Advanced Low Emittance Rings Technology (ALERT) 2014 Workshop

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IFIC

Synchrotron Radiation Extraction Mirrors

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Many thanks to:
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Contents

- Introduction
- Extraction mirrors
  - Functionality
  - Constraints / Issues
- Heating and Solutions (LEP,SLAC,KEK,SSRF)
- LHC experience with extraction mirrors
- Wave-front distortion and methods to measure it

Introduction

- **Synchrotron radiation**
  - Comes for free in many accelerators
  - Can be produced by dedicated insertion devices

- **Extraction** and **monitoring** of synchrotron radiation can be used for
  - Transverse beam size (emittance) measurements
    - Imaging, interferometry
  - Longitudinal diagnostics
    - Streak-cameras
    - Counting / Integrating (photo multipliers, longitudinal density monitors)

SR monitoring constraints/issues

Different

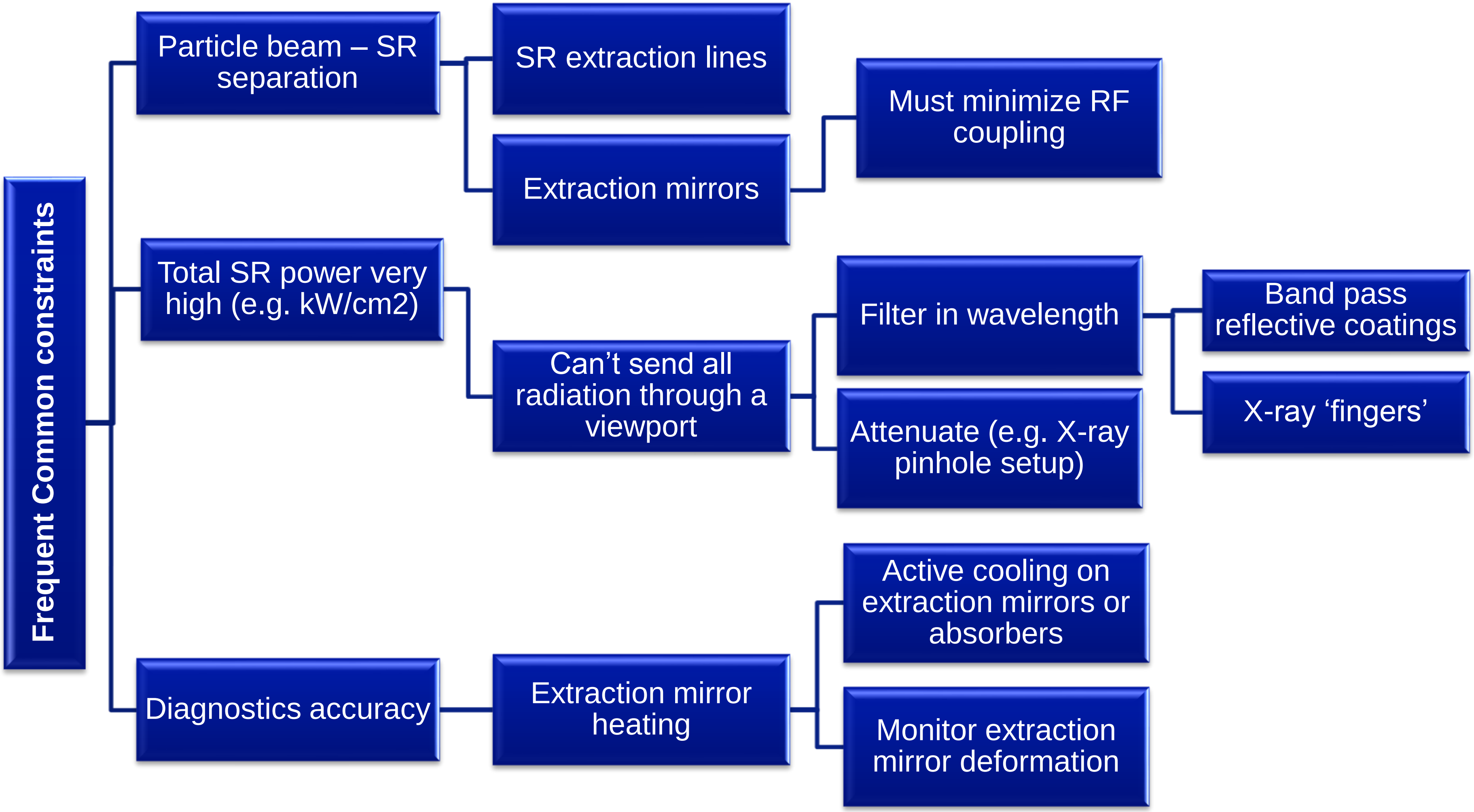
- Applications
- Beams
- Facilities
- …

often imply different constraints and specifications for the radiation extraction

BUT: there are constraints/issues that are quite common

→ see next slide

SR monitoring constraints/issues



References (used for most of the following)

- Toshi Mitsuhashy : MANY private communications !

- MONITORING THE BEAMS IN SPEAR WITH SYNCHROTRON LIGHT, A. P. Sabersky. Stanford Linear Accelerator Center. Stanford University, Stanford, 1973, SLAC-PUB-1207
- ADAPTIVE OPTICS FOR THE LEP 2 SYNCHROTRON LIGHT MONITORS, Burtin, G.; Colchester, R.J.; Gras, J.J.; Jung, R.; Vouillot, J.M., CERN SL-99-049 BI
- DESIGN OF THE SYNCHROTRON-LIGHT MONITORS FOR PEP-II**,** A.S. Fisher et al., SLAC
- MECHANICAL DESIGN OF THE HER SYNCHROTRON LIGHT MONITOR PRIMARY MIRROR Edward F. Daly, Alan S. Fisher, Nadine R. Kurita and J Brian Langton, Stanford Linear Accelerator Center, Stanford CA USA, SLAC-PUB-14605
- SYNCHROTRON RADIATION MONITOR AND MIRROR AT SSRF ,K.R. Ye, Y.B. Leng, J. Chen, J. Yu, G.B. Zhao, W.M. Zhou, Sinap, Shanghai, 210200, China T. Mitsuhashi, KEK, Japan , DIPAC09
- DIAMOND MIRRORS FOR THE SUPERKEKB SYNCHROTRON RADIATION MONITOR, J.W. Flanagan, M. Arinaga, H. Fukuma, H. Ikeda, KEK, Tsukuba, Japan, IBIC2012
- U.Iriso, L.Torino: Private communications

Extraction Mirror Materials

Extraction mirror materials

- Be, Copper, Invar (Ni-Fe alloy), GlidCop
  - Good mechanical – thermal properties
  - Good reflectivity after polishing
  - Bad for EM coupling
  - Can have effective active cooling
- Beryllium toxicity
  - e.g. @ CERN (LHC era): its use highly NOT recommended (even not sure if it’s manipulation is allowed)

- Silicon, fused silica
  - Less prone to EM coupling
  - Need coating to reflect visible light
  - Difficult to cool

In general: material choice also depends on x-ray absorption

Interesting example of material studies:

MONITORING THE BEAMS IN SPEAR WITH SYNCHROTRON LIGHT

A. P. Sabersky. Stanford Linear Accelerator Center. Stanford University, Stanford, 1973

$$Q = k/(1+\nu)\alpha$$

$k =$ thermal conductivity
$\nu =$ Poisson ratio
$\alpha =$ coefficient of thermal expansion

Factor to qualify materials, deformation is inversely proportional to Q

Setting Q_Cu = 1:
Q_Be: 0.44
Q_Inv: 0.08
(Q_Si: 0.04)

Copper and Invar were rejected due to plastic deformations under very dense energy deposition
→ Beryllium as only option

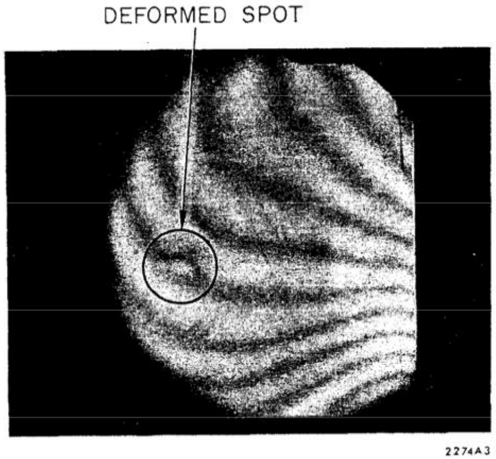


FIG. 1--Interferogram of permanent deformation in a thick Invar mirror which has been subjected to spot heating. $\lambda = 6328$ Å.

Extraction mirror materials - Diamond

DIAMOND MIRRORS FOR THE SUPERKEKB SYNCHROTRON RADIATION MONITOR
J.W. Flanagan, M. Arinaga, H. Fukuma, H. Ikeda, KEK, Tsukuba, Japan, IBIC2012

- Development for **Super KEK B**
- Quasi-monocrystalline diamond
  - higher heat conductance
  - a lower thermal expansion coefficient

  w.r.t. Beryllium
- Estimated error on beam size meas. Via interferometer
  - 43% with Be mirror
  - 3 % with Diamond mirror

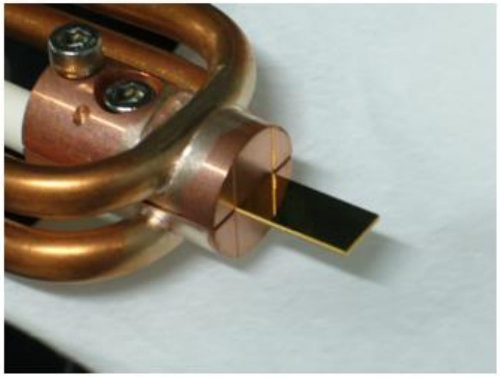


Figure 3: Copper mirror mount, with prototype mirror mounted in it.

2e-6

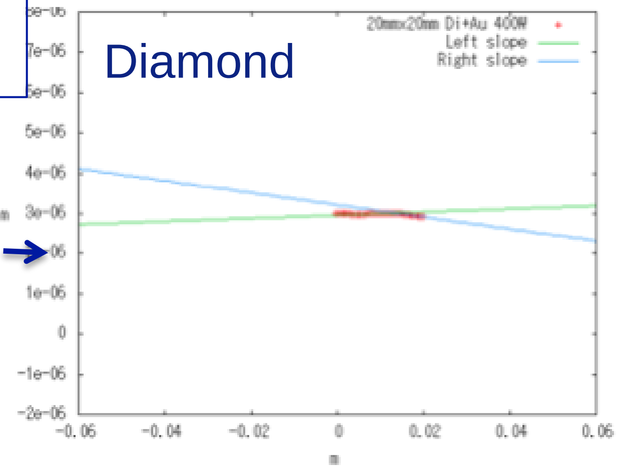


Figure 6: Surface deformation of 1-mm thick monocrystalline diamond mirror due to 400 W applied over 20 mm width of mirror.

8e-6

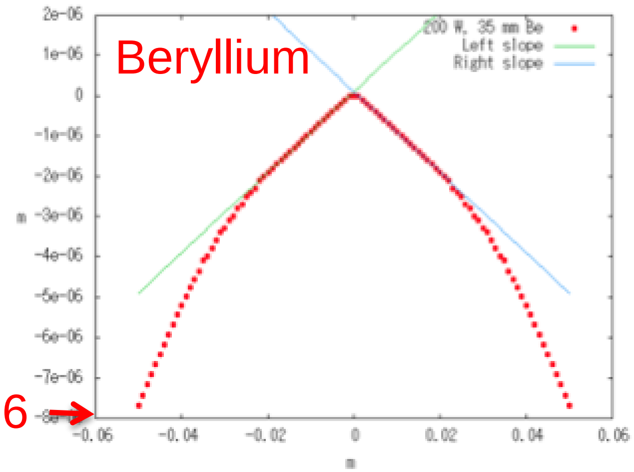


Figure 7: Surface deformation for Be mirror of type used at KEKB for 200 W applied over 35 mm width of mirror.

