Conceptual design for SR monitor
in the FCC
Beam emittance (size) diagnostic

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Agenda for my talk

1. FCC e-e

- ☆ FCC e-e SR source point parameter
- ☆ Vertical beam profile at source point
- ☆ Properties of Synchrotron Radiation
- ☆ Comparison of conventional method for beam size measurement
- ☆ SR extraction
- ☆ X-ray interferometer
- ☆ Summary

2. FCC h-h

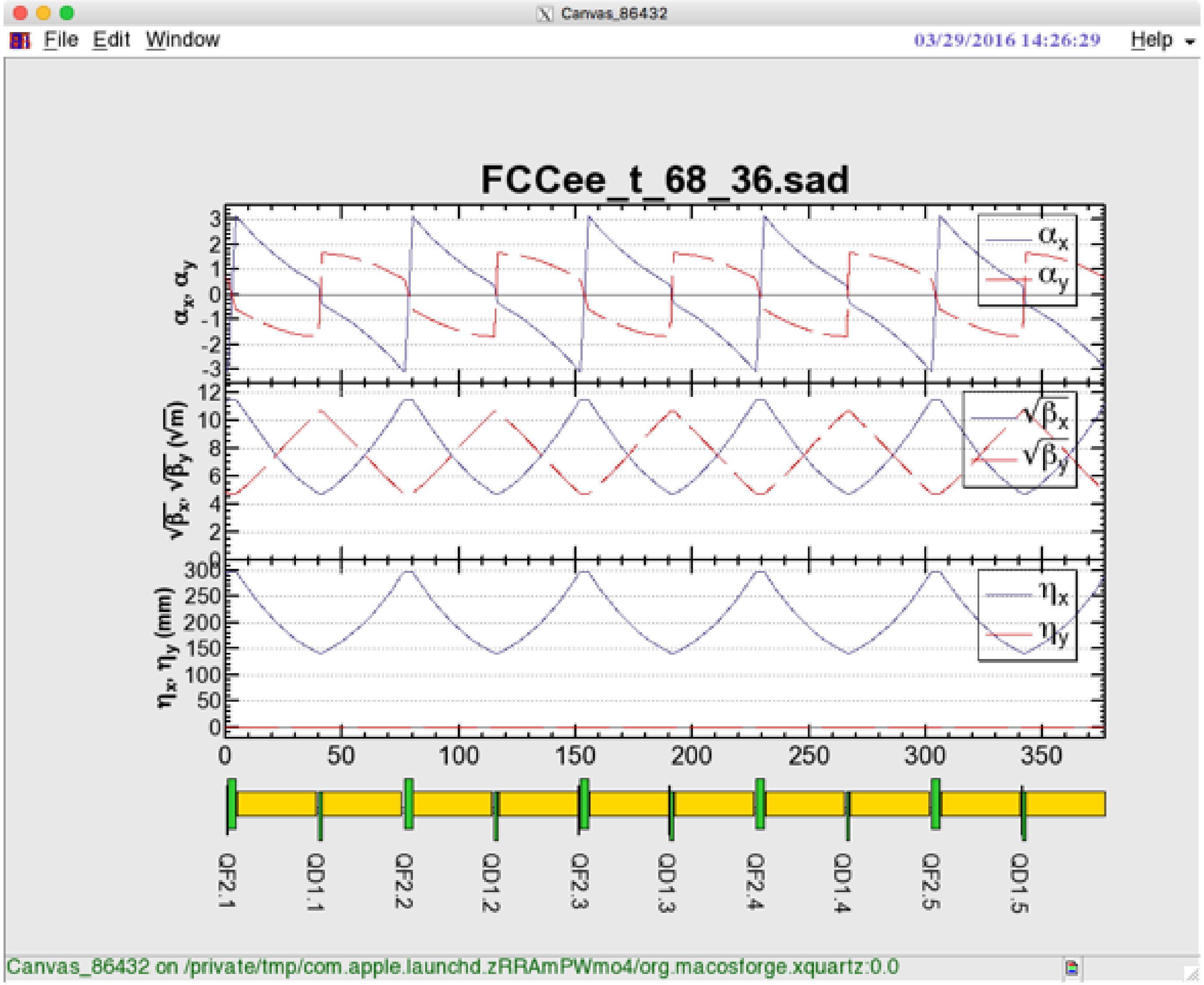
- ☆ FCC h-h SR source point parameter
- ☆ Properties of Synchrotron Radiation
- ☆ SR extraction
- ☆ Possible instrumentation
- ☆ X-ray pinhole camera
- ☆ Summary and request for SR source point

1. Measurement of beam size in the FCC e-e

Parameters of FCC-ee at source point

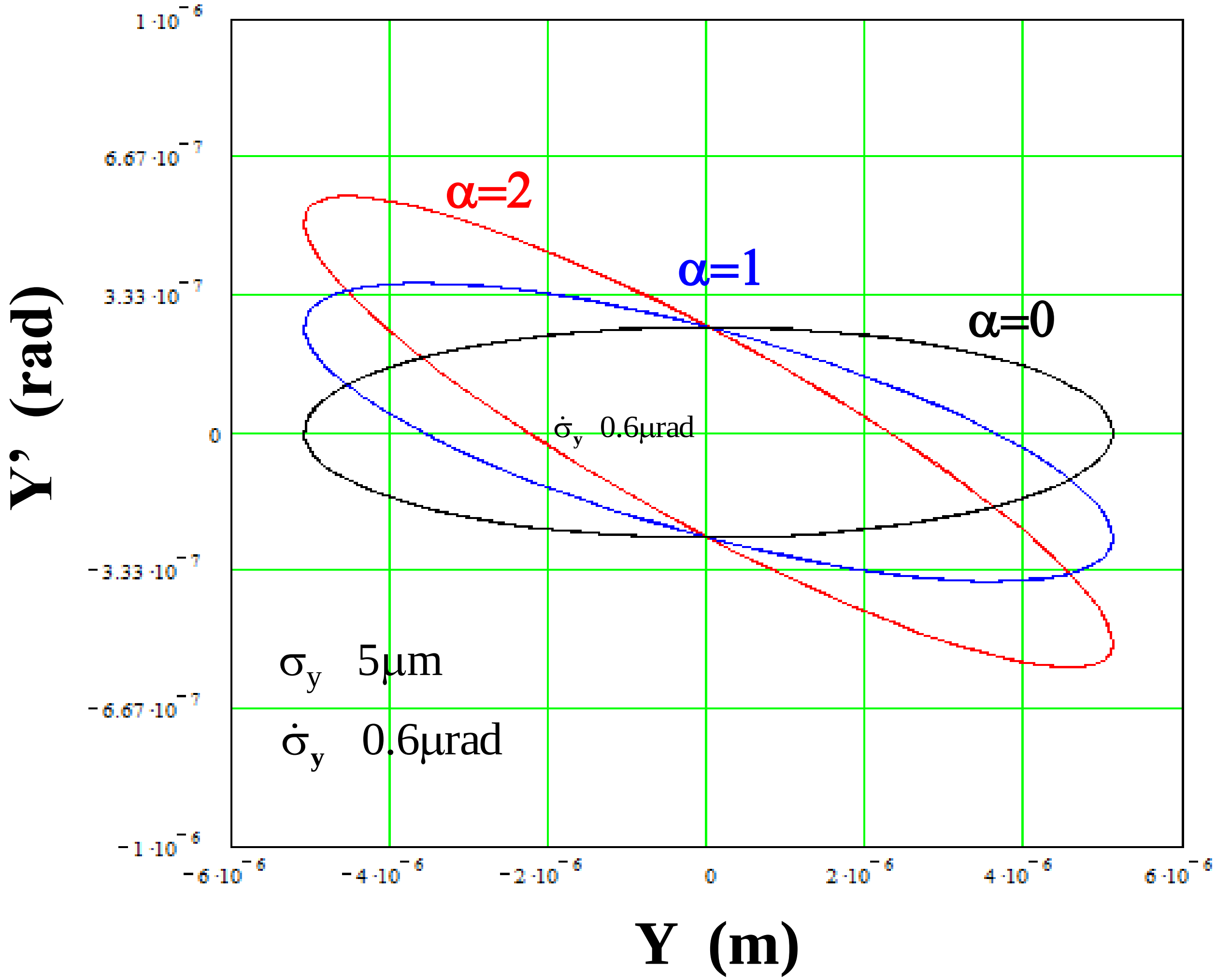
Bending magnet length	24.585m
Bending radius	11590.8m
Magnetic field strength	0.0503T
Bending angle	2.144mrad
Beam energy and current	175GeV 6.6mA 45GeV 1500mA
emittance	1.3pmrad
Estimated vertical beam size	σ_y =5.1μm / β=20m =0.05μrad / 100m

Lattice for FCC e-e



Beam profile in phase space β=20m

Source point: last bend of arc.



