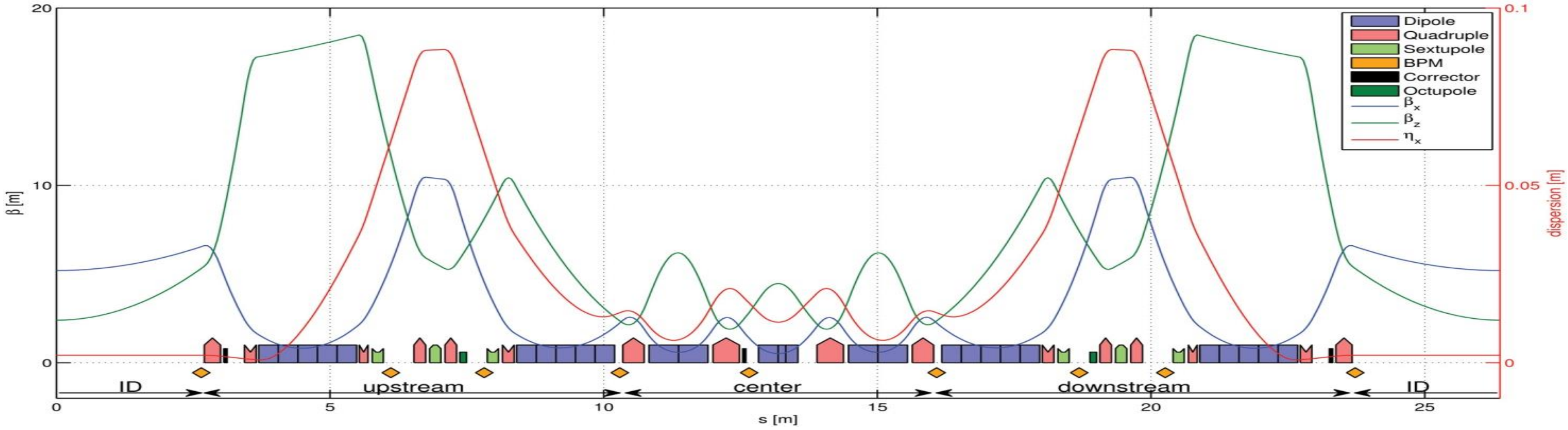
The presence of independent magnet power supply is largely exploited for linear optics correction and will be extended to non linear optics and off energy beam dynamics.

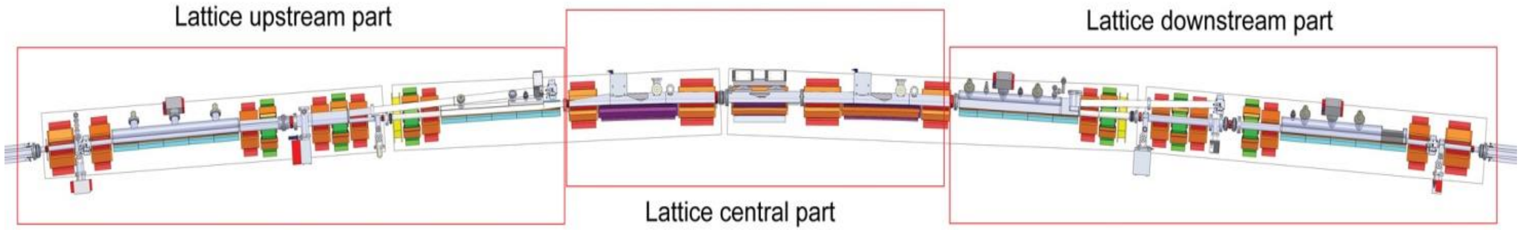
THANK YOU FOR YOUR ATTENTION!

BACKUP

- Lattice Engineering: vacuum, RF
- More details on optics, matching, phase space, injection section
- Booster emittance vs energy deviation
- Path lengthening effect
- Chromaticity scan and fixed chromaticity scan
- MOGA details
- Momentum aperture detail
- Tune working point scan
- Bpm phase advance and beta
- Tolerance table
- Emittance monitor and fast orbit feedback
- Survey and orbit for the beamlines.

VACUUM CHAMBER LAYOUT



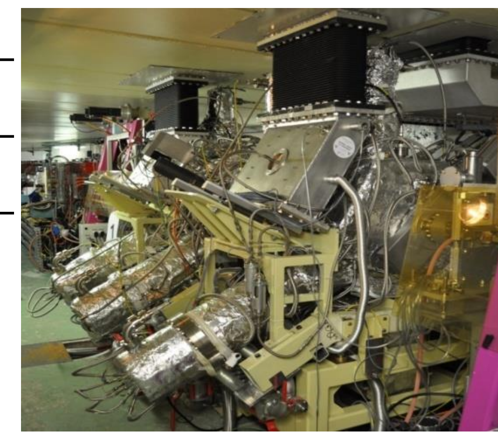


Layout with 12 chambers with aperture defined in 3 regions adapted to the beta functions.

Courtesy of Engineering Design group

RADIOFREQUENCY

RF parameters	Present	New
Energy loss (incl 0.5 MeV/turn for IDs)	5.4 MeV/turn	3.1 MeV/turn
Longitudinal damping time	3.5 ms	8.86 ms
RF frequency	352.200 MHz	352.371 MHz
Harmonic number	992	992
Nominal RF voltage	8 MV	6 MV
RF energy acceptance	2.9%	4.9%
Number of cavities	5 five-cell cav's	14 mono-cells HOM damped

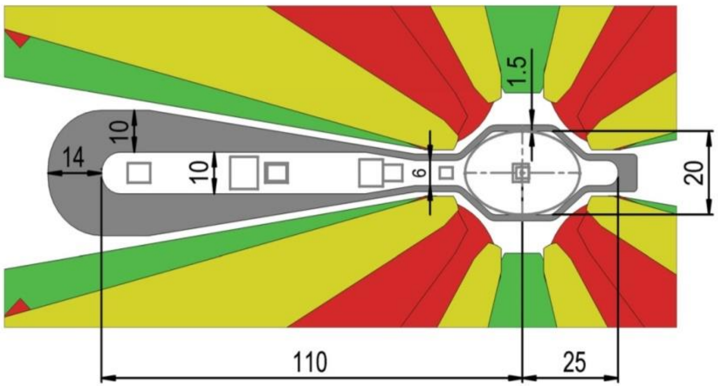


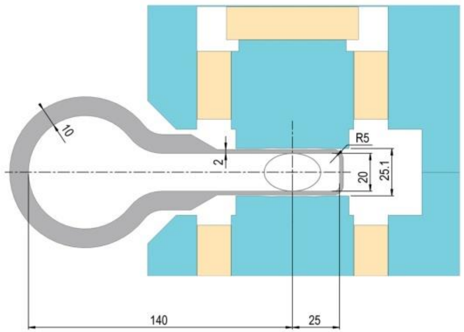
- 3 cavity prototypes installed in the SR, powered by SSA
- 12 cavities ordered