ANSYS simulations

Effect of heating and solutions

Effect of heating and solutions – CERN LEP

Beryllium Mirror

Deformation of the extraction mirror was predicted by simulations and nicely measured with beam

Idea:

- Correct cylindrical deformations with a deformable mirror before the telescope optics
- Correct spherical deformations (=shifted image plane) by moving the CCD camera detector

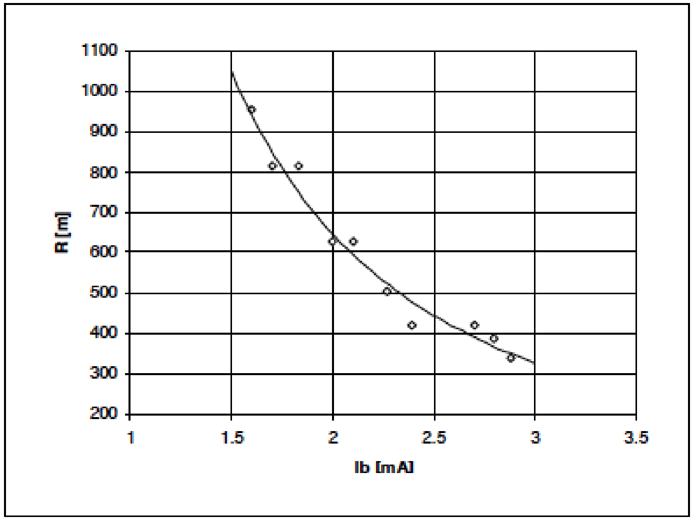


Figure 4: Curvature radius of the Be mirror as a function of beam current measured at 94.5 GeV.

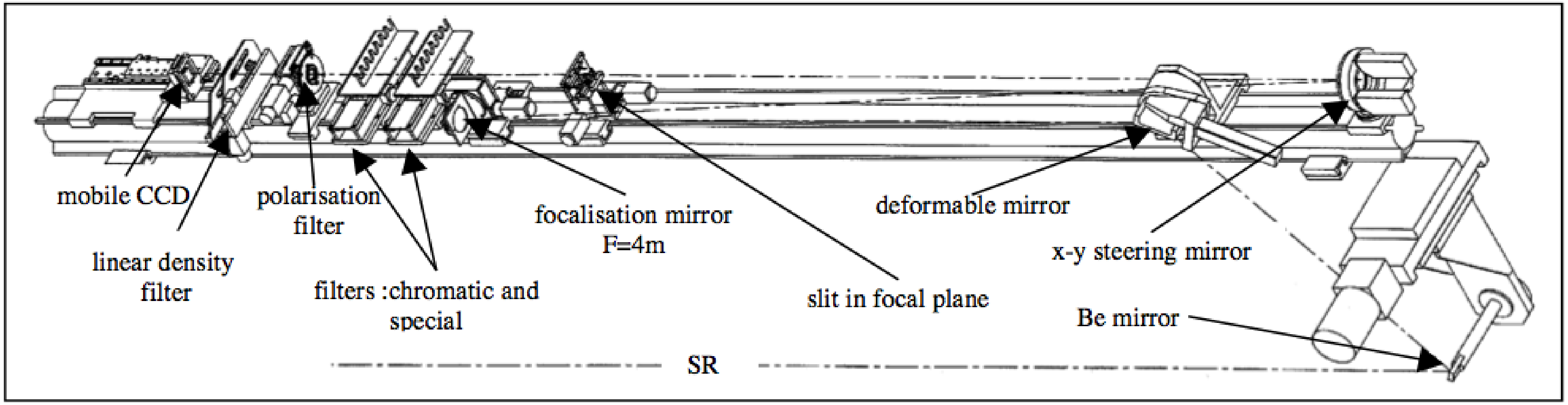
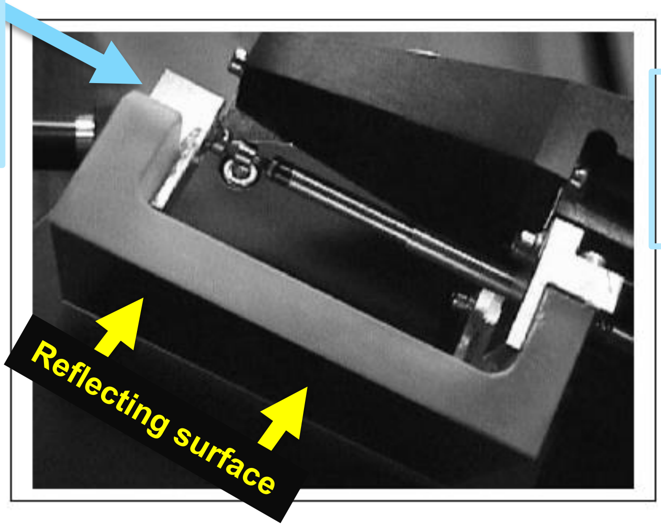


Figure 7: Layout of the SR telescope in the LEP 2 version

LEP deformable mirrors

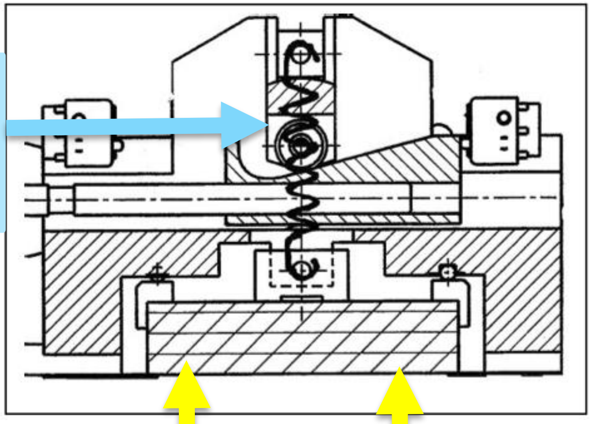
Piston introducing deformation of U shape

Deformable mirror 1



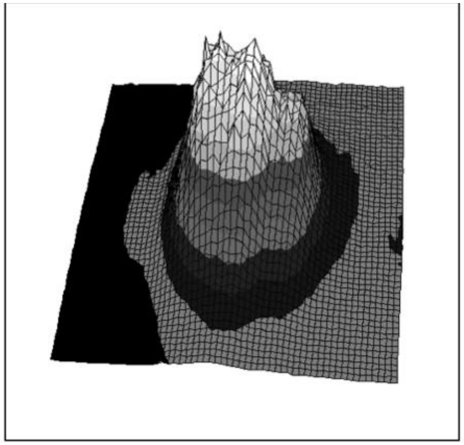
Spring pulling the central part of the mirror

Deformable mirror 2



Deformable mirror (type 1) setting as function of beam energy and intensity

Deformable Mirror Flat



Deformable Mirror Set

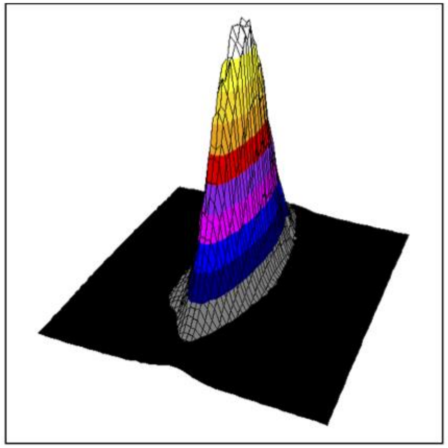
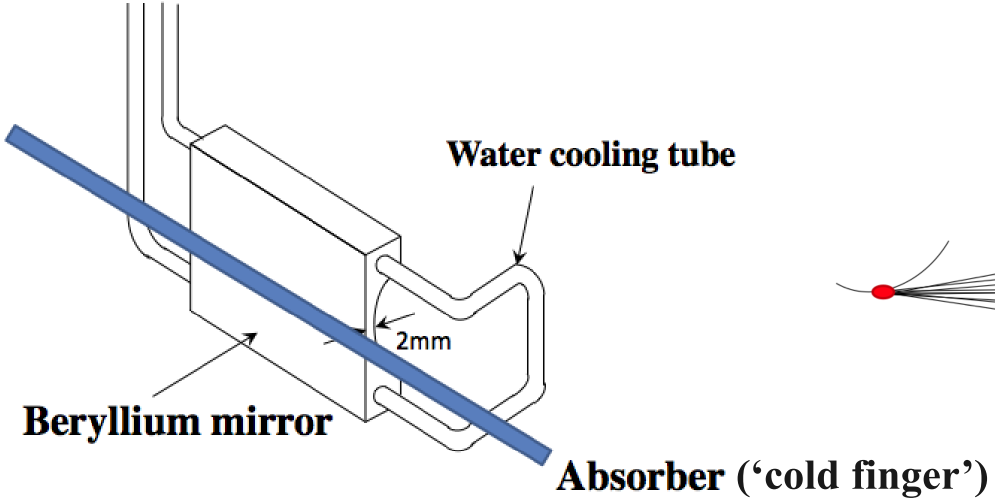


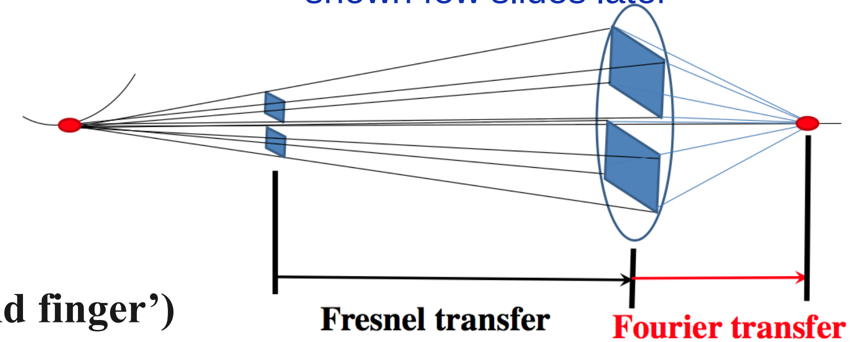
Figure 8: Left: beam imaged with the flat folding mirror and no polarisation filtering, for 2.2 mA at 94.5 GeV. Right: same beam with folding mirror set to calculated curvature and vertical polarisation attenuated.

Effect of heating and solutions – KEK

- Photon Factory, E=2.5GeV, r=8.66m, , photon critical energy: 4 KeV
- X-ray (=heating) fan is concentrated in the middle of the vertical radiation opening
- Idea: insert X-ray absorber, giving up visible light in the central region



'Cold finger' effect on imaging shown few slides later



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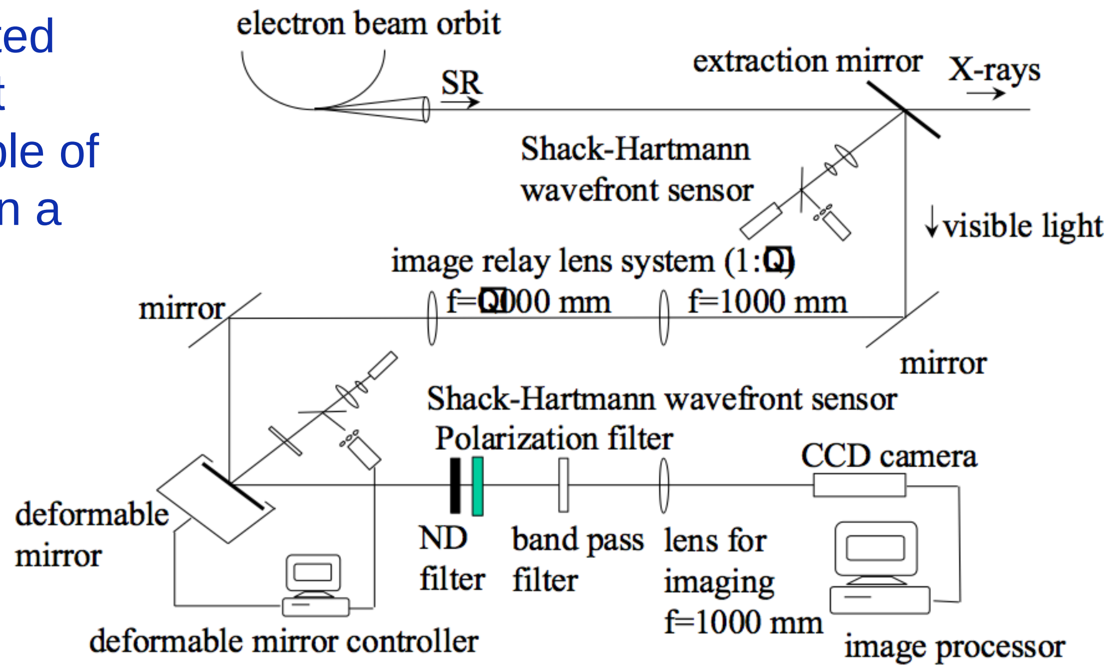
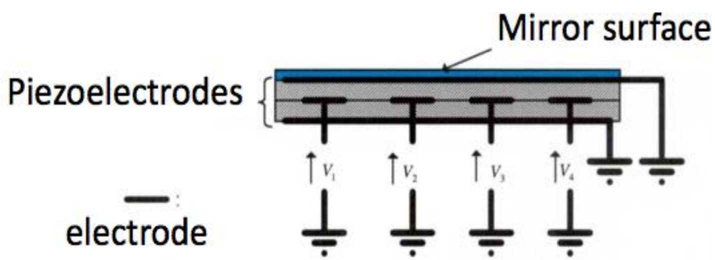
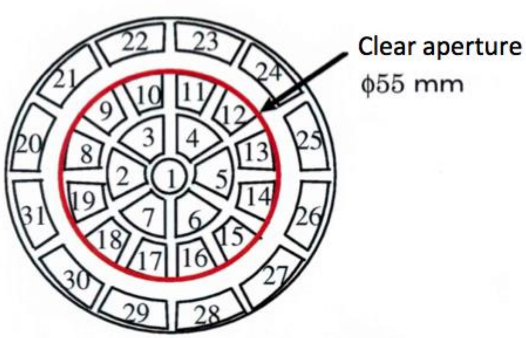
Effect of heating and solutions – KEK

