Non-linear behaviour of the ESRF lattice: a few puzzling points

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Outline

- The ESRF lattices
- Model and experimental tuning
- Real physical aperture
- Dynamic aperture
  - ✓ Measuring technique
  - ✓ On-momentum results
  - ✓ Off-momentum aperture
- Conclusions

The ESRF lattices (1)

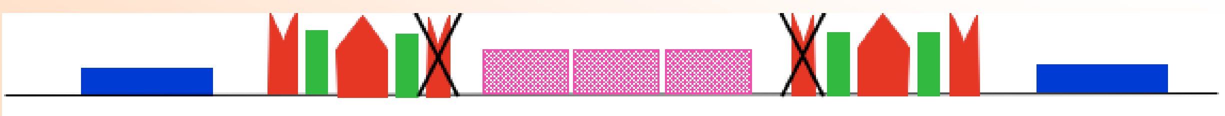
1992: Initial 7 nm expanded Chasman-Green lattice

1995: Moved to a distributed dispersion lattice

1996: Reduction of β_z from 13 m to 2.5 mm in undulator straight sections — **low β_z**

2000: Horizontal focusing optics — **HFO**

2006: Switch from triplets to doublets in straight sections — **noQD1QD8**



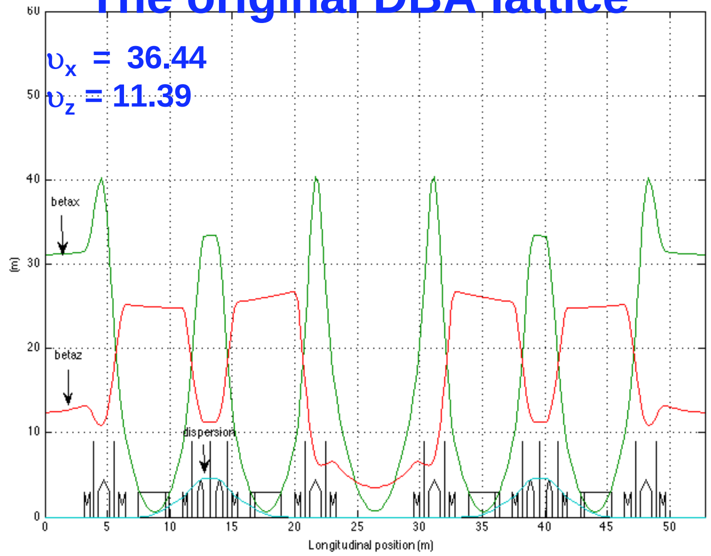
β_z=3 or 3.5 m

2007: Detuning of one or several straight sections

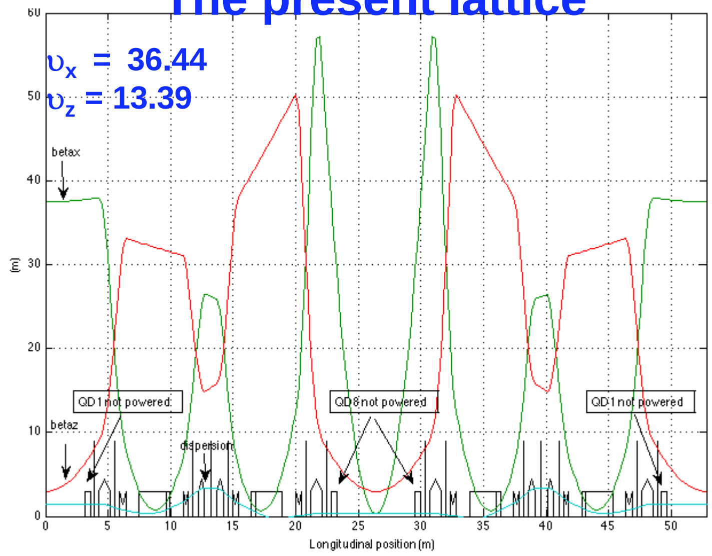
The ESRF lattices (2)

- 10 (**8**) quadrupole families powered in series
- 6 (**7**) sextupole families (2 ---> **3** chromaticity, 4 harmonic) powered in series

The original DBA lattice



The present lattice



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The ESRF lattices: Detuning of straight sections (1)

Future upgrade of straight section length from 6 to 7 m

Will be implemented on a limited number of straight sections to minimise cost and downtime

Symmetry breaking of the lattice

- ✓ Dynamic aperture reduction
- ✓ Injection efficiency and lifetime reduction

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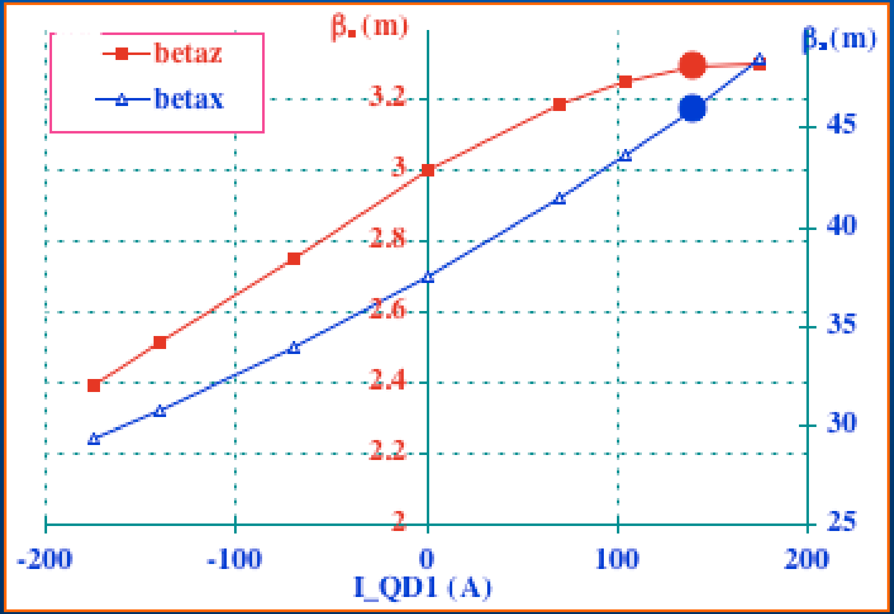
The ESRF lattices: Detuning of straight sections (2)

The impact of the symmetry breaking can be approached by detuning one or several straight sections and changing locally the β-functions

Quadrupoles and sextupoles can be individually powered in ID4, ID6, ID11 and ID20



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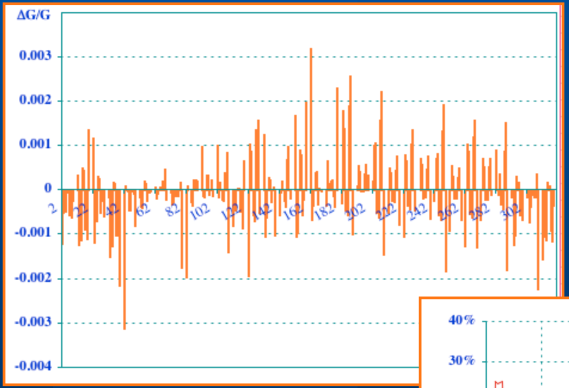
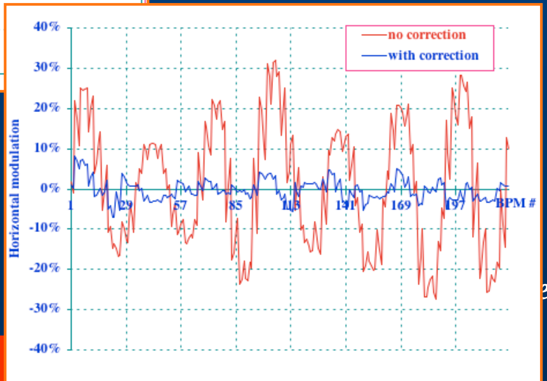
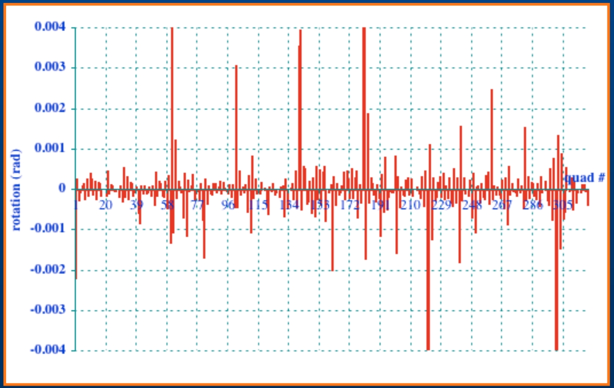
Model and experimental tuning (1)

