# Beam emittance (size) diagnostic

## Recent progress

**T. Mitsuhashi**

**KEK**

1. Review of X-ray interferometer
2. Possibility for bunch by bunch beam size measurement

   Undulator

   wide aperture interferometer

   Inverse-contrast interferometer

3. Proposal for X-ray interferometer at ALBA

# Parameters of FCC-ee

| | |
|---|---|
| **Bending magnet length** | **24.585m** |
| **Bending radius** | **11590.8m** |
| **Magnetic field strength** | **0.0503T** |
| **Bending angle** | **2.144mrad** |
| **Beam energy and current** | **175GeV 6.6mA**<br>**45GeV 1500mA** |
| **emittance** | **1.3pmrad** |
| **Estimated vertical beam size** | $\sigma_y$ **=5.1μm / β=20m**<br>**=0.05μrad / 100m** |

**175GeV**

**ρ=11590.8m**

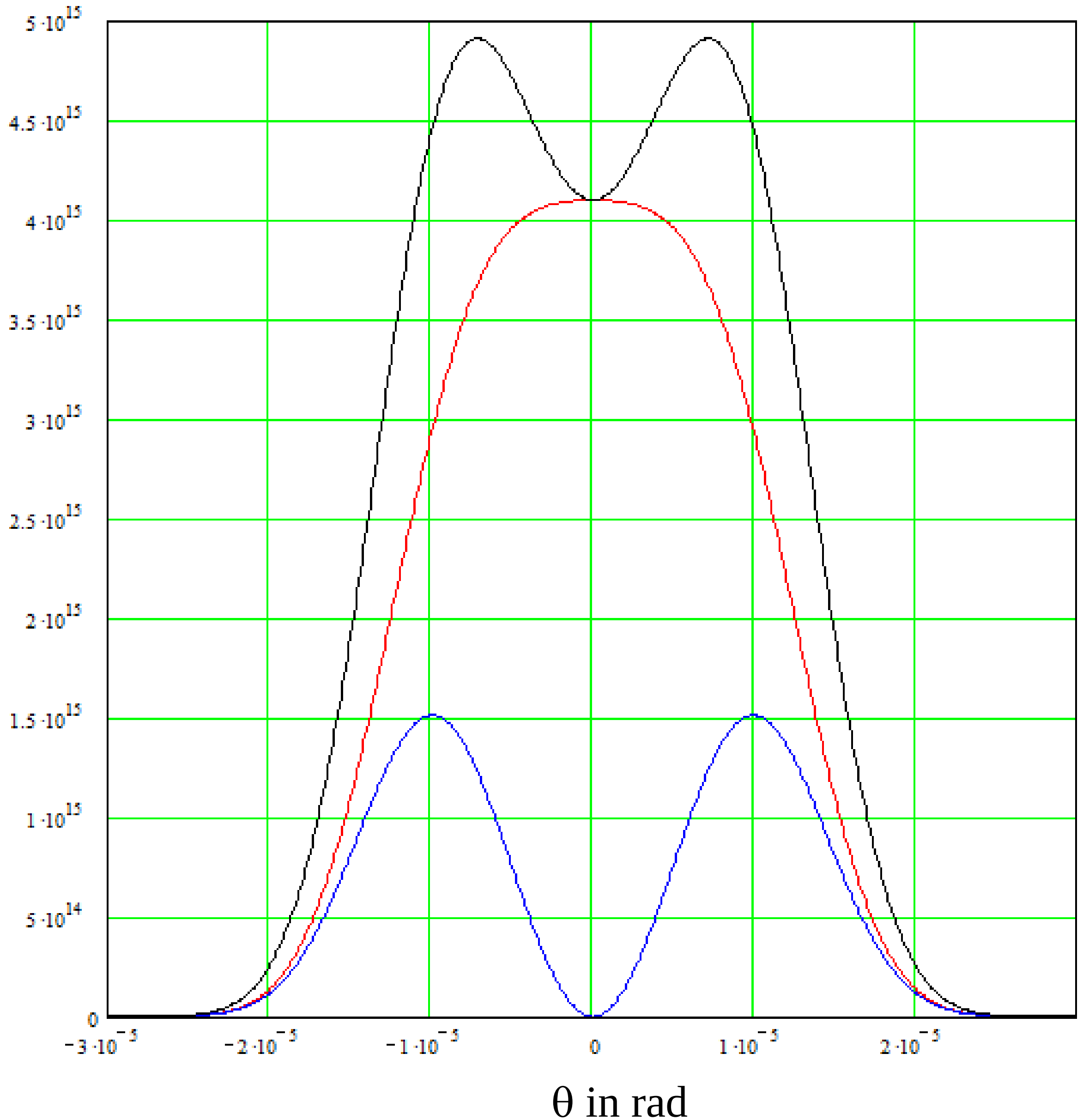
**0.1nm**

**Divergence of beam**

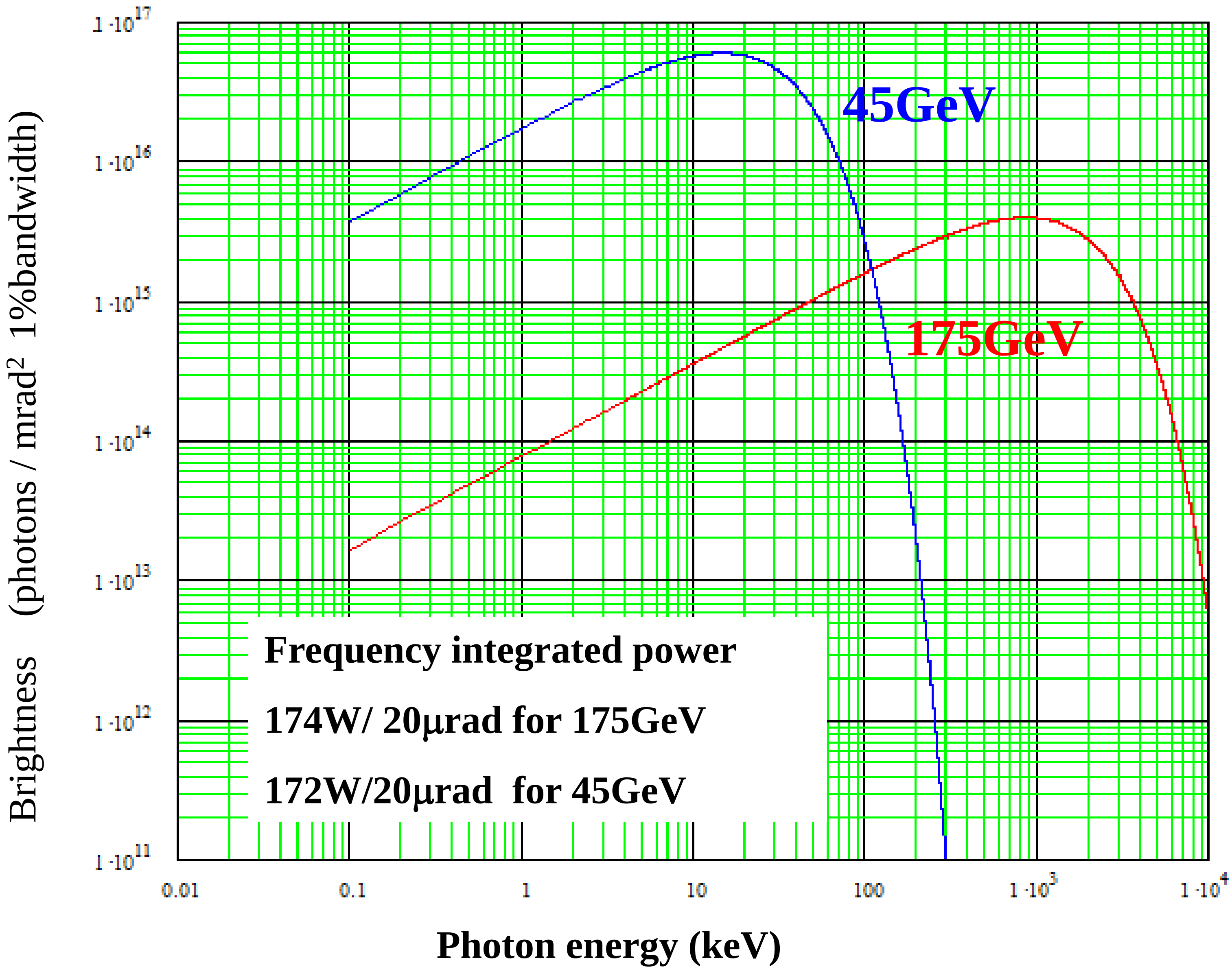
**Order of $10^{-7}$rad**

**Divergence of SR**

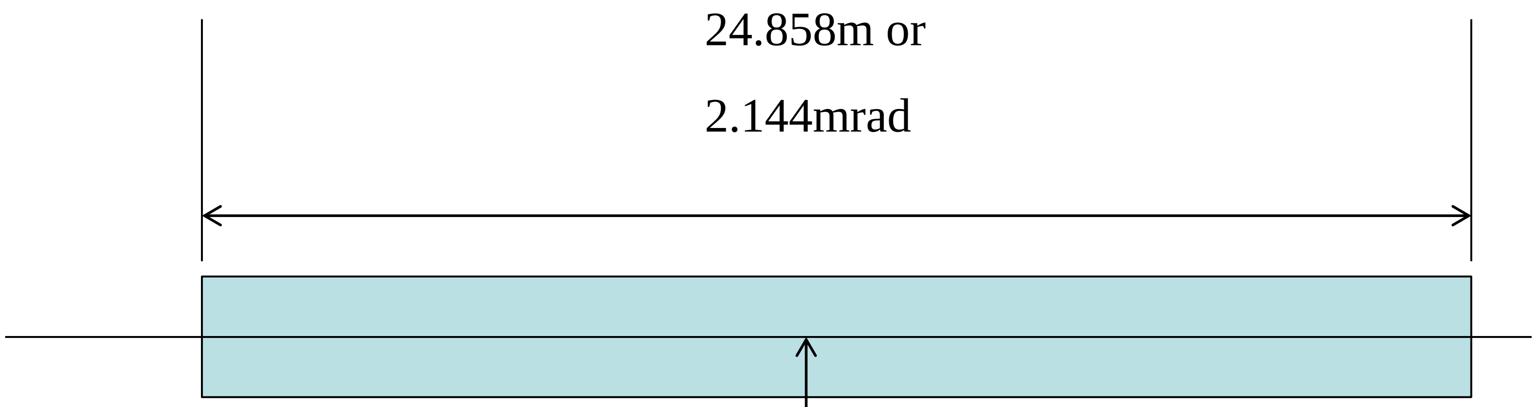
**Order of $10^{-5}$rad**



# Expected spectrum from the bending magnet FCC-ee



# Character of bending magnet in FCC-ee




**Bending angle of 2.144 mrad is 100 times larger than tail to tail opening of SR at 0.1nm (0.002mrad).**

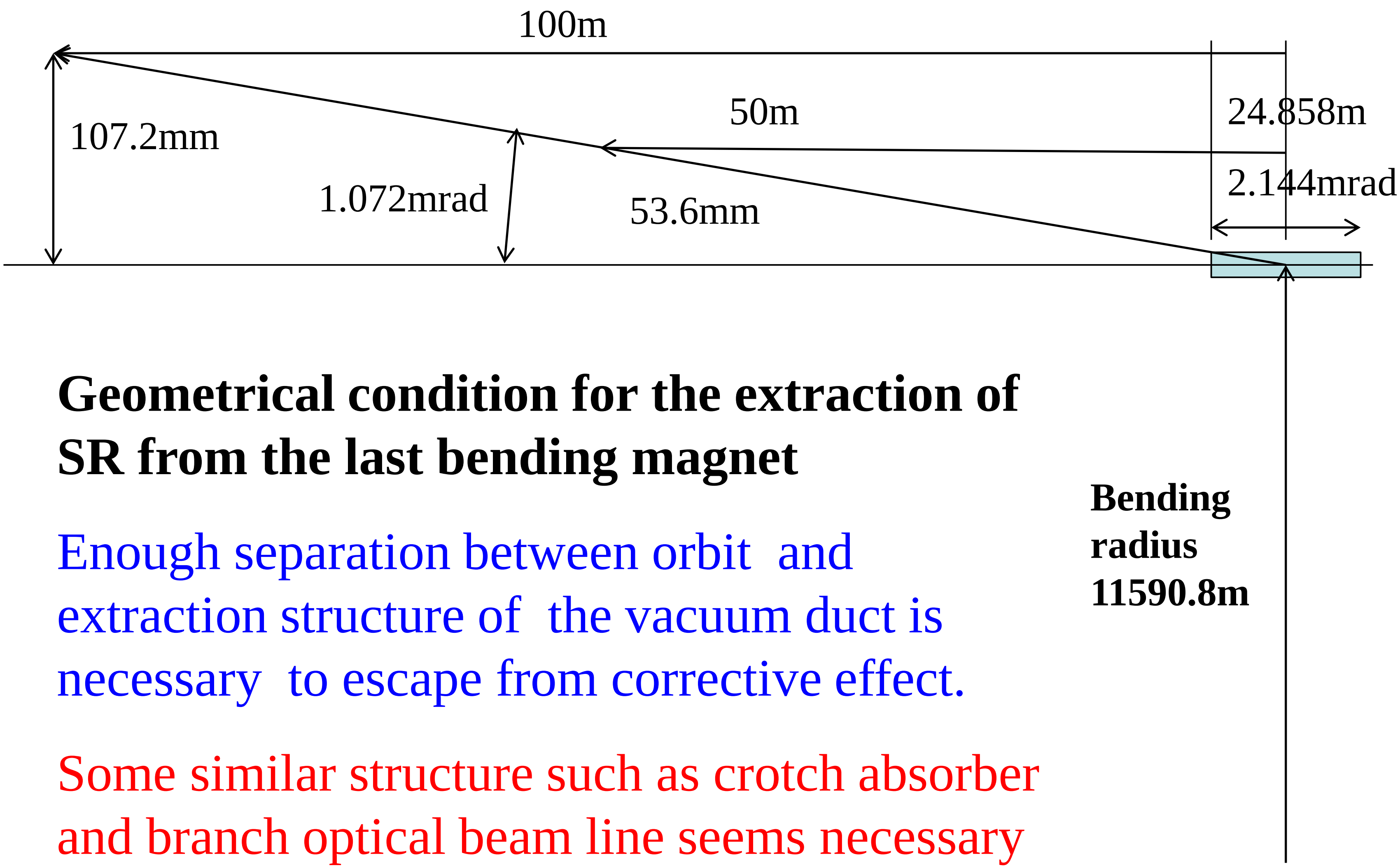
**<u>So, this bend is classified as long magnet.</u>**

**TR from magnet edge is week enough in X-ray region.**

# Extraction of hard X-rays from the ring

1. **Light source**

   **use last bending magnet in Arc.**



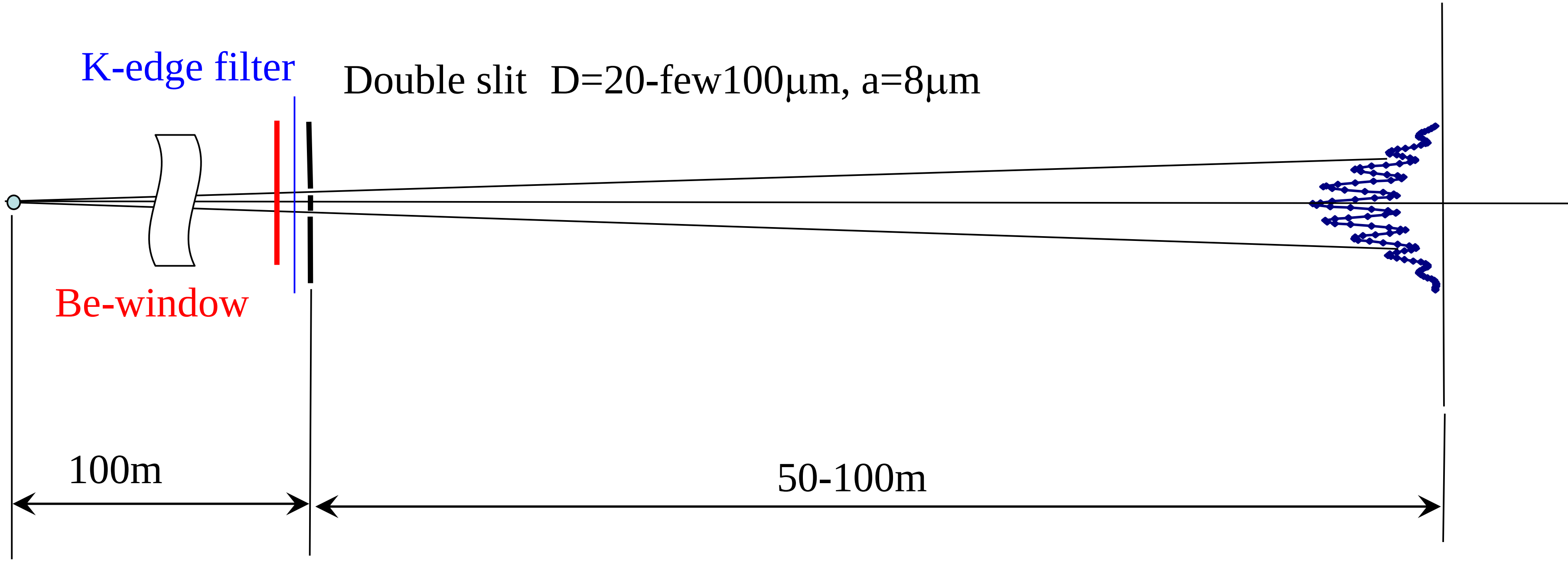

**Geometrical condition for the extraction of SR from the last bending magnet**

Enough separation between orbit and extraction structure of the vacuum duct is necessary to escape from corrective effect.