Courtesy of RF group

Upstream & downstream

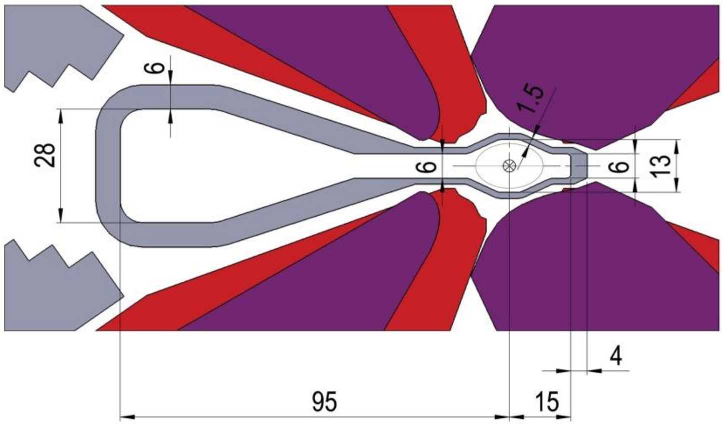
50*20 mm



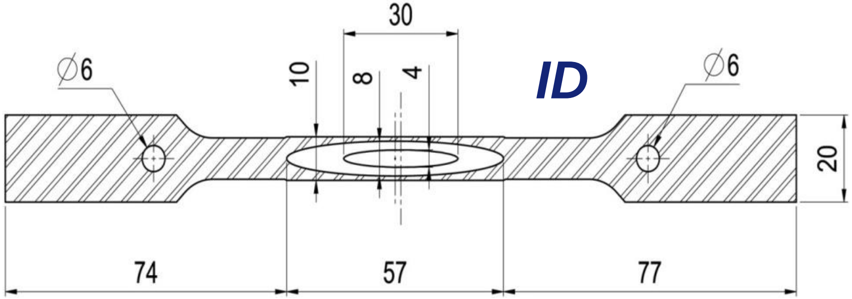


Centre

30*13 mm



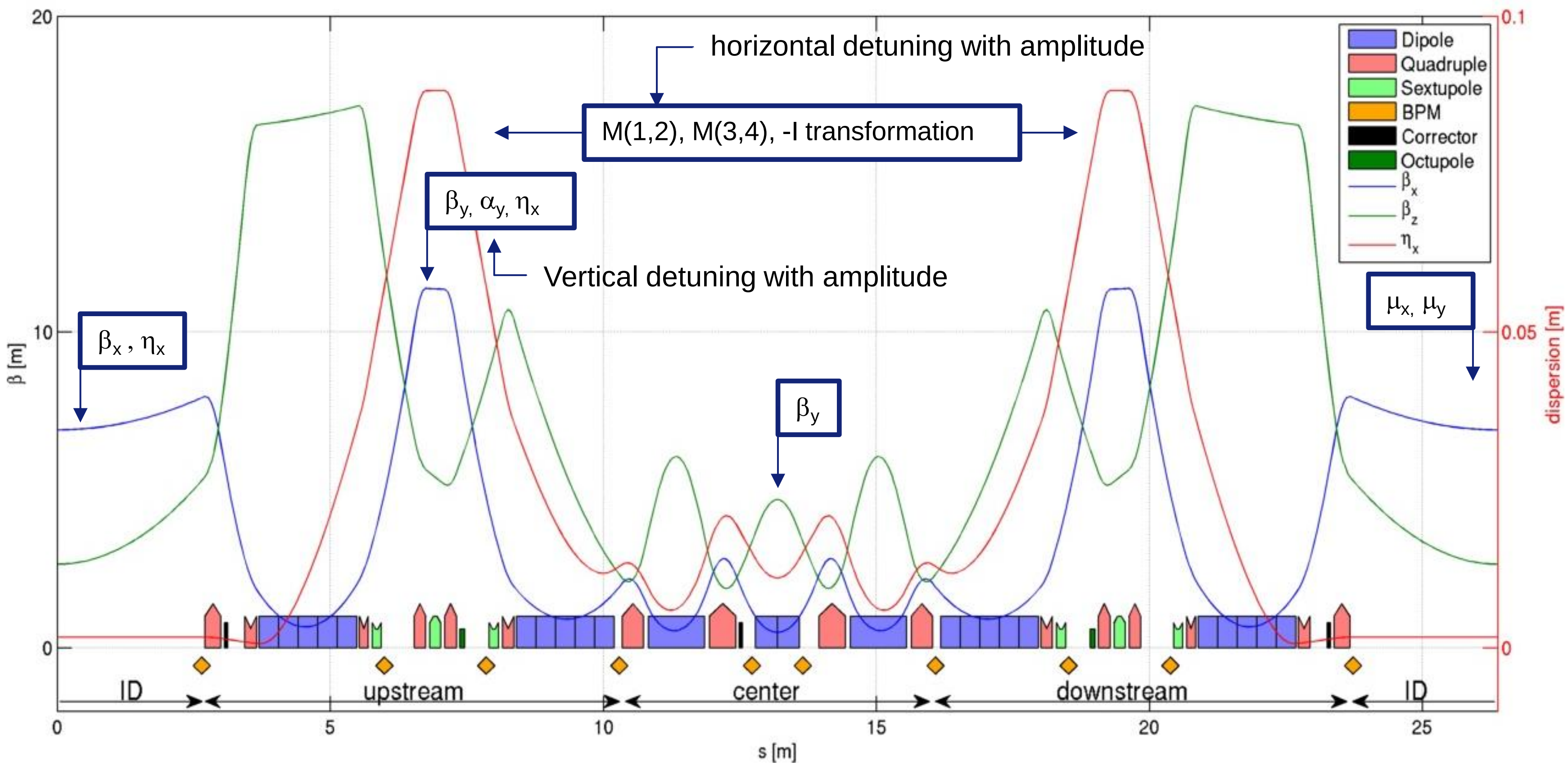
ID



(reuse of existing ID chambers)

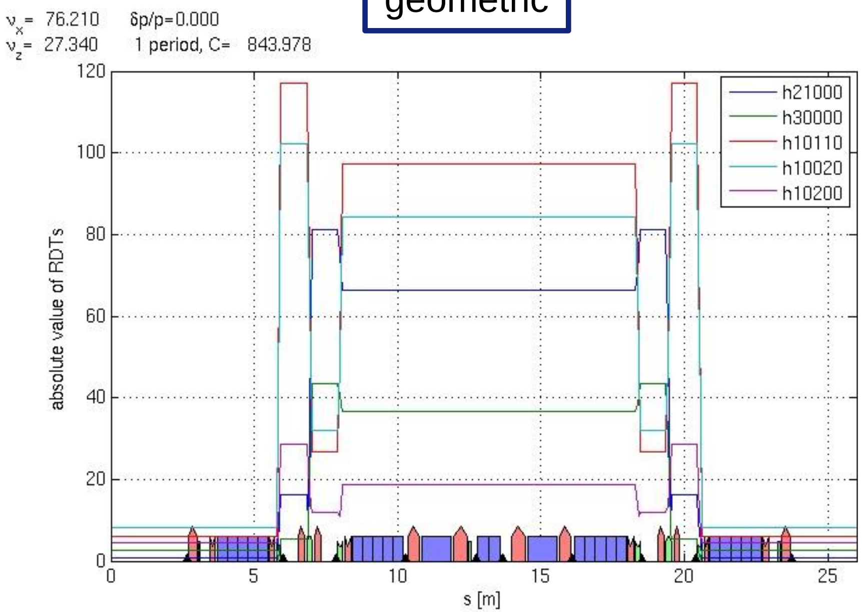
Courtesy of Engineering Design, Vaccum, ID, … group