- Analysis of focusing errors from orbit response matrix
  - -Quadrupolar errors
  - -Quadrupolar correctors to minimise β-beat

- Correction of the difference and sum coupling resonances
- Coupling errors (rotation of quadrupoles + correction) deduced from response matrix measurements

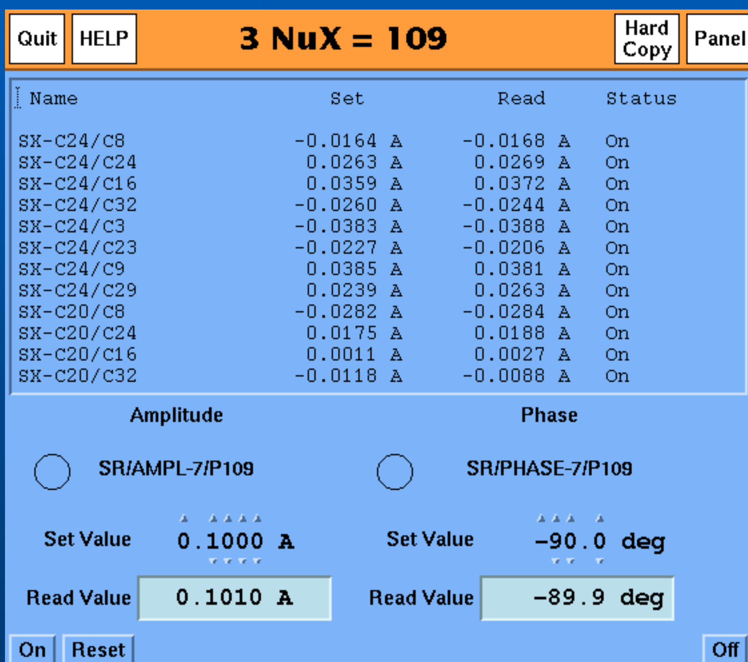


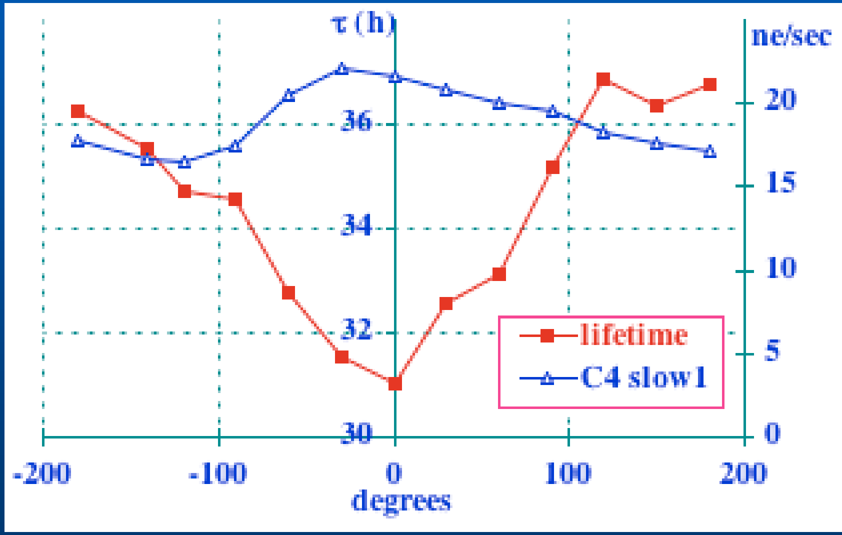




Model and experimental tuning (2)

- Scan of sextupolar correctors to improve the lifetime





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Model and experimental tuning (3)

- Field errors in magnets (individual results from magnetic measurements)

  dipoles, quadrupoles, closed orbit correctors

- Insertion devices not included (open during experiments)

- Physical aperture

  Horizontal: injection septum located at -19 mm of beam axis

  Vertical: low gap ID chambers

  beam stay-clear: ± 4 mm

  length: 5 m

  in-vacuum undulators

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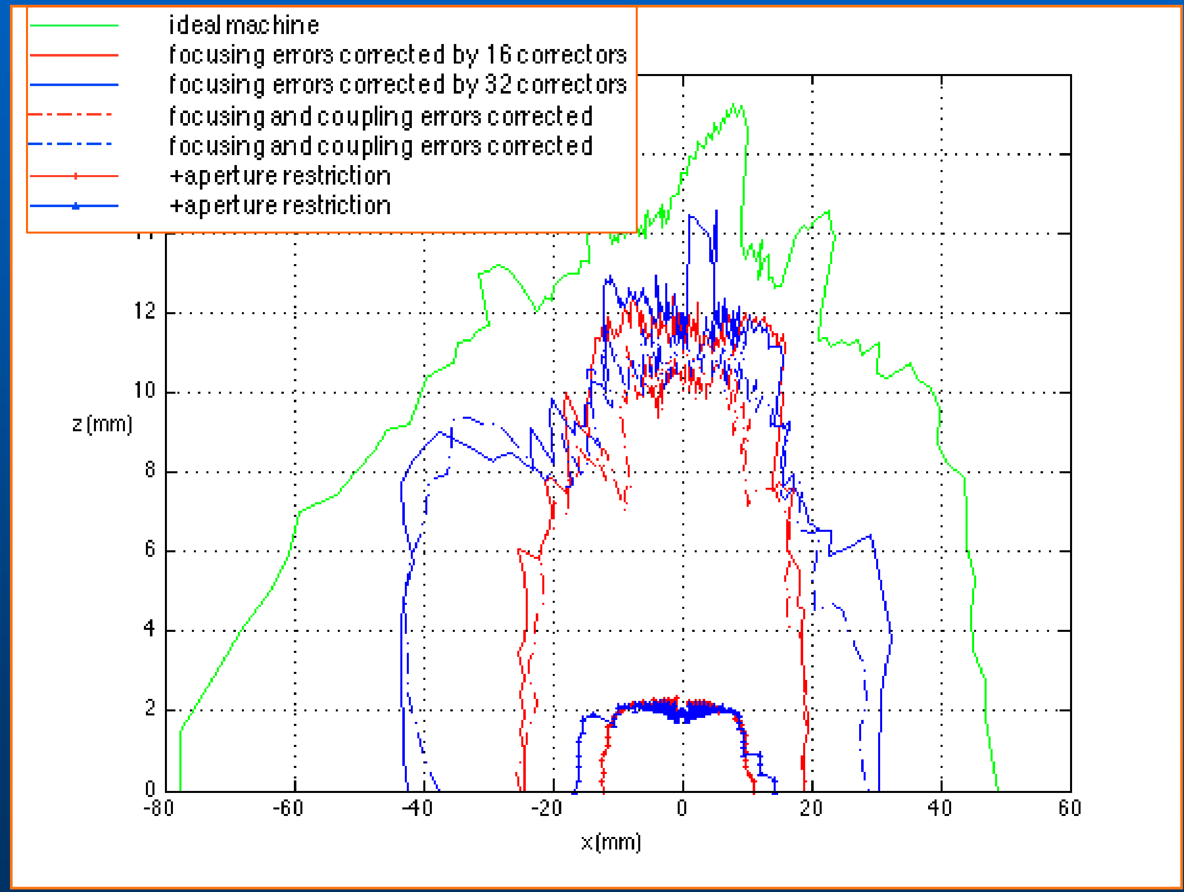
Model versus ideal lattice