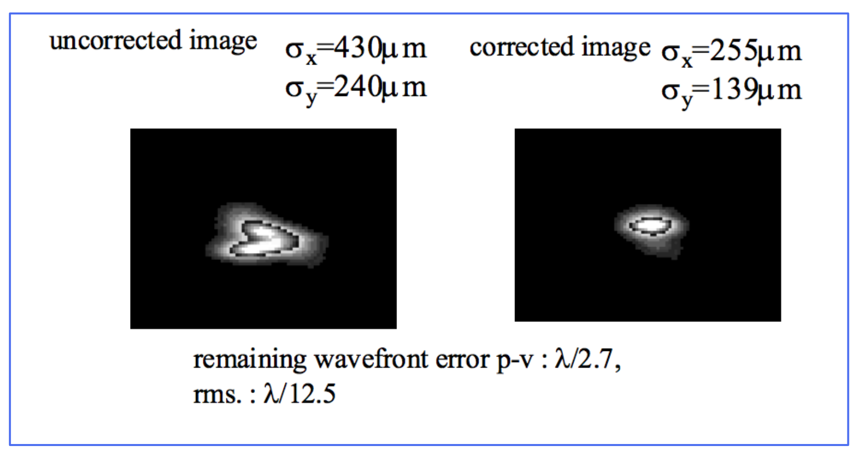
Like @ LEP, they also implemented the ‘deformable mirror’ setup, but based on piezo-electrodes capable of deforming the reflective surface in a more sophisticated way







Beam current:12.5mA



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Effect of heating and solutions – SLAC

- PEP II HER: 9 GeV, r=165m, photon critical energy: 9.8 keV
- GlidCop* mirror, coated with Electroless Nickel (9% Sulphur, 180˚ C bath)
  - thermal loading up to (2kW / cm^2)
  - Slot in the reflecting surface allowing x-rays to pass towards an x-ray absorber

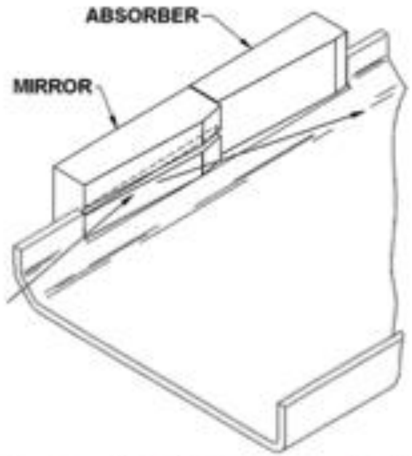
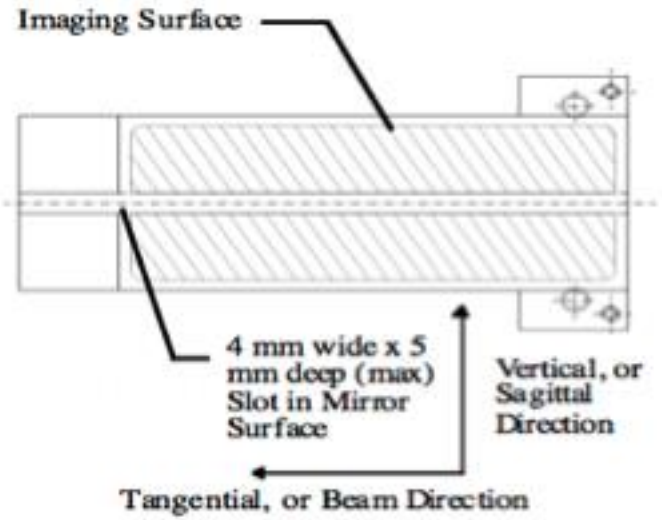
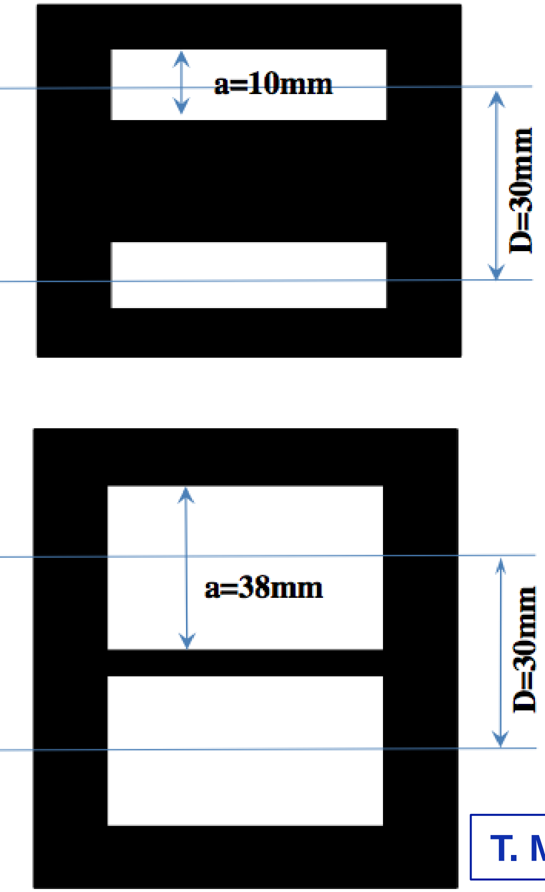


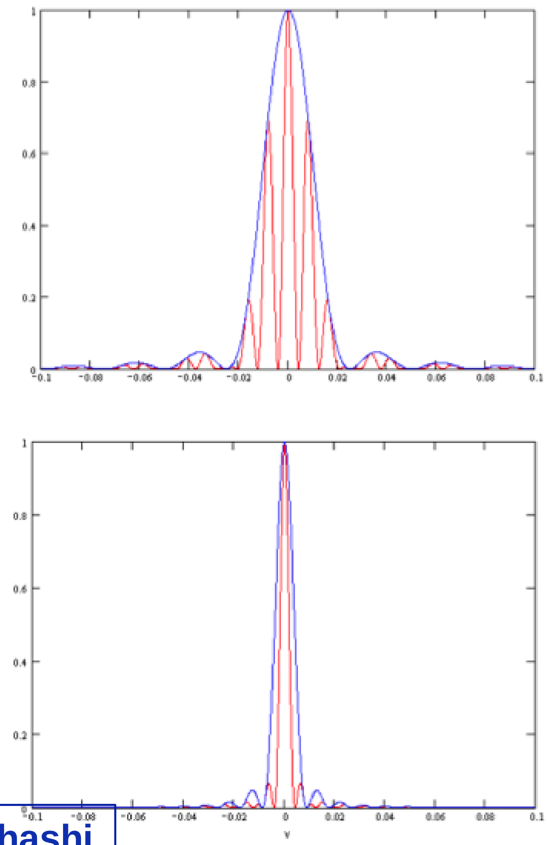
Figure 2. The slotted first mirror and the x-ray absorber, both mounted in the HER chamber wall.



* GlidCop = copper-based metal matrix composite (MMC) alloys mixed primarily with aluminum oxide ceramic particles. The addition of small amounts of aluminum oxide has minuscule effects on the performance of the copper at room temperature (such as a small decrease in thermal and electrical conductivity), but greatly increases the copper's resistance to thermal softening and enhances high elevated temperature strength. The addition of aluminum oxide also increases resistance to radiation damage. (Wikipedia ;-))

Effect of ‘cold finger’ on imaging





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Diffraction envelope (blue) depends on ‘cold finger’ height

Interference fringes (red) lay inside diffraction envelope and only depend on ‘double aperture’ distance D

Often: ‘cold finger’ effect on PSF broadening is less than mirror deformations due to heating (+effect can be calculated)

Alternative solution to ‘cold finger’ if visible light power is enough (e.g. CELLS-ALBA):

- Only use upper part of the mirror → xrays not intercepted, no interference between upper and lower part

Effect of heating and solutions – SSRF

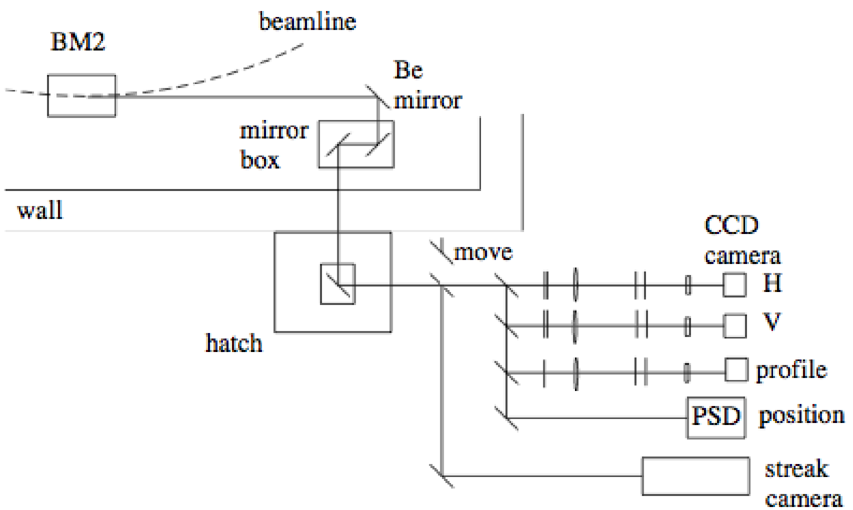
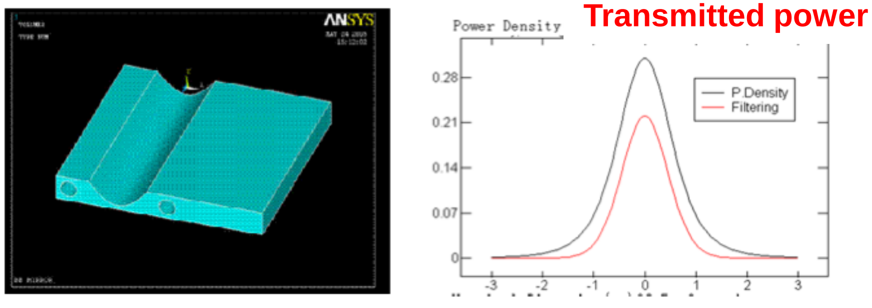


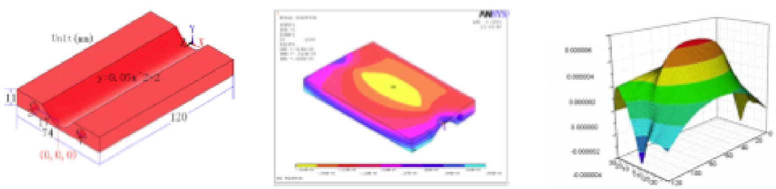
Figure 1: General arrangement of synchrotron radiation monitor.

3.5 GeV, photon critical energy: 9.96 keV



(a) (b)

Figure 2: (a): The design of mirror which has two water-cooling tubes. (b): Power Density distributions.