Some similar structure such as crotch absorber and branch optical beam line seems necessary to protect the crotch of the vacuum chamber from strong irradiation of SR.

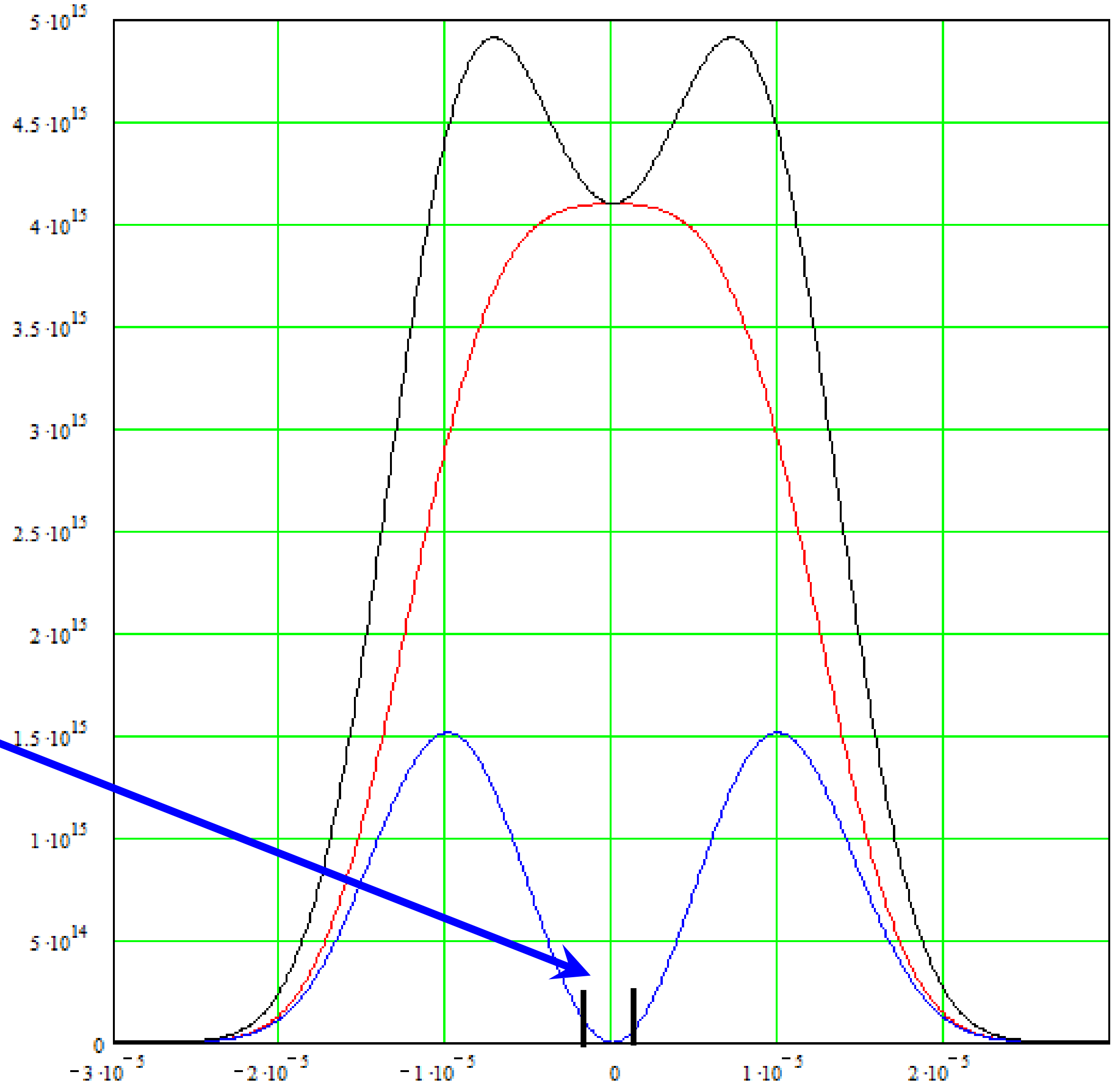
# X-ray interferometer

# Simple double slit X-ray interferometer (Young type)



**175GeV**

**ρ=11590.8m**



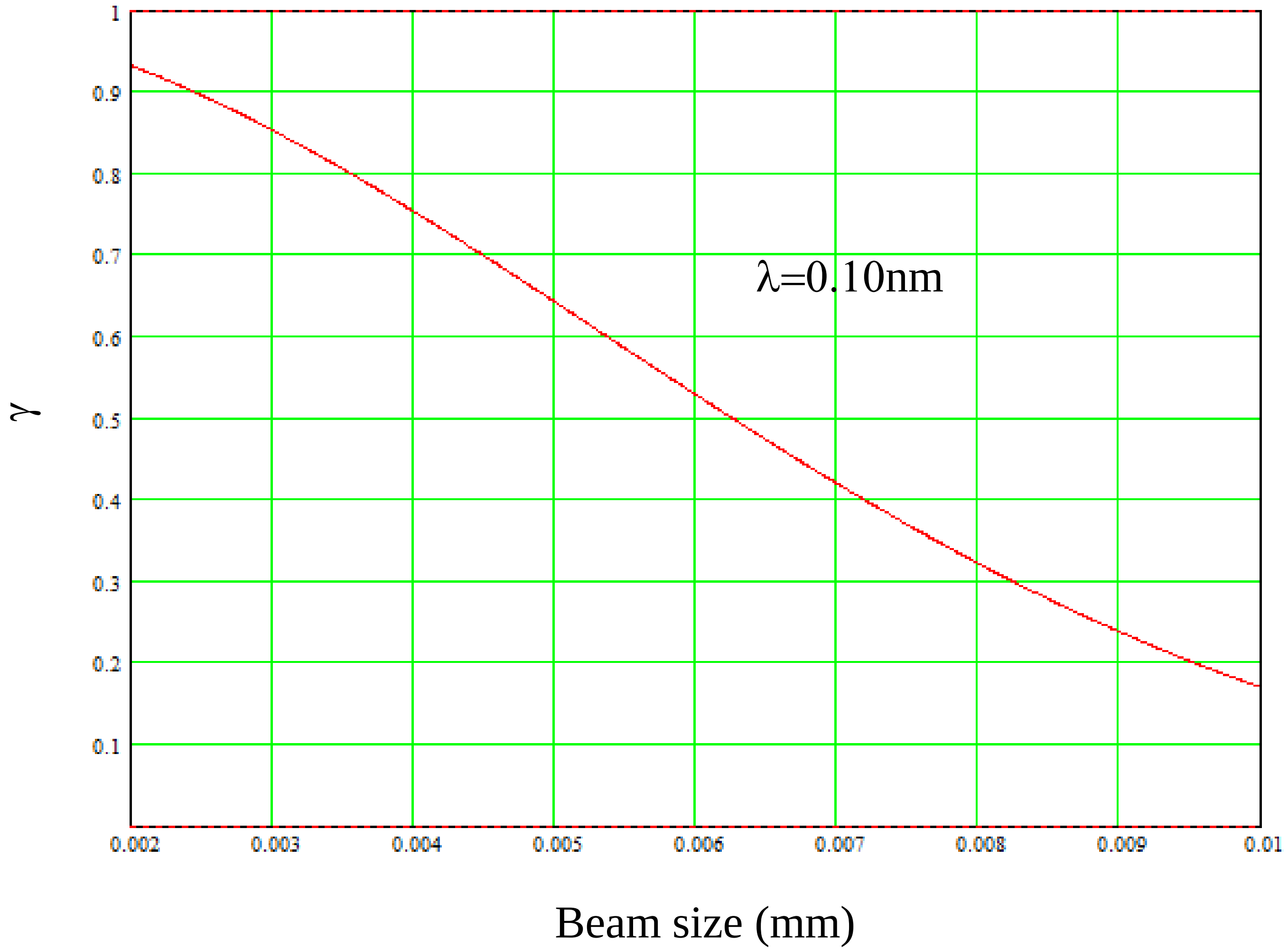

θ in rad

**Double slit location**

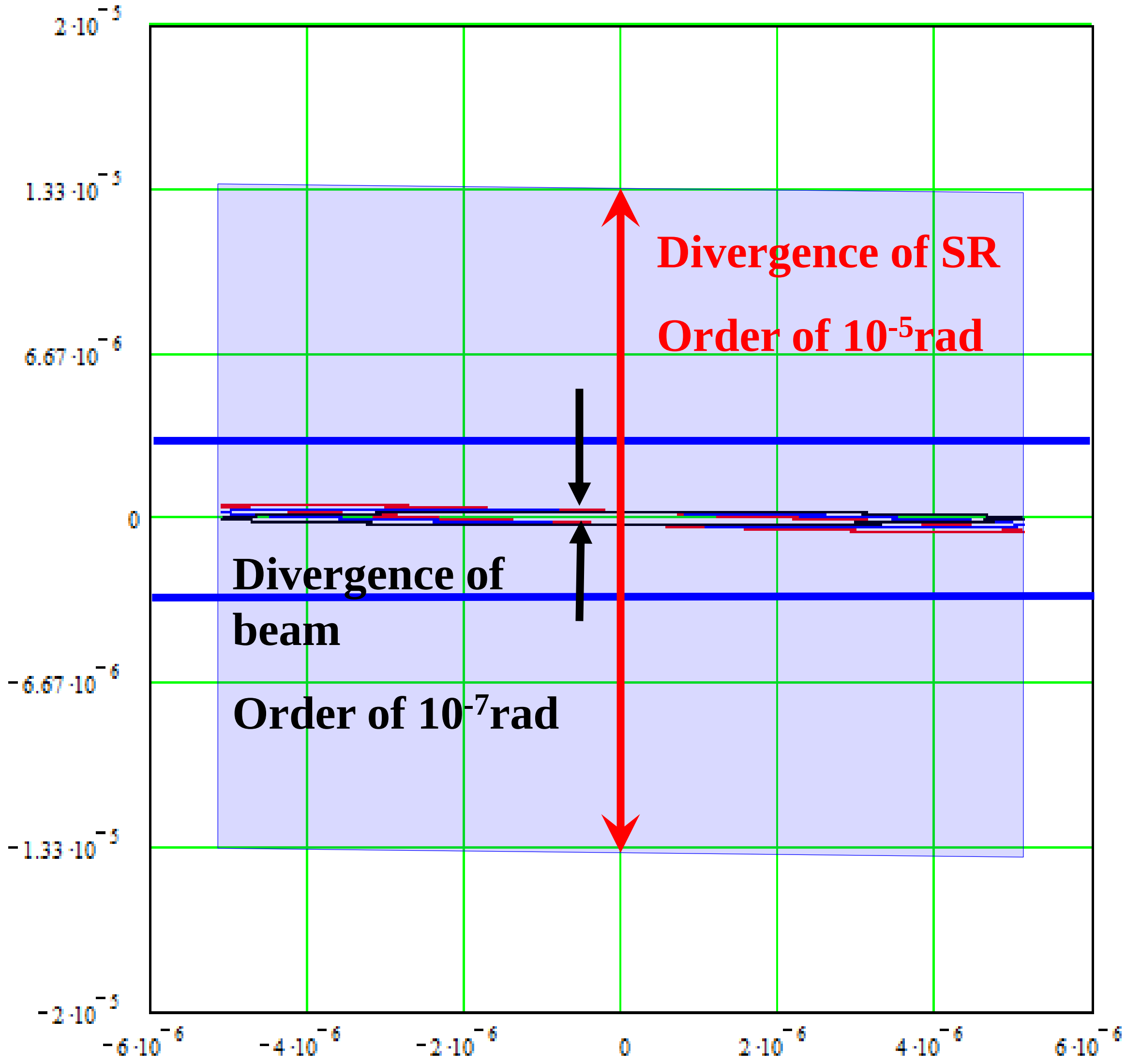
$I_v / I_h = 0.016$

**We do not need selection of polarization**

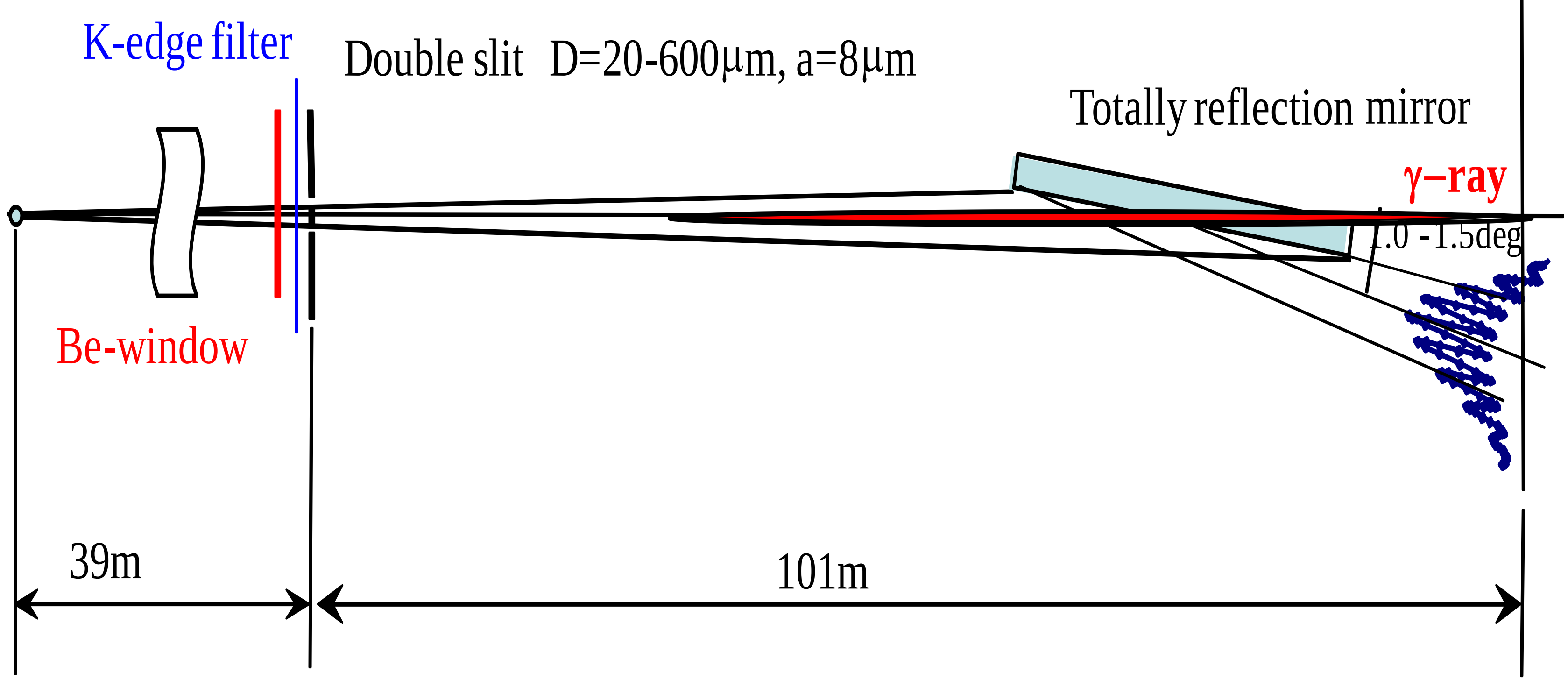
# Spatial coherence vs. beam size    D=300um, f=100m