175GeV

ρ=11590.8m

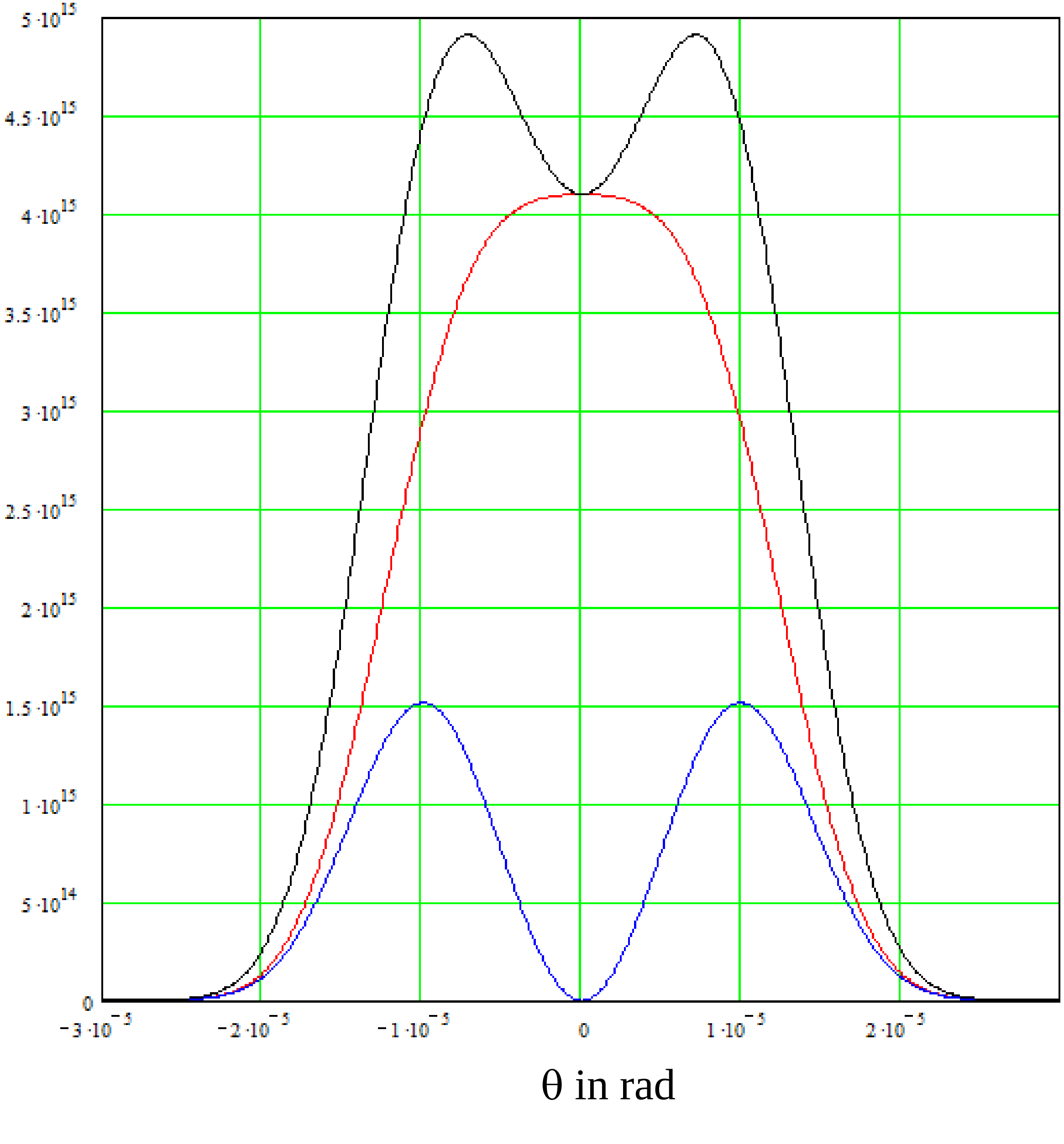
0.1nm

Divergence of beam

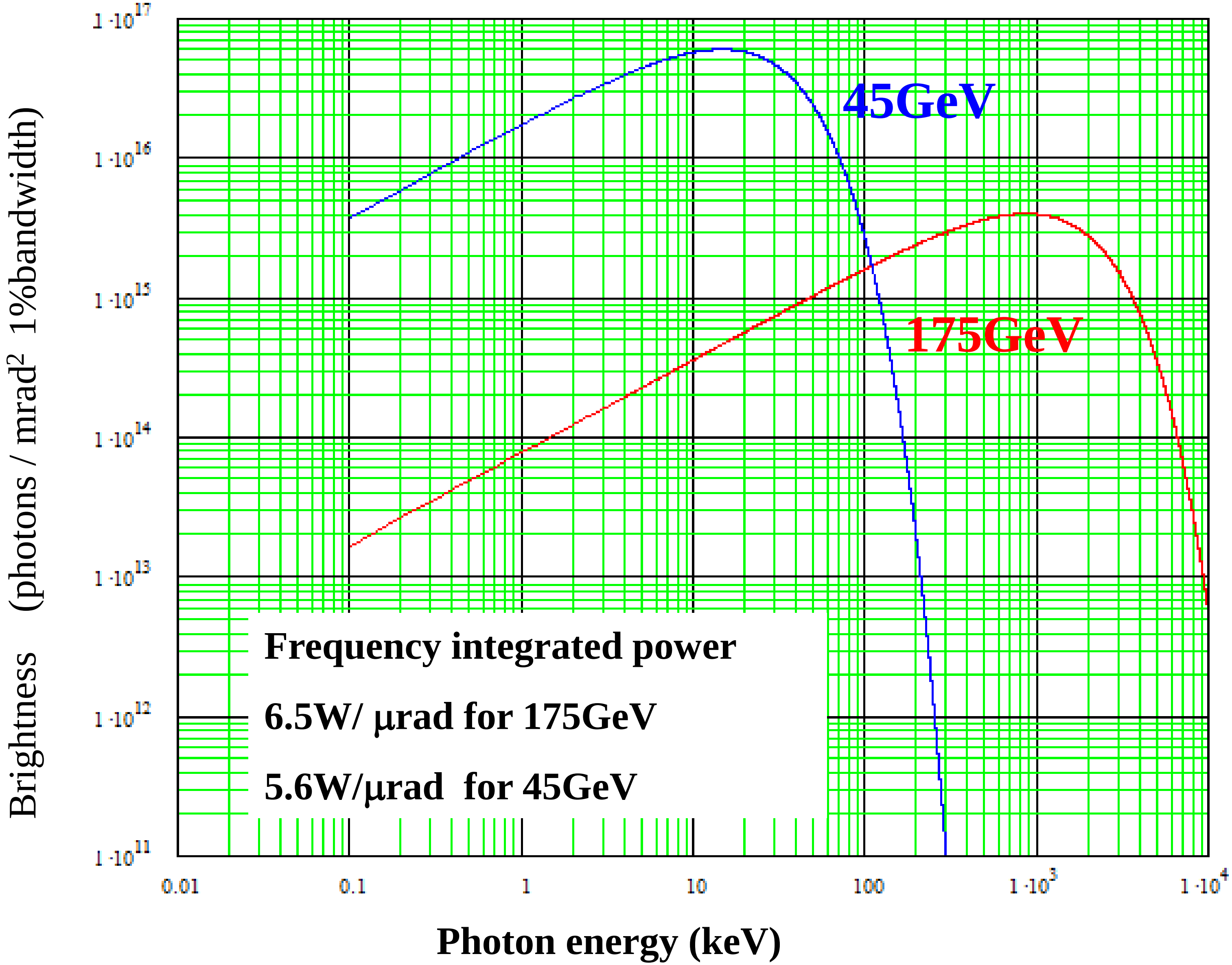
Order of 10^{-7}rad

Divergence of SR

Order of 10^{-5}rad



Expected spectrum from the bending magnet FCC-ee

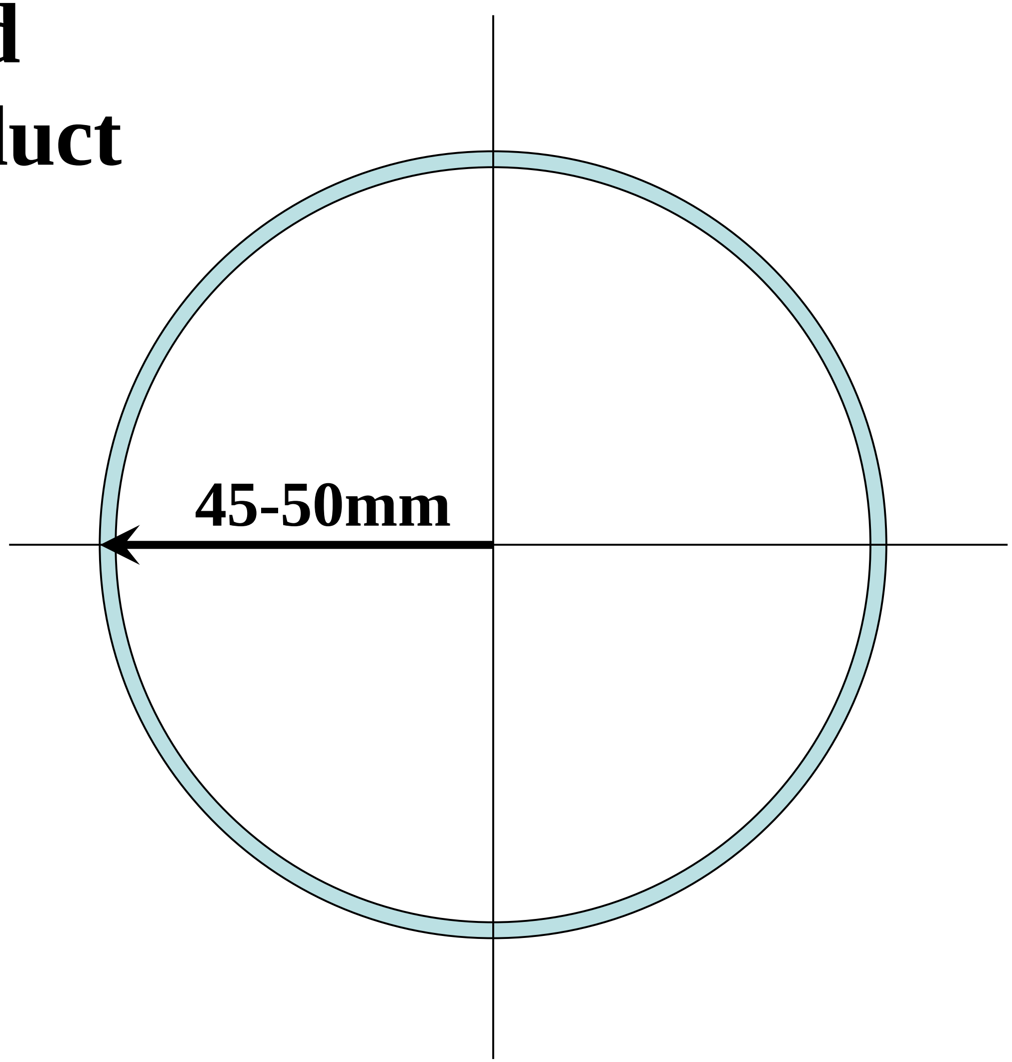


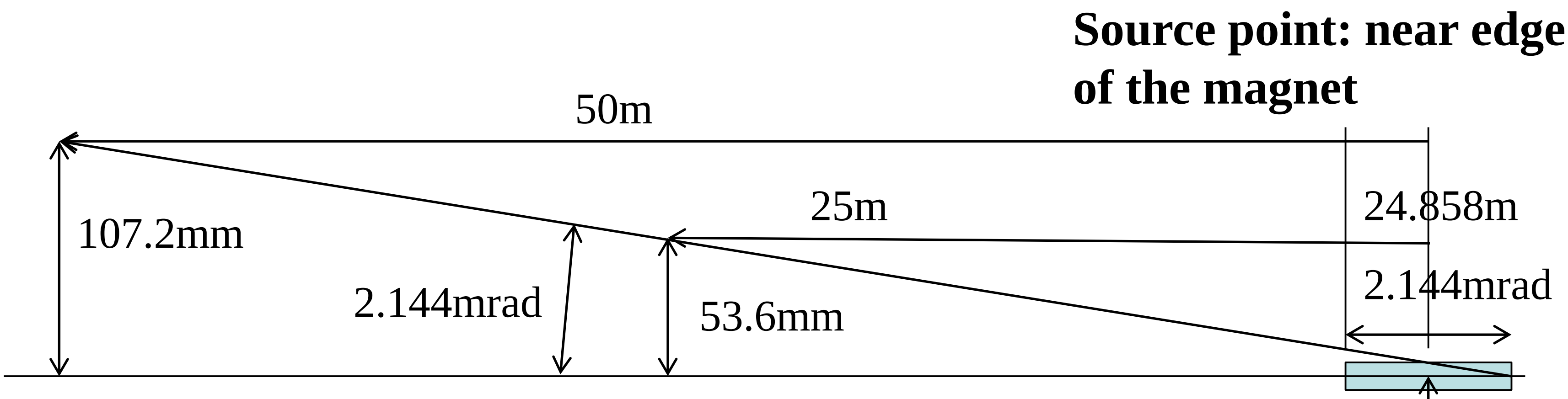
Extraction of hard X-rays from the ring

1. **Light source**

   use last bending magnet in Arc.

Estimated vacuum duct

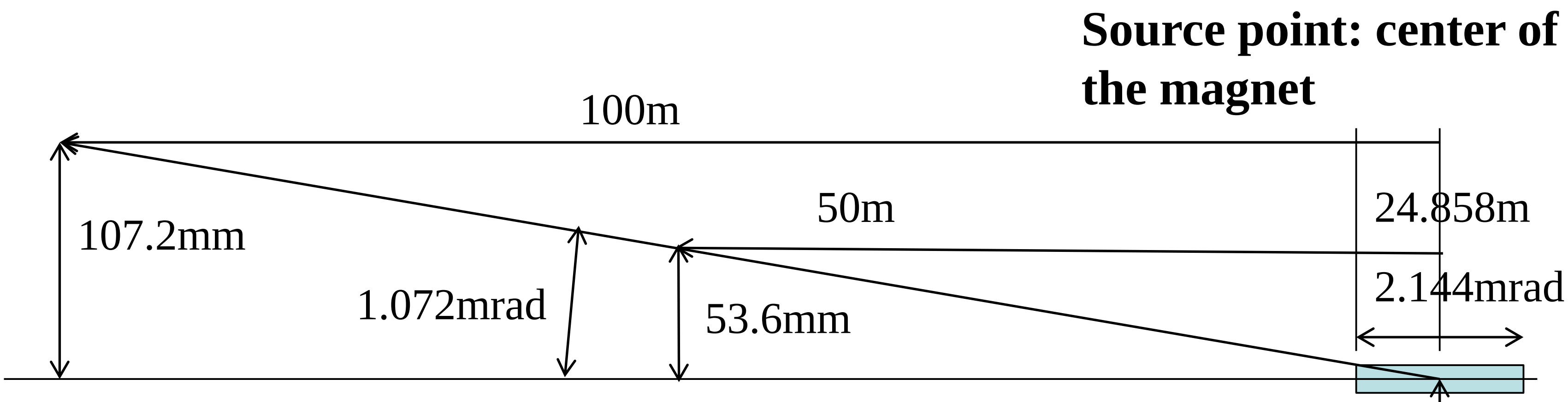




Geometrical condition for the extraction of SR from the last bending magnet

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.



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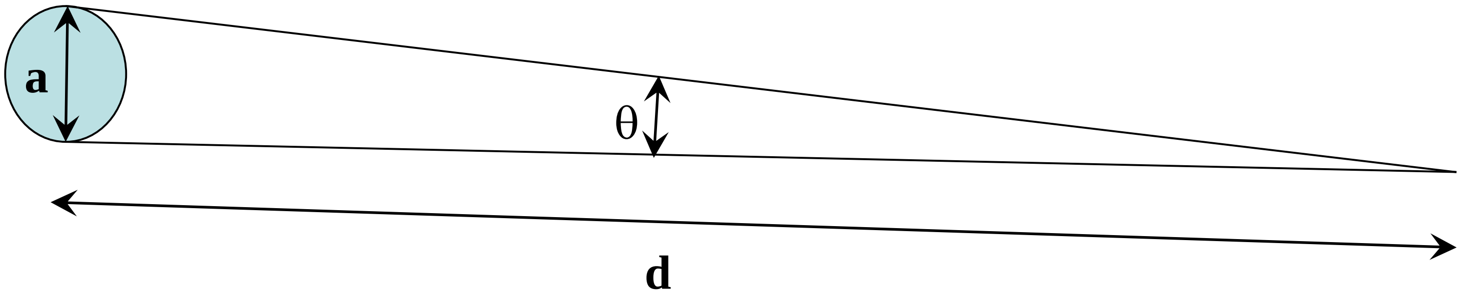
method	wavelength	measurable minimum beme size in angular diameter in μrad	Corresponding size in 100m in μm	Corresponding size in 1000m in μm
Visible light imaging	500nm	50	500	5000
X-ray pinhole	0.1nm	0. 5	50	500
FZP imaging Of soft X-ray	0.35nm	0.3	30	300
Visible light interferometry	400nm	0.47	47	470
Visible light Interferometry with imbalance input	400nm	0.2 (scaled) No measurement	20	200
Coded aperture	0.3nm	0.5 0.1 (estimation) No measurement	50 10	500 100
X-ray Interferometry (new method)	0.1nm	0.01	1	10μm

Angular diameter



Object locates having a size a at certain distance d

Angular diameter is given by,

$$\theta = a/d$$

or

$$\theta_{\sigma} = \sigma/d$$

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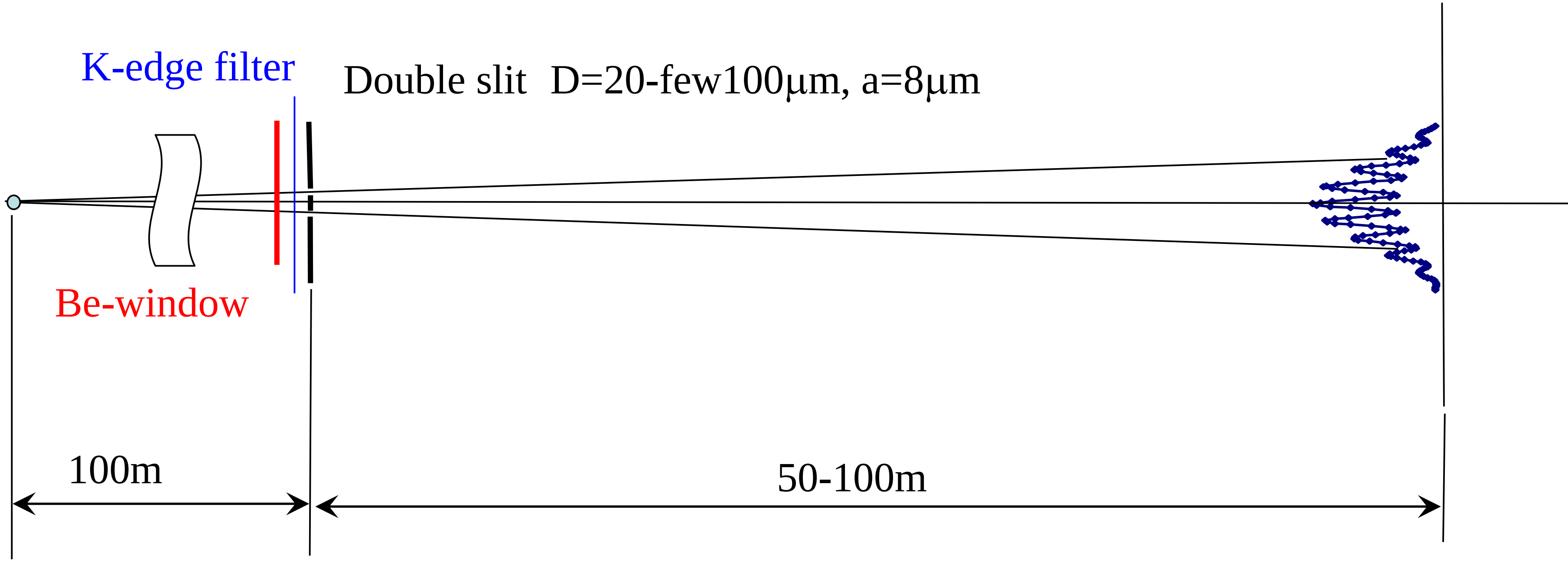
Simple double slit X-ray interferometer (Young type)