(a)Shape of Be mirror (b)Temperature distribution (c)Deformation distribution

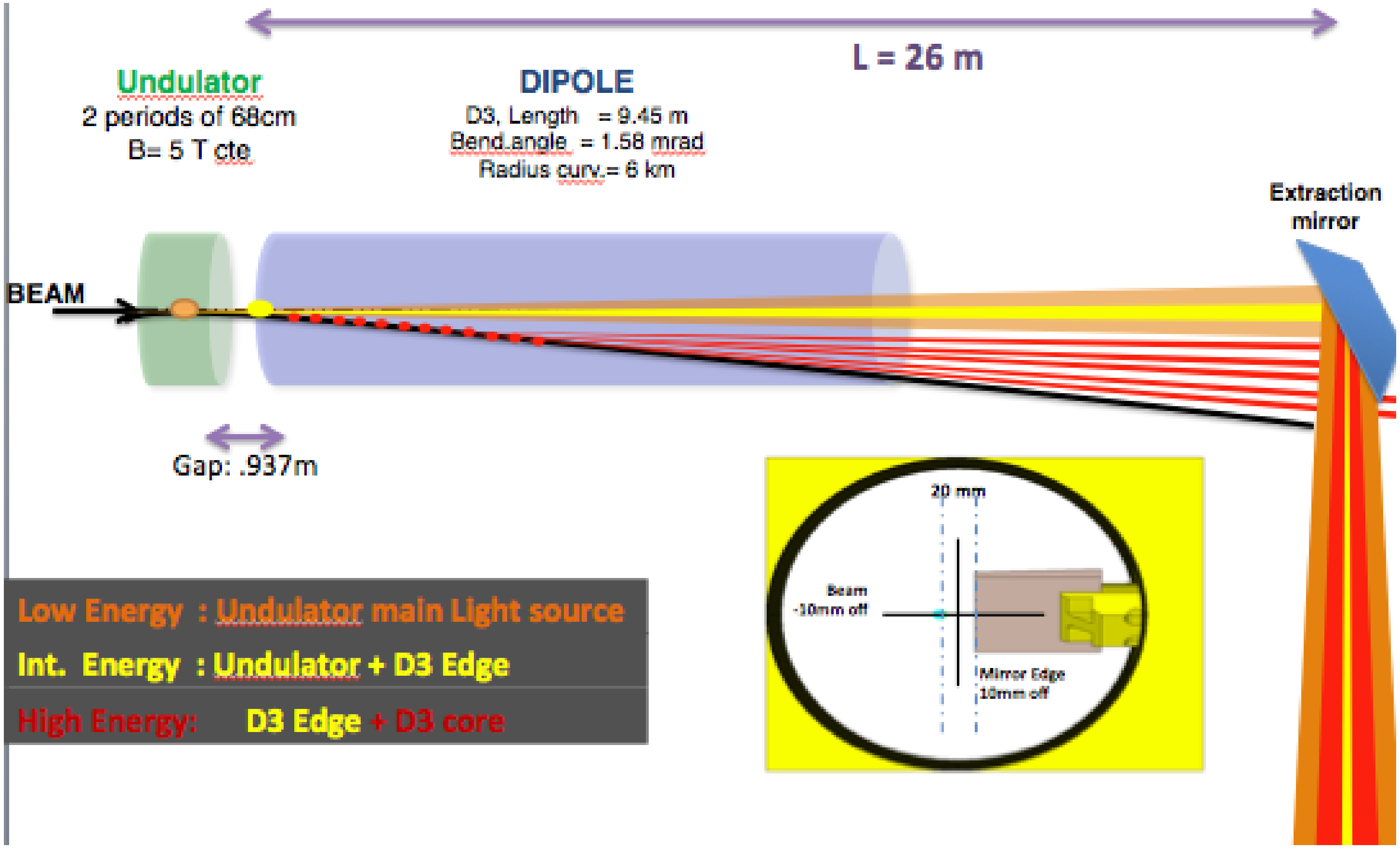
Figure 1: Design and simulation of the Be mirror.

Be mirror, thinner at location of x-rays fan

LHC experience with extraction mirrors

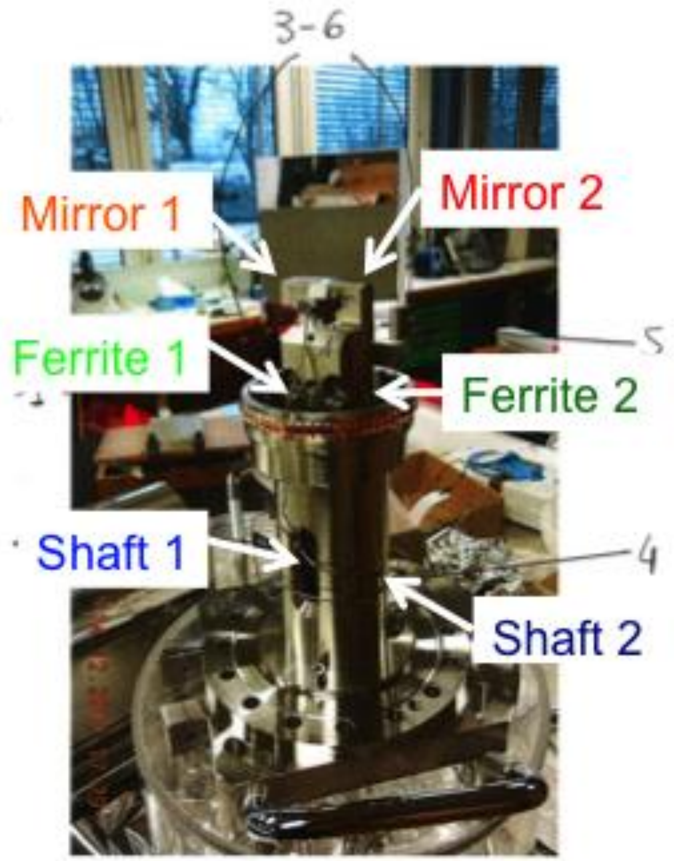
Synchrotron Radiation Monitor @ LHC

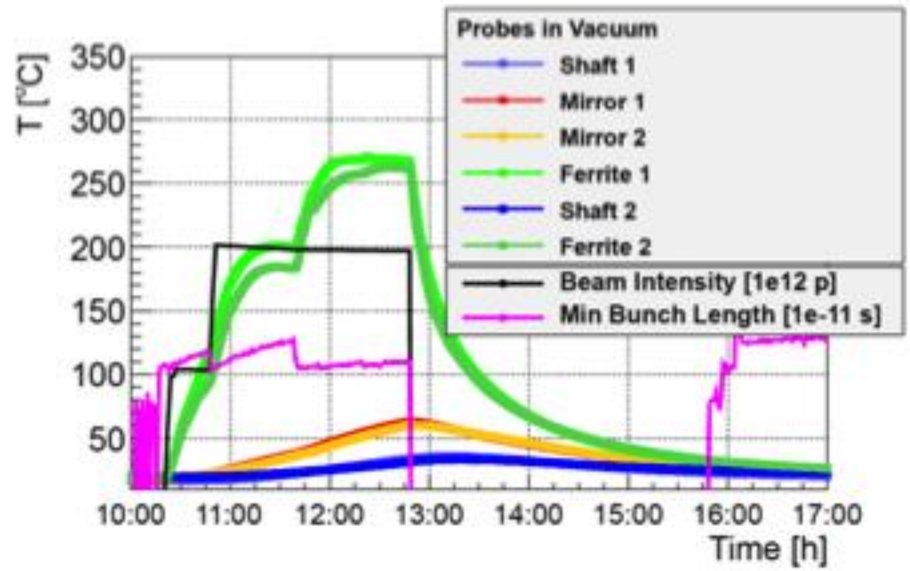
Protons, E=7TeV, R=6km
Photon critical energy ~ 20eV → no problem of x-rays (even though we have UV)



LHC –Experience 2012

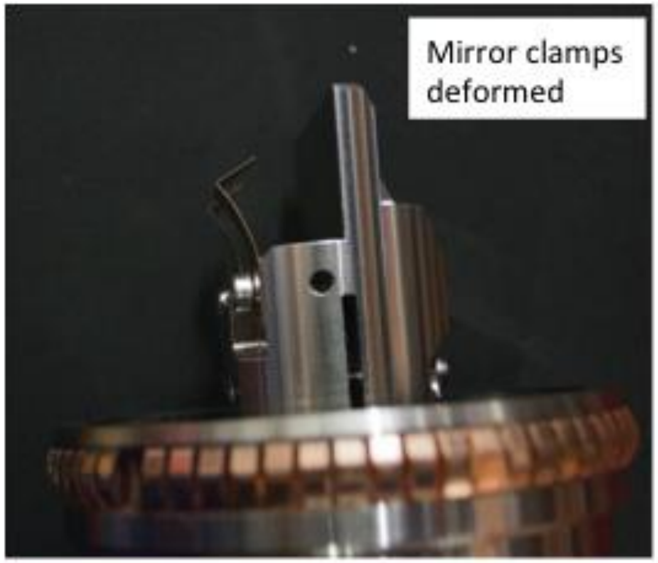
Temperature probes location inside extraction mirror assembly





- We clearly correlated the heating to the beam intensity and frequency spectrum

LHC


Mirror clamps
deformed

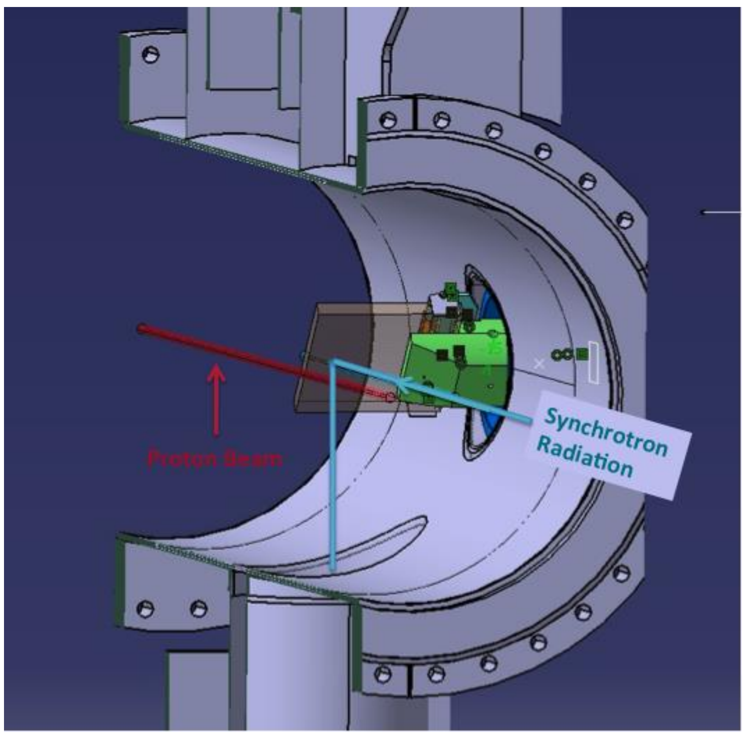

Mirror damaged (or
dust - sector 3-4?)