Errors of the real machine destroy the 16-fold periodicity

Even a residual 2 % modulation induces a drastic reduction of the dynamic aperture

Non-linear HV coupling responsible for the additional reduction



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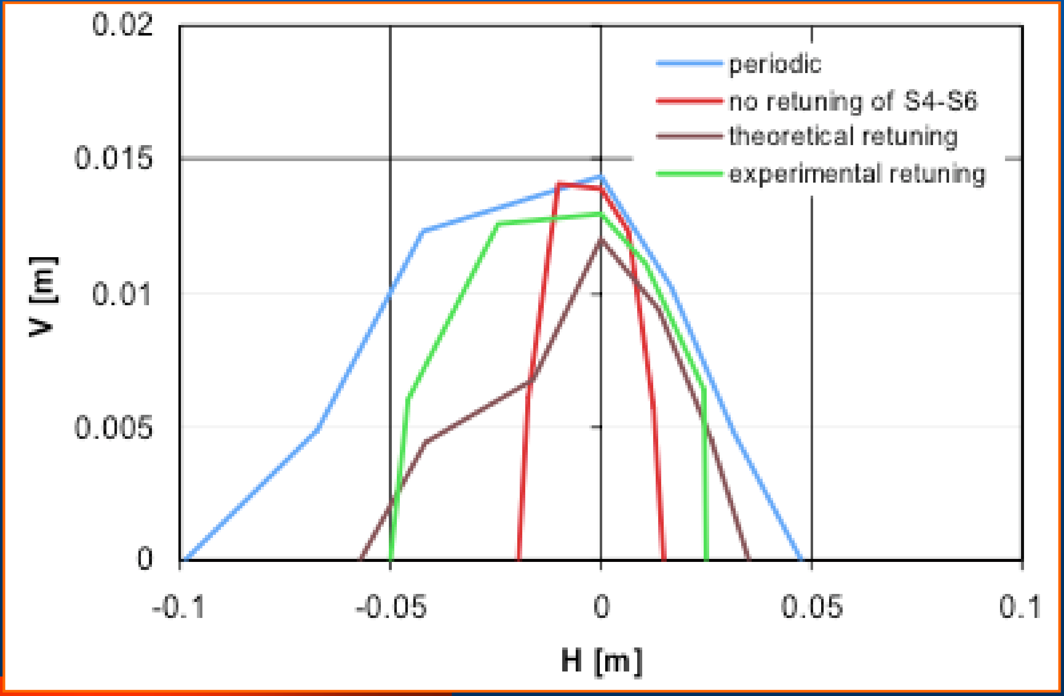
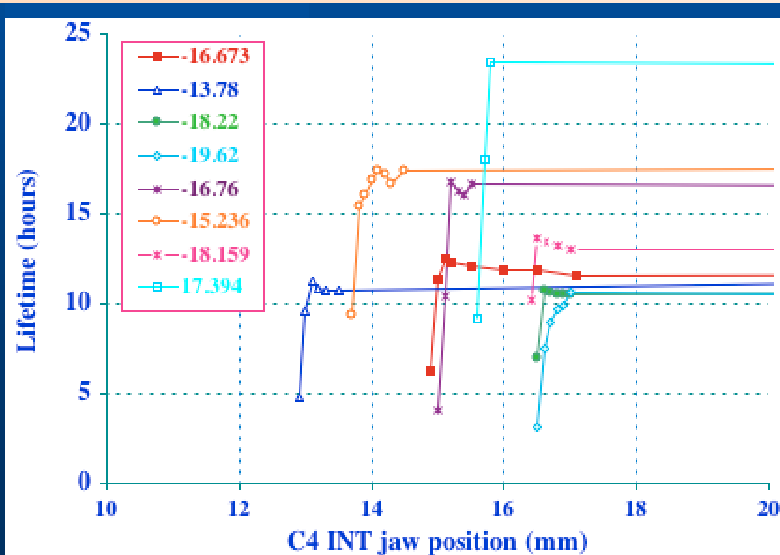
Detuning of a straight section

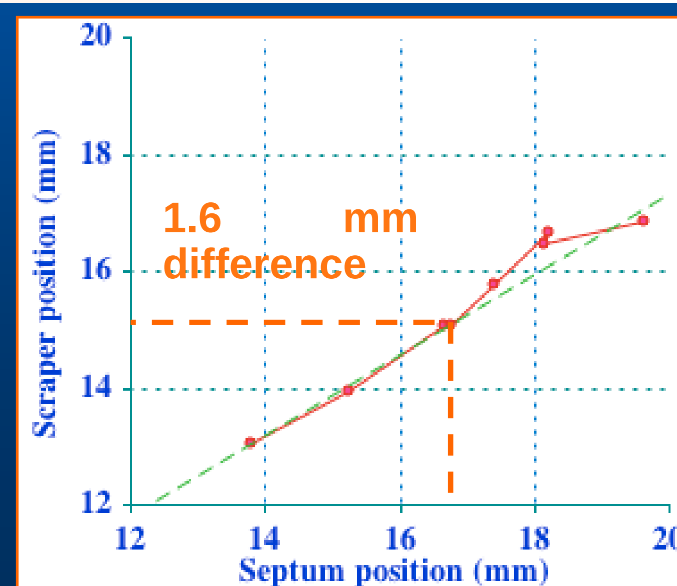
- Strong reduction of the aperture of the ideal machine
- Can be partly restored with retuning the 2 sextupoles of the straight section



Horizontal physical aperture

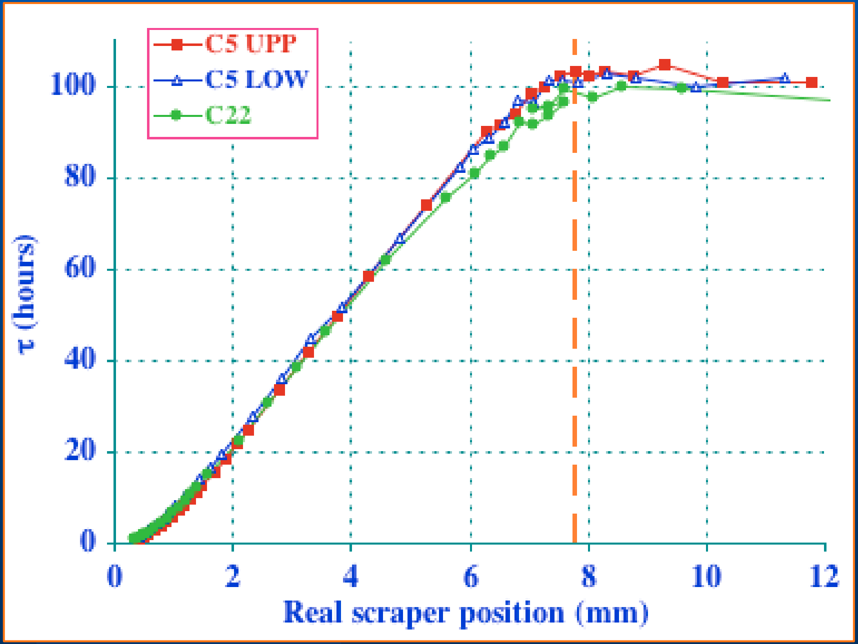
- Move the septum by steps
- Increase the amplitude of the closed injection bump until the lifetime of the stored beam is significantly affected
- Close the internal jaw of the scraper until the lifetime starts to decrease