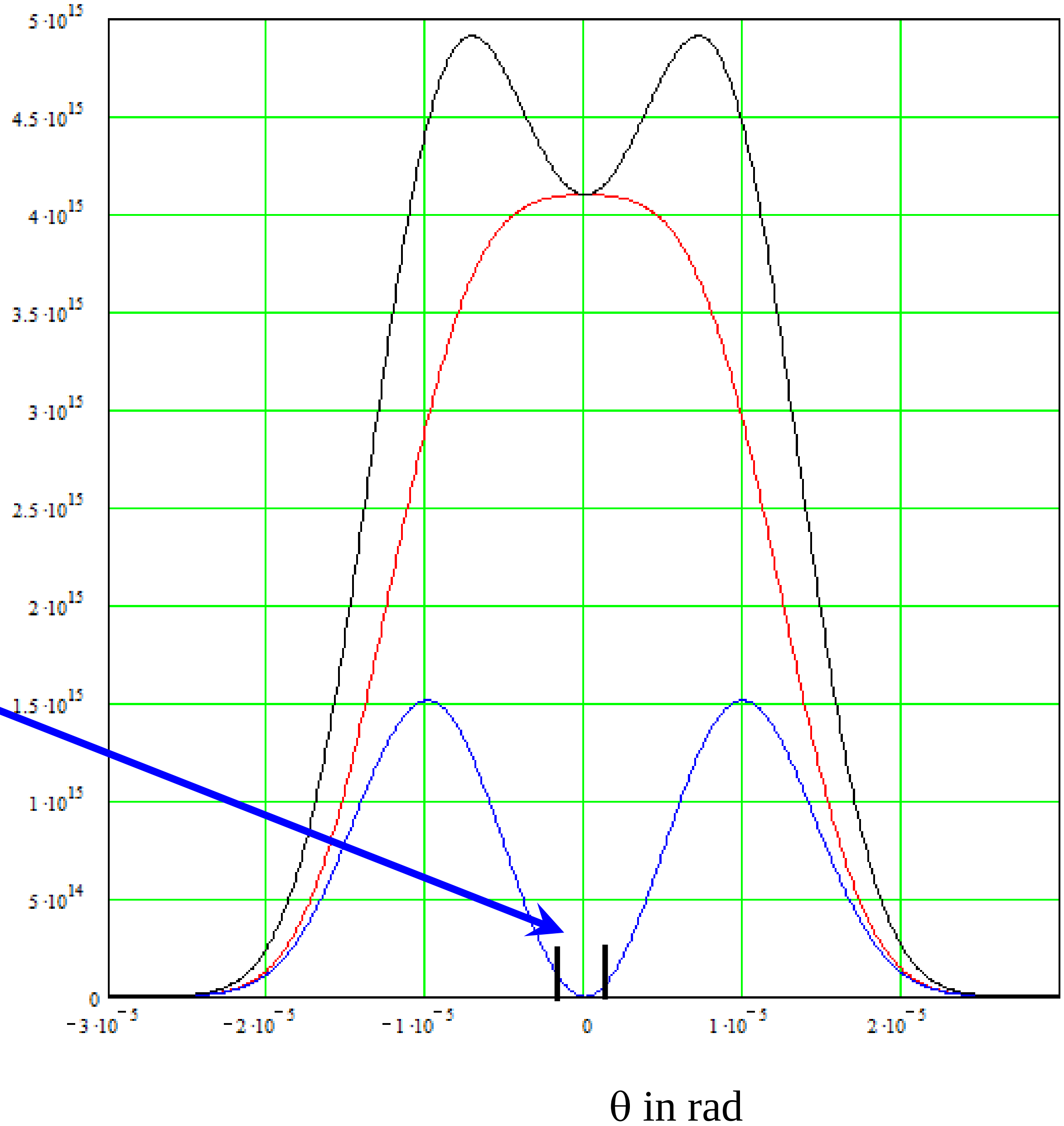
175GeV

ρ=11590.8m

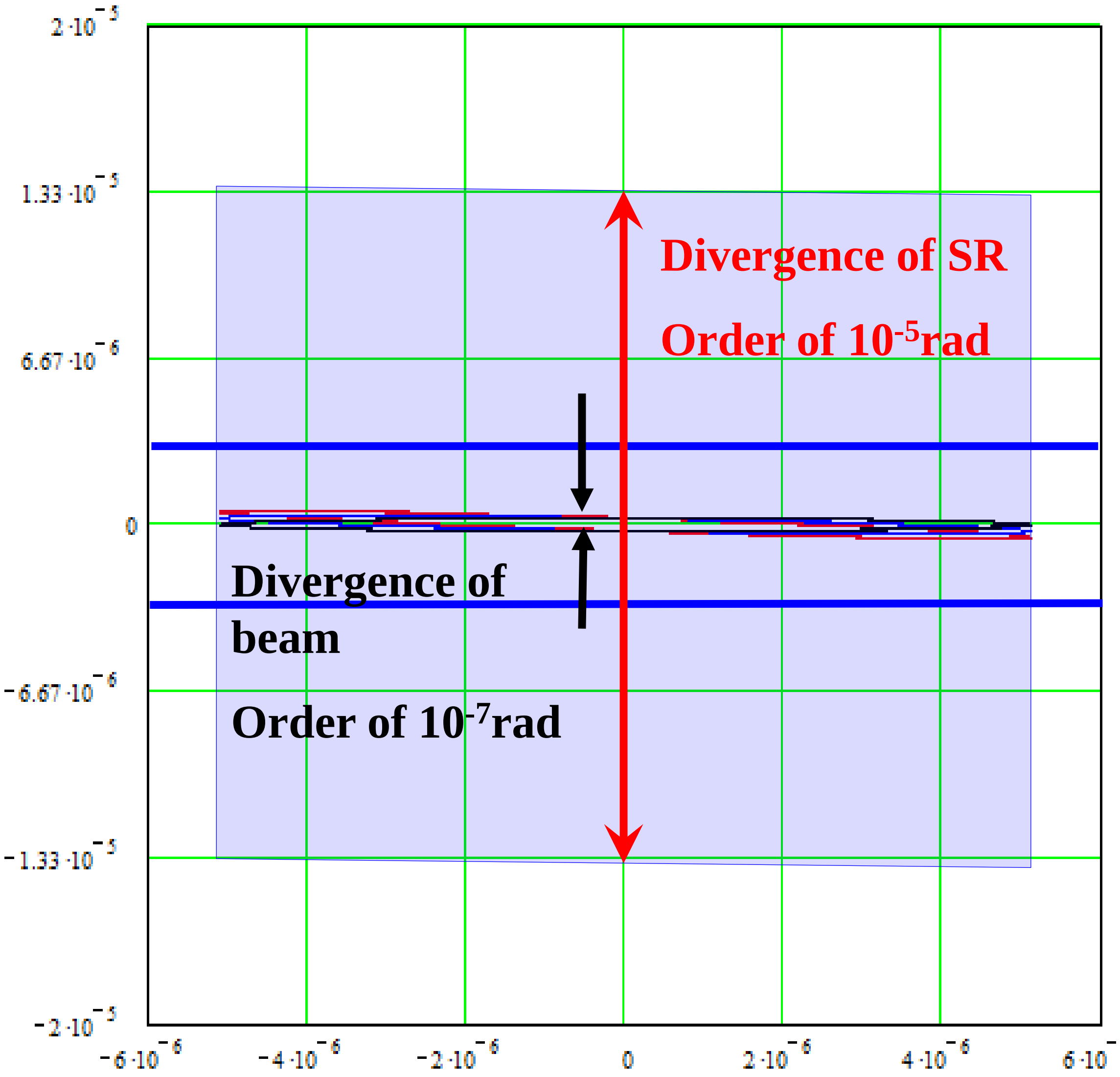
Double slit location

I_v / I_h =0.016

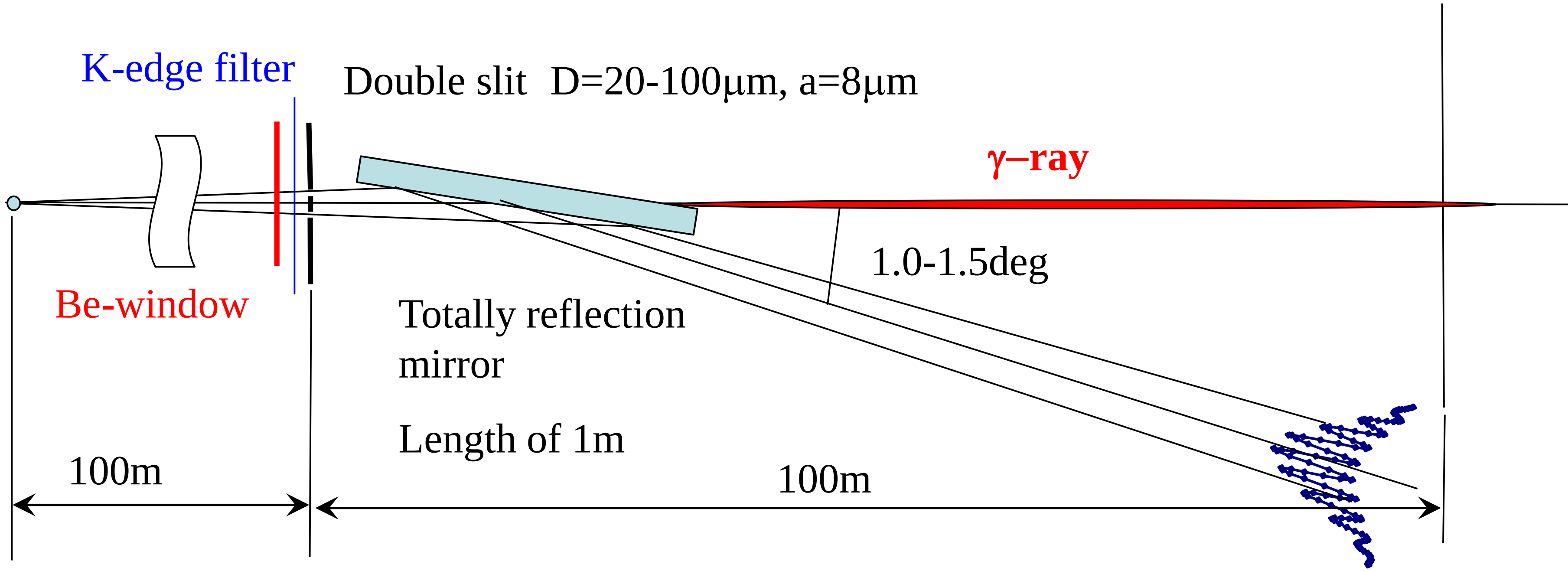
We do not need selection of polarization



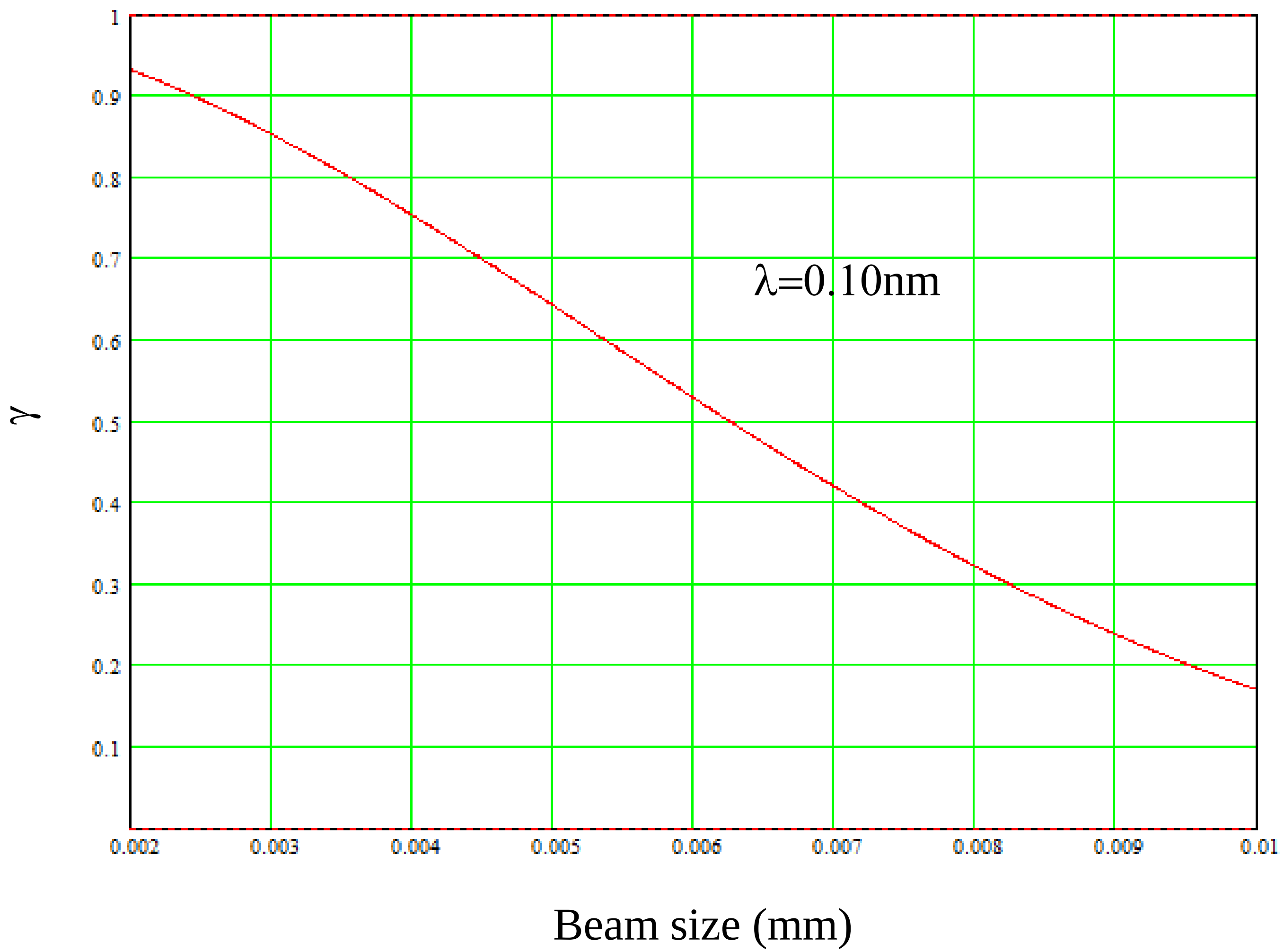
Double slit of interferometer will not miss the beam size information



Double slit interferometer (Young type) with total reflection mirror

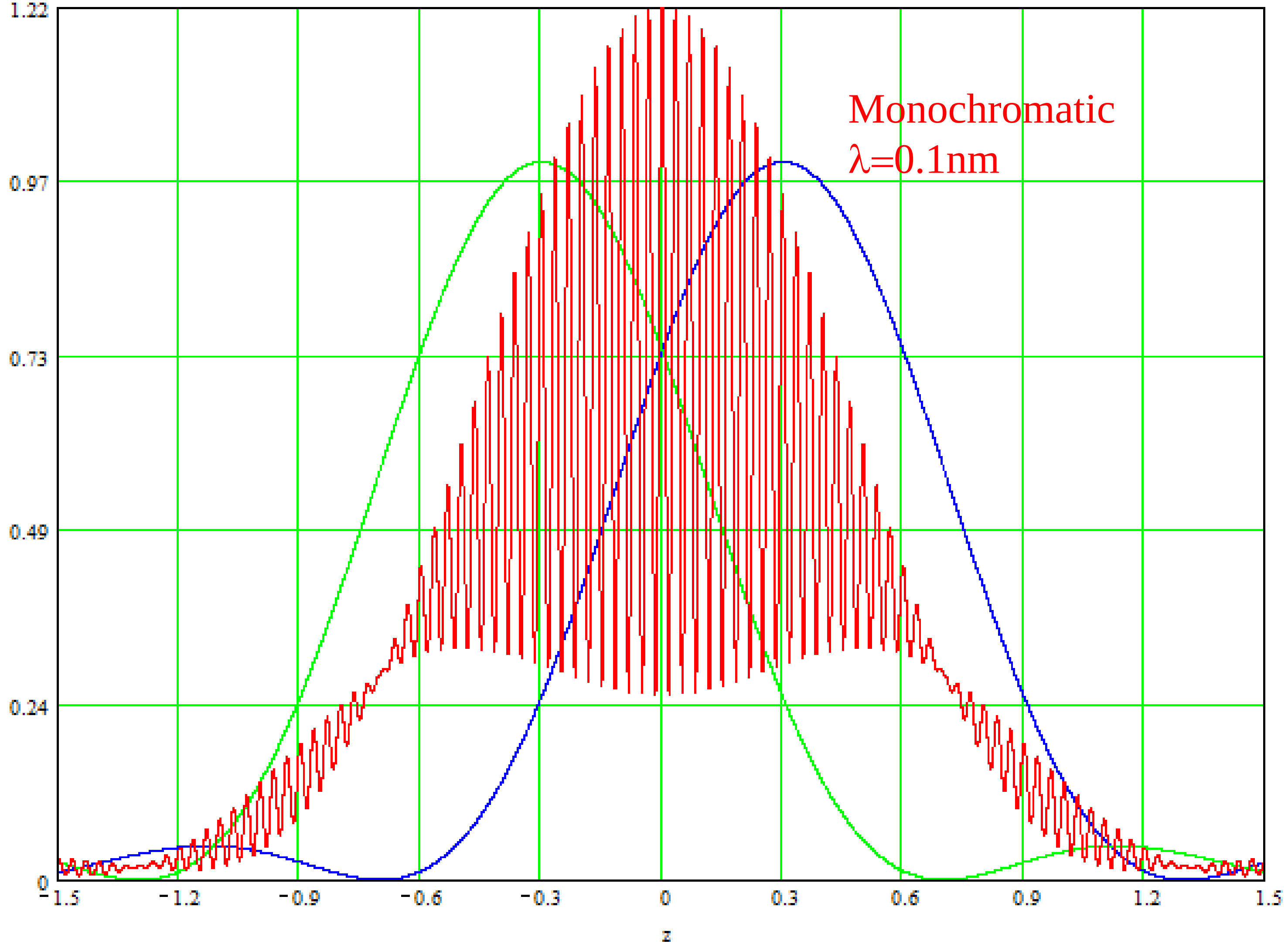


Spatial coherence vs. beam size D=300um, f=100m

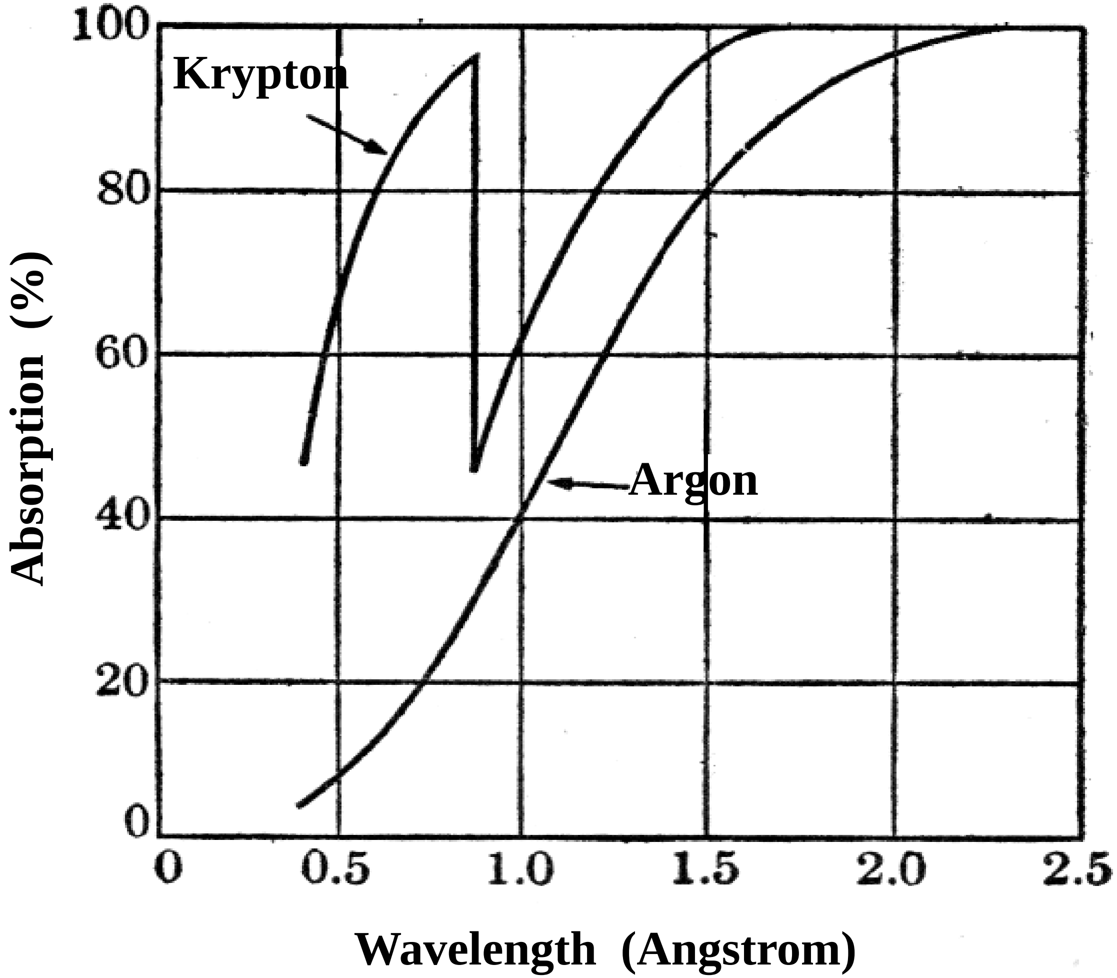


Expected interferogram for γ=0.65 (beam size of 5μm at 100m)

