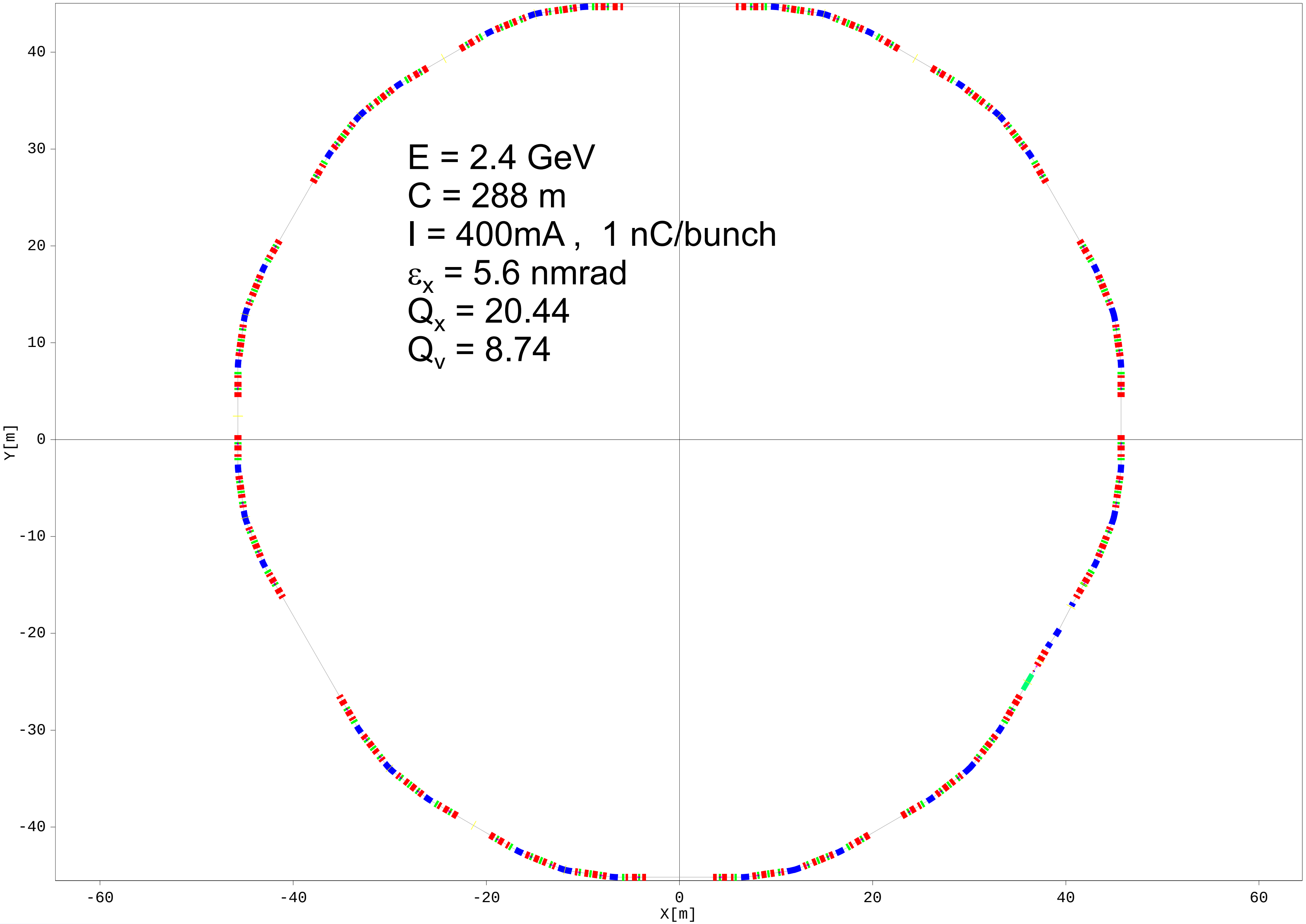
High Precision Emittance Measurements and Coupling Suppression in the SLS

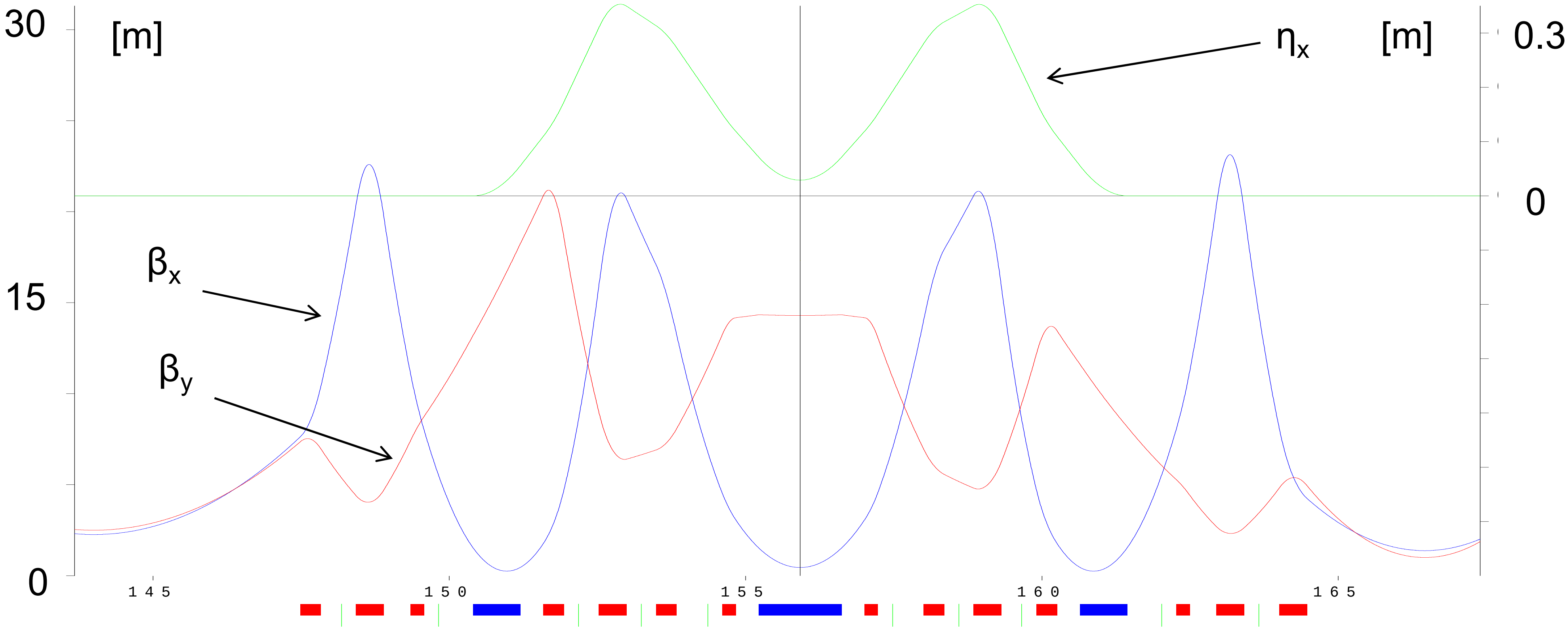
Å. Andersson*, M. Böge, A. Lüdeke, V. Schlott, A. Streun
Paul Scherrer Institute
Swiss Light Source

