Beam size measurement with gratings at BEPCII

Zhang Wan

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Contents

- Background
- Theory
- Setup
- Results
- Potential

Background

Particle Physics **Circular accelerator**

1st Generation
(Accessory product)

2nd Generation
(Insert Application)

3rd Generation
(More and better inserts)

4th Generation
(Breaking diffraction limit)

higher coherence, higher brightness, lower emittance and smaller beam sizes

Background

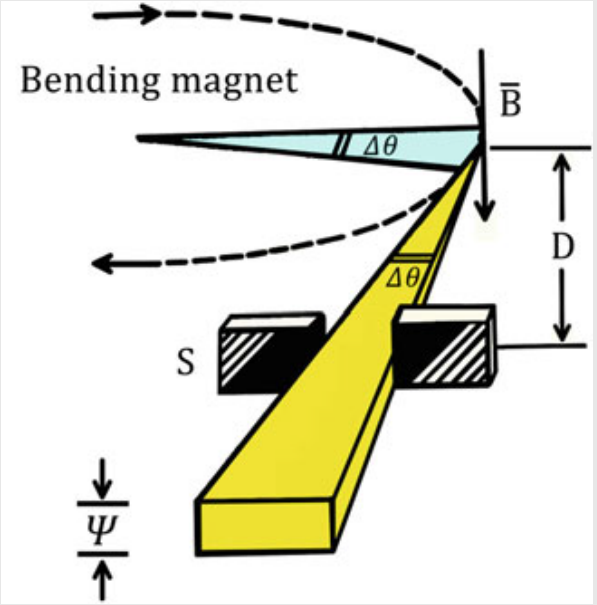
Beam size

Beam emittance

Transverse dynamics of bunches

Light source size of beamline

Beam size measurement

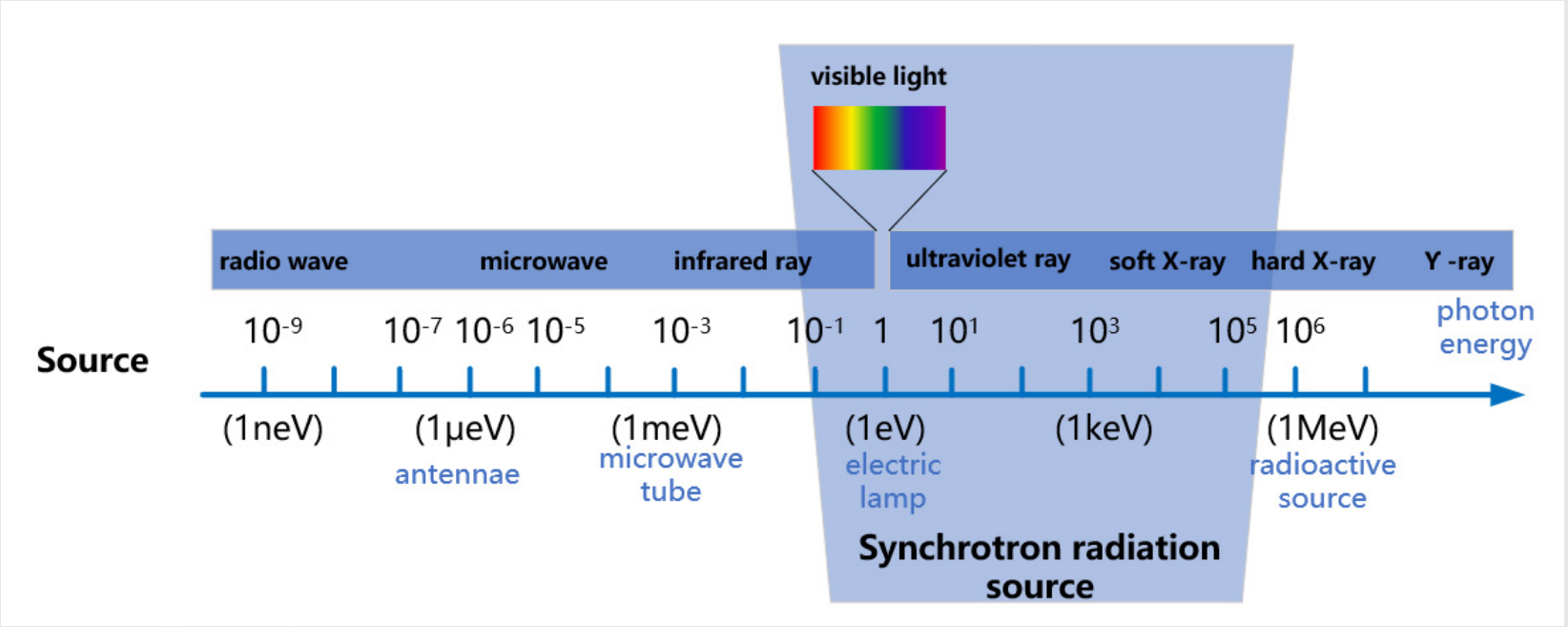


Synchrotron light

(unstoppable, natural photo isolation, the light source size is almost equal to the beam size)

