Design and Construction of Optical System of the Coronagraph for Beam Halo Observation in SuperKEKB

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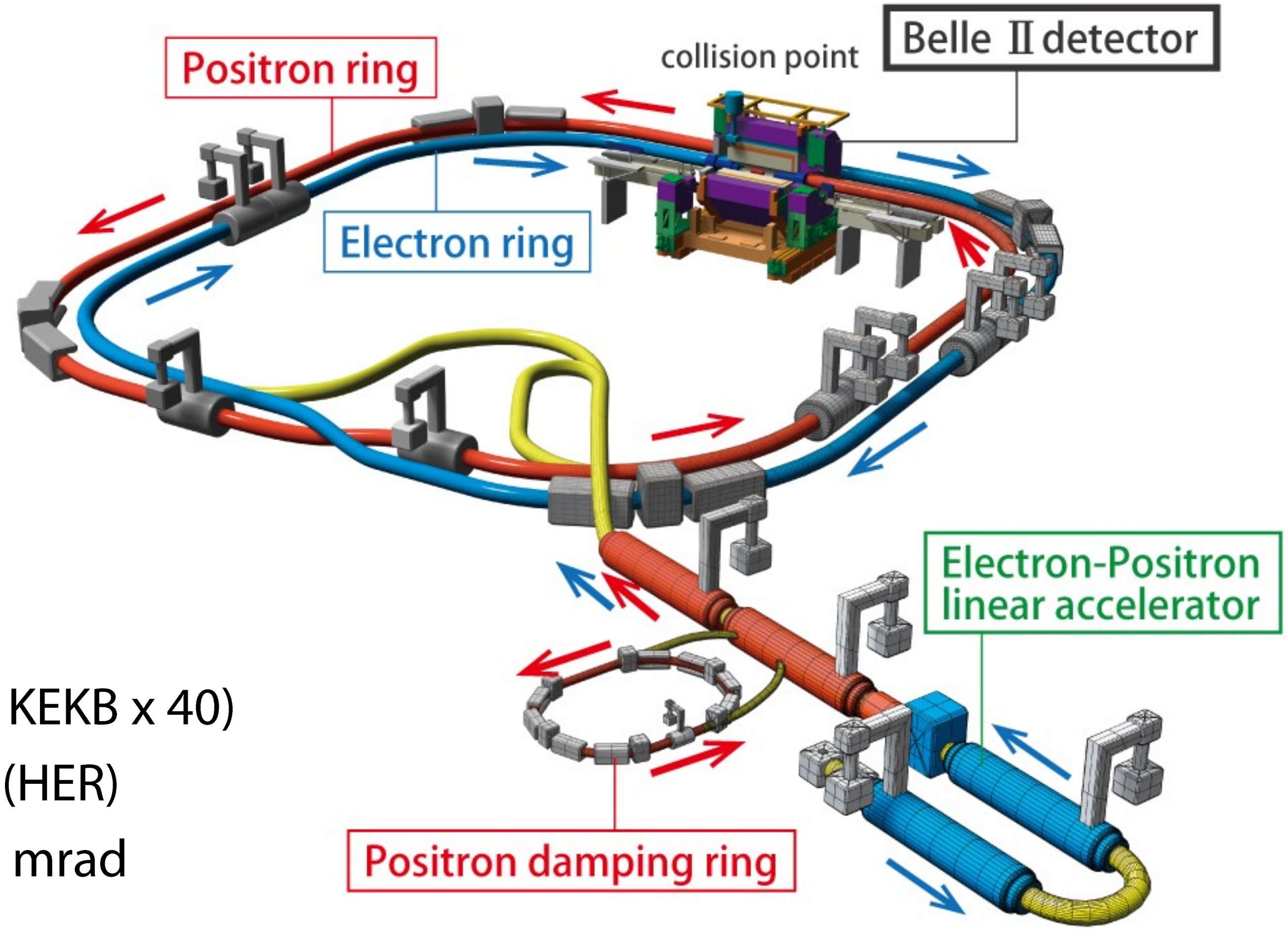
Outline

- Introduction to the SuperKEKB e^+e^- collider
- Design and construction of the coronagraphs in SuperKEKB
- First measurements in the SuperKEKB low/high energy rings
- Summary

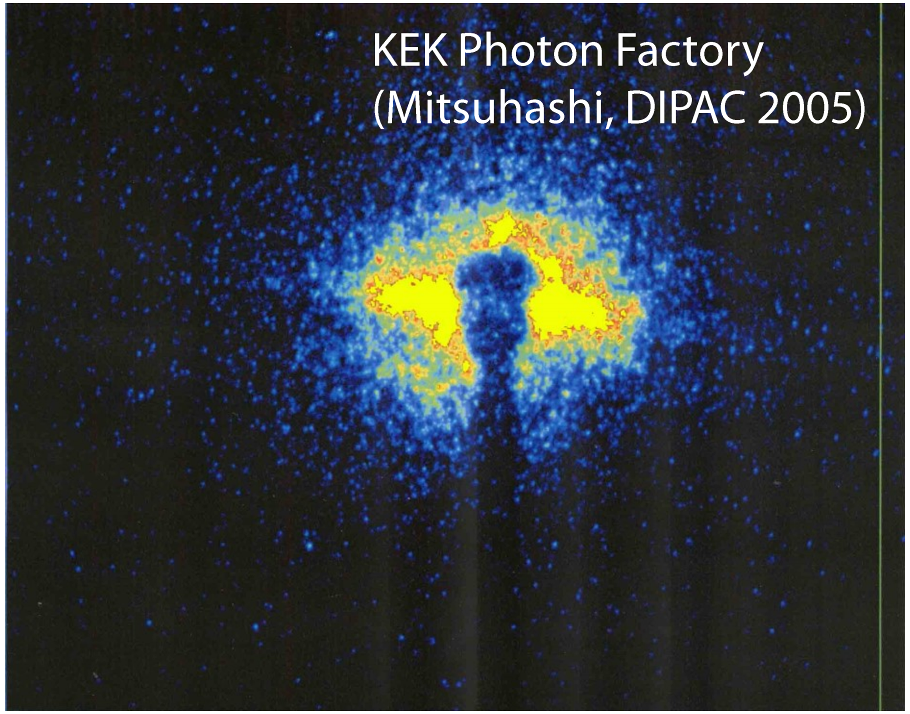
The SuperKEKB e^+e^- collider

See MOPLXGD1 (Funakoshi)

