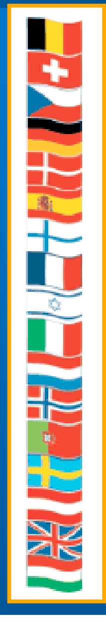
Operation and accelerator physics trends at the ESRF

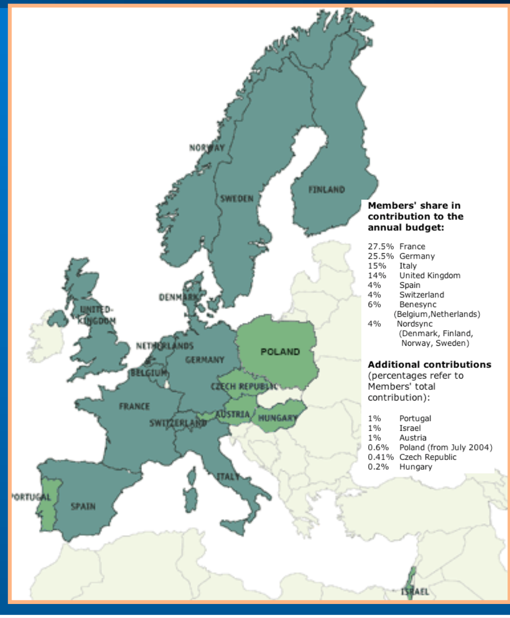
Outline

- The ESRF today
- The roadmap for brilliance increase
- Machine physics
- Future plans

A.Ropert@esrf.fr

The ESRF

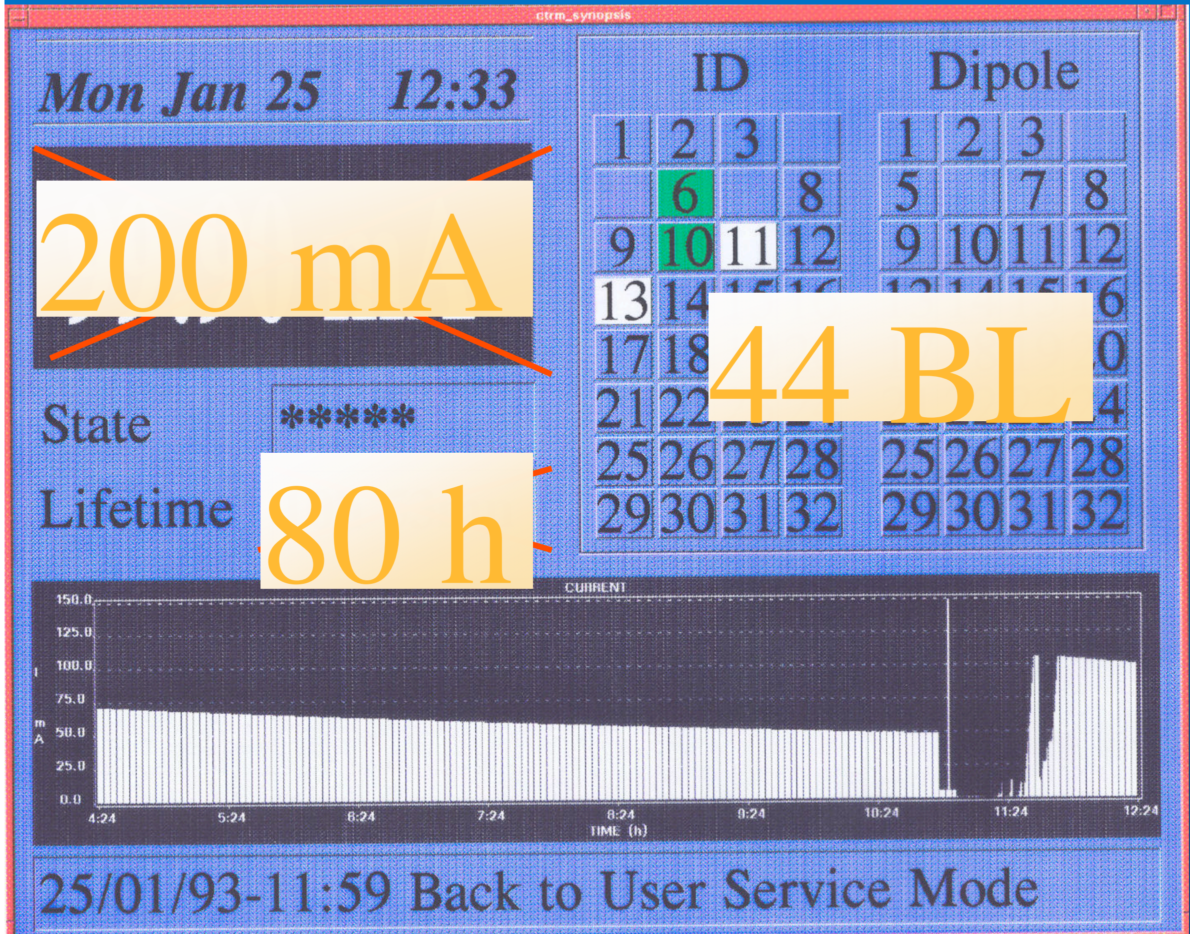




- Joint facility supported and shared by 18 European countries
- 2002 budget: 72 Million Euros
- About 600 people working at ESRF
- About 3500 researchers / year

A.Ropert@esrf.fr

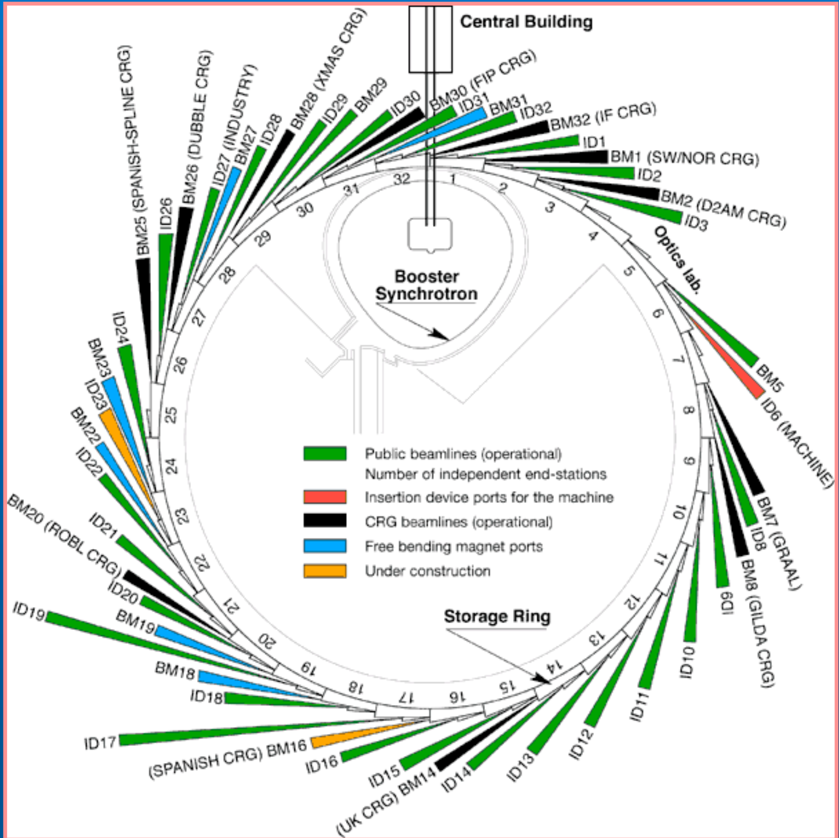
12 years after commissioning



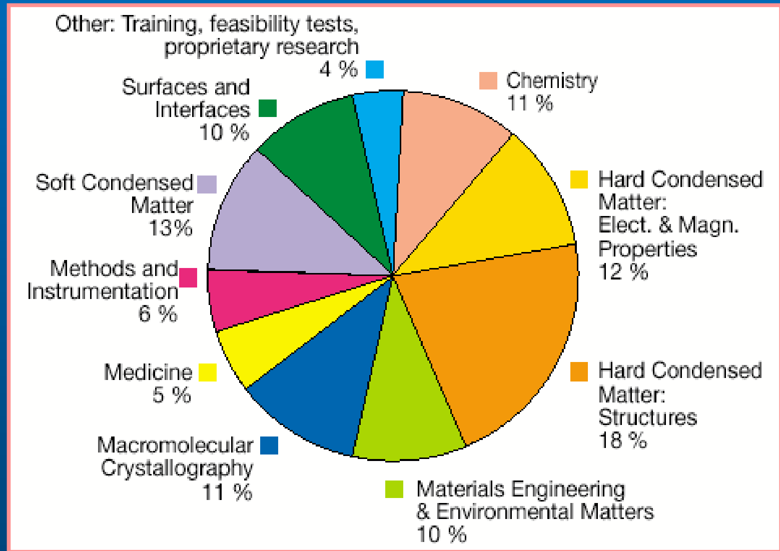
Circumference	844 m
Particles	Electrons
Energy	6.04 GeV
Multibunch Current	200 mA
Lifetime (Uniform filling)	80 h
Horizontal emittance	4 nm
H/V coupling	0.6 % (25 pm)

12 years after commissioning (2)

31 ID + 13 BM beamlines



Scheduled shifts by scientific area (Feb-Jul 2002)



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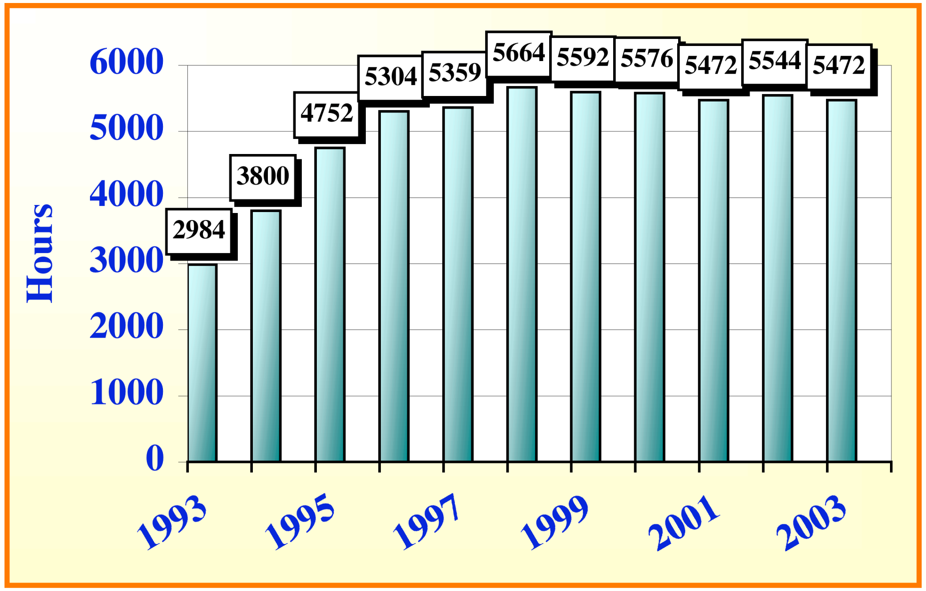
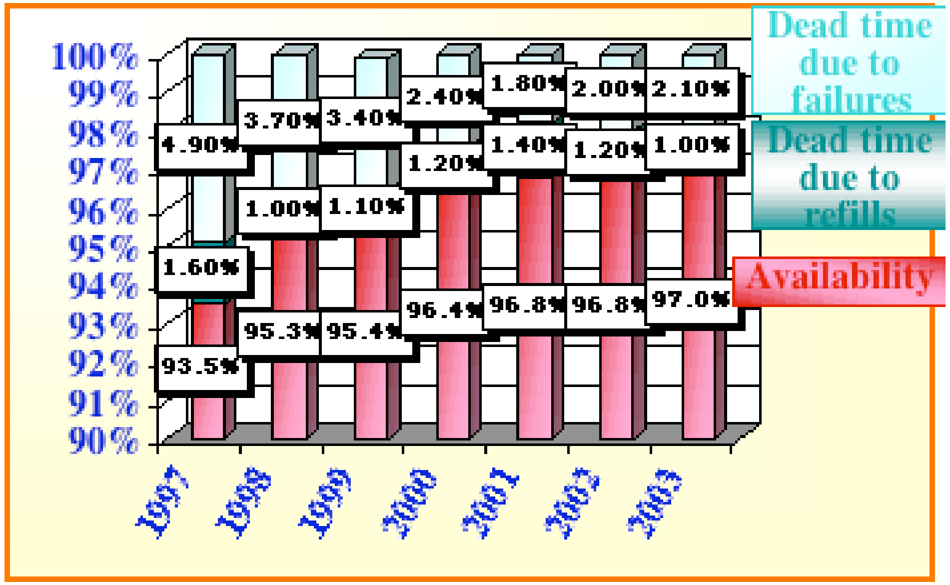
Operational statistics