Background

visible light { imaging directly
interference(double-slit interferometer)



short wavelength ← X-ray { pinhole imaging
focused imaging (KB mirror, CRL, FZP)
• • •

high resolution

Background

Method by using X-ray

Methods	X-ray pinhole imaging	X-ray double-slit interferometer	X-ray focused imaging (KB mirror, CRL, FZP)	Grating Talbot effect
optical device	simple	complex	complex	simple
Measuring Direction	Any direction	One direction	Any direction	Any direction
real-time measurement	Yes	Yes	Yes	No
Measurable beam size (μm)	>10μm	about 5μm	about 5μm	<5μm

Background

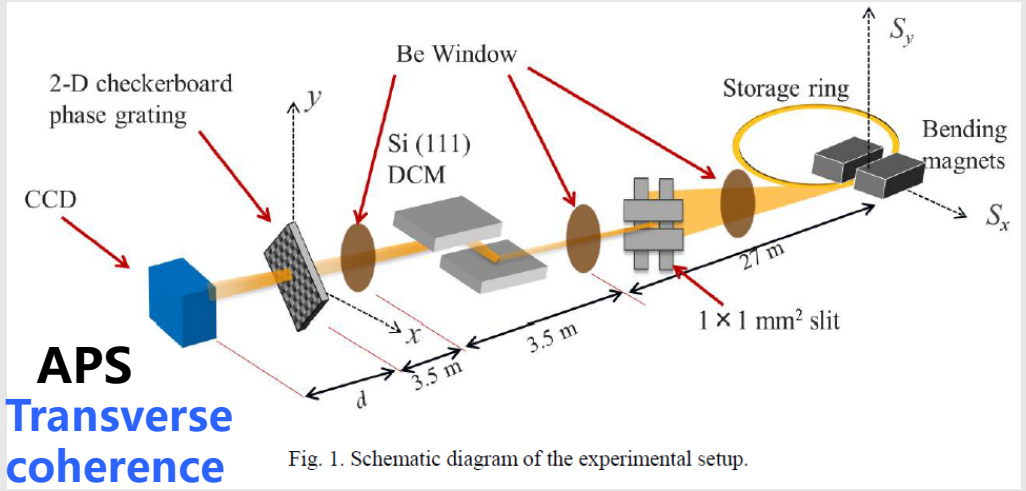
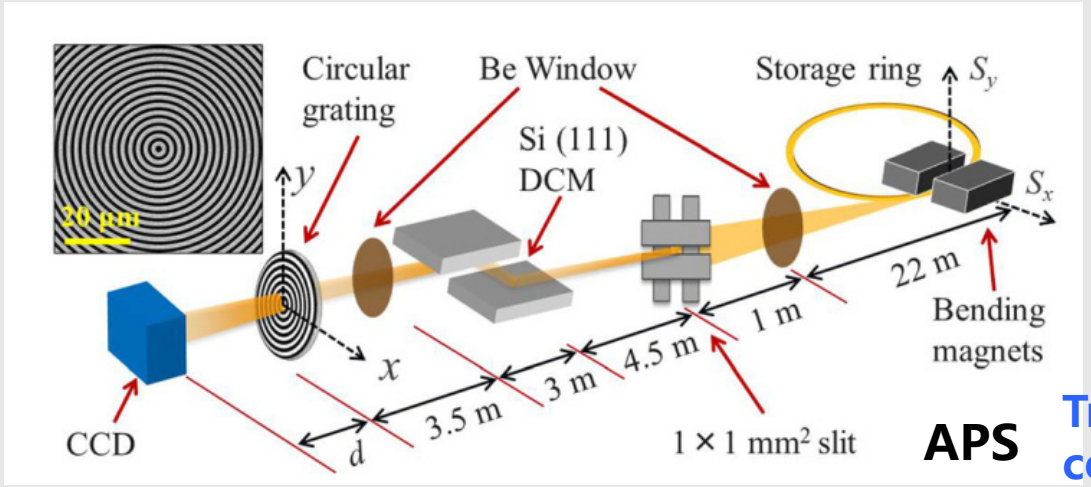


Fig. 1. Schematic diagram of the experimental setup.

APS

Transverse coherence

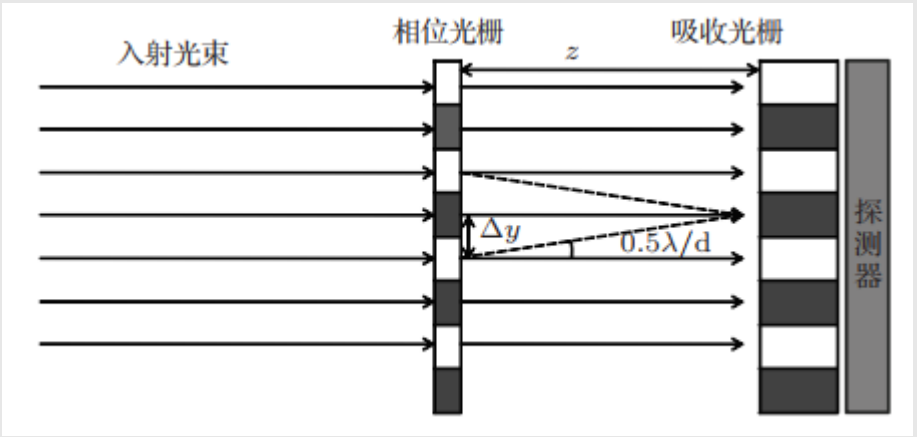
**Marathe S et al. Optics express, 2014, 22(12): 14041-14053.*