- Major upgrade to the preceding KEKB e^+e^- collider
- Provides tons of B, τ, etc. to Belle II
- Two main rings
  - 7 GeV e^- storage ring (HER)
  - 4 GeV e^+ storage ring (LER)
- Injector complex
  - Electron/positron linac
  - 1.1 GeV positron damping ring (DR)
- "Nano-beam" collision scheme
- Design parameters
  - Target Luminosity: 8×10^{35} $cm^{-2}s^{-1}$ (= KEKB x 40)
  - Beam Currents: 3.6 A (LER) and 2.6 A (HER)
  - Horizontal crossing Angle: 41.5+41.5 mrad
  - $\beta_y^* \sim 0.3$ mm
  - $\sigma_x^* \sim 10$ μm, $\sigma_y^* \sim 50$ nm, $\sigma_z \sim 6$ mm



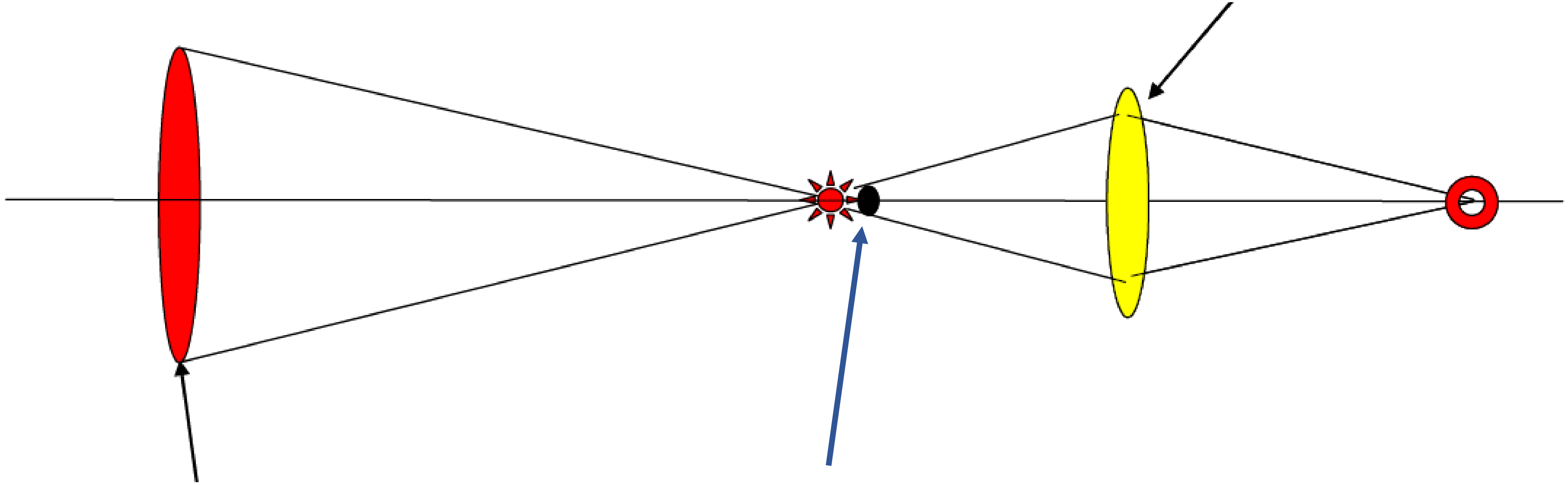
Eclipse of the Sun and accelerators



- Beam halo may cause unwanted beam loss or long-term irradiation leading to luminosity degradation and damage to accelerator components.
- Understanding and hopefully lowering beam halos have been attempted in high-power and/or high-luminosity accelerators.
- **Our challenge: non-invasive measurements with sensitivity better than 1e-5.**

Can we use a normal telescope to see beam halo?