Double slit a=5um, D=300um f=100m

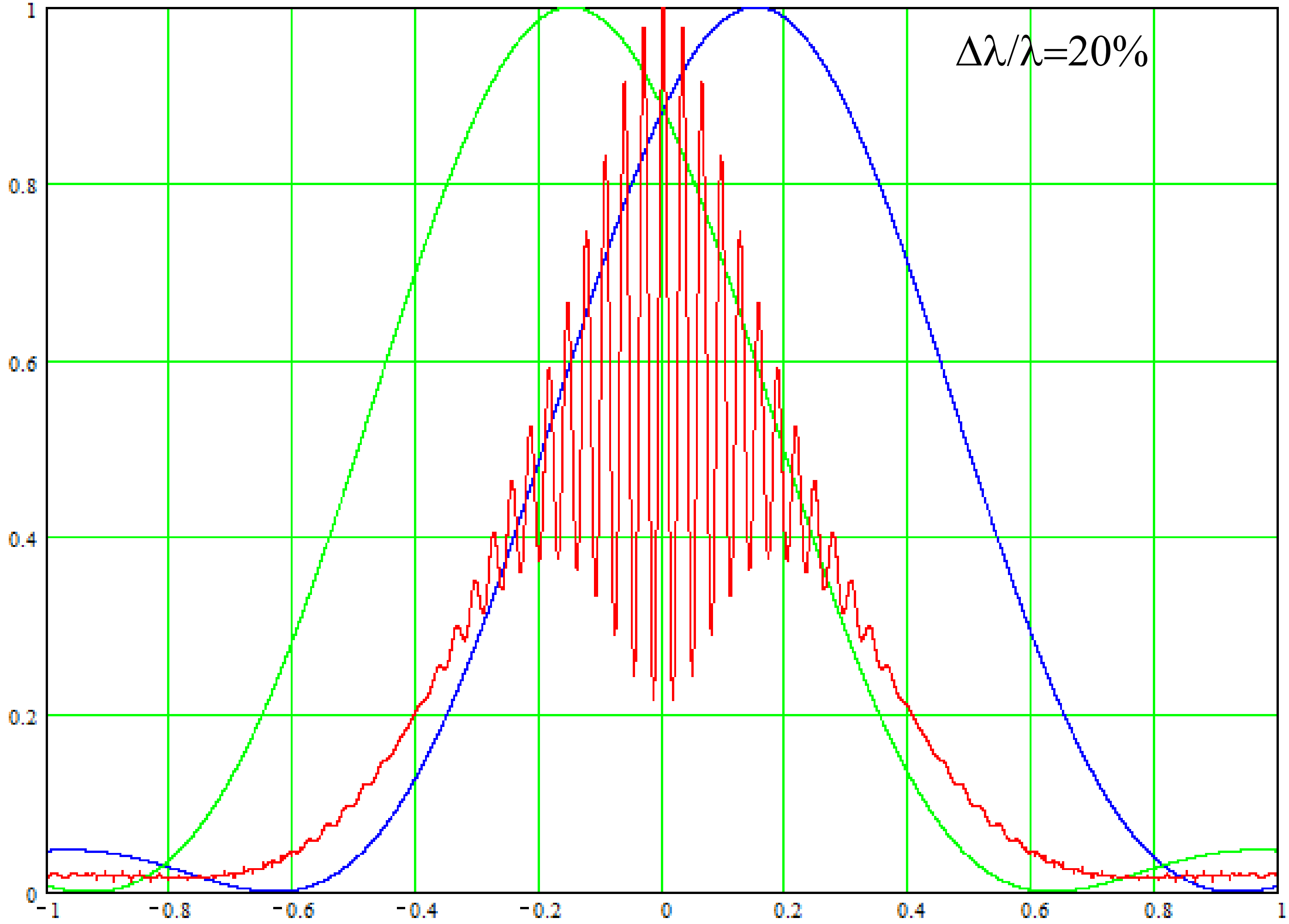


Gas absorption filter length is 100mm

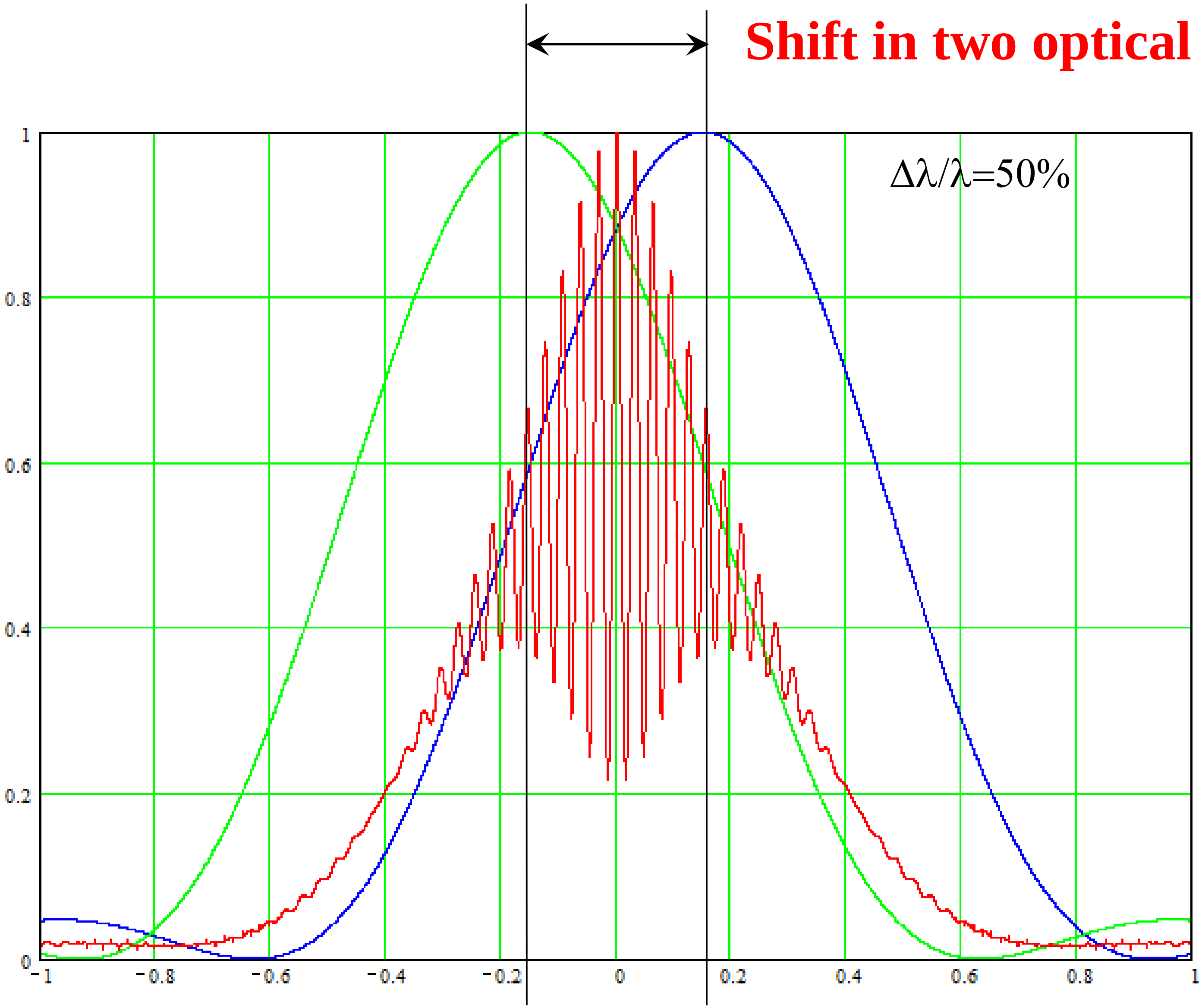


Krypton gas filter has a nice window around 10keV

With quasi-monochromatic ray
Kr gas filter 100mm

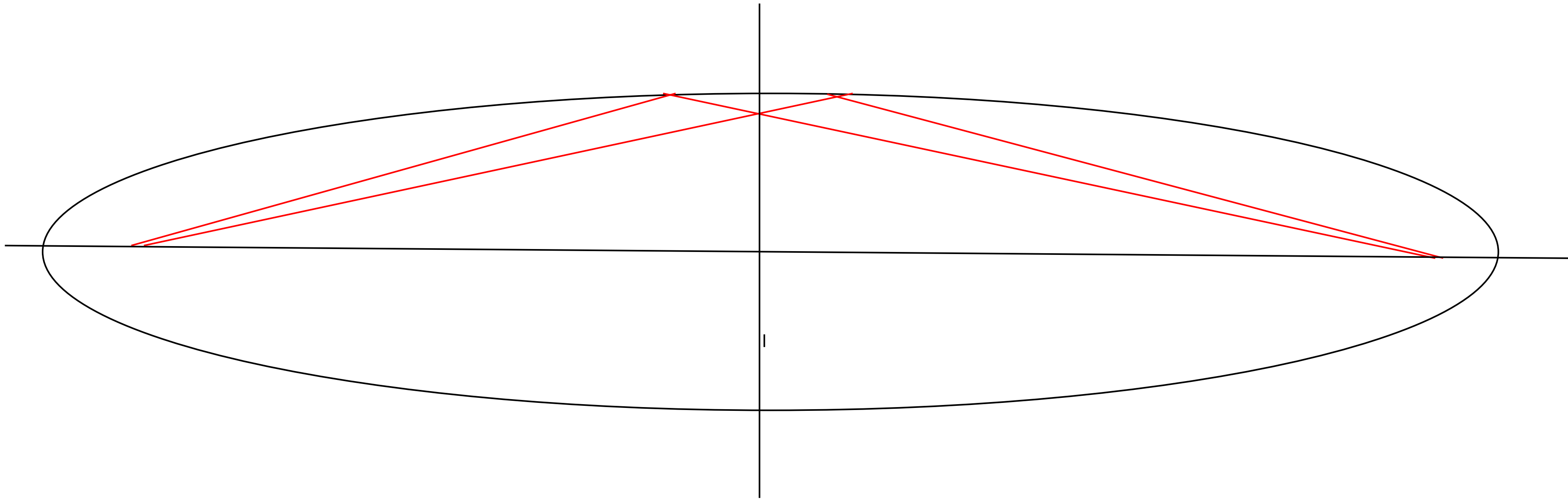


Shift in two optical axis

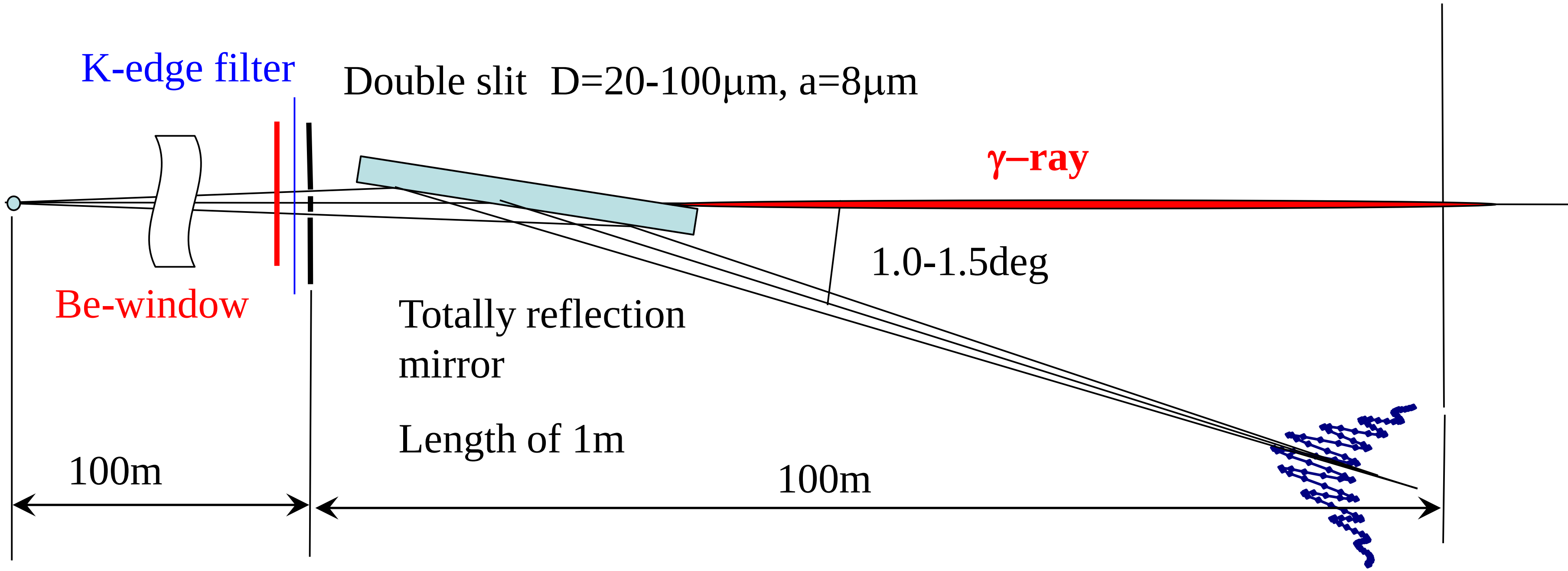


Escape from the shift in two optical axis

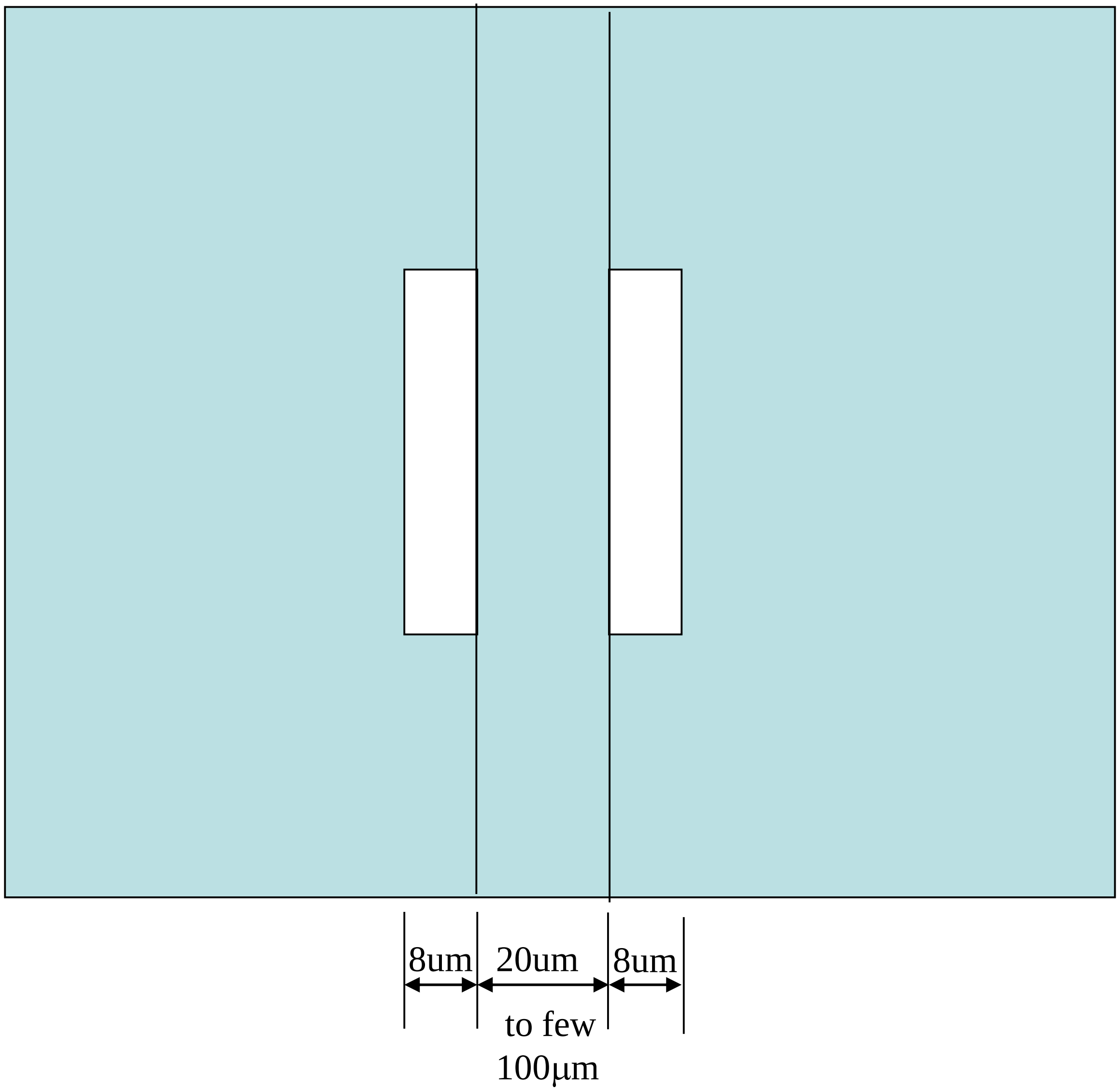
Elliptically deformed total reflection mirror