Scheduled hours in User Service Mode



X-ray availability over the years



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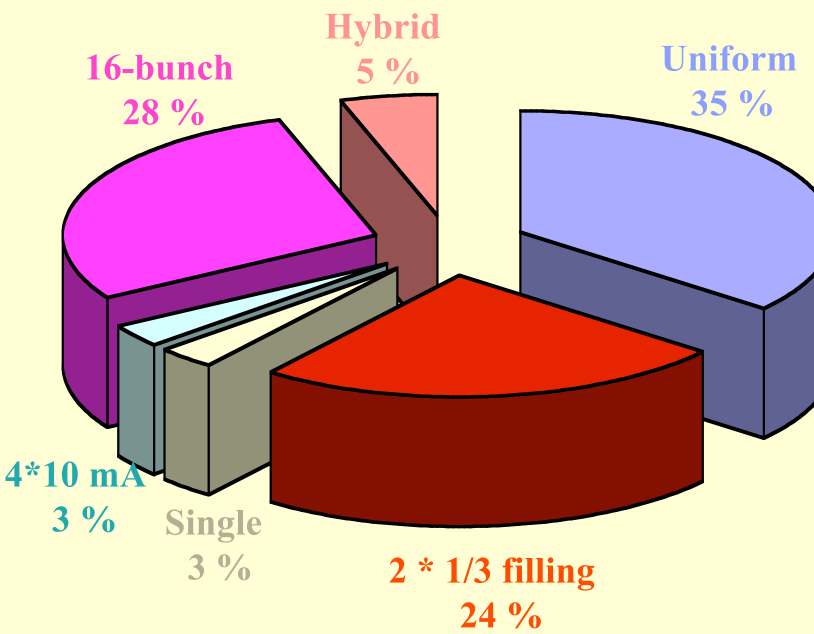
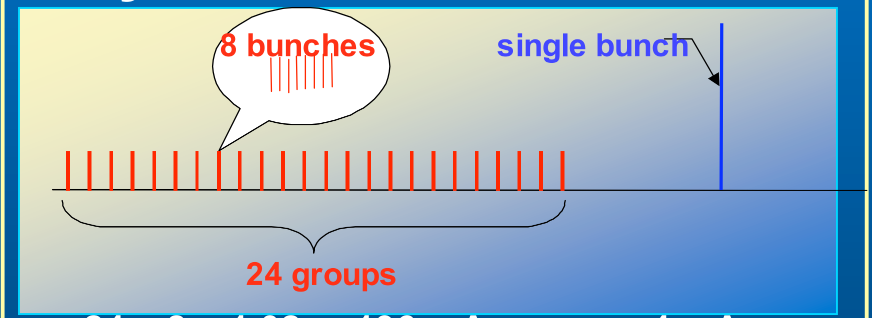
Filling modes

Filling modes at the ESRF in 2003



New time structure modes

- hybrid



24 x 8 x 1.02 = 196 mA   4 mA

- 4 x 10 mA

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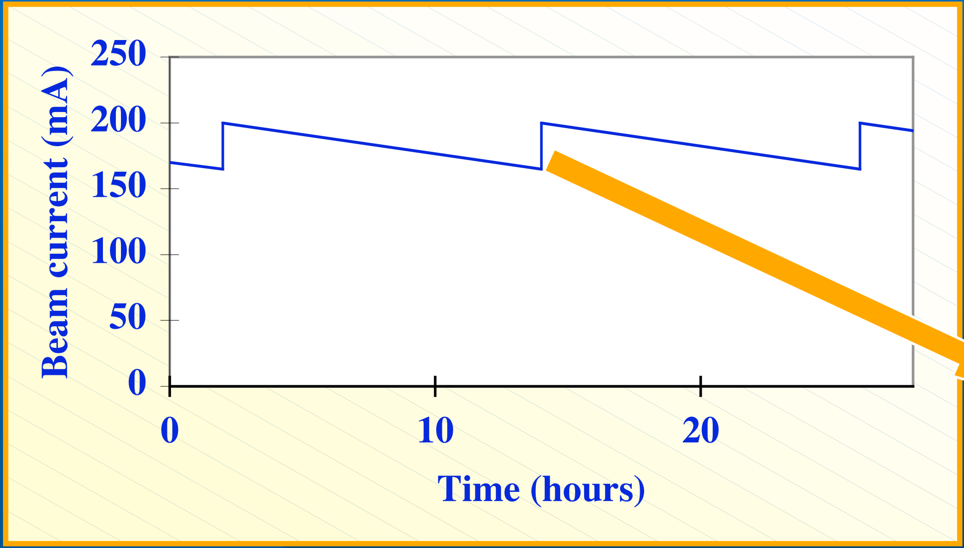
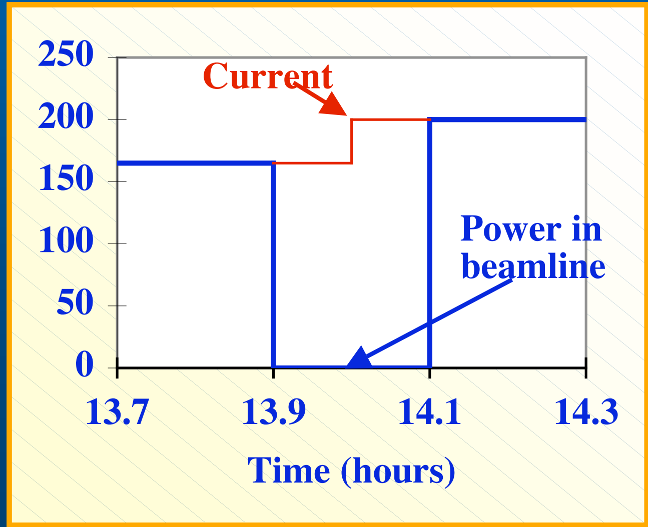
Injection with front-ends open (1)

In use since February 2003

- Improve thermal stability on beamlines





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Injection with front-ends open (2)

- **Technically simple but safety issue**

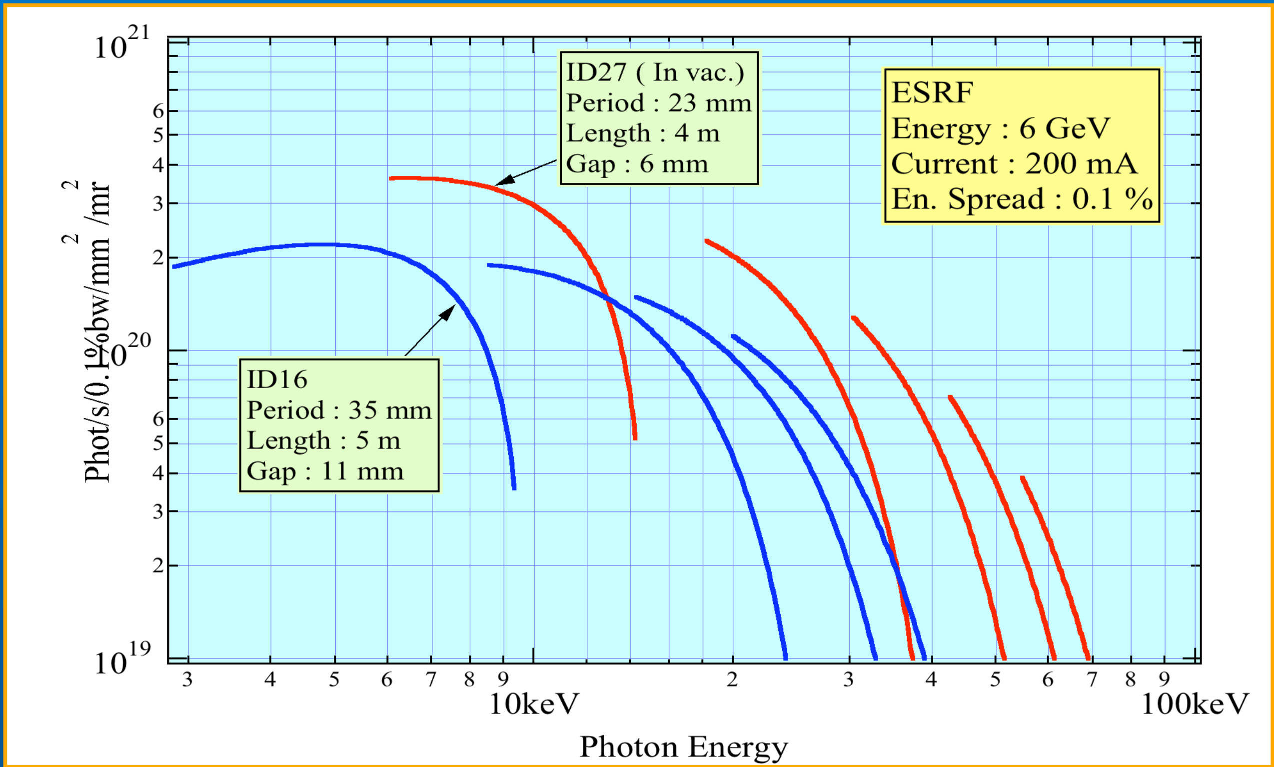
  Demonstrate the impossibility of steering a beam from the booster into a beamline if a beam is already stored in the storage ring

  - Integration of a dedicated current monitor in the machine personnel safety system
  - Permanent monitoring of the radiation dose on each beamline

- **Operation**
  - ☞ Same injection repetition rate
  - ☞ Opening of in-vacuum ID gaps to 8 mm to avoid demagnetisation
  - ☞ Gating signal provided to users