# Double slit of interferometer will not miss the beam size information

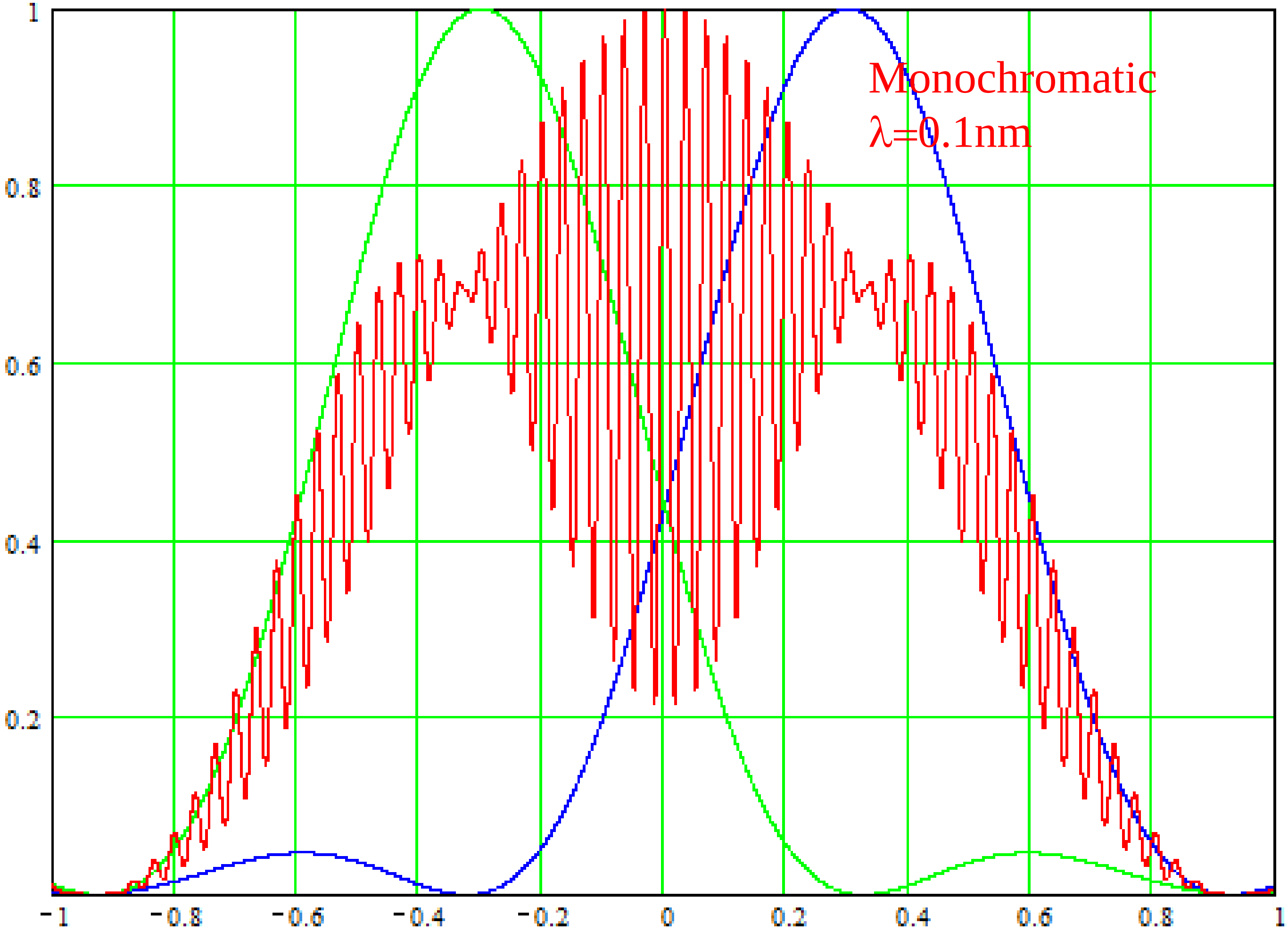


# Double slit interferometer (Young type) with total reflection mirror

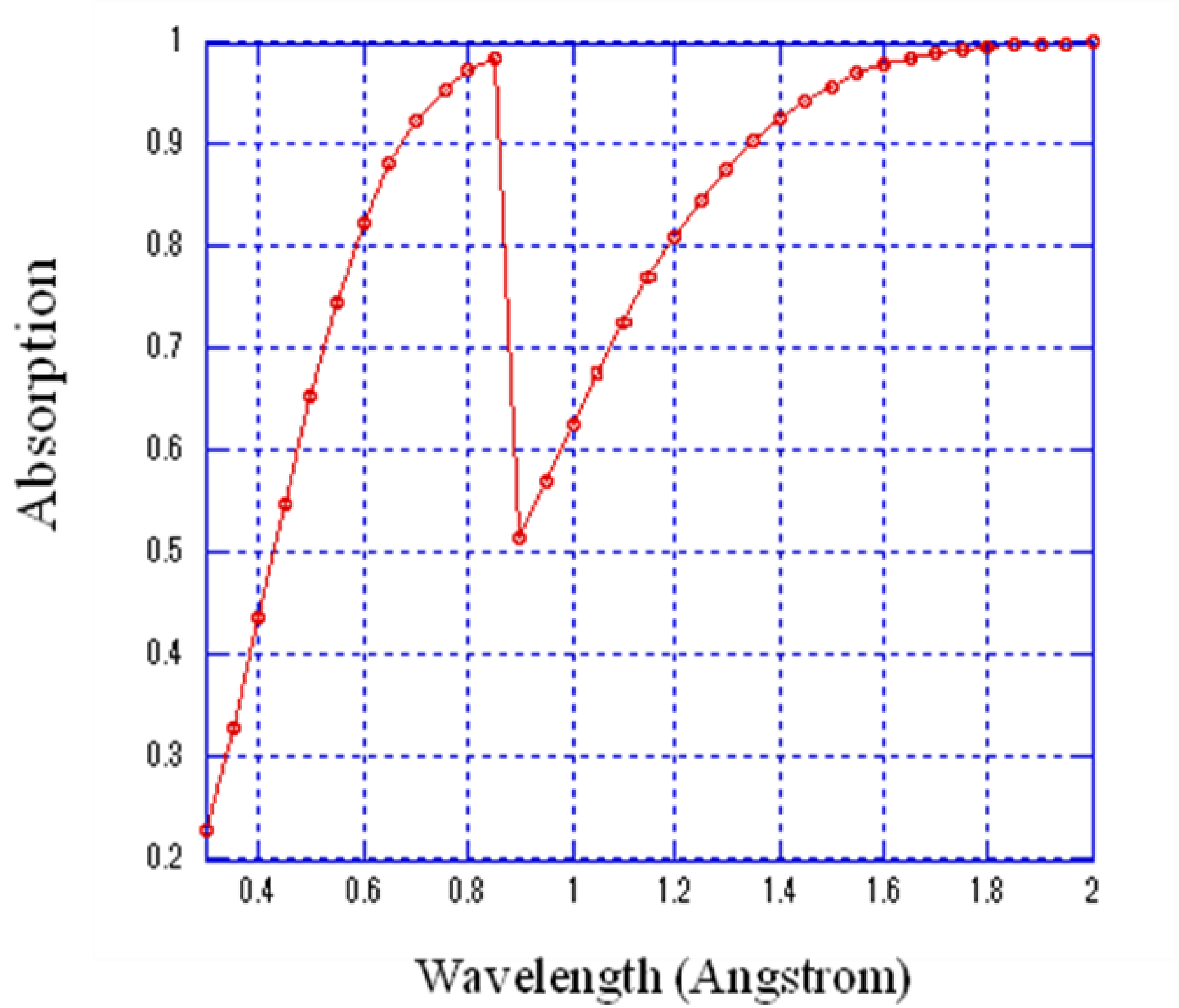


**Expected interferogram for γ=0.65 (beam size of 5μm at 100m)**

**Double slit α=8μm, D=300μm f=100m**

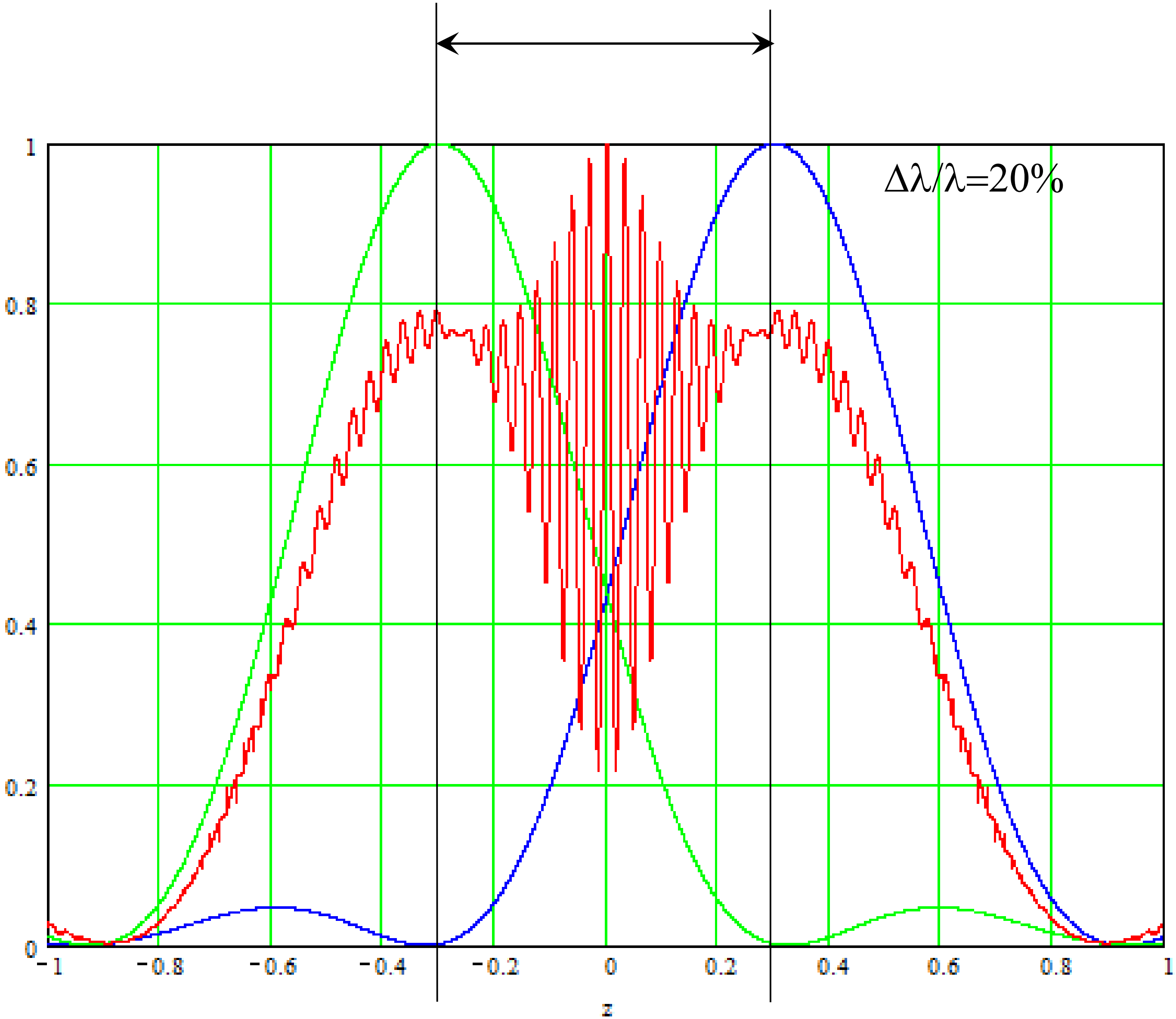


**Absorption of Krypton gas K-edge filter (1 atm, 100 mm pass).**

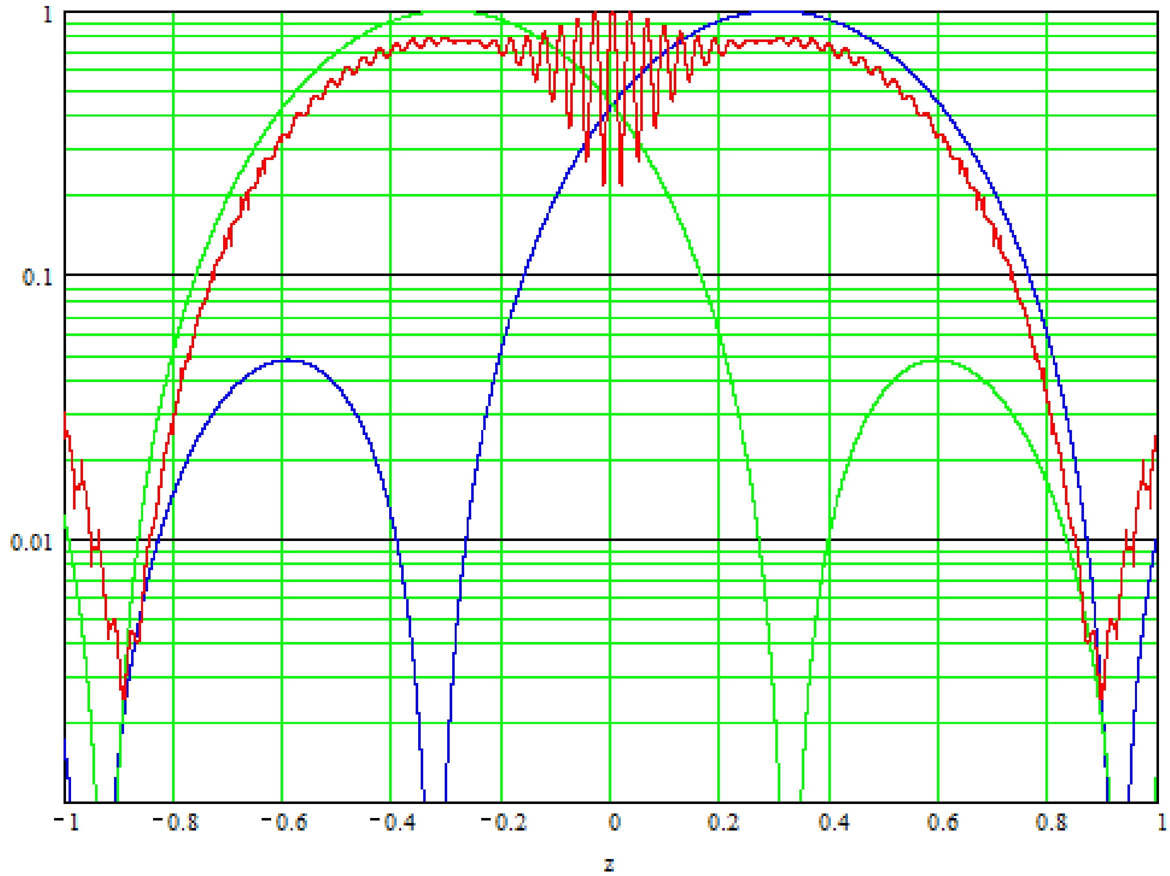



**Krypton gas filter has a nice window around 10keV**

# Shift in two optical axis



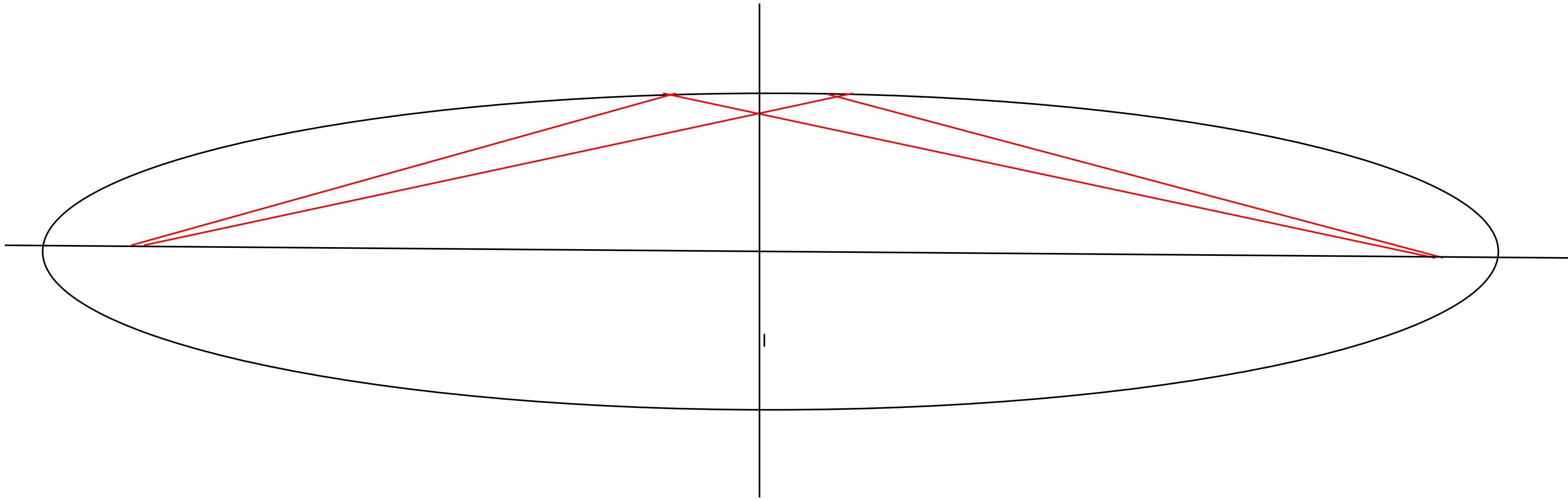
# Background subtraction problem



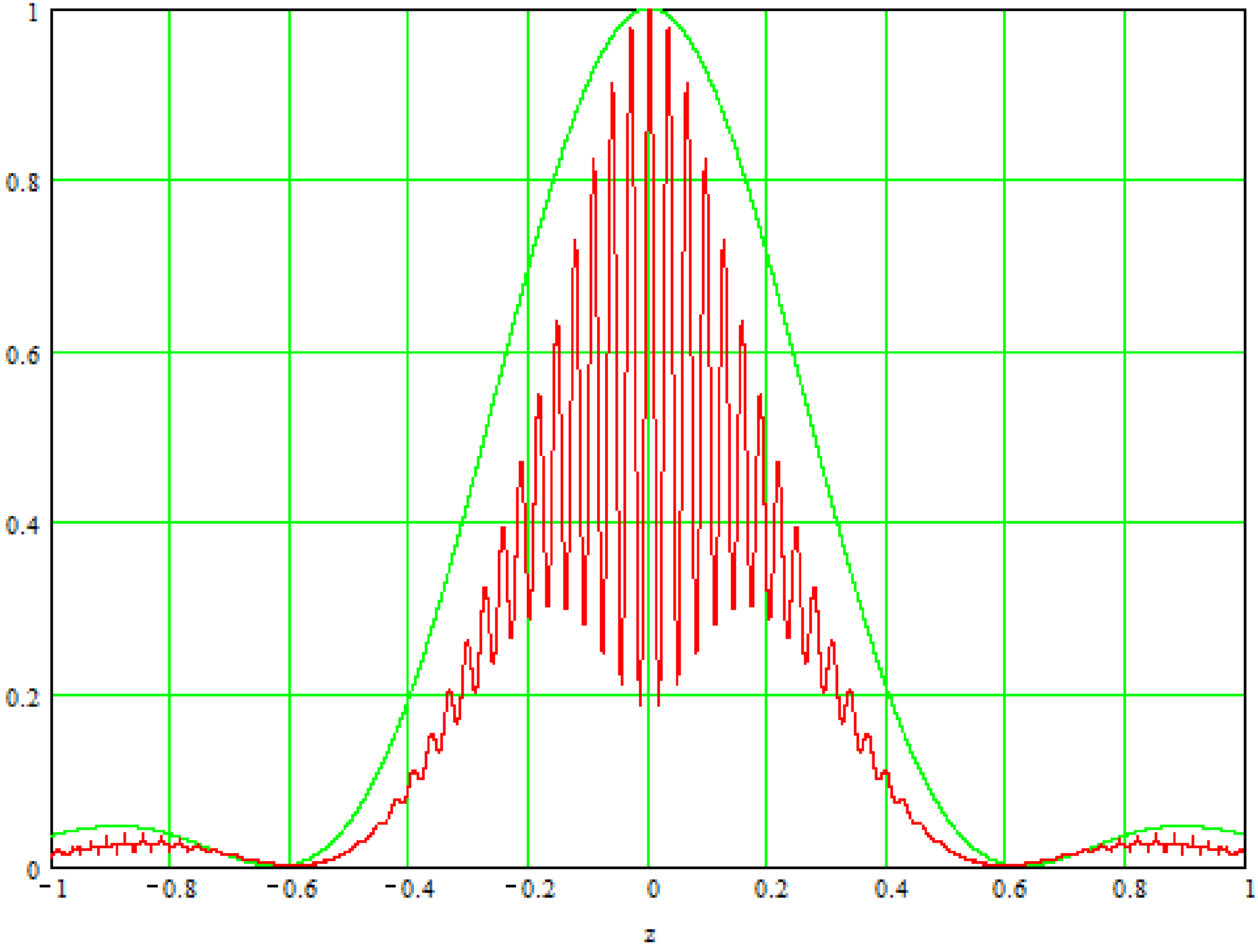

**Log scale plot for the interference fringe with two diffraction envelopes of slit**

# Escape from the shift in two optical axis

## Elliptically deformed total reflection mirror



# Interferogram by elliptically deformed total reflection mirror



# Possibility for bunch by bunch beam size observation

## Rough estimation from experience for interferometry using visible light in the ATF

**ATF has 1nc in the single bunch.