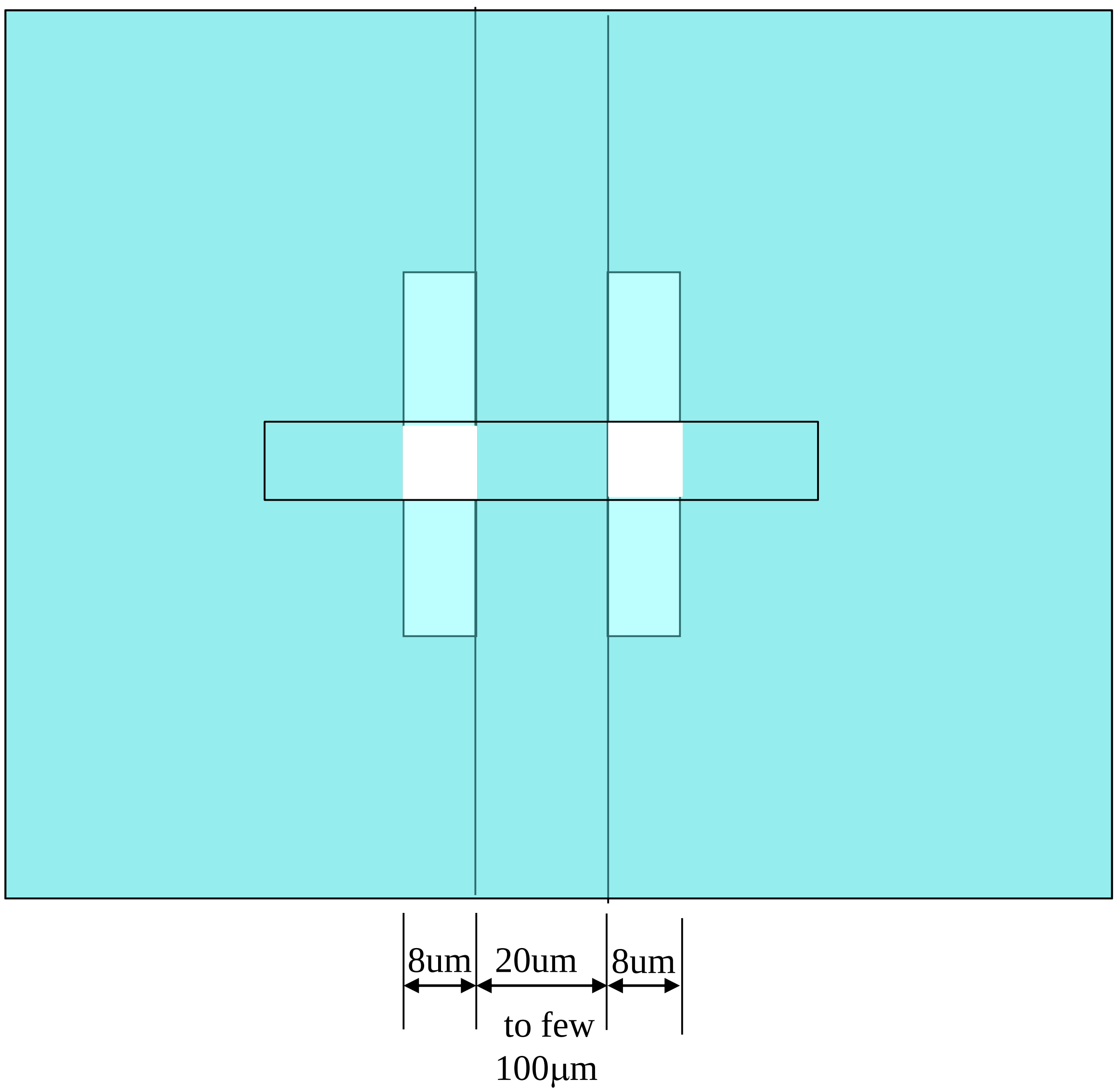
Double slit interferometer (Young type) with curved total reflection mirror (mechanically vended)



Double slit construction



Double slit construction



Summery for FCC e-e

1. X-ray interferometer has a good resolution for 5μm beam size in FCC e-e with distance of 100m.

2. The system seems very simple, and easy to construction.

3. A similar system such as crotch absorber etc. are necessary to safety extraction of X-rays.

4. Angle between beam duct and X-ray branch beam line is very small (1 mrad without total reflection mirror, 1deg with total reflection mirror) , some difficulty will be expected for duct design for example, connection flange.

Comment for longitudinal and dynamical diagnostics

Streak camera for observation of bunch by bunch longitudinal dynamical observation.

Visible SR beam line should be necessary.

Heat deposit onto the SR extraction mirror is not so larger than existing SR machine, so we can use mirror design in SR facilities.

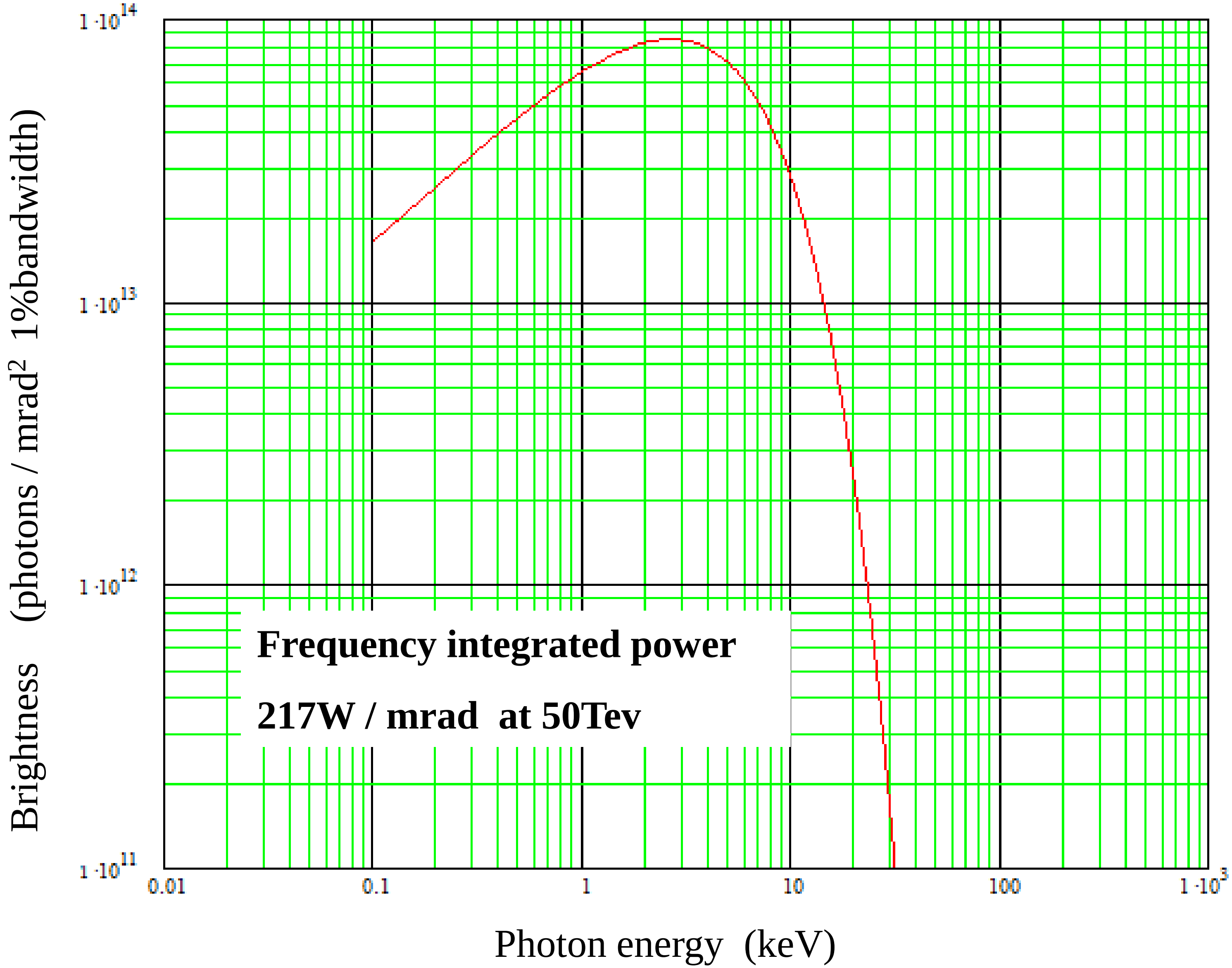
2. Measurement of beam size

in the FCC h-h

Parameters of FCC-hh

Bending magnet length	14.3m
Bending radius	10514.7m
Magnetic field strength	15.85T at 50TeV 0.951T at 3TeV
Bending angle	1.36mrad
Beam energy and current	50TeV 500 mA 3TeV injection
emittance	20pmrad
Estimated beam size	σ_y =30μm / β=60m σ_y ≈200μm / high β σ_x =30μm / β=60m σ_y ≈200μm / high β

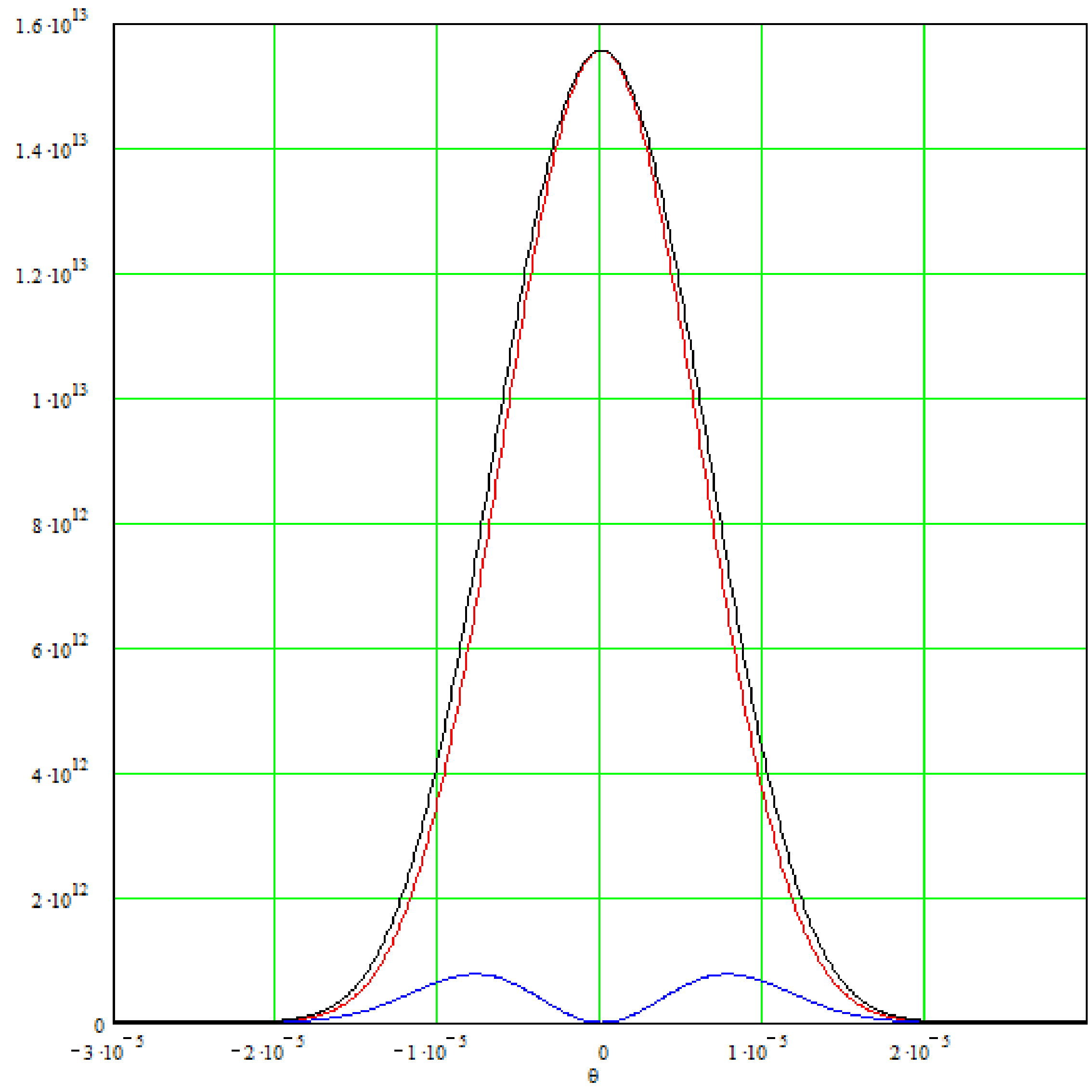
Expected spectrum from the bending magnet FCC-HH at 50TeV



