The new Beam Size Monitor at SLS

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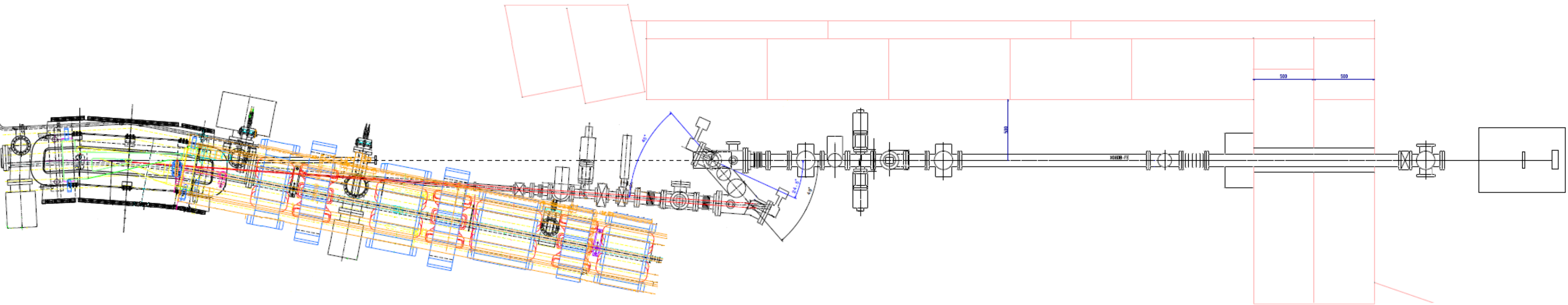


ALERT 2014 Workshop, IFIC Valencia May 5th 2014

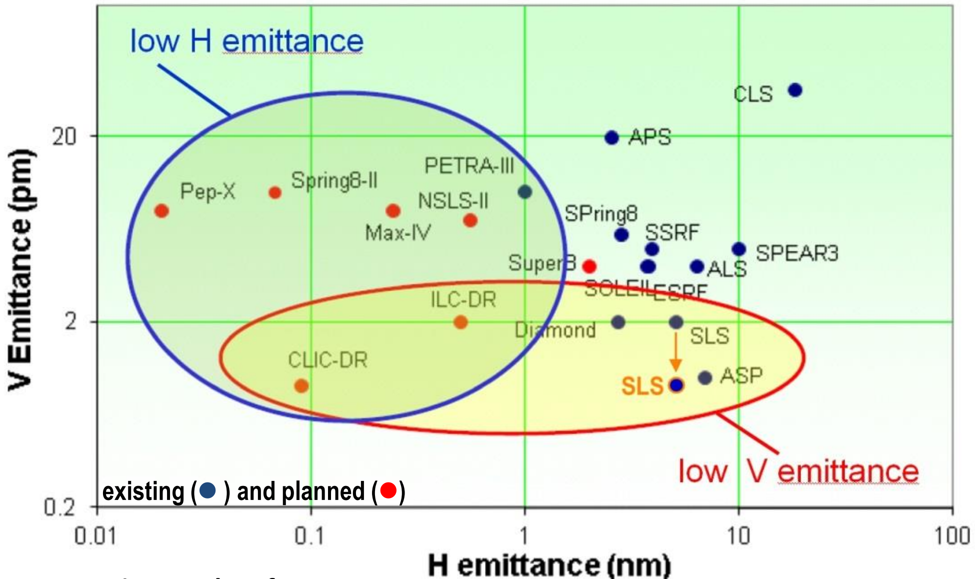
Intro

Some years ago a program was launched at SLS towards the minimization of the vertical equilibrium emittance…

- beam assisted realignment of girders
- correction of roll errors in BPMs
- Model-based and random correction schemes using skew quadrupoles

} Minimization of β-coupling and vertical dispersion

Horizontal and Vertical Emittances of Storage Rings



- vertical beam size: **3.6 ± 0.6 µm**
- vertical emittance: **0.9 ± 0.4 pm**

M. Aiba et al., *Ultra Low Vertical Emittance at SLS Through Systematic and Random Optimization*, NIM-A 694 (2012) 133-139

How was that measured?
Can we improve it?

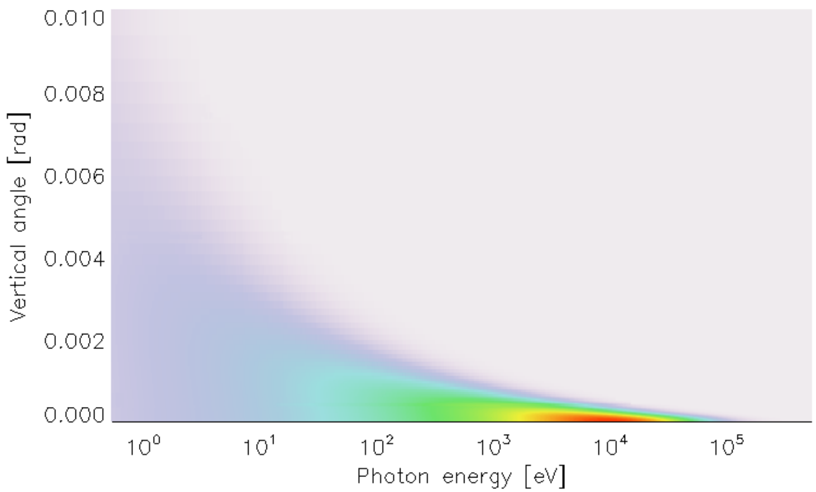
Figure taken from:

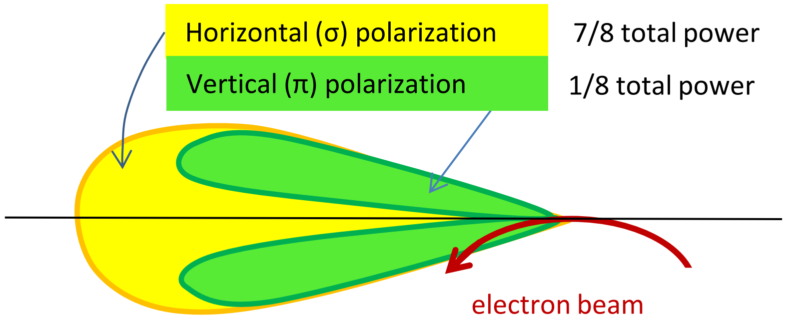
R. Bartolini, Low Emittance *Ring Design*, ICFA Beam Dynamics Newsletter, No. 57, Chapter 3.1, 2012 – and updated.