A.Ropert@esrf.fr

Brilliance (1)



Upgrade by a factor 100 of the initial brilliance performance

A.Ropert@esrf.fr

ESRF

Brilliance (2)

Beam current

$$B = \frac{\text{number} \cdot \text{of} \cdot \text{photons/s}}{\kappa \varepsilon_x^2} f(E, \text{gap}, \text{field})$$

Coupling

Horizontal emittance

Insertion Devices

$\sigma_x \sigma'_x \sigma_z \sigma'_z$

Convolution of
electron emittances
and
photon emittances

$\sigma_e = \sqrt{\beta\varepsilon}$

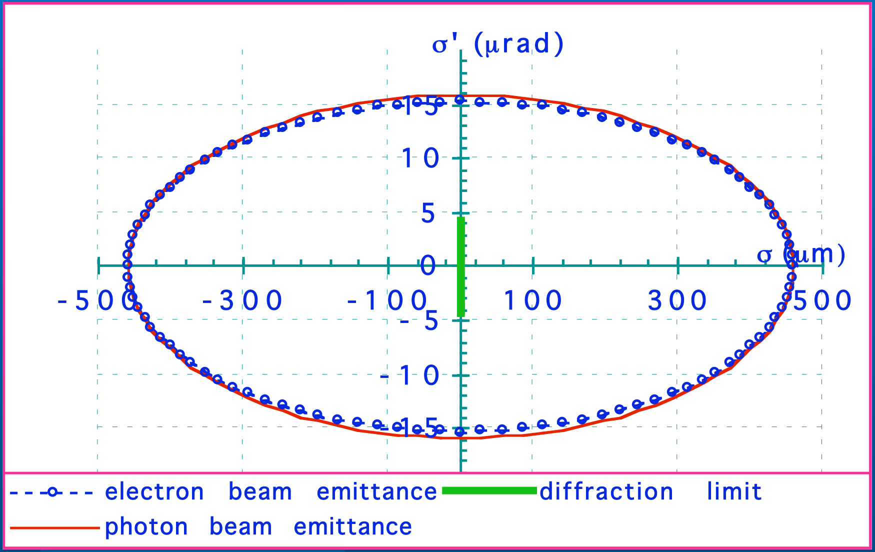
$\sigma'_e = \sqrt{\frac{\varepsilon}{\beta}}$

$\sigma_R = \frac{\sqrt{\lambda L}}{4\pi}$

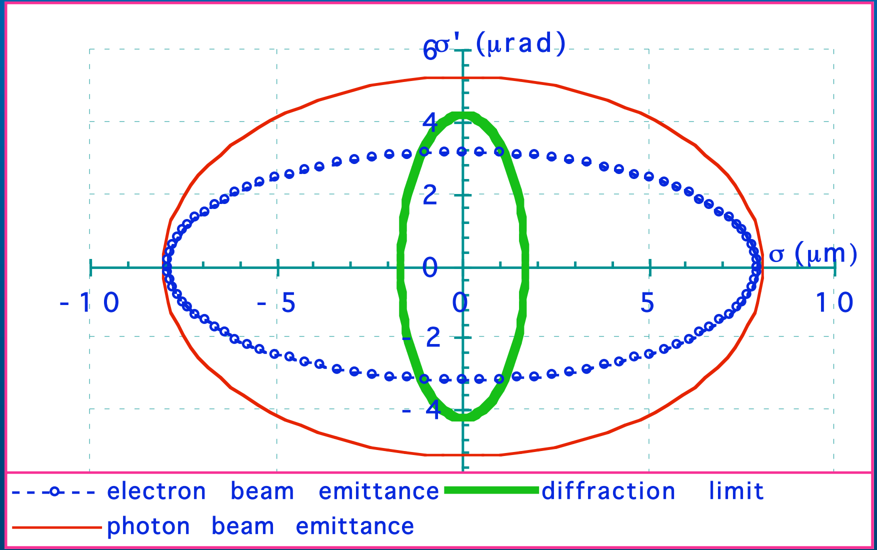
$\sigma'_R = \sqrt{\frac{\lambda}{L}}$

Brilliance (3)

Horizontal plane: ε_x = 4 nm



Vertical plane: ε_z = 25 pm



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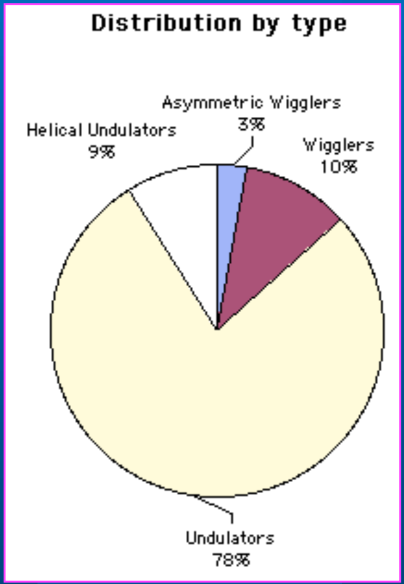
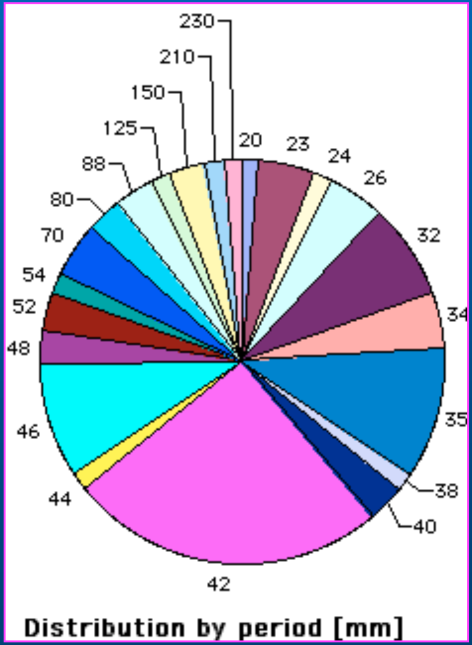
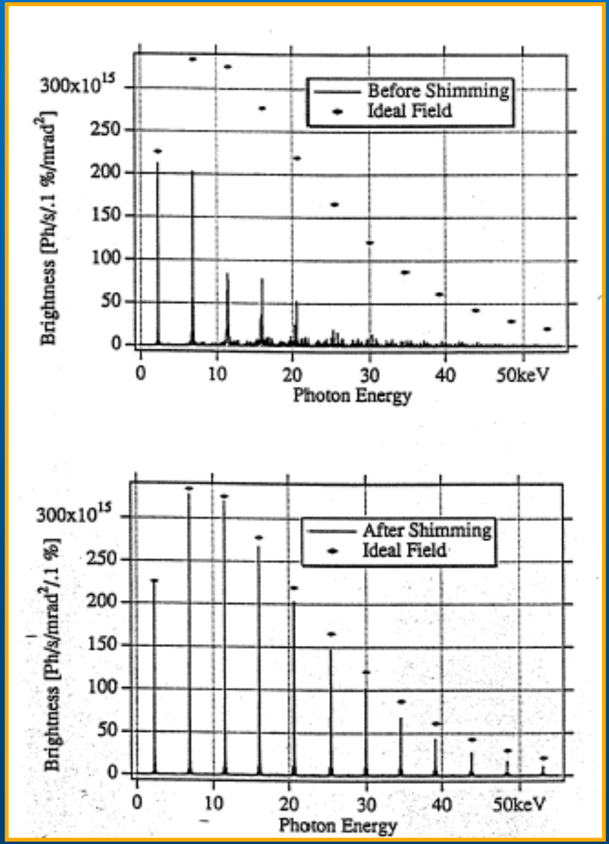
Insertion devices (1)

69 ID segments installed in 2004





Spectral shimming



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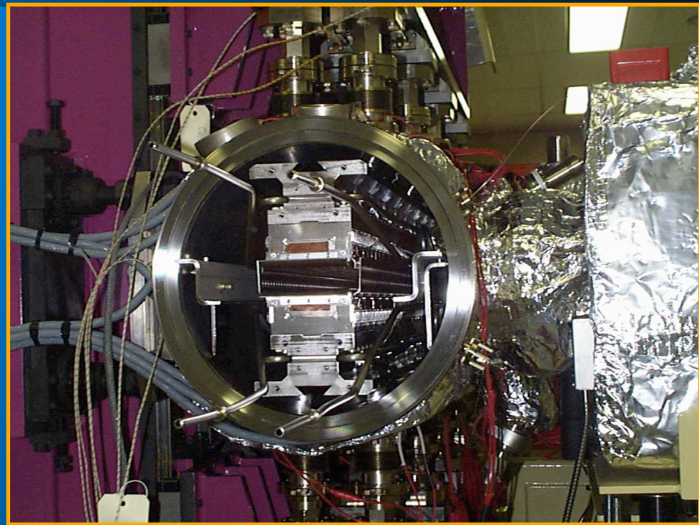
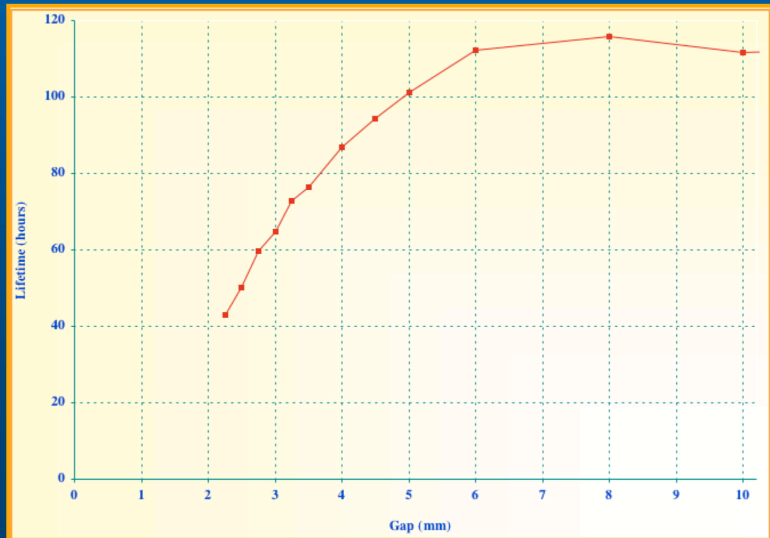
Insertion devices (2)

Gap reduction
20 -->15 -->11 --> 5mm
↓
In-vacuum IDs

	Period (mm)	Length (m)	Magnetic Structure	Min. Gap (mm)	Operation
ID11	23	1.6	Hybrid	5	Jan 99
ID22	23	2	PPM	6	Jul 01
ID9	17	2	PPM	6	Jul 01
ID29	21	2	PPM	6	Dec 02
ID13	18	2	PPM	6	Jul 02
ID27	23	2	PPM	6	Jan 04
ID27	23	2	PPM	6	Jan 04
ID11	22	2	PPM	6	Jan 04