Mirror as it would have been in place

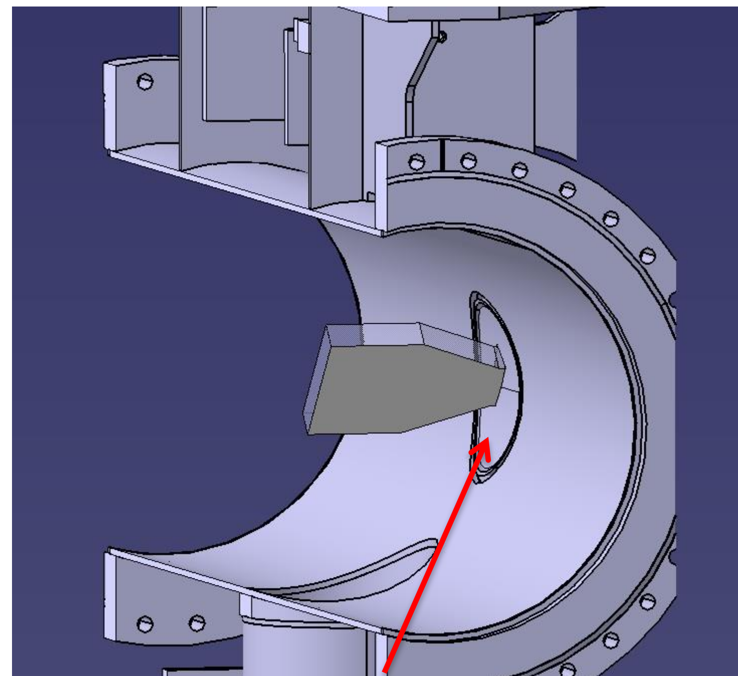

Traces of heating at
the ferrite location

BSRT – Extraction Mirrors

Old system: metallic mirror holder + Silicon bulk mirror sticking into beam pipe



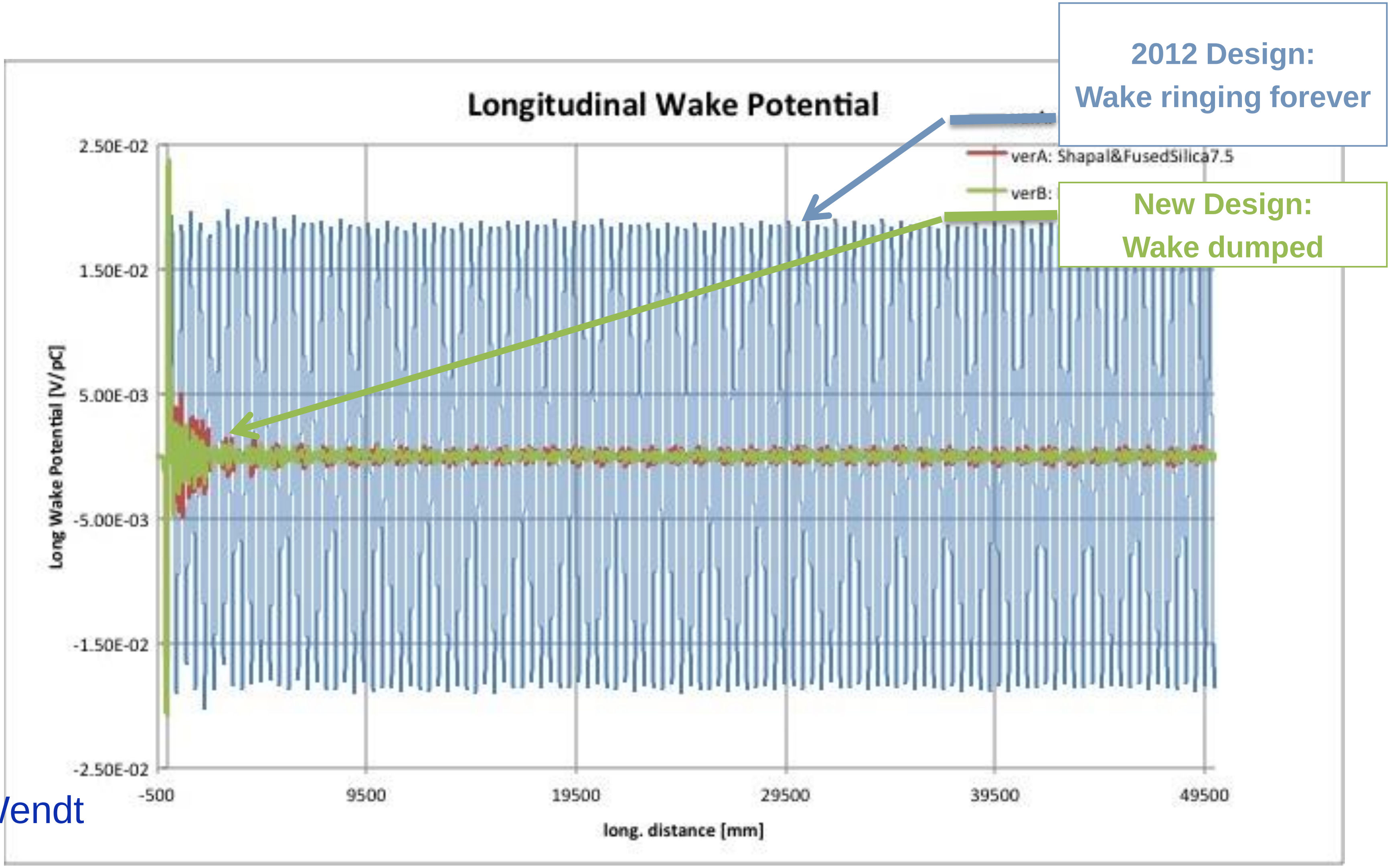
New system (2015): only fused silica bulk mirror sticking into beam pipe



Metallic screen fitting cylindrical beam pipe when mirror @ IN position

BSRT – RF coupling studies

Time domain simulations



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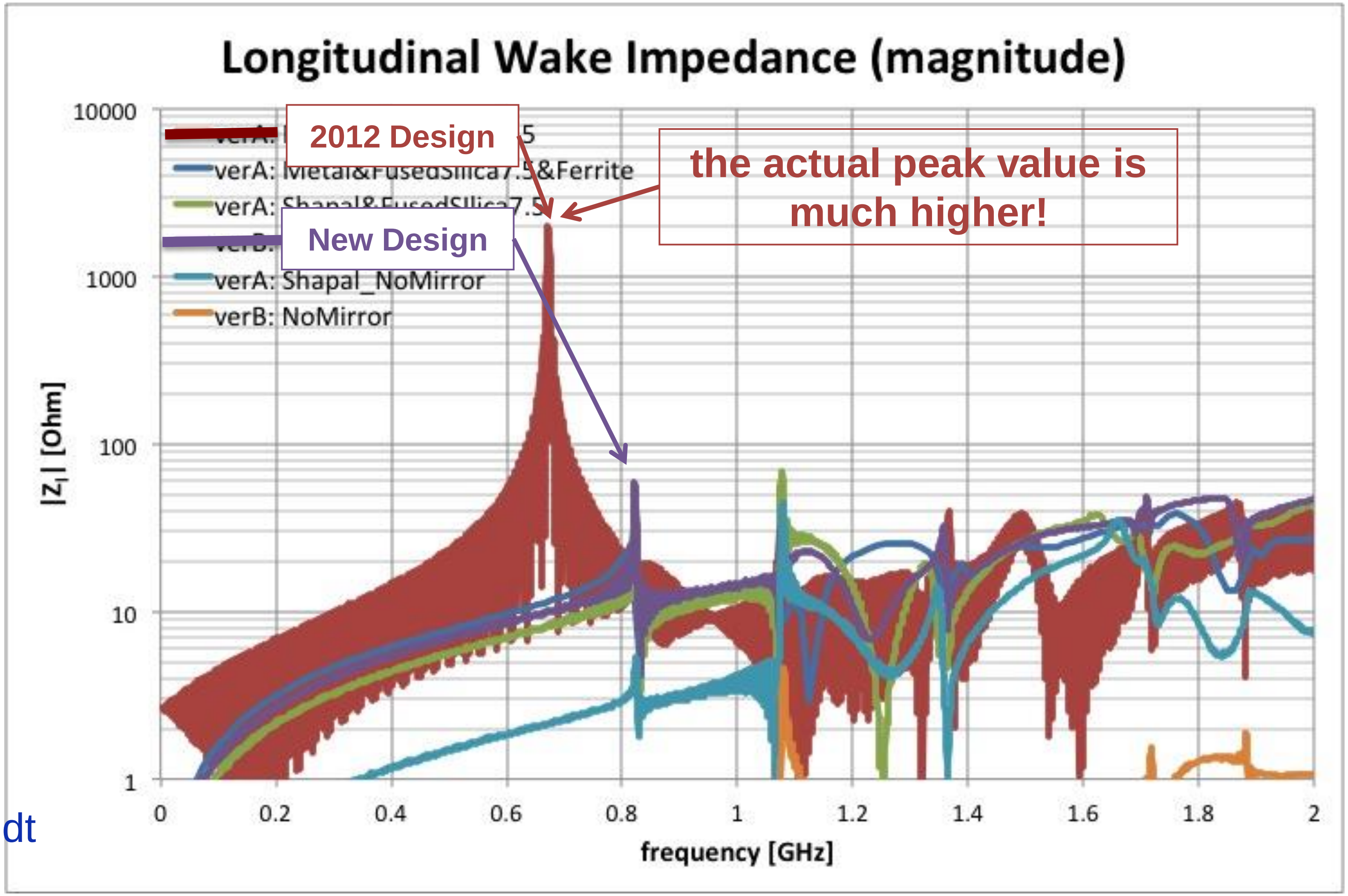
BSRT – RF coupling studies

Frequency domain simulations



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BSRT – RF coupling studies

BSRTM Re-design summary in terms of expected power coupled to the system

	System :	Old	New	Old (no mirror)	New (no mirror)
Narrow Band Power [Watt] @ 1st resonance ~ 800 MHz	Simulations	>>76	1.0	0.05	~0
	Lab meas.	>>48	0.7	0.04	~0
Wide Band Power [Watt] (covering LHC beam spectrum)	*Simulations*	>>103	1.1	0.34	~0
	Lab. Meas.	>>66	0.3	0.09	~0

(1380 bunches, 1.6e11 p / bunch)

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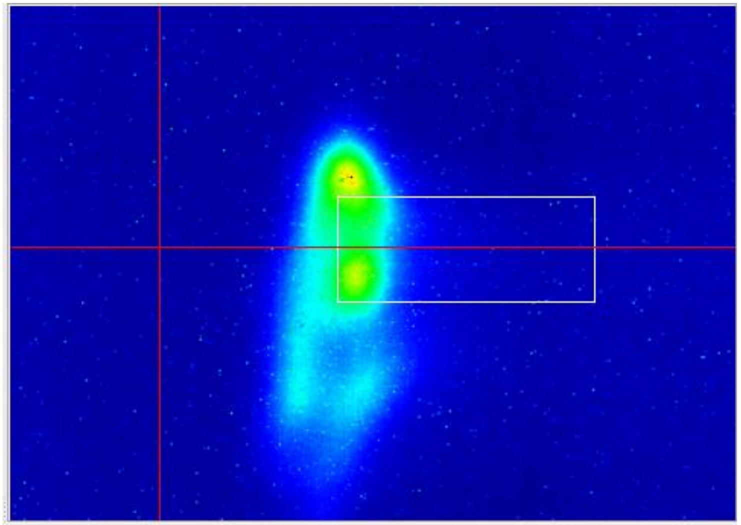
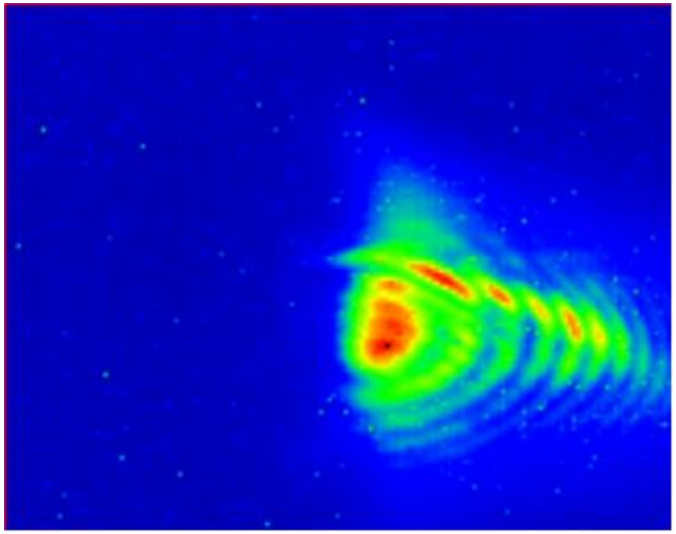
LHC - Experience