50TeV

ρ=11590.8m

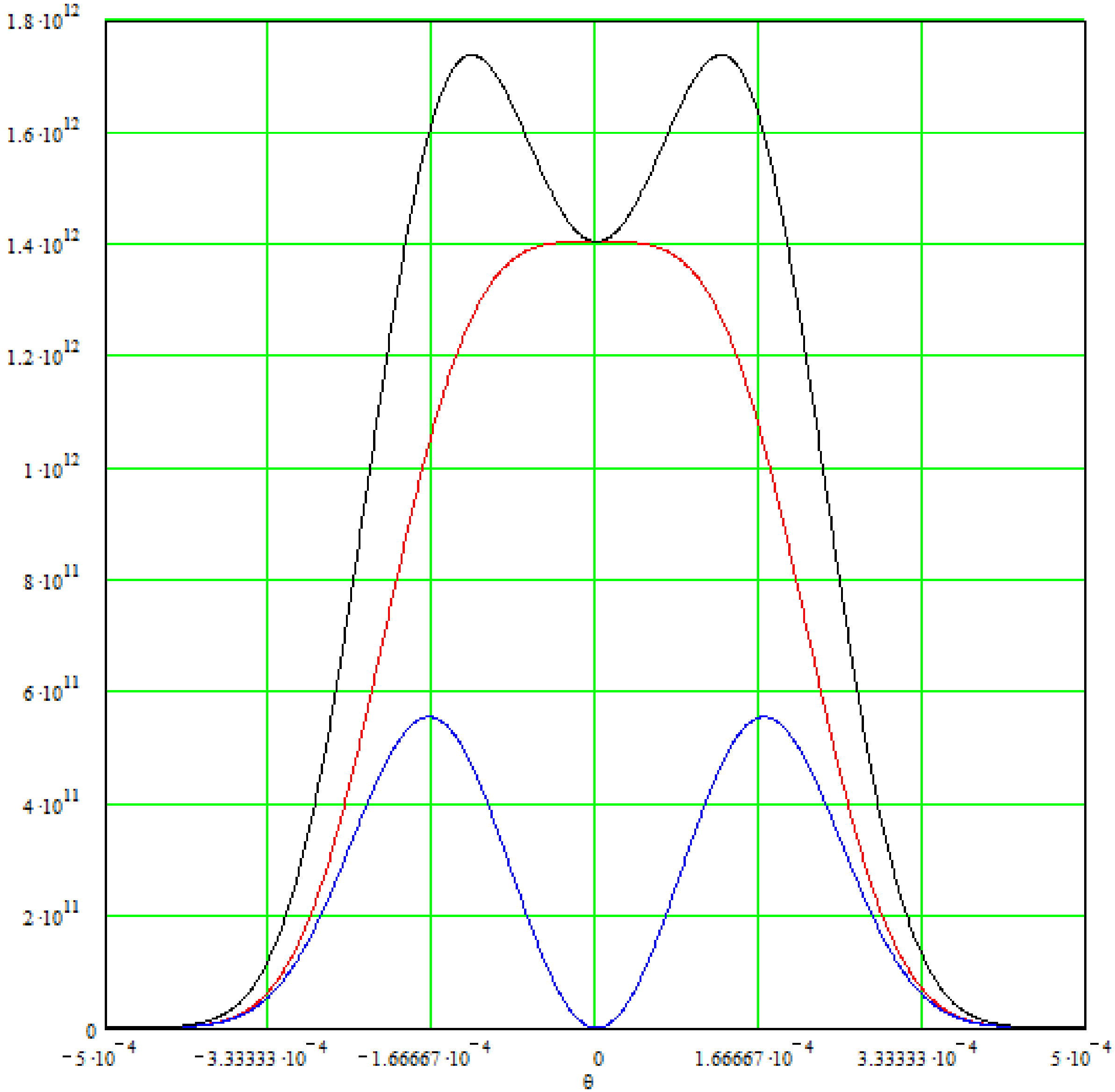
λ=0.1nm



50TeV

ρ=11590.8m

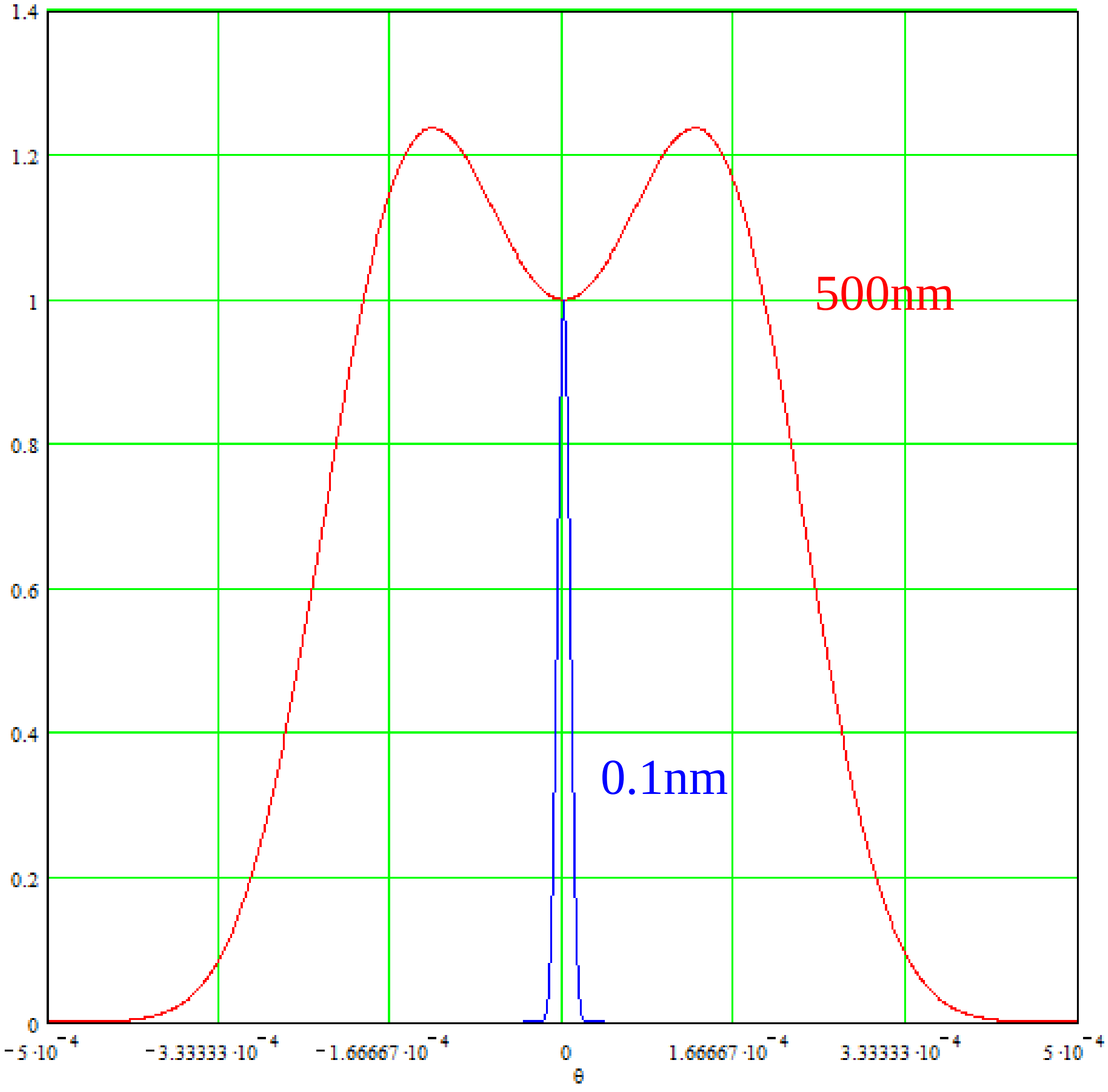
λ=500nm



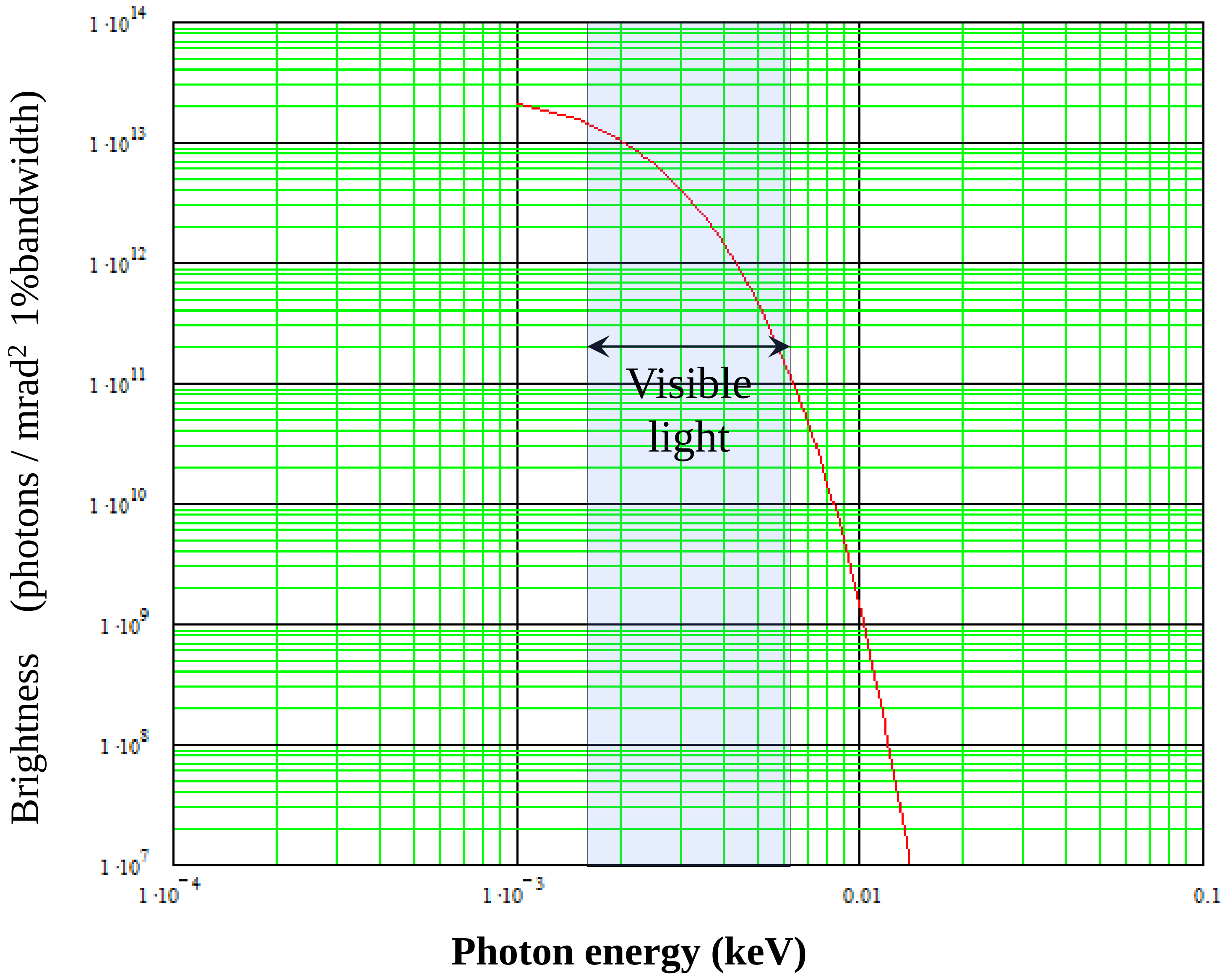
Comparison

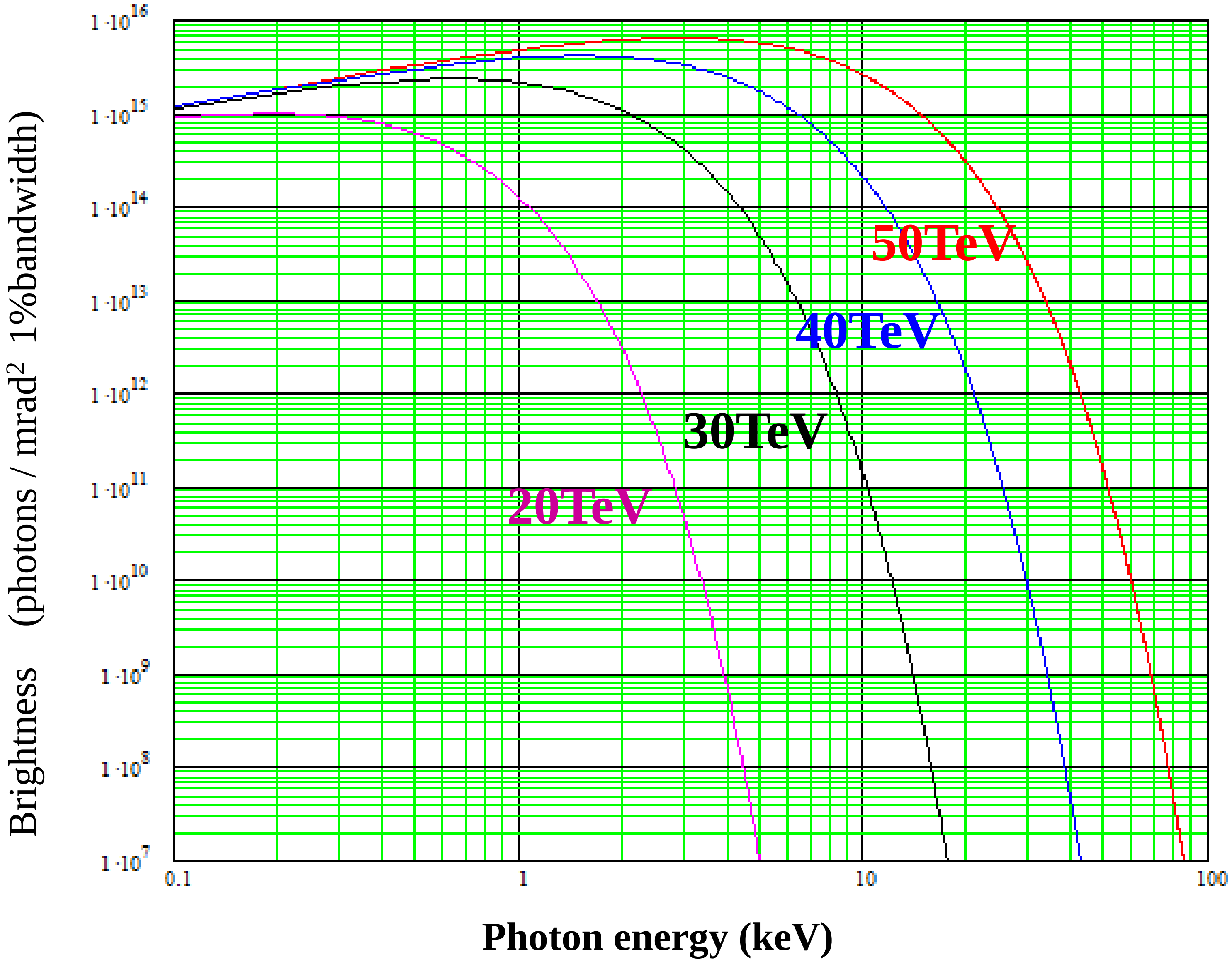
λ=0.1nm

λ=500nm



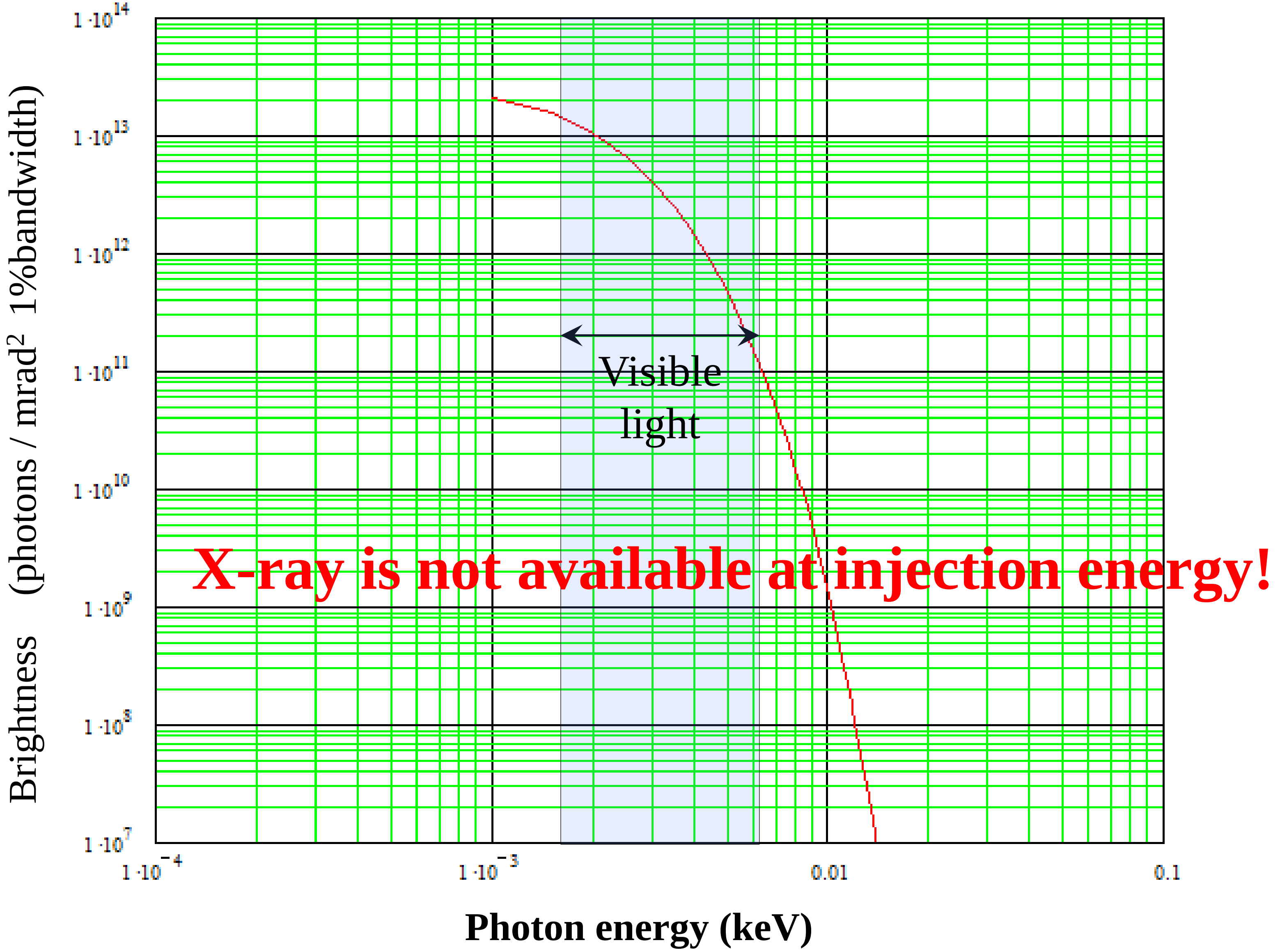
Expected spectrum from the bending magnet FCC-HH at 3TeV



