

Longitudinal and Transverse Beam Diagnostic using Synchrotron Radiation at ALBA

Laura Torino



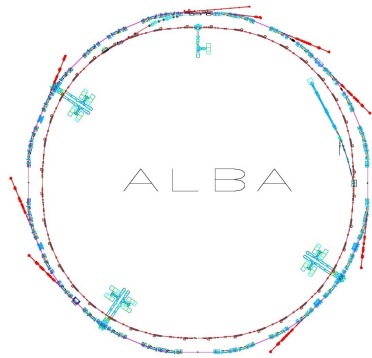
October 23, 2015
Pisa, Italy

ALBA



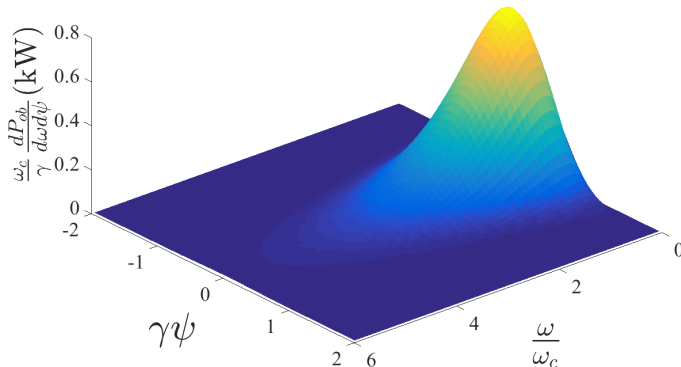
The Facility

- ▶ Energy: 3 GeV
- ▶ Current: up to 400 mA
- ▶ RF-Frequency 500 MHz
- ▶ Seven active beamlines
 - ▶ +1 Optical beamline
 - ▶ +1 x-ray Fronted

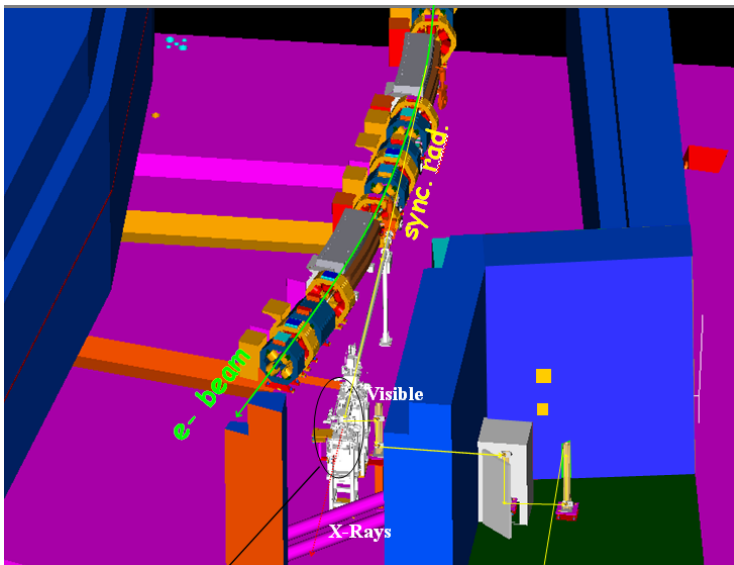


$\psi \rightarrow$ Emission angle
 $\omega \rightarrow$ Photon frequency

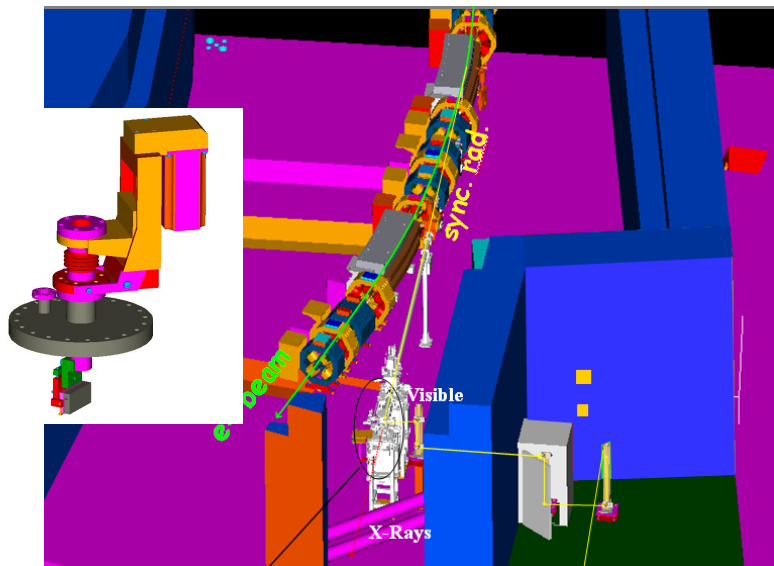
$$\varepsilon_c \simeq 8 \text{ keV}$$



XANADU



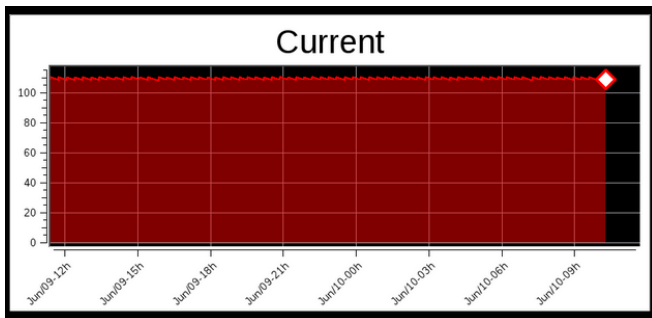
XANADU



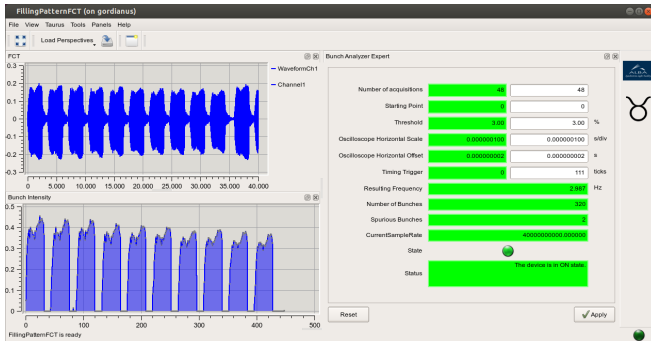
SUMMARY

MOTIVATIONS

Filling pattern: amount of current per bucket
Measurements are needed for selective top-up operation.
Future bunch purity measurements will be needed for time resolved experiments.