- Example of deformed images

Glass mirror aluminum coated while heated up by RF coupling



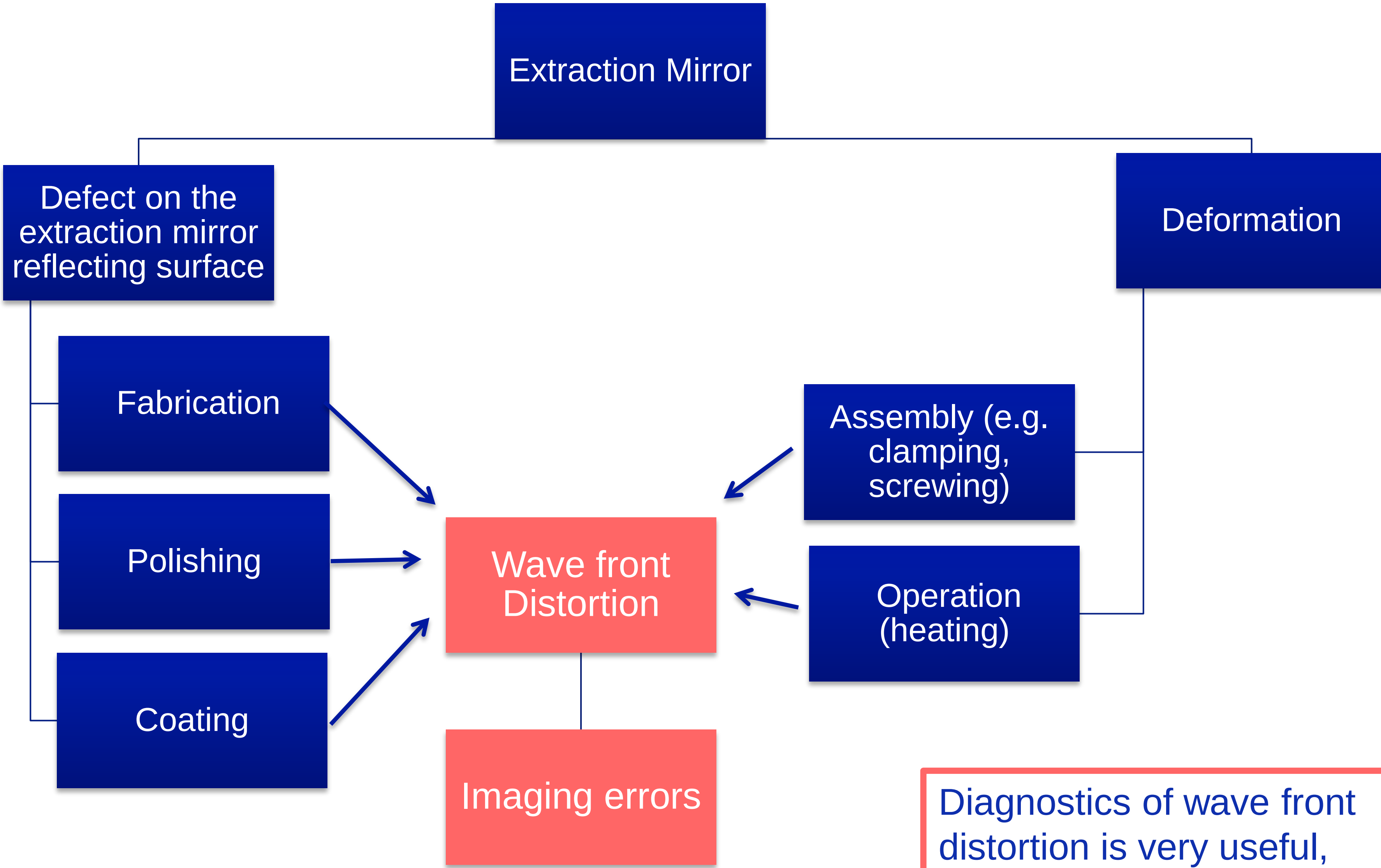
Polished silicon mirror (no coating) even before heating



Wave front distortion

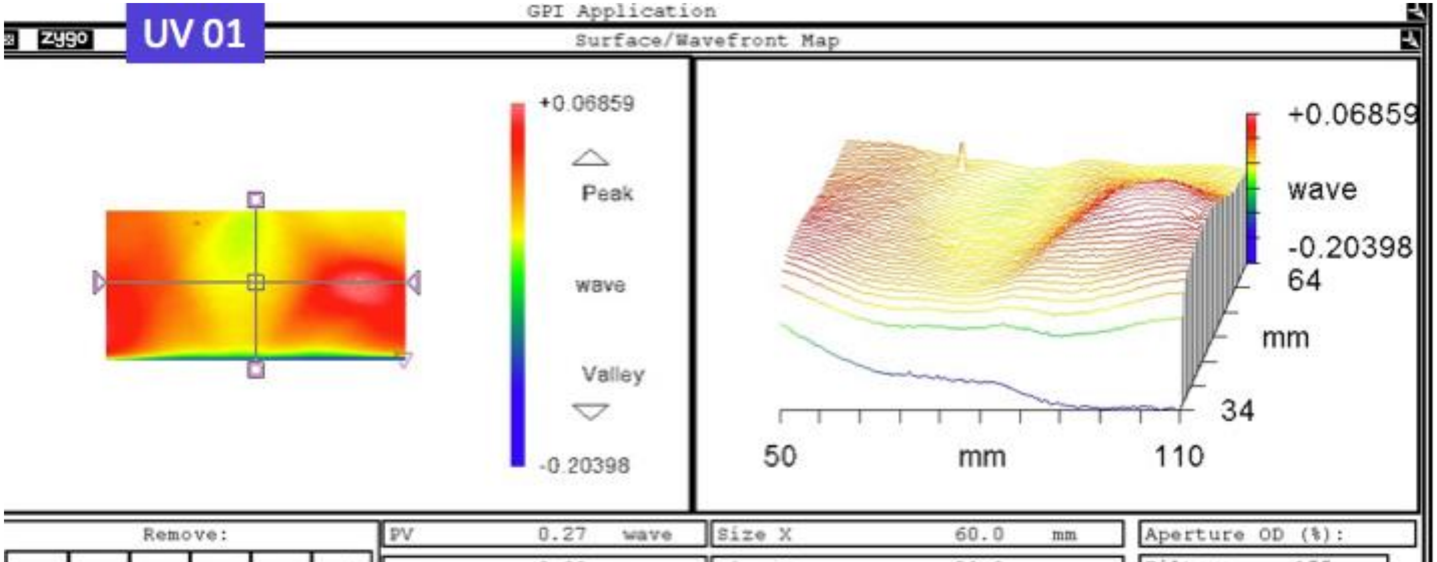
(due to extraction mirror defects or deformation)

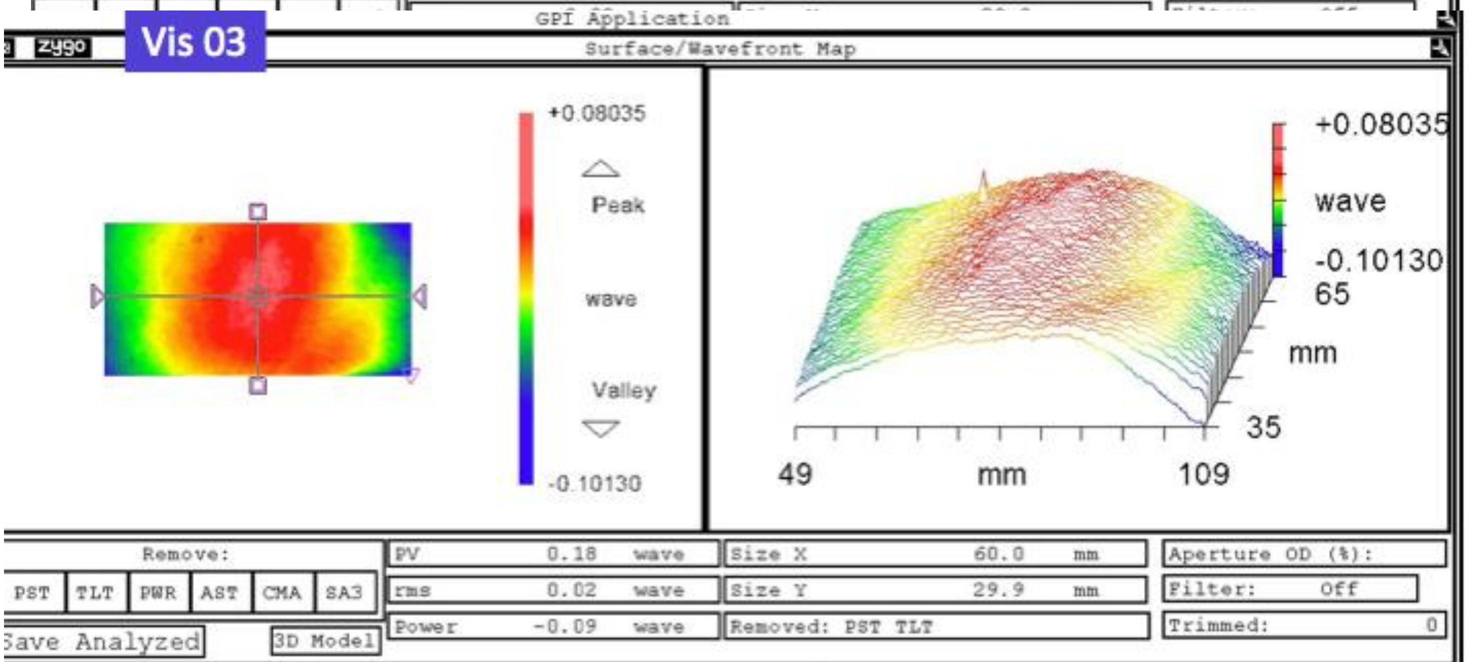
Wave front distortion



Diagnostics of wave front distortion is very useful, sometimes strictly necessary

LHC mirrors after polishing and coating





Example of two different mirrors we received:

Different non planarity patterns

Different absolute value of the peak to valley

Both outside the requested spec of lamda/8

LHC mirrors after polishing and coating

Summary of planarity for 8 mirrors we received this year

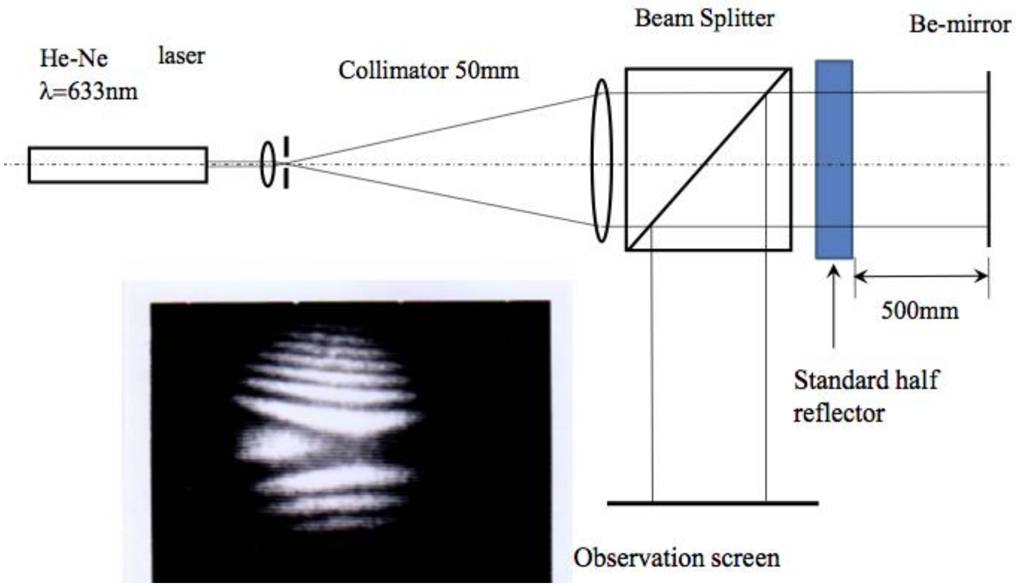
Labda / 8 = 0.12 peak-to-valley

Almost all out of specs!