Measurement of small beam sizes at SLS

non-invasive diagnostics → image formation methods using synchrotron radiation from bending magnets

SR spectrum from bending magnet (1.4 T @ 2.4 GeV)

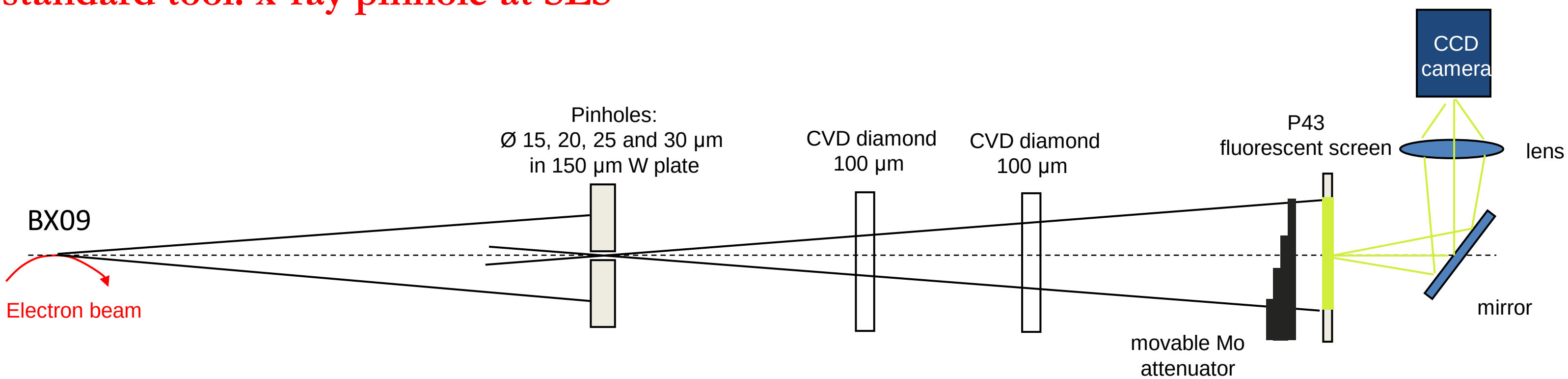


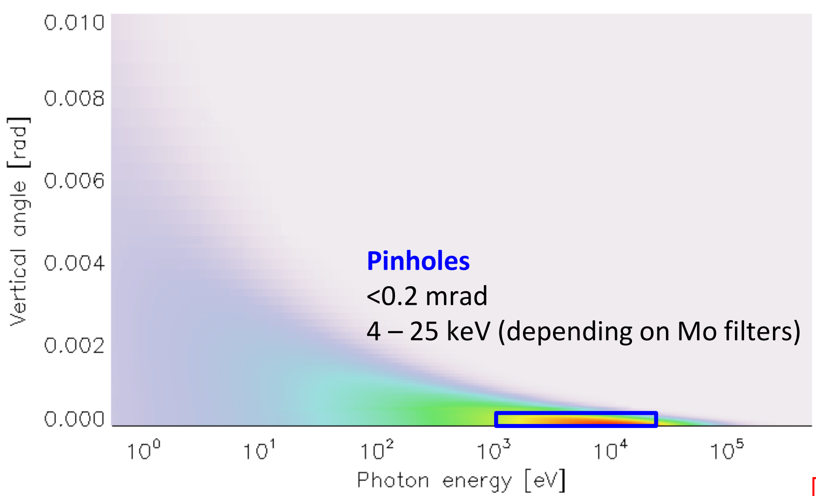


Measurement of small beam sizes at SLS

non-invasive diagnostics → image formation methods using synchrotron radiation from bending magnets

A standard tool: x-ray pinhole at SLS





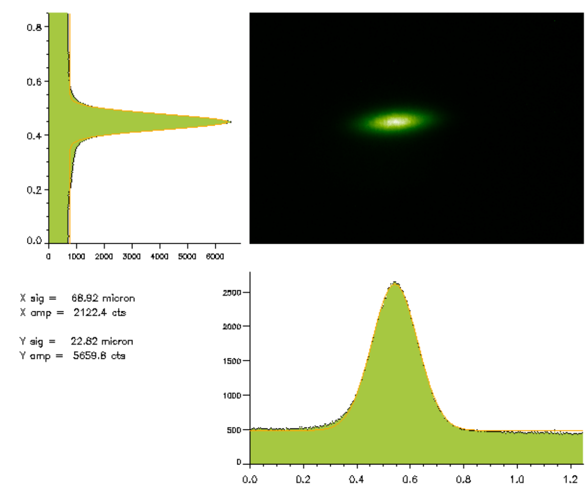


Image = Source profile * PSF

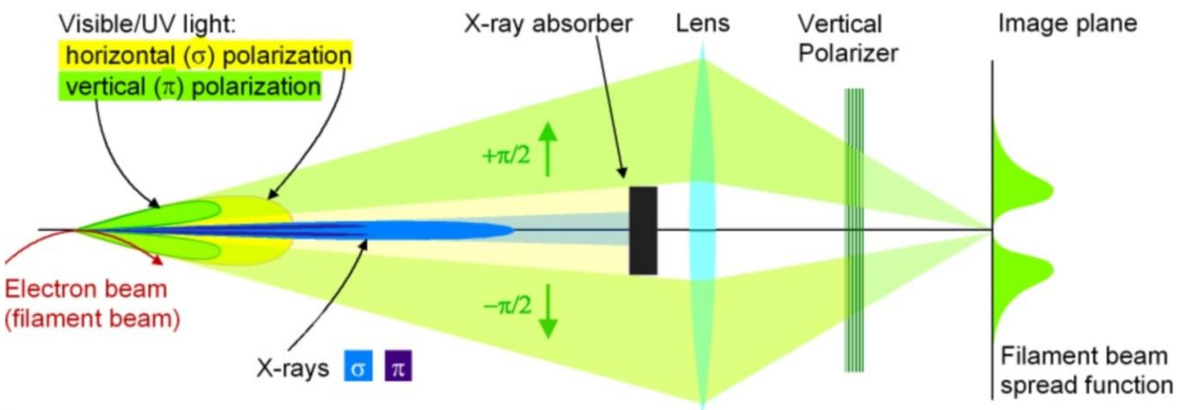
PSF : 9 -25 µm

→ prone to errors for σ_y < PSF

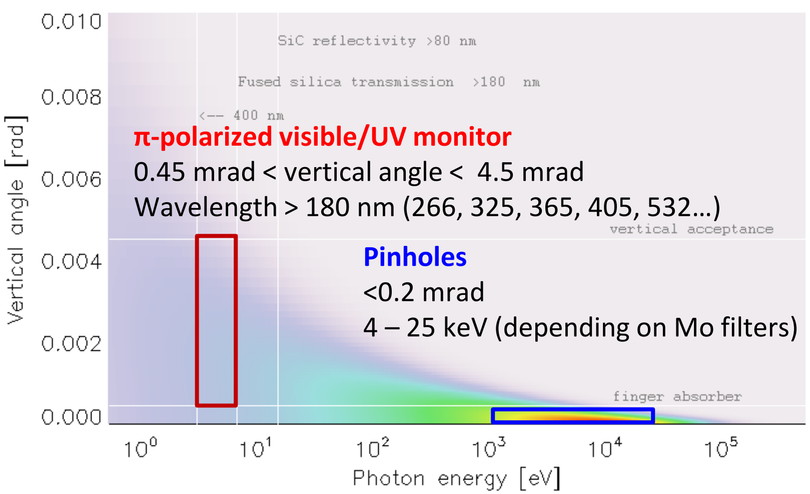
Measurement of small beam sizes at SLS

non-invasive diagnostics → image formation methods using synchrotron radiation from bending magnets