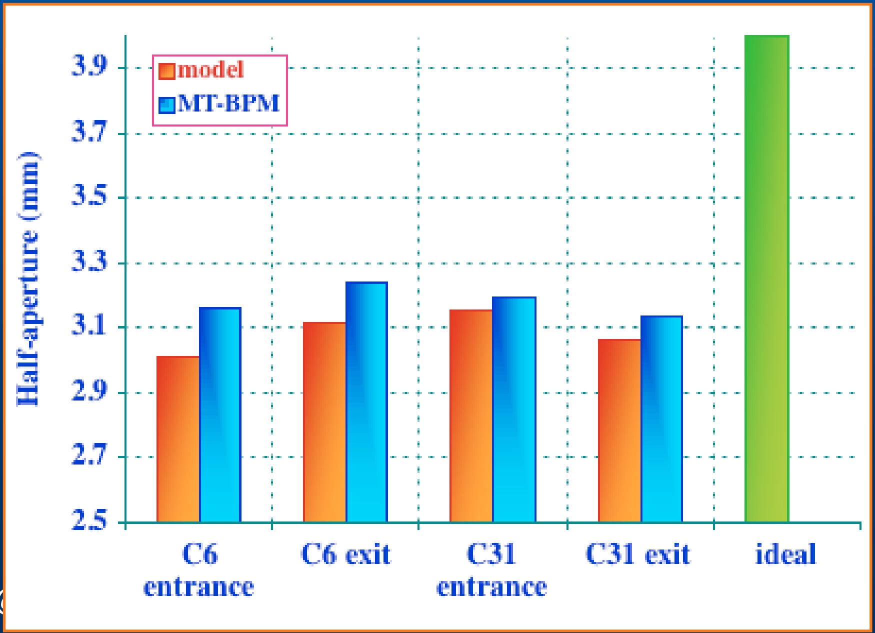


Vertical physical aperture

● Record the lifetime when reducing the acceptance with a vertical scraper jaw



● $\sqrt{\frac{\beta_{CV5000}}{\beta_{scraper}}}$ scaling for the acceptance at the ends of CV5000 vessels



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Dynamic aperture measurements (1)

Method #1

- Lifetime recorded versus amplitude of an horizontal oscillation driven by permanently running the injection kicker
- Kick calibrated by a scraper jaw
- Scraper offset calibration

Method # 2

- Measurement of the relative change in beam current $\frac{I_n - I_{n-1}}{I_{n-1}}$ after a single kicker shot

- Kick calibrated by a scraper jaw
- Scraper offset calibration

Method #2 is faster and has been adopted

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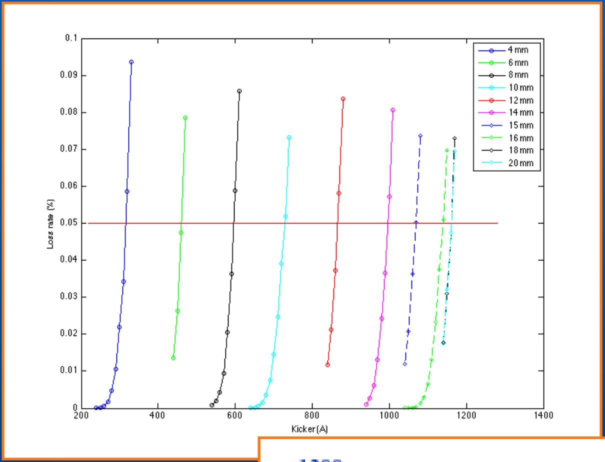
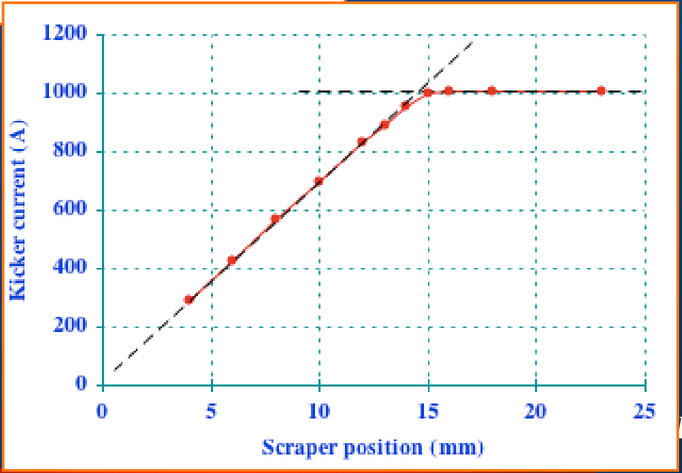
Dynamic aperture measurements (2)

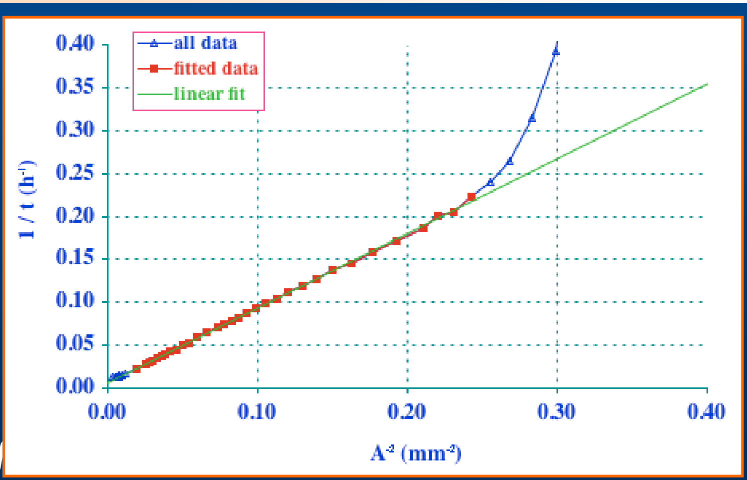
Kick calibration





Scraper offset calibration

- Analysis of the elastic gas scattering lifetime evolution when closing the scraper
- Inverse lifetime fitted to a linear law $\frac{1}{\tau_{meas}} = b + \frac{a}{(scraper\_position - offset)^2}$



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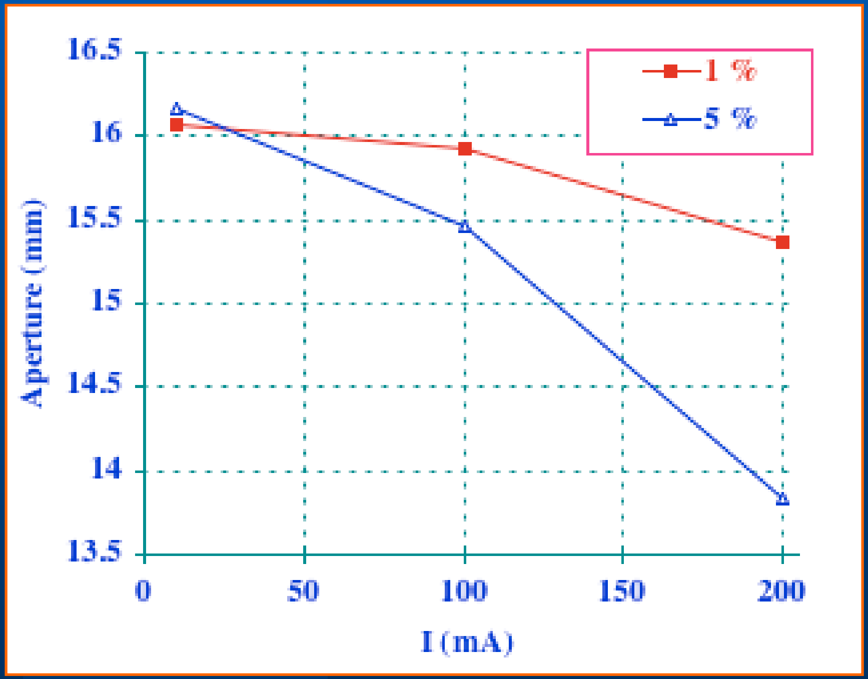
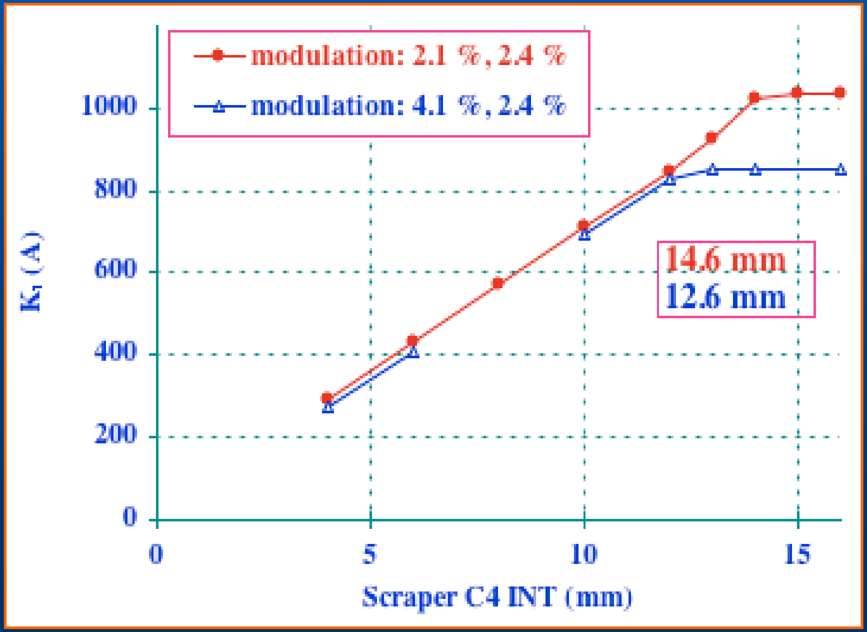
Dynamic aperture measurements (3)

