Lattice evolutions at E.S.R.F.

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Lattice developments

- 7 m long straight sections
  - Simulations
  - Experiments

- Transverse aperture
  - On-momentum
  - Off-momentum

- Other studies
  - Injection perturbations
  - Filling patterns

Longer straight sections

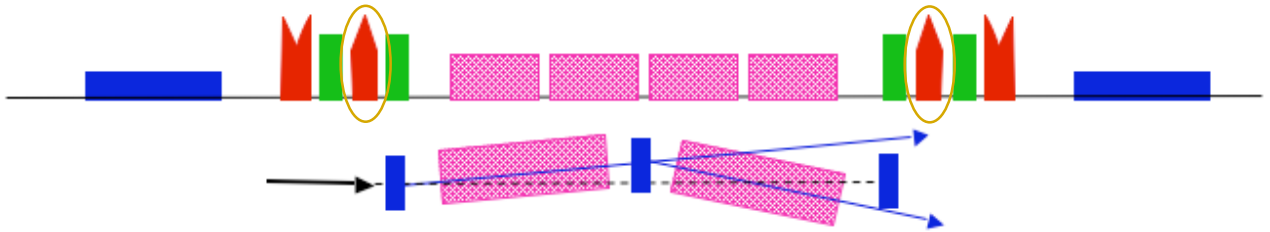
Initial configuration: triplet (for flexibility)

6.3 m between yokes, 5 m for ID

1st step: remove 1 pair of quadrupoles

7.4 m between yokes, 6 m for ID

2nd step: shorten the remaining quads



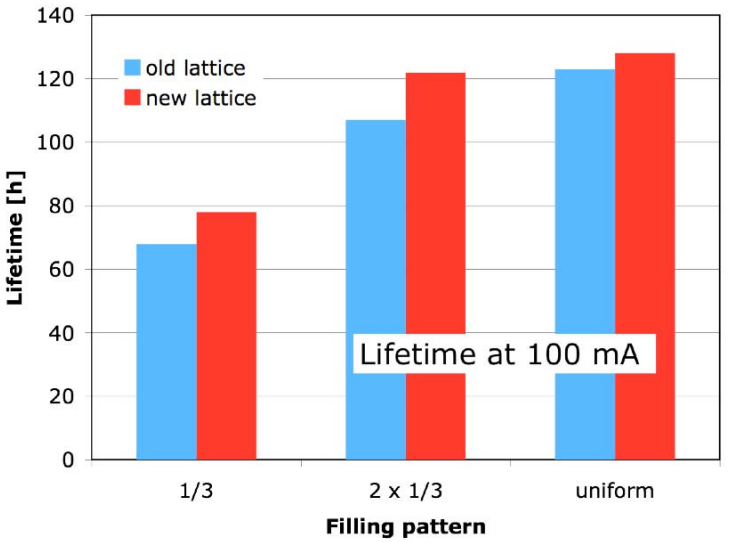
8.4 m between yokes, 7 m for ID

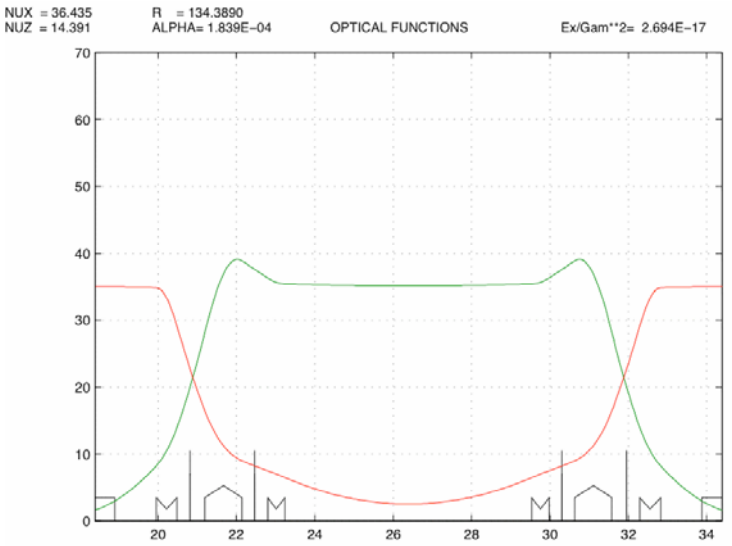
From 5 m to 6 m

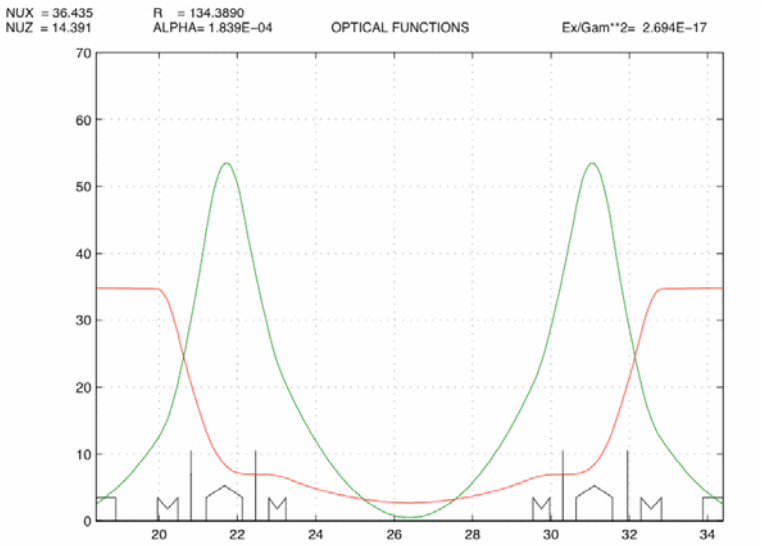
- Done on all sections
- In operation for 1 year now
  - Quadrupoles still in place but inactive,
  - A preliminary design of a 6m ID vacuum chamber is in progress
- New matching of the vertical β to optimize the vertical aperture
  - A first version (β_z = 3.5 m, ν_z = 12.39) gave a short lifetime
  - The present version (β_z = 3.0 m, ν_z = 13.39) is better than before