A.Ropert@esrf.fr

Beam current

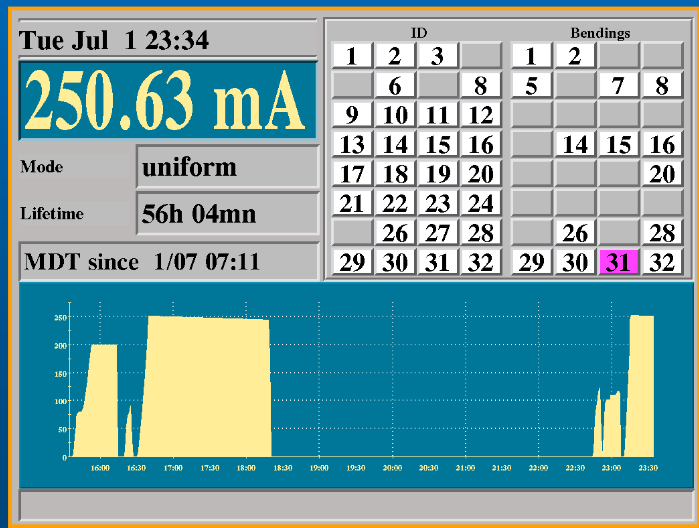
Design current 1992	1996	~~2003~~	2006
100 mA	200 mA	~~250 mA~~	300 mA

Main limitation: HOM driven coupled-bunch instabilities

- Cured up to 200 mA by a precise control of cavity temperature

- No stable temperature settings for the whole 0 - 250 mA range

- Solution for higher current: fast multibunch longitudinal feedback



Emittance reduction (1)

Equilibrium emittance determined by an equilibrium between 2 competing effects

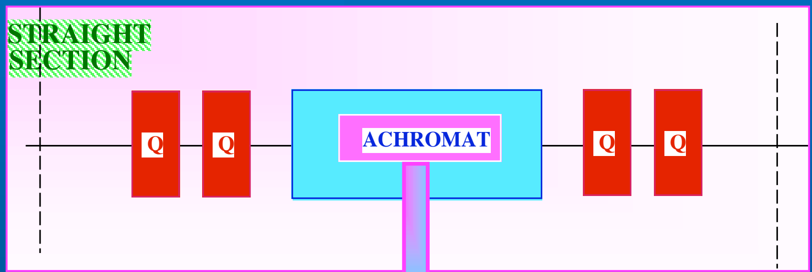
✓ Quantum excitation when photons are emitted in the dipoles
✓ Damping by the RF which restores the energy lost by synchrotron radiation

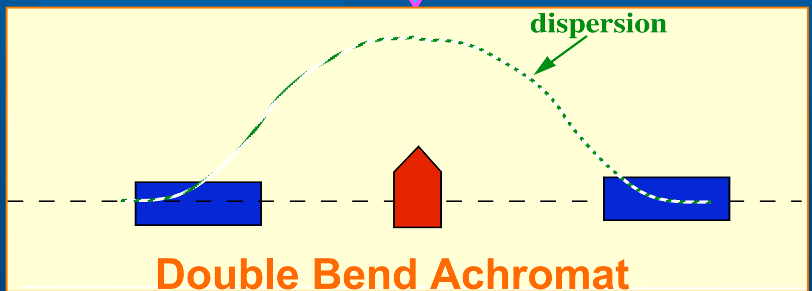
$$\varepsilon_{x_0} = \frac{C_q \gamma^2}{J_x \rho_0} < H >_{mag}$$ with $$H = \gamma_x \eta^2 + 2\alpha_x \eta\eta' + \beta_x \eta'^2$$

Minimisation of emittance $\longrightarrow$ minimisation of the H function

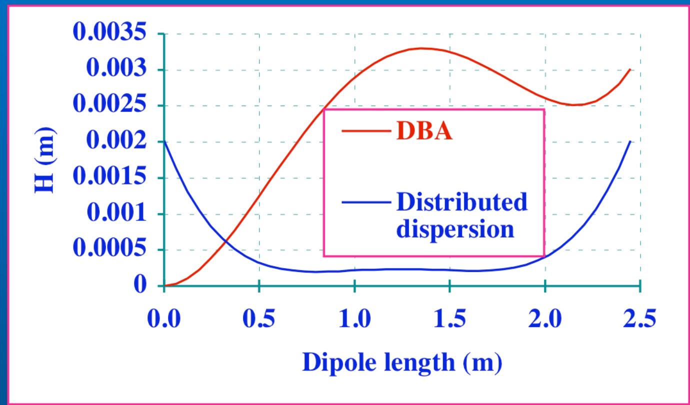
Emittance reduction (2)

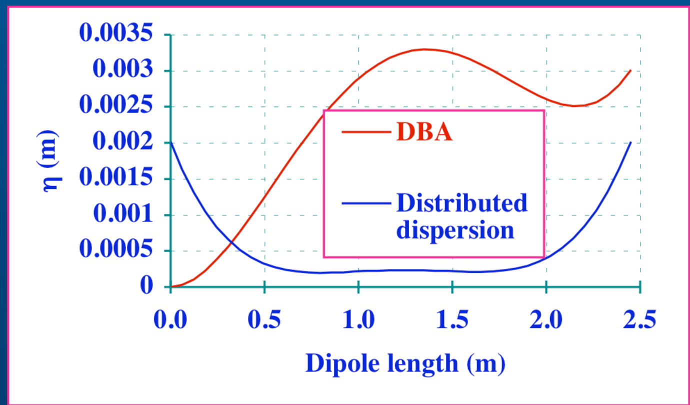
Basic structure of one cell





Minimisation of H





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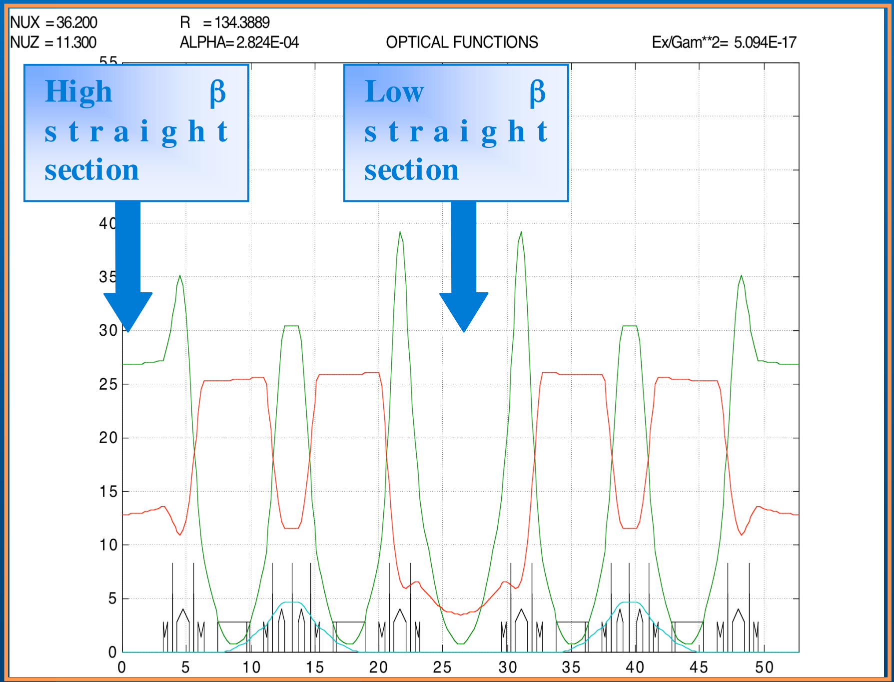
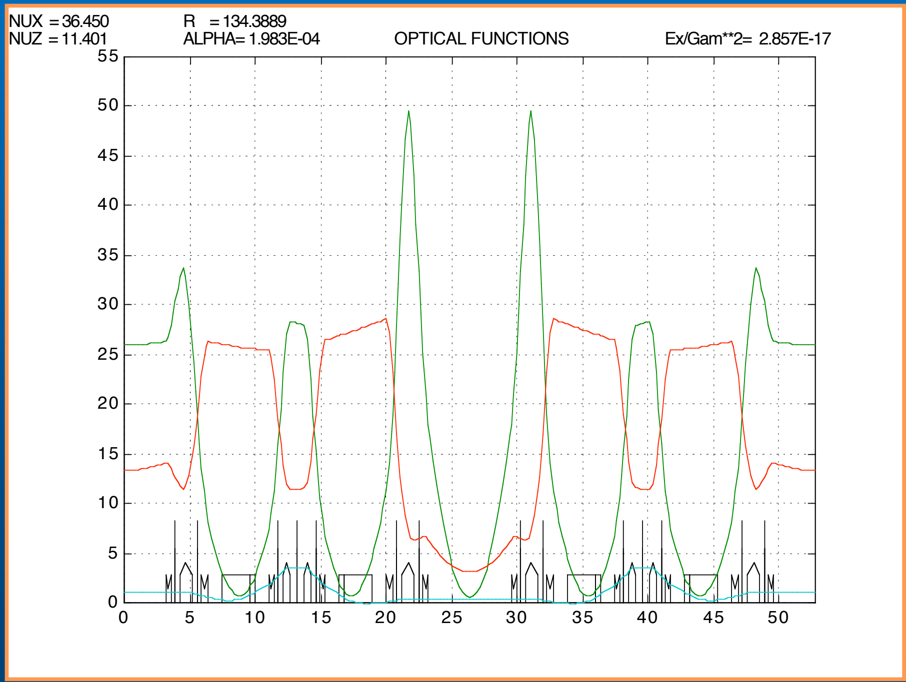
Emittance reduction (3)

From 7nm (zero dispersion) to 4nm (distributed dispersion)





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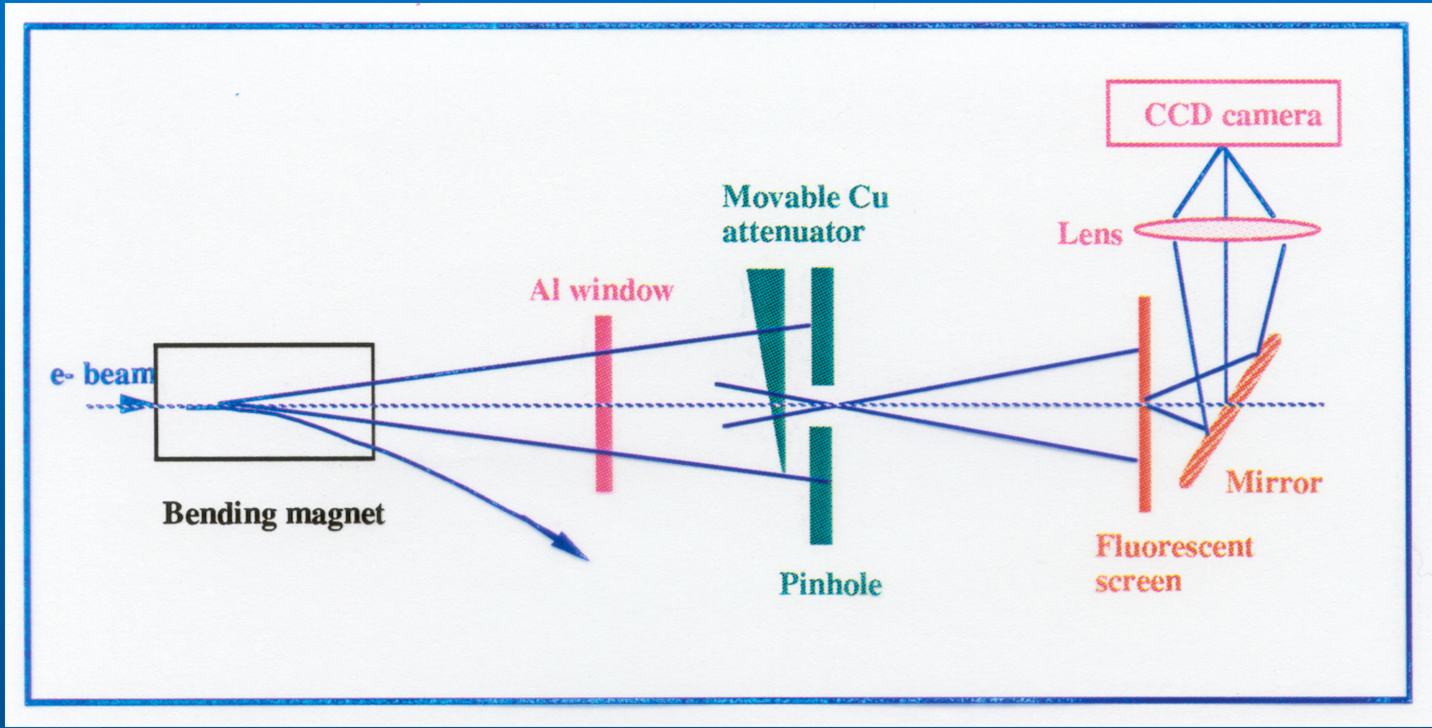
Emittance measurement (1)