A high resolution tool: π-polarized visible/UV monitor at SLS

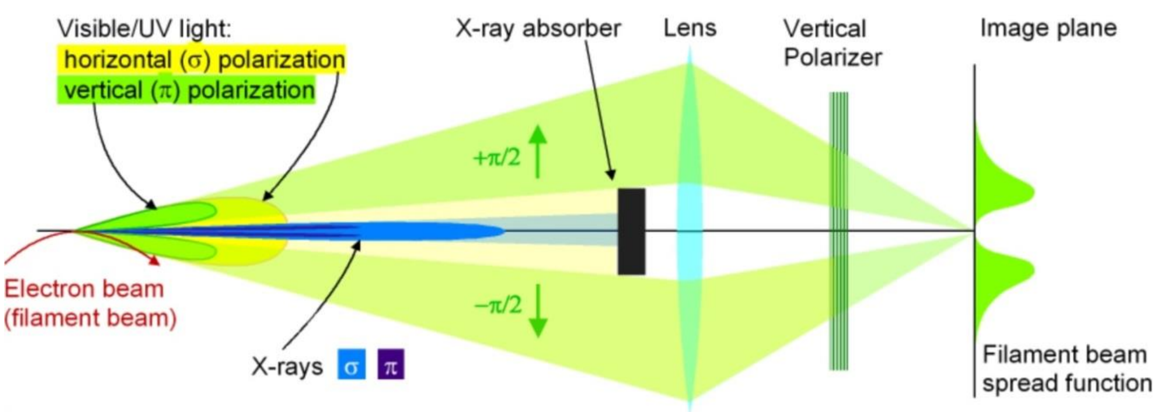


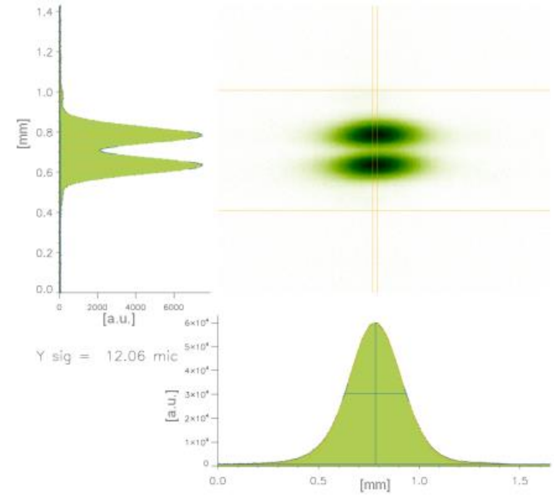
Å. Andersson et al., *Determination of Small Vertical Electron Beam Profile and Emittance at the Swiss Light Source*, NIM-A 592 (2008)



Principle of π–polarized Imaging Monitor

A high resolution tool: π-polarized visible/UV monitor at SLS



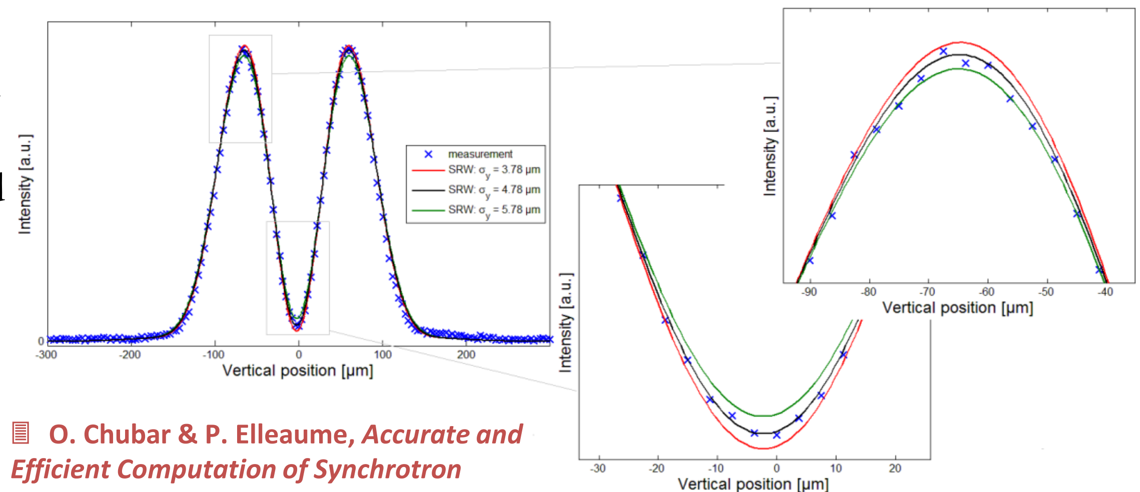


- imaging of vertically polarized SR in the visible/UV
- phase shift of π between two radiation lobes

  → destructive interference in the mid plane

  zero intensity for a point-like beam

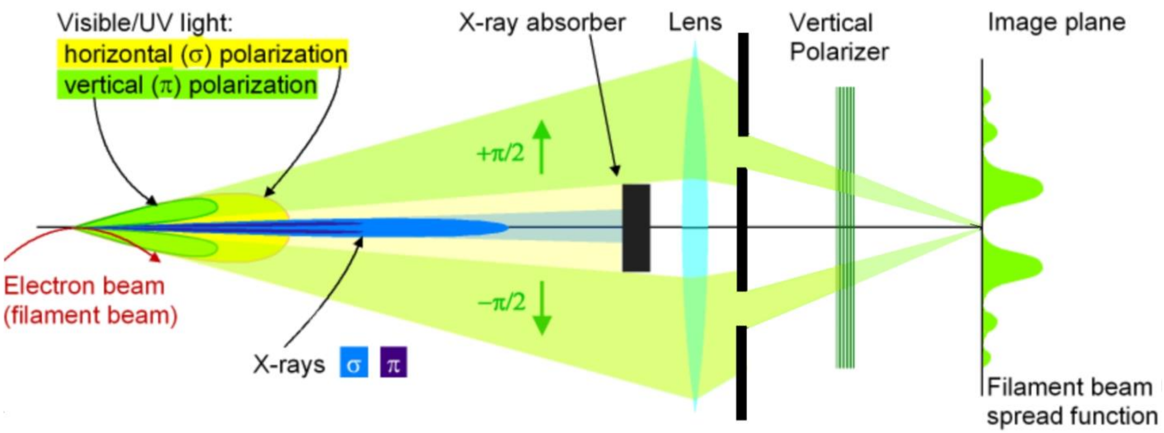
  residual intensity for a beam with finite vertical beam size
- theoretical calculations with SRW for beam size determination