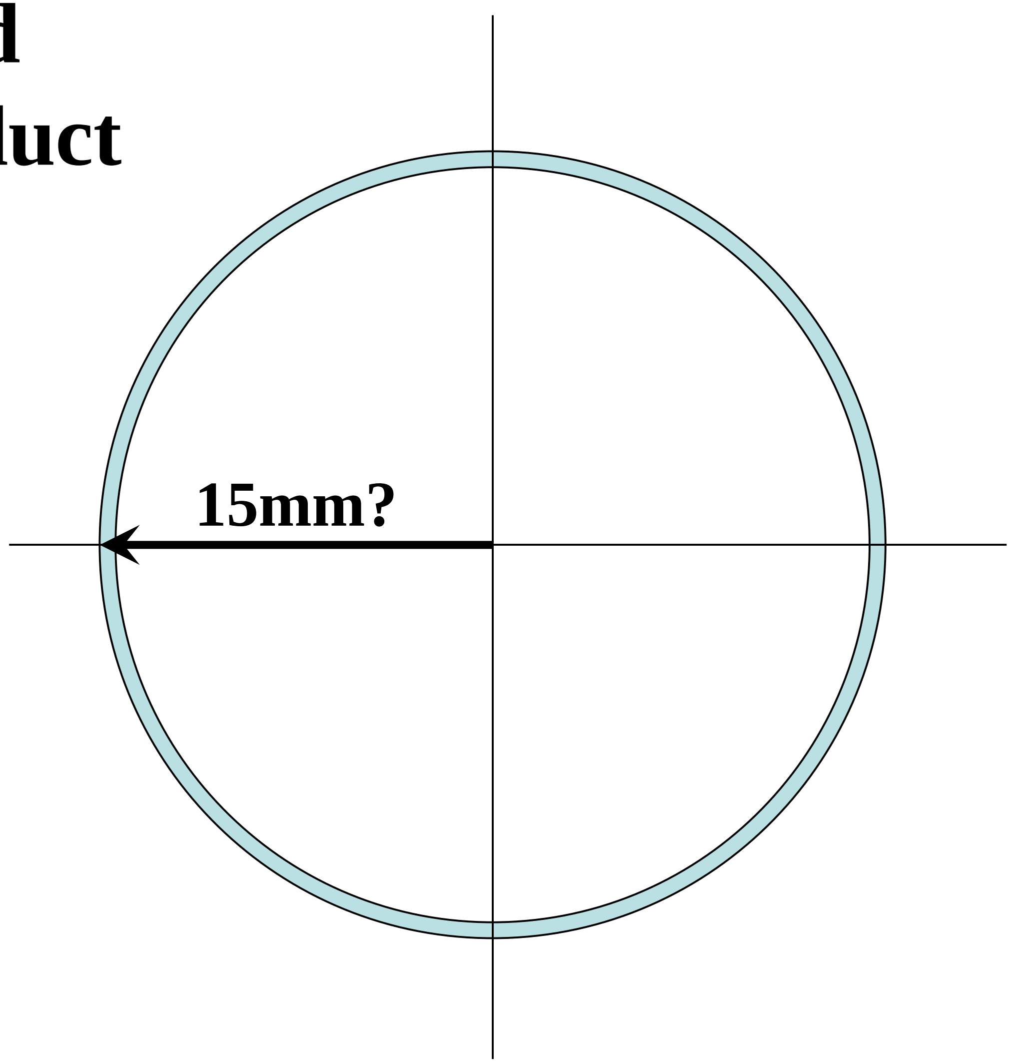


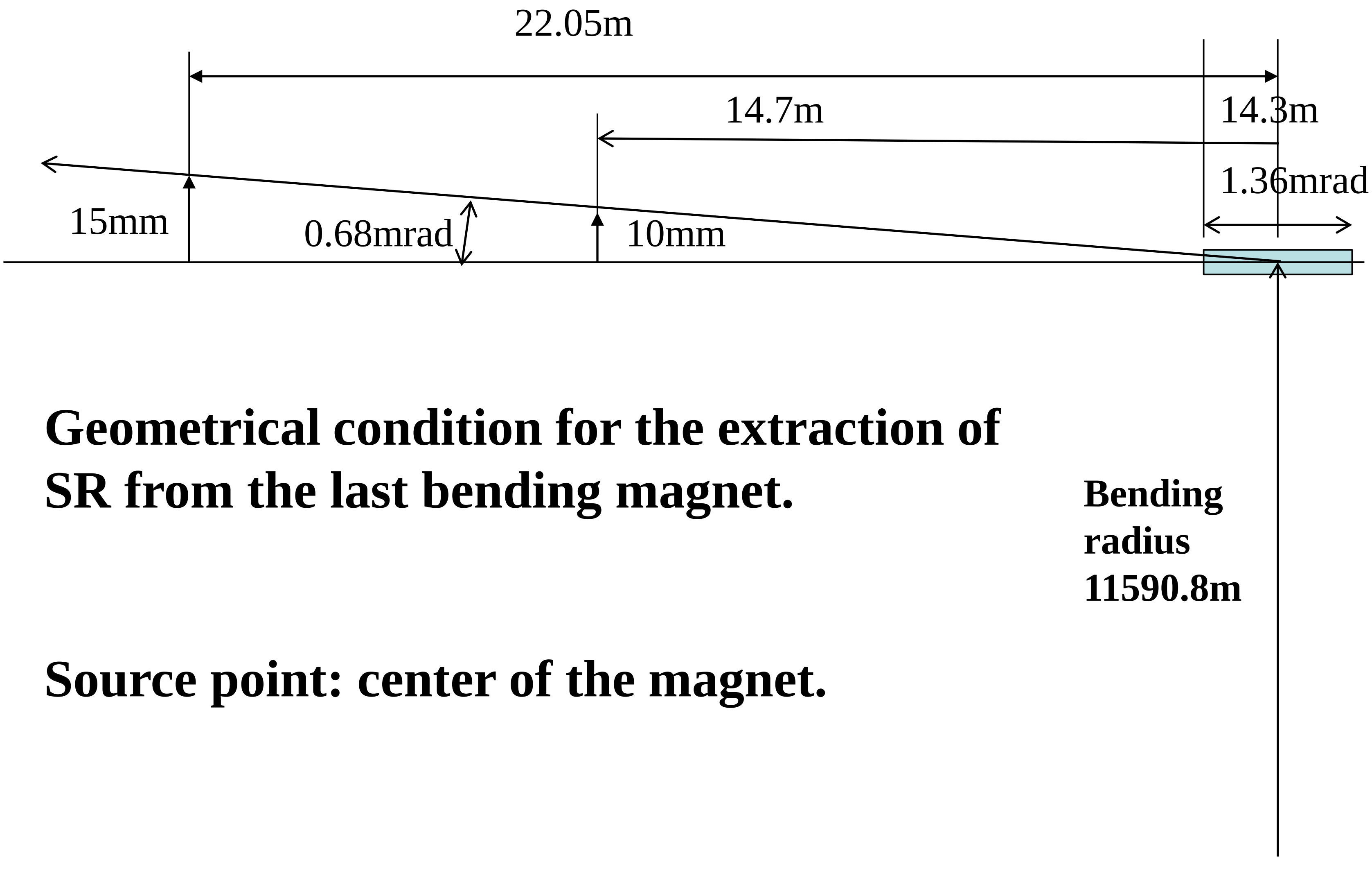
Brightness (photons / mrad² 1%bandwidth)
1·10^16
1·10^15
1·10^14
1·10^13
1·10^12
1·10^11
1·10^10
1·10^9
1·10^8
1·10^7
50TeV
40TeV
30TeV
20TeV
0.1
1
10
100
Photon energy (keV)

Expected spectrum from the bending magnet FCC-HH at 3TeV



Estimated vacuum duct

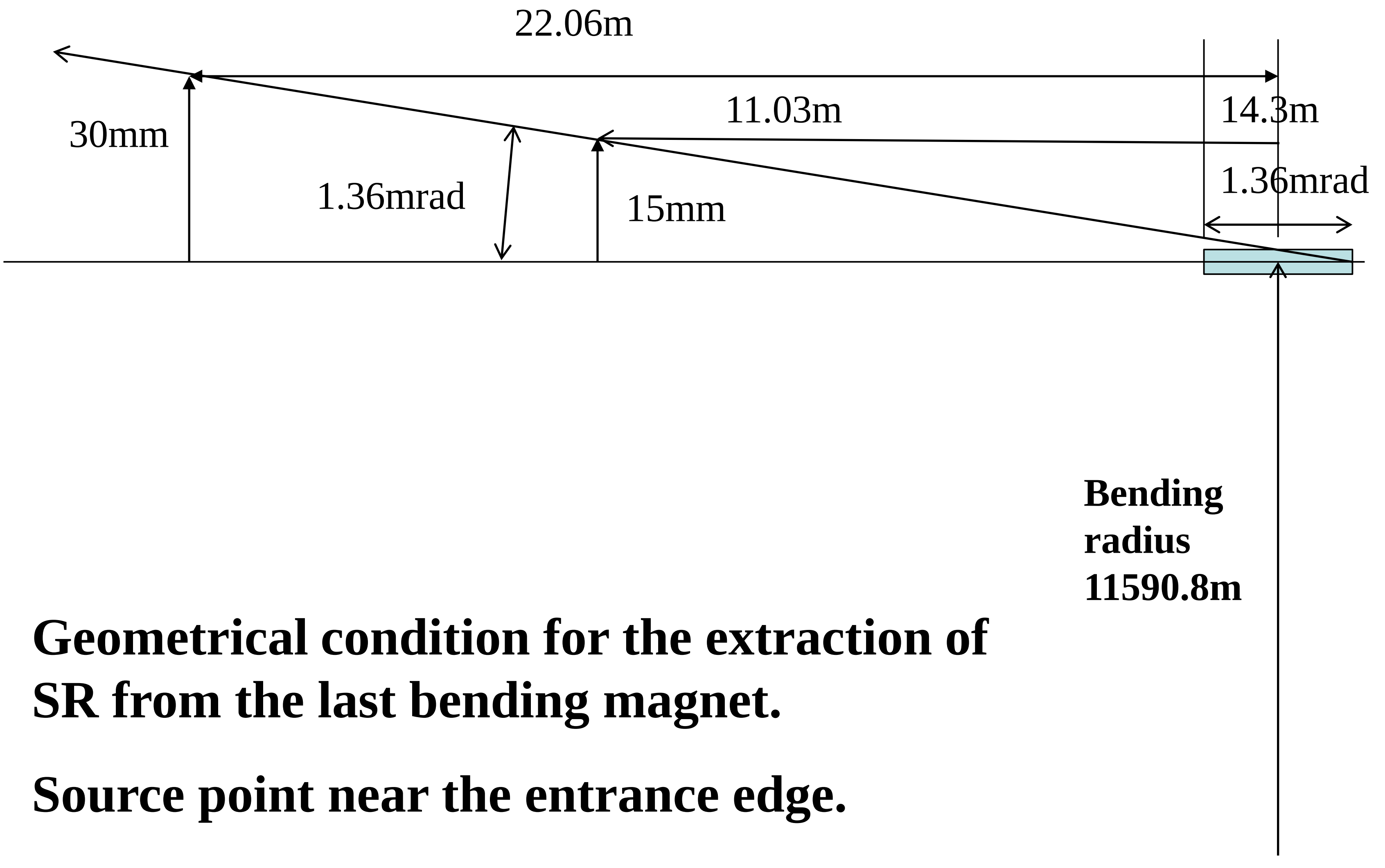




Geometrical condition for the extraction of SR from the last bending magnet.

Bending radius 11590.8m

Source point: center of the magnet.



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

Source point near the entrance edge.

Summary of SR in FCC h-h

1. **Visible SR is available for all energy range.**
2. **X-ray is available in higher than 30TeV**

For the SR source, the complicated scheme as in LHC;

Wavelength shifter for injection energy

Edge radiation for middle energy range

Bending radiation for high energy range

are not necessary.

Various diagnostics system using visible SR in the LHC will be useable for all Energy range.

Imaging system

Coronagraph

Streak camera

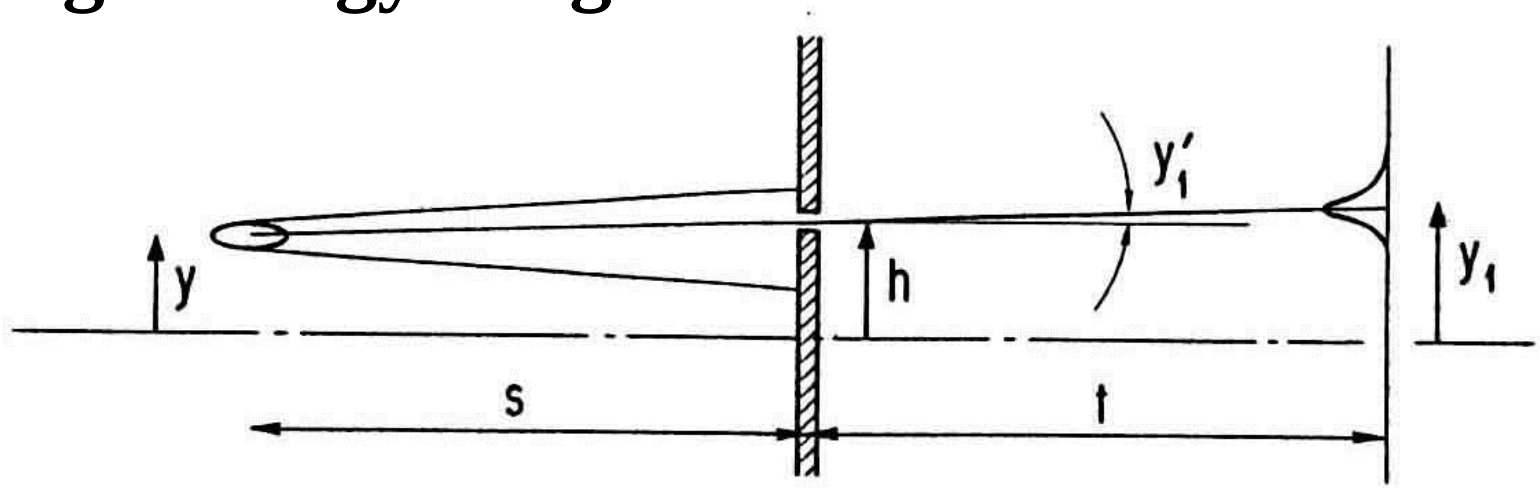
We need large β section for SR source to obtain larger beam size

SR Interferometer

etc.

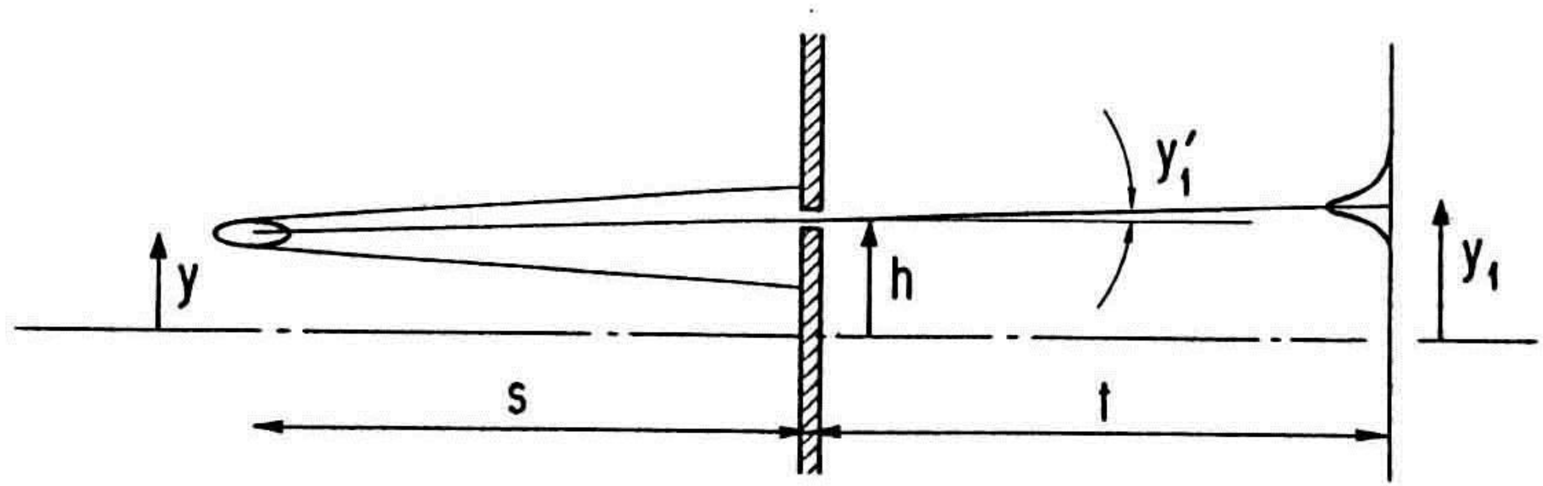
Heat deposit onto SR extraction mirror is larger than LHC due to hard X-ray component, but not larger than existing SR facilities. But still direct cooling for mirror seems key issue.