UPGRADE ESRF (S28B) MATCHING CONDITIONS

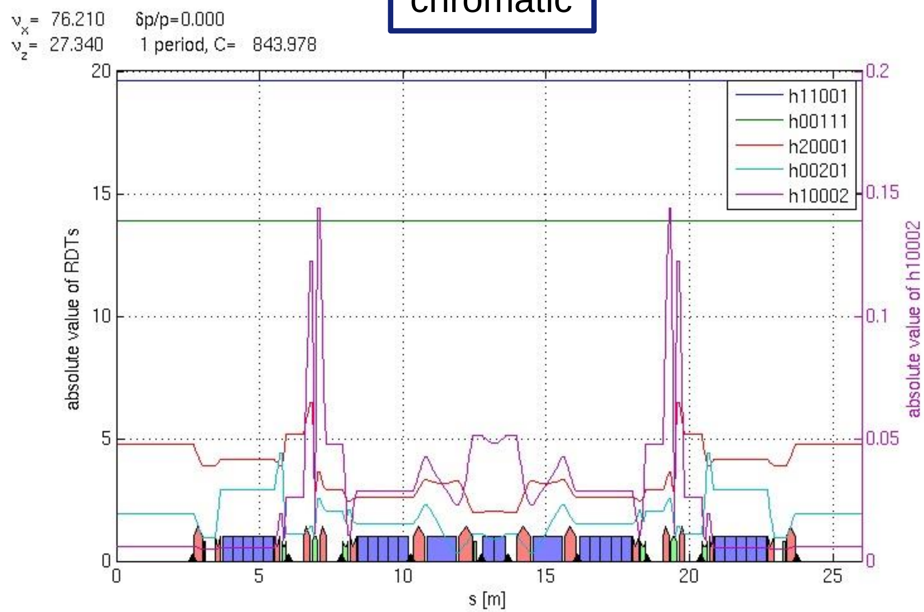


UPGRADE ESRF (S28B) SEXTUPOLE RDT

geometric



chromatic

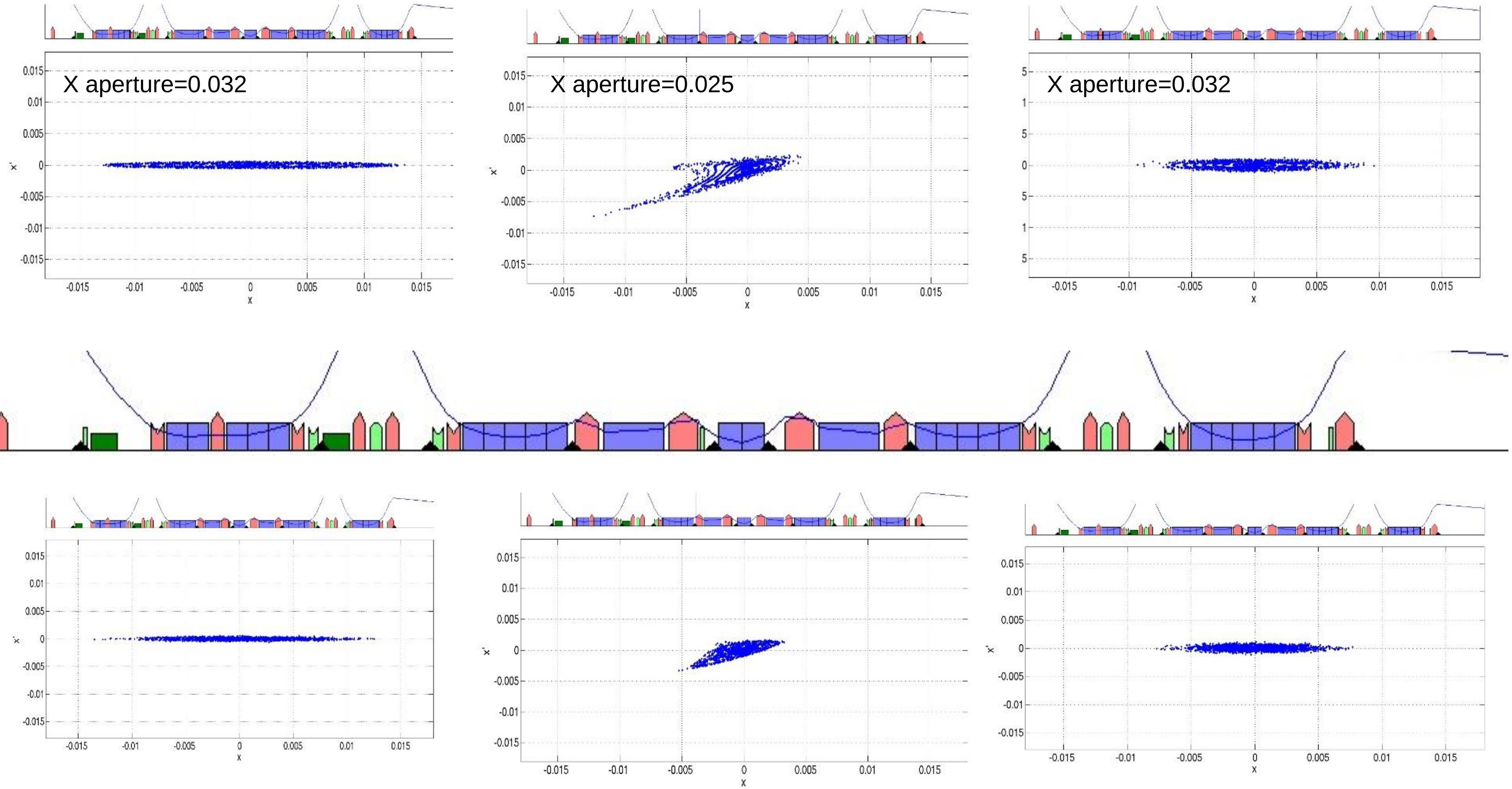


Periodic sextupole RDTs cancel within the cell thanks to appropriate phase advance choices.

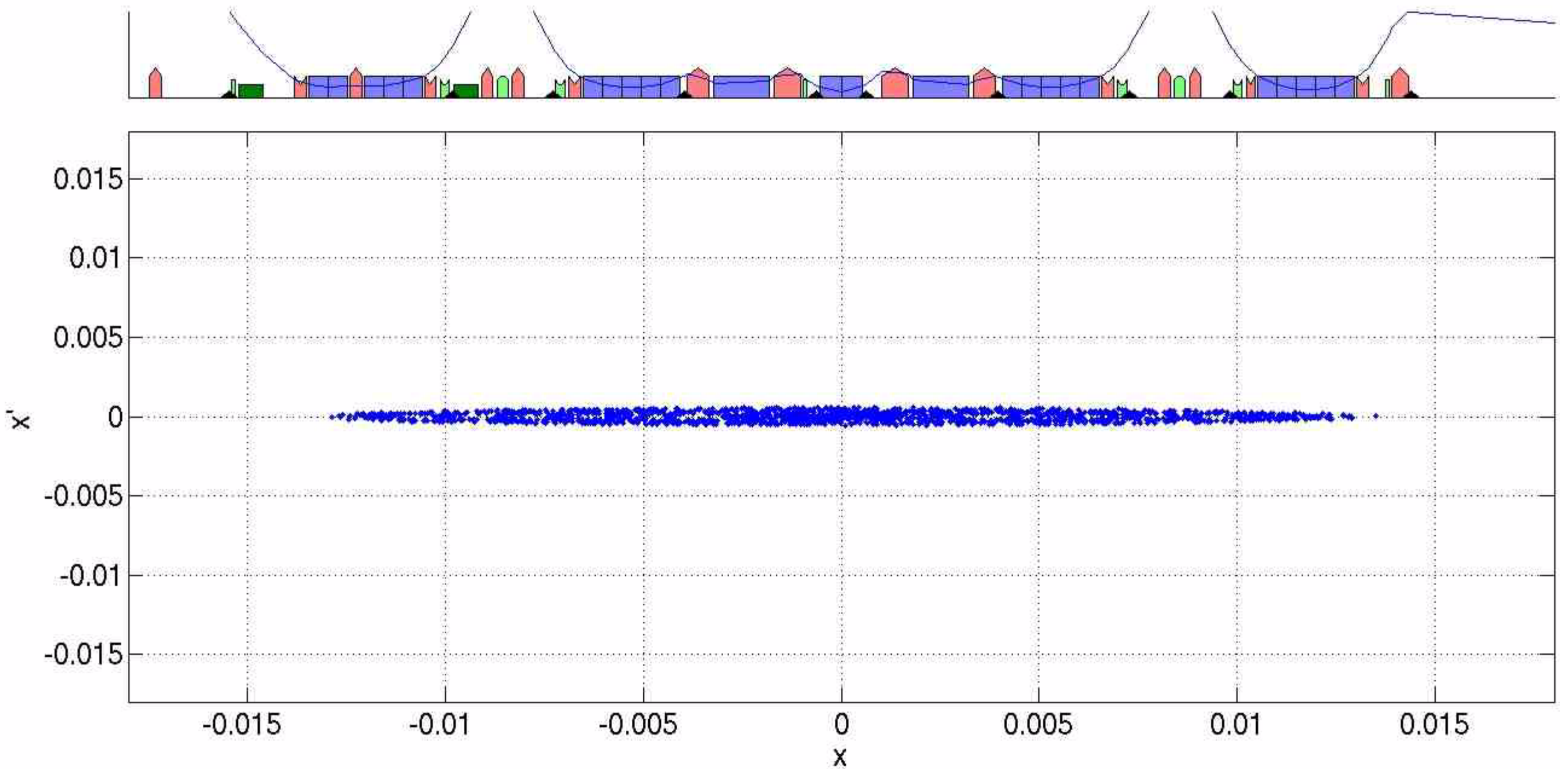
UPGRADE ESRF (S28B) PHASE SPACE PLOTS ALONG THE CELL

On energy

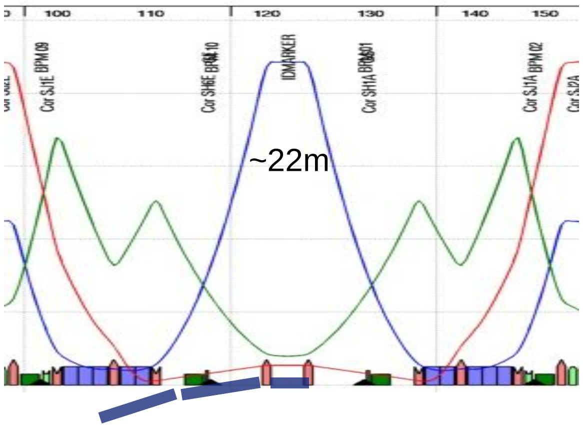
+2%

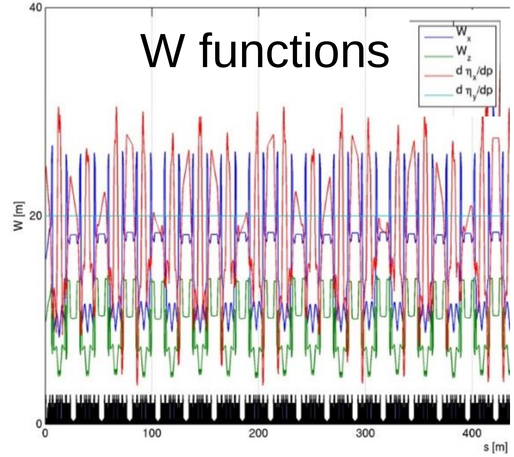


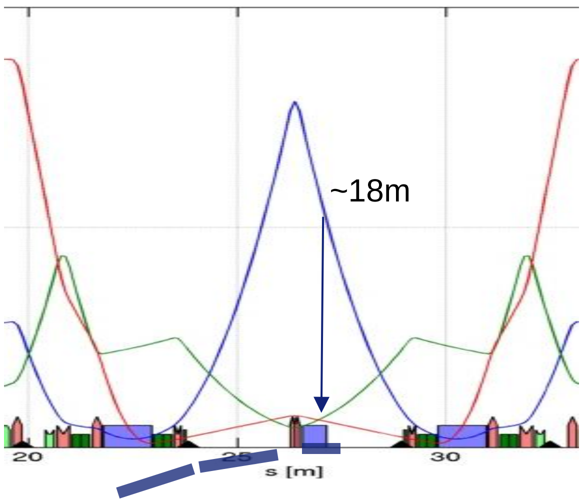
PHASE SPACE EVOLUTION ALONG LATTICE

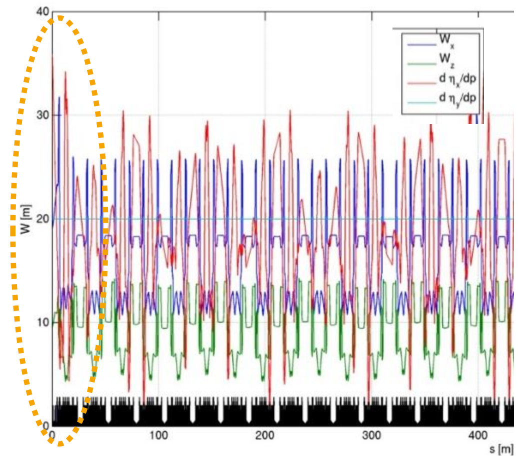


INJECTION CELL LAYOUT AND OPTICS MAY IMPACT STRONGLY THE LIFETIME





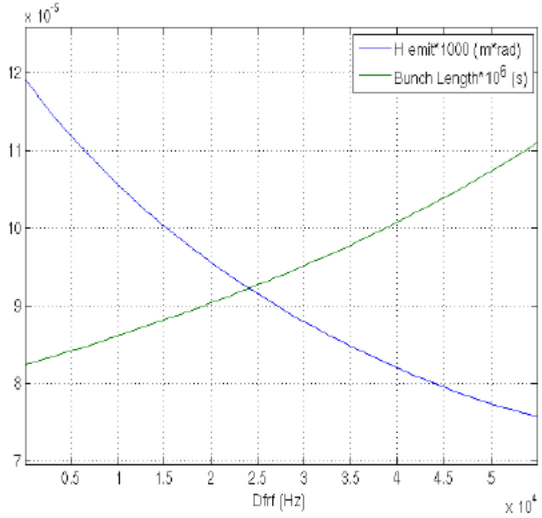




The injection section adopted in S28B allows to have minimal impact on the lifetime and has larger beta functions at injection. Sextupoles tuning in the injection section is crucial and different from the standard cell