From 5 m to 6 m

- No penalty in lifetime
- Reasonably small difference at source point







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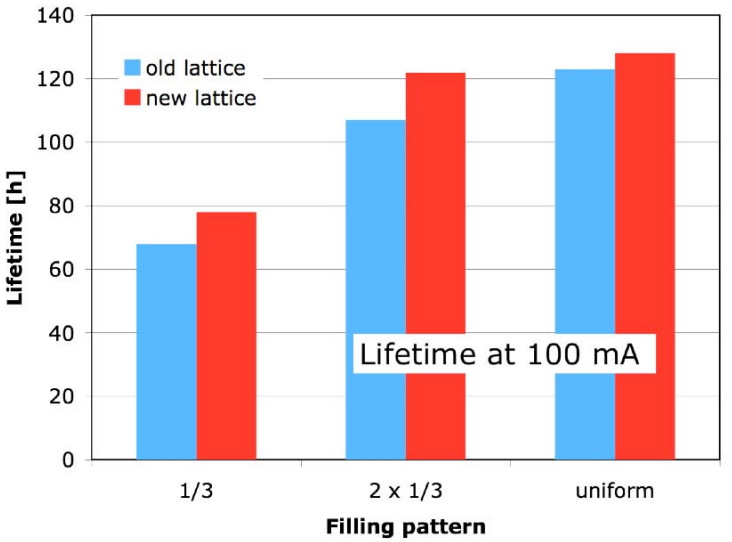
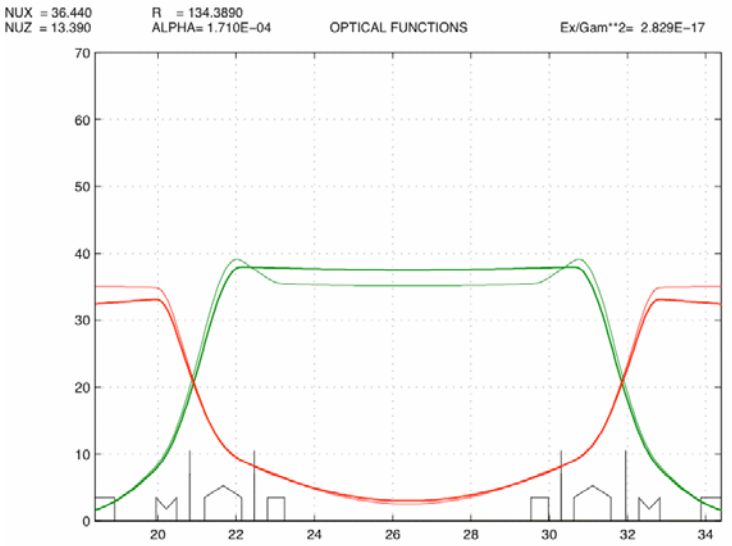
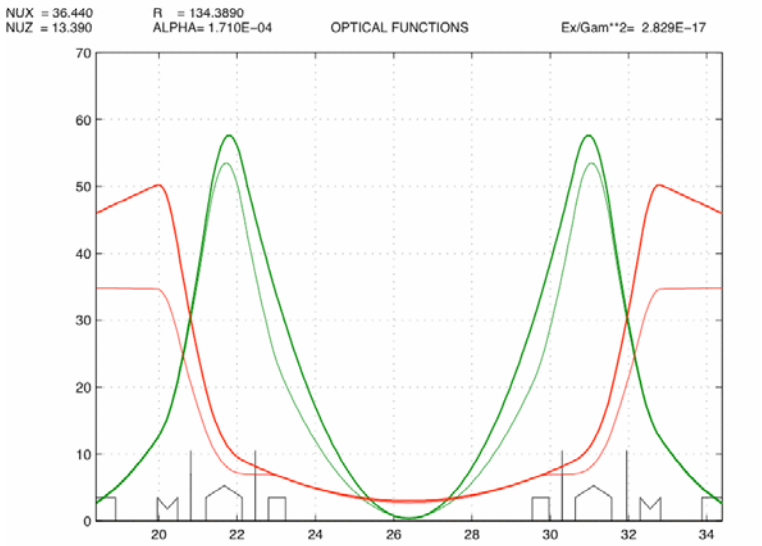




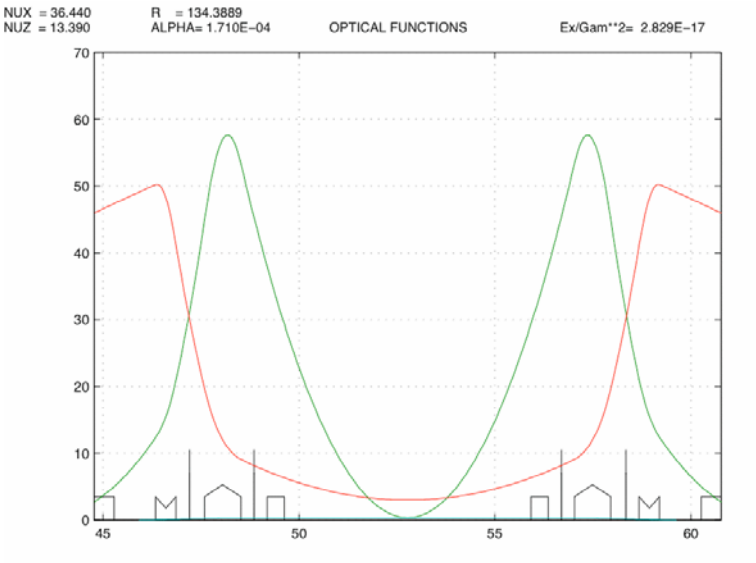


From 6 m to 7 m

- Reduce the length of the quadrupoles
- Keep the same layout on high and low-β cells
- More difficult on low-β sections
  - 1st idea: design a new focusing quad with very large gradient: 35 T/m
  - 2nd approach: balance the length of the 2 quadrupoles to get similar gradients (25 T/m)
- Sections will be modified 1 by 1 (or by pairs…)
  - Cost / unavailability of the machine
  - Initially few candidate beam lines
- Symmetry breaking of the lattice