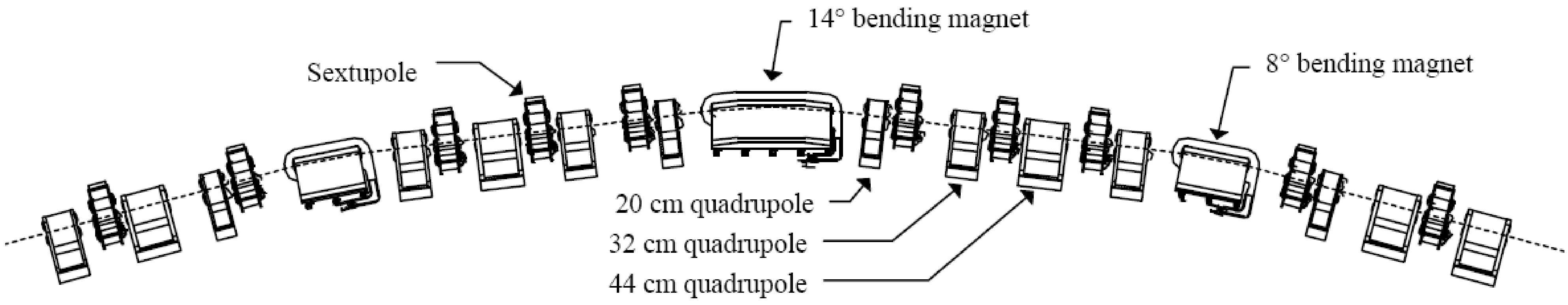
*Now at the MAX-IV Light Source Project, Lund, Sweden

Details in: NIM A 591(2008)437-446 and EPAC'08 "Coupling Control at the SLS"



E = 2.4 GeV
C = 288 m
I = 400mA , 1 nC/bunch
ε_x = 5.6 nmrad
Q_x = 20.44
Q_y = 8.74


30
[m]
15
0
η_x
[m]
0.3
0
β_x
β_y
145
150
155
160
165


14° bending magnet
Sextupole
8° bending magnet
20 cm quadrupole
32 cm quadrupole
44 cm quadrupole

Emittances:

$$\varepsilon_{x,y} = \left(\sigma_{x,y}{}^2 - (\eta_{x,y}\sigma_\delta)^2\right) / \beta_{x,y}$$

In the centre of the middle bending magnet we measure:

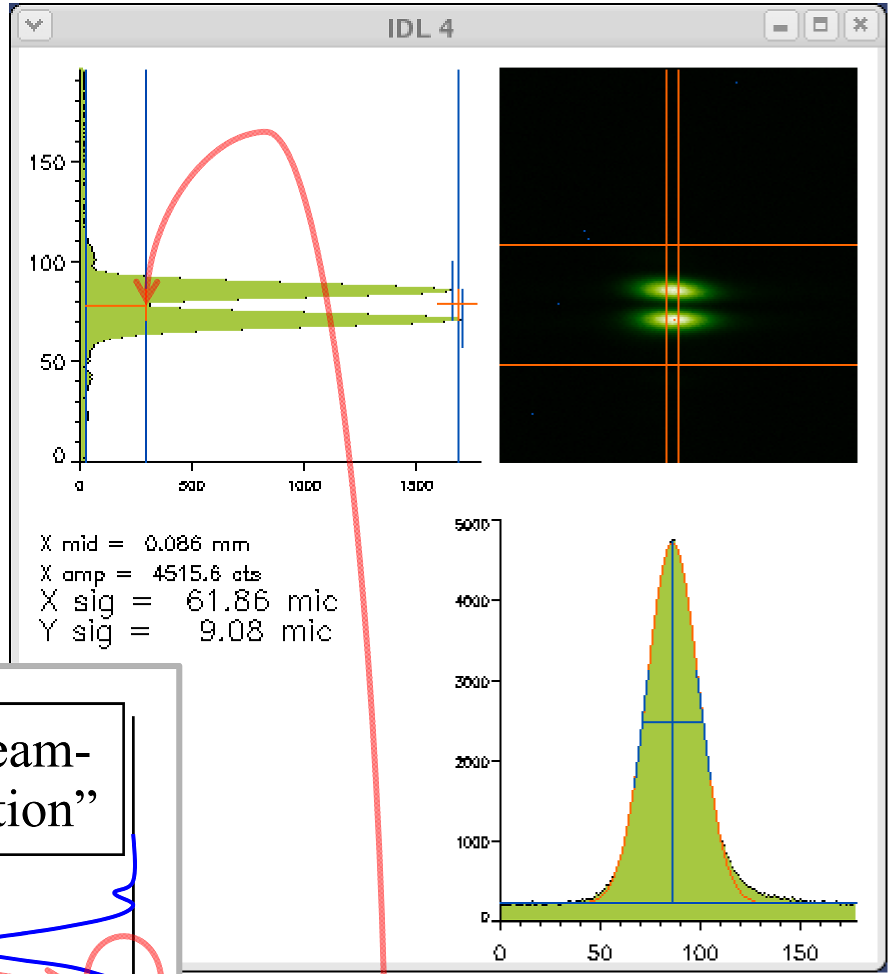
- Horizontal and vertical rms beam sizes, $\sigma_{x,y}$, and beam tilt angle.
- Horizontal and vertical dispersions, $\eta_{x,y}$.

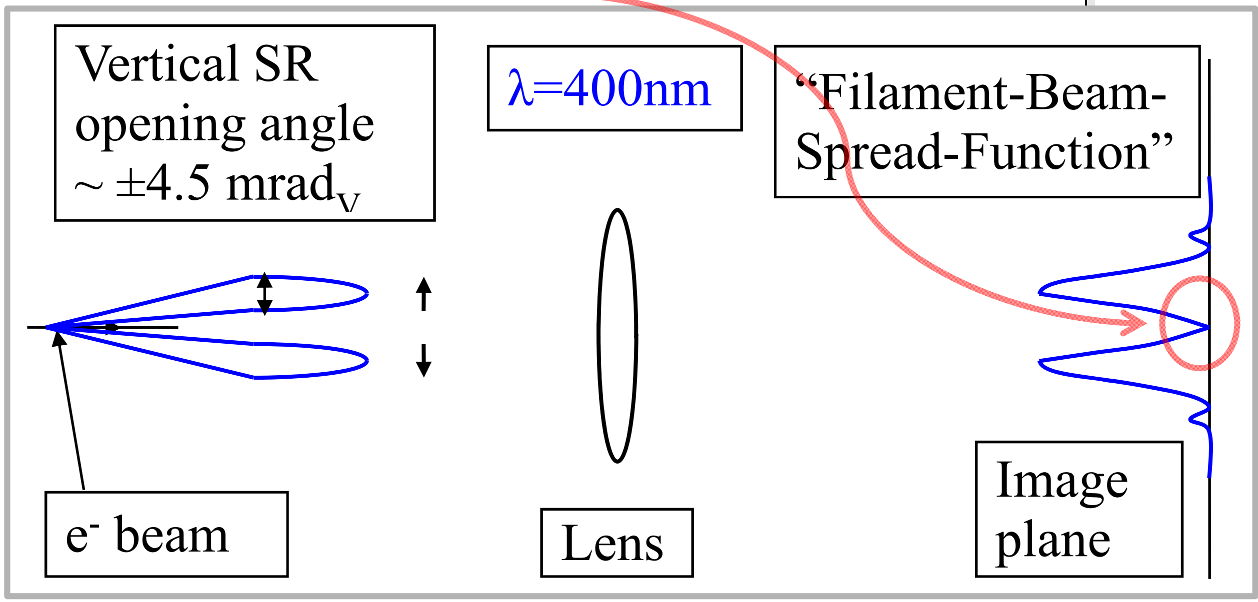
- We perform an entire measurement of the (average) horizontal and vertical beta functions in all 177 quadrupoles (1%, 0.5% rms precision), and use these to fit the model beta functions. The model gives the beta functions, $\beta_{x,y}$, in the centre of the dipole.
- The natural rms energy spread, σ_δ, is assumed to within 10%, since the beam shows longitudinal stability. Verified by streak camera measurement.