FILLING PATTERN



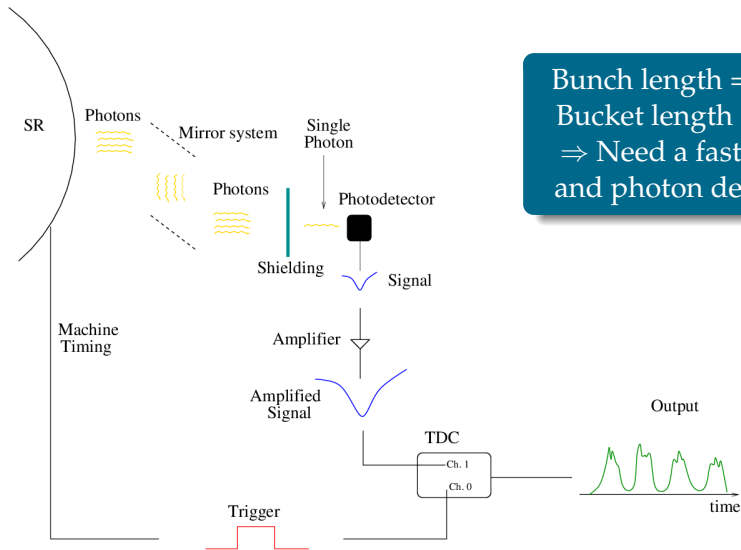
Longitudinal scheme:

- ▶ 448 Buckets
- ▶ Bucket length = 2 ns
- ▶ Bunch length = 16 ps

Operational Filling Pattern:

- ▶ 10 Trains
- ▶ 32 Bunches + 12 Empty Buckets
- ▶ 20 Buckets Abort Gap

TIME CORRELATED SINGLE PHOTON COUNTING

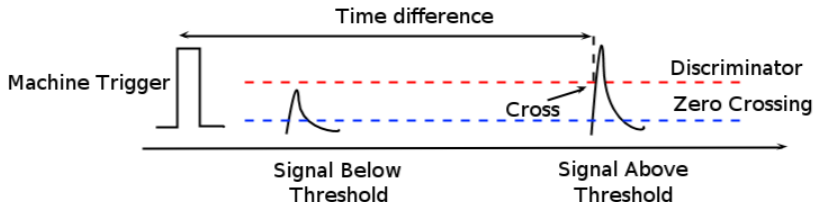


Bunch length = 16 ps
Bucket length = 2 ns
⇒ Need a fast TDC
and photon detector

PHOTON COUNTER

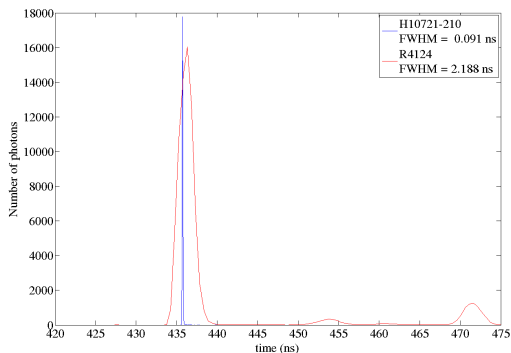


PicoHarp300	
Input voltage range	0 to -800 mV
Bin width	4-8...512 ps
Maximum sync rate	84 MHz
Dead time	< 95 ns



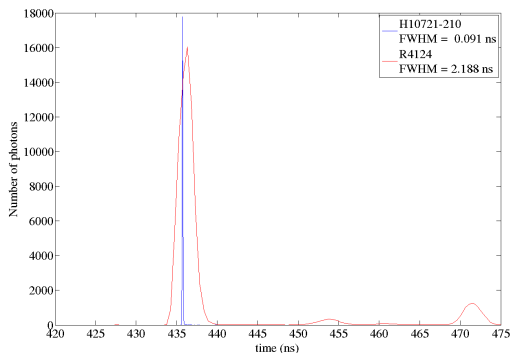
PHOTON DETECTOR

	H10721-210	R4124
Photocathode Material	Ultra Bialkali	Bialkali
Spectral Response	230-700 nm	300-650 nm
Dark Current	10 nA	1-15 nA
Rise Time	0.57 ns	1.1 ns
Transit Time Spread	0.091 ns	2.188 ns



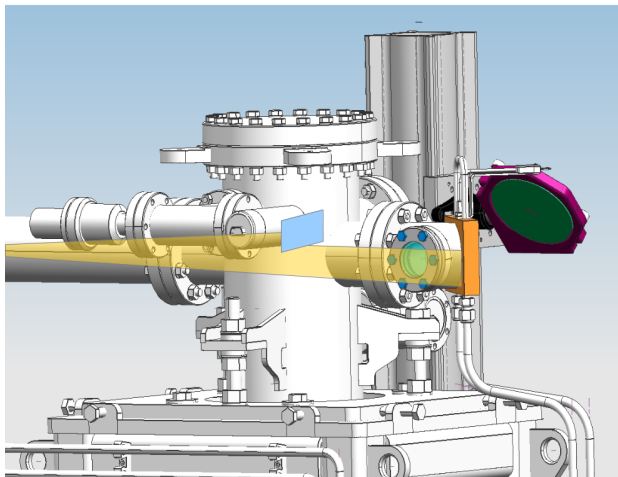
PHOTON DETECTOR

	H10721-210	R4124
Photocathode Material	Ultra Bialkali	Bialkali
Spectral Response	230-700 nm	300-650 nm
Dark Current	10 nA	1-15 nA
Rise Time	0.57 ns	1.1 ns
Transit Time Spread	0.091 ns	2.188 ns