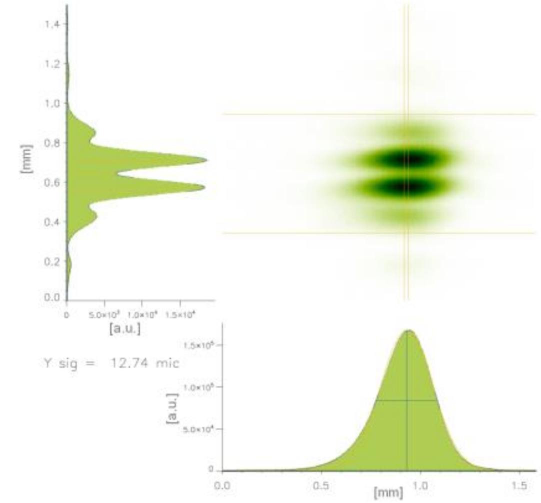


O. Chubar & P. Elleaume, *Accurate and Efficient Computation of Synchrotron Radiation in the Near Field Region*, EPAC98

Principle of π–polarized Interference Monitor

A high resolution tool: π-polarized visible/UV monitor at SLS





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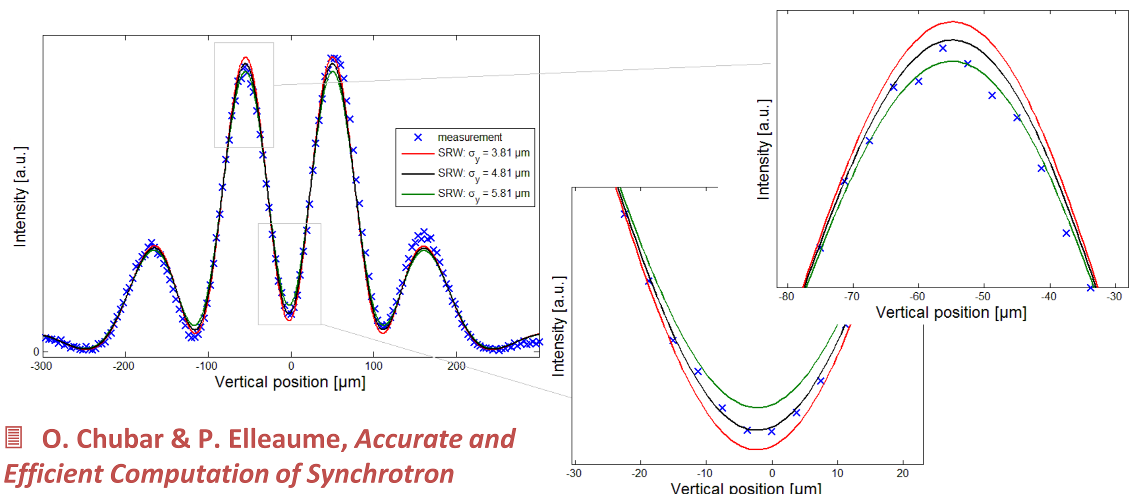
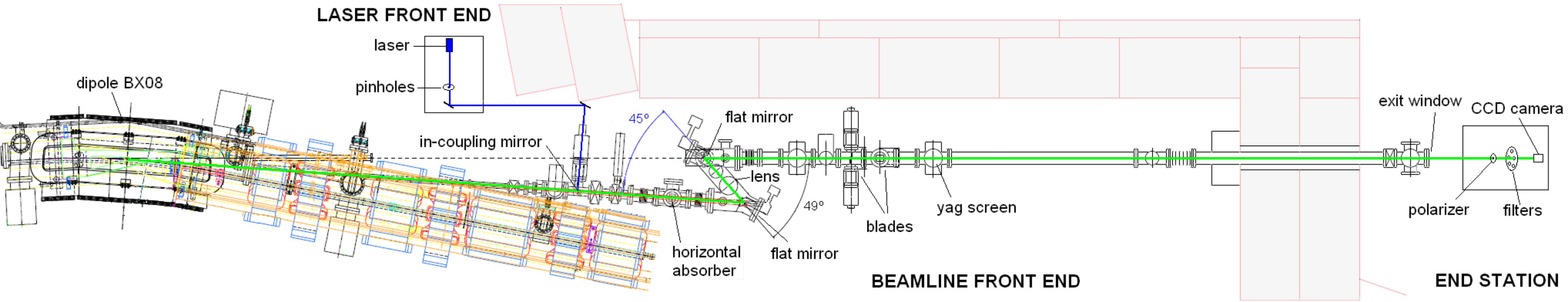


O. Chubar & P. Elleaume, *Accurate and Efficient Computation of Synchrotron Radiation in the Near Field Region*, EPAC98

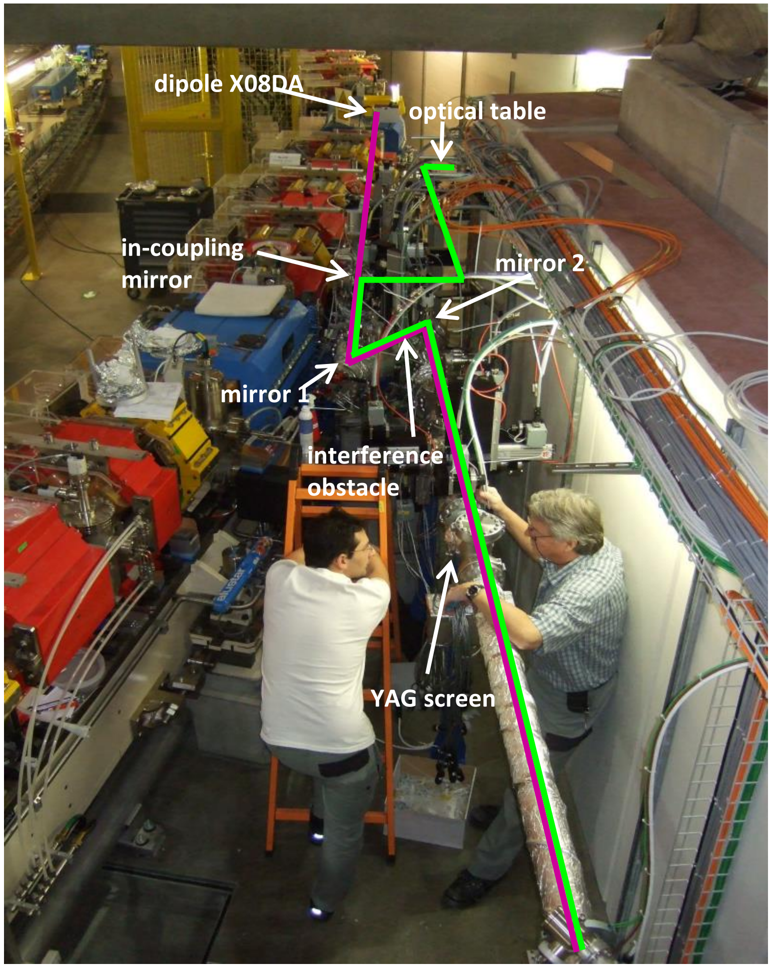
Design of the new SLS Beam Size Monitor



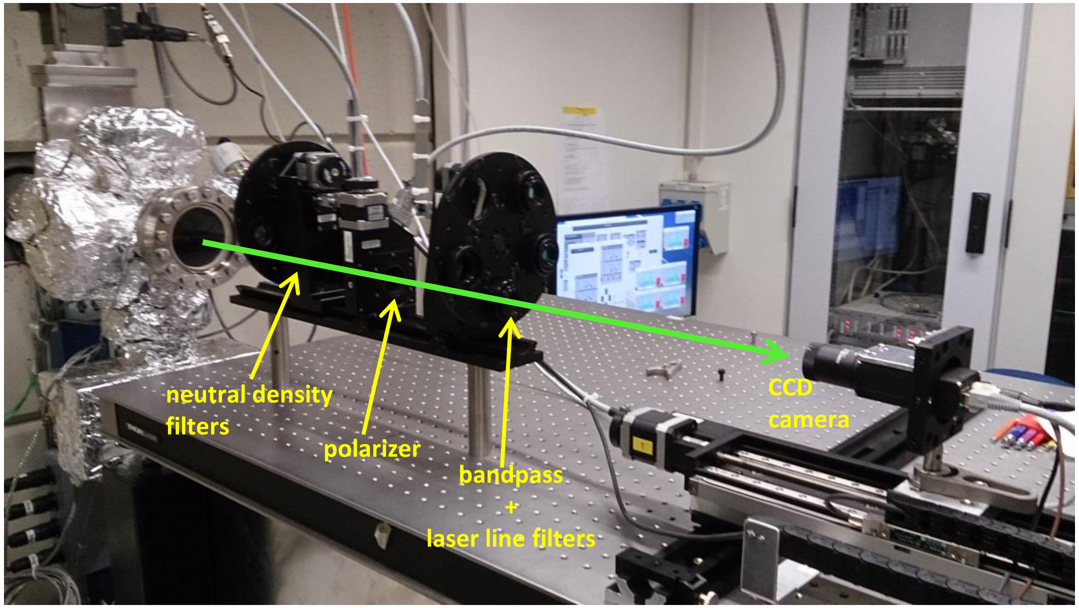
- Higher optical magnification ratio, 1.45 (new) vs 0.84 (old) and smaller pixel size
  - ⟶ more active pixels on the CCD camera
  - ⟶ increase of measurement precision
- imaging & interferometric method
  - ⟶ complementary measurement methods
  - ⟶ cross-checking of results
- Longer beamline (X08DA)
  - ⟶ optics table outside tunnel: accessible during machine operation
- Laser front end
  - ⟶ alignment check of focusing element (minimize optical aberrations)
  - ⟶ online monitoring optical component quality with lasers at 405 and 532 nm