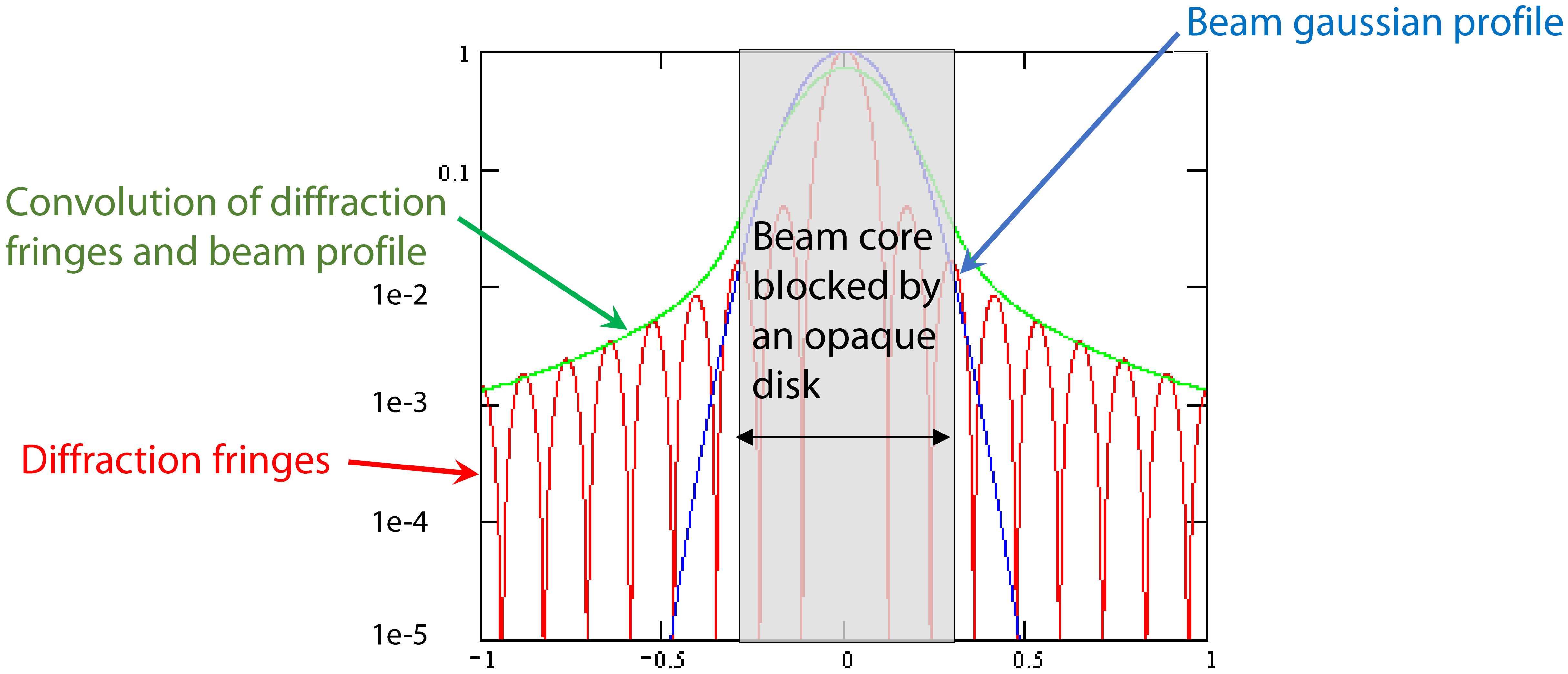
Magnifier lens



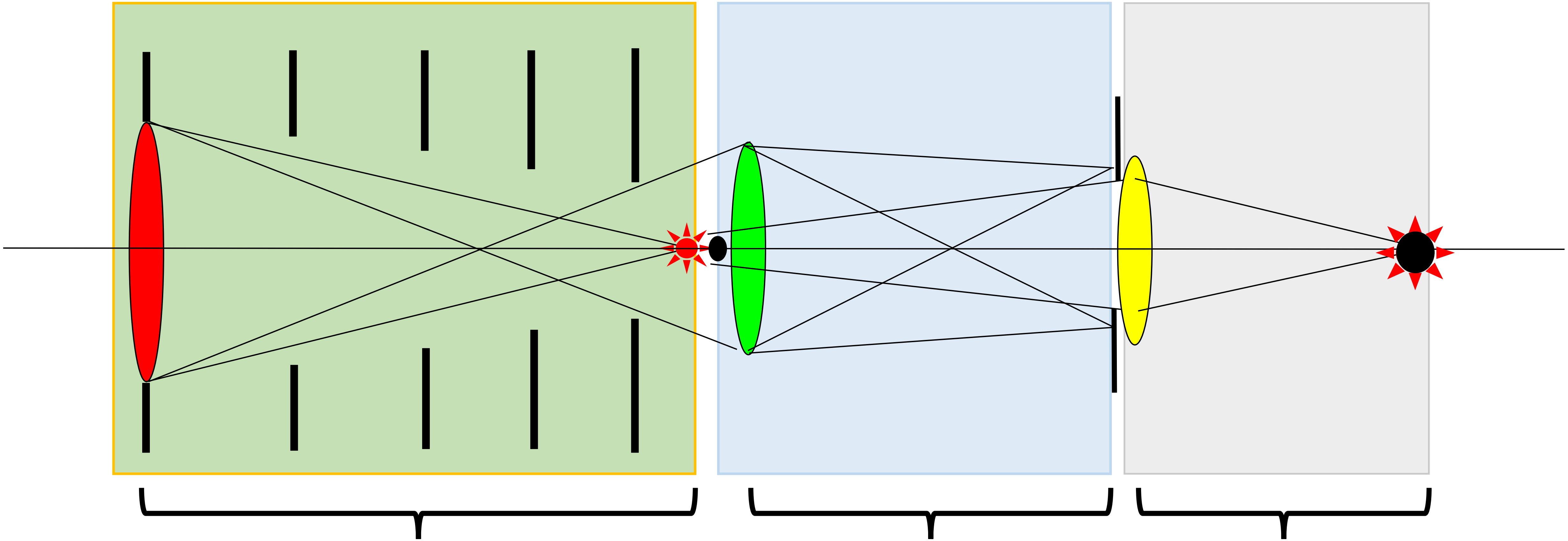
Objective lens

How about blocking glare of a beam core by an opaque disk?