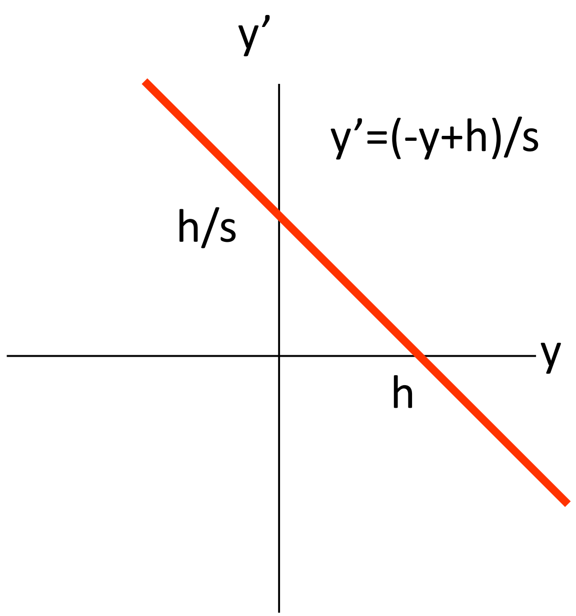
A simple X-ray pinhole camera should be convenient for beam profile/size monitor in high energy range



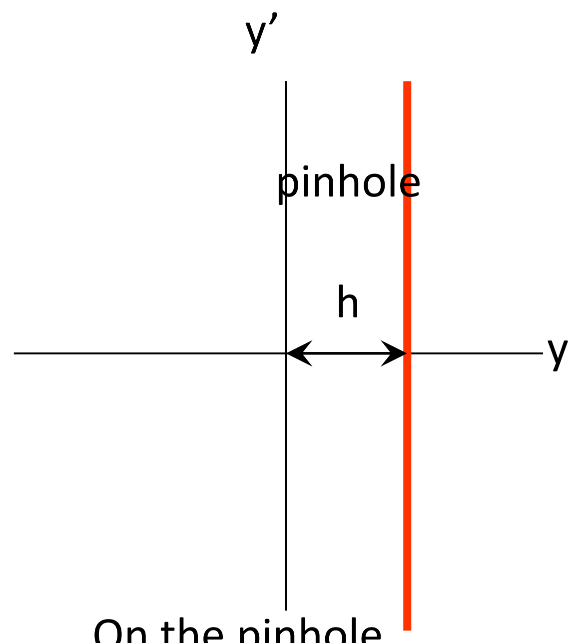
$$\begin{pmatrix} y_1 \\ y_1' \end{pmatrix} = \begin{pmatrix} 1 & s+t \\ 0 & 1 \end{pmatrix} \begin{pmatrix} y \\ y' \end{pmatrix} .$$

Representation in the phase space





On the source point



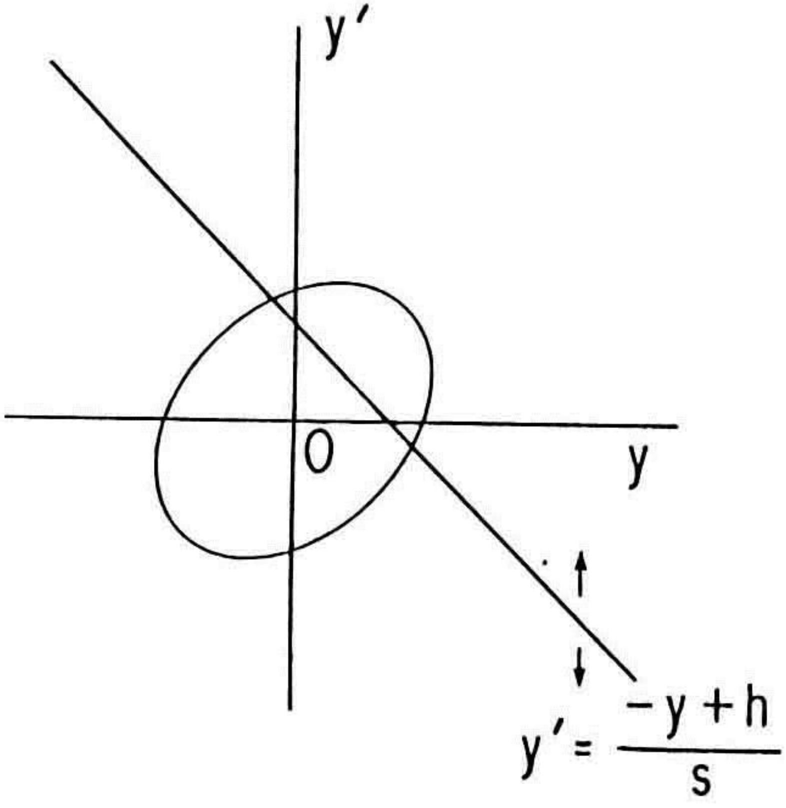
On the pinhole

Pinhole in phase space on source point

$$\begin{pmatrix} h \\ y'_p \end{pmatrix} = \begin{pmatrix} 1 & s \\ 0 & 1 \end{pmatrix} \begin{pmatrix} y \\ y' \end{pmatrix}$$

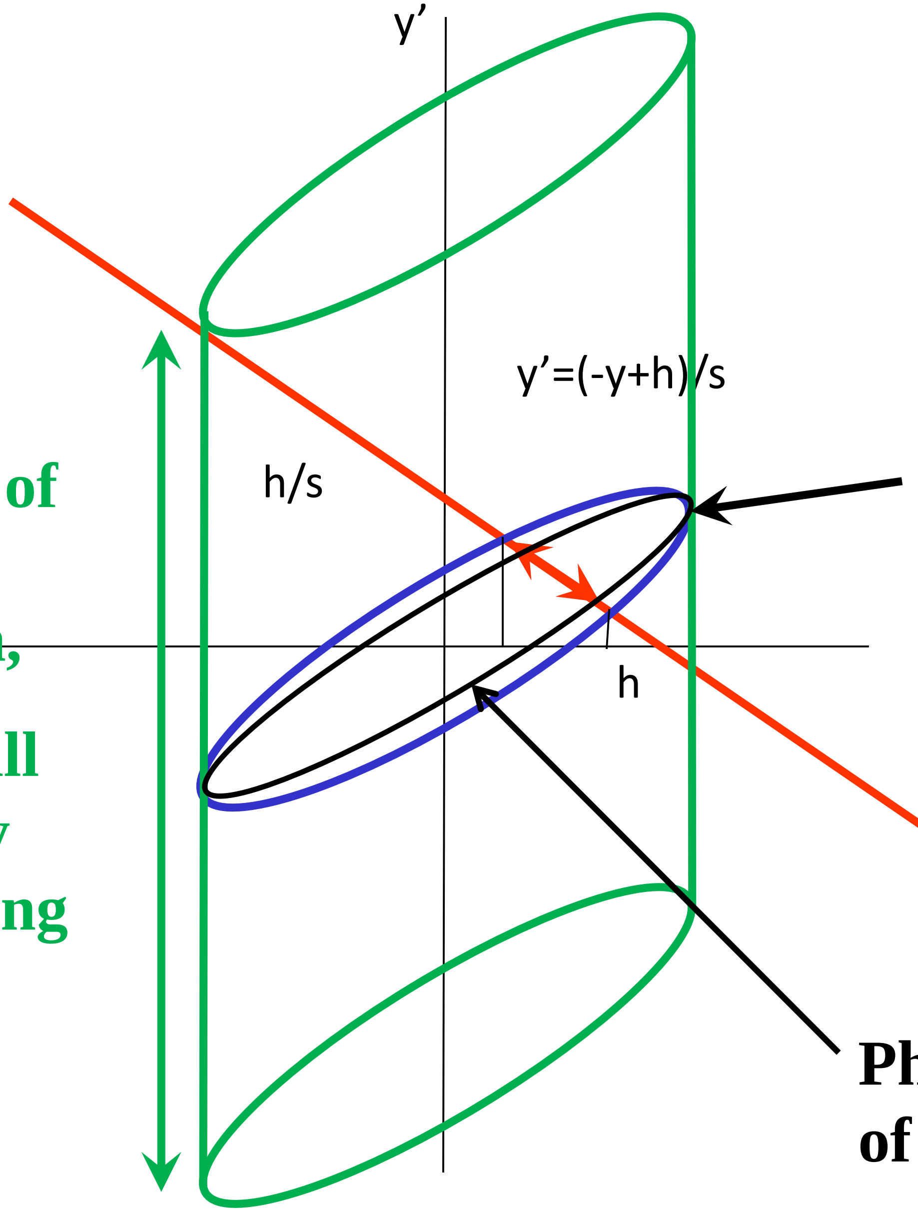
$h = y + sy'$

$y' = (-y + h)/s$



In the case of longer wavelength,

ellipsoid will smeared by large opening angle of radiation

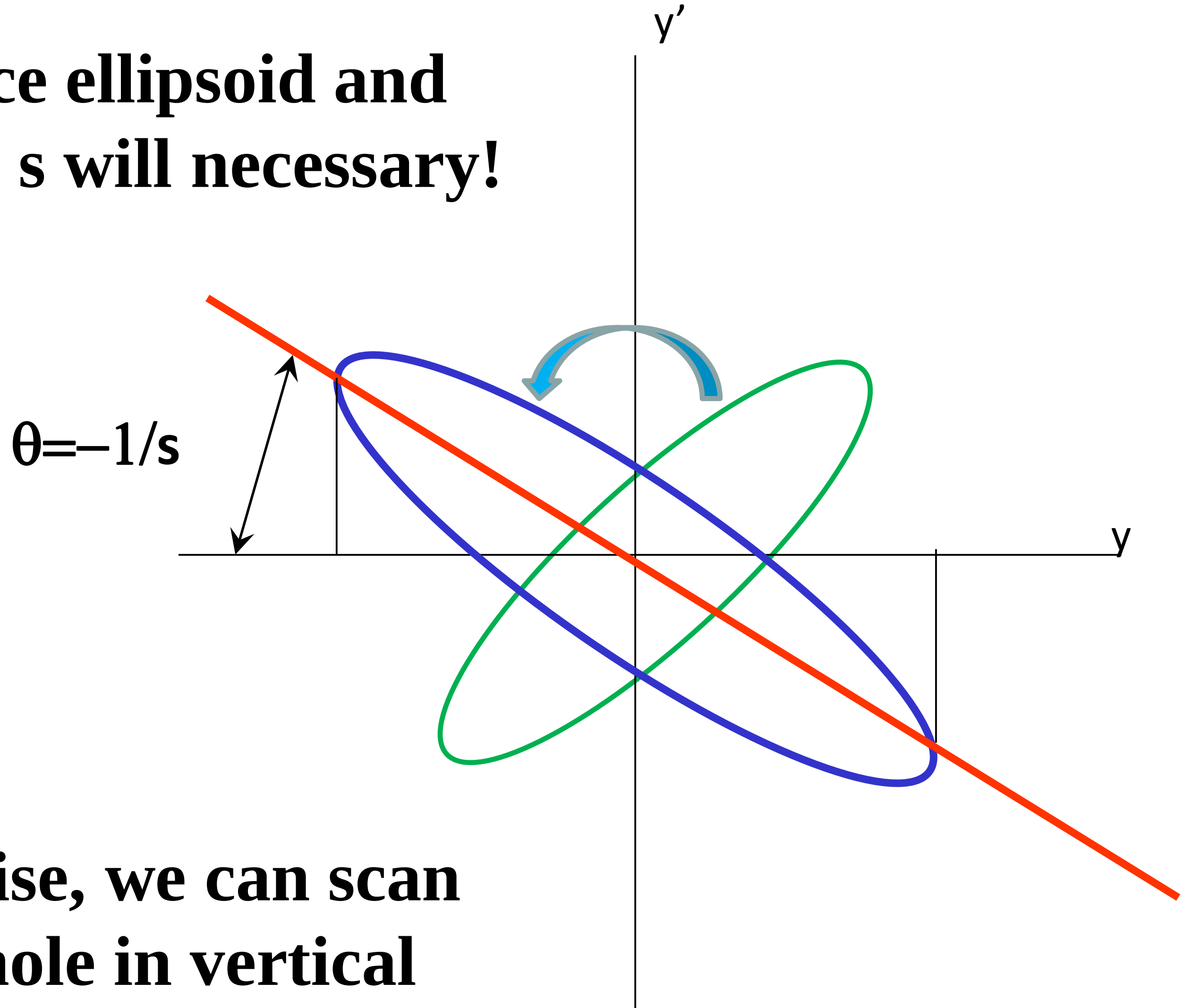


In the case of short wavelength such as X-ray

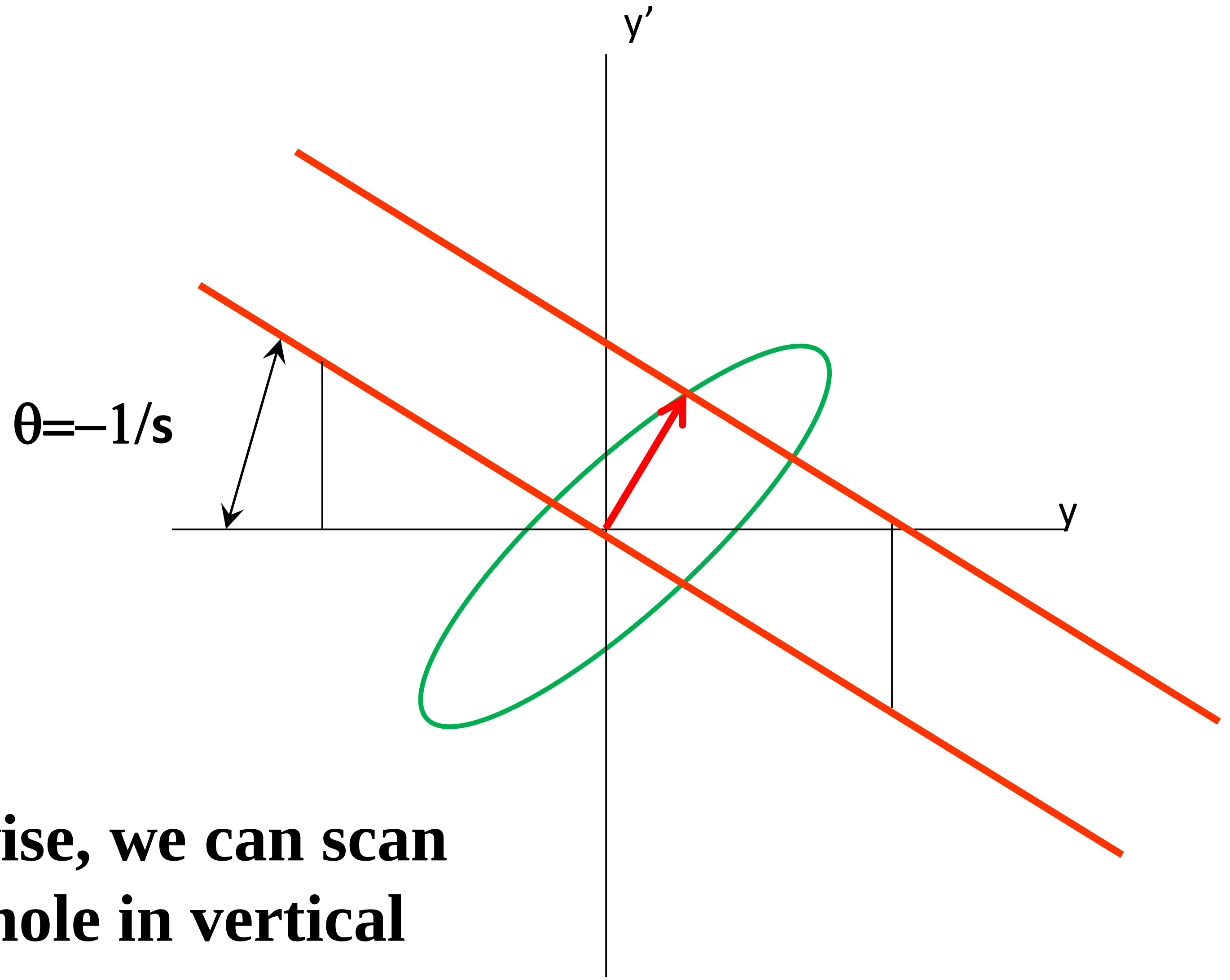
Phase space plot of proton beam

Optimization between

emittance ellipsoid and distance s will necessary!



Otherwise, we can scan the pinhole in vertical



Otherwise, we can scan the pinhole in vertical

Summery for FCC H-H

1. We can use visible SR for all energy range for diagnostics.

2. The hard X-ray is available higher than 40TeV.

3. Various diagnostics system using visible SR in the LHC will be useable for all Energy range.

4. Simple pinhole camera should be convenient for beam size measurement at 40-50TeV.

*** Request for SR source point**

1. **For the pinhole camera, we need to optimize lattice parameter at the source point.**
2. **For the convenience of diagnostics, we need *high β-section* to obtain a large beam size at the source point.**
3. **Dedicated source point such as chicane will be necessary in *high β-section.***

*** For the visible SR extraction mirror**

Heat deposit onto the extraction mirror is larger than LHC.

We need to consider direct cooling of extraction mirror.

(water cooling or liquid Nitrogen cooling)