Beam size measurement

The π-polarization method(*):
An image of the beam is formed from vertically polarized visible-UV synchrotron radiation.

A π phase shift between the two radiation lobes ==> $I_{y=0}=0$ in "FBSF"



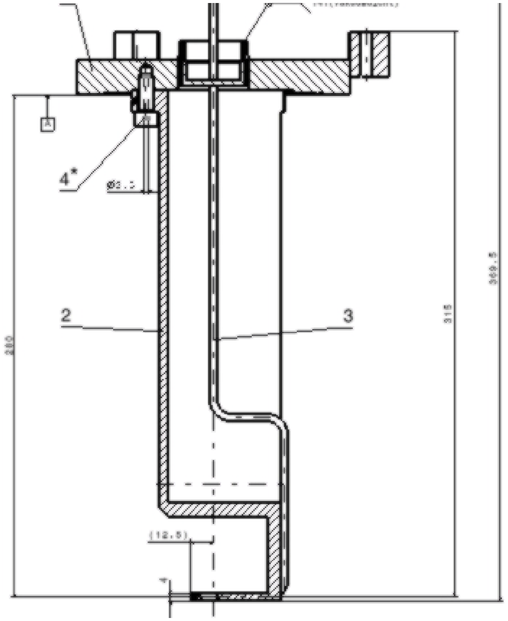


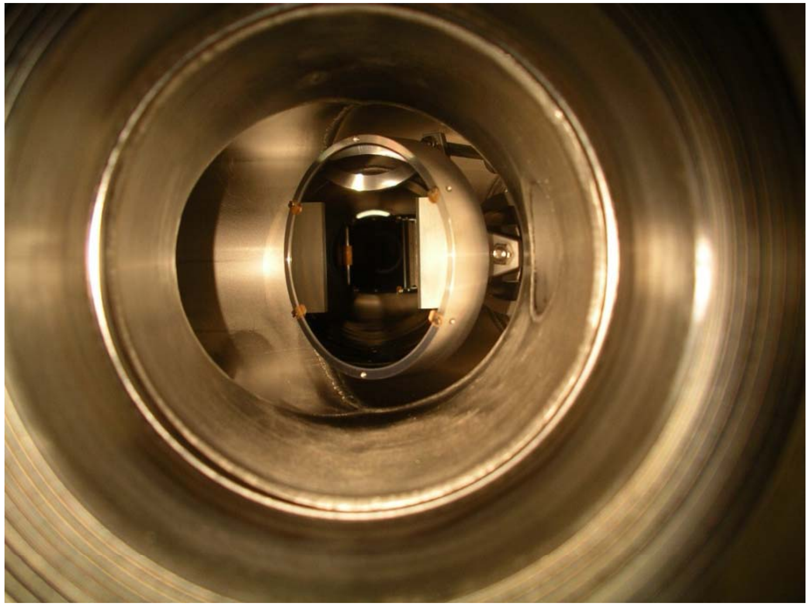
Finite vert. beam size ==>

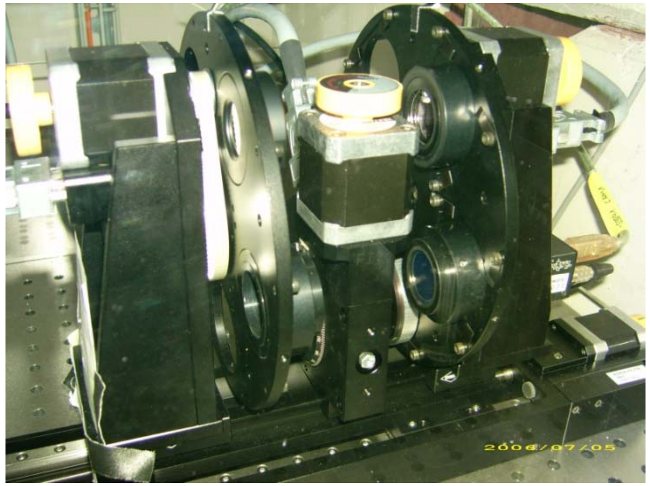
Non-zero central intensity

*) Old idea springing from MAX-lab, see EPAC'96 Andersson, Eriksson, Chubar

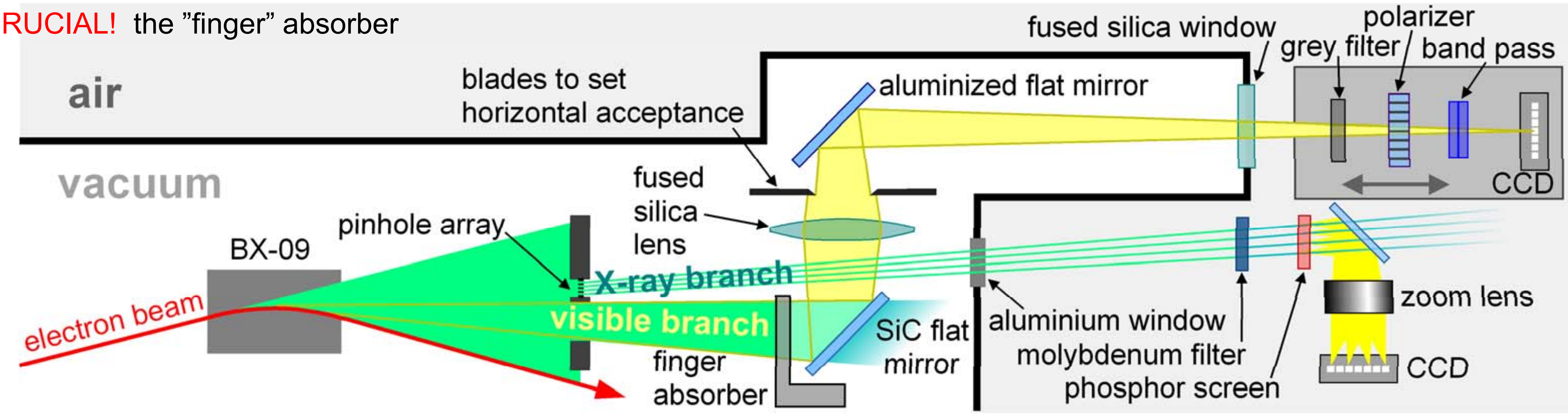
Beam size measurement: beamline components