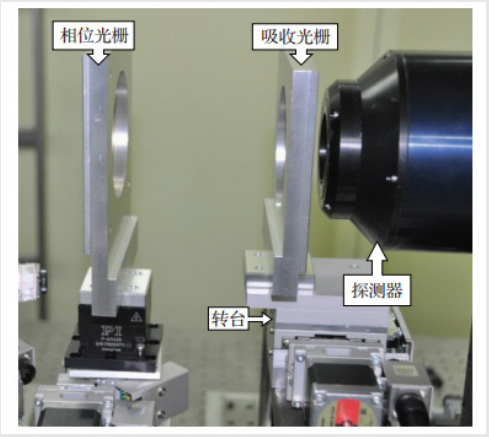


APS

Transverse coherence

**Shi X et al. Applied Physics Letters, 2014, 105(4): 041116.*





SSRF

(33keV, measured:23μm, theoretical :22 μm)

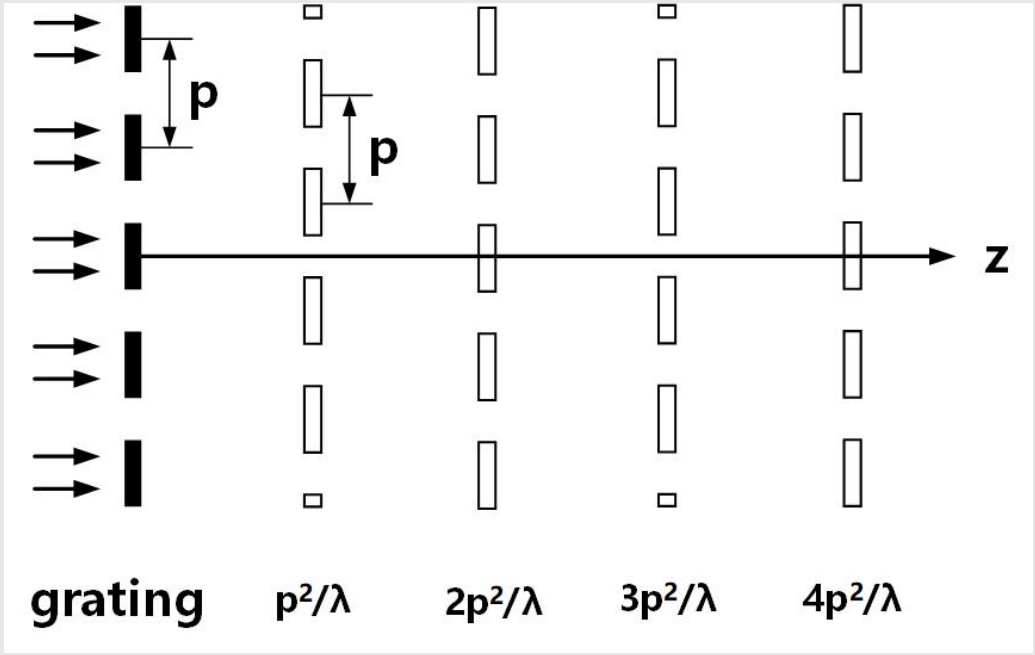
**Qi J C et al. Acta Phys. Sin. 2014, 63(10): 104202.*

Theory

Grating Talbot effect

images of grating

Monochromatic light

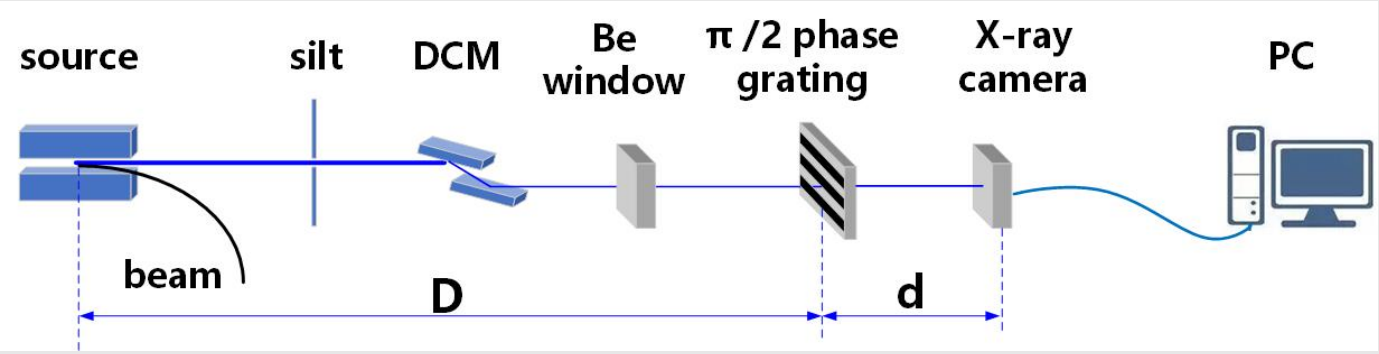


p is grating period, λ is the transmission wavelength

Completely coherent light source → Visibilities of images are equal

Partially coherent light source → Visibility decreases with the increase of transmission distance → spatial coherence