Touschek lifetime	
No injection	22.8 h
Previous injection	15.7 h
Injection S28B	21 h

Lifetimes for S28A, predecessor of S28B

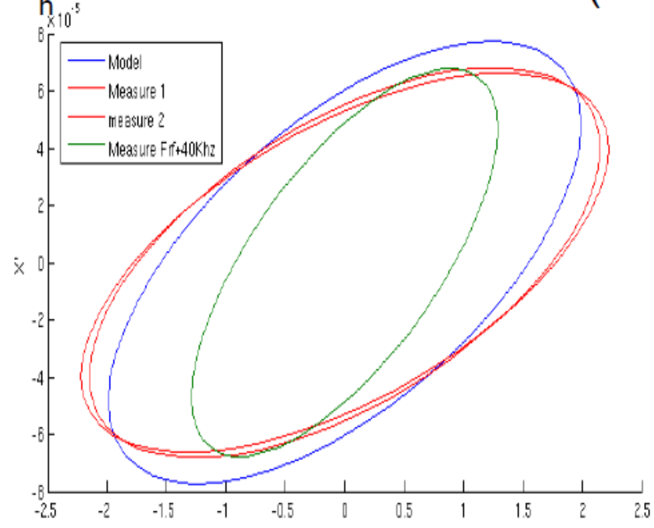


Case tested with Frf=Nominal+40Khz

Emittance measurement done using quadrupole scan in transfer line after extraction from the booster.

ε_h=120 nm model and initial measurement

ε_h=63.1 nm For Frf+40kHz (TGTBT)



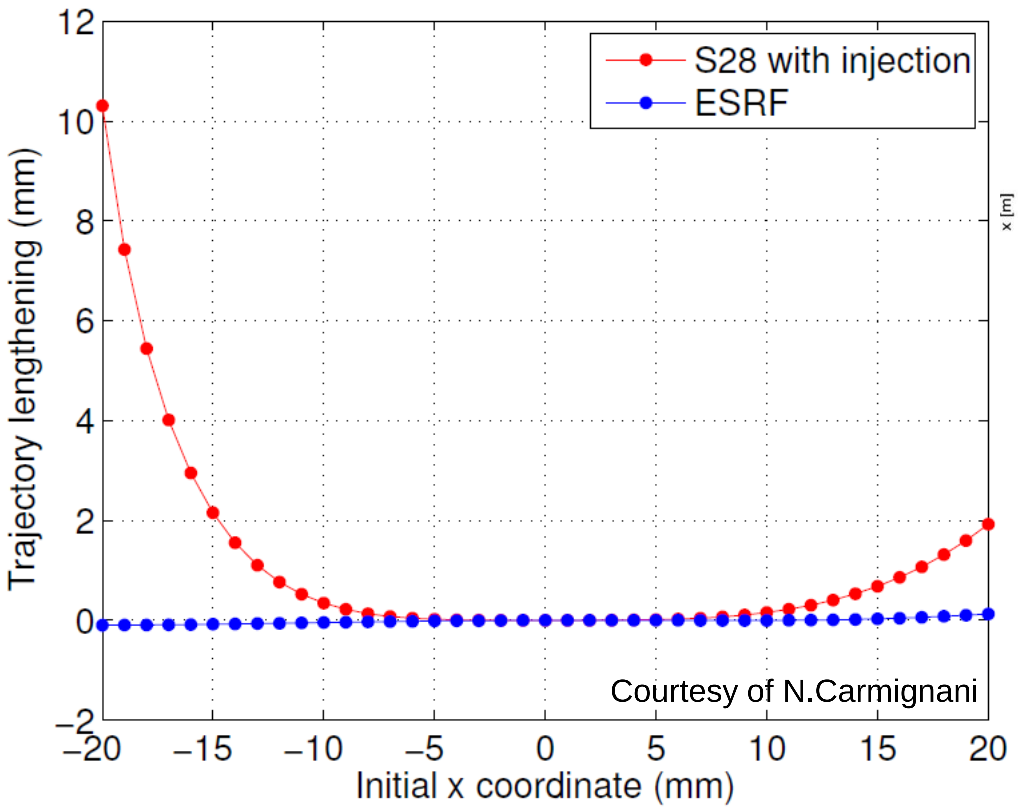
Measurement on a visible light monitor in SY before extraction:

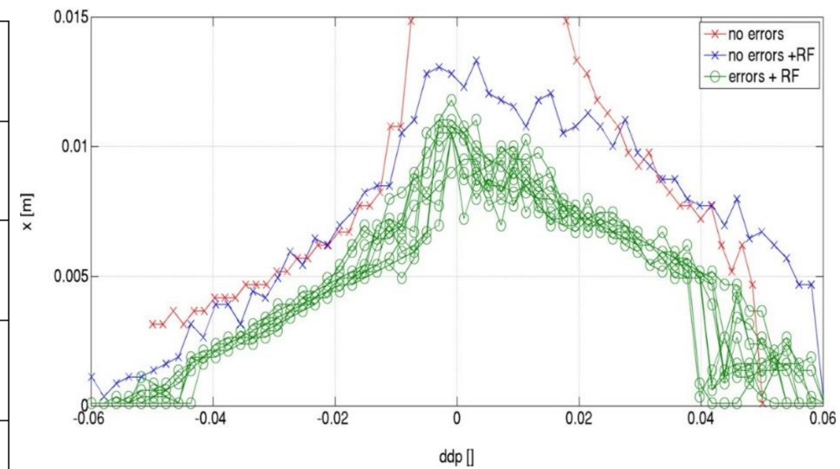
ε_h=270 nm nominal

ε_h=190 nm for Frf=40kHz

Needs careful calibration

PATH LENGTHENING EFFECT COMPARED TO PRESENT LATTICE





The beam arrives later in the cavity, particles loose energy, the dynamic aperture off energy is smaller so they are lost. Stronger sextupoles reduce this effect.

SEXTUPOLE AND OCTUPOLE OPTIMIZATION: WORKING POINT 75.58 27.62

First optimizations without chromaticity constraints showed good solutions at both positive and negative vertical chromaticity, so we fixed vertical chromaticity to 0.

Variables:

5 sextupole families; 2 octupole families.

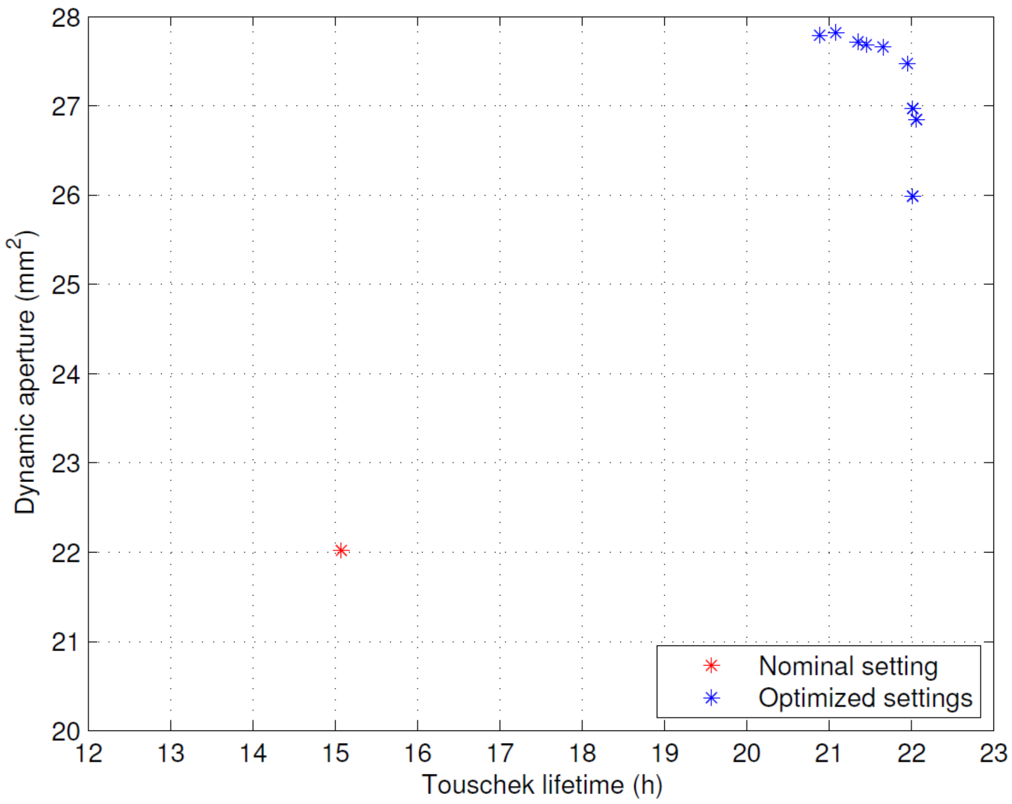
Constraints:

vertical chromaticity = 0.