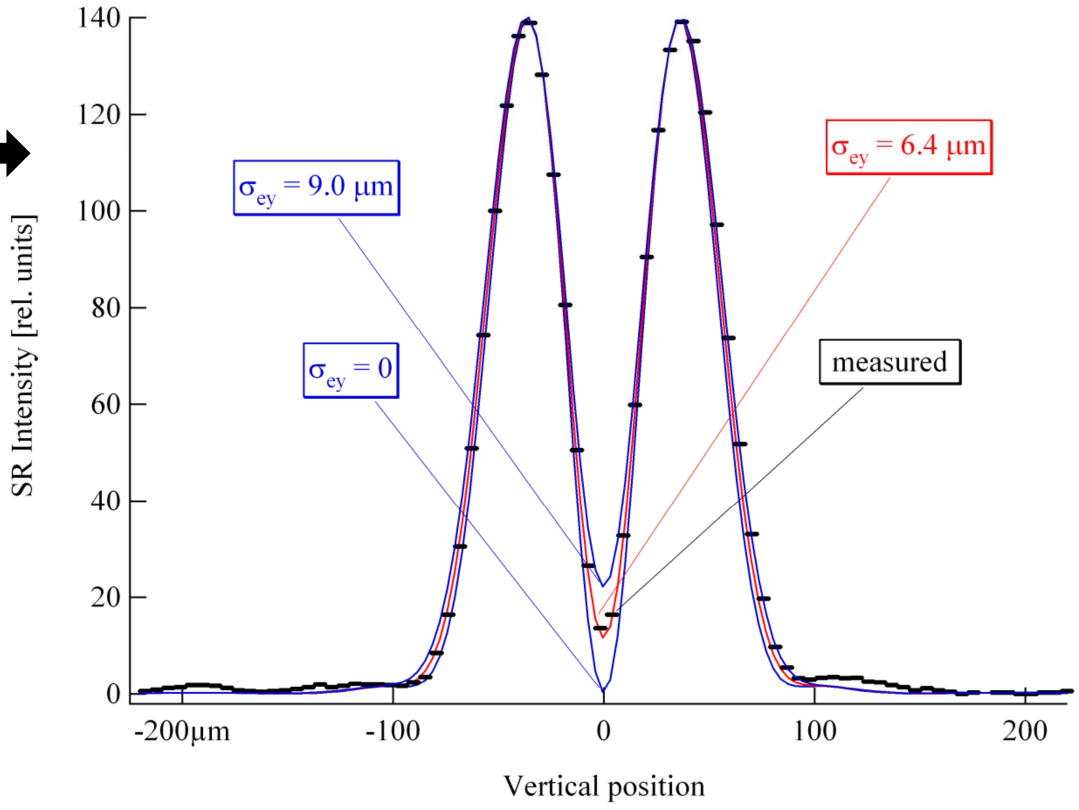


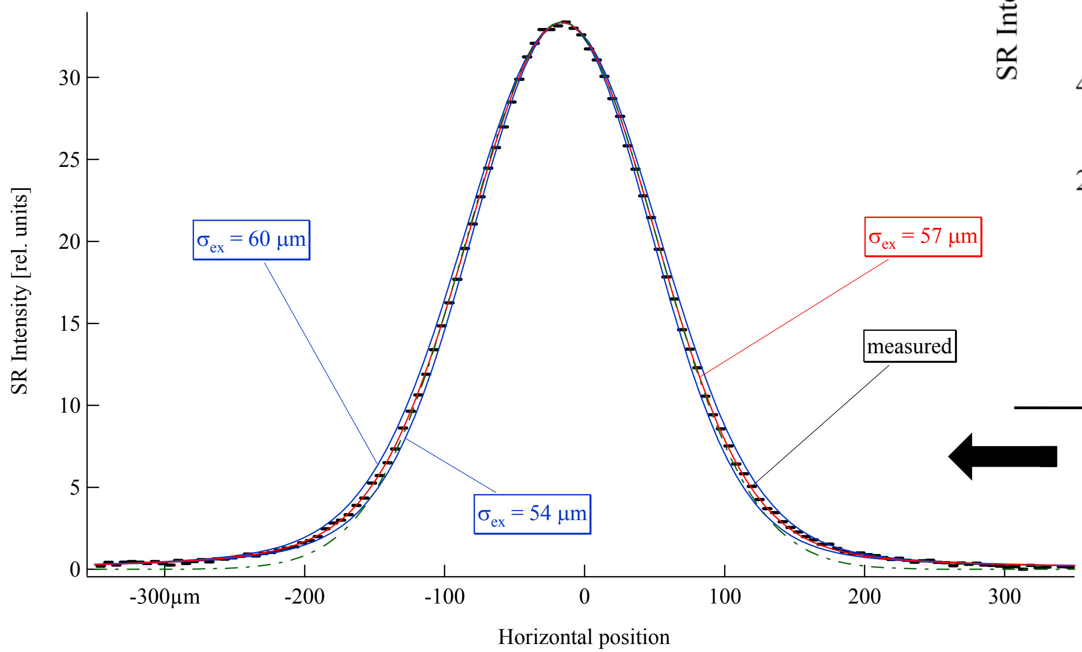
CRUCIAL! the "finger" absorber



Beam size measurement: precision

Vertical: Predicted profiles (SRW*) for beam height values 0, 6.4, 9.0 µm, and measured.
Statistical rms error = 0.1µm





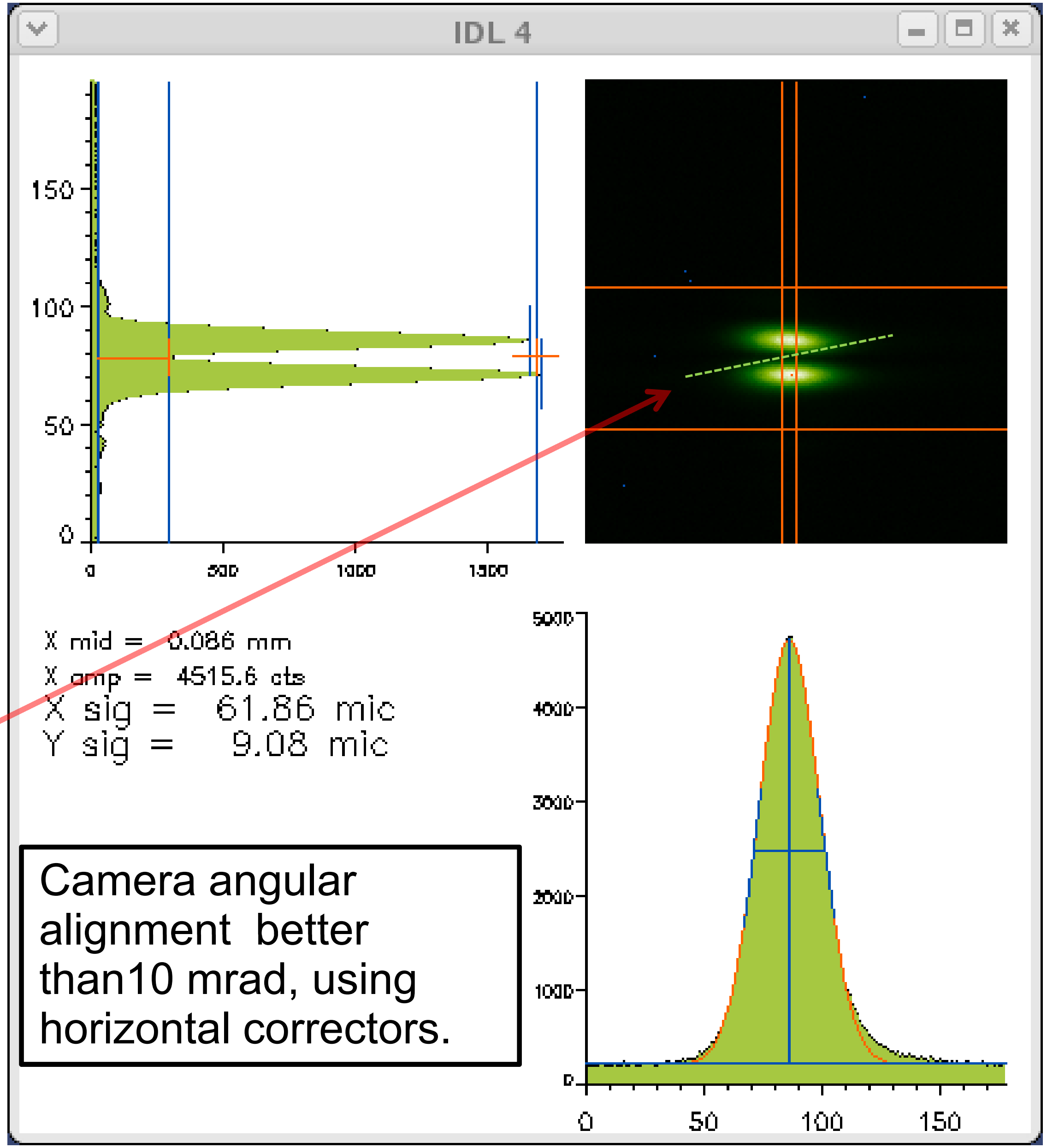
Horizontal: Predicted profiles (SRW) for beam width values 54, 57, 60 µm, and measured.
Statistical rms error = 0.3µm