**

**Our experience in before, light intensity of 50 bunch is necessary for beam size measurement.**

**Still many parameters are not precise to make reliable estimation, but roughly speaking about 1-2 order more intensity will necessary for bunch by bunch beam size observation.**

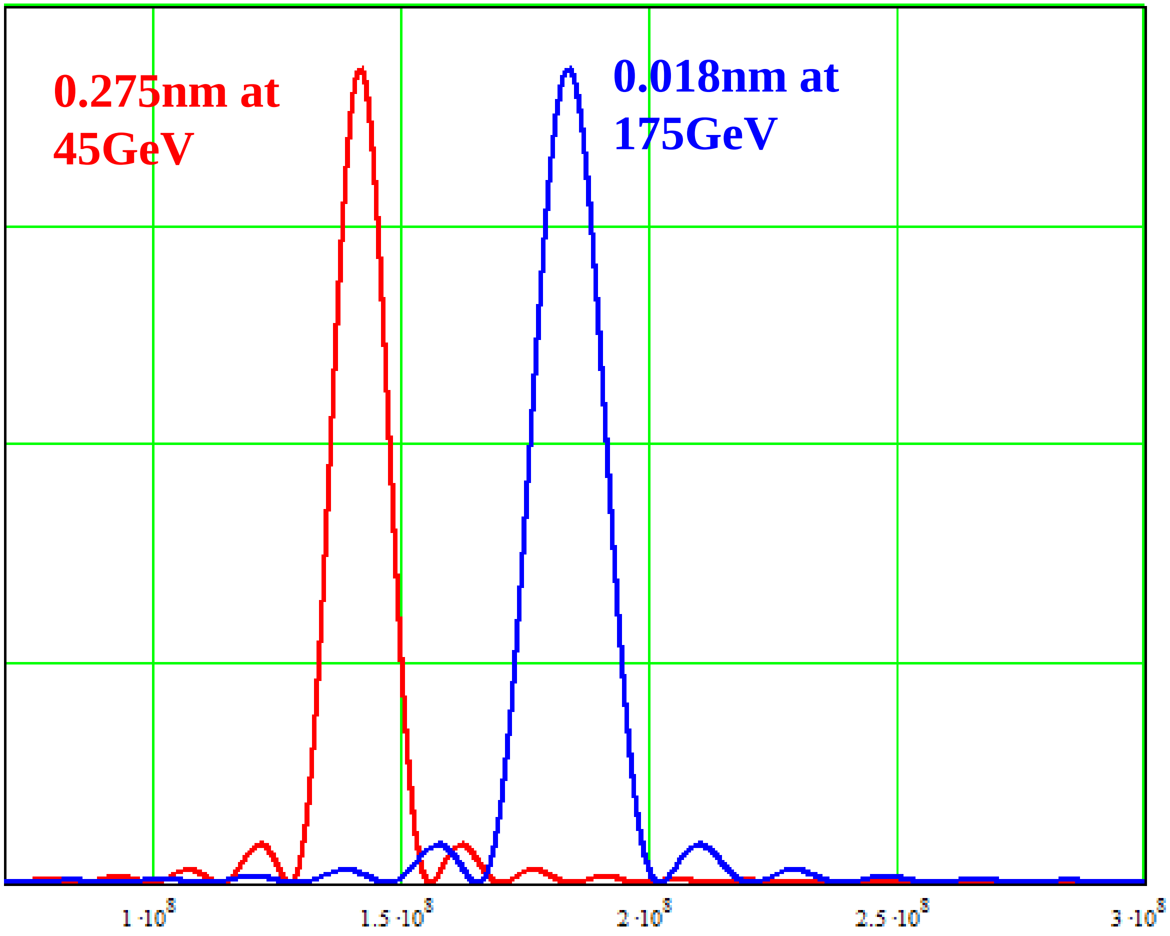
**Wide aperture optics (so-called coded aperture is using in the super B factory in the KEK)**

**Increase flux density of the SR by inserting some undulator (an assumption)**

## Parameters of Undulator

| | |
|---|---|
| **Magnetic field** | **1T** |
| **period** | **20** |
| **λu** | **100mm** |

Spectrum from Undulator (not including energy spread of the beam



**Problem**

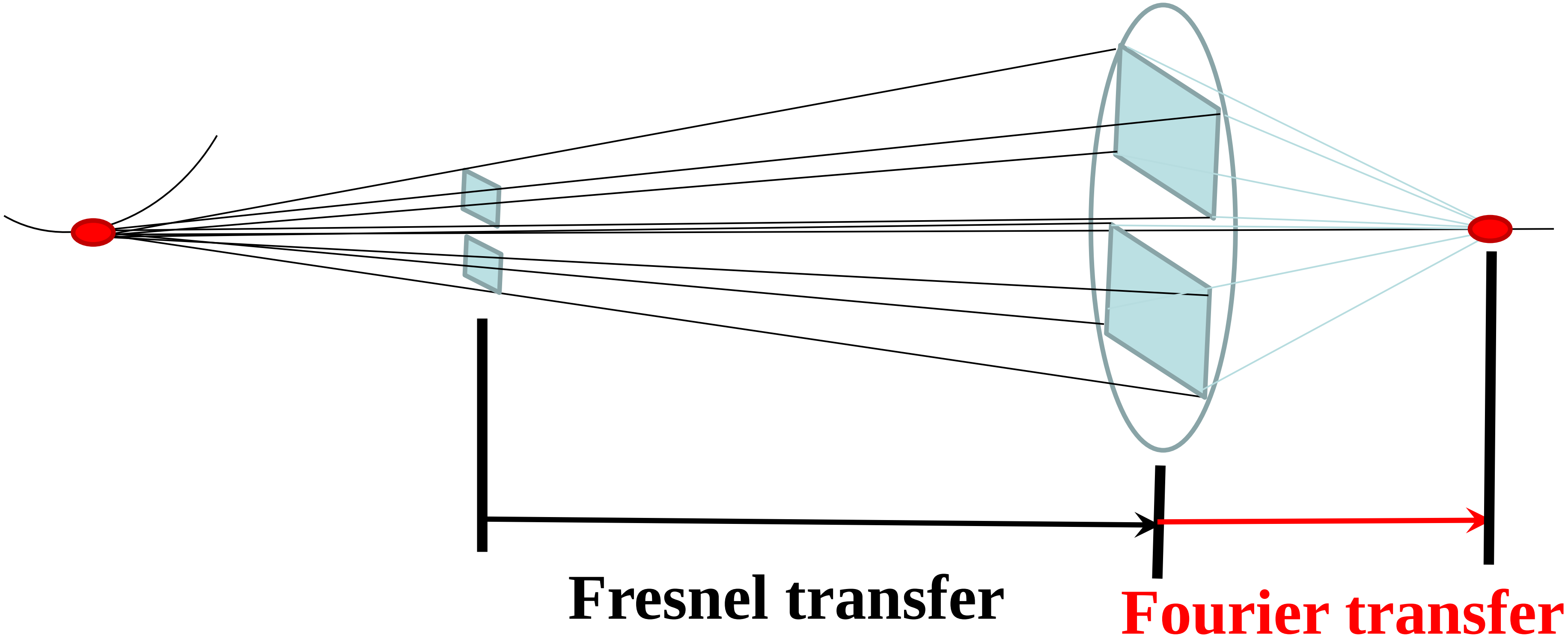
**Simple fixed period undulator cannot cover the energy range from 45GeV to 175GeV.**

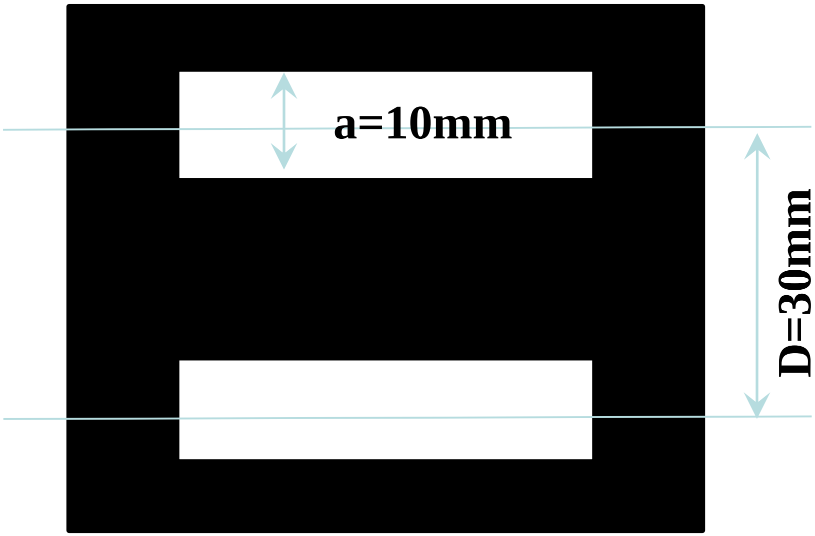
**Questions**

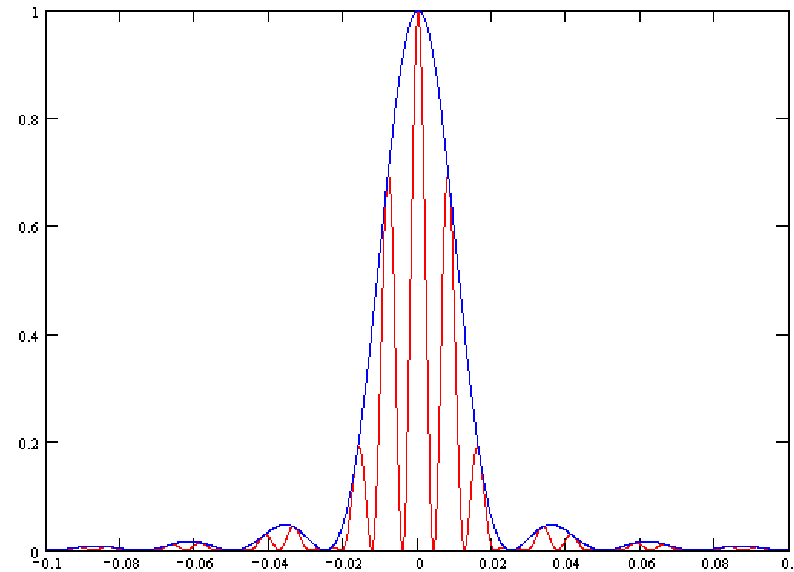
**Double slit can accept high flux density?**

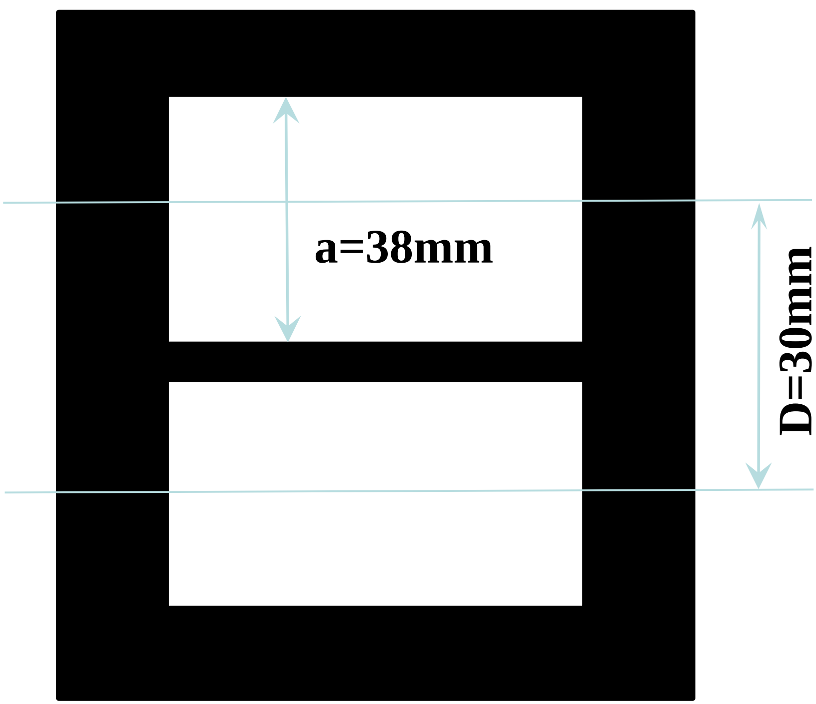
**Is there any space for undulator(3-4m)?**