Installation of the new SLS Beam Size Monitor

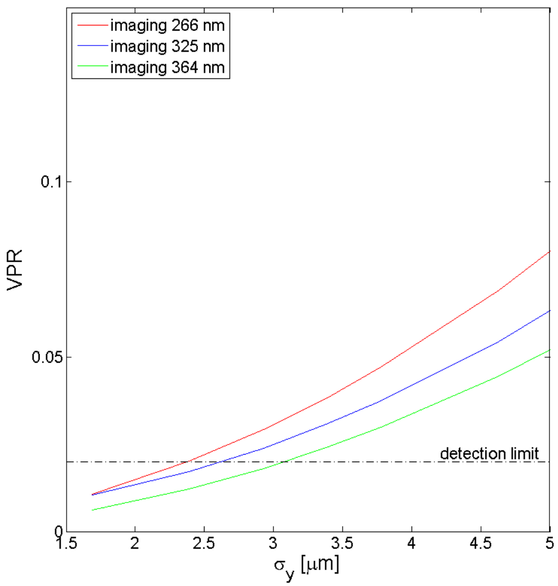
Beamline frontend

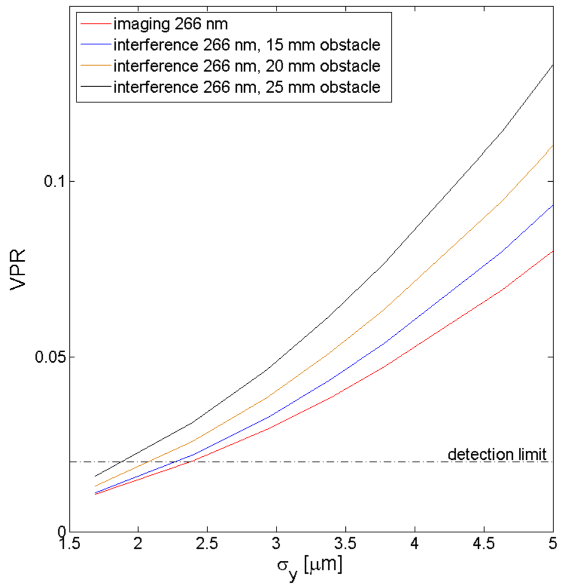


Measurement Station



Resolution limits

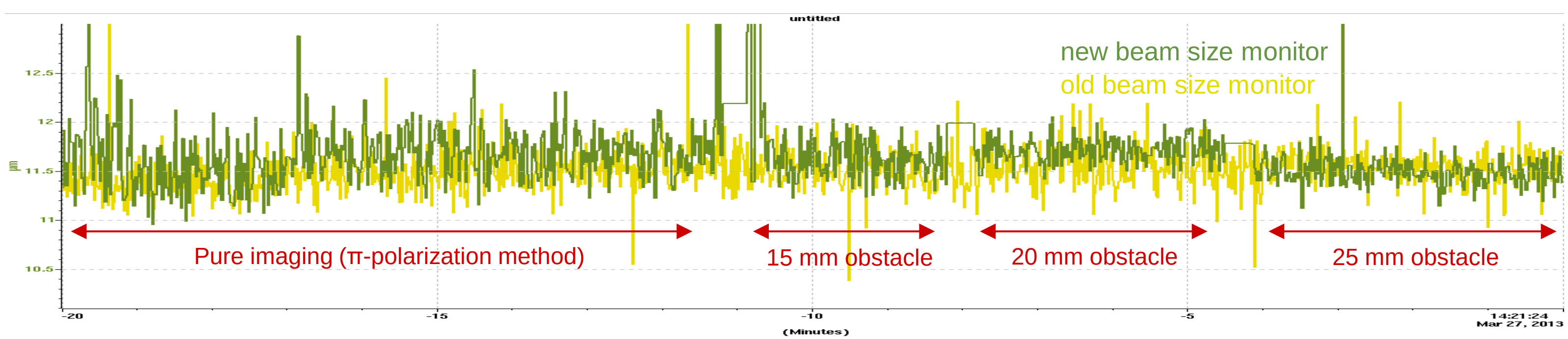




Simulated valley-to-peak ratios for different wavelengths and measurement methods as a function of the vertical beam size.

→ improved resolution (2% valley-to-peak ratio)

→ beam size measurements ~ 2 µm



- Comparison of the vertical beam size measured simultaneously with the old and the new monitor.
- On the new monitor the measurement method has been changed successively.

→ Consistent results for the different methods on the new monitor (also for the different wavelengths)

From beam size to emittance

We cannot measure the emittance directly… but we can measure the beam size.
in a synchrotron β-functions and dispersions are well known

vertical emittance $$\varepsilon_y = \frac{1}{\beta_y}\left(\sigma_y^2 - \sigma_\delta^2 \eta_y^2\right)$$

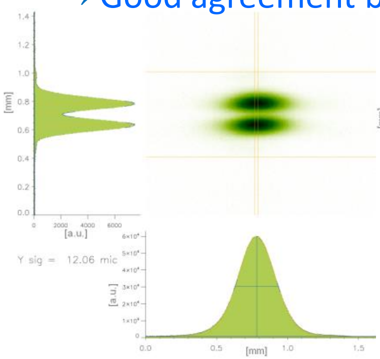
At the center of dipole BX08:

Parameter	Theoretical	Measured (2013)	
β_x β_y [m]	0.452 13.6	0.481 ± 0.008 13.41 ± 0.05	Quadrupole strength variation method
η_x η_y [mm]	29 0	27.2 ± 0.4 -1.0 ± 0.2	From beam displacement at the monitor with energy variations
σ_x [µm]	56	54 ± 2	From beam size monitor / pinholes
σ_δ	$8.6 \cdot 10^{-4}$	---	Equilibrium value @2.4GeV

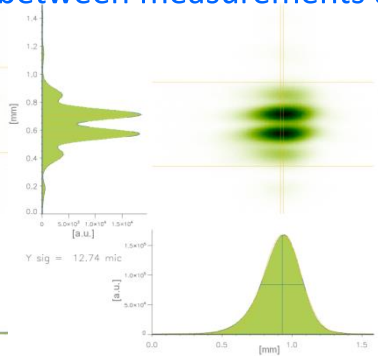
Results

- Screenshots of the graphical interface showing the CCD camera readout for the different measurement methods.
- SRW simulation result for direct comparison.