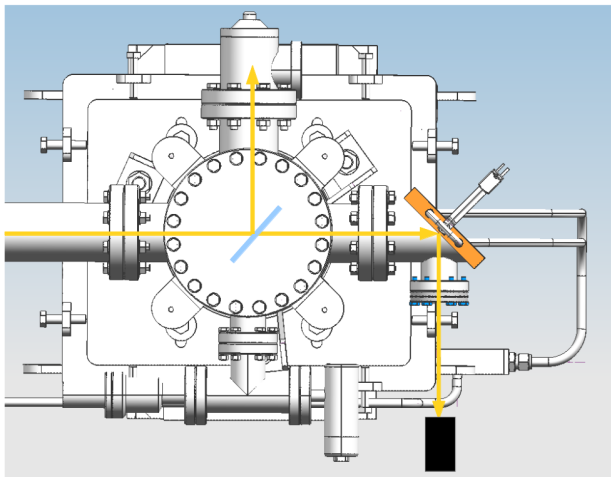


Problem:
The PMT cannot
stay in Xanadu

FRONTEND



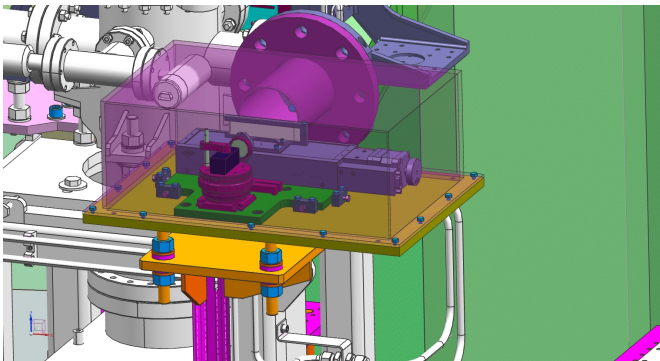
FRONTEND



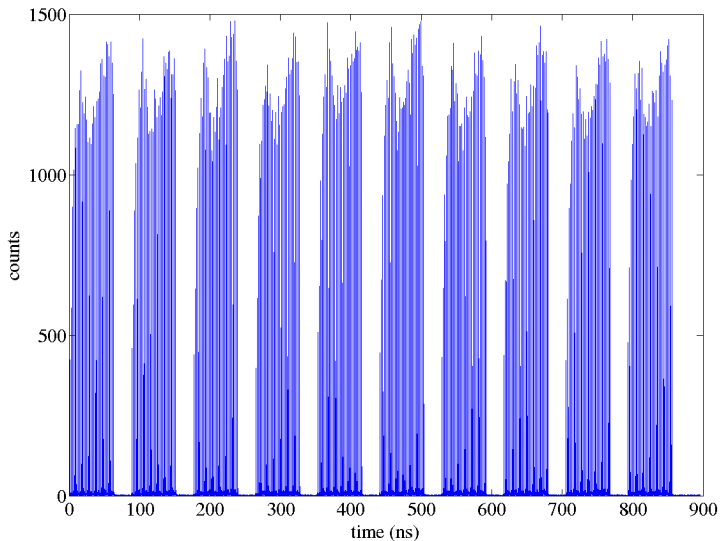
FRONTEND



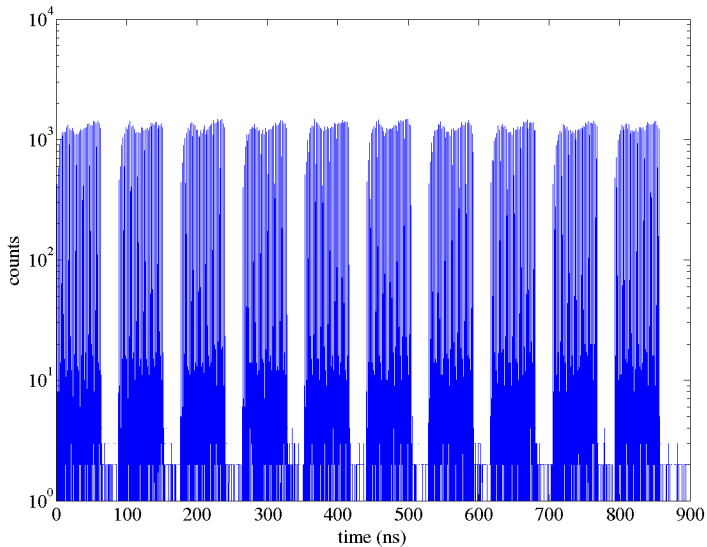
FRONTEND



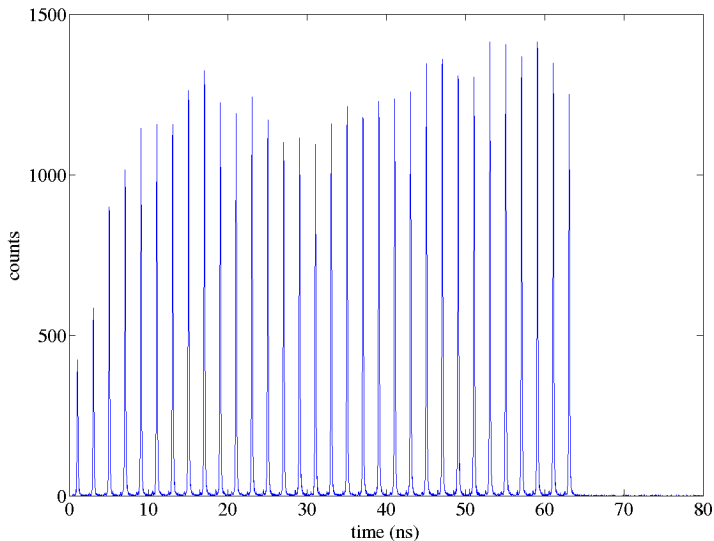
FILLING PATTERN



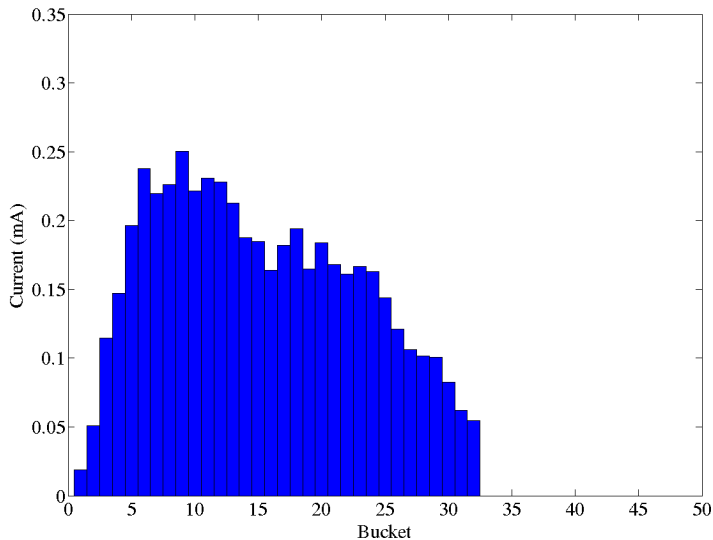
FILLING PATTERN



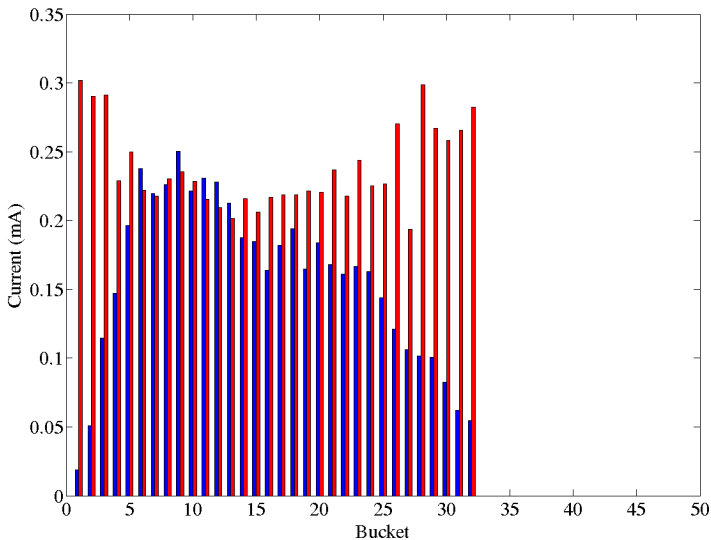
FILLING PATTERN



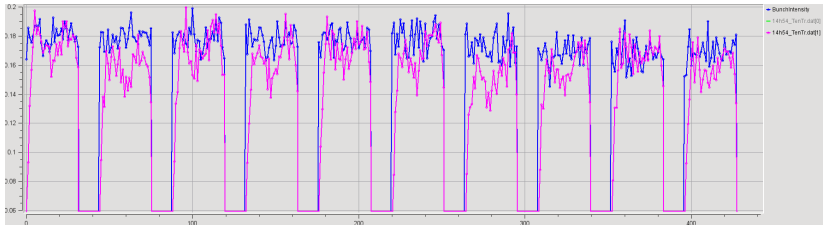
APPLICATION: TOP-UP SELECTIVE REFILLING



APPLICATION: TOP-UP SELECTIVE REFILLING

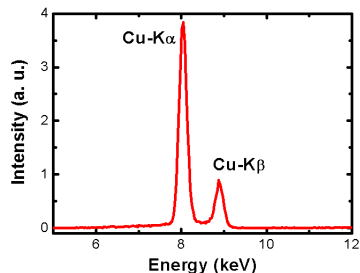
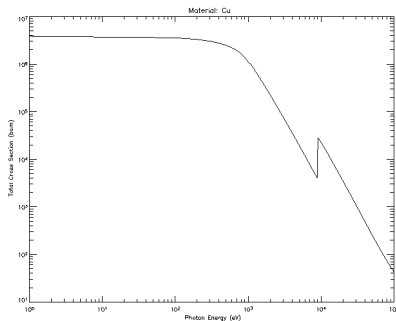


APPLICATION: TOP-UP SELECTIVE REFILLING



NEXT STEPS

- ▶ The set-up is still not definitive, the design of the final set-up is ready, waiting for the actual implementation
- ▶ Use a avalanche photodiode (APD) to use x-rays from the $K\alpha$ decay of copper to improve the dynamic range:
 - ▶ Measure the sensitivity of the APD for soft x-rays at the Xaloc beamline



TRANSVERSE BEAM SIZE

Problem

ALBA beam size: $\sigma_x \simeq 55 \mu\text{m}$ and $\sigma_y \simeq 25 \mu\text{m}$



Diffraction limited using visible radiation



$$d = \frac{\lambda}{2n \sin \theta} \simeq 100 \mu\text{m}$$

TRANSVERSE BEAM SIZE

Problem