X-ray pinhole camera



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Emittance measurement (2)

Horizontal plane
2 pinholes at dispersive and non-dispersive locations
-- > $\varepsilon_x + \sigma_E$

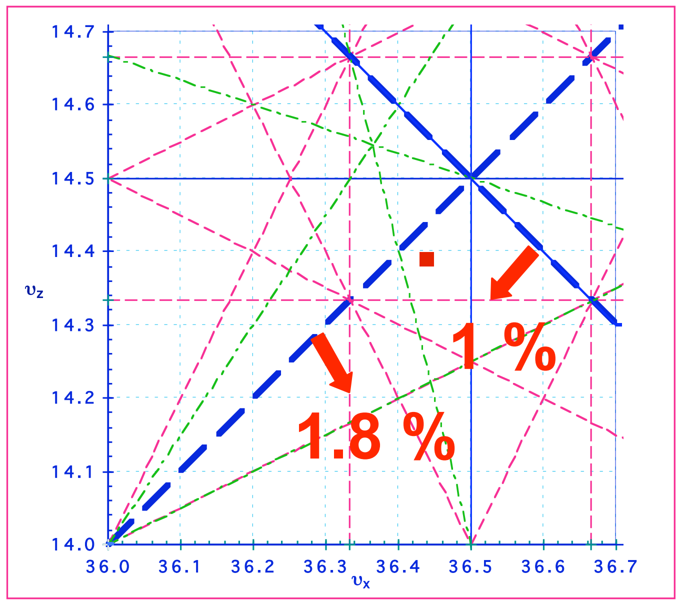
Vertical plane

Design value:	10 %, i.e. 0.7 nm	
Early operation:	10 % measured	
2000 routine value in USM	25 pm	10 pm
	0.6 %	0.25 %

A.Ropert@esrf.fr

Coupling correction (1)

Correct the two coupling resonances in the vicinity of the working point



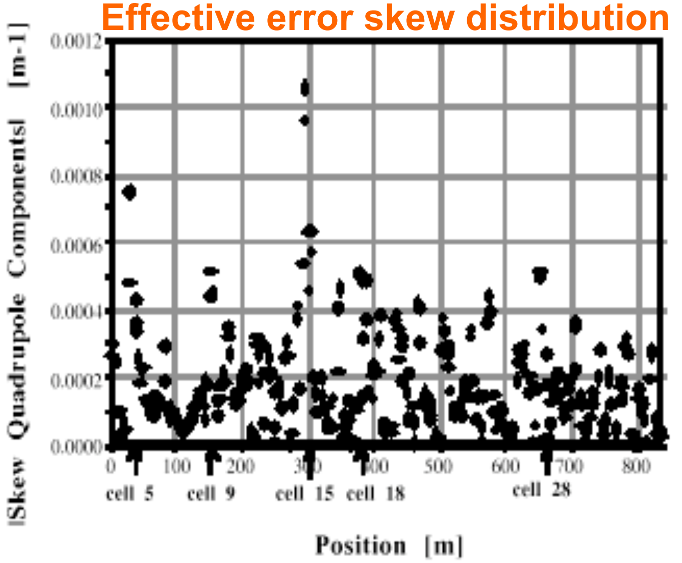
Minimise the vertical spurious dispersion

0.6 %

Coupling correction (2)

Use the measured coupled-orbit response

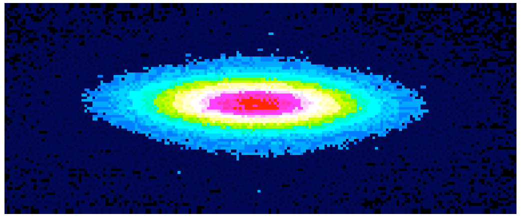
Effective error skew distribution

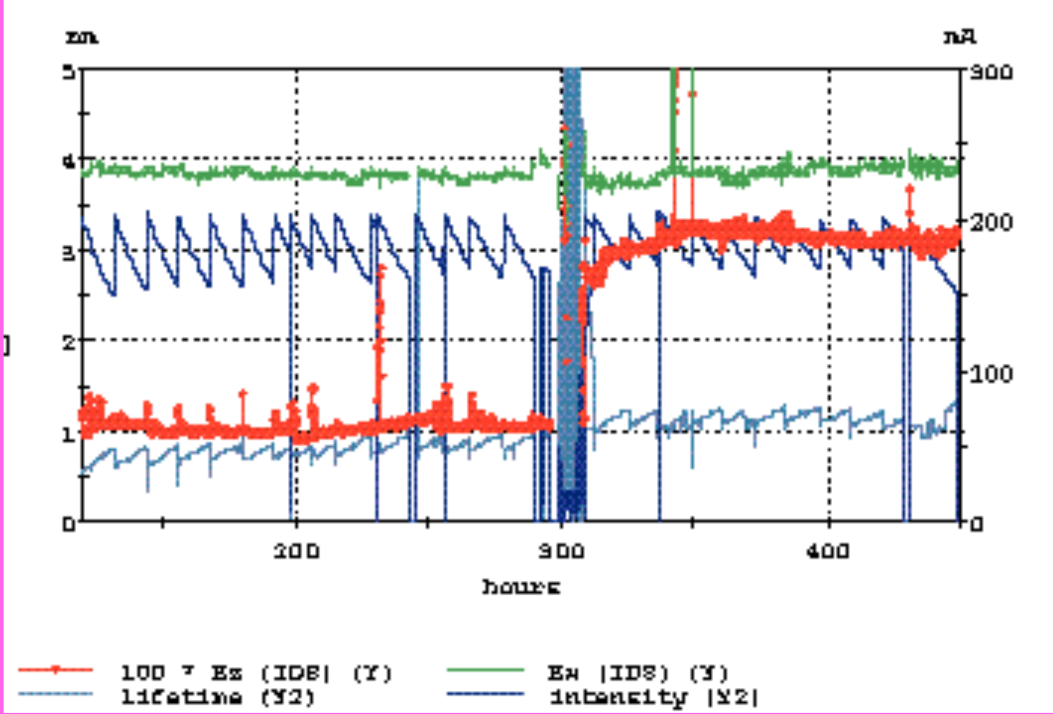


Find the most effective corrector positions and apply the model solution to the machine → 0.3 %

A.Ropert@esrf.fr

Coupling correction (3)





A.Ropert@esrf.fr

Lifetime issues

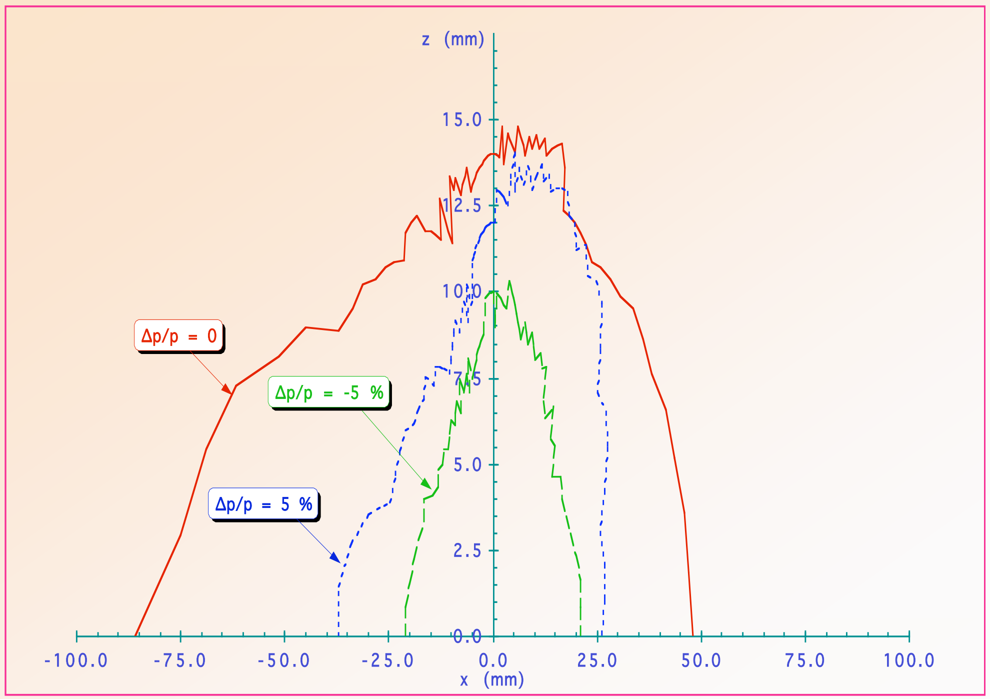
The lifetime is also an important figure of merit to quantify machine performance

- Reduction of integrated brilliance due to short lifetimes
- Non constant heat-load which is detrimental to beamline stability

Even at 6 GeV, the Touschek contribution is dominating the multibunch lifetime due to the high bunch density

Strategy for increasing the lifetime (1)

Sextupole optimisation in order to enlarge the dynamic aperture of the perfect machine