We aren't free from strong diffraction fringes



Three stages of the Lyot's coronagraph

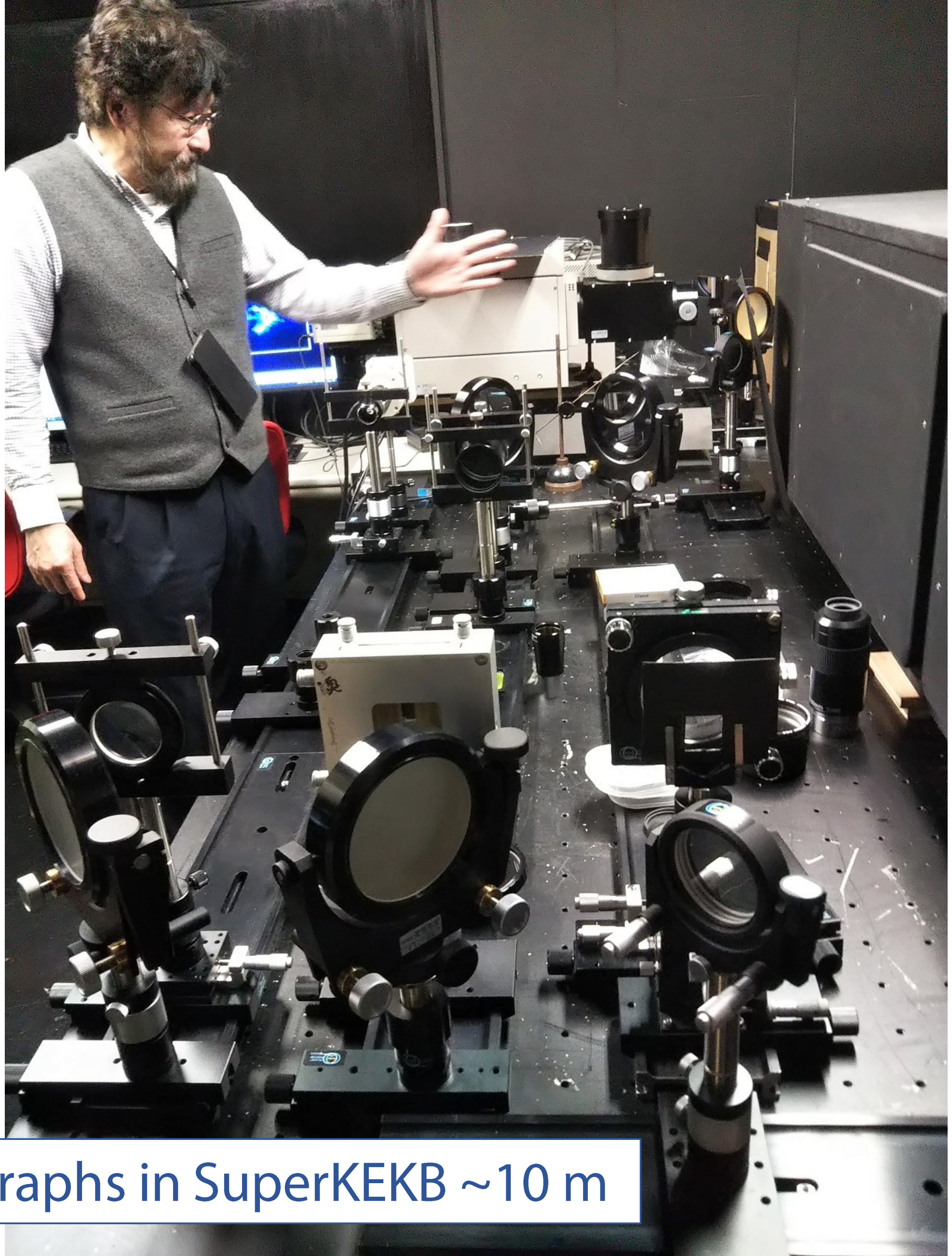


1st stage:
Objective lens system

2nd stage:
Re-diffraction system

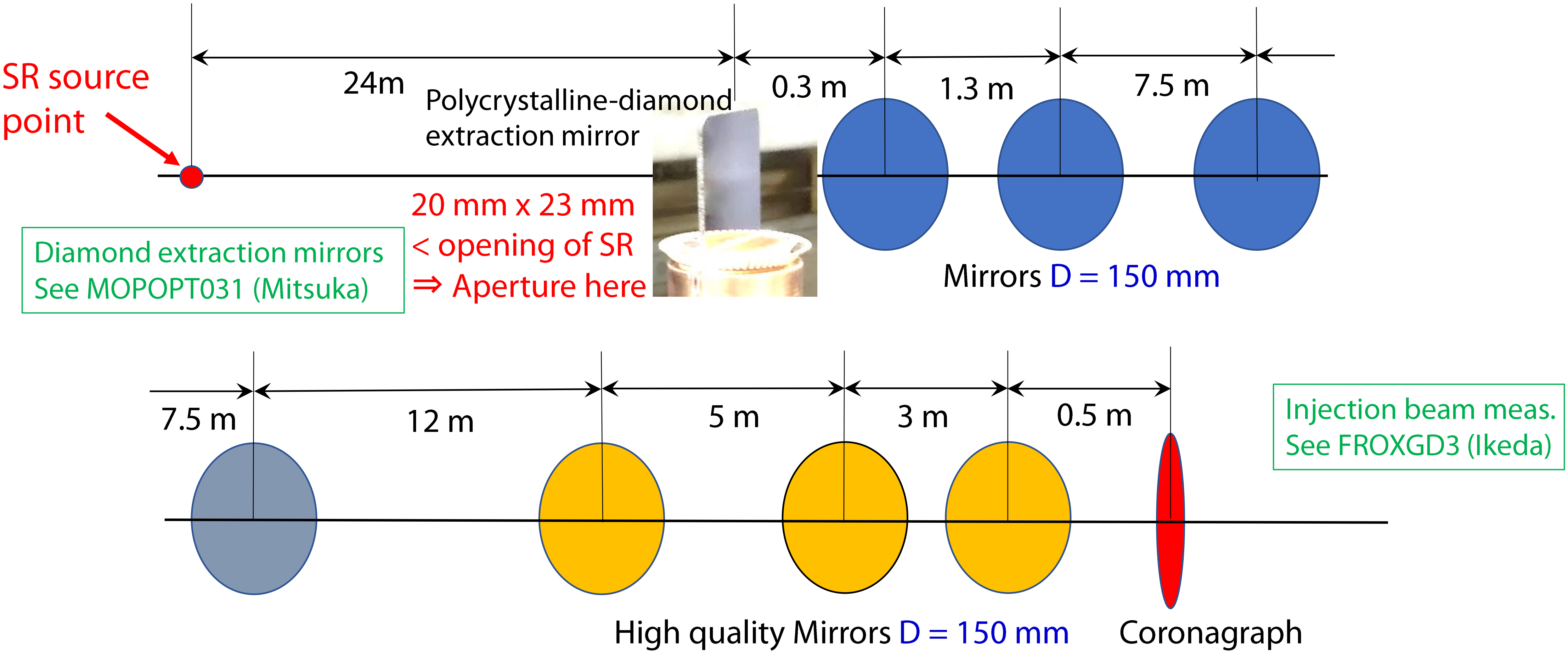
3rd stage:
Relay lens

Ref: B. F. Lyot Month. Notice Roy. Ast. Soc, p580, 99 (1939).



Length of the coronagraphs in SuperKEKB ~10 m

Synchrotron radiation beam line in SuperKEKB



Coronagraph is ~60 m downstream of the SR source point.