Theory

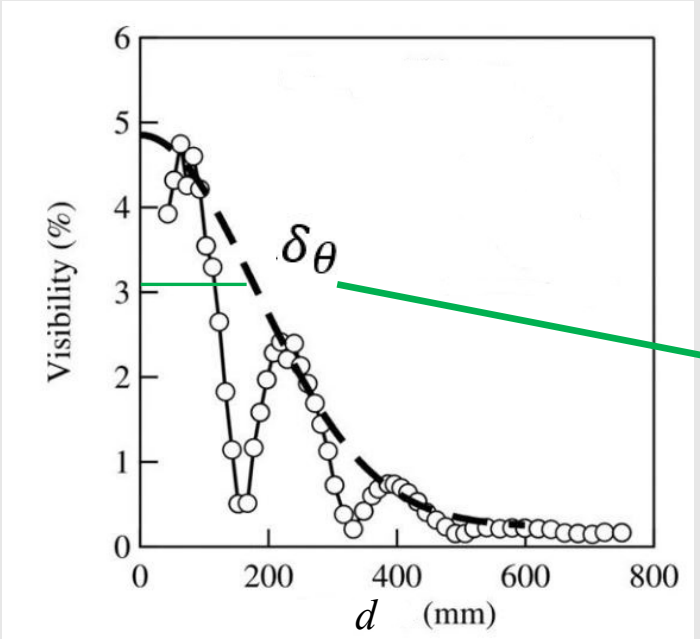


distance from source to grating

$$\xi_x = \frac{\lambda D}{2\pi\sigma_x}, \xi_y = \frac{\lambda D}{2\pi\sigma_y}$$

spatial coherence length

source size



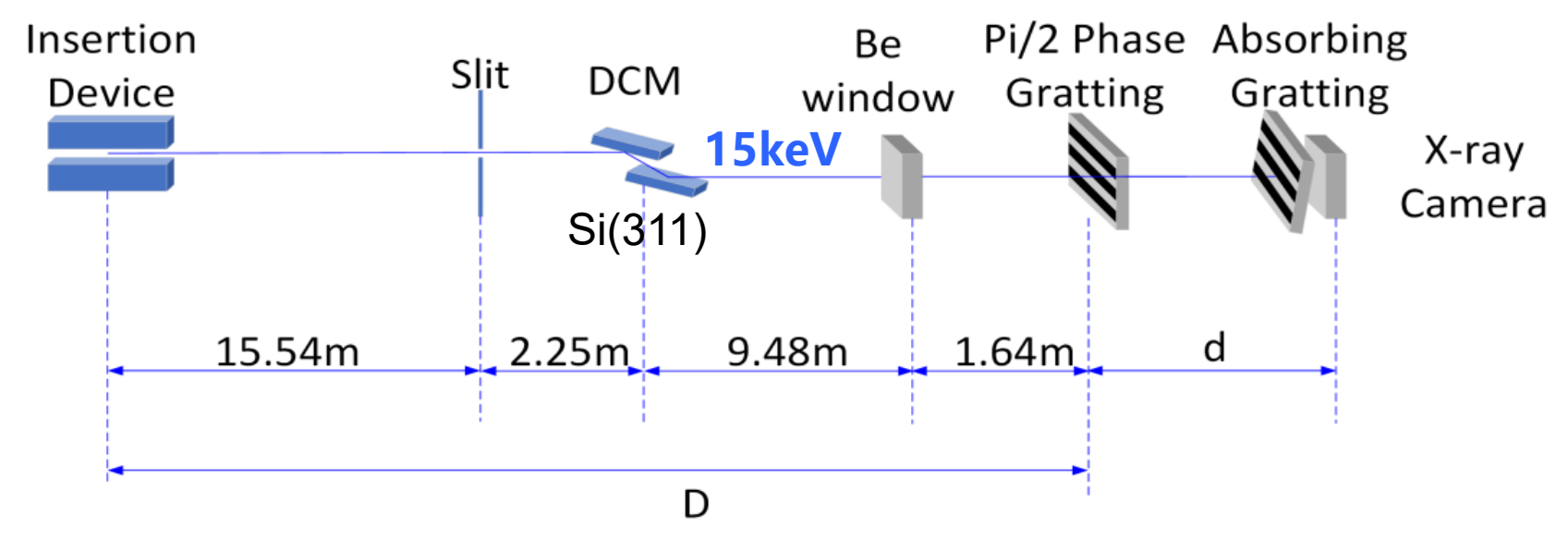
Width of envelope function

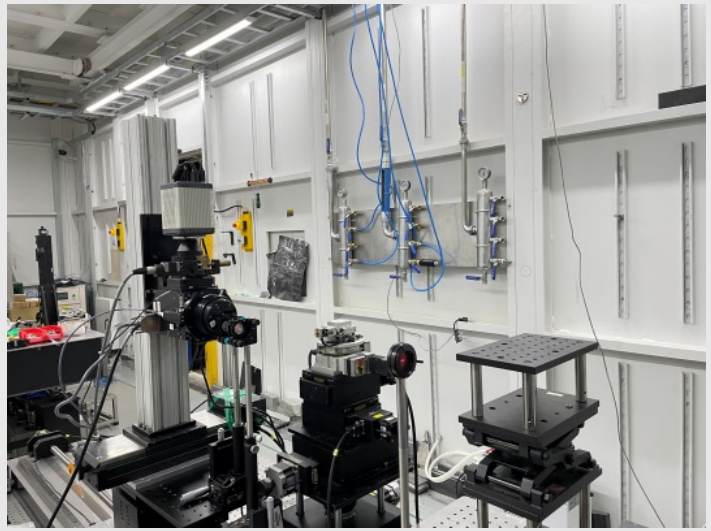
$$\xi_{exp,\theta} = \frac{\lambda\delta_\theta}{p_\theta}$$