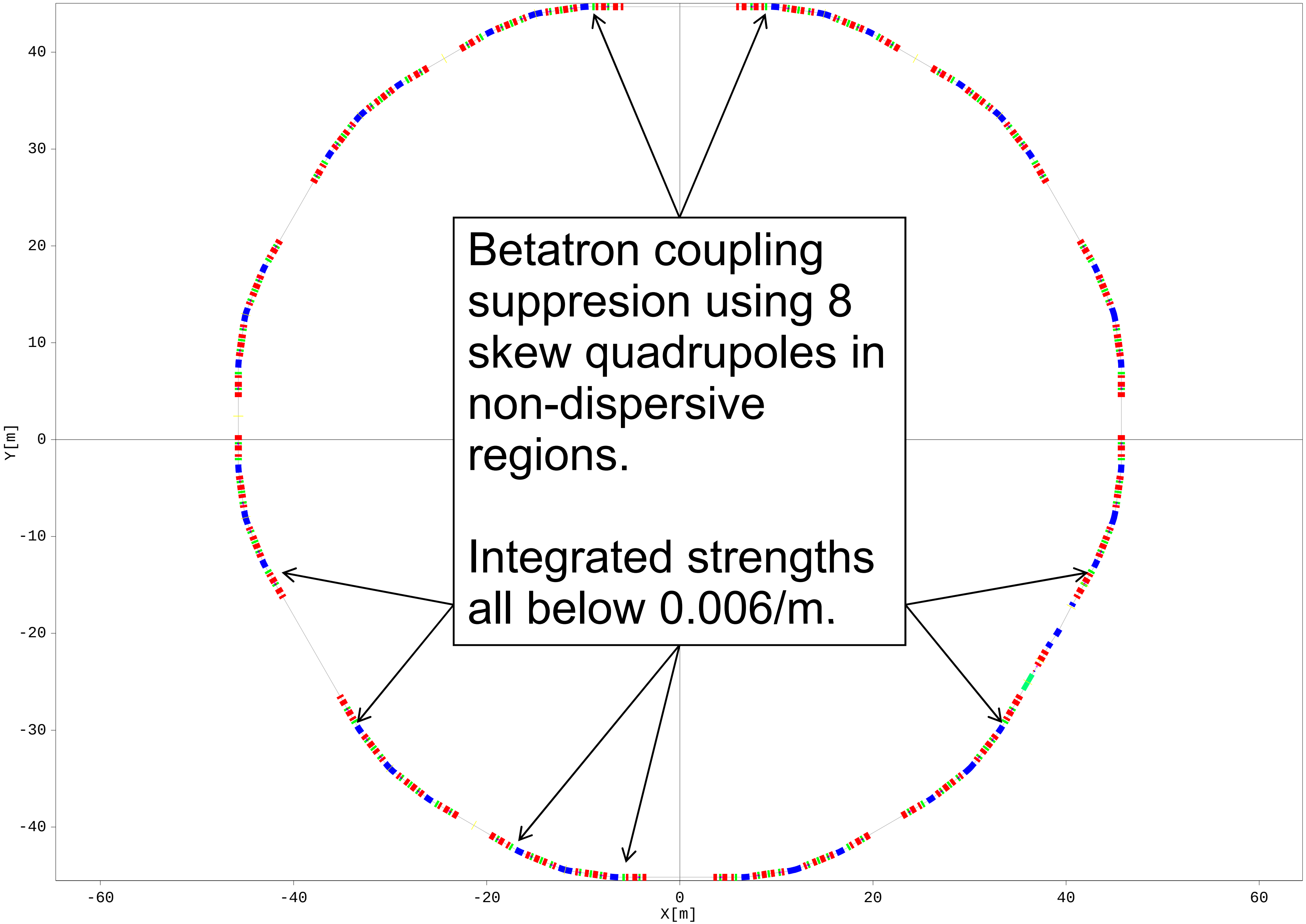
*) Synchrotron Radiation Workshop, see EPAC'98 Chubar, Ellaume

Dispersion measurements

- Dispersions are measured *in the same source point*, by tracking the image "centre of gravity"-movement for small RF changes.
- ±500 Hz ⇔ (α known) $\Delta E/E = \pm 0.165\%$ ==> $\Delta x \sim \pm 40 \mu m$; $\Delta y \sim \pm 4 \mu m$
- Rms precision = 0.4 µm