Key parameters in the 1st objective stage design

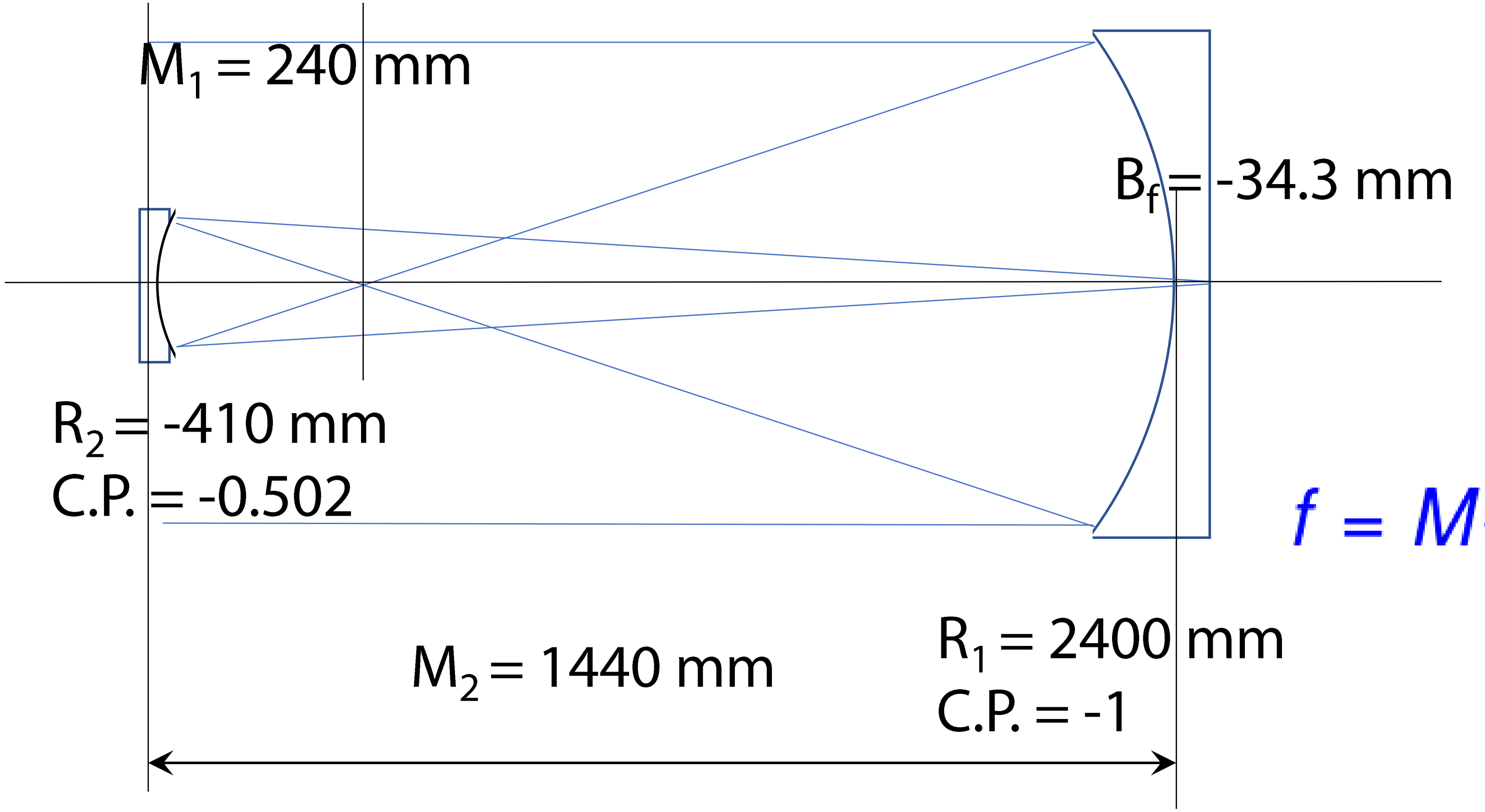
1. Large transverse magnification is necessary, because leakage backgrounds in the 3rd stage are anti-proportional to the transverse magnification of the 1st objective system.
   → Needs long focal length

2. Front principal plane of the objective system is set at the diamond mirror aperture.

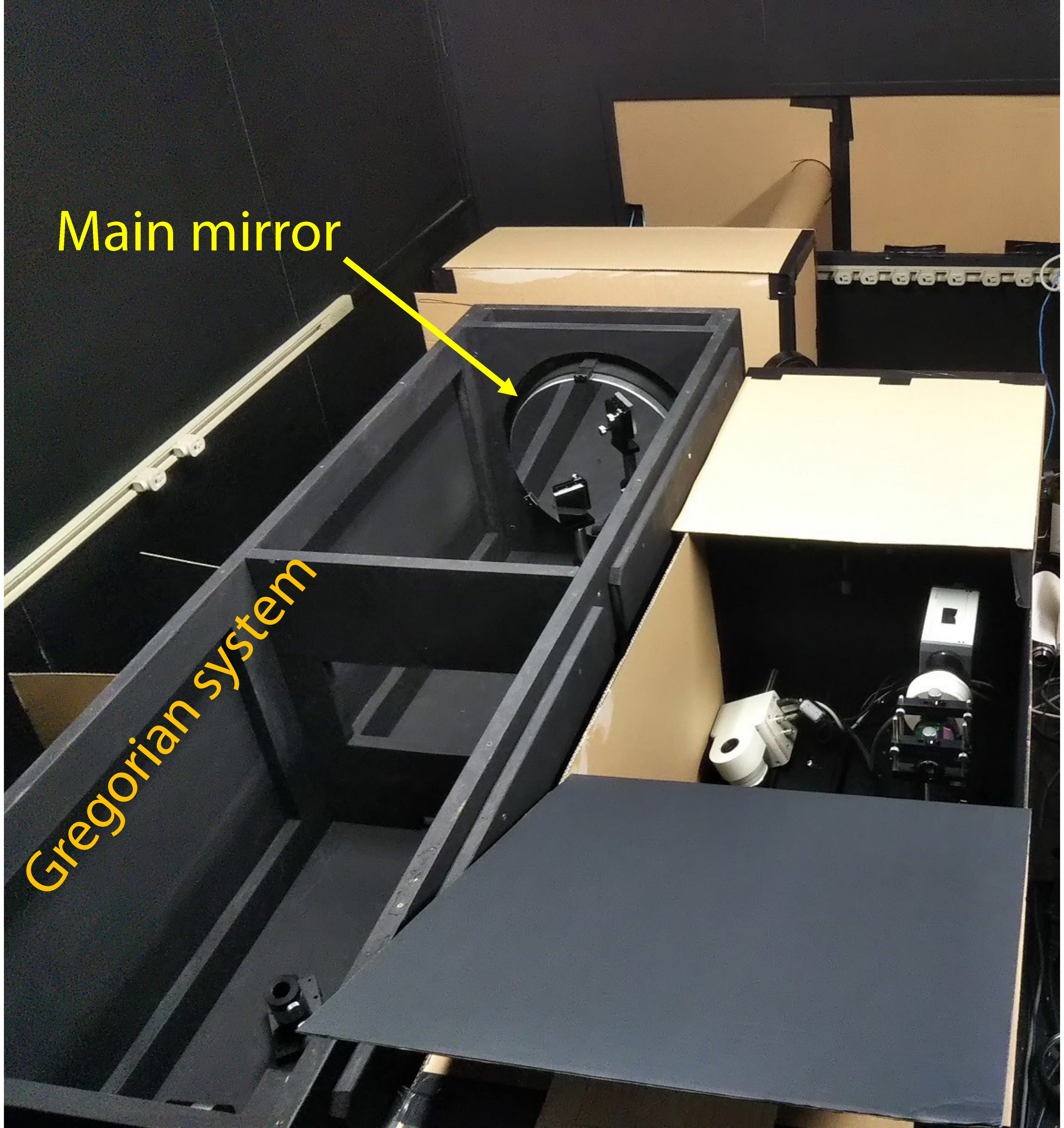
We follow a telephoto system for the 1st objective system.