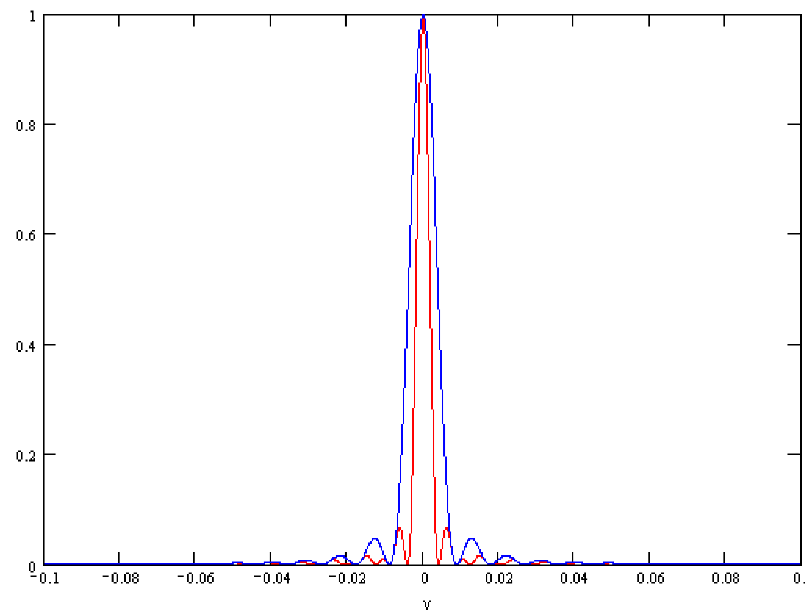
# Wide aperture interferometer


Fresnel transfer
Fourier transfer

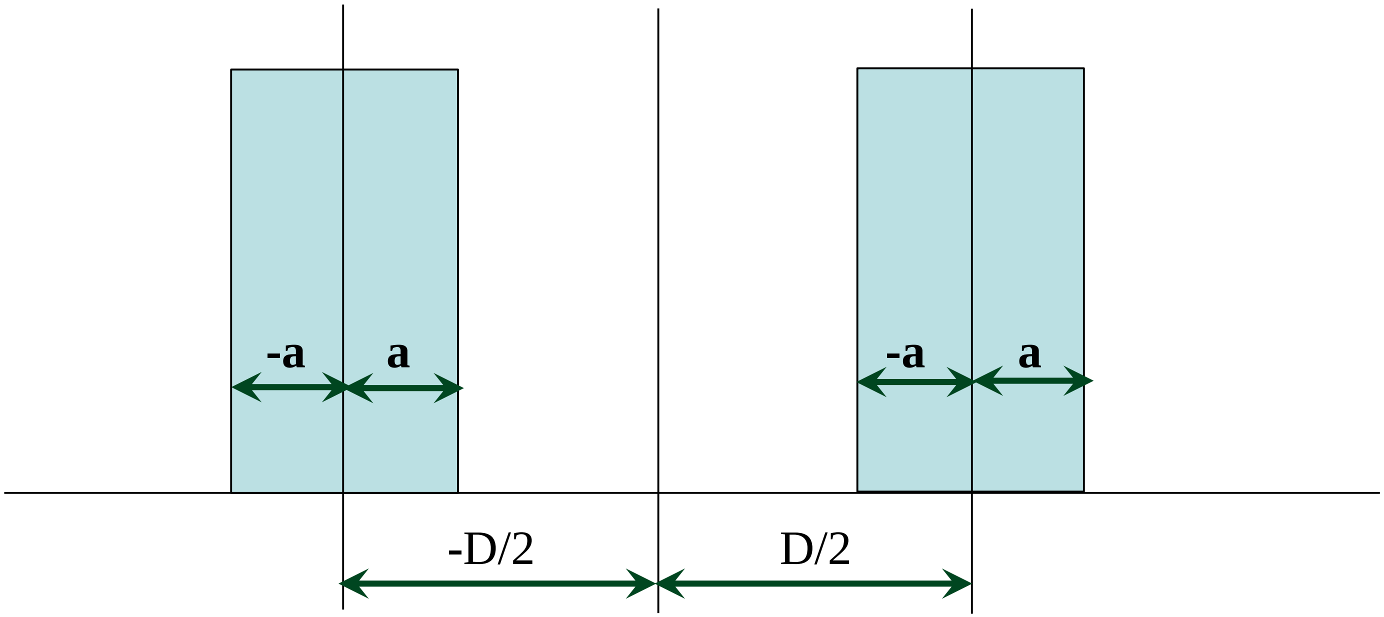

a=10mm
D=30mm


1
0.8
0.6
0.4
0.2
0
−0.1
−0.08
−0.06
−0.04
−0.02
0
0.02
0.04
0.06
0.08
0.1


a=38mm
D=30mm


1
0.8
0.6
0.4
0.2
0
−0.1
−0.08
−0.06
−0.04
−0.02
0
0.02
0.04
0.06
0.08
0.1
v

# Diffraction treatment for interferometer




$$E_1(y) = u\left(2a, -\frac{D}{2}\right) \qquad E_2(y) = u\left(2a, +\frac{D}{2}\right)$$

$$E(y) = E_1(y) + E_2(y)$$

$$= u\left(2a, -\frac{D}{2}\right) + u\left(2a, +\frac{D}{2}\right)$$

**Diffraction by this aperture is given by Fourier transfer of *E***

$$f(\omega) = \mathcal{F}(E)$$

$$= \frac{1}{2}\left(e^{i\frac{D}{2}\pi\omega} + e^{-i\frac{D}{2}\pi\omega}\right)\sin c\left(\frac{\omega}{2a}\right)$$

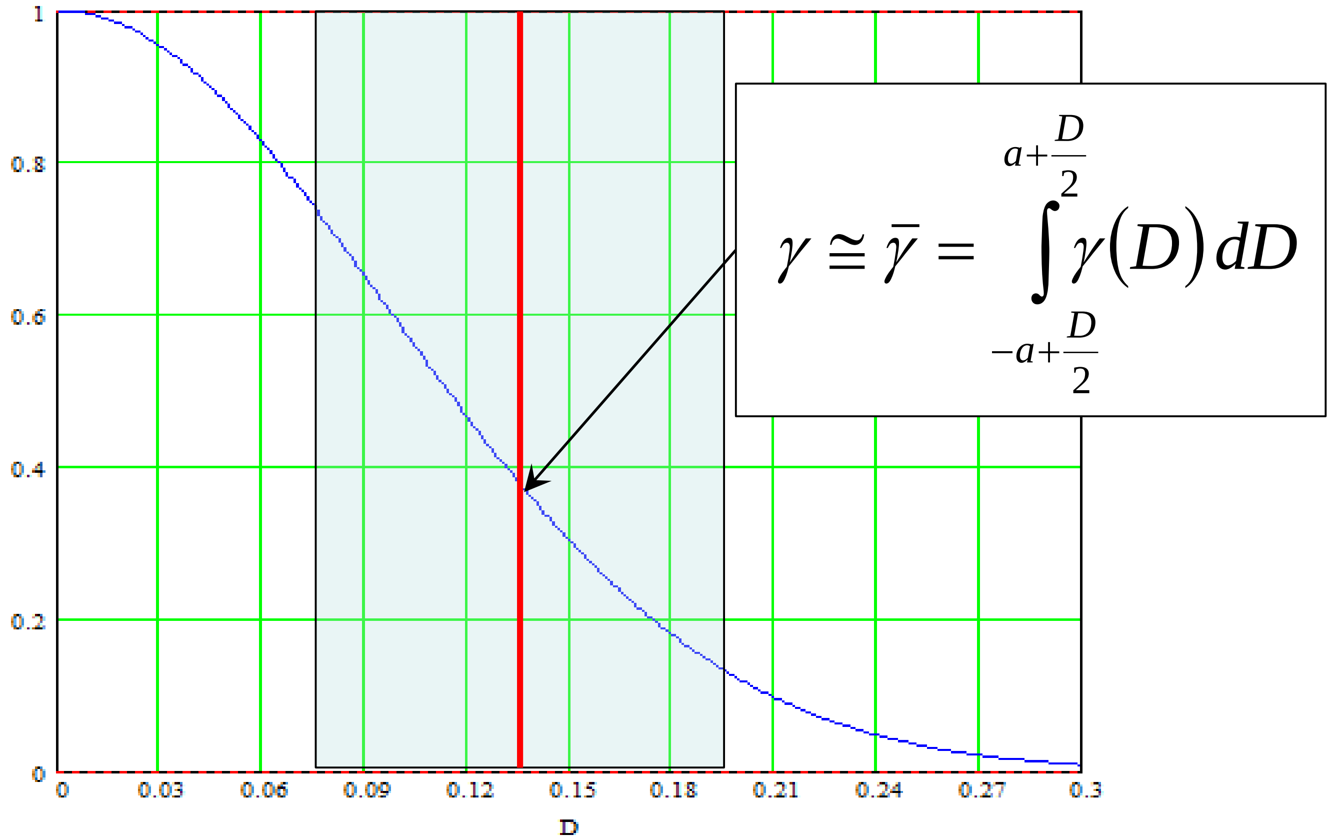
$$= \cos\left(\frac{D}{2}\pi\omega\right)\sin c\left(\frac{\omega}{2a}\right)$$

**Then the intensity is given by square of *E***

$$I(\omega) = \cos^2\left(\frac{D}{2}\pi\omega\right)\sin c^2\left(\frac{\omega}{2a}\right)$$

$$= \frac{1}{2}\left(1+\cos(D\pi\omega)\right)\sin c^2\left(\frac{\omega}{2a}\right)$$

**This treatment is assuming the spatial coherence will be 1. When the spatial coherence is not equal to 1 as**



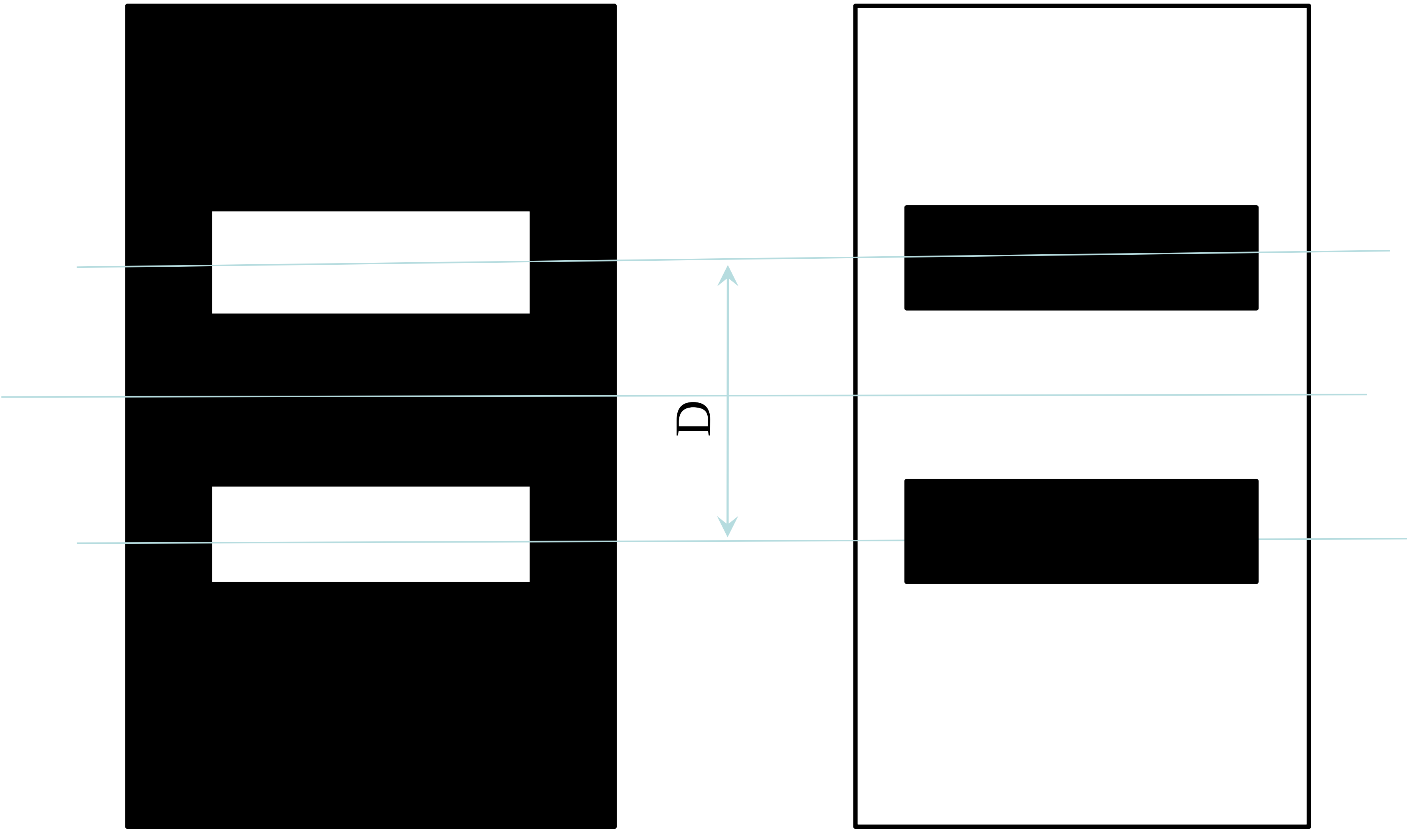

$$\gamma \cong \bar{\gamma} = \int_{-a+\frac{D}{2}}^{a+\frac{D}{2}} \gamma(D)\, dD$$

This large aperture interferometer can use  under following condition.

$$\gamma \cong \bar{\gamma} = \int_{-a+\frac{D}{2}}^{a+\frac{D}{2}} \gamma(D)\, dD$$

Since we can enlarge the slit width 10-50 times more, this method is very useful for increase the intensity.

# Inverse-contras interferometer



**Using Babinet's principle, Synthesize of two mask is given by,**

$$u_0(Q) = u_{ob}(Q) + u_{ap}(Q)$$

**Then obstacle mask is given by**

$$u_{ob}(Q) = u_0(Q) - u_{ap}(Q)$$

**Double slit mask is given by,**

$$u_{ap}(Q) = u_{ap1}(Q) + u_{ap2}(Q)$$

**Then double obstacle mask is given by**

$$u_{ob}(Q) = u_0(Q) - \left(u_{ap1}(Q) + u_{ap2}(Q)\right)$$

The intensity is given by square of $u$,

$$I_{ob}(Q) = \left[u_0(Q) - \left(u_{ap1}(Q) + u_{ap2}(Q)\right)\right]^2$$

$$= u^2{}_0(Q) - 2u_0(Q)\left(u_{ap1}(Q) + u_{ap2}(Q)\right)$$

$$+ \left(u_{ap1}(Q) + u_{ap2}(Q)\right)^2$$

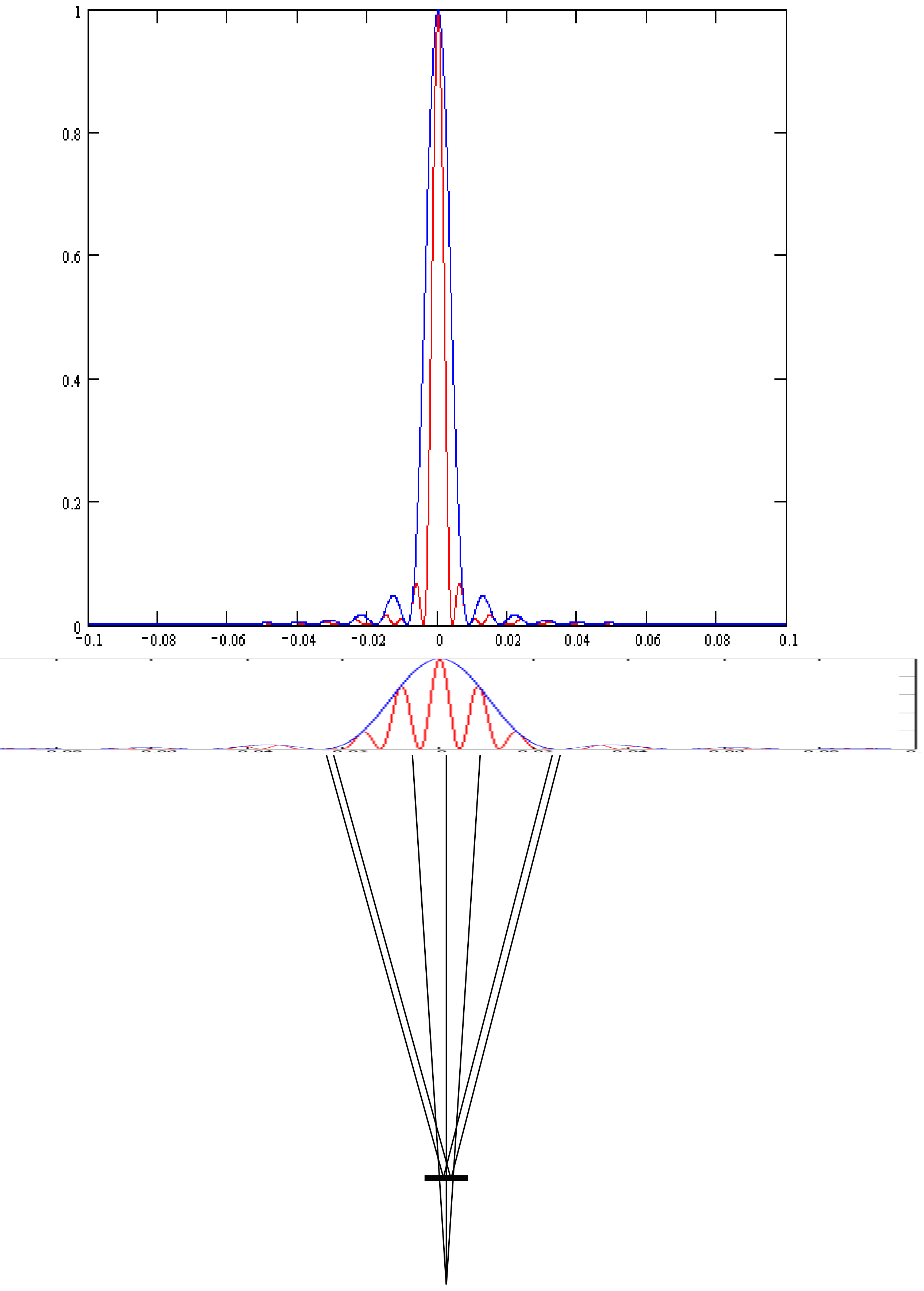
$$= I_0 - 2u_0 u_{ap1} - 2u_0 u_{ap2}$$

$$+ I_{ap1} + I_{ap2} + 2u_{ap1}u_{ap2}$$

$I_0$ is intensity of aperture having no double obstacle, $I_{ap1}$, $I_{ap2}$ are intensities double slit corresponding to double obstacle

$u_0 u_{ap1}$, $u_0 u_{ap2}$ are interference between disturbance of aperture having no obstacle and double slit corresponding to double obstacle. $u_{ap1} u_{ap2}$ is interference between double slit corresponding to double obstacle.