This is before assembly and any deformation due to heating

Auftr.Nr.: 26908		**Date:**	20.03.2014	
Position:				
	Measured as on drawing		**Shifted Analysis mask 2mm**	
Upper limit:	**0.10**	**0.125**	**0.125**	
Analysis mask	*Ø25.4mm*	*60 x 30mm*		
	Producer 1			
UV_01	0.06	0.270	0.114	
UV_02	0.06	0.150	0.113	
UV_03	0.04	0.170	0.146	spare part
UV_04	0.05	0.170	0.130	
UV_05	0.04	0.190	0.142	spare part
	Producer 2			
VIS 01	0.03	0.22		
VIS 02	0.03	0.10		
VIS 03	0.03	0.18		
Unit	*PV: [wave] @ 632.8 nm*			

Wave front distortion measurements - Fizeau interferometer



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The wave front quality comes from the interference between the waves reflected by

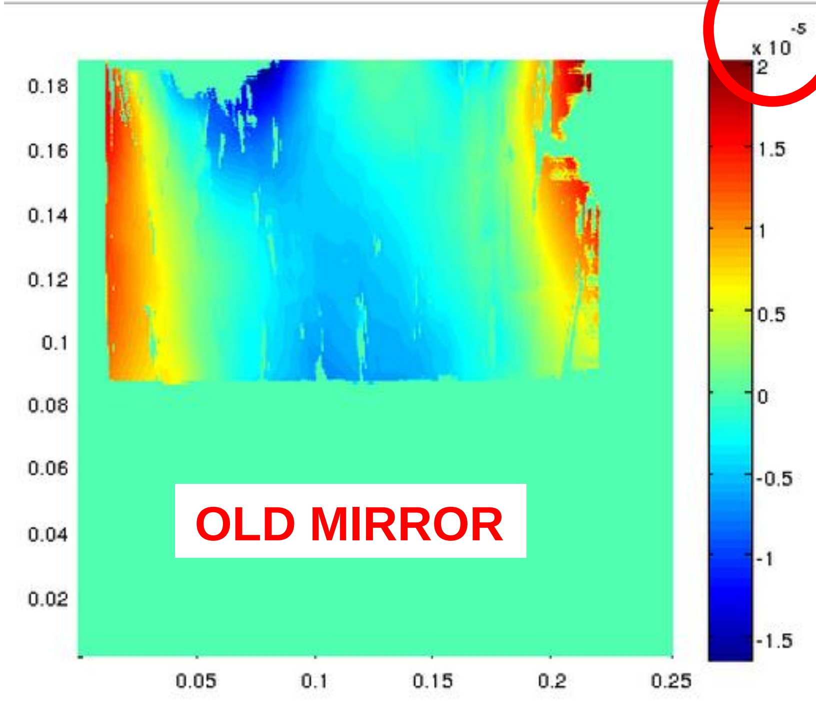
- the back surface of semi-transparent reflector (high quality, considered as a reference)
- the surface under test (e.g. Be mirror)

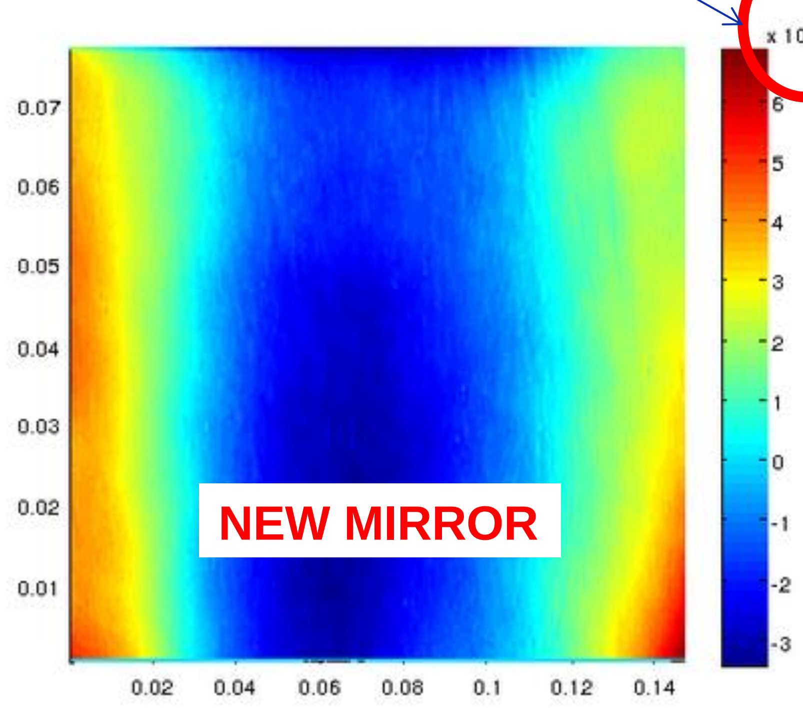
Commercially available
Relatively cheap
Sensible to floor vibrations

Fizeau interferometer @ ALBA

- After fabrication

Two orders of magnitude!





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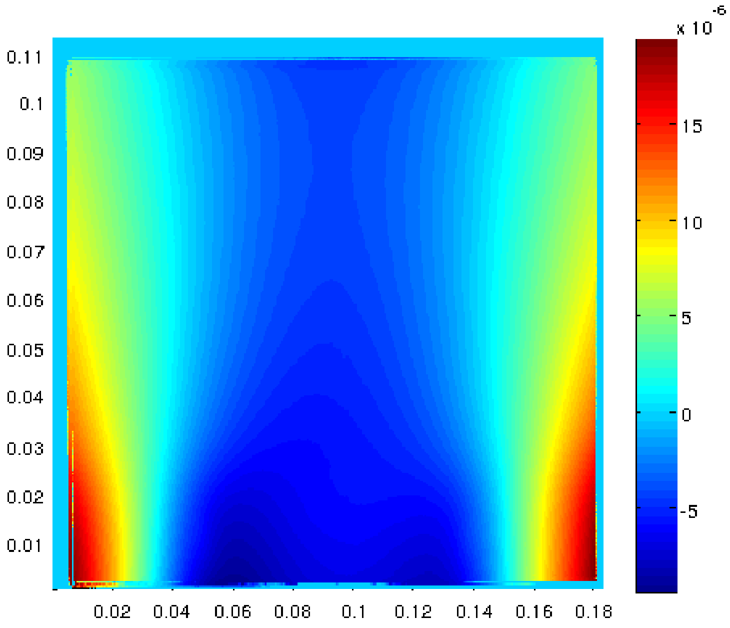
Fizeau interferometer @ ALBA

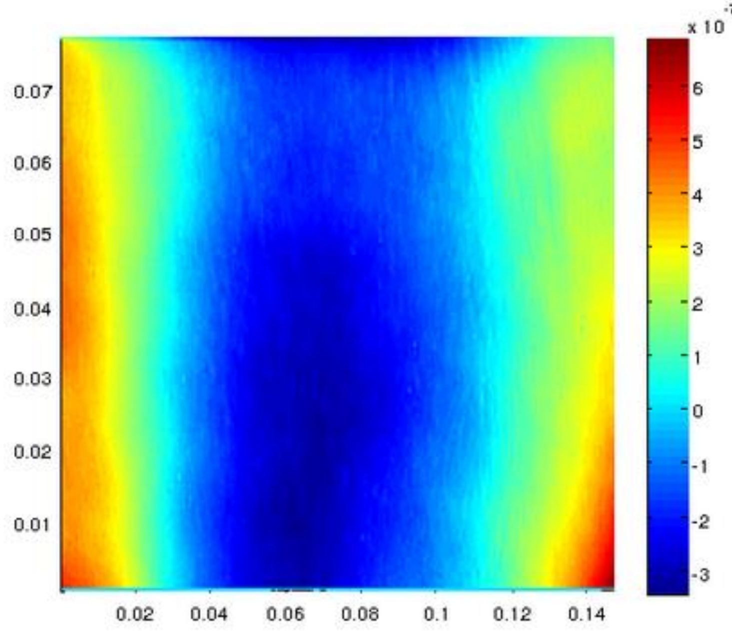
- After assembly

Tightening screws deforms mirror

Fixation screws tightened

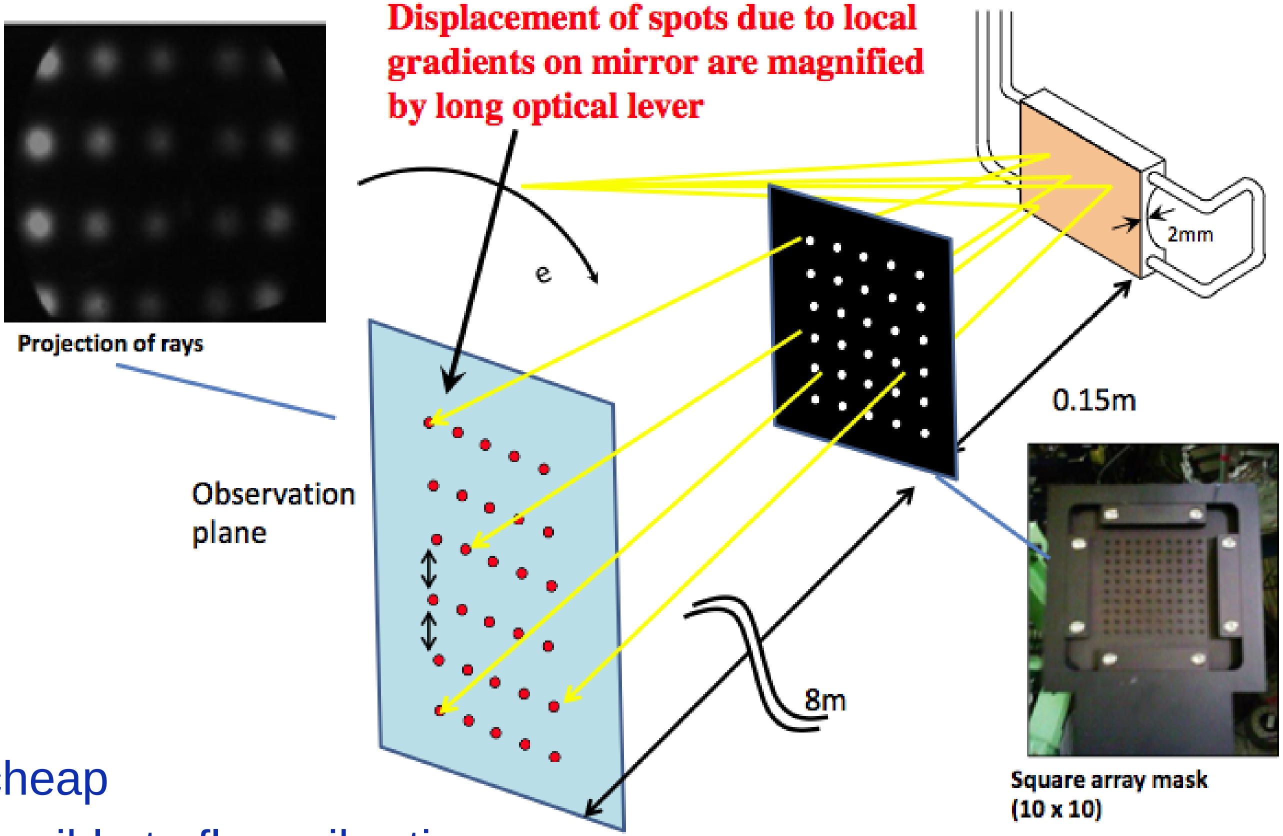


Fixation screws relaxed



U.Irisom L.Torino

Wave front distortion measurements - Hartmann mask



- Very cheap
- Not sensible to floor vibrations
- Need
  - the mask as close as possible to the mirror → normally is ‘destructive’, can’t split light to other devices before the mask
  - mask-screen lever arm as long as possible

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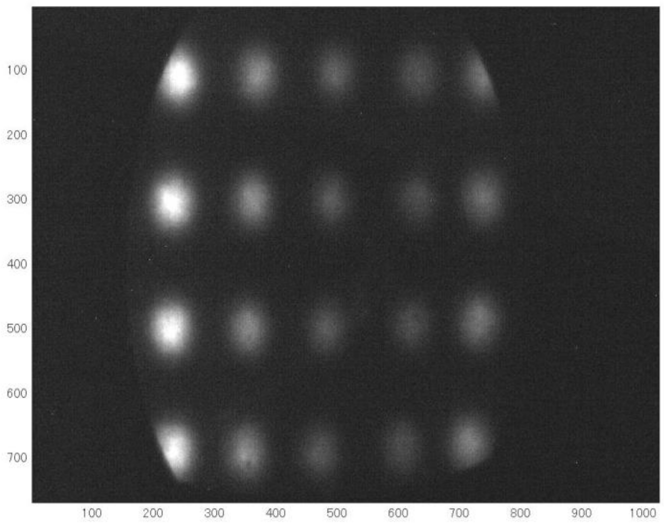
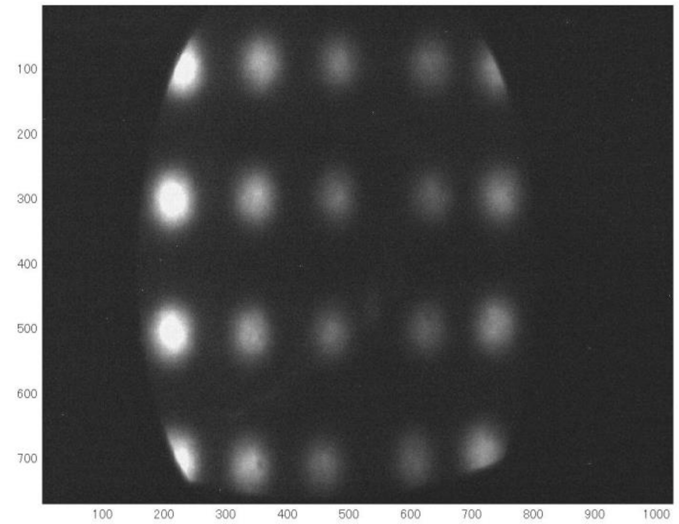
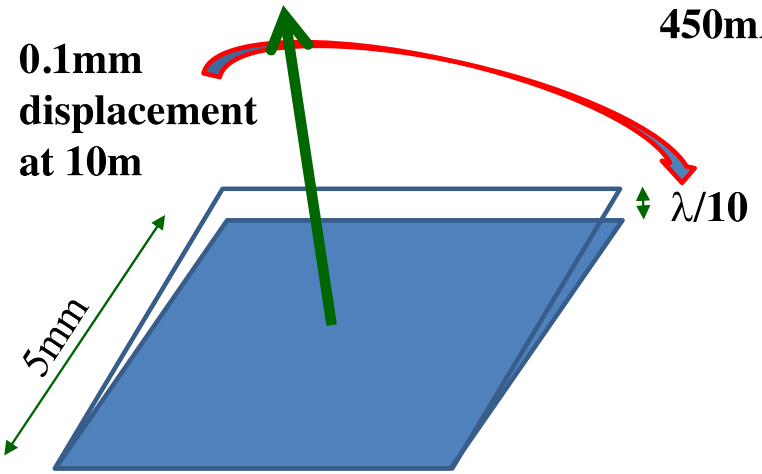
Hartmann mask @ KEK