Simulations

- Transverse aperture simulations
  - The aperture is strongly reduced by the detuning
  - It can be partially restored by tuning the 2 sext. families in the detuned section
  - The relationship with the lifetime is difficult to estimate



Example for experimental detuning of ID20

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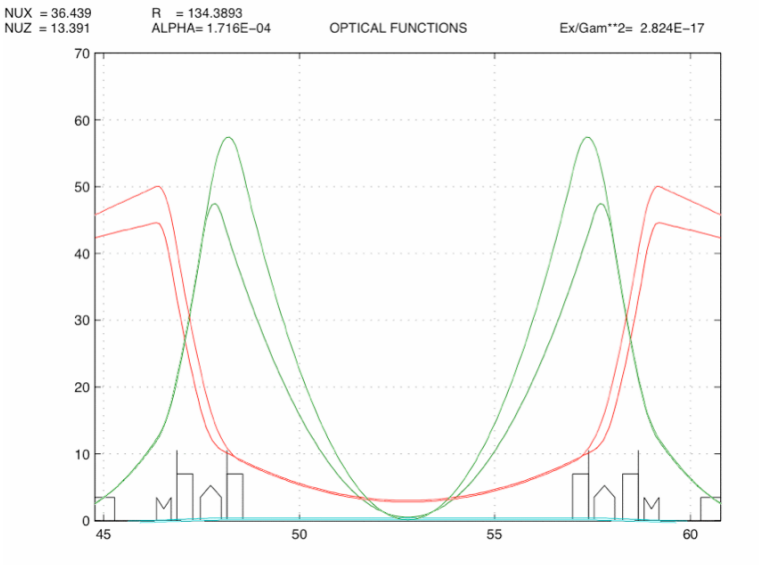

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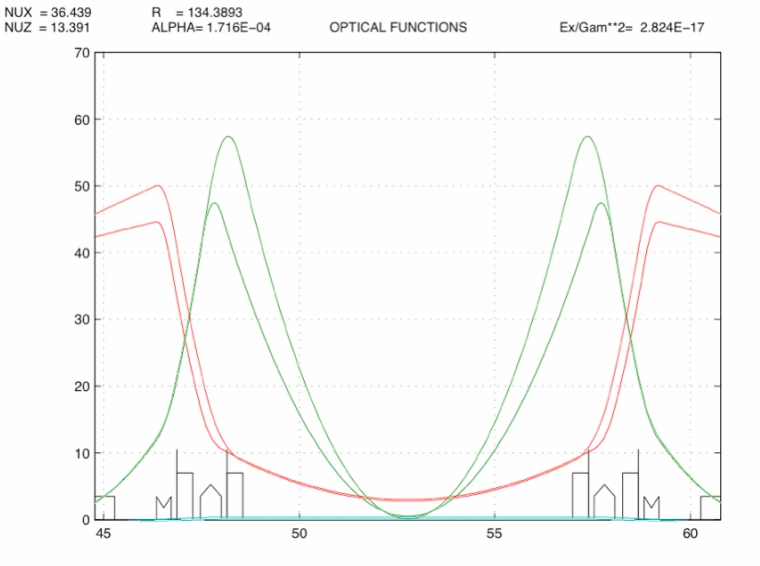
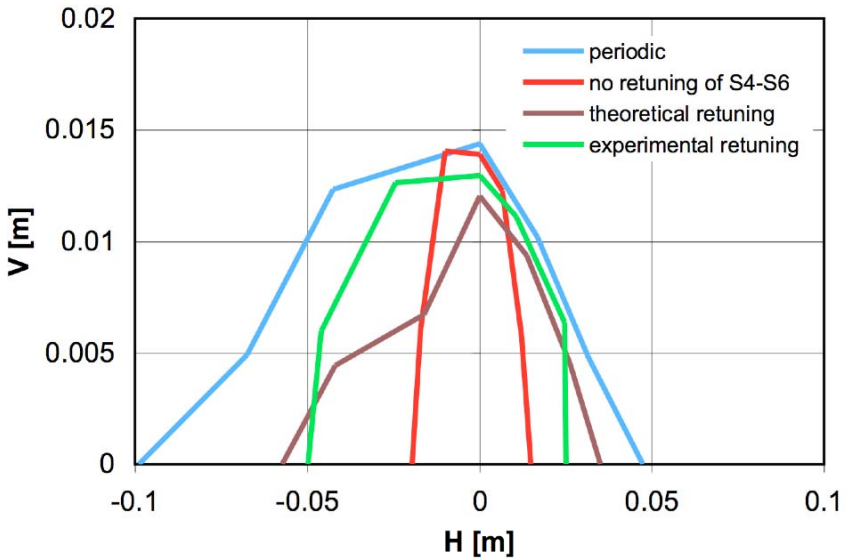




Example for experimental detuning of ID20

Experiments

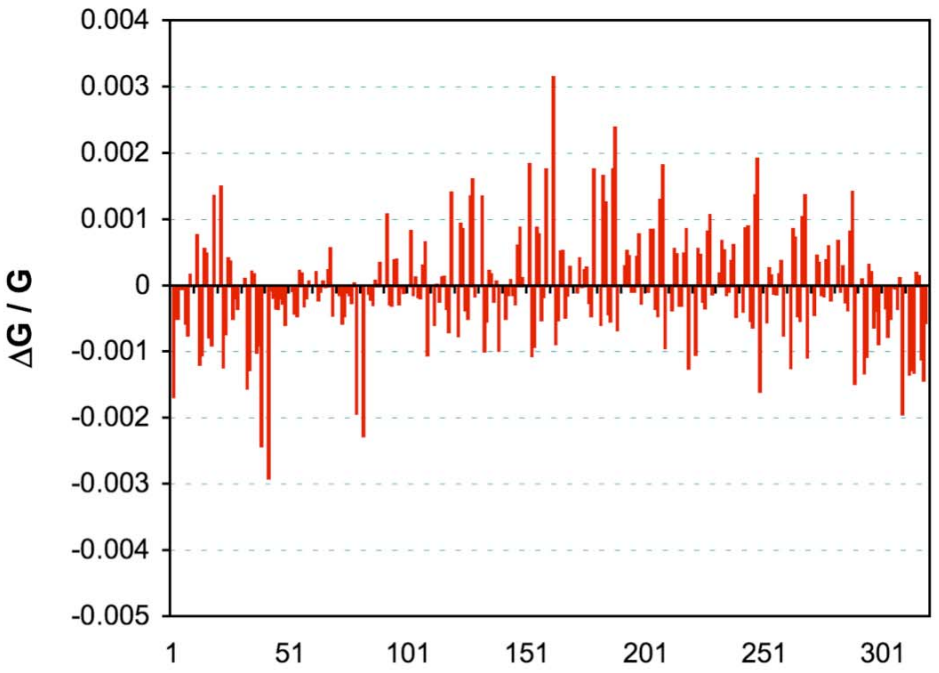
- Though we cannot simulate the behaviour of a 7m straight section, we can power the (now) unused quadrupoles QD1/QD8 in a single straight section to introduce a symmetry breaking in the lattice
- We implemented this capability in 4 straight sections:
  - High-β: ID4, ID6, ID20 (ID4 and ID20 are 180º apart)
  - Low-β : ID11
- We tried different combinations of detuned straight section
- Are pairs of modified straight sections (180º apart) better ?