Observing the intensity in infinite distance (very far away), the first 3 terms are localized in center (width of order of full aperture diffraction) , and last 3terms gives same intensity distribution ob double slite interferometer

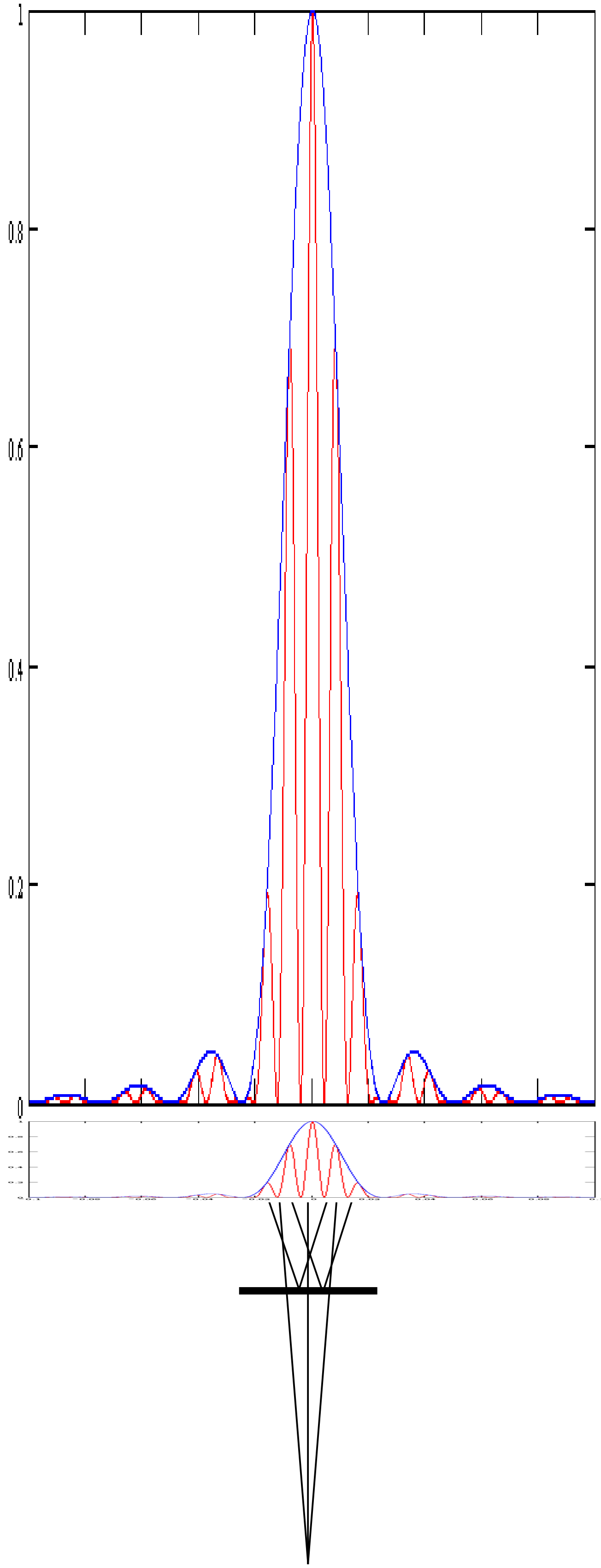


1
0.8
0.6
0.4
0.2
0
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1

When we observe the intensity distribution at diffraction width of single slit is almost same as opening of $I_0$ , $u_0 u_{ap1}$, $u_0 u_{ap2}$ those are interference between disturbance of aperture having no obstacle and double slit corresponding to double obstacle will appear, and it's intensity is enhanced by $u_0$.

This can contribute intensity increase in observation.

***But we need check experimentally.***


1
0.8
0.6
0.4
0.2
0

# Proposal for test of X-ray interferometer

# at

# Long range beam line

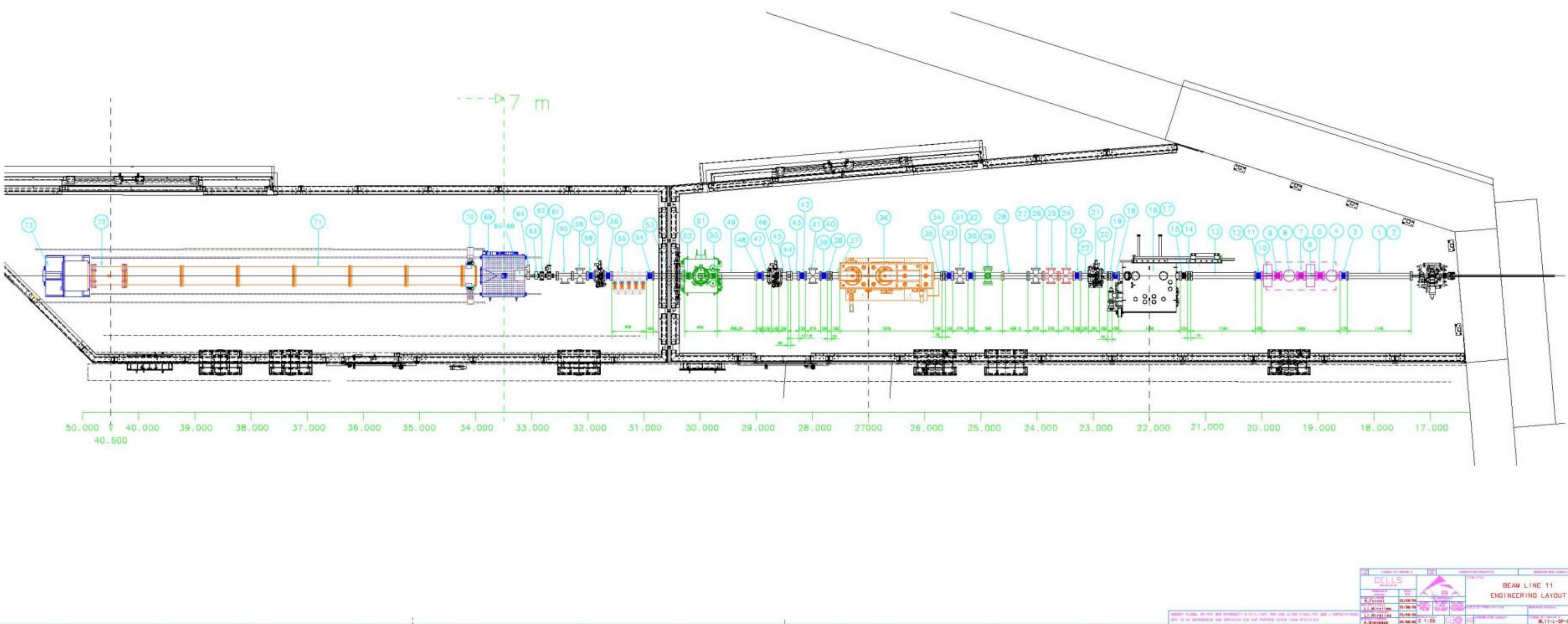
# ALBA

T. Mitsuhashi and Ubaldo Irizo

# Source point to double slit 33.5m

# 10m will available for interferometer

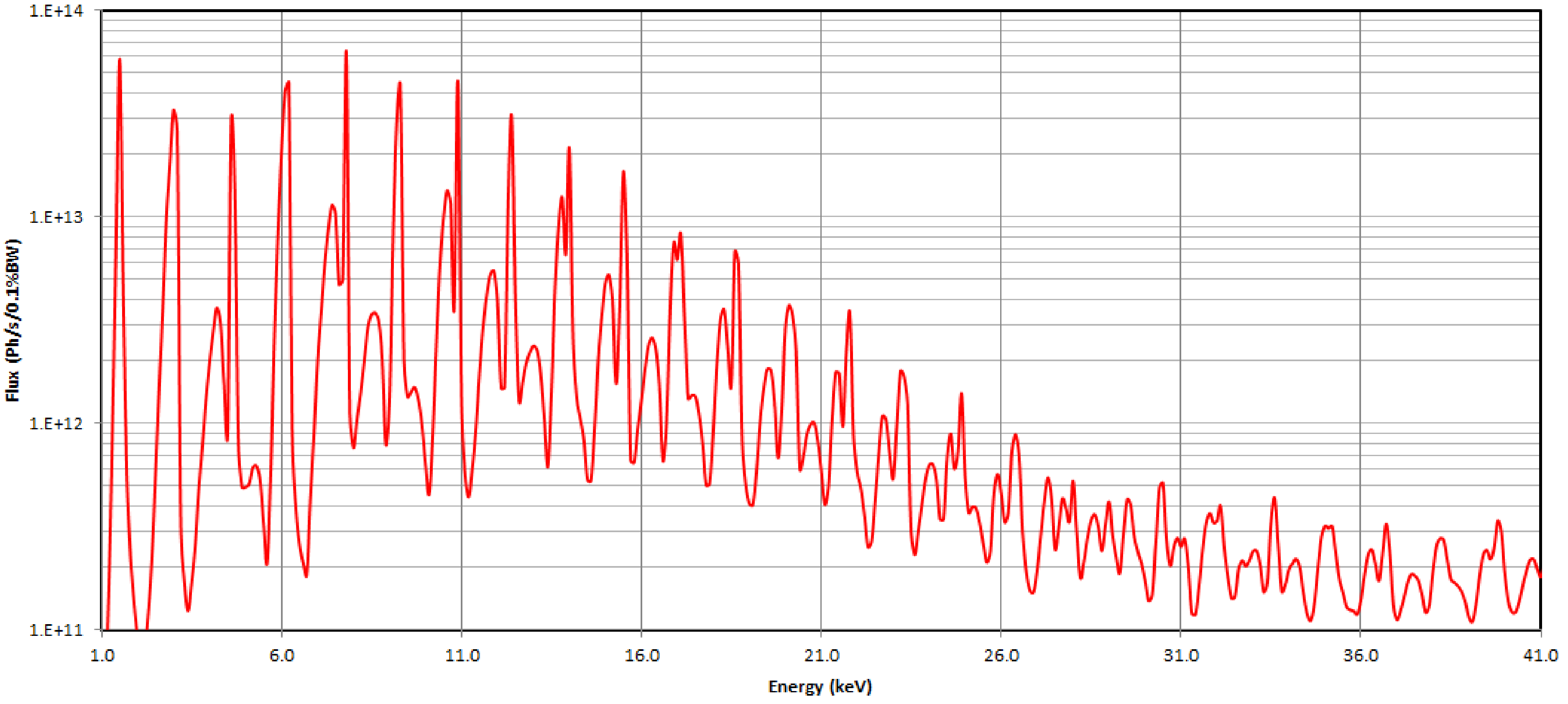
| | | |
|---|---|---|
| 1 | Beam Pipe | 1/11 |
| 2 | Vacuum Control Station | 1/1 |
| 3 | Bellow | 1/17 |
| 4 | Pumping Station | 1/2 |
| 5 | Bellow | 2/17 |
| 6 | Fixed Mask 1 | 1/2 |
| 7 | Bellow | 3/17 |
| 8 | Pumping Station | 2/2 |
| 9 | Bellow | 4/17 |
| 10 | Fixed Mask 2 | 2/2 |
| 11 | Bellow | 5/17 |
| 12 | Ion Pump | 1/4 |
| 13 | Beam Pipe | 2/11 |
| 14 | VAT Valve Series 010 UHV | 1/5 |
| 15 | Bellow | 6/17 |
| 16 | Monochromator | 1/1 |
| 17 | Turbomolecular Pump | 1/1 |
| 18 | Bellow | 7/17 |
| 19 | VAT Valve Series 010 UHV | 2/5 |
| 20 | Beam Pipe | 3/11 |
| 21 | JJXRay Slits | 1/3 |
| 22 | Beam Pipe | 4/11 |
| 23 | Bellow | 8/17 |
| 24 | Attenuator 1 | 1/2 |
| 25 | Attenuator 2 | 2/2 |
| 26 | Ceramic – Fluorescent Screen | 1/2 |
| 27 | Ion Pump | 2/4 |
| 28 | Beam Pipe | 5/11 |
| 29 | Quad Diode Diagnostic | 1/1 |
| 30 | Bellow | 9/17 |
| 31 | Diafragm – Strangulation Unit | 1/2 |
| 32 | Ion Pump | 3/4 |
| 33 | Bellow | 10/17 |
| 34 | VAT Valve Series 010 | 3/5 |
| 35 | Beam Pipe | 6/11 |
| 36 | Mirror | 1/1 |
| 37 | Beam Pipe | 7/11 |
| 38 | VAT Valve Series 010 | 4/5 |
| 39 | Bellow | 11/17 |
| 40 | Ion Pump | 4/4 |
| 41 | Diafragm – Strangulation Unit | 2/2 |
| 42 | Bellow | 12/17 |
| 43 | Beam Pipe | 8/11 |
| 44 | Fast Closing Valve | 1/1 |
| 45 | Beam Pipe | 9/11 |
| 46 | JJXRay Slits | 2/3 |
| 47 | Beam Pipe | 10/11 |
| 48 | Bellow | 13/17 |
| 49 | Beam Pipe | 10/11 |
| 50 | Bellow | 14/17 |
| 51 | Photon Shutter | 1/1 |
| 52 | Bellow | 15/17 |
| 53 | Beam Pipe | 11/11 |
| 54 | Bellow | 16/17 |
| 55 | Delay Line | 1/1 |
| 56 | Bellow | 17/18 |
| 57 | High Stability Slits – JJXRay | 3/3 |
| 58 | Bellows | 18/18 |
| 59 | Fluorescent Screen | 5/5 |
| 60 | Ion pump | 1/1 |
| 61 | Vacuum Control Station | 2/3 |
| 62 | Trigger Unit | 1/1 |
| 63 | VAT valve Series 01 | 1/1 |
| 64 | Vacuum Control Station | 3/3 |
| 65 | 2 x Fast XRay Shutters | 2/2 |
| 66 | Gord Slits | 1/1 |
| 67 | Mica Windows | 1/1 |
| 68 | Ion Chamber | 1/1 |
| 69 | Sample Table | 1/1 |
| 70 | Nose Cone | 1/1 |
| 71 | Camera Tube | 1/1 |
| 72 | Mylar Window | 1/1 |
| 73 | 2D Detector Table | 1/1 |