ALBA beam size: $\sigma_x \simeq 55 \mu\text{m}$ and $\sigma_y \simeq 25 \mu\text{m}$



Diffraction limited using visible radiation



$$d = \frac{\lambda}{2n \sin \theta} \simeq 100 \mu\text{m}$$

Pinhole

Use X-Rays



Choosing the correct energy
and magnification diffraction
limit is bypassed

TRANSVERSE BEAM SIZE

Problem

ALBA beam size: $\sigma_x \simeq 55 \mu\text{m}$ and $\sigma_y \simeq 25 \mu\text{m}$



Diffraction limited using visible radiation



$$d = \frac{\lambda}{2n \sin \theta} \simeq 100 \mu\text{m}$$

Pinhole

Use X-Rays



Choosing the correct energy and magnification diffraction limit is bypassed

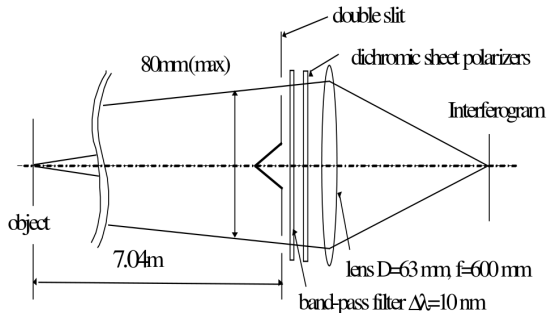
Interferometry

Use Visible radiation



Measuring the degree of spatial coherence of the produced radiation

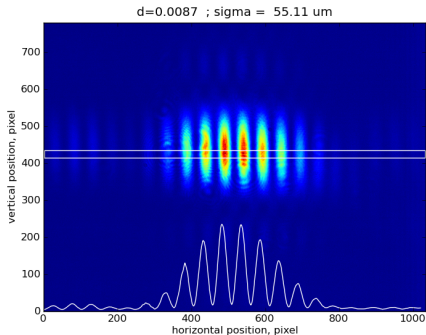
MITSUHASHI SR INTERFEROMETER



$$I = I_0 \left\{ \text{sinc} \left(\frac{2\pi ax}{\lambda f} \right) \right\}^2 \times \left\{ 1 + V \cos \left(\frac{2\pi Dx}{\lambda f} \right) \right\}$$

$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}}$$

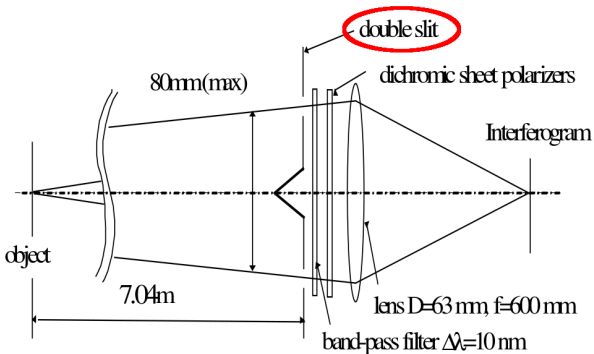
MITSUHASHI SR INTERFEROMETER



$$I = I_0 \left\{ \text{sinc} \left(\frac{2\pi ax}{\lambda f} \right) \right\}^2 \times \left\{ 1 + V \cos \left(\frac{2\pi Dx}{\lambda f} \right) \right\}$$