Same procedure to be used to ensure fair comparison: beam current, loss rate criteria, resonance correction,…





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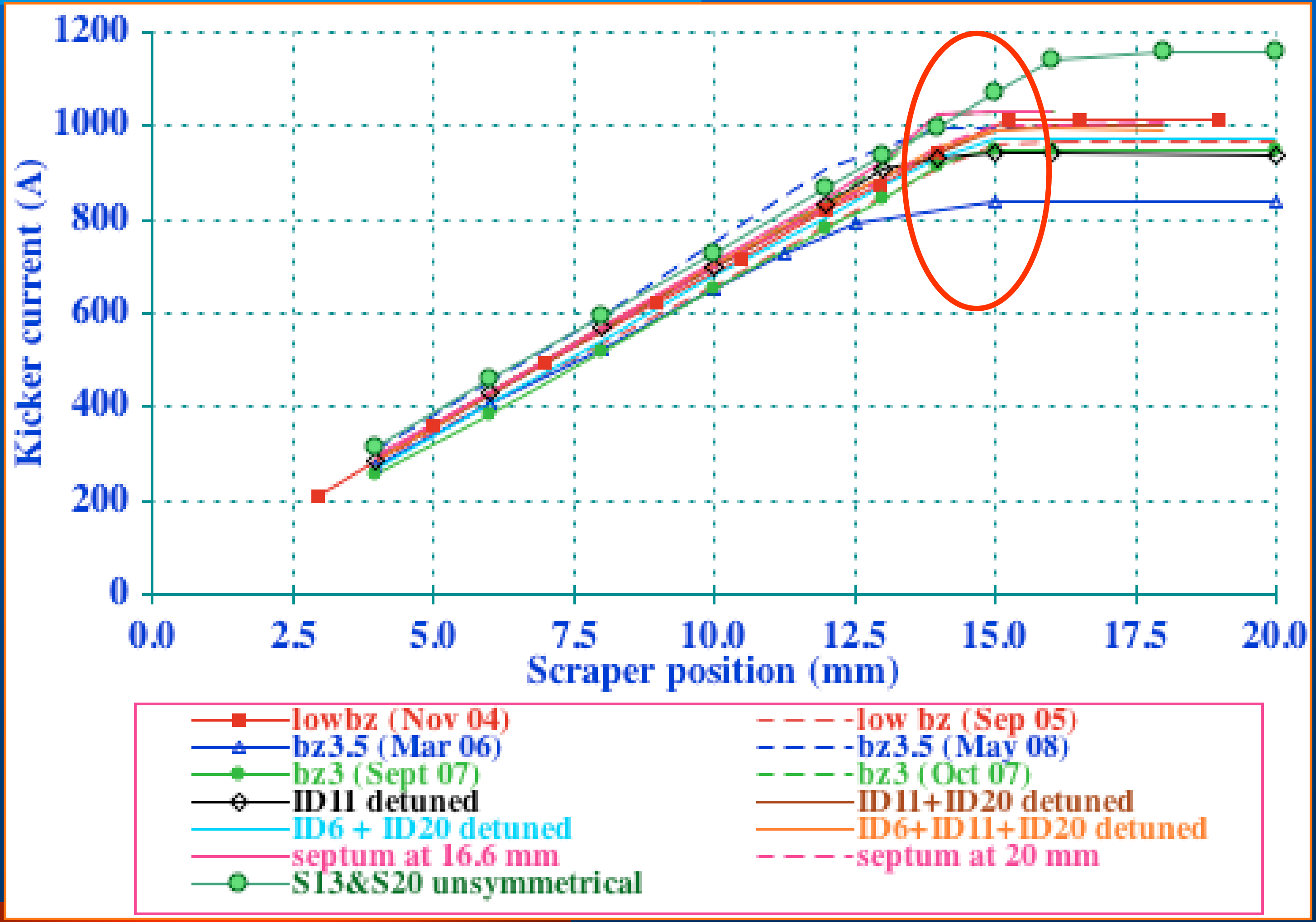
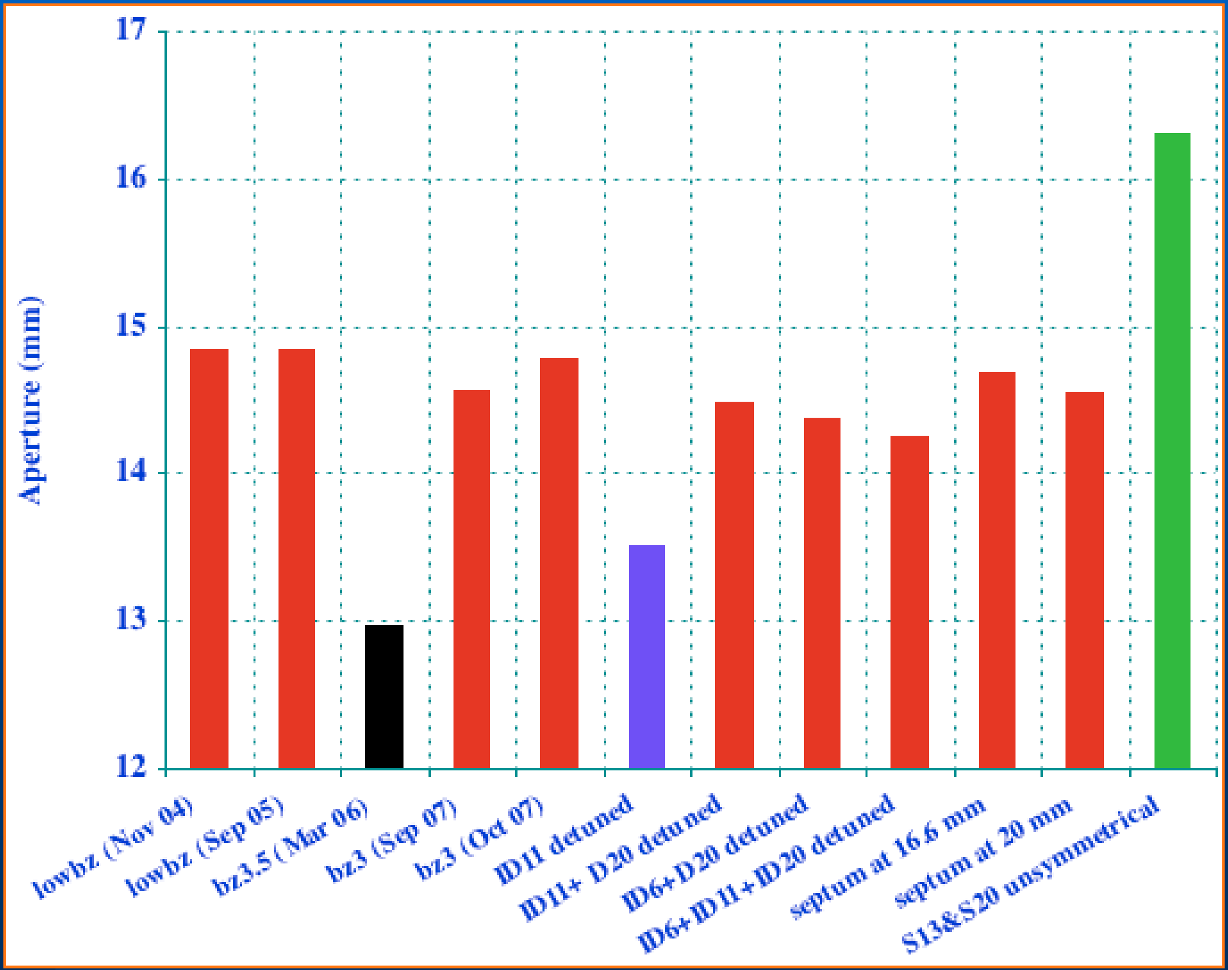
Aperture results (1)