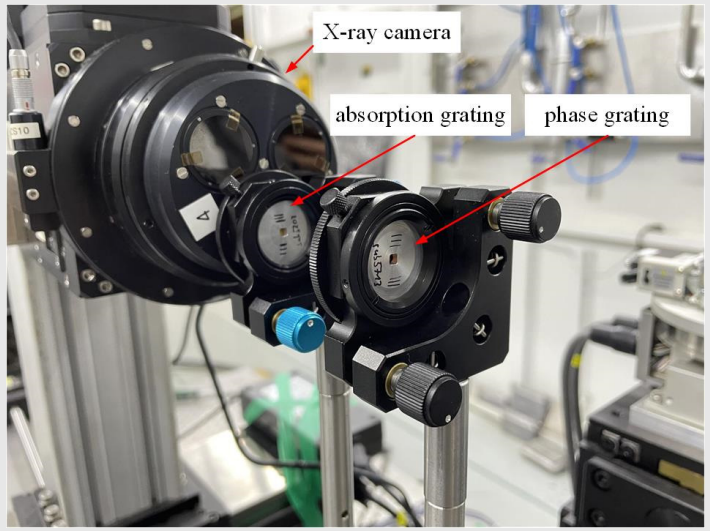
period of grating image

$$\sigma_x = \frac{p_x D}{2\pi\delta_x}, \quad \sigma_y = \frac{p_y D}{2\pi\delta_y}$$

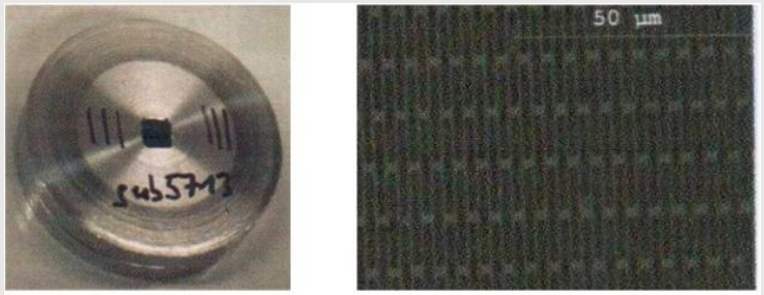
Setup


Insertion Device
Slit
DCM
Be window
Pi/2 Phase Gratting
Absorbing Gratting
X-ray Camera
15keV
Si(311)
15.54m
2.25m
9.48m
1.64m
d
D