280mA

450mA



T. Mitsuhashi

Conclusions

- When aiming at precise beam size measurements (especially for low emittance/high photon critical energy machines)
  - optical quality of extraction mirrors after polishing/coating/assembly is fundamental

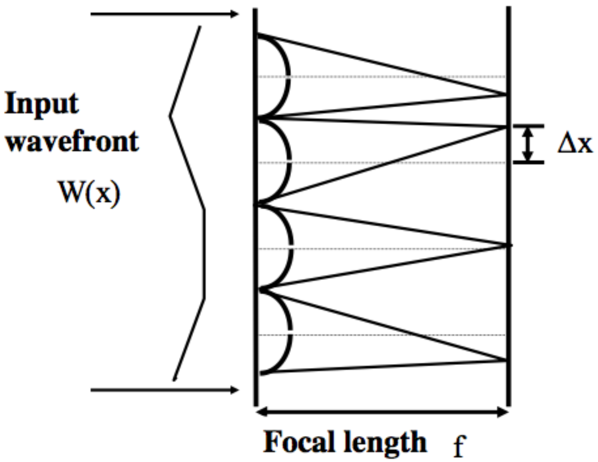
- Most extraction mirrors designs face problems of heating that cause deformation, for which it is necessary
  - Cooling
  - Wave front distortion diagnostics (to correct for deformation)
  - Deformable mirrors (look to me a complicated way-out of the problem)

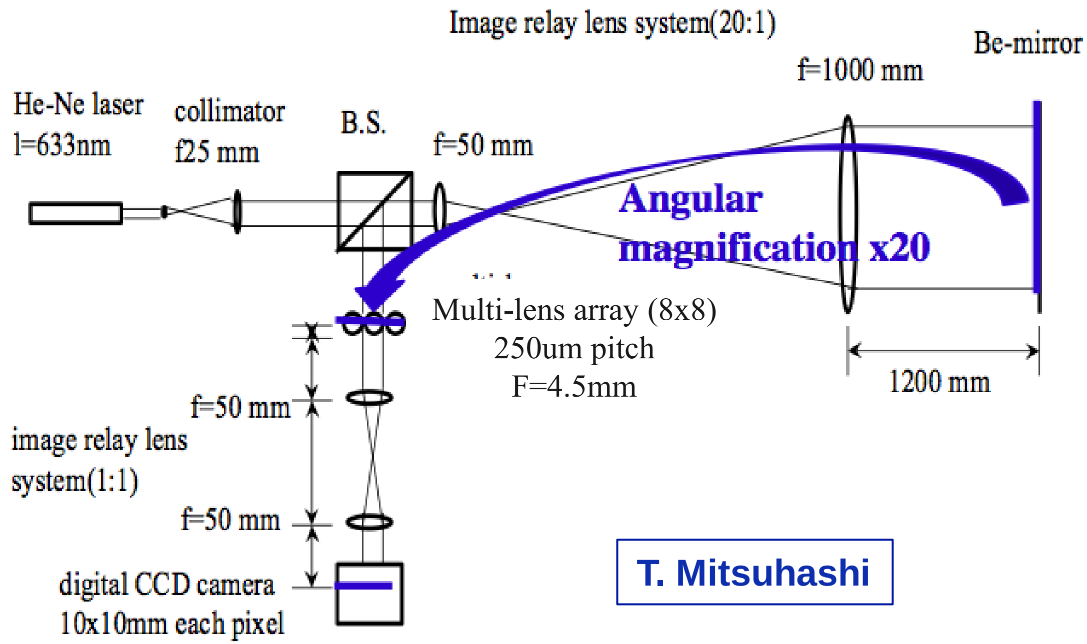
- Never forget EM coupling ! (see LHC)

- Disclaimer: I don’t claim having found/discussed here all mirror type/designs existing or ongoing…

Wave front distortion measurements
Schack-Hartmann Sensor

$$\frac{dW(x)}{dx} = -\frac{\Delta x}{f}$$





- Micro lens array + sensor assemblies commercially available (affordable prices)
- Normally needs to be integrated into optical setup in order to achieve good resolution

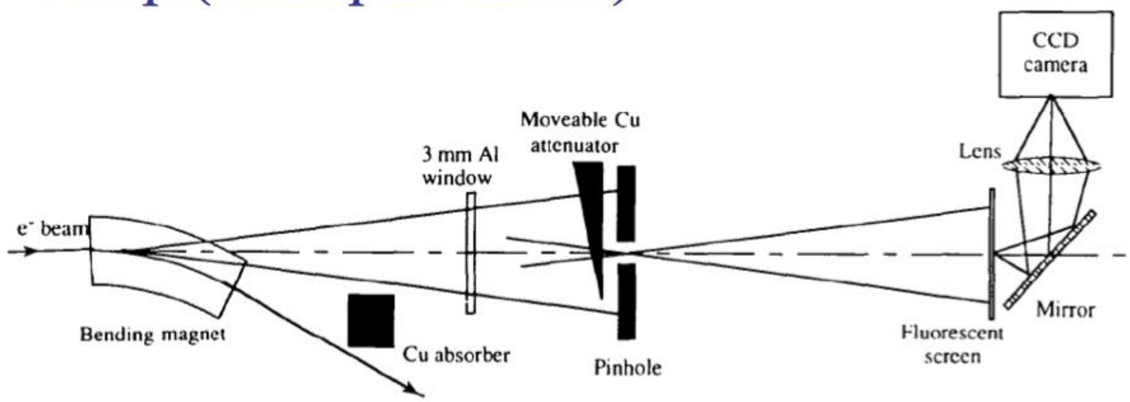
- We'll likely test this method in two weeks at ALBA (within CERN-CELLS collaboration)

SPARE SLIDES

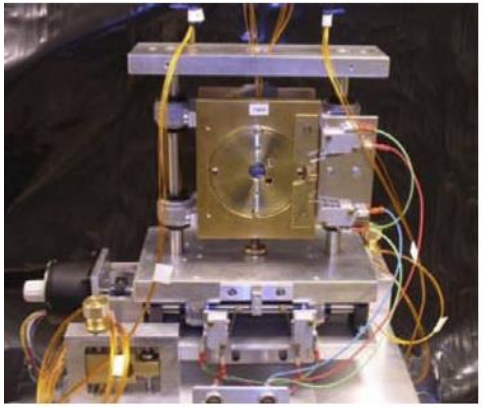
ESRF – X-ray imaging pinhole setup (no mirror)

Setup (example: ESRF)

P.Elleaume, C.Fortgang, C.Penel and E.Tarazona, J.Synchrotron Rad. **2** (1995) , 209



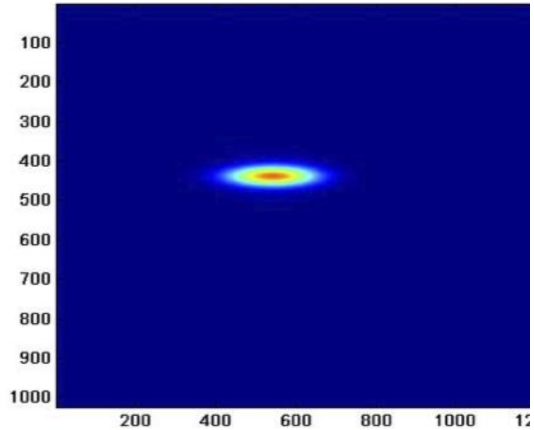
ID-25 X-ray pinhole camera:



pinhole setup @ DORIS

resolution:

$\sigma_{res} \approx 20\,\mu m$



courtesy of K.Scheidt, ESRF

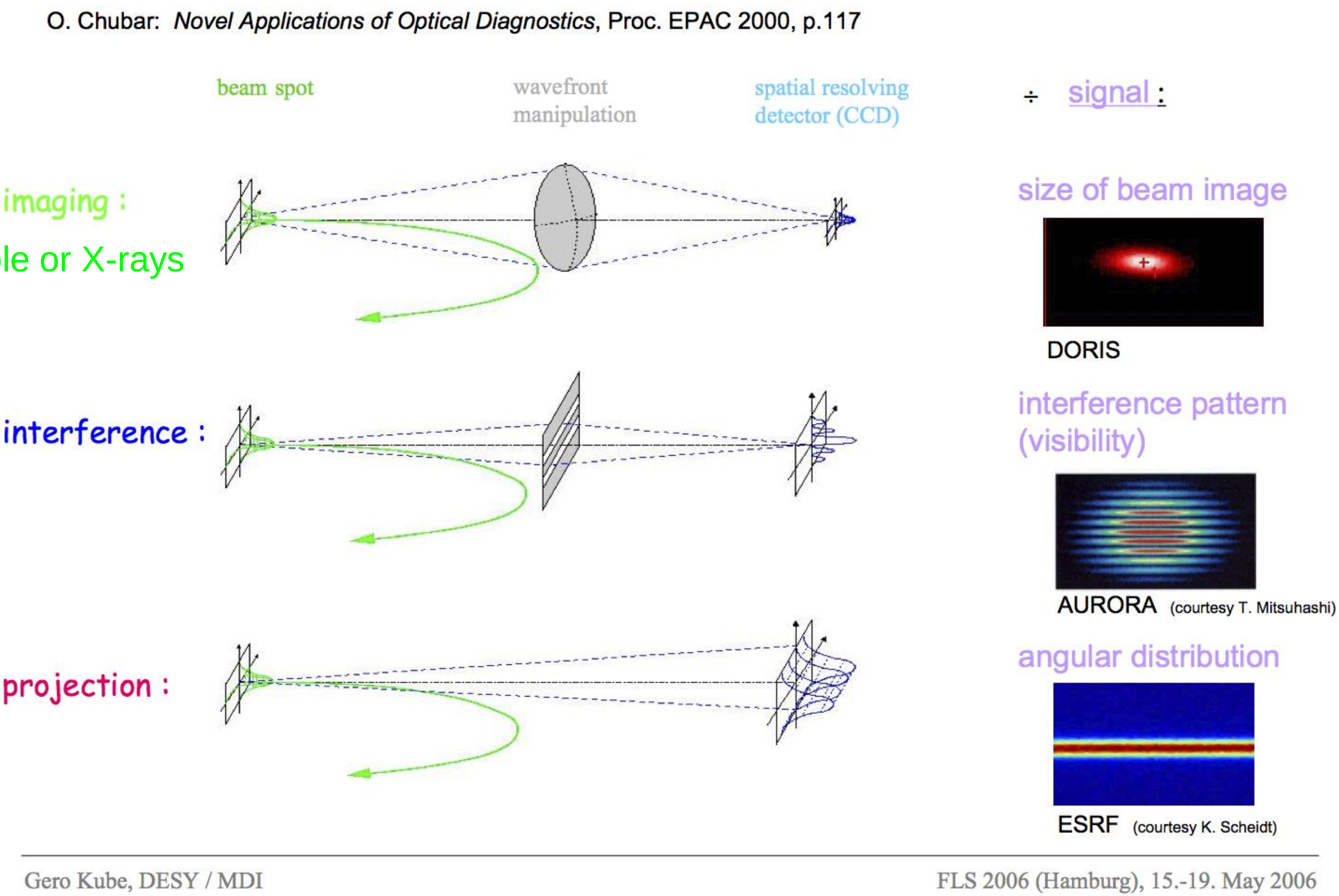
Kube, DESY / MDI

FLS 2006 (Hamburg), 15.-19. May 2(

Synchrotron radiation for beam diagnostics

Transverse beam size monitoring

Visible or X-rays



LHC –Experience 2012