Tuning of a single section

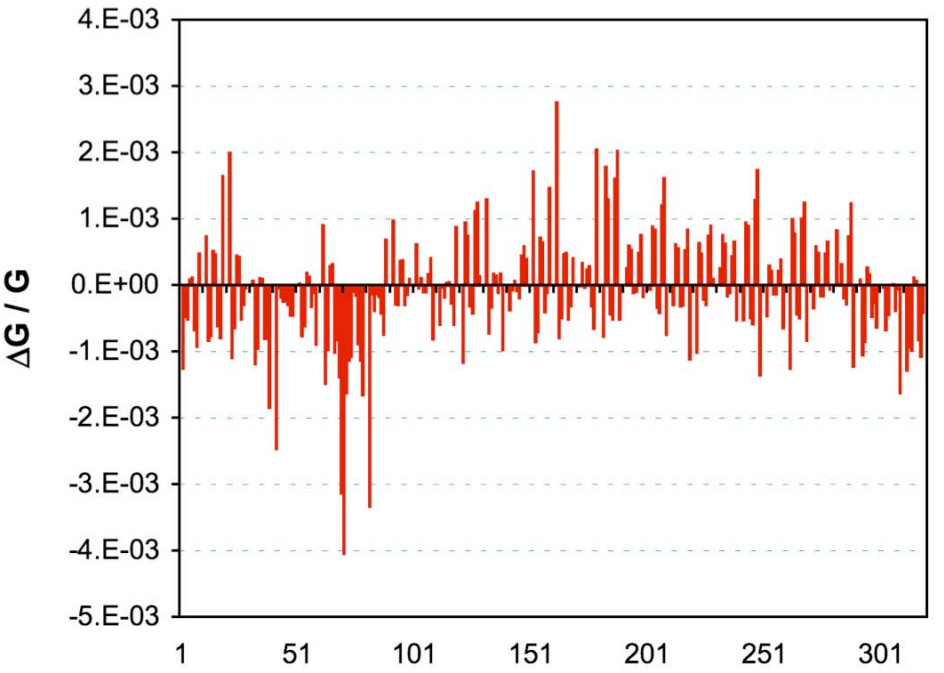
- 1st order tuning
  - Response matrix analysis
    (Initial setting was always good)
- Sextupole tuning
  - Start with simulation results
  - Scan the 2 families to optimise the lifetime
- Quadrupolar corrections
  - Use response matrix analysis to minimise β-modulation
- H/V coupling corrections
- Sextupolar corrections
  - Scan the correction of the 2 neighbouring 3rd order resonances to optimise the lifetime

Quad. Error modelling

Example of quad error analysis used in correcting quad errors:



Periodic lattice



ID11 detuned

Experimental results

- 1 high-β straight
  - Lifetime (200 mA, 2/3 filling, all ID gaps and scrapers open, vertical emittance ~ 20 pm)

Tuning step	Lifetime (h)
Periodic machine	70
Detuned ID20	32
Sextupole scan	57
Quad. error Correction	65
Sext. error Correction	75

  - Horizontal aperture: no difference
  - Injection efficiency: no difference

Experimental results

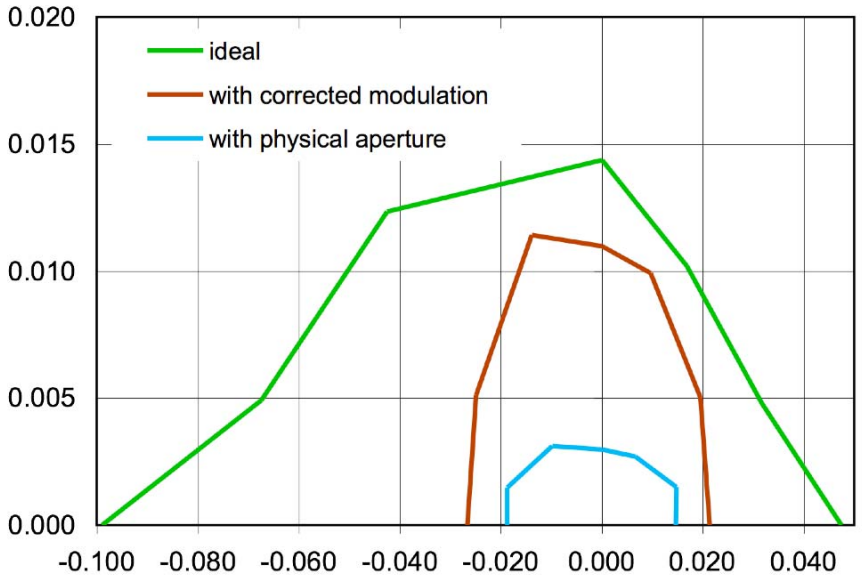
- Several straights
  - As the lifetime depends on the machine conditioning, the results may vary between experiments…