Aperture results (2)

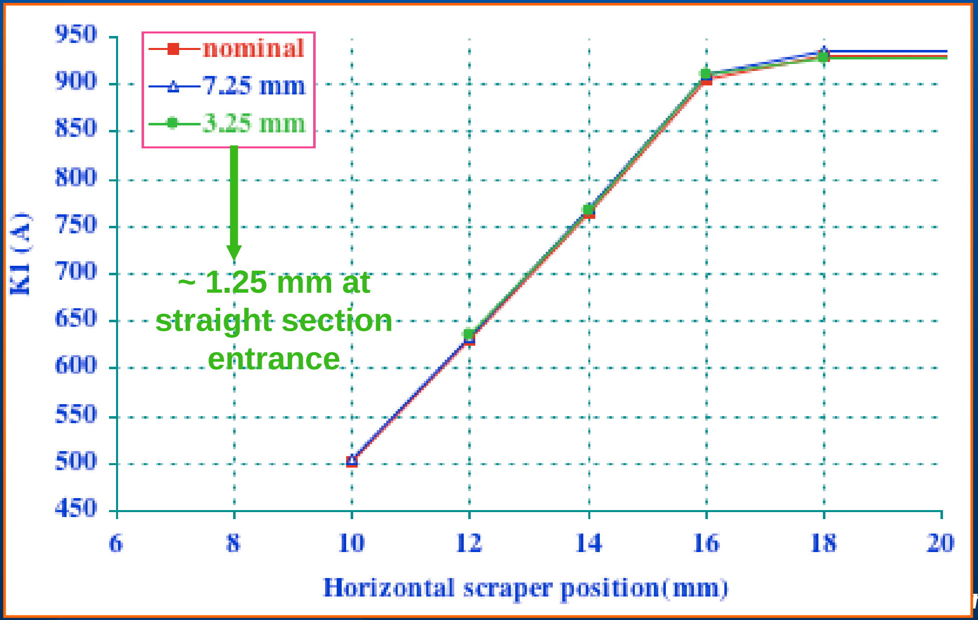


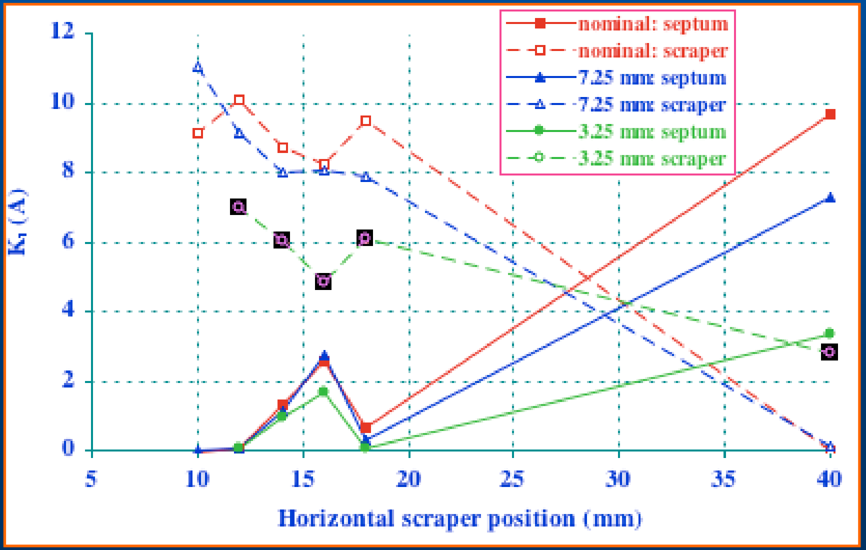
- Good accuracy and reproducibility
- Aperture limitation around 15 mm is almost an "ESRF" constant
- The septum is not the limiting factor
- No clear explanation for the limitation of the on-momentum aperture

Aperture results (3)

Could the horizontal-vertical coupling be responsible for the limitation, as suspected in simulations ?

Aperture measurements with closing a vertical scraper jaw and monitoring losses





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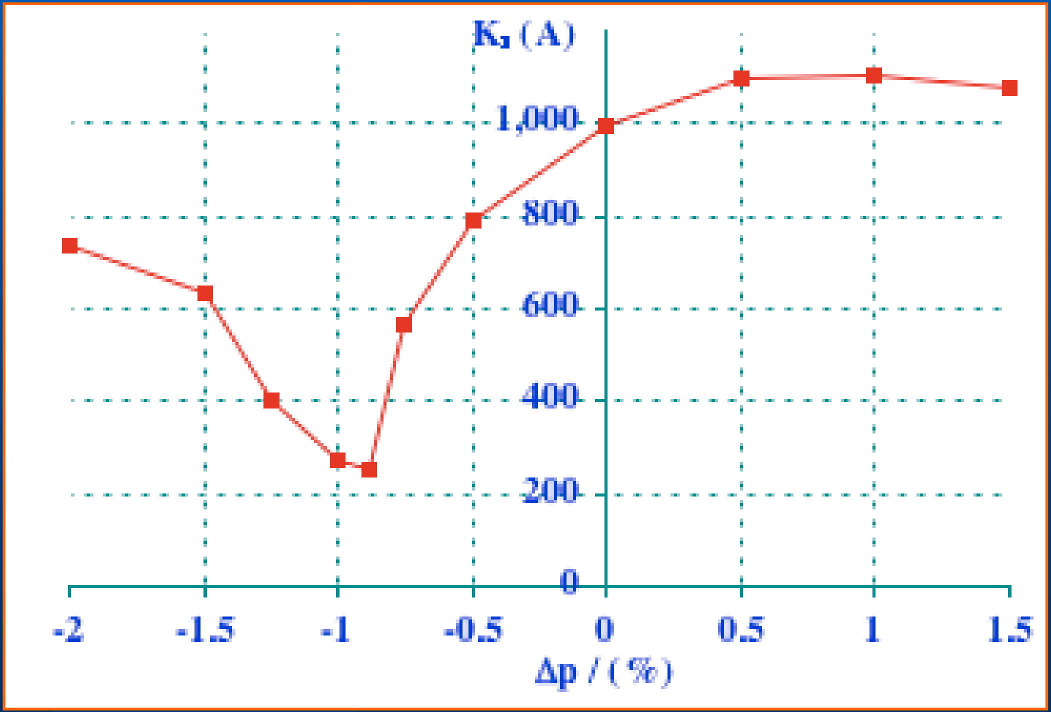
Off-momentum aperture (1)