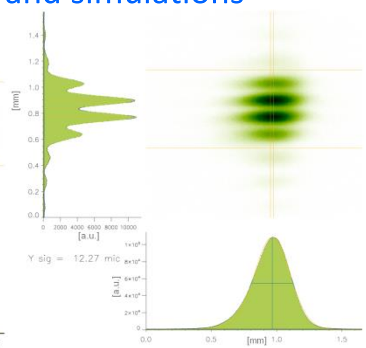
→ Good agreement between measurements and simulations



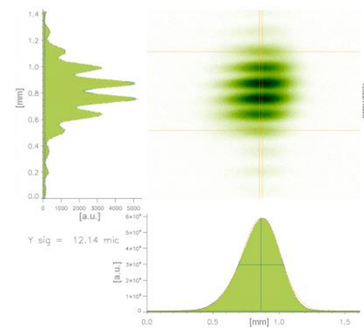
Measurement
Pure imaging



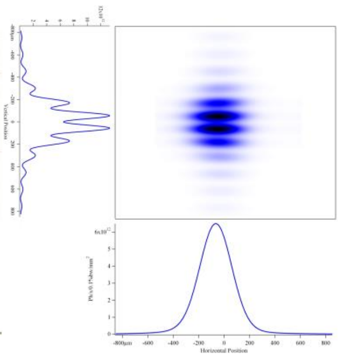
Measurement
Interferometric method
15 mm obstacle



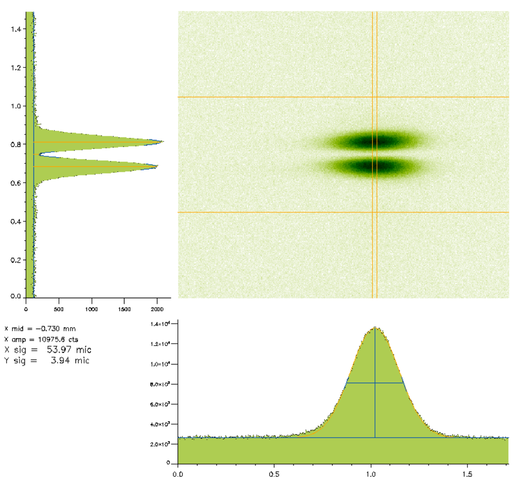
Measurement
Interferometric method
20 mm obstacle



Measurement
Interferometric method
25 mm obstacle



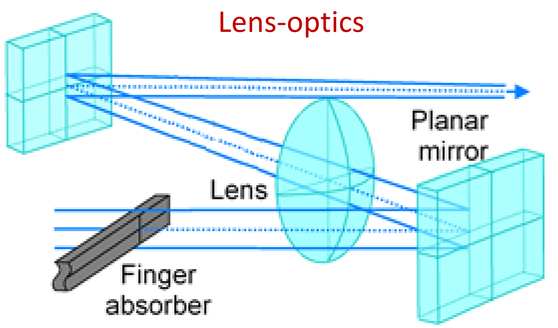
SRW simulation
Interferometric method
25 mm obstacle



Smallest beam size measured so far at the new monitor
in lens-based configuration, using the π-polarization imaging method

$\sigma_y = 4.3 \pm 0.3\ \mu m \rightarrow \varepsilon_y = 1.3 \pm 0.2$ pm·rad

Monitor Upgrade (January 2014)

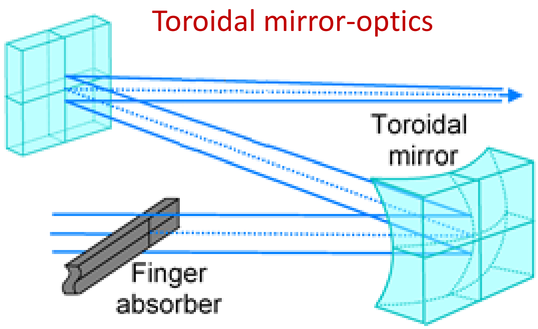


Exchange of the lens for a toroidal mirror as the focusing element

→ free selection of SR wavelength without shift of image plane

→ allows broader spectral bandwidth (increases intensity on camera)

→ might allow shorter wavelength measurements with increase resolution



But imaging with a toroidal mirror is *tricky*…

Critical issues:

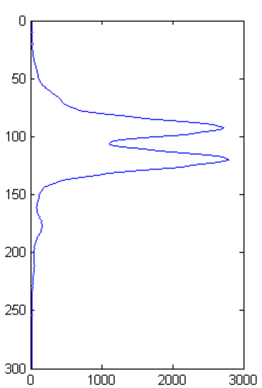
- Misalignments (offsets, tilts, rotation around axis)
- Surface quality: modeled to set specifications

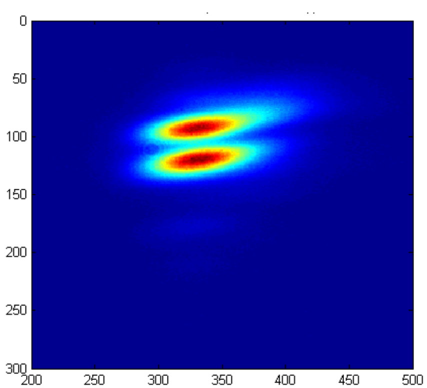
Commissioning

→ Testbench where to image in parallel with a twin toroidal mirror

→ Limiting aperture on light path: ongoing work to realign beamline

→ Adjustment of incident angles (tight constrained with toroid-optics) by tilting gimbal mount





Summary

New high resolution beam size monitor installed at SLS

→ application of complementary measuring methods (π-polarization/interferometric)

→ expected measurements resolution for vertical beam height ~ 2 μm

→ commissioned for lens-optics, measured $\varepsilon_y = 1.3 \pm 0.2$ pmrad so far

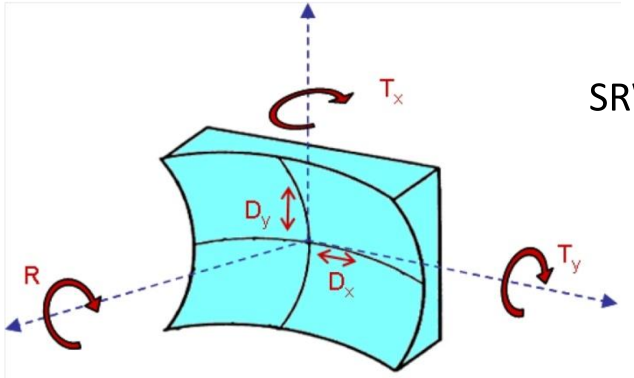
→ upgrade (toroidal focusing mirror) provides an easier selection of SR wavelength but commissioning is tricky and still ongoing

Thank you for your attention!!!