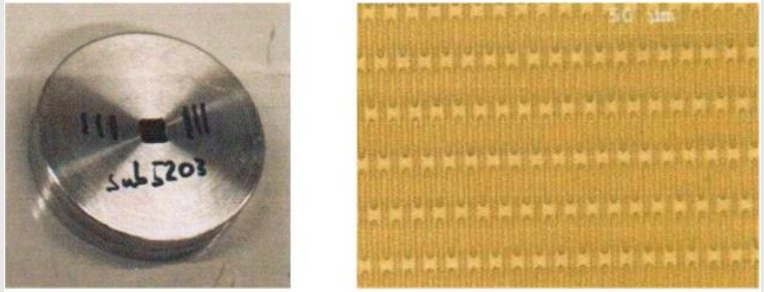



X-ray camera
absorption grating
phase grating

Setup



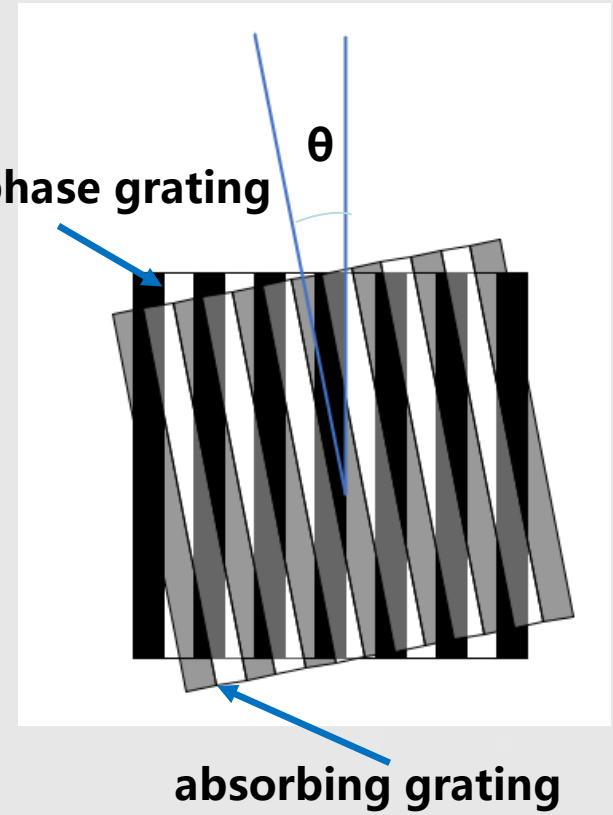
(a) phase grating

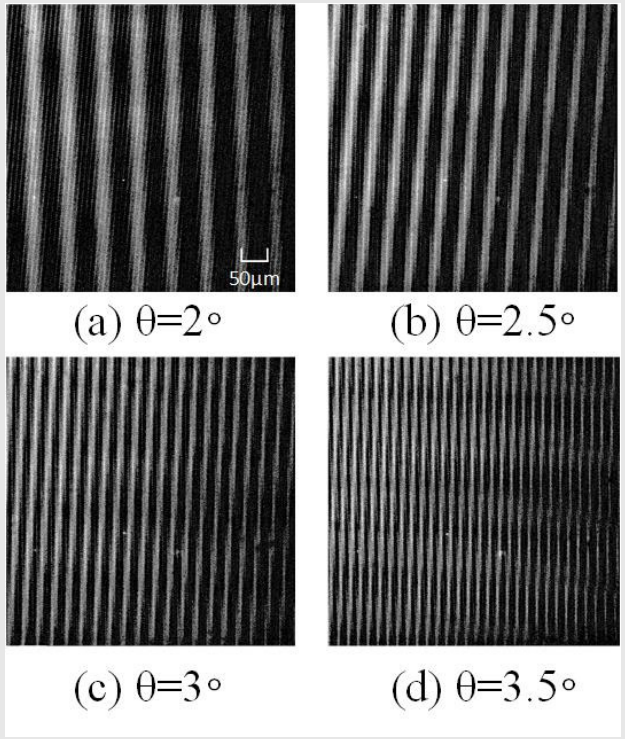


(b) absorption grating

Parameters	phase grating	absorption grating
Period	2.4µm	2.4µm
Duty Cycle	0.53±0.01	0.51±0.01
Area	>2.5×2.5mm²	>2.5×2.5mm²
Height	Polymer 18.6µm	Gold 14±1µm
Substrate	10µm Polyimide	10µm Polyimide