# Light source: In vacuum Undurator

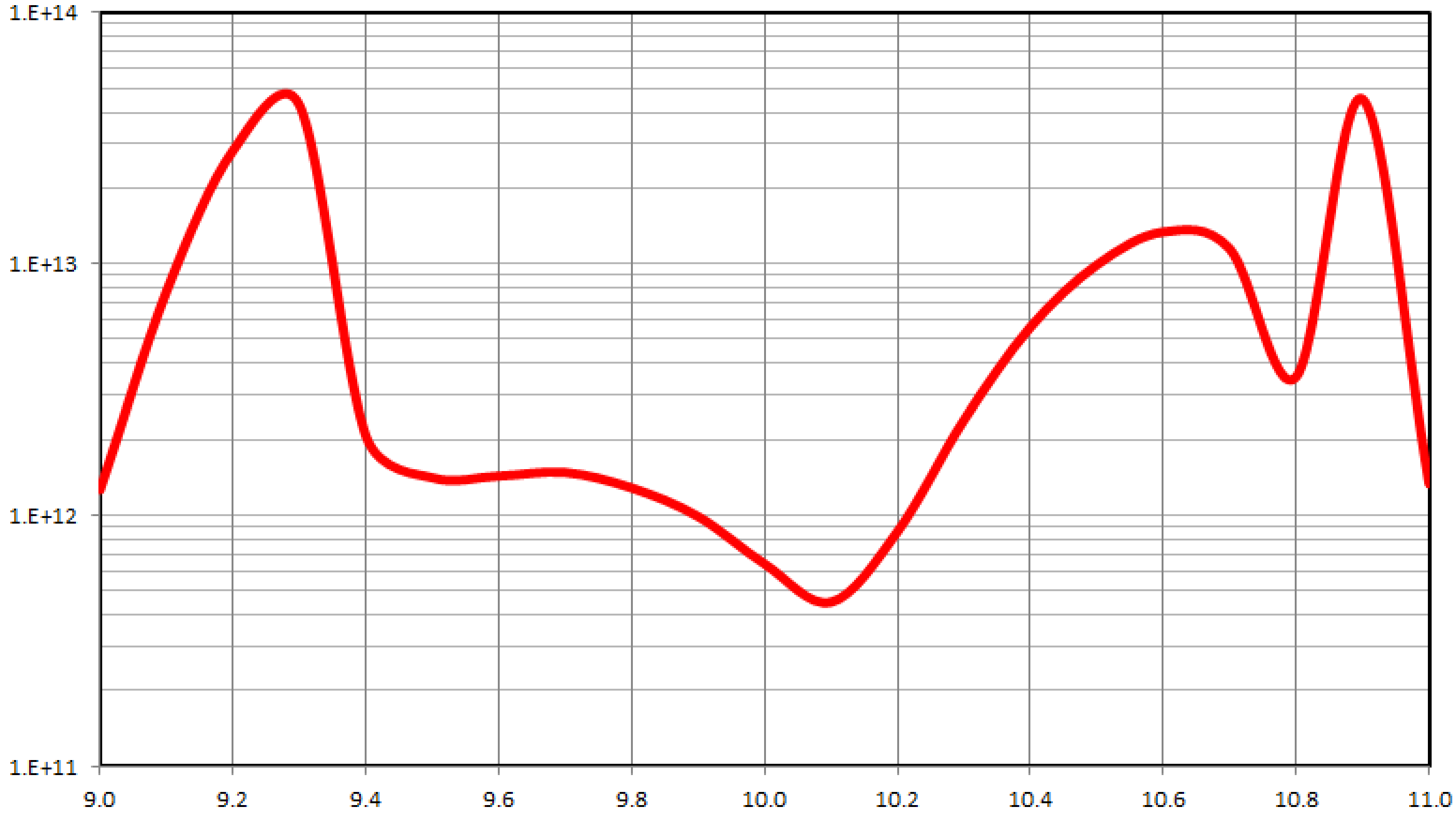
| | |
|---|---|
| Material | $Sm_5Co_{17}$ Pure Permanent Magnet |
| Period | 21.3 mm |
| Number of periods | 92 |
| K at minimum gap | 1.6 |
| source size (FWHM) | 309 x 18 $\mu m^2$ (HxV) |
| source divergence (FWHM) | 112 x 28-22 $\mu rad^2$ (HxV) |

# Spectrum of undulator radiation

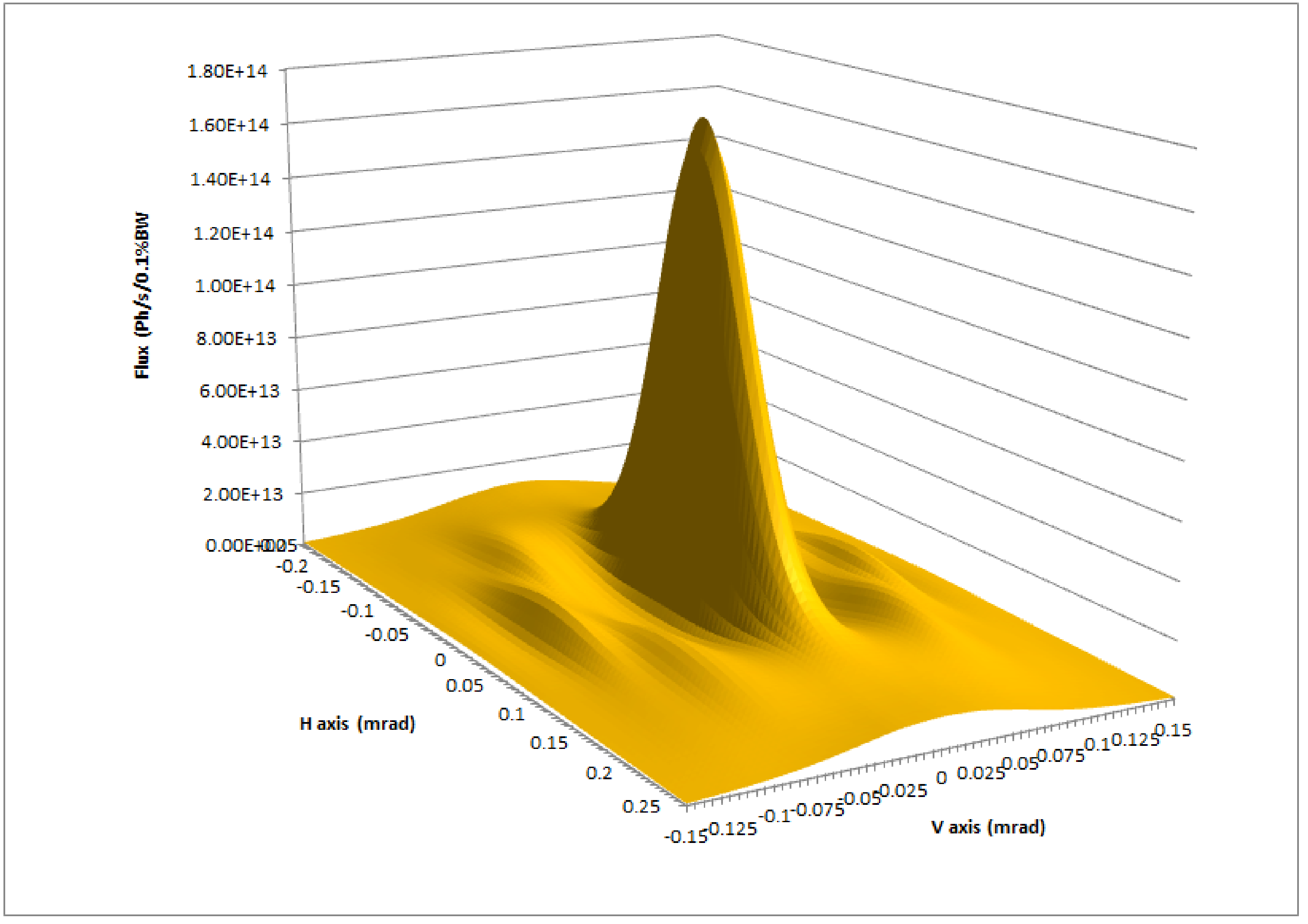


# $7^{th}$ harmonics

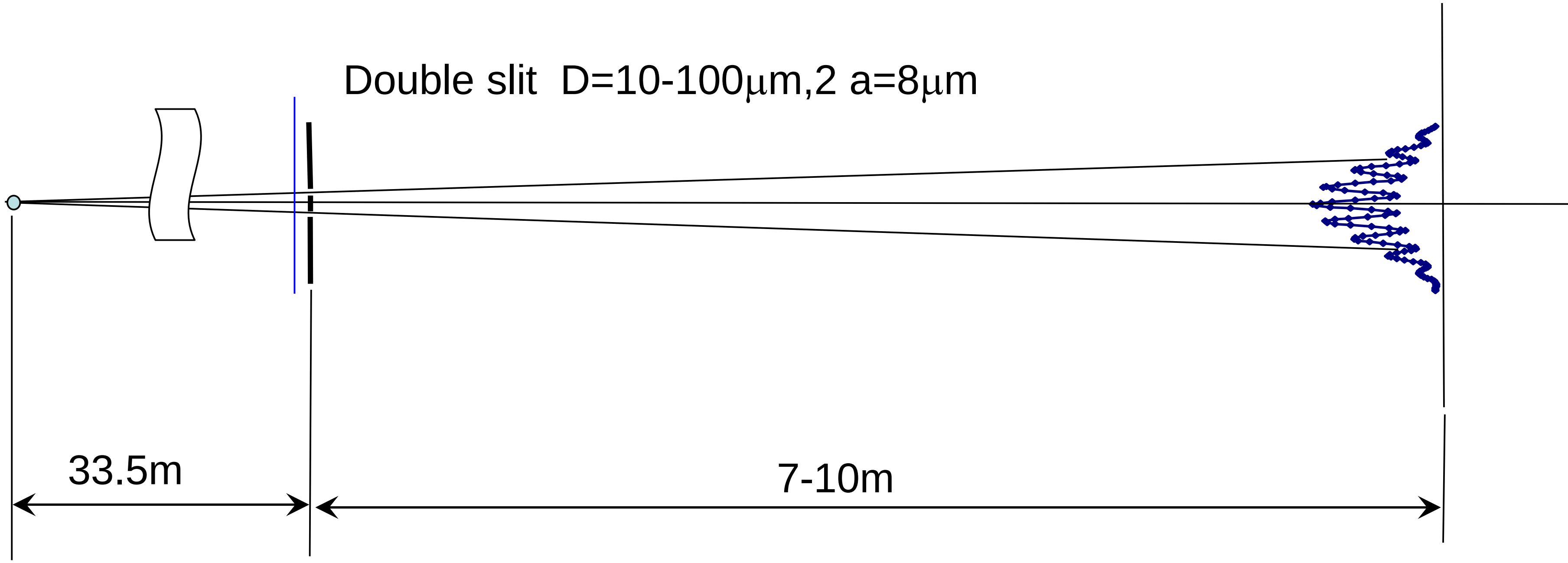
# at 11.06KeV



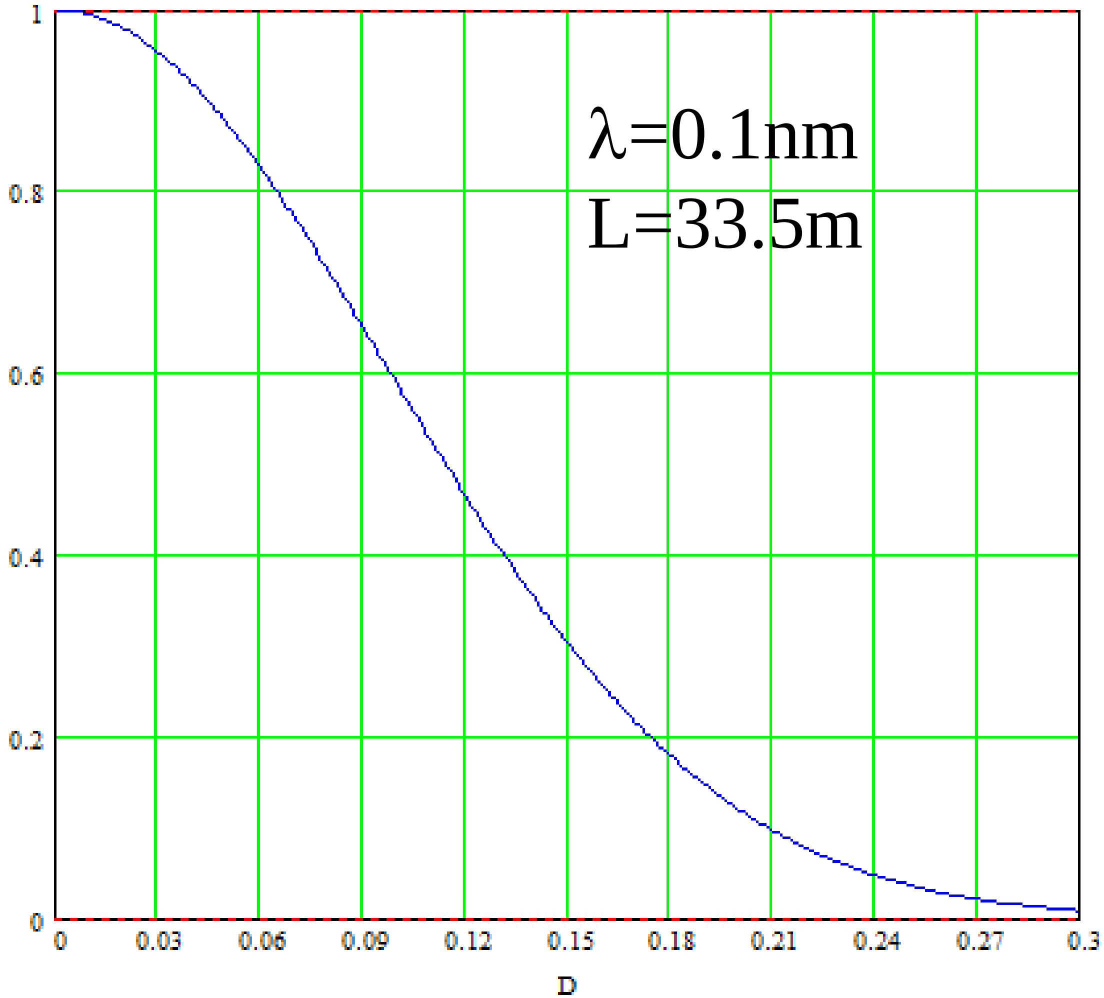
# Angular distribution of 7th harmonics



# Simple double slit X-ray interferometer (Young type)



# Spatial coherence of X-ray with beam size of 5.5μm



# Diffraction from single opening of the interferometer

**Intensity of diffraction is given by Fresnel transform of pupil function F of the single opening of the double slit.**

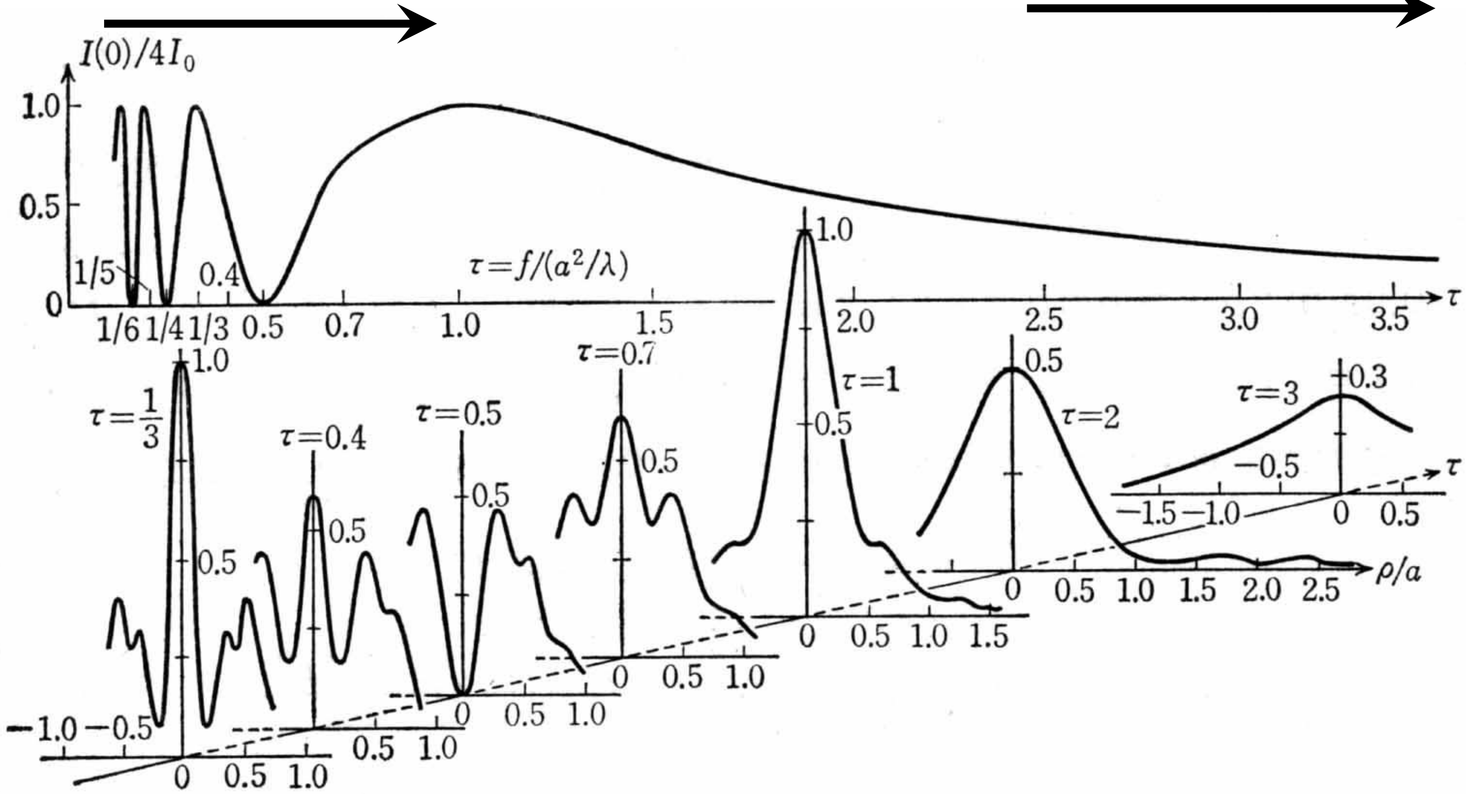
$$I(x, y) = \left| \iint F(x_0, y_0) \exp\left\{ \frac{ik}{2z} \left[ (x_0 - x)^2 + (y_0 - y)^2 \right] \right\} d\xi d\eta \right|^2$$