Additional slides

Critical issues: misalignments

Toroidal mirror used for imaging → peak/valley ratio extremely sensitive to misalignments



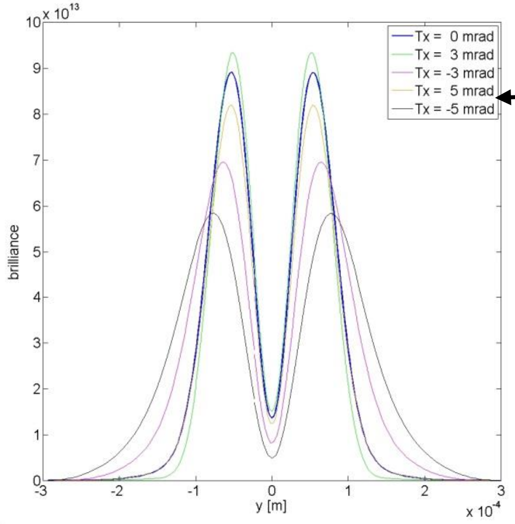
SRW simulations used to define constraints on mechanical alignment

Offsets

- horizontal offset D_x
- vertical offset D_y

} → not critical within ± 50 μm

Tilts and Axis Rotation

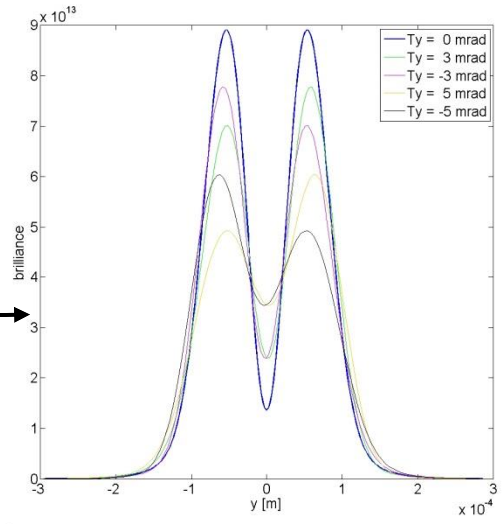


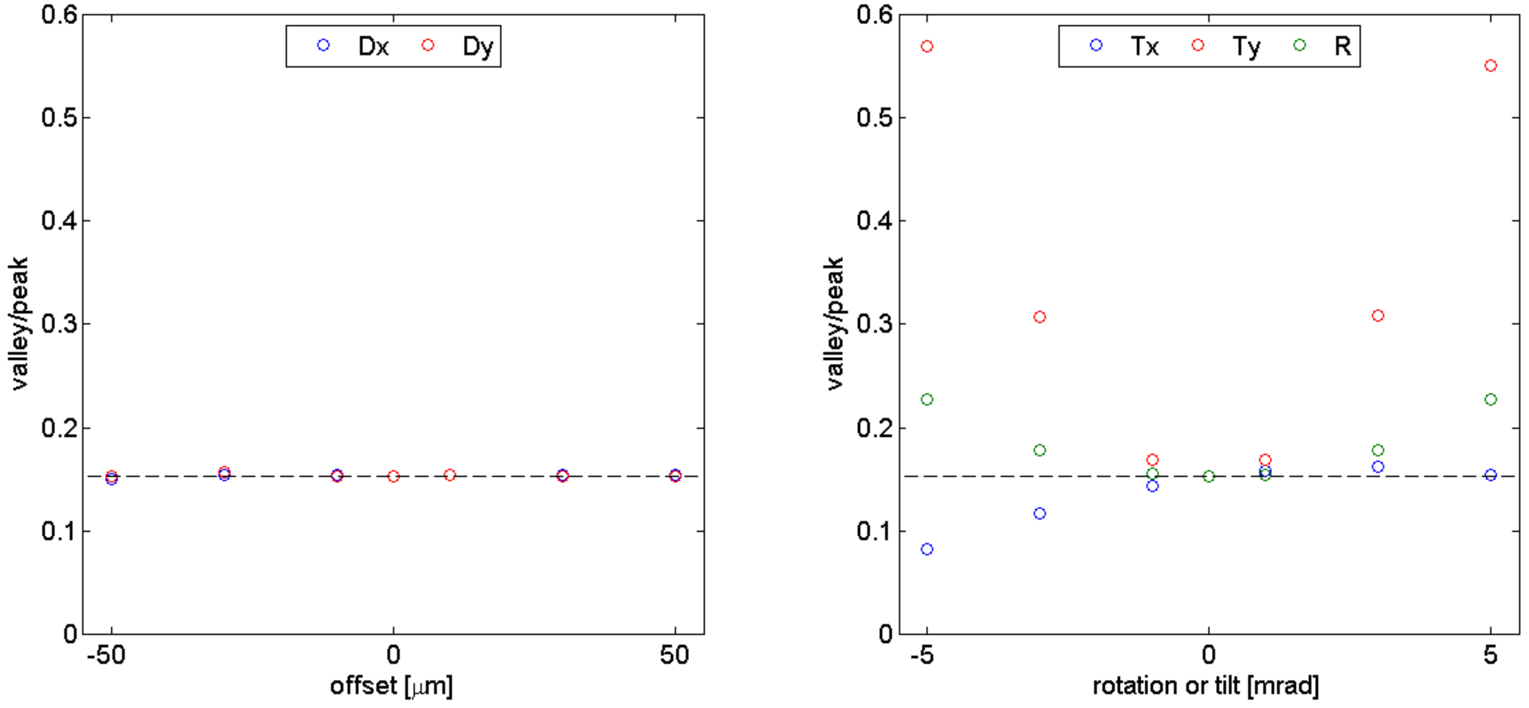
horizontal tilt T_x

symmetric broadening and
and washing out of peak-to-valley
pattern

rotation around mirror axis R
and vertical tilt T_y

asymmetric washing out of
peak-to-valley pattern for R & T_y




Dx
Dy
valley/peak
offset [μm]
Tx
Ty
R
rotation or tilt [mrad]

Critical issues: surface quality

Surface errors modify path length → modeled to set specifications of optical elements

M. Sanchez del Rio and A. Marcelli, *Waviness effects in ray-tracing of real optical surfaces*, NIM-A 319 (1992)

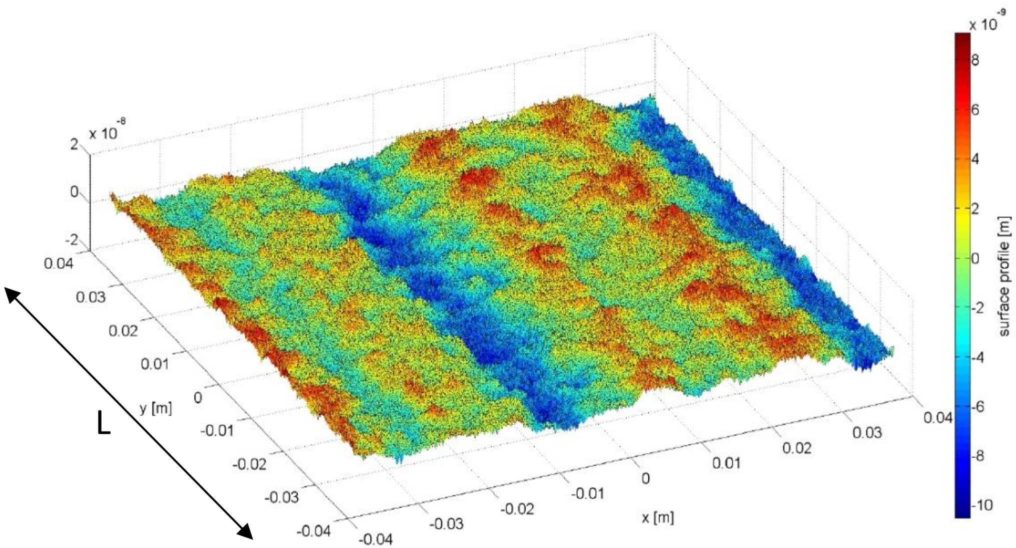
Model principle

$$\text{Surface waviness} \sim \sum_n A_n \sin\left(\frac{n\cdot y}{L} + \phi_n\right)$$