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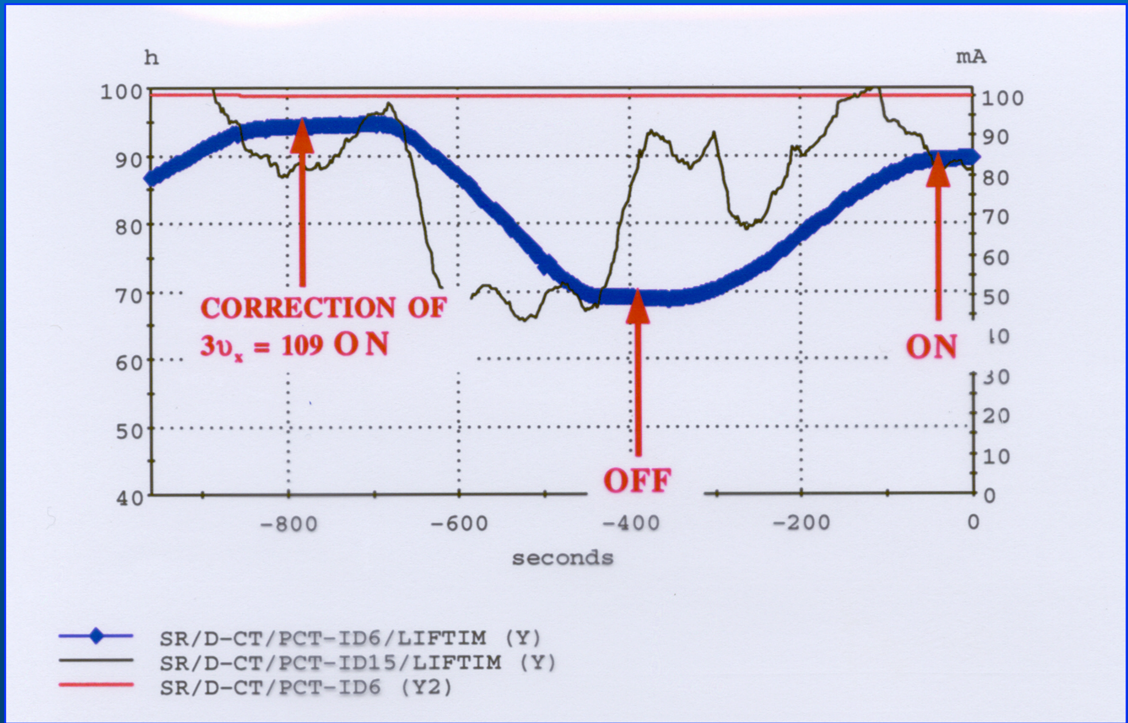
Strategy for increasing the lifetime (2)

Correction of non-systematic resonances to minimise the detrimental effects of field errors on the dynamic aperture



A.Ropert@esrf.fr

Machine studies

- Measurement of the vacuum chamber coupling impedance
- Restoration of machine periodicity
- Transverse beam dynamics studies

A.Ropert@esrf.fr

Impedance measurements

T. Perron, L. Farvacque

Motivation

Understand the vertical impedance of critical components (narrow gap vessels, in-vacuum IDs,…) in order to keep the total impedance as low as possible

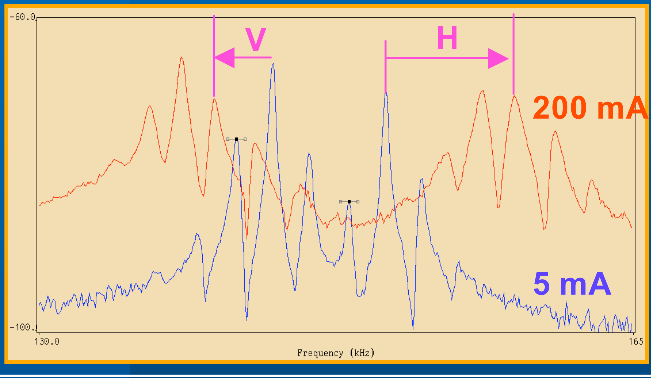
Reduction of the straight sections beam vertical stay-clear in in order to reduce ID gaps

Material	Internal aperture (mm)	External aperture (mm)	Length (m)		Number
SS	15	19	5		1
SS	11	15	5		8
SS + 50 μm Co	8	10	5	NEG	2
Al	11	15	5	NEG	2
Al	11	15	2	NEG	4
Al	8	10	5	NEG	8

Vacuum chamber evolution

Transverse impedance increase

- Reduction of single bunch threshold: 25 mA ↘ 15 mA
- Increase of incoherent tune shifts



Lack of pumping

- Higher pressure profile along the chamber
- Higher Bremsstrahlung background in the experimental hutches

Installation of extruded Aluminium vessels

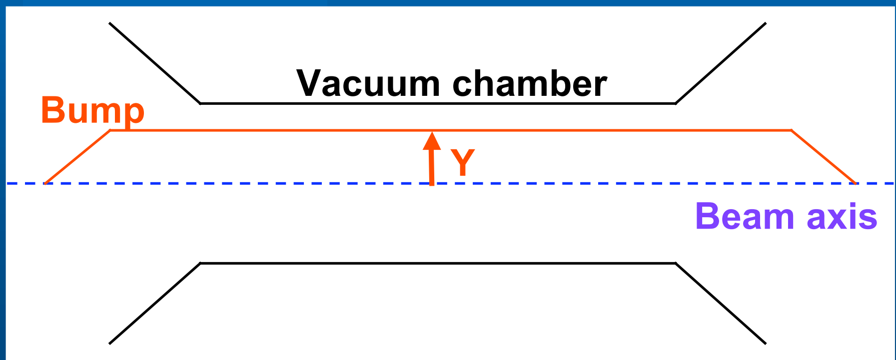
Reduction of manufacturing costs

Reduction of the excitation of the resistive wall impedance

Impedance measurements: Method

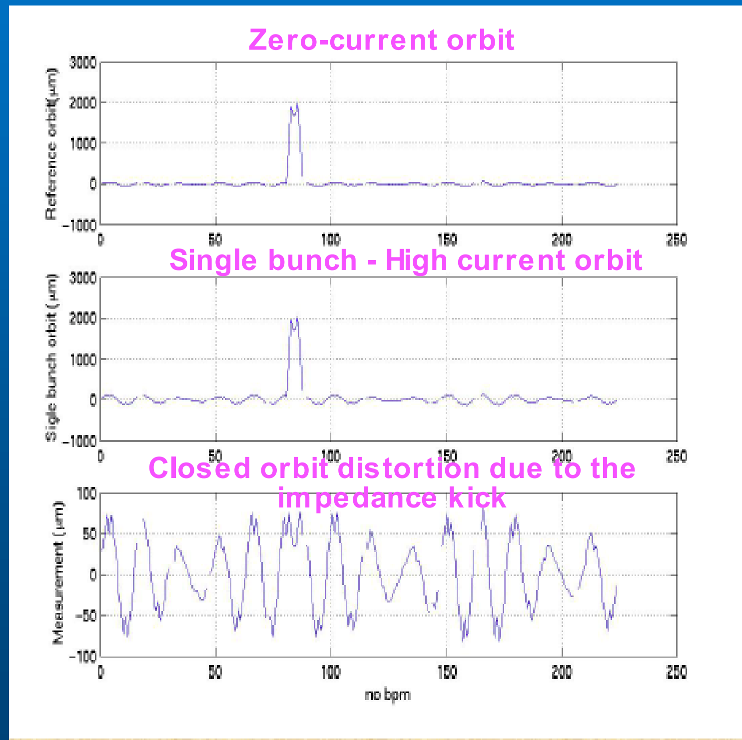
Initiated by L. Emery, G. Decker and J. Galayda at APS

Displace the beam vertically, using a static orbit deviation, at the place where one wants to measure the impedance



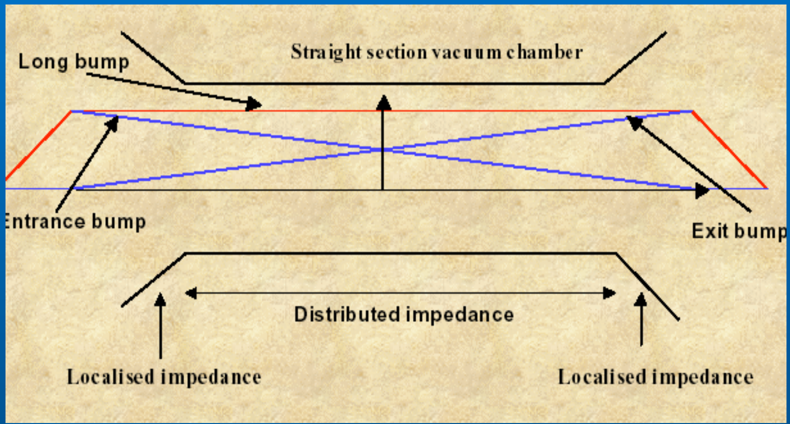
Impedance Z --> angular kick proportional to Y, I, $Im(Z_{eff})$

Kick determination



Impedance measurements: Method (2)

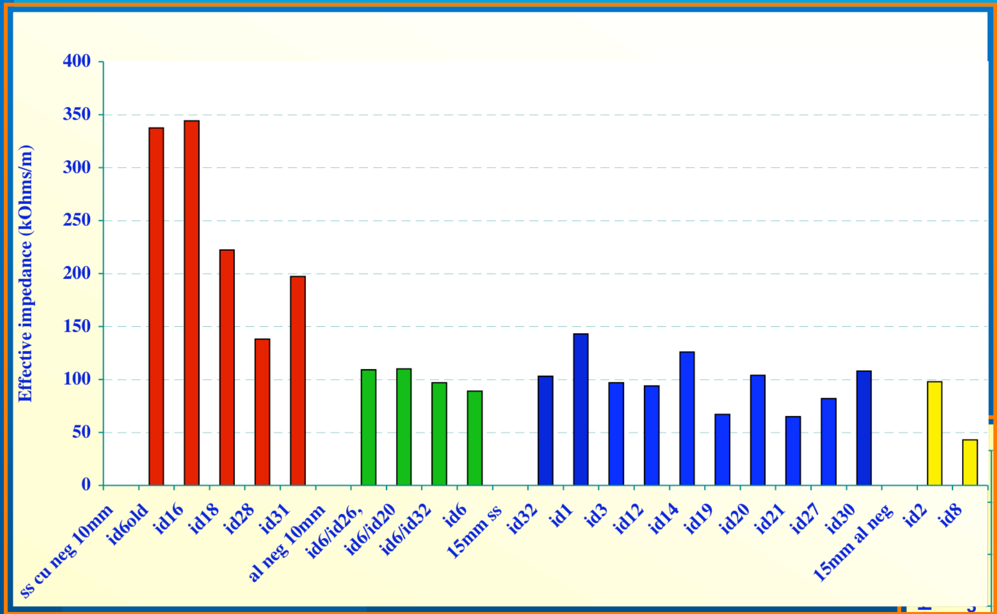
Local measurements

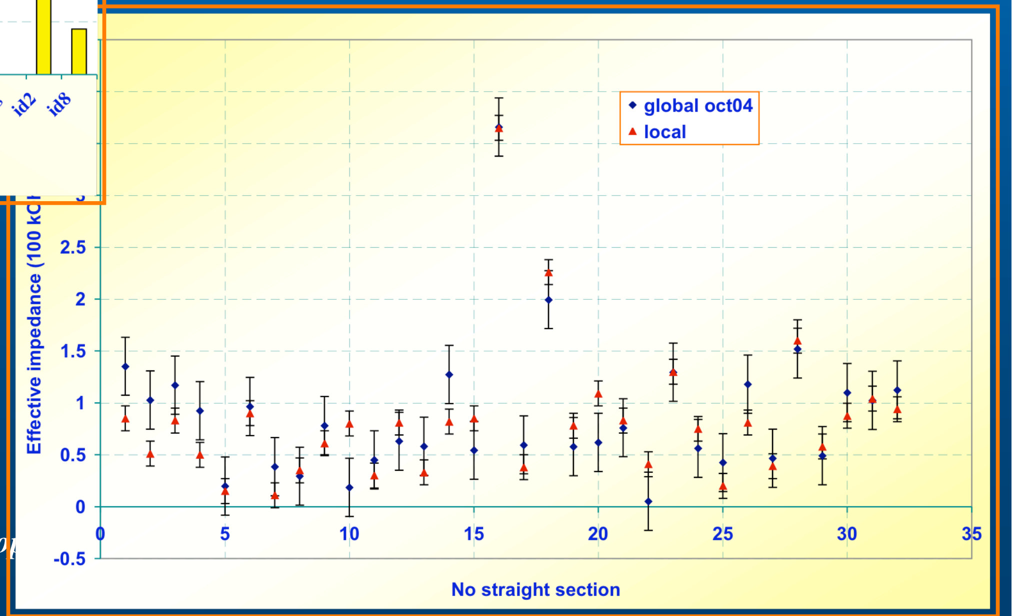


Global measurements

- Apply a series of orbit oscillations probing the impedance all around the machine
- Processing extracting an impedance value for each straight section