$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}}$$

MITSUHASHI SR INTERFEROMETER



$$I = I_0 \left\{ \text{sinc} \left(\frac{2\pi nx}{\lambda f} \right) \right\}^2 \times \left\{ 1 + V \cos \left(\frac{2\pi Dx}{\lambda f} \right) \right\}$$

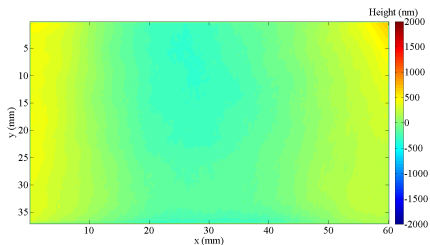
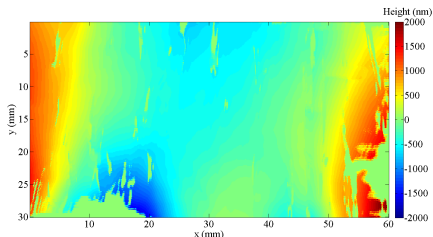
$$\sigma = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{V}}$$

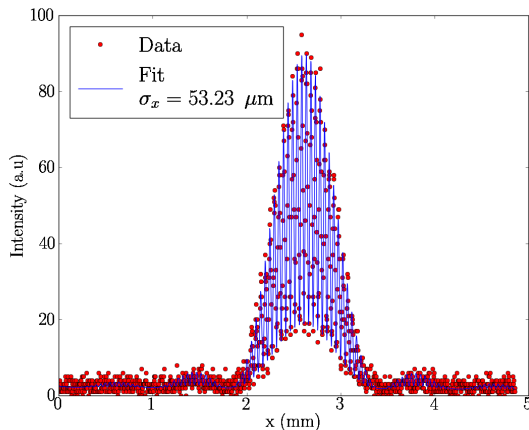
XANADU UPGRADE

Interferometry
techniques to measure
such small source size
need an optimal optical
quality of the optical
components



Full upgrade of Xanadu
beamline after a testing
all the optical
components



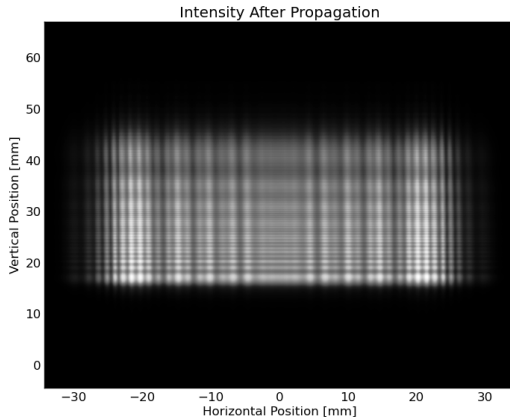


- ✓ OK horizontal measurements
- × No good results for vertical measurements



Not easy to align and fit

DOUBLE SLIT INTERFEROGRAM



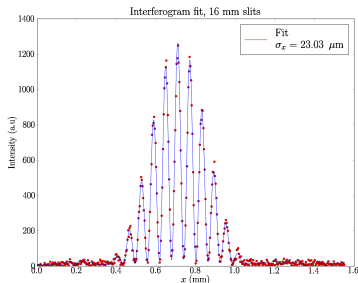
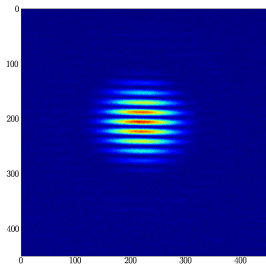
✓ OK horizontal
measurements
× No good results
for vertical
measurements



Not easy to align
and fit

DOUBLE PINHOLES

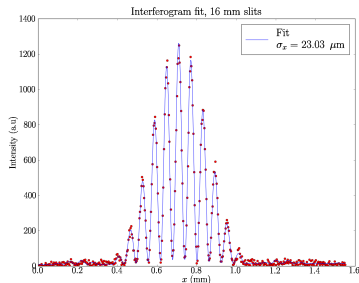
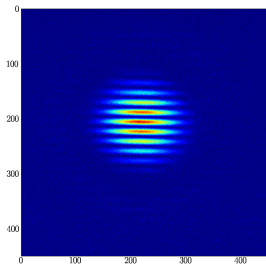
Using double pinholes instead of slits
diameter = 3 mm



$$I = I_0 \left\{ \frac{J_1 \left(\frac{2\pi ax}{\lambda f} \right)}{\left(\frac{2\pi ax}{\lambda f} \right)} \right\}^2 \times \left\{ 1 + V \cos \left(\frac{2\pi Dx}{\lambda f} \right) \right\}$$

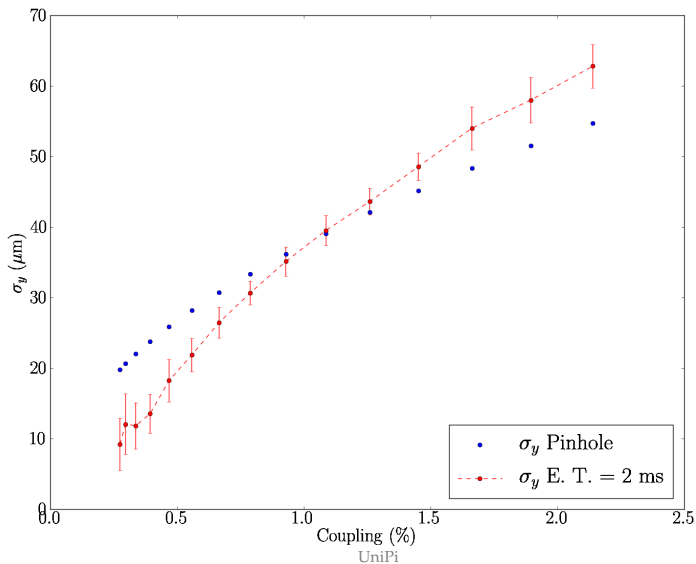
DOUBLE PINHOLES

Using double pinholes instead of slits
diameter = 3 mm



$$I = I_0 \left\{ \frac{J_1 \left(\frac{2\pi ax}{\lambda f} \right)}{\left(\frac{2\pi ax}{\lambda f} \right)} \right\}^2 \times \left\{ 1 + V \cos \left(\frac{2\pi Dx}{\lambda f} \right) \right\}$$