- RF frequency changed in steps
- Aperture measured by the loss rate method



Puzzling dip around -1 % already observed in 2000

Cannot be reproduced in tracking simulations except with very exotic conditions

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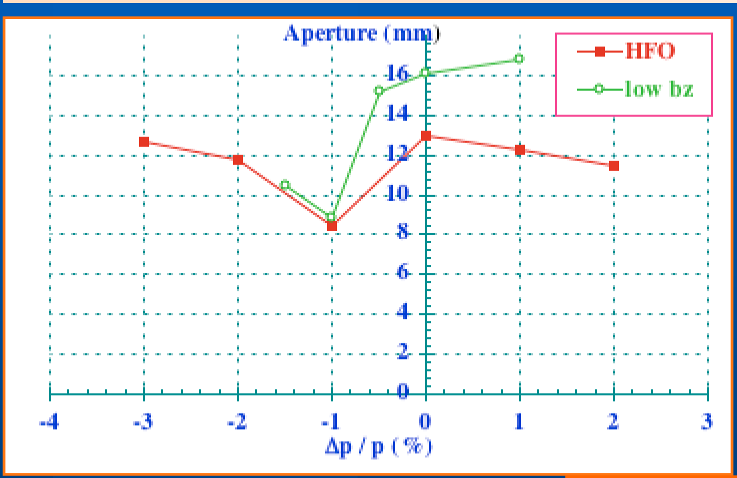
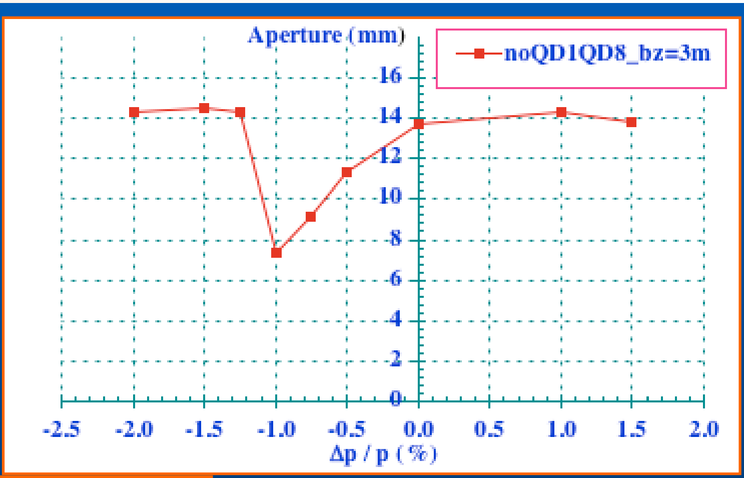
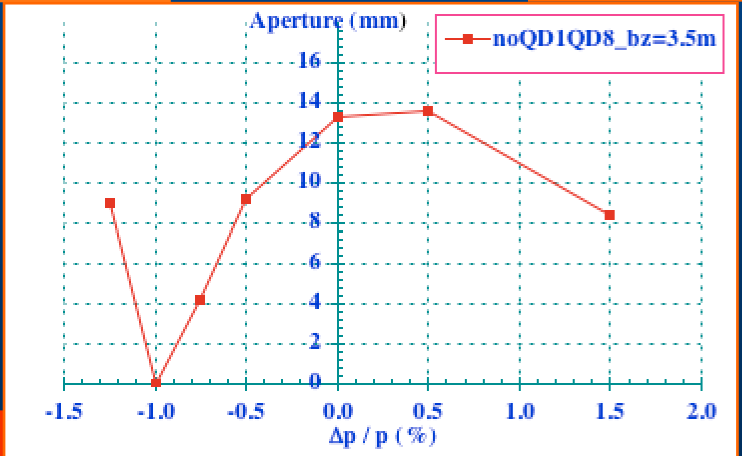
Off-momentum aperture (2)

- The dip exists for all lattices tuned on 0.44 / 0.39



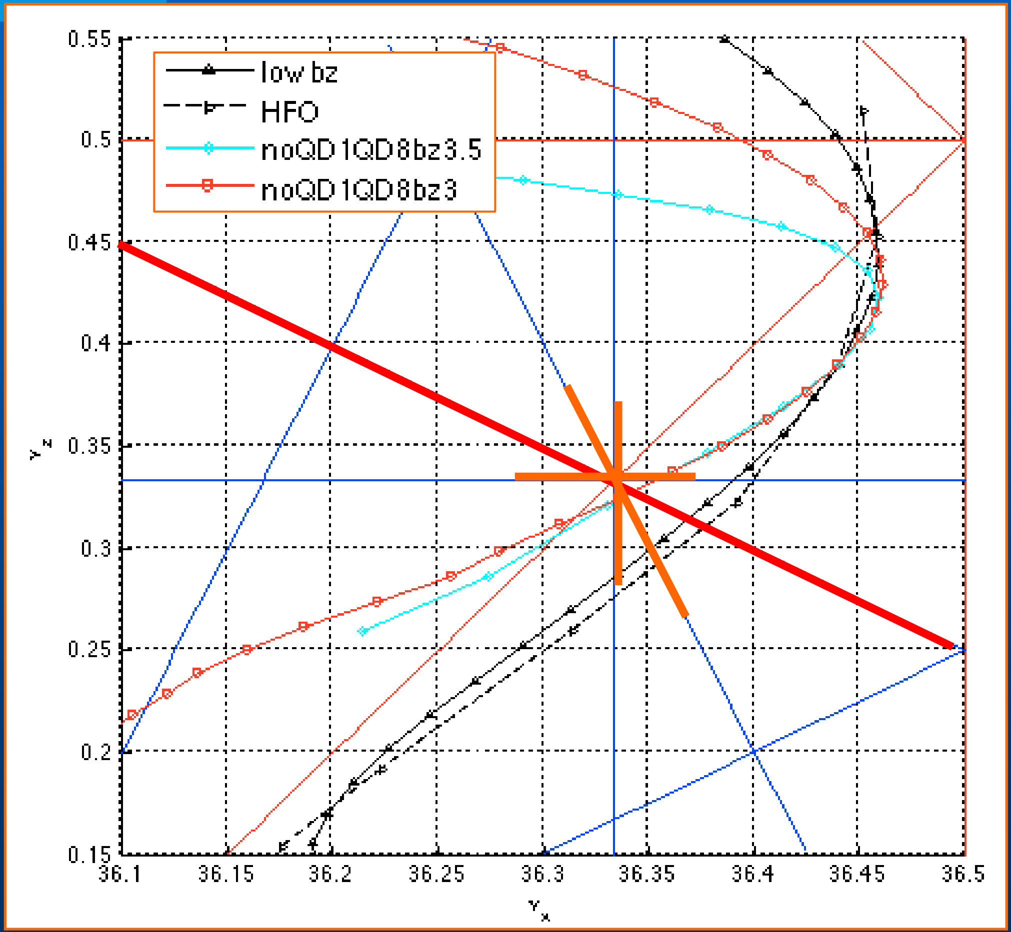




Off-momentum aperture (3)

2 candidates to explain the phenomena

- ✓The $\upsilon_x + 2\,\upsilon_z$ resonance
- ✓The node 0.33/0.33 of 3[rd] order resonances