$\tau = f/(a^2/\lambda) < 1$

**Fresnel like region**

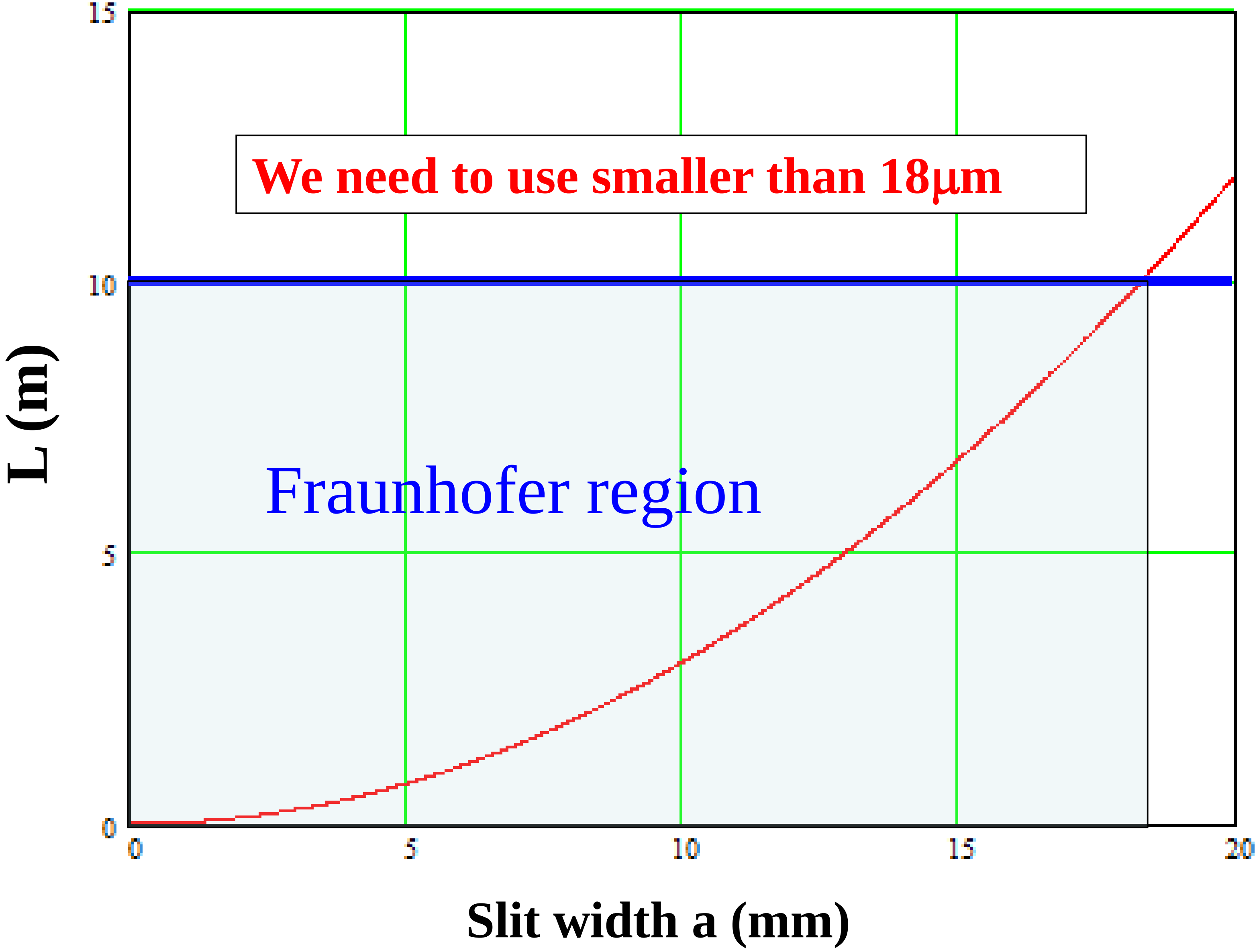
$\tau = f/(a^2/\lambda) > 3$

**Fraunhofer like region**




**In the case of ALBA, $\lambda$=0.1nm, a=8$\mu$m**

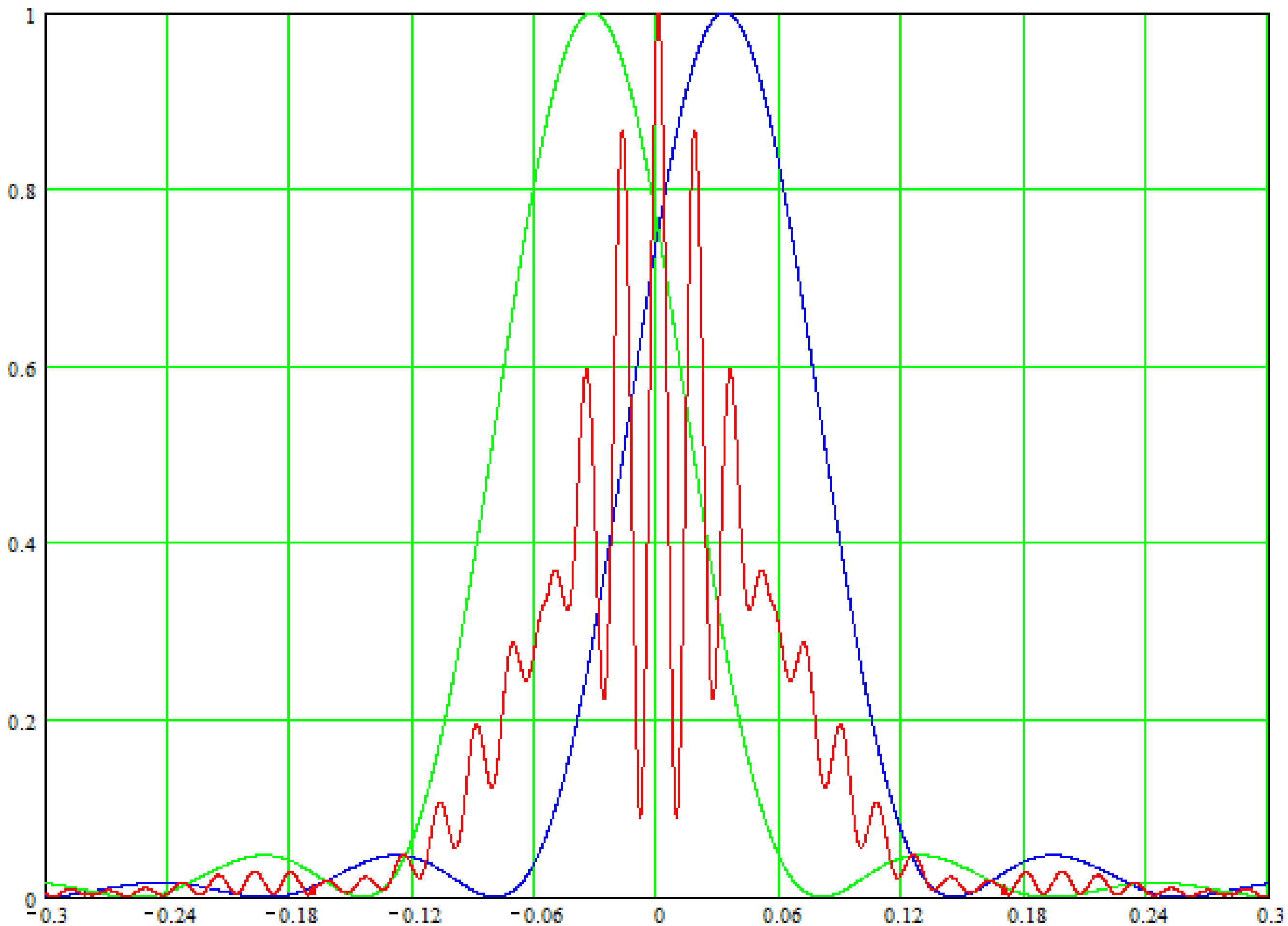
**Fraunhofer region > 1.92m**



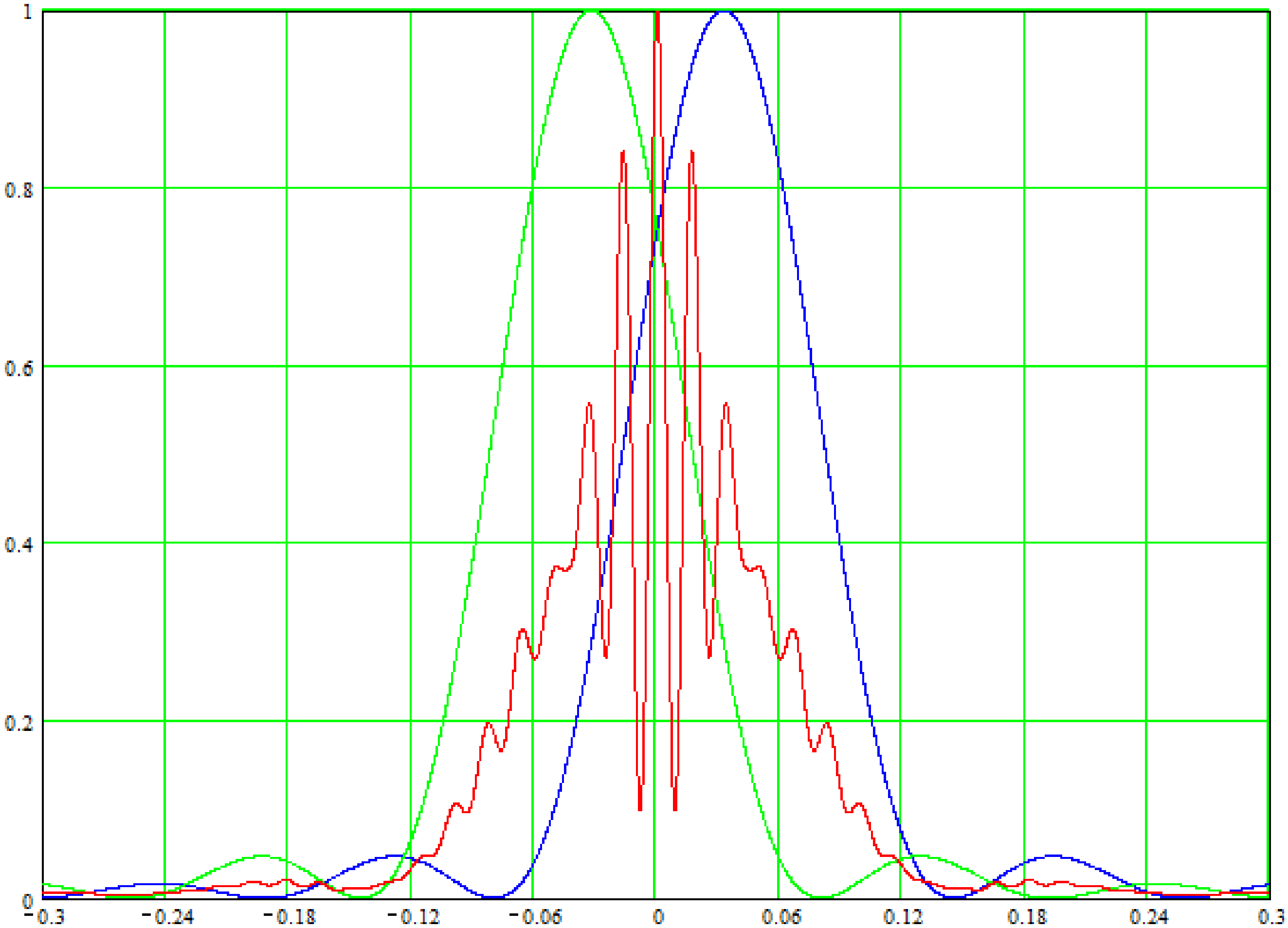
We need to use smaller than 18μm
Fraunhofer region
L (m)
Slit width a (mm)
0
5
10
15
20
0
5
10
15

# Interferogram wide view with monochromatic ray

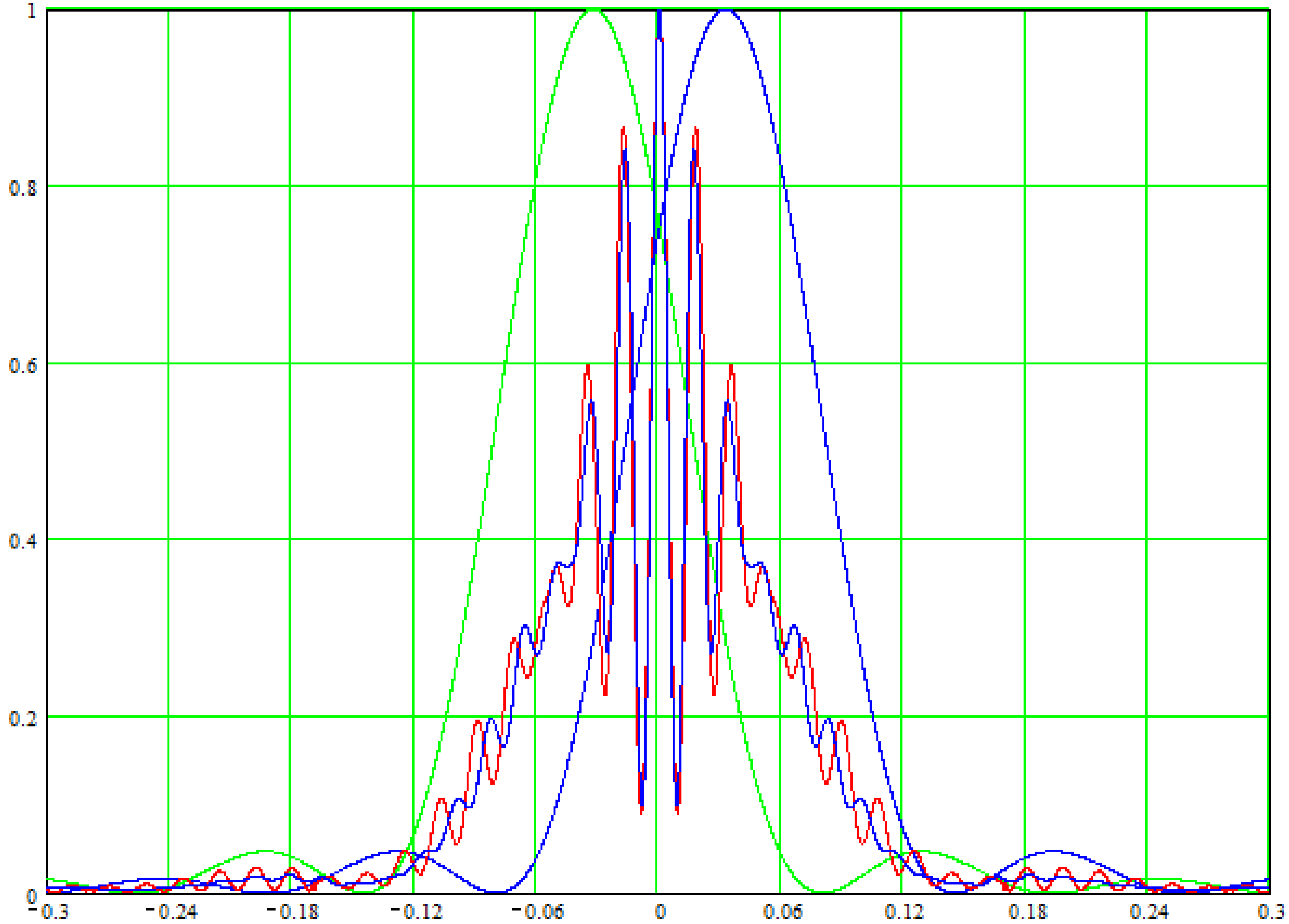
# D=50μm,  λ=0.1nm,  σ=5.5μm



# 20%  K-edge filter at 0.1nm



# In Comparison



**Phase 1**

***Measure single slit pattern in**

***Measure single slit diffraction pattern**

**with slit + ribbon**

***Measure interference fringe with white beam**

***Apply a metal K-edge filter in the beam line**

***Observe floor vibration issue**

***Lattice regulation for obtain small beam size**

## Status

*Double slit

Will be design in ALBA (may be one Doctor student available)

*Guarder for setting the double slit

Using the guarder in beamline

*Positioner stage for double slit

Using positioner stage in beamline in ALBA

***Image sensing**

**Use a YAG screen (ALBA) spatial resolution is about 1μm**

**With  microscope + fast gated II camera (ALBA or KEK)**