DA and LT are computed for 10 error seeds and the average is used. Touschek LT is computed at multi bunch current.

After about 100 iterations, both LT and DA are increased.

3-4 days using the full ASD cluster.



Courtesy of N.Carmignani

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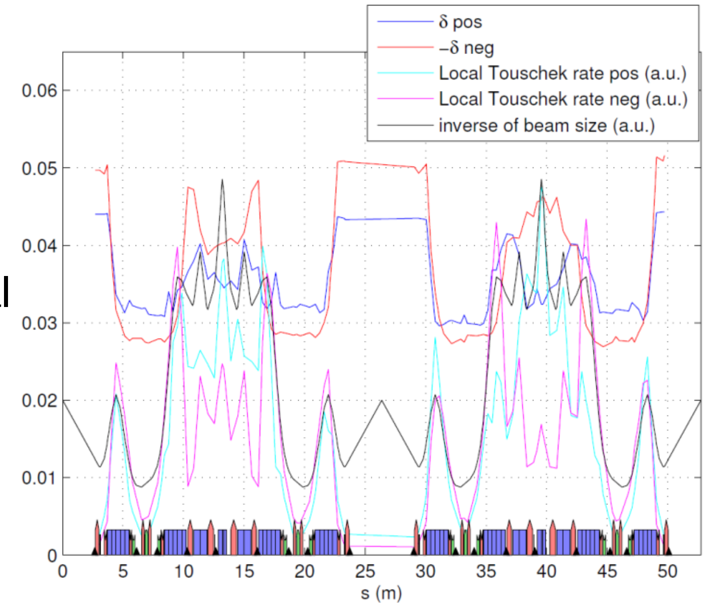
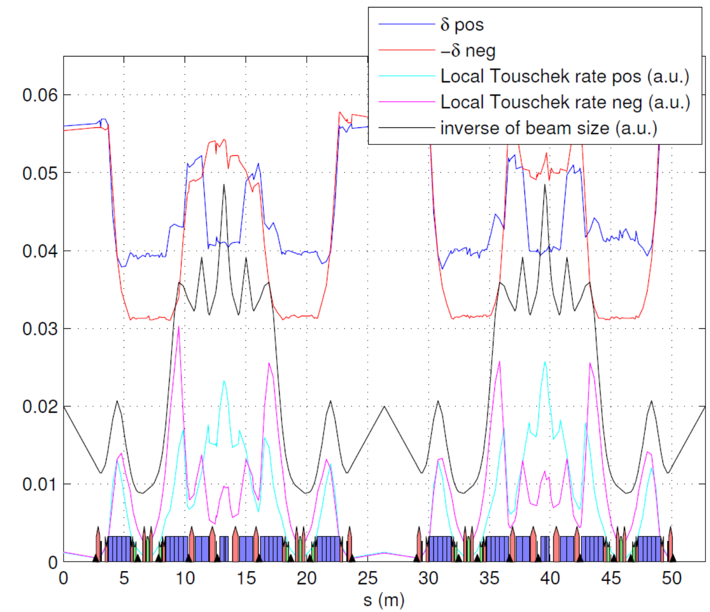
THE SECOND WORKING POINT: 76.20 27.30

	SD1A SD1E	SF2A SF2E	SD1B SD1D	SD3A SD3E	SF4A SF4E	SD3B SD3D	OF1B OF1D	OF2B OF2D
Nominal	-84.35	74.00	-69.35	-56.35	80.00	-41.35	-2338.3	-2006.7
Optimized	-69.30	85.46	-68.18	-68.14	77.09	-55.17	-2326.5	-1482.9

Nominal
6 MV



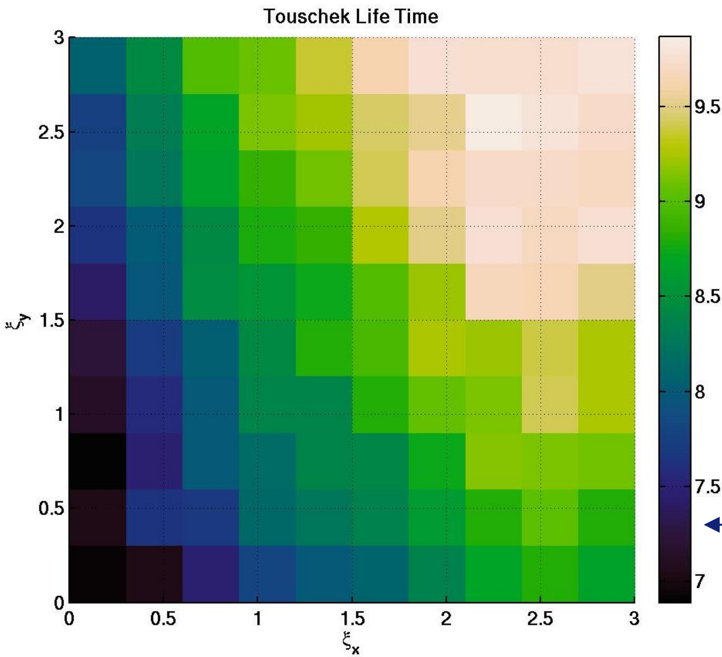


Optimized
6 MV

The working point 76.20 27.30 has a smaller horizontal emittance: 142 pm.
After the optimization, horizontal chromaticity is 8.3, detuning is not exactly zero.

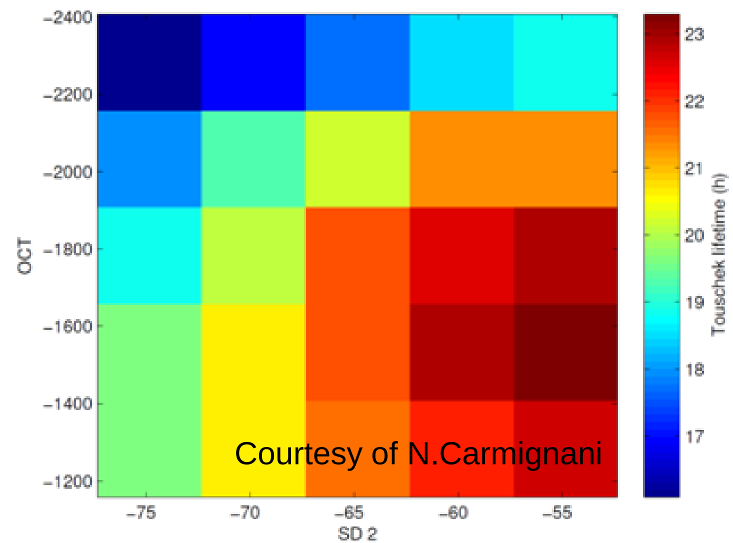
LT increases from 12.5h to 24h, with ~20% larger dynamic aperture area.

Courtesy of N.Carmignani

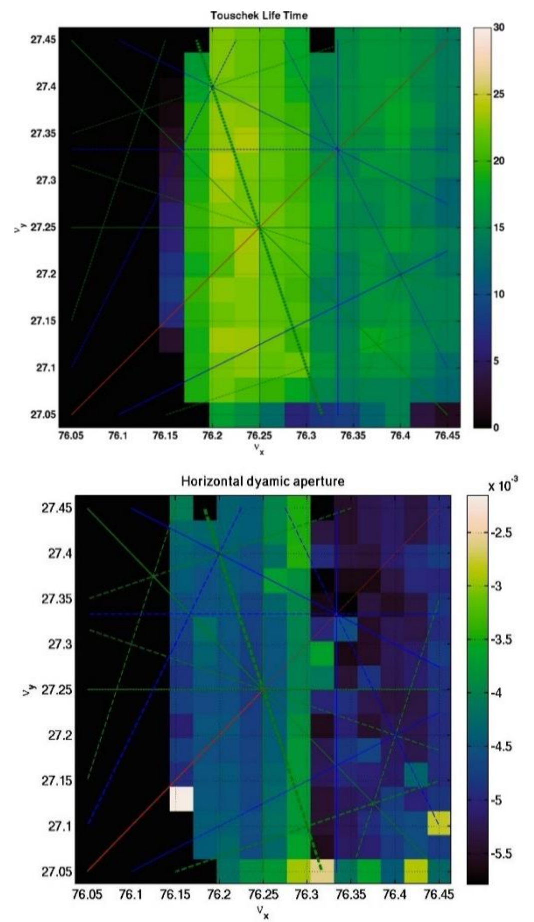


For an old (>1 year ago) lattice we noticed that chromaticity improved lifetime (a wrong sextupole set gave higher chromaticity and larger lifetimes!).
The scan was then performed with 1 seed of errors. The chromaticity is not normalized.