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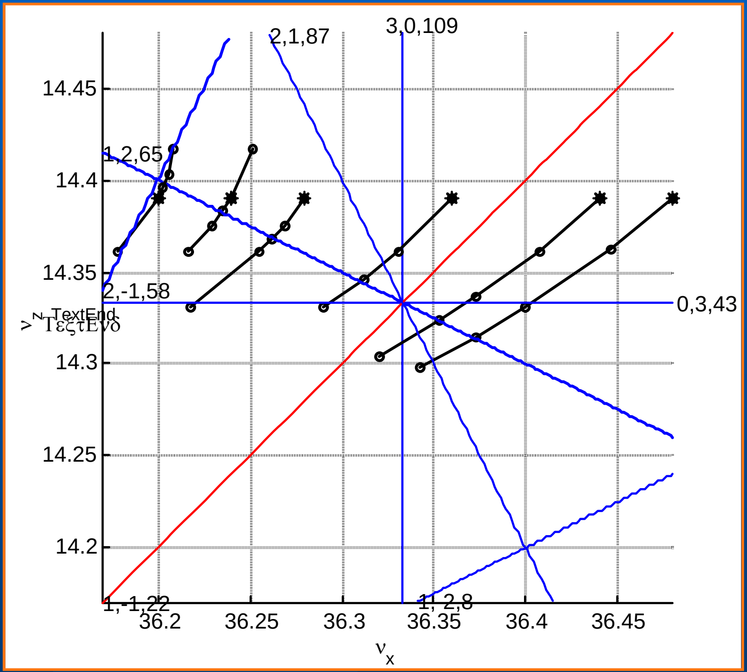
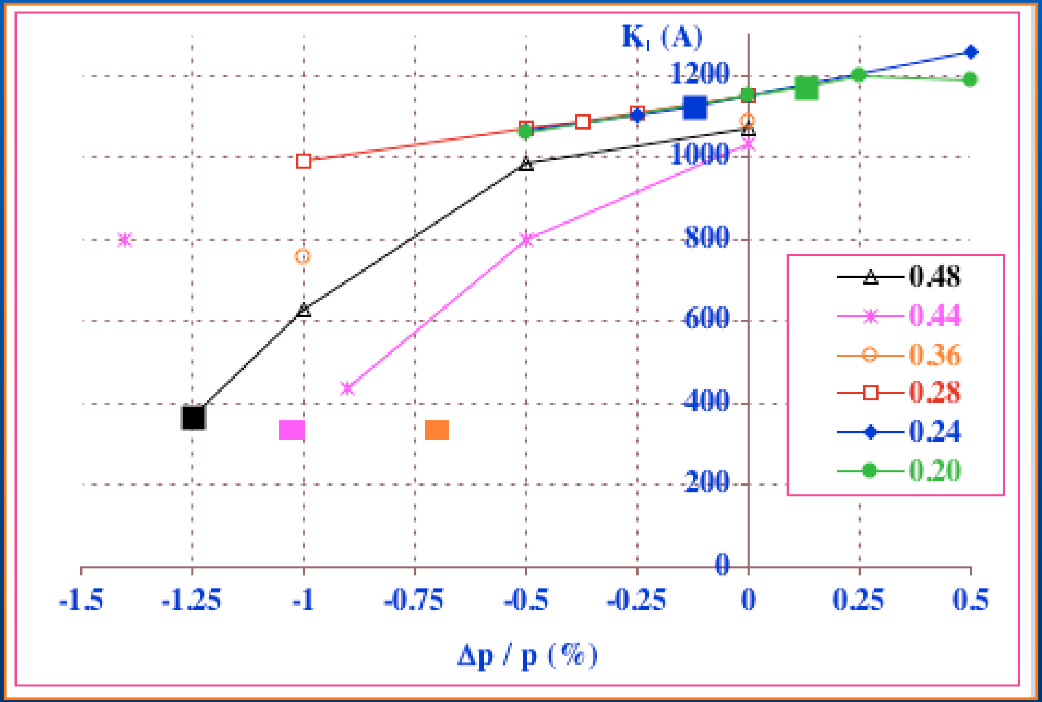
Off-momentum aperture (4)

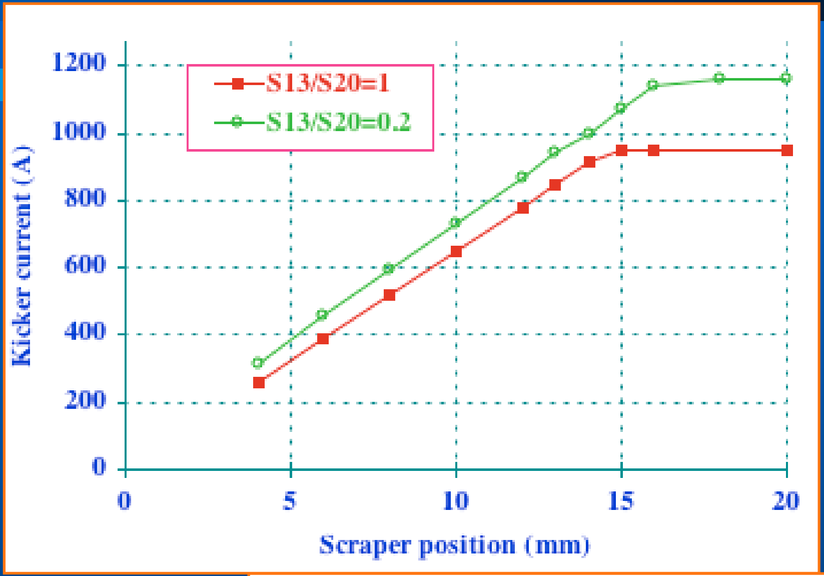


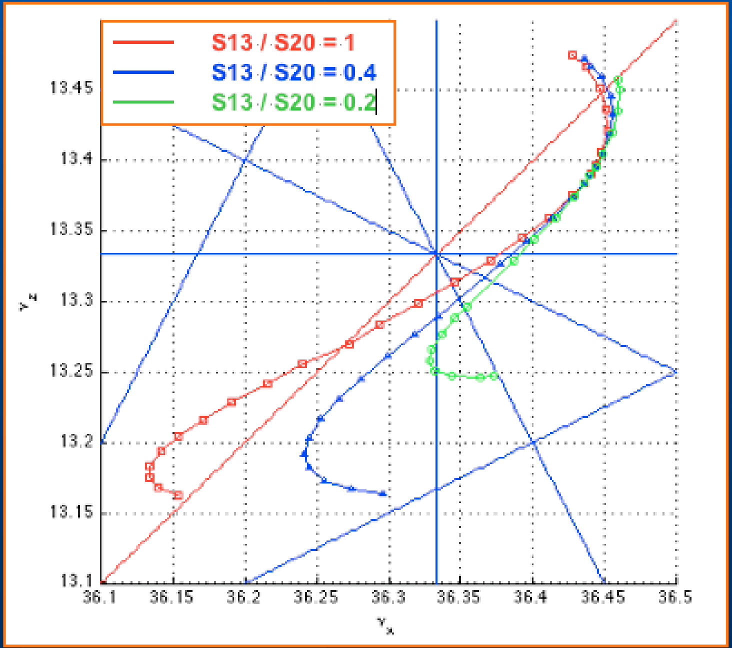


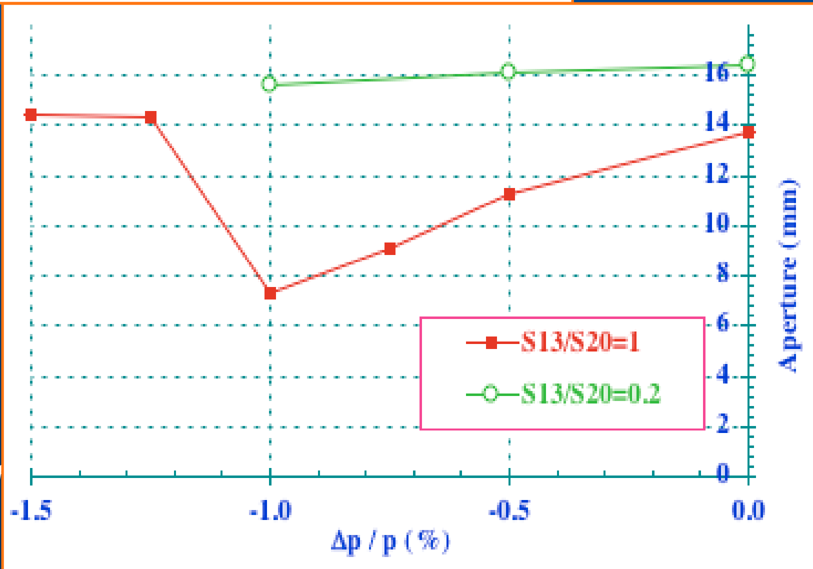
No clear conclusion from the experiments to discriminate between the 2 assumptions

Promising tuning

- Very recent possibility of individually powering the vertical chromaticity sextupoles







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Conclusions

- For most of the experienced lattices, the on-momentum aperture is smaller than predicted

- The dip in the measured off-momentum aperture depends on the crossing of third-order resonances but cannot be modelled by tracking

  - Missing ingredients in the tracking ?

  - Directions to improve the understanding ?

- One promising tuning to further characterise

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