+

$$\text{Surface roughness} \sim \text{random noise}$$

Toroidal mirror specifications	
Slope error	0.2 arcsec
Roughness	21 nm p-v (λ/30), <4 nm RMS
Waviness pattern	vertical (also radial)



met by the manufacturers…

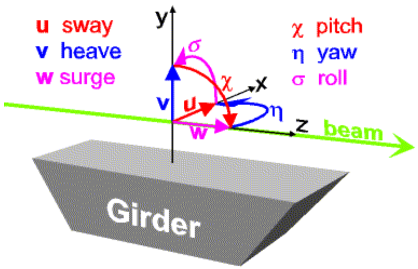
Pre-Requisites and Tools for Vertical Emittance Tuning

1. high beam stability as a pre-requisite

top-up operation → high thermal (long term) stability

precise BPMs: ~ 100 nm rms (< 100 Hz)
fast orbit feedback
} orbit control & short term stability

2. procedures & equipment for vertical emittance tuning



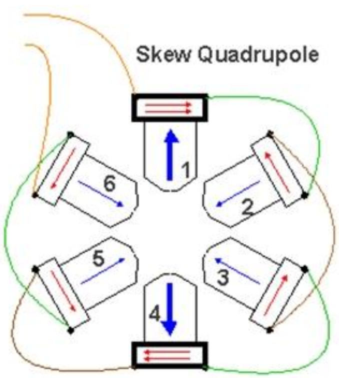
re-alignment (beam-assisted girder alignment) of storage ring

→ remote positioning of 48 girders

skew quadrupoles for coupling control (36 in case of SLS)

→ sextupoles with additional coils

high resolution beam size monitor



Procedure for SLS Vertical Emittance Tuning

1. **measurement and correction of BPM roll error**

   → avoid "fake" vertical dispersion readings (from 48 dispersive BPMs with $\eta_x \neq 0$)

2. **realignment of magnet girder to remove main sources of vertical dispersion**

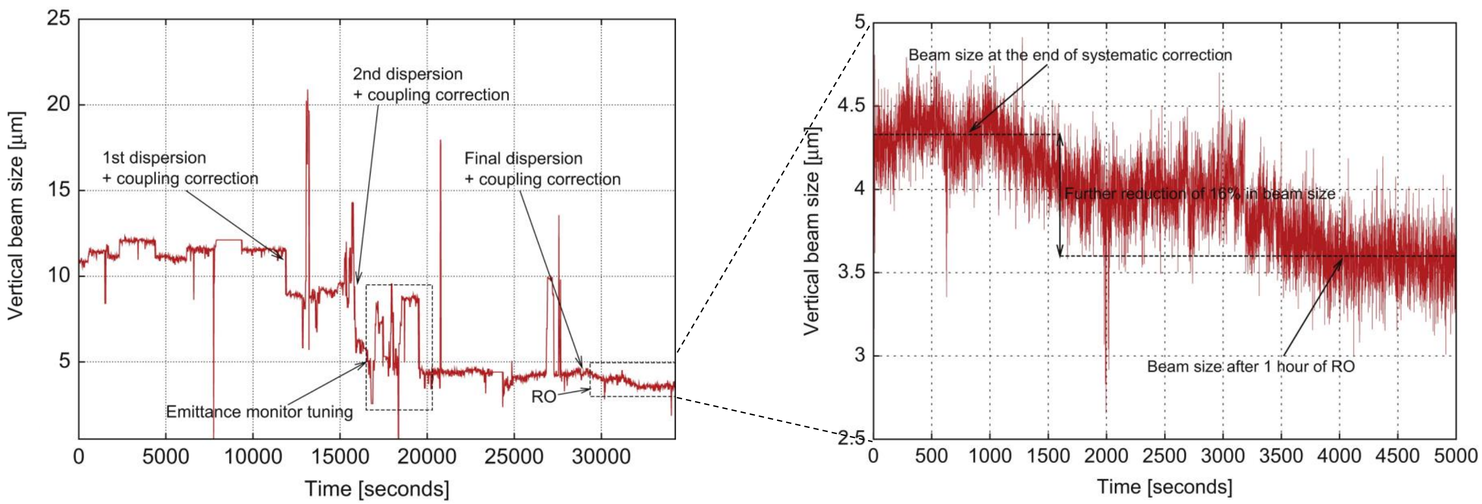
   → reduction of rms vertical correction kick from ~ 130 µrad to ~ 50 µrad

3. **measurement & correction of vertical dispersion and betatron coupling**

   → model-based skew quadrupole corrections (12 dispersive and 24 non-dispersive skew quads)

4. **"random walk" optimization of vertical beam size**

   → skew quadrupole corrections using beam size measurements from profile monitor



σ_y = 3.6 ± 0.6 µm

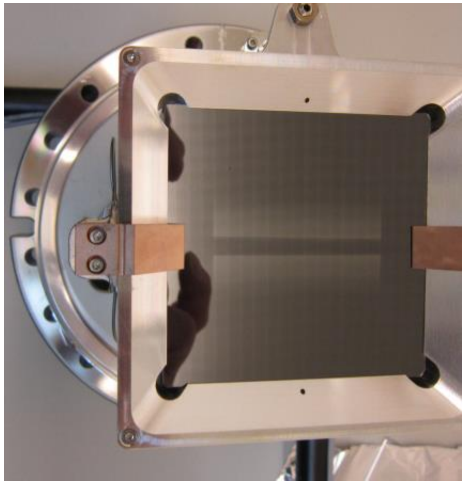
↓

ε_y = 0.9 ± 0.4 pm

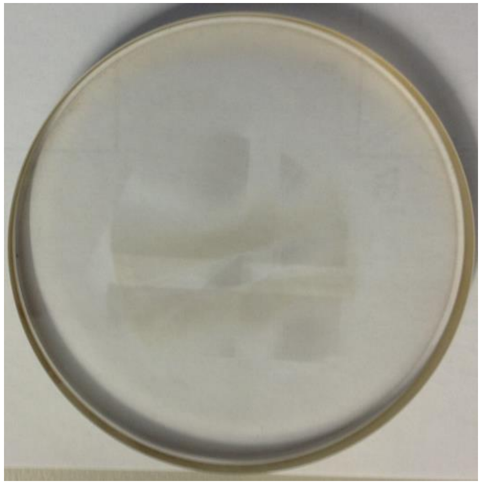
M. Aiba, et al., *Ultra Low Vertical Emittance at SLS Through Systematic and Random Optimization,* NIM-A 694 (2012) 133-139

Maintenance and non(yet)-solved problems

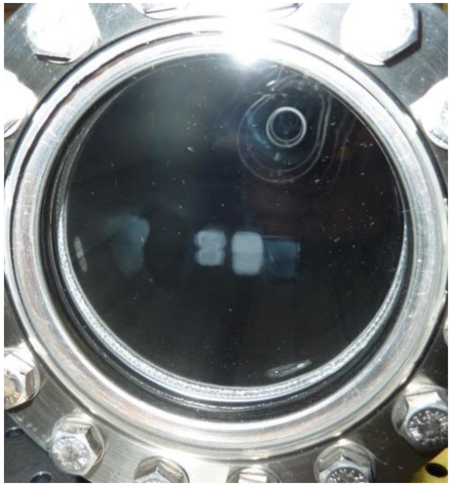
- Fused silica elements get UV damaged
  → deteriorate imaging quality and eventually need to be replaced



flat mirror



lens



exit window

- Image vibrations at the camera 50 – 100 µm rms
  → (unknown spectrum but exposure time <0.5 ms to avoid image blurring)
  Beamline related (laser suffers them)!