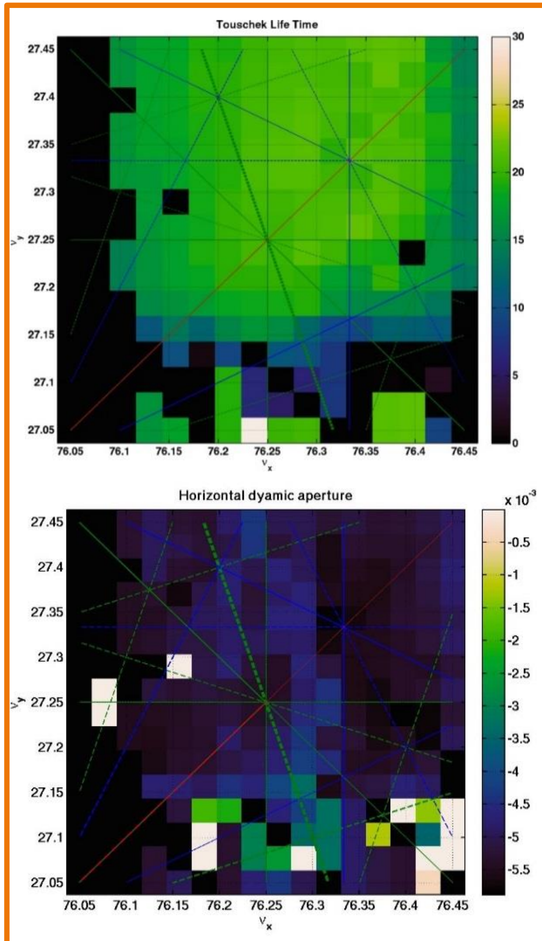
Scans of octupole and sextupole strength at fixed chromaticity (6,4) were performed.
(the lattice cell has 3 sextupoles and 1 octupole, 2 sextupoles are used to fix the chromaticity)