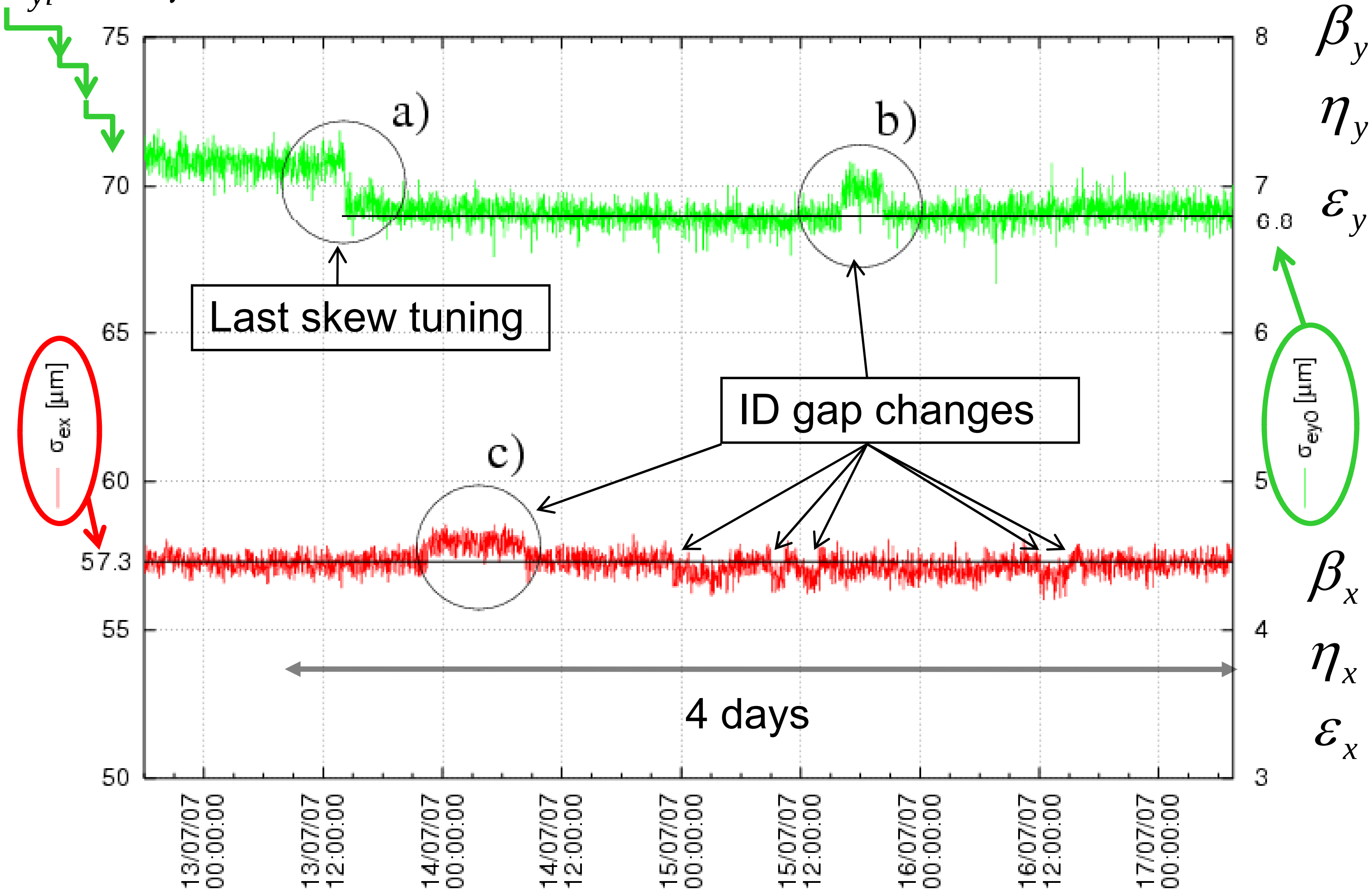
Rms precision in dispersion determination ~ 0.25 mm




Betatron coupling suppresion using 8 skew quadrupoles in non-dispersive regions.
Integrated strengths all below 0.006/m.
Y[m]
X[m]
40
30
20
10
0
-10
-20
-30
-40
-60
-40
-20
0
20
40
60

ε_y reduction in user top-up operation, I=400mA

$\sigma_{yi} \approx 10\,\mu\text{m}$



$$\beta_y = (13.55 \pm 0.14)\,\text{m}$$
$$\eta_y = (2.3 \pm 0.55)\,\text{mm}$$
$$\varepsilon_y = (3.2 \pm 0.7)\,\text{pm}$$

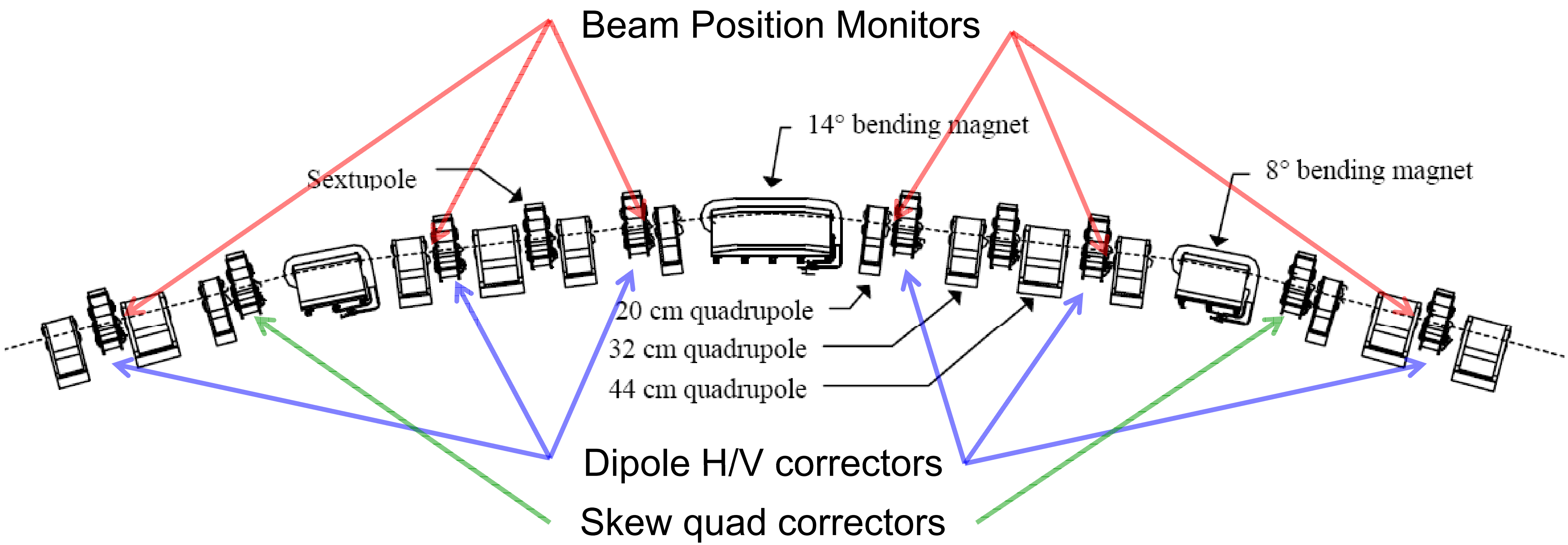
$$\frac{\varepsilon_y}{\varepsilon_x} = (0.05 \pm 0.02)\,\%$$

$$\beta_x = (0.431 \pm 0.009)\,\text{m}$$
$$\eta_x = (27.3 \pm 1.0)\,\text{mm}$$
$$\varepsilon_x = (6.3 + 0.7 - 0.9)\,\text{nm}$$

Error margins represent lineary added maximum errors in each measurement.

Which are the contributing factors for acheiving the low emittance ratio in SLS?