Tuning step	Lifetime (h)
Periodic machine	70
1 high-β straight	75
1 low-β straight	67
2 high-β straights	68
1 high-β + 1 low-β	69
2 high-β + 1 low-β	68

  - Horizontal aperture: again no difference, more later…

Horizontal aperture

- For long, the reason for the limitation of the horizontal aperture at 15 mm is unclear



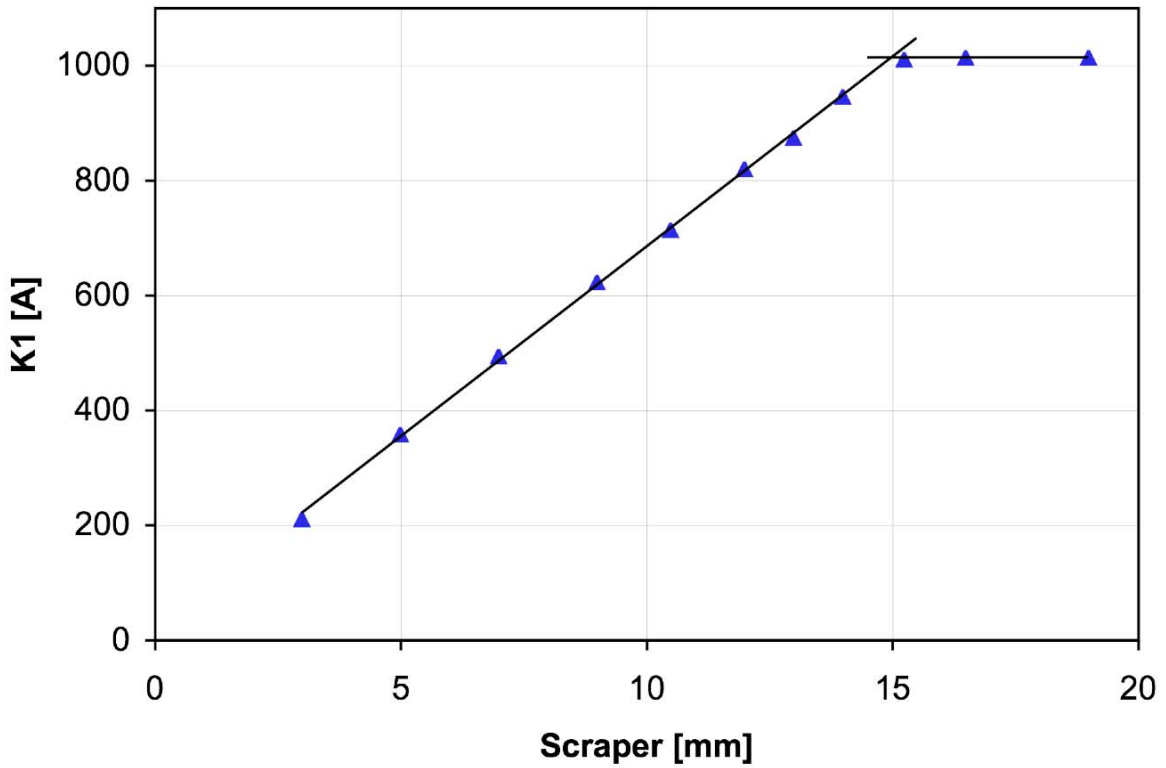
- With new (and distorted) lattices, we have more measurements.
- The aperture limitation is an “ESRF constant”, valid for ~any lattice

Measurement method

- The β-modulation is carefully corrected (~2.5%)
- An horizontal scraper is introduced in the ring
- The beam is kicked by an injection kicker with an increasing strength
- For each given strength, $\Delta I/I$ is averaged over a few kicks
- The maximum kicker strength corresponding to a given scraper aperture is conventionally defined by $\Delta I/I=5\%$
- The measurement is repeated when varying the scraper position, providing a calibration of the kicker current in terms of machine aperture

Aperture measurements

- Reproducibility and accuracy are excellent: ~0.1 mm
- Nearly all measurements give ~15 mm
- The septum is NOT the limitation



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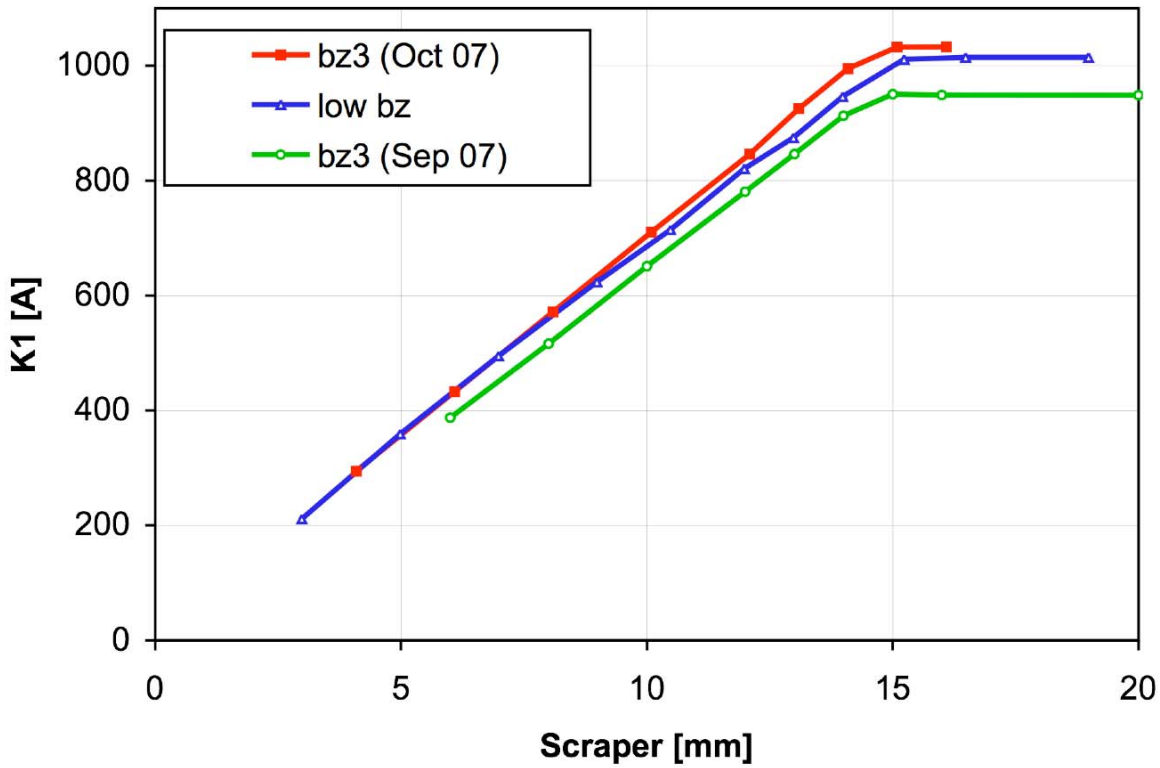