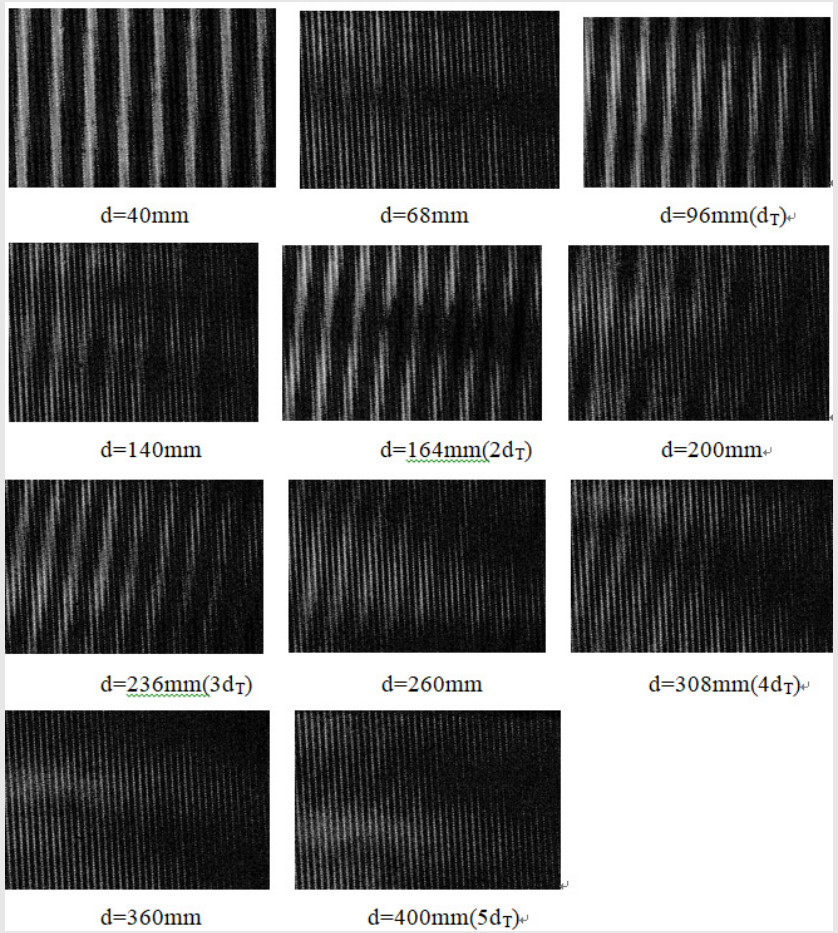
Results





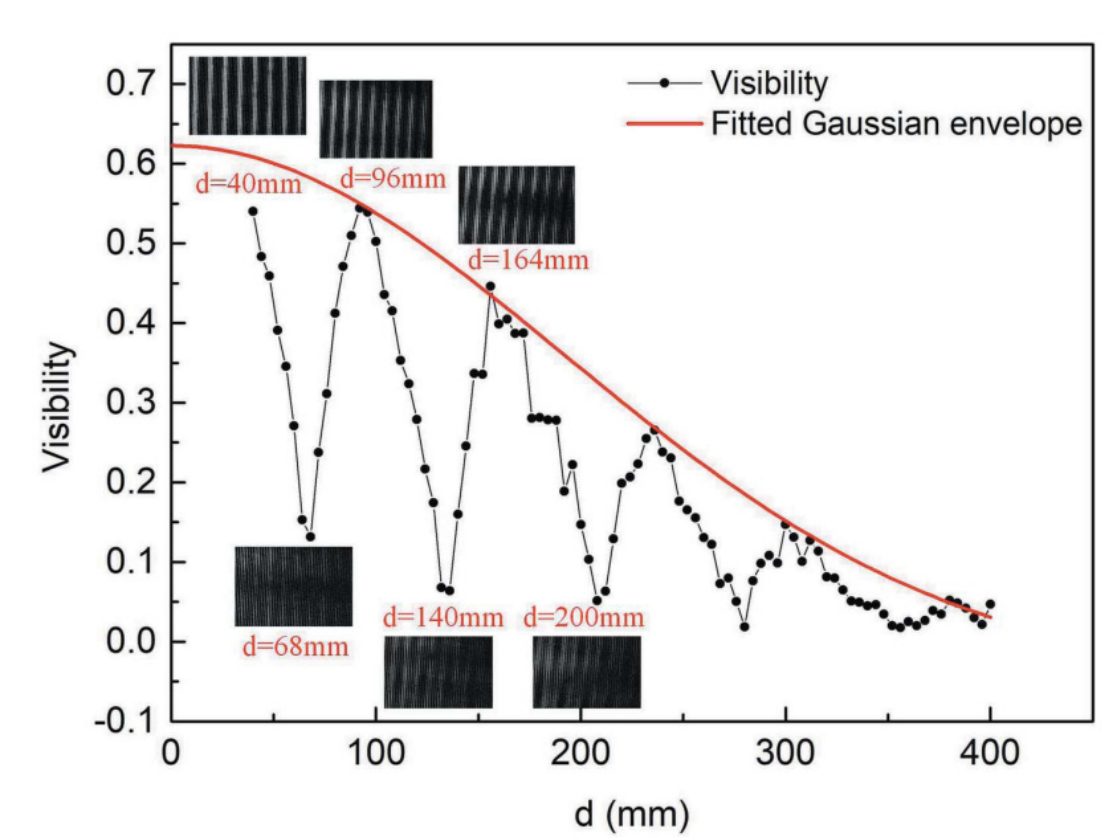
Moire fringe images

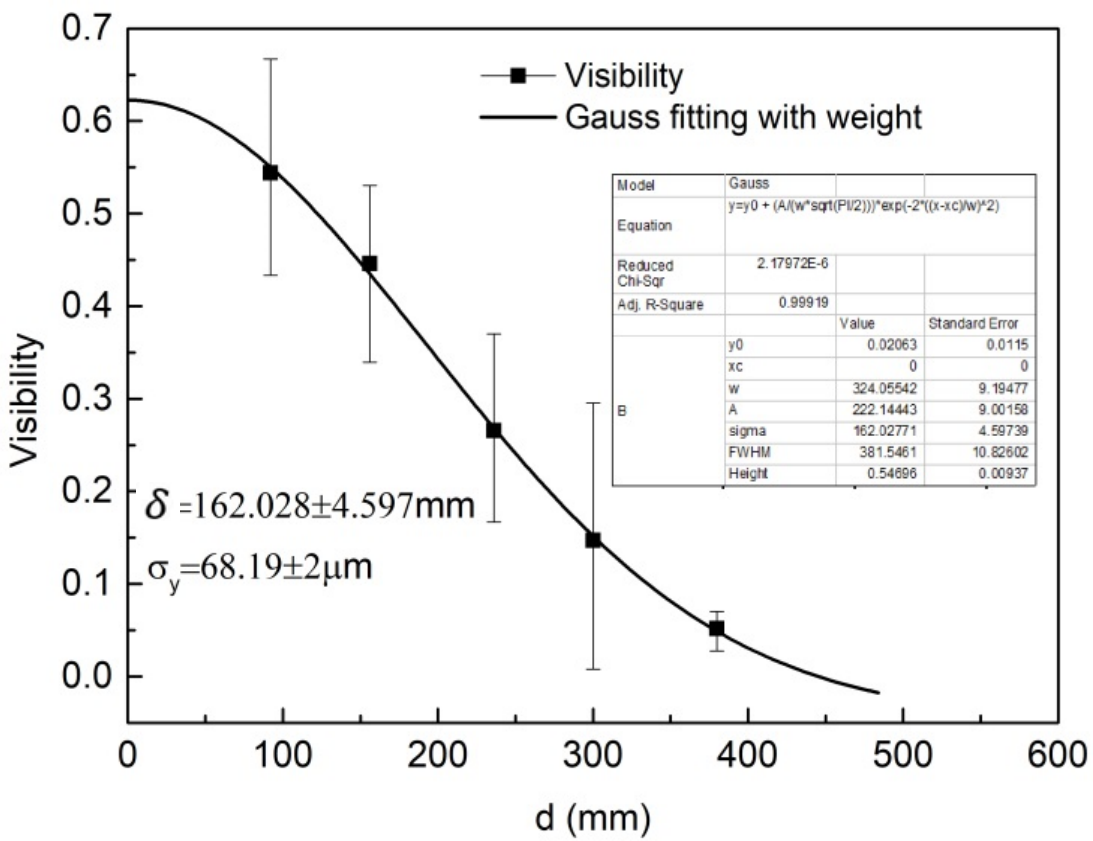
θ=2°



The interference images at different Talbot distances

Results





The visibility shows periodic oscillations. The local maximum of visibility at fractional Talbot distance decreases gradually due to the partial coherence of the source.