Gregorian system in the 1st objective stage

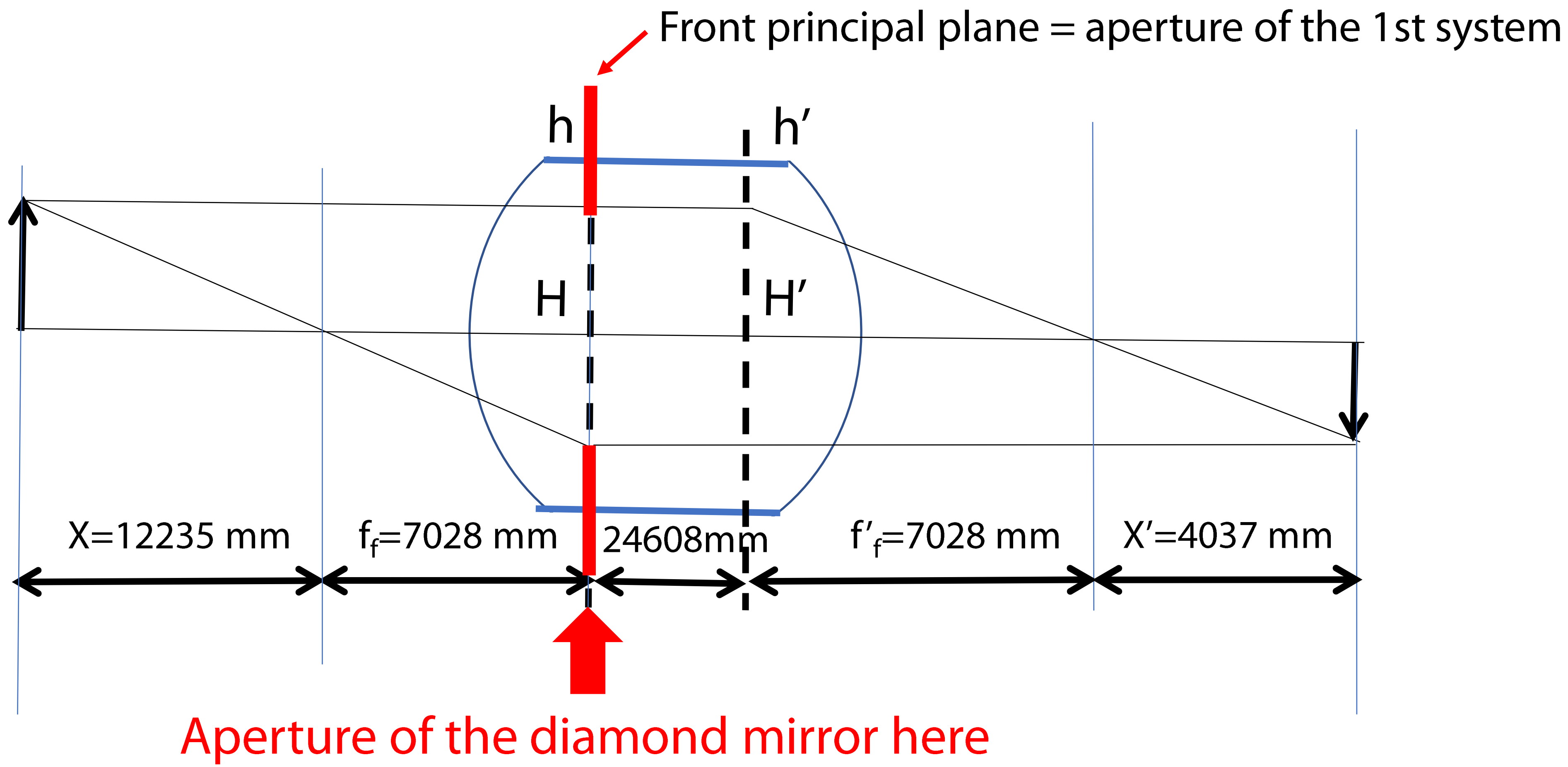
- To eliminate a chromatic aberration, the 1st system adopts a reflective mirror system rather than a refractive lens system.
- We choose a Gregorian system using an elliptical-concave second mirror contrary to a Cassegrain system using a hyperbolic-convex mirror.