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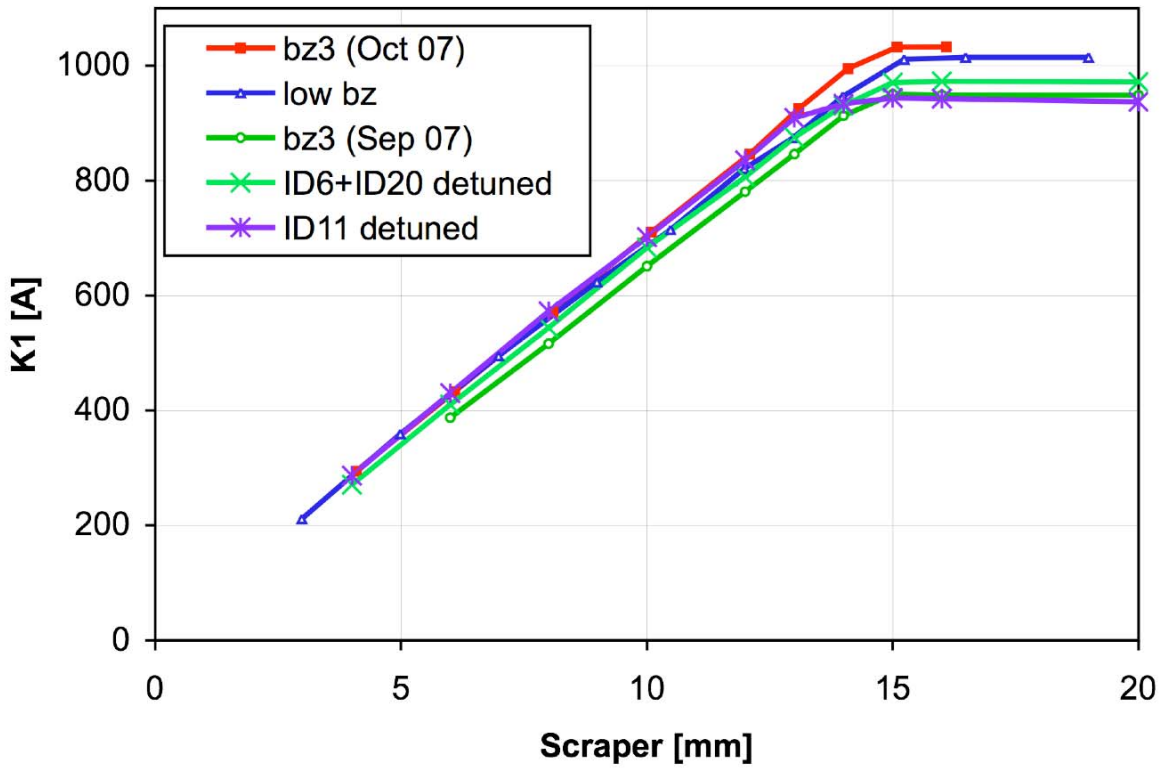
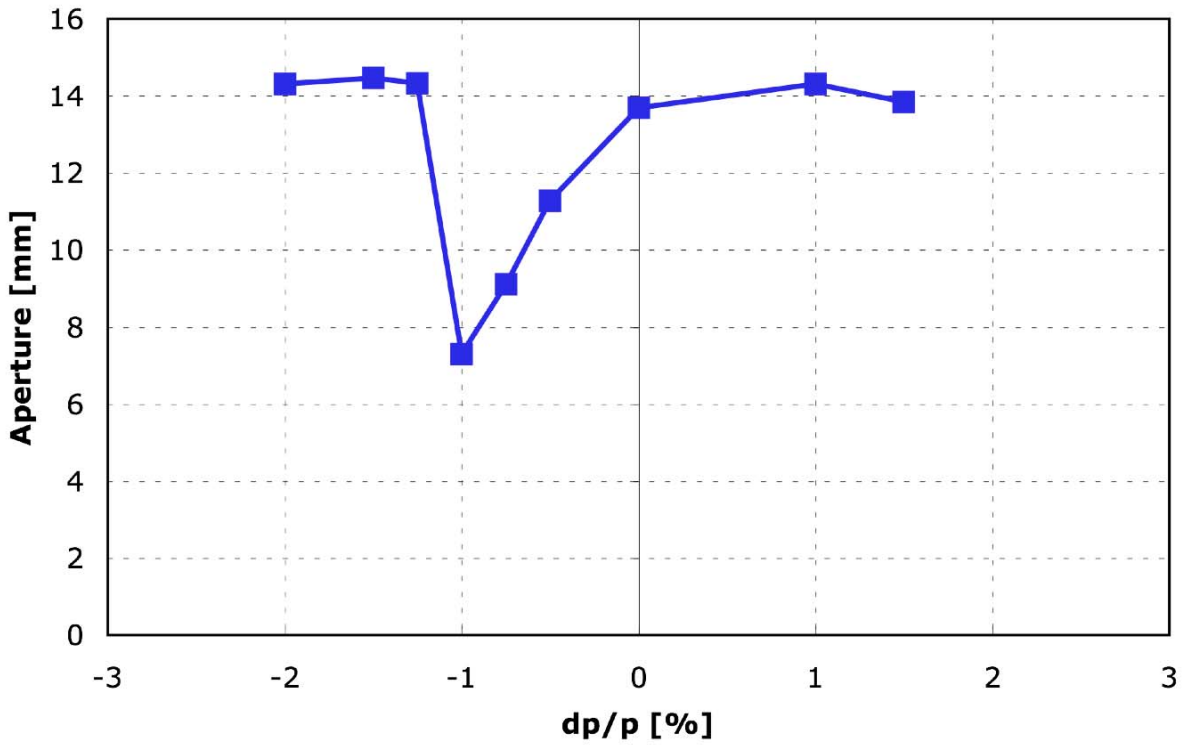