COUPLING SCAN



ISSUES

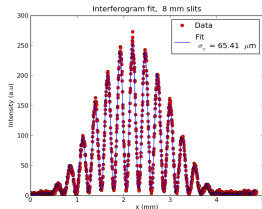
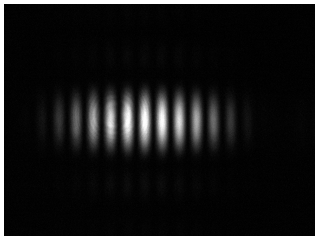
Once we learned how to align...
Additional issues come:



- ▶ Beam size measurements are sensitive to the CCD exposure time
 - ▶ Linearity of the CCD
 - ▶ Mechanical vibration or air turbulence influence
- ▶ Some applications require more light
 - ▶ Further image processing to match images

VIBRATIONS/AIR TURBULENCE

Proper displacement of the interferogram position over the CCD sensor $\Rightarrow$ Accumulating the images for long time generate a fictitious blow of the beam size



Possible solution: match low exposure time images

MATCHING ALGORITHM

Problem:

At low exposure time ($100\ \mu\text{s}$) the images are very noisy $\Rightarrow$ Simply superimposing the maximum might not be enough

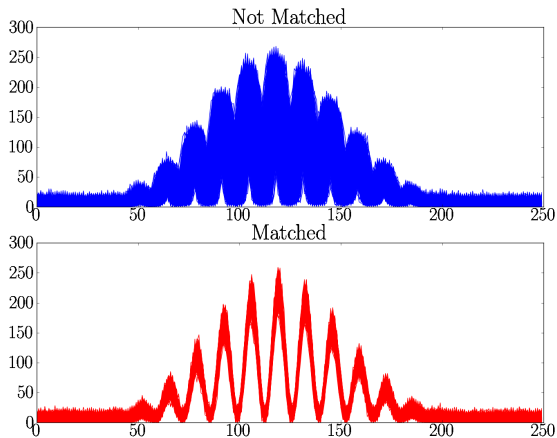
Solution:

A bit of image processing:

- ▶ Chose a Reference and an Image
- ▶ Apply a low pass filter
- ▶ Normalize
- ▶ Compute the correlations: $(\text{Reference} \otimes \text{Image})^2$
- ▶ Find the maximum of the correlations matrix
- ▶ Displace the Image of the given amount
- ▶ Sum the shifted images

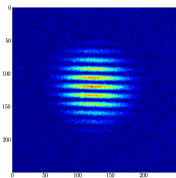
Many thanks to Josep Nicolás

CORRECTION

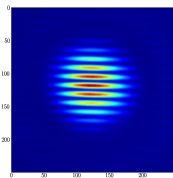


RESULTS

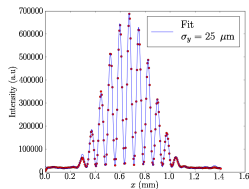
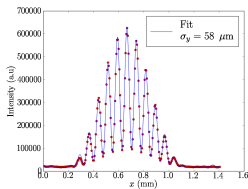
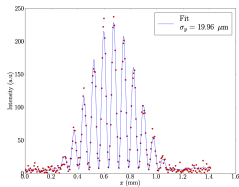
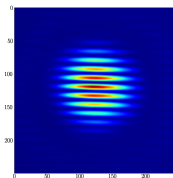
Raw Image



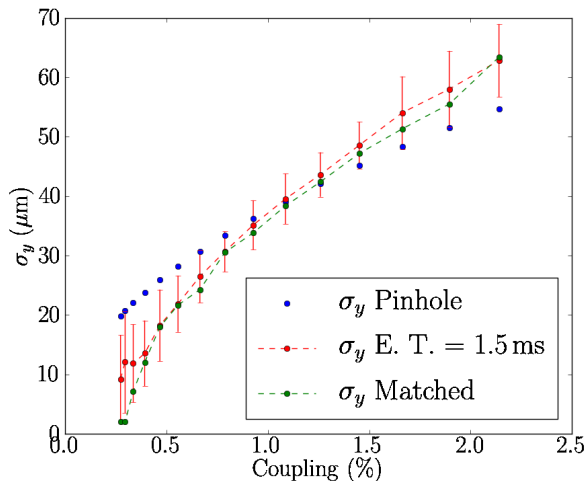
Superposition



Matching Algorithm



COUPLING SCAN USING MATCHED IMAGES



NEXT STEPS

Single bunch size measurements to study beam instabilities
using a Fast Gated Camera

- ▶ Select the proper fast gated camera
 - ▶ Linearity and distortion tests
- ▶ Use the matching algorithm to improve the dynamic range



LONGITUDINAL

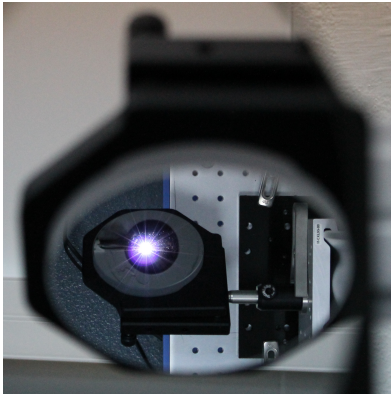
- ▶ TCSPC has been developed at ALBA
- ▶ Two PMTs were characterized and one has been chosen for filling pattern measurements
- ▶ TCSPC is now integrated in the ALBA operative system and will be used for selective top-up injection
- ▶ An APD will be calibrated and tested for TCSPC using X-Rays to improve the dynamic range

TRANSVERSE

- ▶ Synchrotron radiation interferometry is now operative at ALBA
- ▶ A full upgrade of Xanadu was needed to obtain good results
- ▶ Pinhole were substituted to slits and coupling scans were performed to verify results
- ▶ A matching algorithm has been developed to obtain a good dynamic range in case of low radiation level
- ▶ Image intensifiers will be tested to perform single bunch size measurements

CONCLUSIONS

Two new synchrotron radiation based diagnostic system were implemented at ALBA in the last three years.