$$f = M\frac{R_1}{2} = 7028\ \mathrm{mm}$$

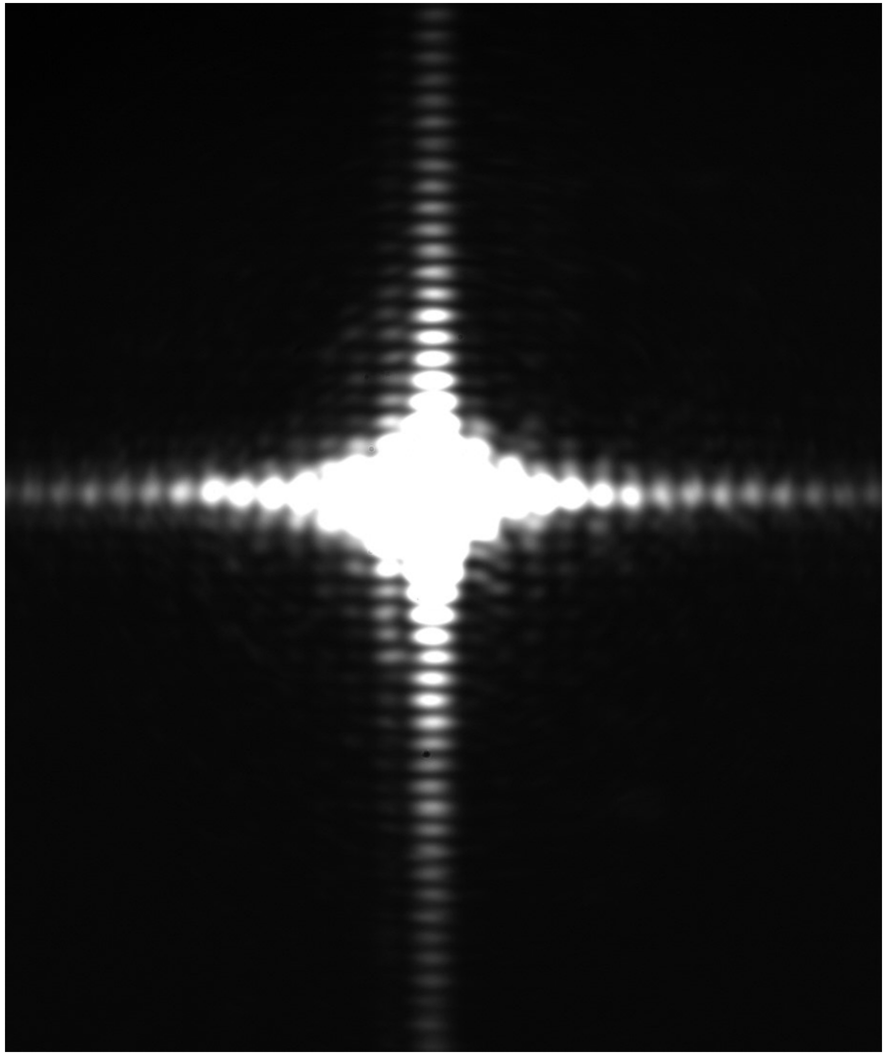

Main mirror
Gregorian system

Relation of source point and mirror image



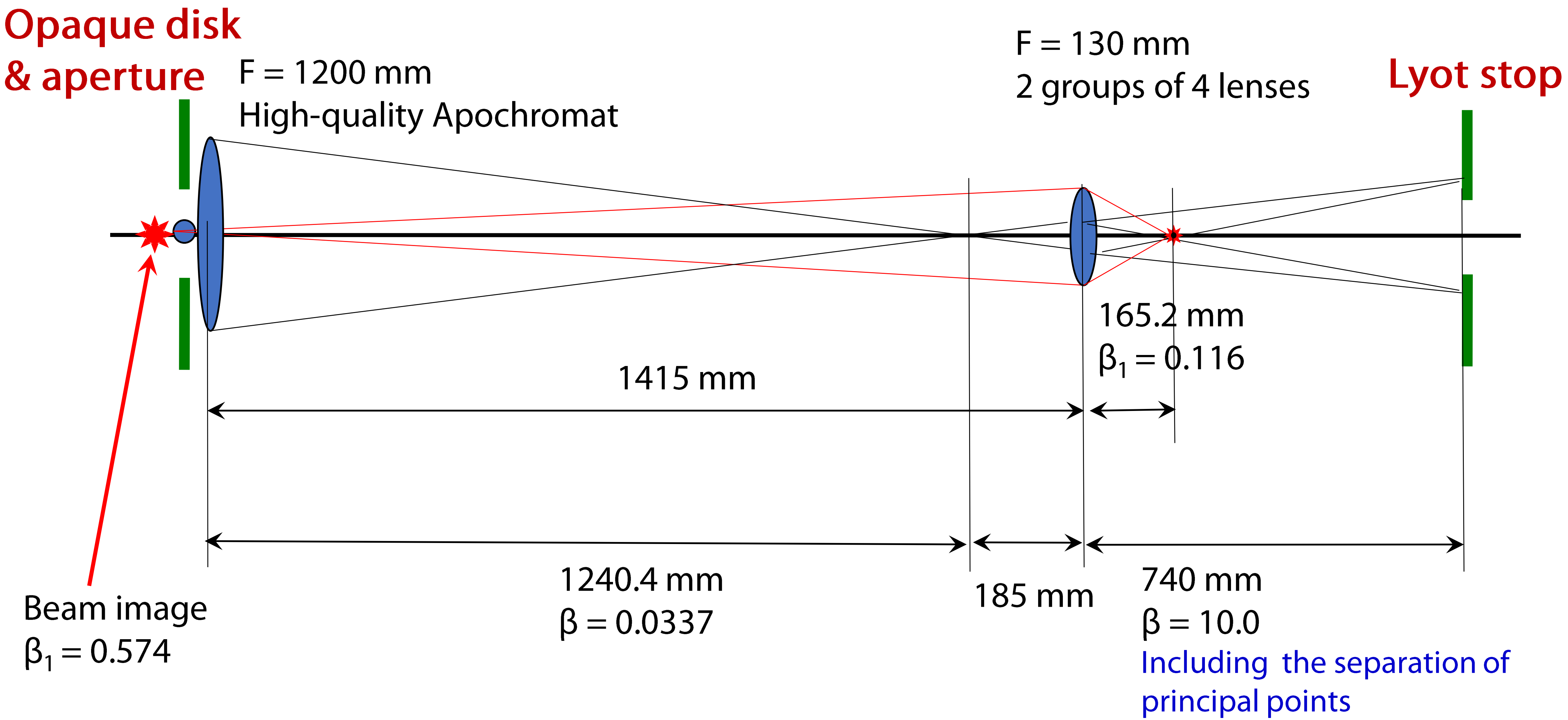
Transverse magnification $\beta = \frac{7028}{12235} = 0.574$