Impedance measurements: Results





A.Ro

β-function modulation

L. Farvacque

320 quadrupoles powered in 8 families

16 + 16 quadrupolar correctors generated by the additional coils of the sextupoles

Classical method

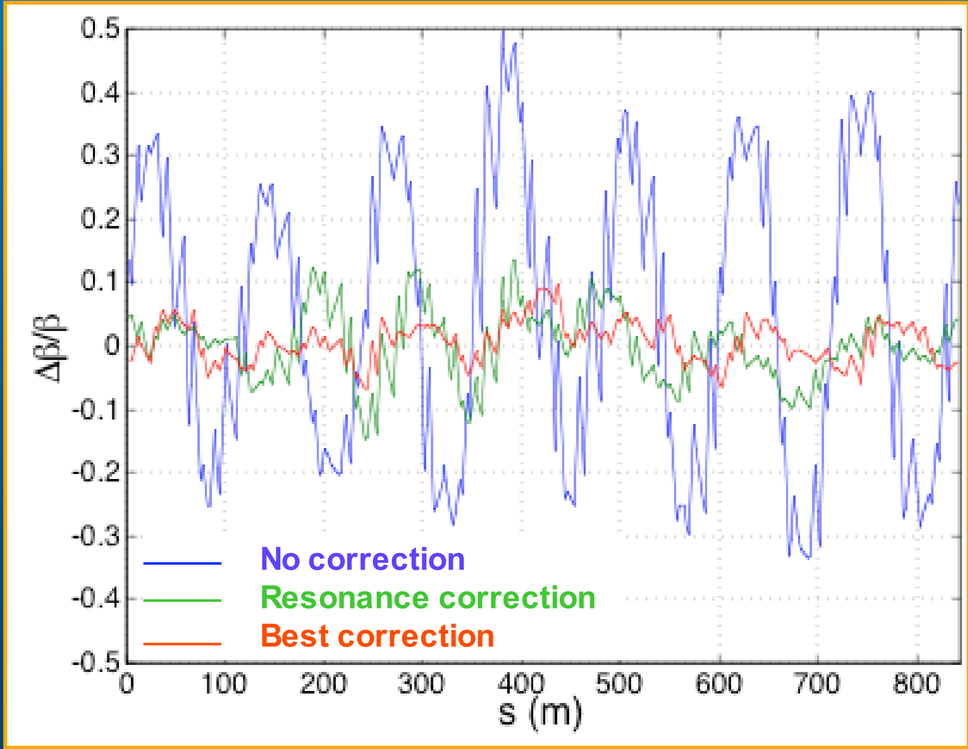
- Correction of the closest quadrupolar resonances by moving the working point and optimising manually the correctors
- The half-integer line is corrected in each plane

New method

- Response matrix measurement
- Fit of a set of gradient errors restoring the matrix (SVD)
- Computation of the corrector set minimising the modulation
- Application on the machine and iterations

β-function modulation: Results

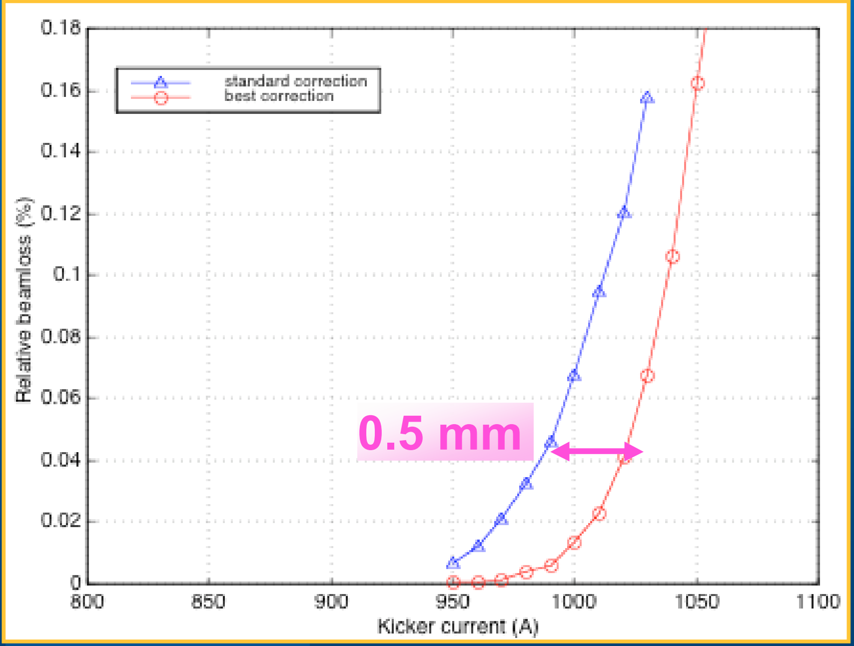
	H	V
No correction	22%	9%
Resonance correction	6%	6%
Best correction	3%	2.5%



A.Ropert@esrf.fr

β-function modulation: Results (2)

Moderate enlargement of the on-momentum horizontal aperture



Lifetime evolution

Correction	100 mA (992 b)	200 mA (992 b)	40 mA (16 b)
Standard	96.4 h	53.7 h	13.5 h
Best	100.9 h	55.9 h	16.2 h

A.Ropert@esrf.fr

Transverse beam dynamics studies

A. Ropert

Motivation

- Understand the limitation of the horizontal aperture
- Improve the lifetime in time structure modes

Studies

- Improvement of the model
- Aperture measurements
- Analysis of losses

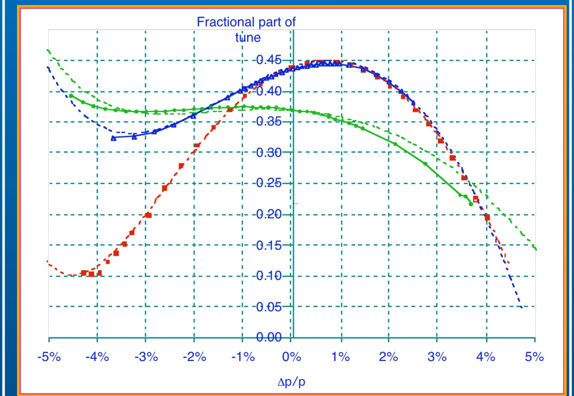
Experimental tools

- Horizontal and vertical scrapers
- Turn-by-turn BPM system + injection kicker + vertical shaker
- Beam loss detectors

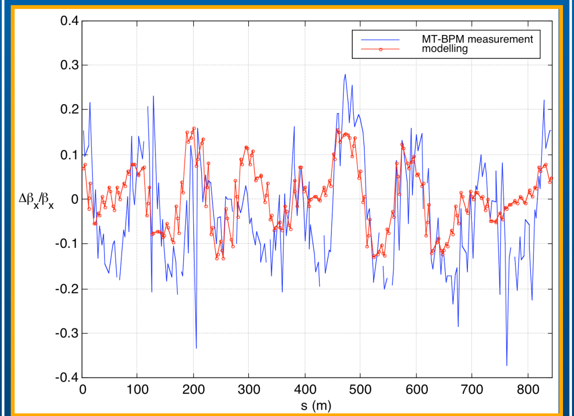
A.Ropert@esrf.fr

Transverse beam dynamics studies: Refinement of the model

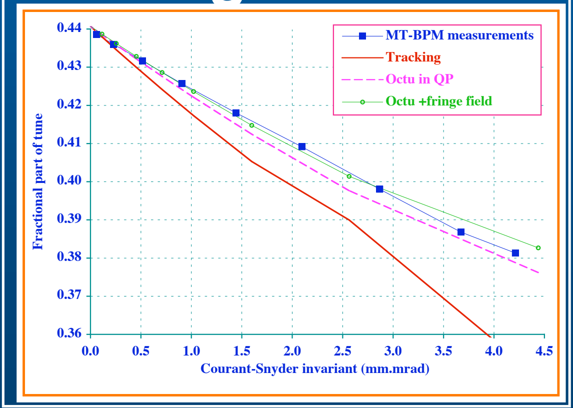
Calibration of sextupoles



Modelling of focusing and coupling errors



Multipolar errors + quadrupole fringe fields



A.Ropert@esrf.fr

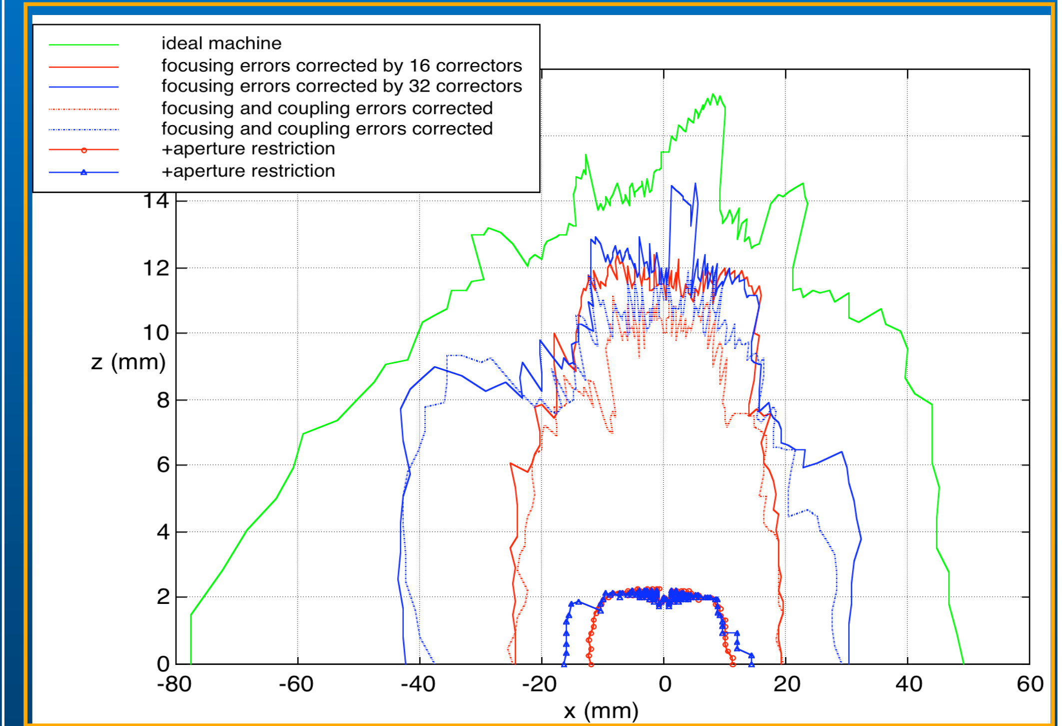
Transverse beam dynamics studies: Limited horizontal aperture (1)