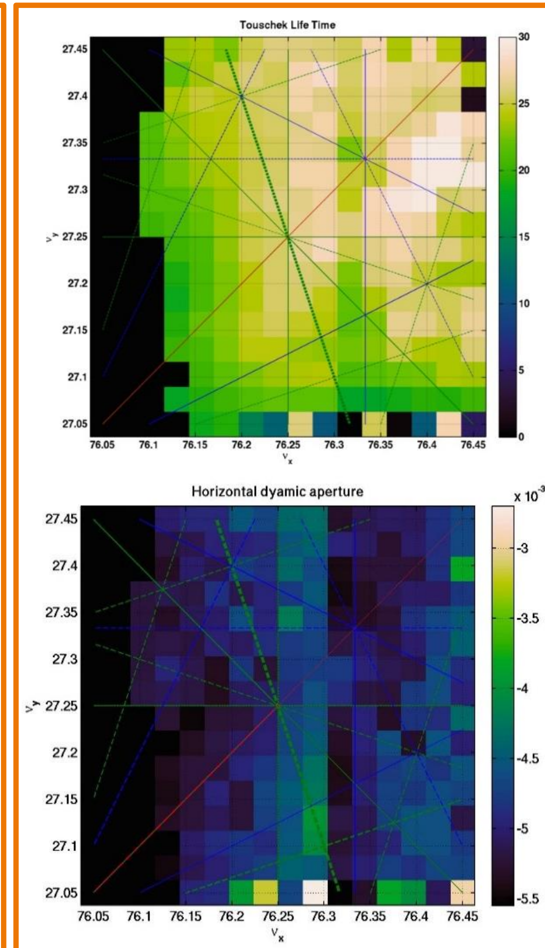
TUNE SCAN VARIATION WITH ERROR SEED



Seed 1

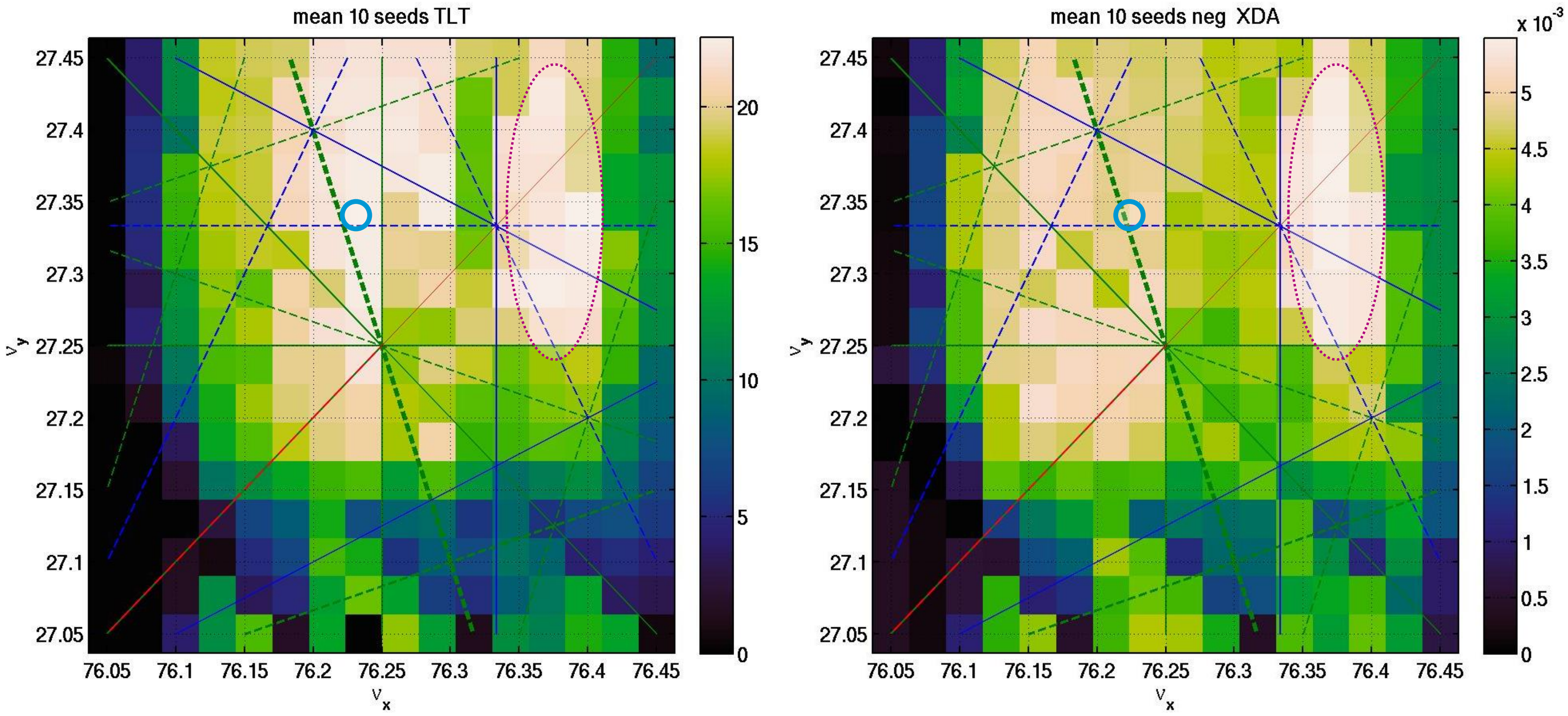


Seed 2



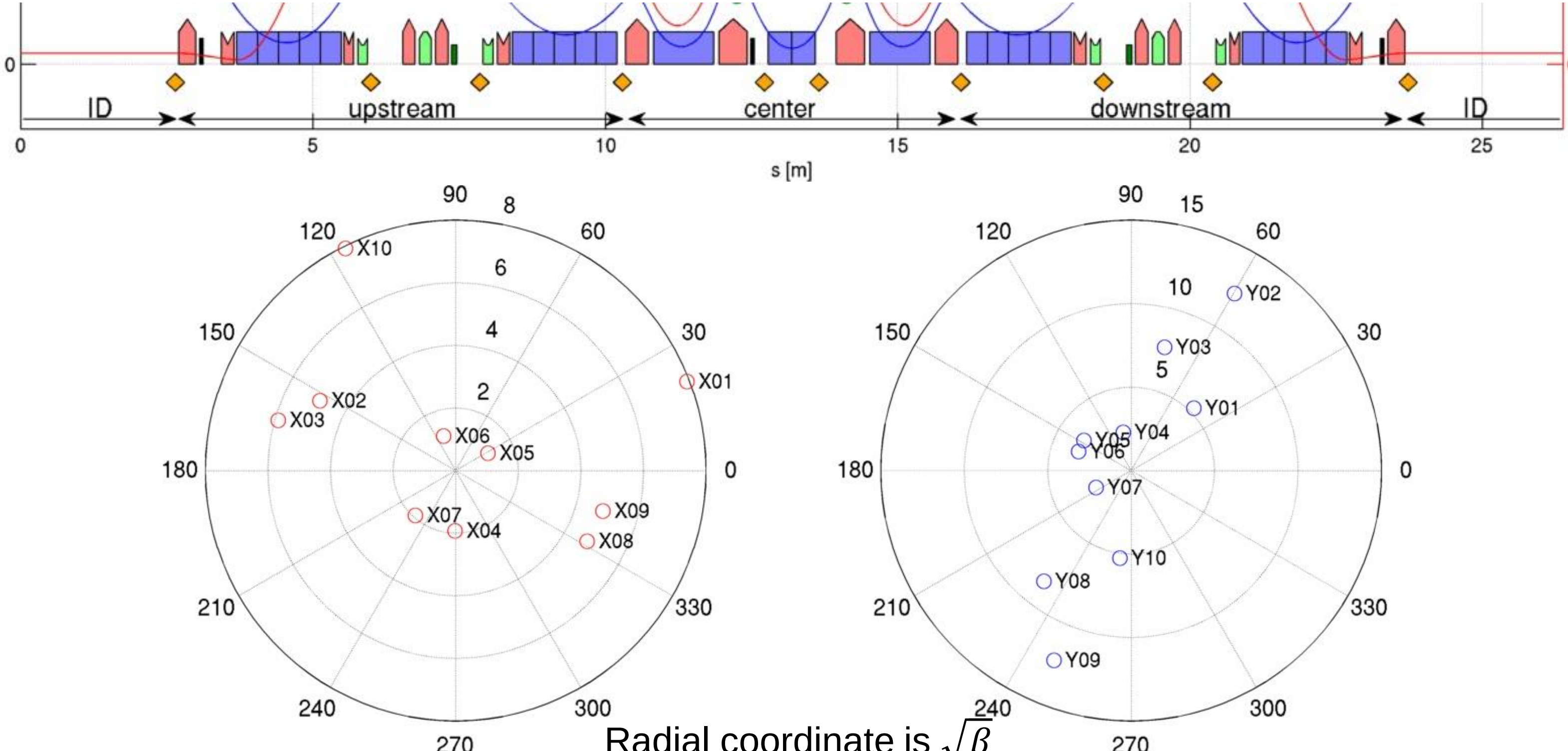
Seed 3

AVERAGE OVER 10 SEEDS



In this figures: sextupoles optimized at (.23, .34) and no injection cell

BPM PHASE ADVANCE AND BETA



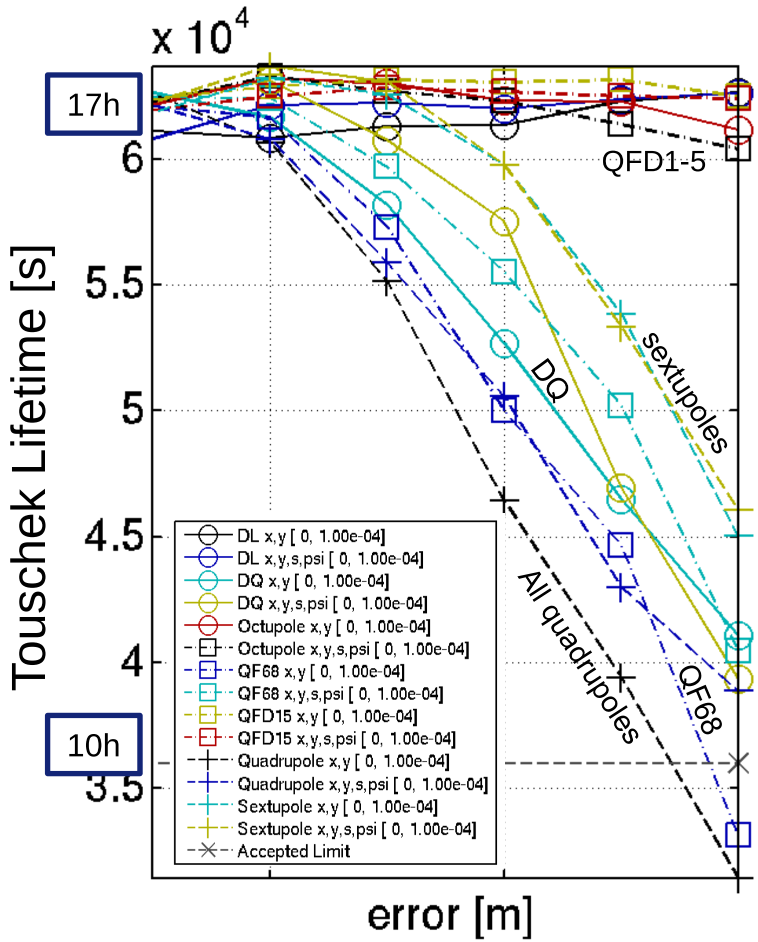
Radial coordinate is $\sqrt{\beta}$

Angle coordinate is μ

Removing BPMs and correctors is possible, but lifetime and dynamic aperture are reduced. Trimming the DQ will be possible but not strictly necessary.

TOLERABLE RANDOM ERRORS

Each point is average of 5 seeds.



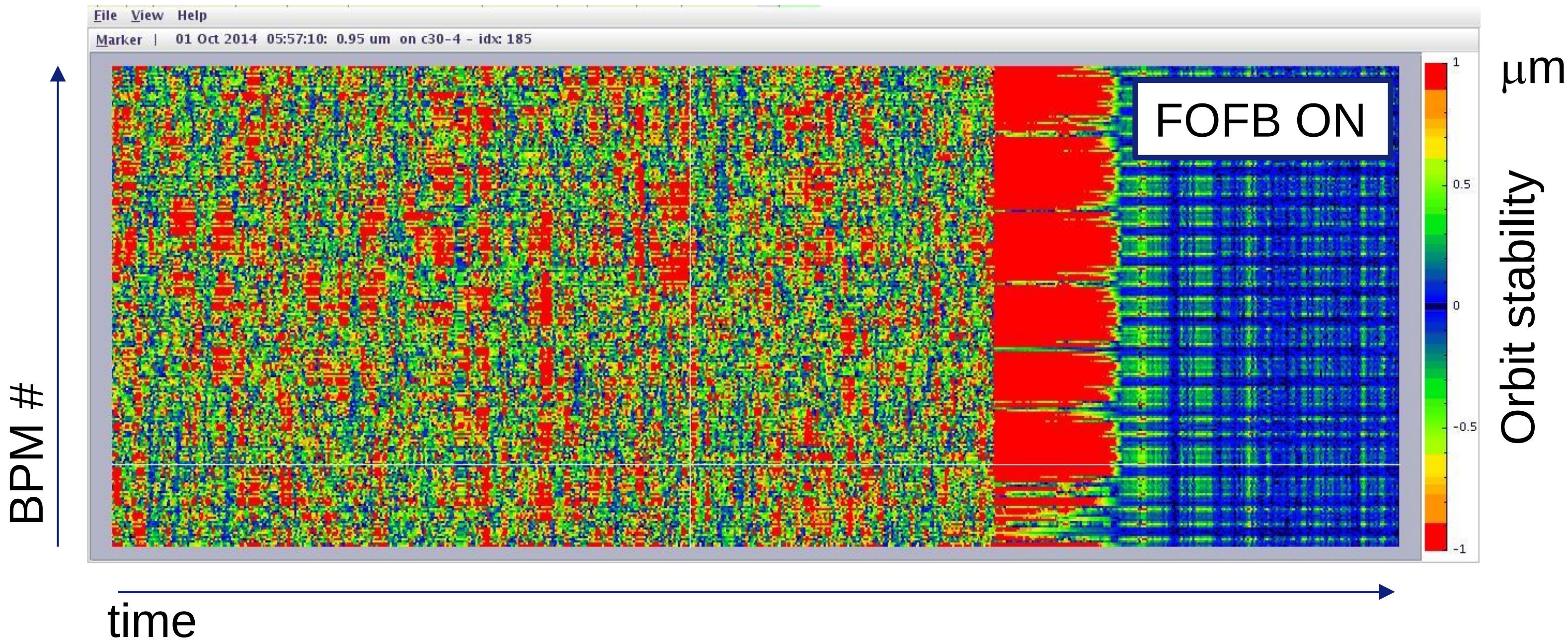
Each error, on each magnet family, is studied individually looking at the dependence of DA, lifetime, emittances and all relevant parameters vs error amplitude.

Required:	DX	DY	DS	DPSI	DK
	μm	μm	μm	μrad	10^-4
DL	>100	>100	1000	500	10
DQ, QF[68]	70	50	500	200	5
Q[DF][1-5]	100	85	500	500	5
SFD	70	50	500	1000	35
OF	100	100	500	1000	

Sextupoles and high gradient quadrupoles are the most relevant limitations, nevertheless, this alignment specifications are currently achievable. (DX=DY=60μm, 84 μm between two magnets).