Magnet Alignments and BPM/Corrector scheme



Alignment tolerances (rms)
Individual elem. on girders:

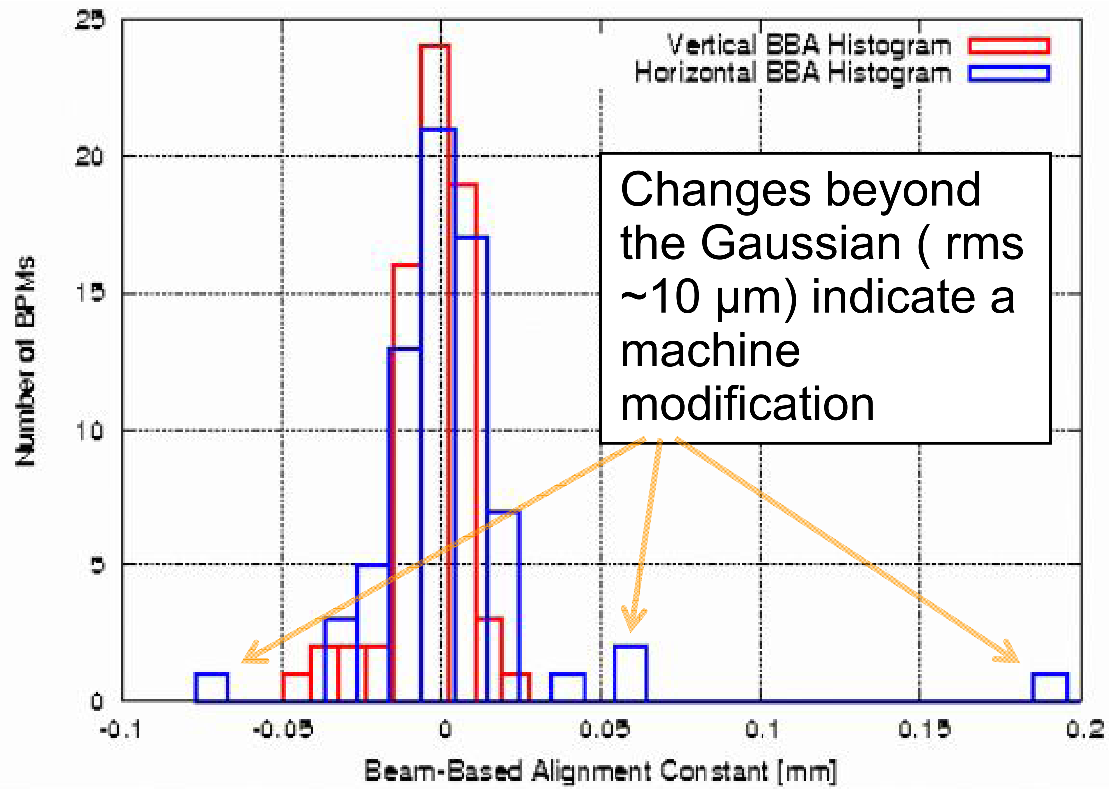
X,Y Quad, Sext	50 µm
Rolls	100µrad

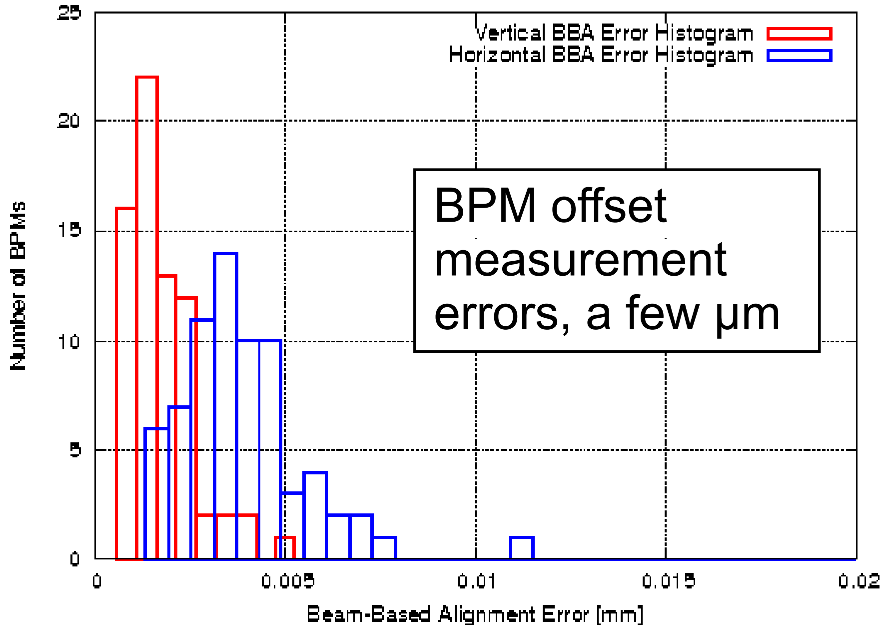
Average phase advance between BPMs:

Y	43 deg
X	102 deg

Contr. 2: Frequent beam-based BPM check-ups

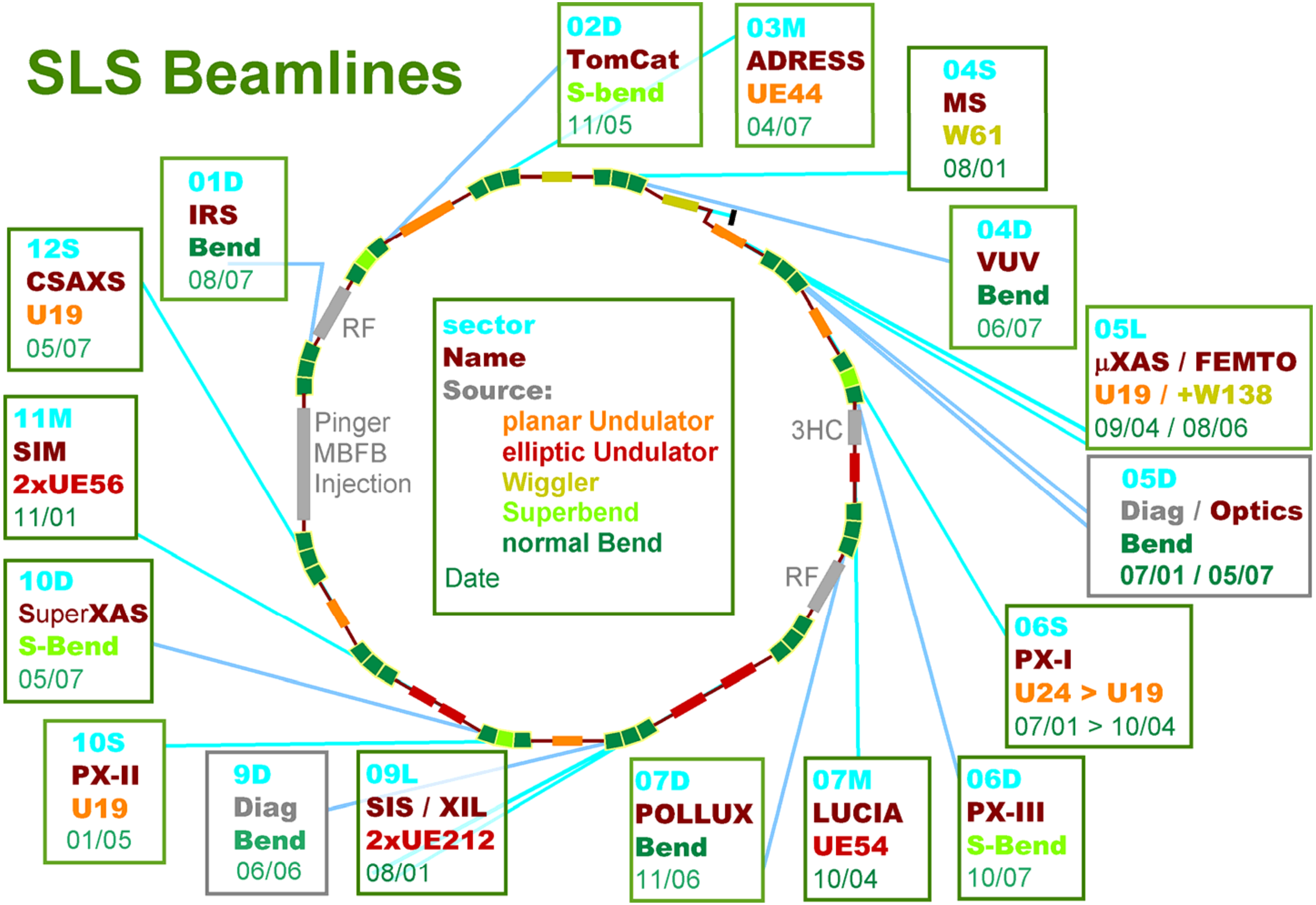
- In each sector the reference orbit is nailed to the centres of the six quadrupoles adjacent to the BPMs, by help of frequently repeated beam-based BPM offset check-ups.