Off-momentum aperture

- Strong limitation at -1%
  - All lattices show this behaviour
  - No model (including errors) can explain it

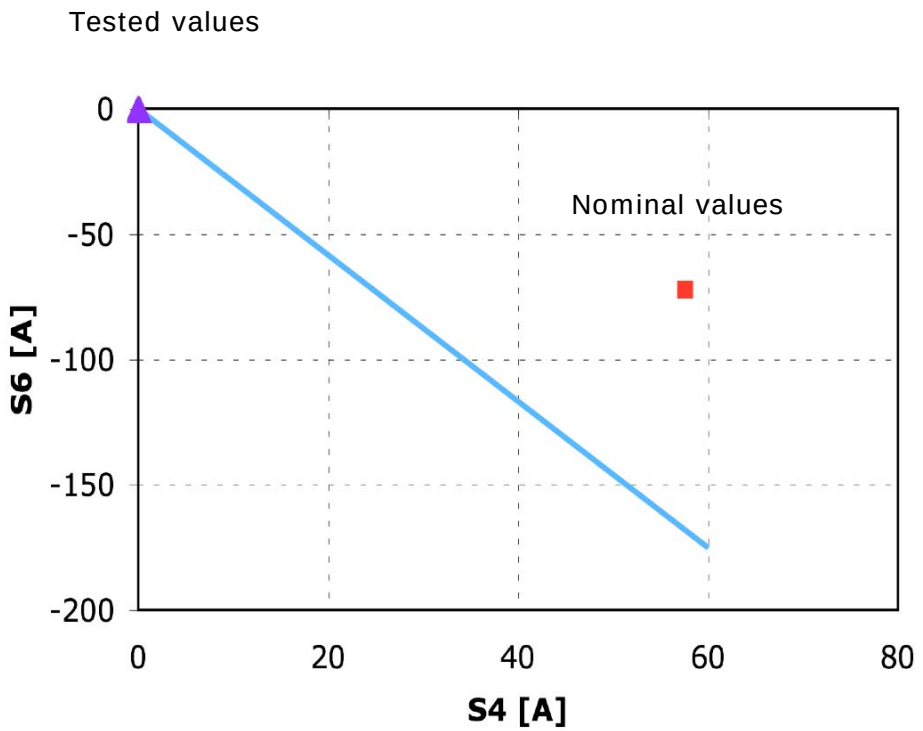


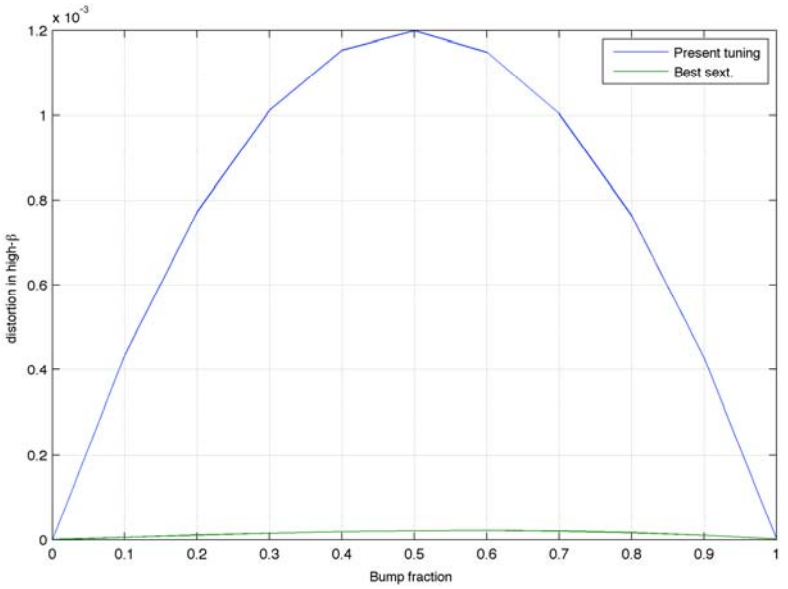
Injection perturbation

- The sextupoles located within the injection bump introduce orbit perturbations for particles experiencing the ramps of the bump (2/3 of the circumference).
- This is penalizing the top-op operation.
- The 2 sextupole pairs within the bump can be adjusted to minimize the perturbations (*H. Tanaka, 2004*)
  - Strong aperture reduction in simulation
  - Retuning the sextupole families restores partially the aperture
  - Some residual oscillation

Injection perturbation

- The best tuning is with sextupoles off
- We observe a strong lifetime reduction
- Other ways to minimise the perturbation ?
  - Additional kicker…



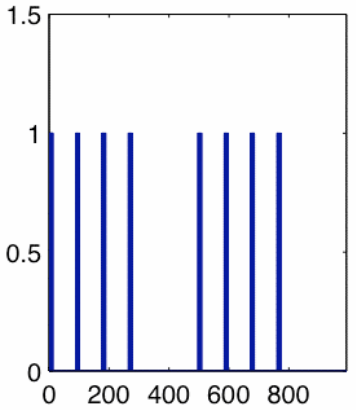


Filling patterns & lifetime

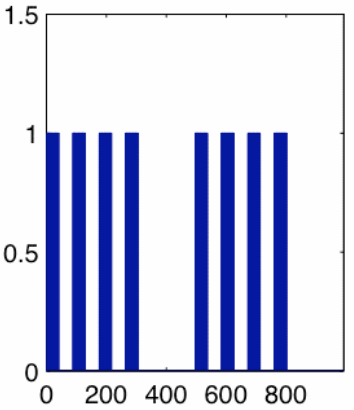
- It looks that the lifetime in uniform filling mode is not as large compared to partial filling as it was in the past
- Try to separate contributions from:
  - Residual gas: Coulomb scattering, Brehmsstrahlung
  - Intra-beam collisions: Toushek effect
- Vary a single parameter:
  - Work at a constant total current: all residual gas-related effects should not vary
  - Vary the electron density by varying the number of bunches in the machine