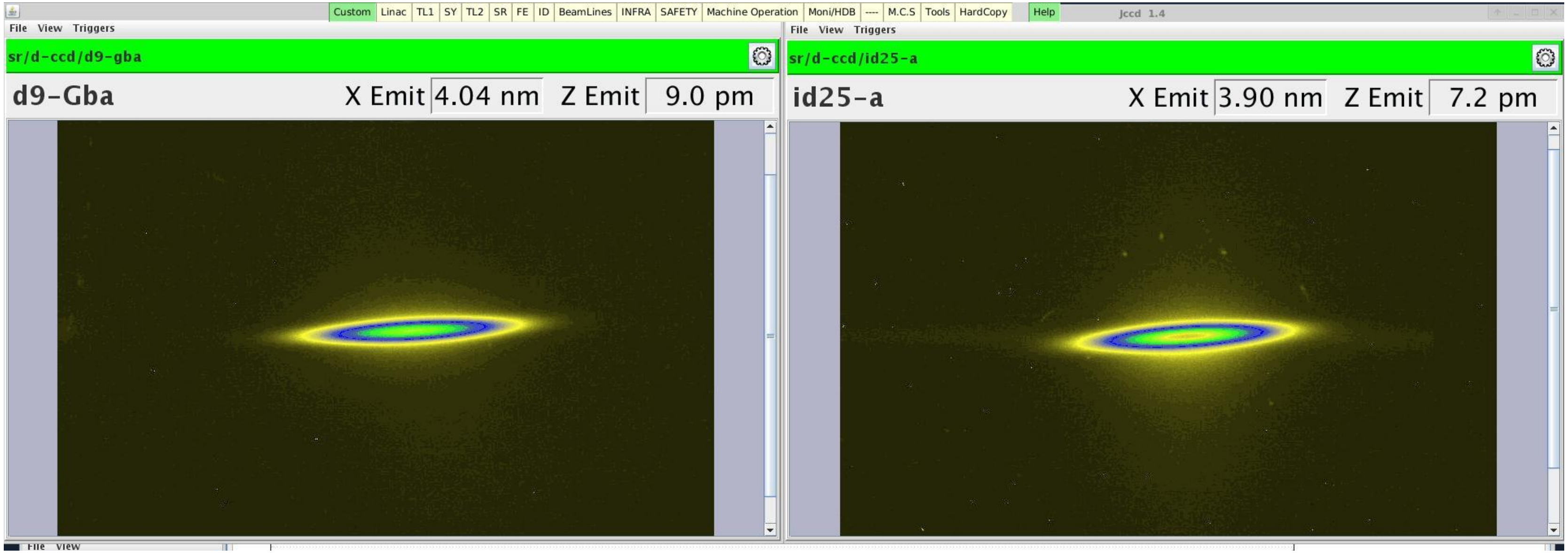
FAST ORBIT FEEDBACK

Sub micrometric beam stability is required for x-ray beamlines. The present fast orbit feedback system will be inherited by the ESRF upgrade, using a subset of the 9 correctors. Nevertheless as the vertical beam stability is already sufficient for the users and the vertical beam size will not change, the system is suitable also for the ESRF upgrade.

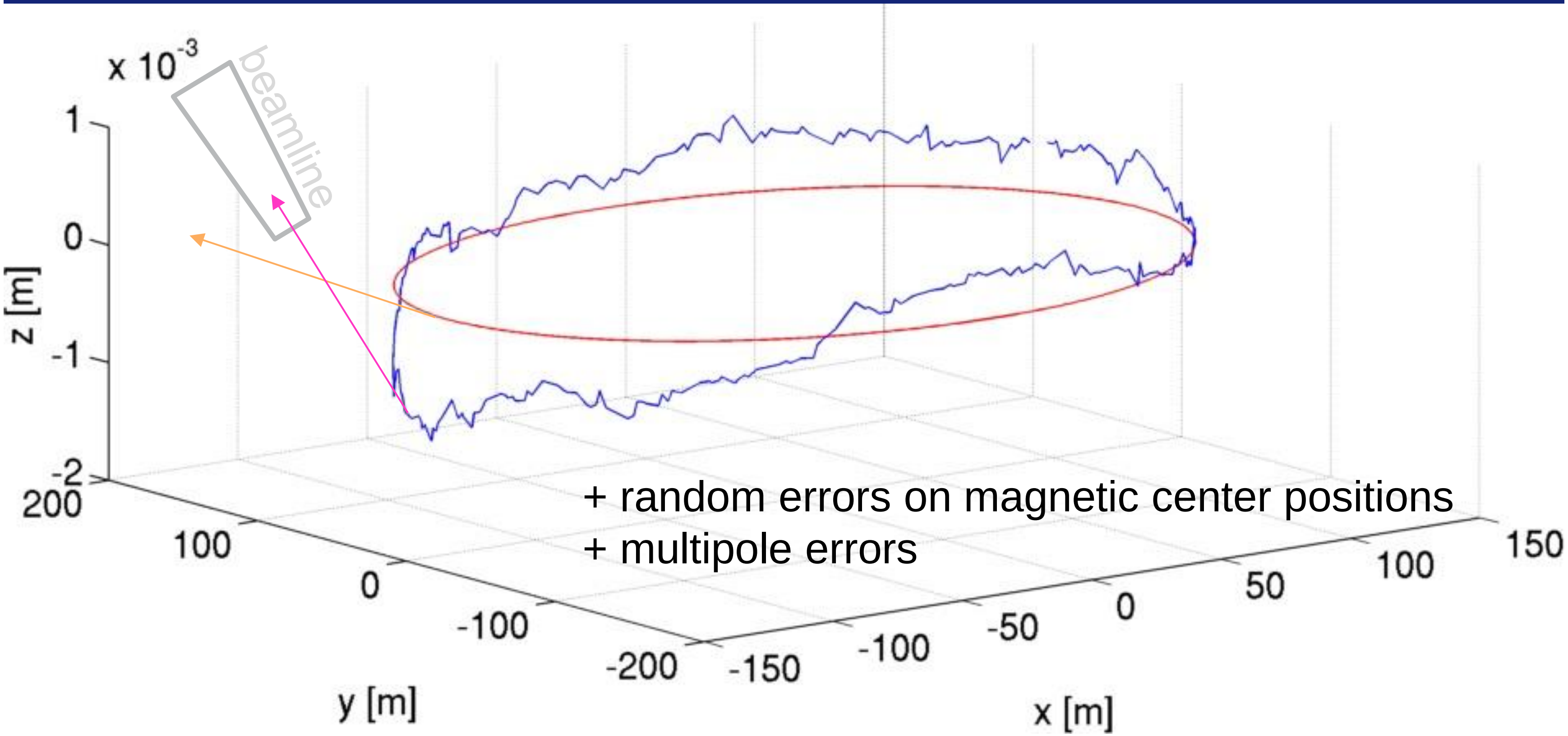


EMITTANCE MEASUREMENTS

Emittance measurements will be performed with x-ray pinhole cameras located at DQ. The resolution of this cameras will allow to resolve an emittance of 5pmrad +/- 1 pm rad.

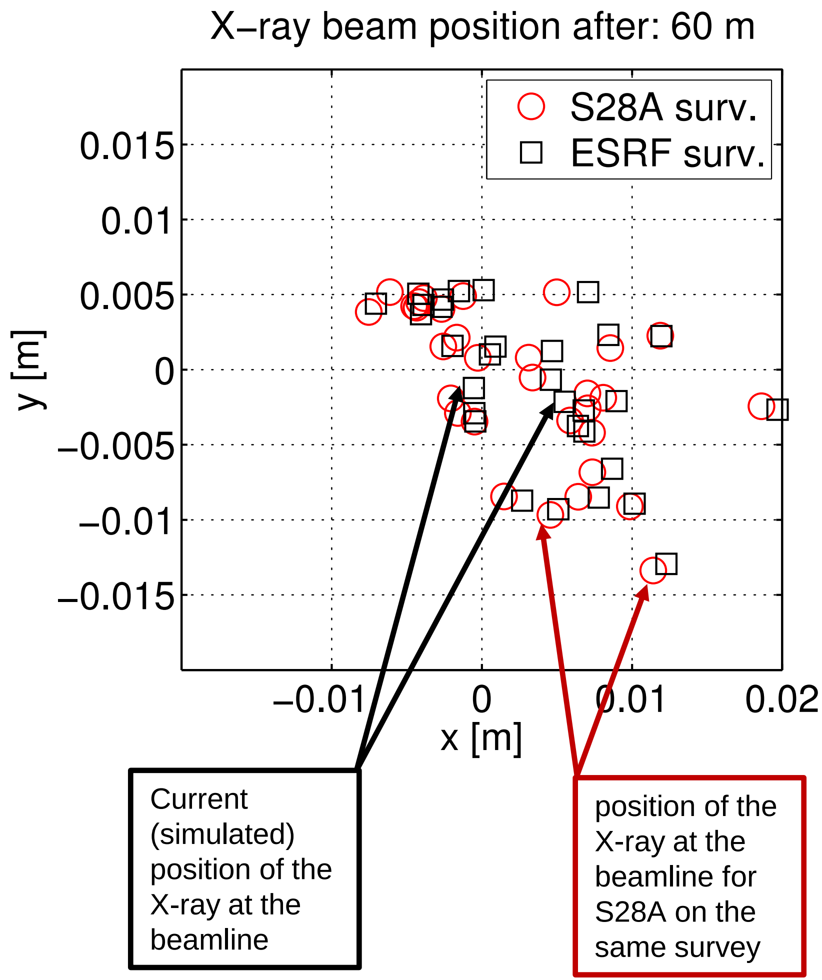


CURRENT ESRF SURVEY



X-ray beam direction is strongly influenced by the position of the storage ring and orbit distortion.

X-RAY BEAM POSITION AT ID (60 METERS)



All ID are assumed to be at 60m from the source.

The position of the beam after 60m is very similar for ESRF and S28A considering the current survey measurement.

The position if the ring was aligned on the reference circumference would be about (0,0) for al ID.