Contr. 3: User facility!

SLS Beamlines



Contr 3: User facility!

User demands

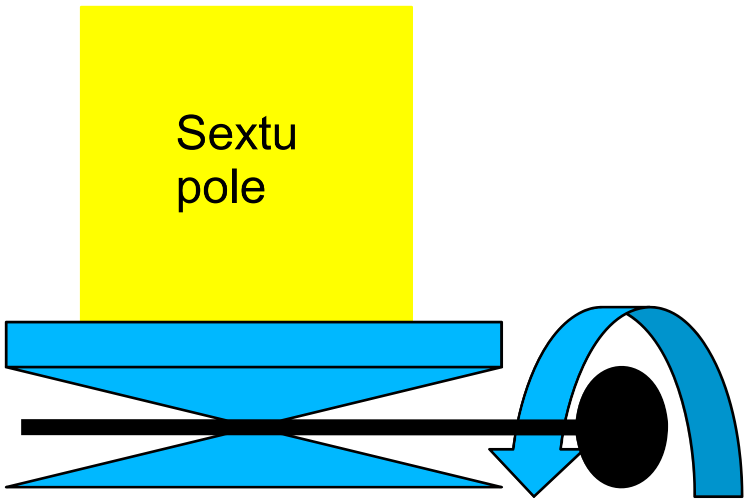
- Orbit stability, short term and long term ==>The orbit position is extremely well probed by the **numerous** beamlines. In principle, all orbit changes are carefully tracked down.
- Constant beam current (Top-up) ==> Thermal stability, possibility for careful fine tuning of skew correctors .
- User orbit bumps? No major problem if less than 300-400 µm. The smallest emittance ratio is reached **with** user bumps. Former, when being in the mm range, they caused $\varepsilon_y \approx 20\mathrm{pm}$.
- IDs? As seen most ID changes have minor influence, and again, the smallest emittance ratio is reach during user operation **with** most ID gaps closed.

Outlook for coupling suppression in SLS:

- There is still a factor 6 to be gained in vertical emittance before the intrinsic limit 0.55 pmrad (due to the fundamental quantum nature of SR emission) in SLS is reached.
- The whole ring was eqipped with 24 instead of the 8 skews in the non-dispersive regions. An SVD based correction scheme was applied, to minimize the coupling ==> Marginal effect on ε_y.
- Simulations show that residual vertical dispersion (rms ~3mm), induced by beam passages off mid-plane in sextupoles, is the major contribution to ε_y.
- 6 new skews in dispersive regions to attack the residual vertical dispersion.

Outlook for damping rings: Sextupoles

- For a ***dedicated damping ring***, one could contemplate adding ***shunts*** (and maybe even remote levelling) to each sextupole and do a proper ***Beam-Based Alignment*** of them (tedious, but maybe most effective?)

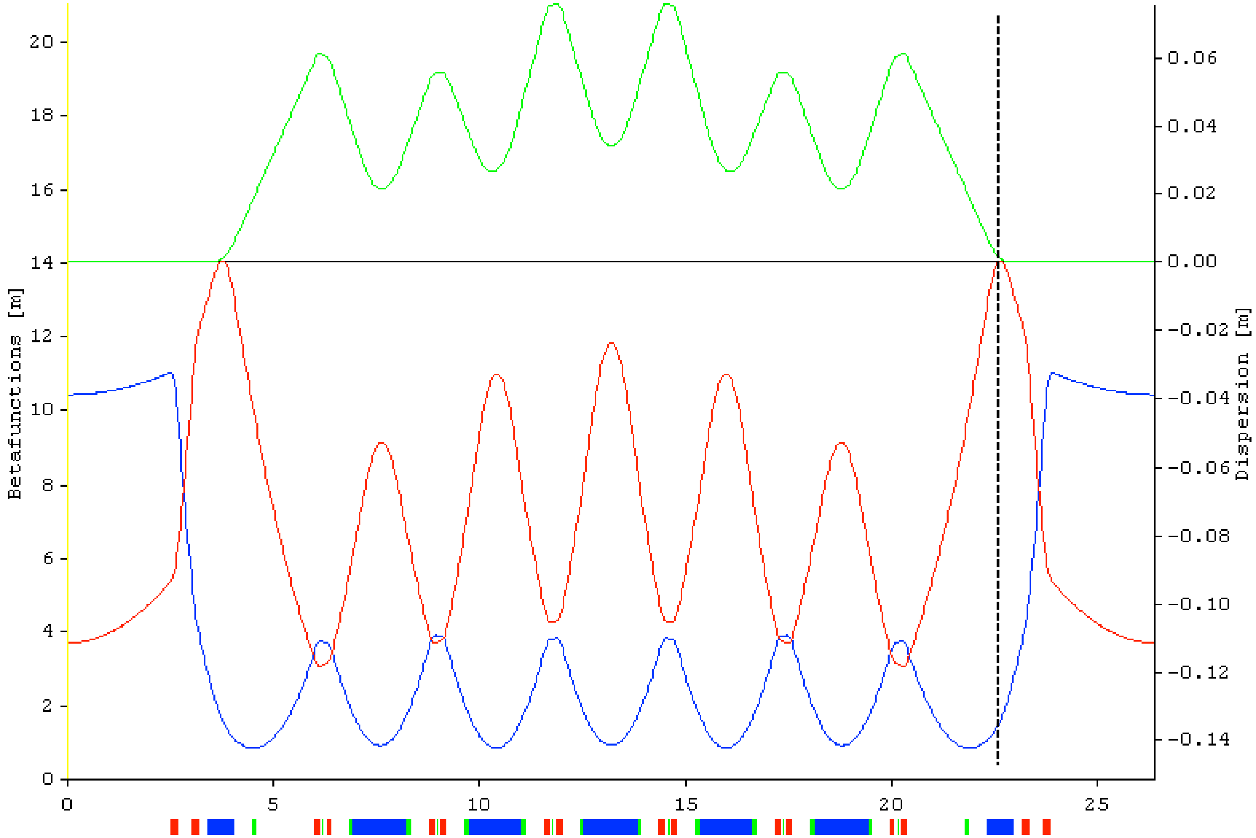


Outlook for damping rings: the π-polariz. metod?

Ex:
Light
source
MAX IV

E = 3 GeV
C = 528 m
I = 500mA
ε_x = 250 pmrad
ε_y = 1 pmrad

MAX-lab



β_y = 14 m ==> σ_y=3.7μm OK!
β_x = 1.8 m ==> σ_x=21μm
Large hor. acc. angle ==> OK!