Filling patterns at 100 mA

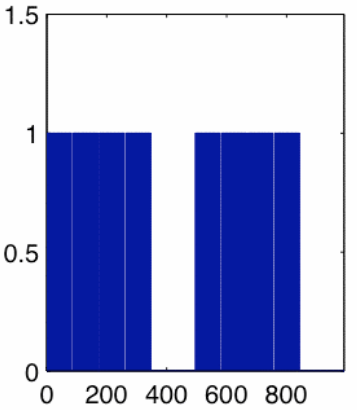
Minimum:
104 bunches

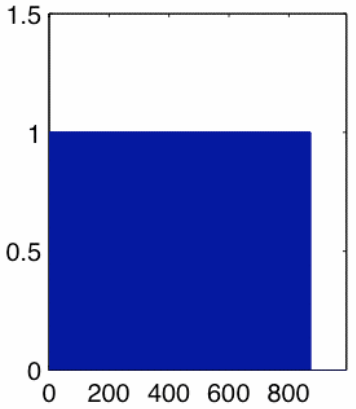


~ 1/3 :
328 bunches

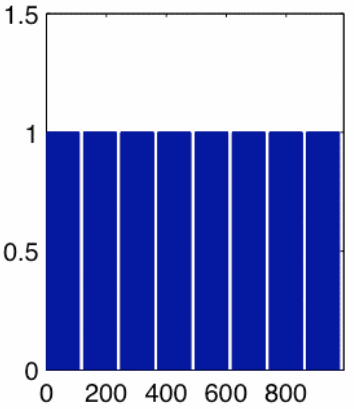


~ 2 x 1/3:
656 bunches

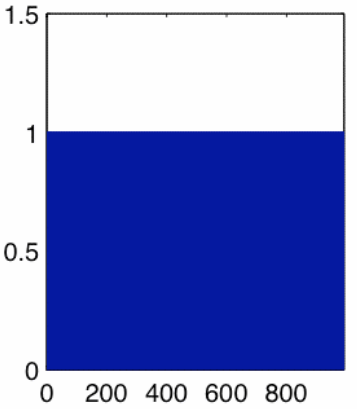




~ 7/8:
872 bunches



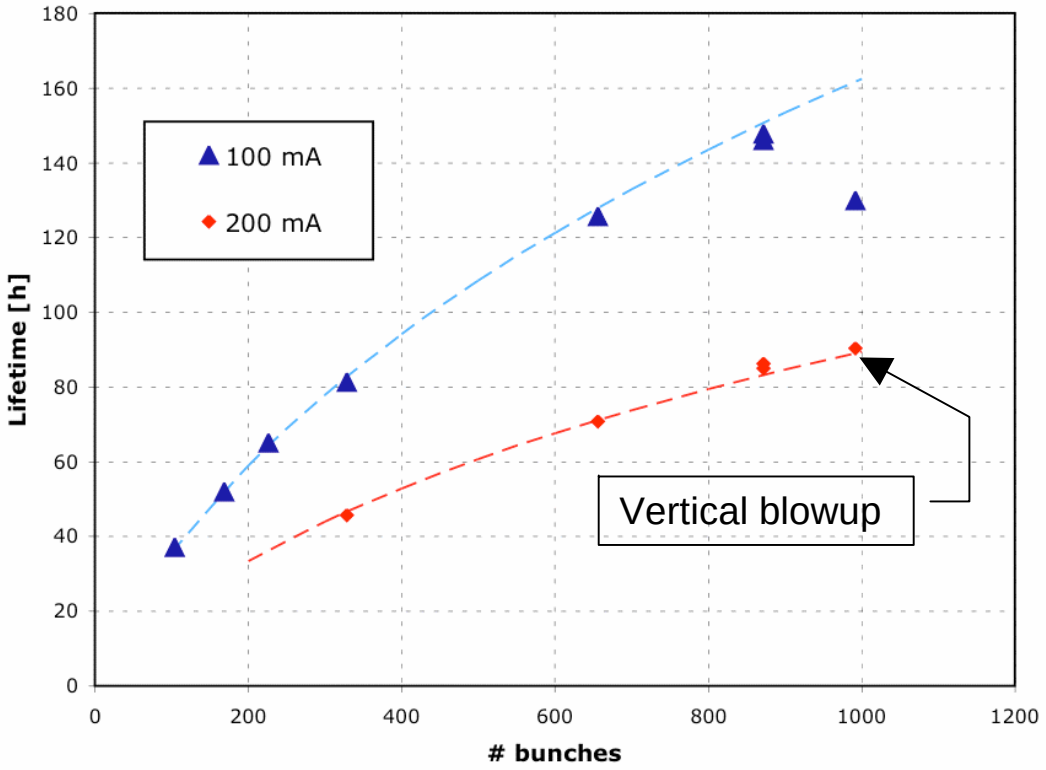
7/8 without large gap:
872 bunches



Uniform:
992 bunches

Single model

$$\frac{1}{\tau} = A_0 + A \cdot I_{total} + B \cdot I_{bunch}^{C}$$



- The model fits all filling patterns except uniform filling
- In uniform filling, the lifetime is much smaller than expected: ion trapping increasing locally the residual pressure seen by the beam ?
- At 200 mA, the emittance blowup created by the ion instability compensates for this effect
- A gap of 15 buckets is enough to avoid the lifetime reduction

Summary

- The installation of modified straight sections 7 m long should have marginal detrimental effects on the machine lifetime,
- Though their installation in pairs should be better in terms of periodicity of the machine, we could not see any difference,
- The limitation of the on-momentum horizontal aperture of the Storage Ring is still unknown.
- The reduction of injection perturbations has a cost in lifetime…