Reduced physical aperture

Horizontal: septum at 19 mm from axis

Vertical: ± 4 mm high, 5 m long ID vessels

Tracking results



A.Ropert@esrf.fr

Transverse beam dynamics studies: Limited horizontal aperture (2)

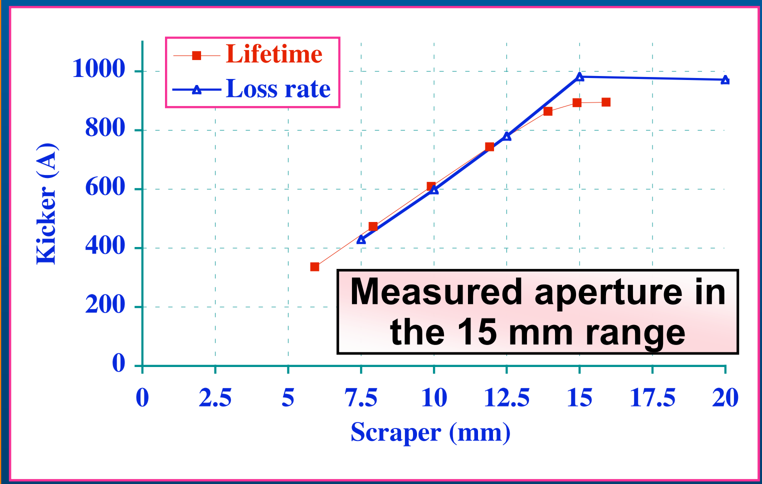
Method #1

- Lifetime recorded versus amplitude of an oscillation driven by permanently running the injection kicker

Method #2 (similar to ALS)

- 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



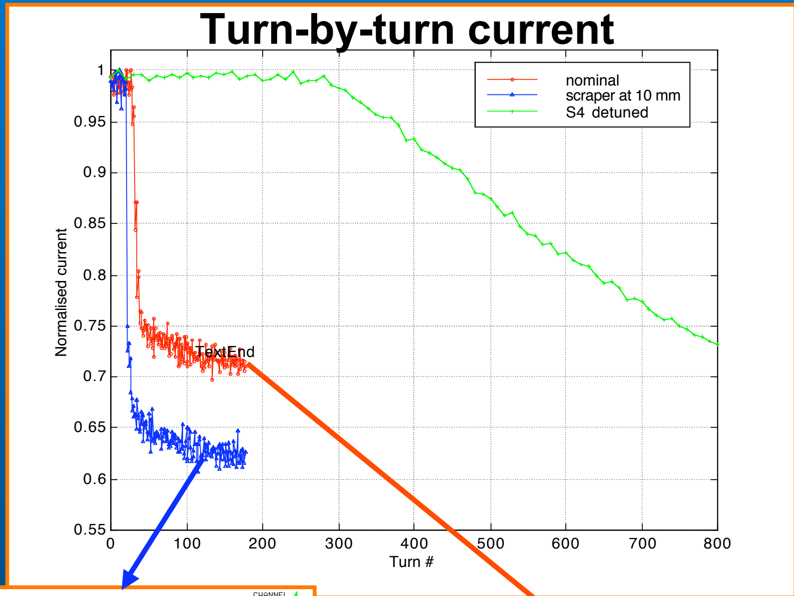
A.Ropert@esrf.fr

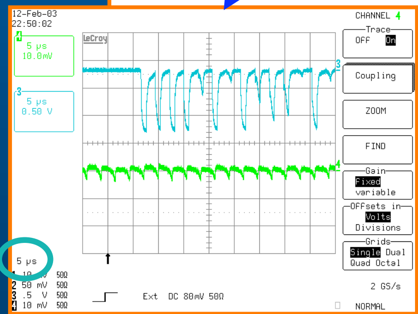
Transverse beam dynamics studies: Physical or dynamic aperture limitation ?

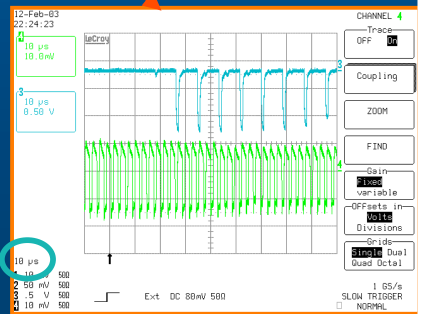
ESRF-SOLEIL collaboration

- Excite an oscillation with the injection kicker until the beam is lost
  - Closing a scraper
  - Detuned sextupoles

- Record the evolution of the turn-by-turn beam current and time resolved beam loss detectors



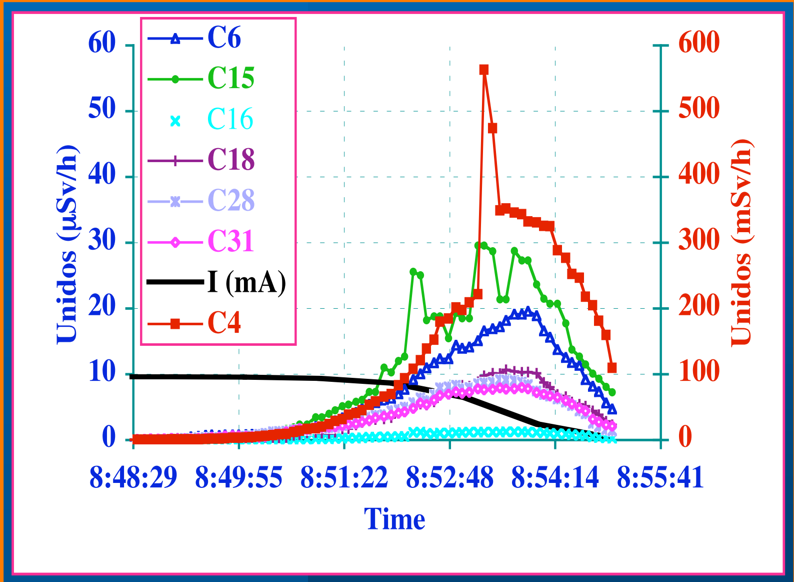


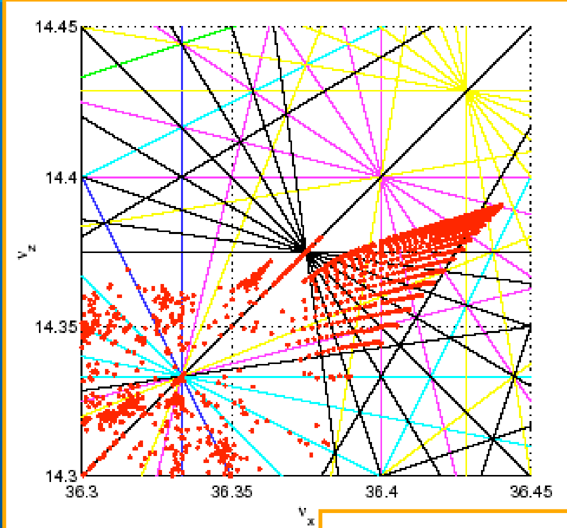


A.Ropert@esrf.fr

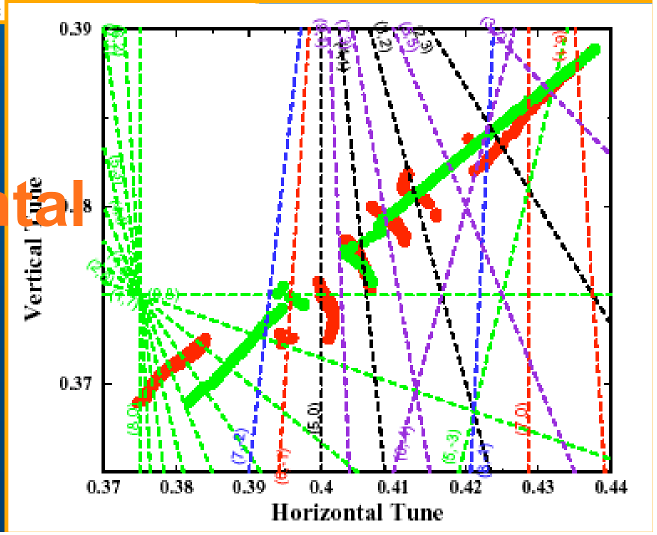
Transverse beam dynamics studies: Understanding the dynamic aperture limitation

The abrupt beam loss at large kicker current corresponds to losses in the horizontal plane





model



experimental

Courtesy of Y.Papaphilippou

A.Ropert@esrf.fr

Future plans (1)
ESRF II

Start a reflection on long-term improvements of the ESRF storage ring performances
with
keeping untouched the existing tunnel and beamlines

Objective: increase the brilliance by at least one order of magnitude

Beam current:	200 mA	→	500 mA
Emittance:	4 nm	→	1 nm

A.Ropert@esrf.fr

Beam current increase
ESRF II

- New vacuum system

- Multibunch feedback presently developed possibly sufficient

- HOM damped cavities
  - Superconducting cavities
    (SOLEIL, Cornell type)
  - Room temperature cavity
    (EU project)

A.Ropert@esrf.fr

Emittance reduction
ESRF II

➢Increase the number of dipoles ➡ TBA

Ultimate emittance for a 6 GeV, 32 cells lattice: 0.66 nm

Dispersion 10 times smaller than for the DBA

⬇

Very small dynamic aperture

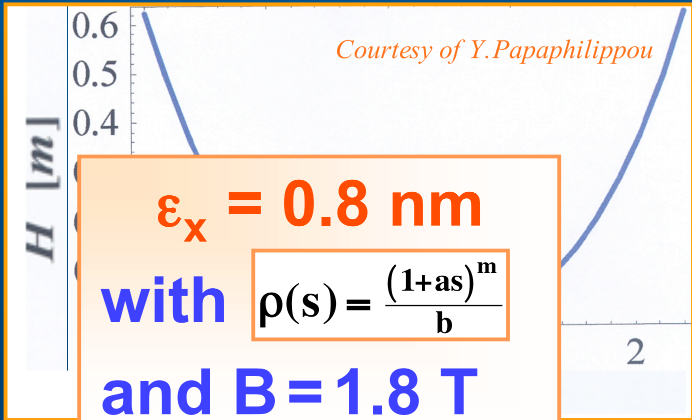
⬇

Relax on the emittance: 1 nm

➢DBA optics with longitudinally varying dipole field

$$\varepsilon_x = \frac{C_q \gamma^2}{J_x} \frac{\oint \frac{H(s)}{\rho^3} ds}{\oint \frac{1}{\rho^2} ds}$$

Raise the bending radius where H is maximum and vice versa



ε_x = 0.8 nm

with $\rho(s) = \frac{(1+as)^m}{b}$

and B = 1.8 T

A.Ropert@esrf.fr