Relatore: F. Cervelli
Co-relatore: U. Iriso
Controrelatore: E. Paoloni

This project is funded by the European Union under contract PITN-GA-2011-289485

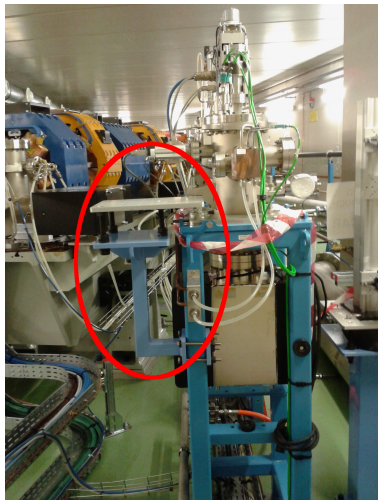
REAL FRONTEND



Problems

- ▶ Support
- ▶ Remote control
- ▶ Single Photon
- ▶ Radiation
- ▶ Light always on

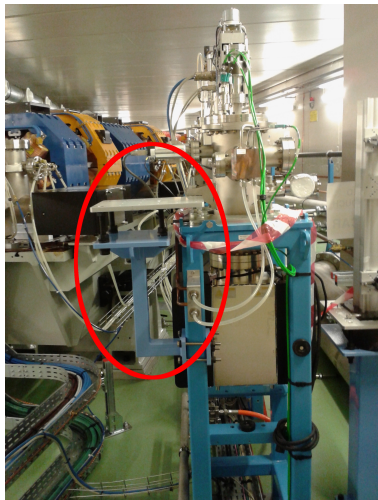
REAL FRONTEND



Problems

- ▶ **Support**
- ▶ Remote control
- ▶ Single Photon
- ▶ Radiation
- ▶ Light always on

REAL FRONTEND

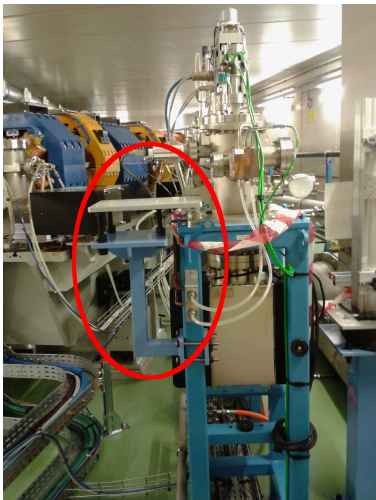


Problems

- ▶ Support
- ▶ Remote control
- ▶ Single Photon
- ▶ Radiation
- ▶ Light always on

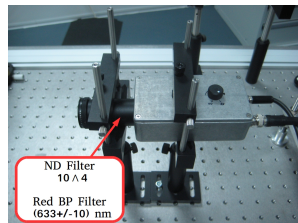
Cabling everything
outside the tunnel

REAL FRONTEND

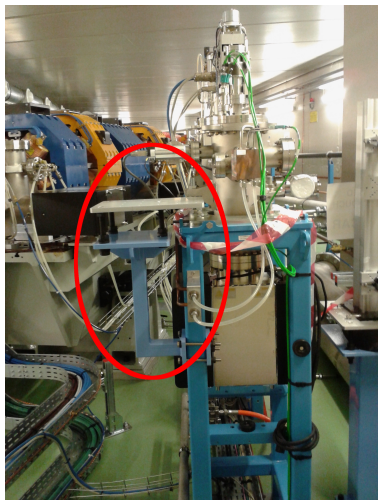


Problems

- ▶ Support
- ▶ Remote control
- ▶ **Single Photon**
- ▶ Radiation
- ▶ Light always on

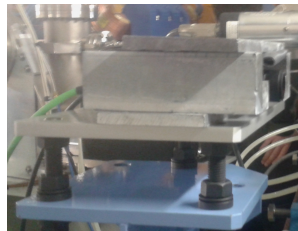


REAL FRONTEND

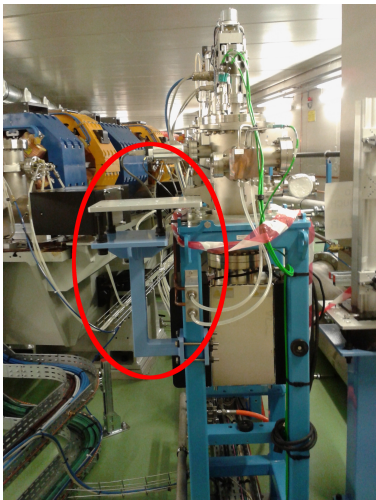


Problems

- ▶ Support
- ▶ Remote control
- ▶ Single Photon
- ▶ **Radiation**
- ▶ Light always on



REAL FRONTEND

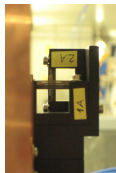
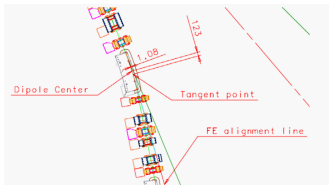
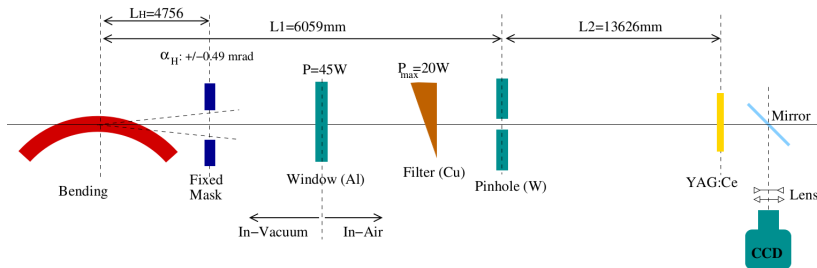


Problems

- ▶ Support
- ▶ Remote control
- ▶ Single Photon
- ▶ Radiation
- ▶ **Light always on**



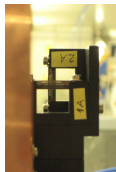
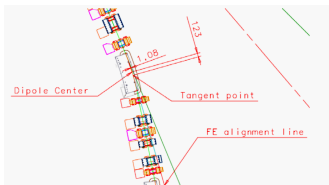
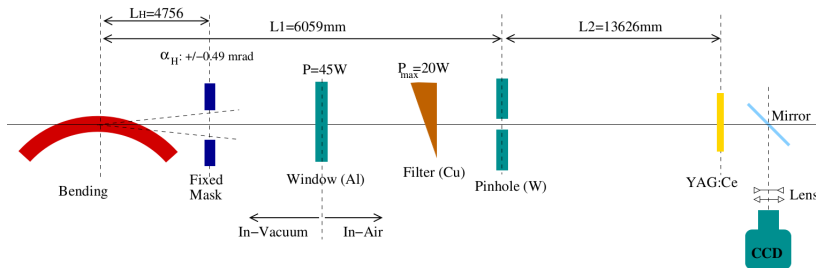
PINHOLE AT ALBA