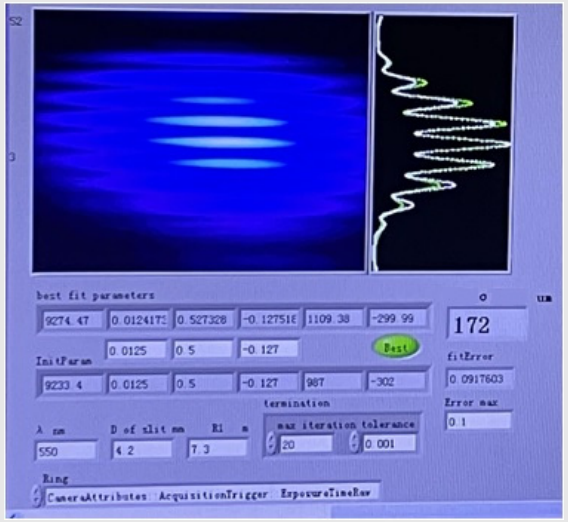
spatial coherence length ξ_y =5.592μm

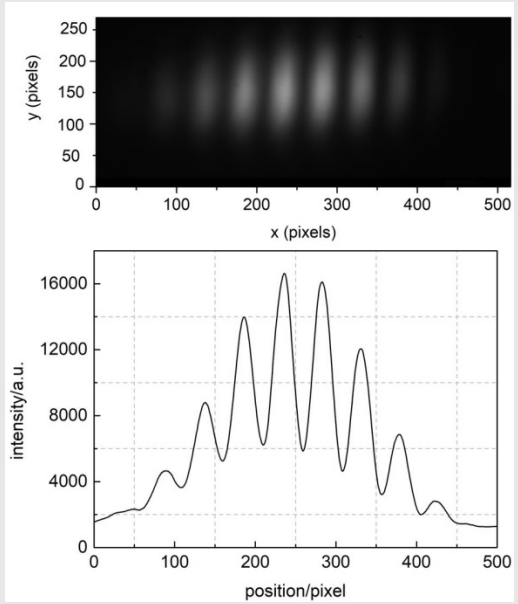
source size σ_y =68.19μm

Results

contrast experiment

The visible light beamline of BEPCII





the vertical beam size measurement with a double-slit interferometer

The comparison of vertical emittance derived from two methods

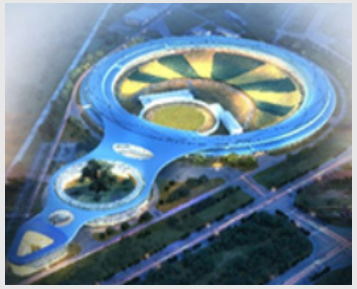
$$\sigma_y^2=\varepsilon_y\beta_y$$

Parameters	3W1	visible light beamline
Method	grating self-imaging	visible light imaging
β_y	3.2877m	20.975m
σ_y	68.19μm	171.4μm
ε_y	**1.41nm•rad**	**1.40nm•rad**

The results of the two methods agree very well

Potential

4th Generation

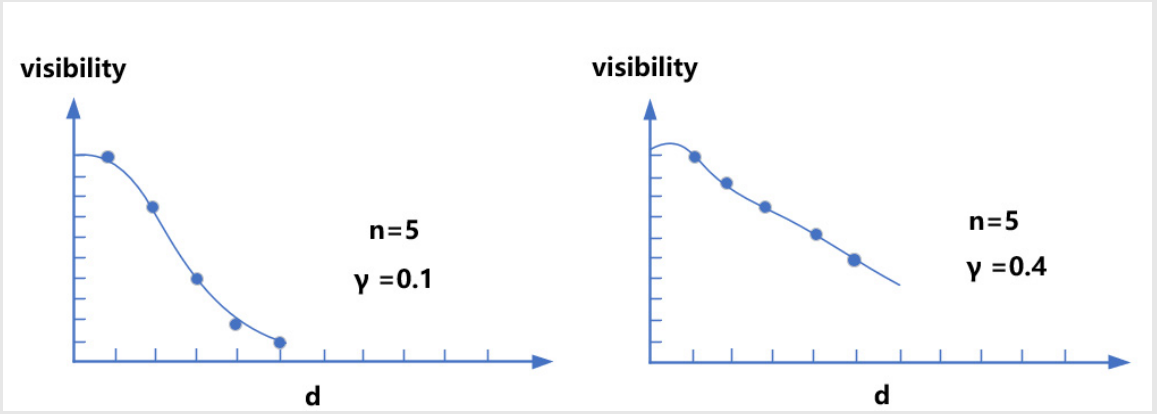


higher coherence

lower emittance

smaller beam size

$$\sqrt{\frac{2ln\gamma}{n(1-n)}}\xi_\theta < p_\theta < \left(\frac{2\lambda d_{max}}{2n-1}\right)^{1/2}$$



Suitable n (n>5)

Suitable $\gamma=V_{min}/V_{max}$

HEPS

stores ring physical parameters	value	unit
linear section with high β		
Beam size in horizontal direction/ and vertical direction(rms)	16.7/5.1	μm
beam divergence angle in horizontal direction/ and vertical direction(rms)	1.65/0.53	μrad

The suitable grating period can be derived according to various conditions.

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Thank you very much !