Copper

To select the
radiation energy
 $E \gtrsim 45$ keV

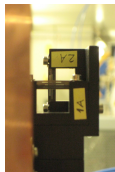
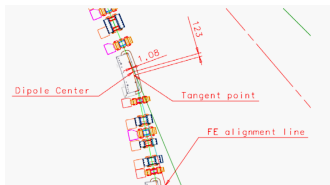
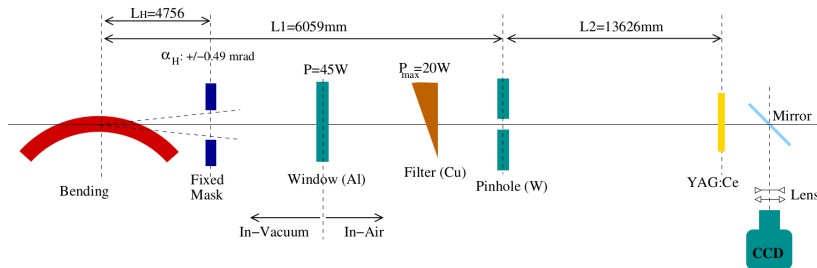
PINHOLE AT ALBA



Magnification

$$X = \frac{L_2}{L_1} = \frac{(13626 - 123) \text{ mm}}{(6059 - 123) \text{ mm}} = 2.275$$

PINHOLE AT ALBA



Beam Size

@ source location

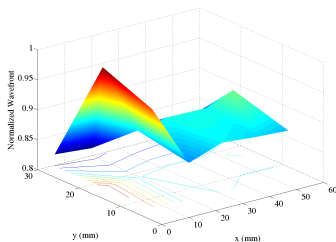
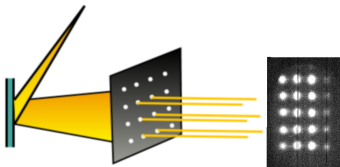
$$\sigma_x = 60 \mu\text{m and}$$

$$\sigma_y = 28 \mu\text{m}$$

WAVEFRONT RECONSTRUCTION

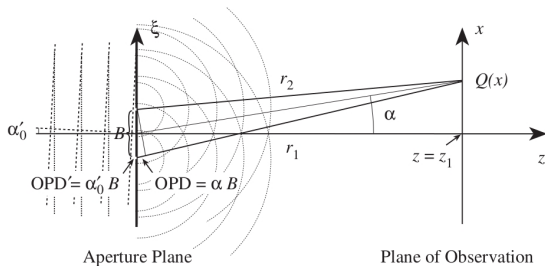
Problems due to heat load $\Rightarrow$ needs to check the optical path condition on-line

Wavefront monitoring using the Hartmann Mask



INTERFEROMETRY PRINCIPLE

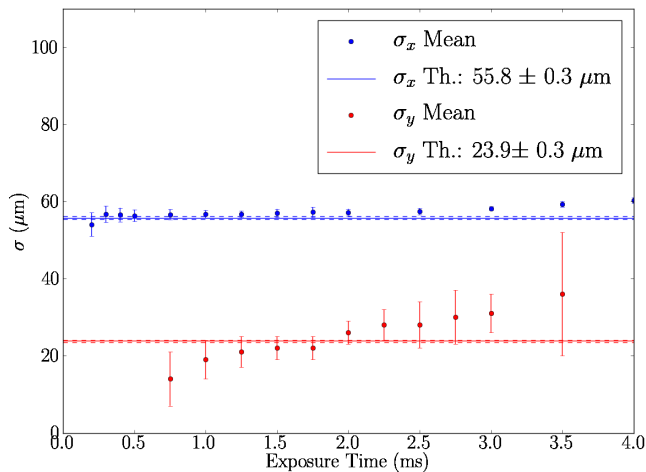
Light coming from an extended source



Introduction to Spatial Interferometry, Andrea Glindeman, ESO Garching

$$I \propto I_0 \left\{ 1 + \cos \left(\frac{2\pi}{\lambda} \alpha B \right) \right\} \qquad I \propto I_0 \left\{ 1 + \cos \left(\frac{2\pi}{\lambda} (\alpha + \alpha'_0) B \right) \right\}$$

CCD EXPOSURE TIME SCAN



VIBRATIONS

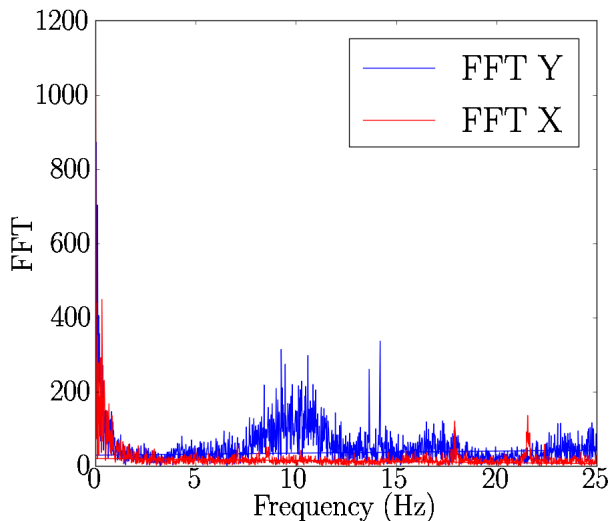
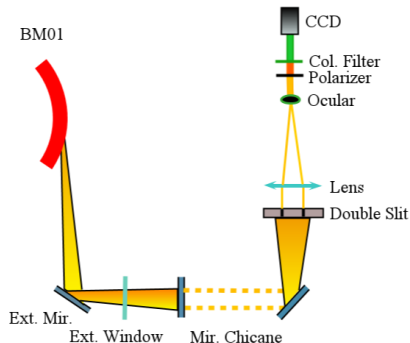


IMAGE ACQUISITION

- ▶ Frame Rate = 100 Hz
- ▶ Exposure time = $100\ \mu\text{s}$
- ▶ Acquisition Time = 30 s



3000 Images to be matched
Effective Exposure Time = 300 ms