Beam image and diffraction fringes

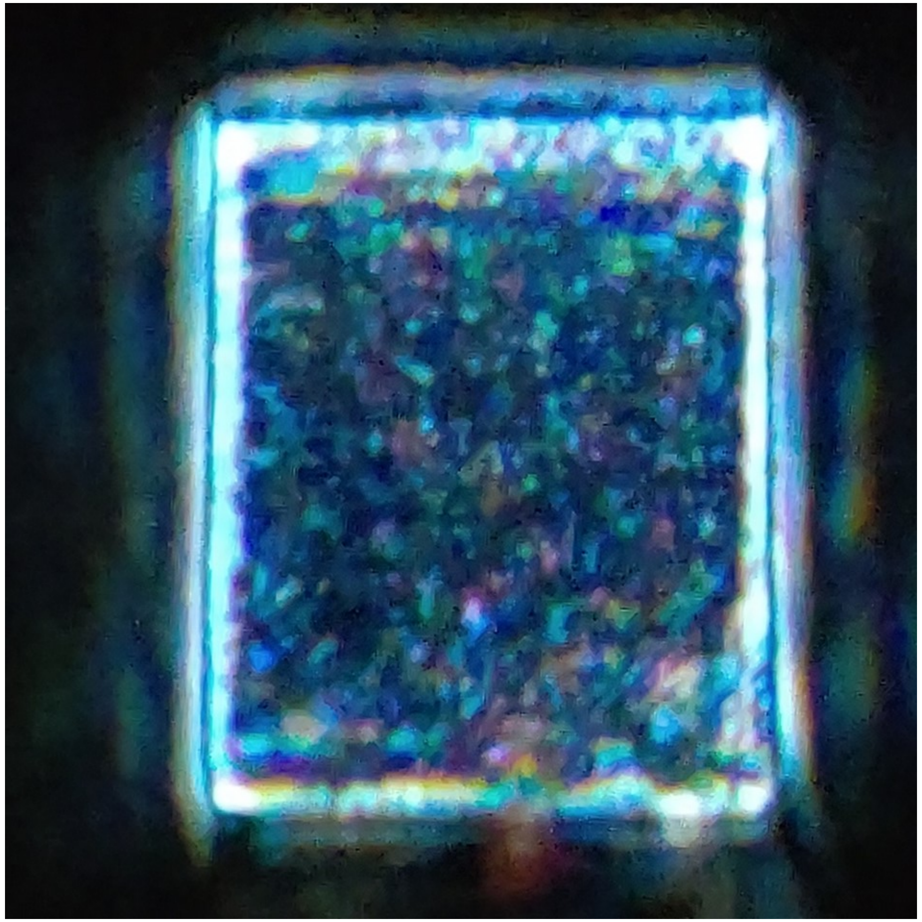


Clearly observed ~15th order fringes

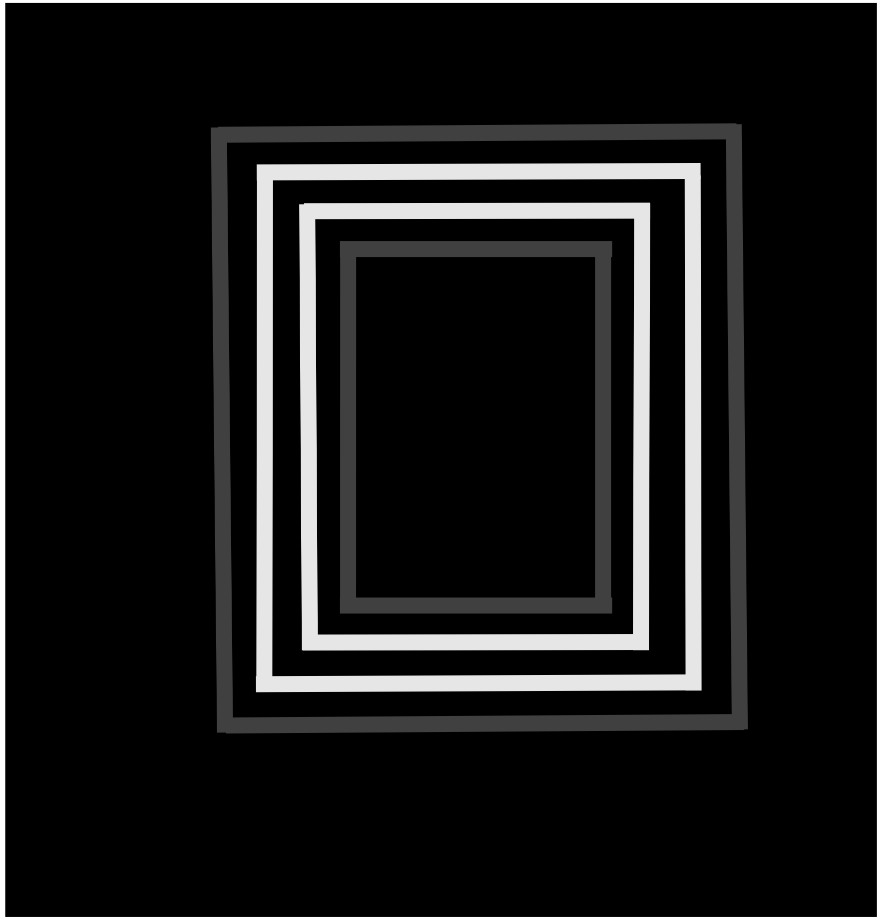
2nd stage: Kepler-type re-diffraction system



Diffraction image on the Lyot stop

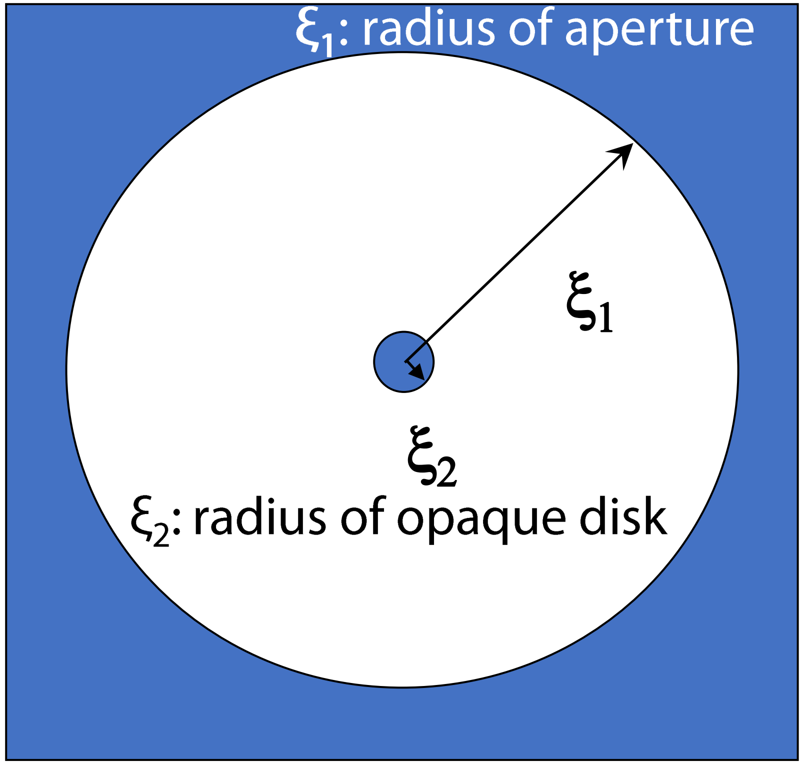


Observed image

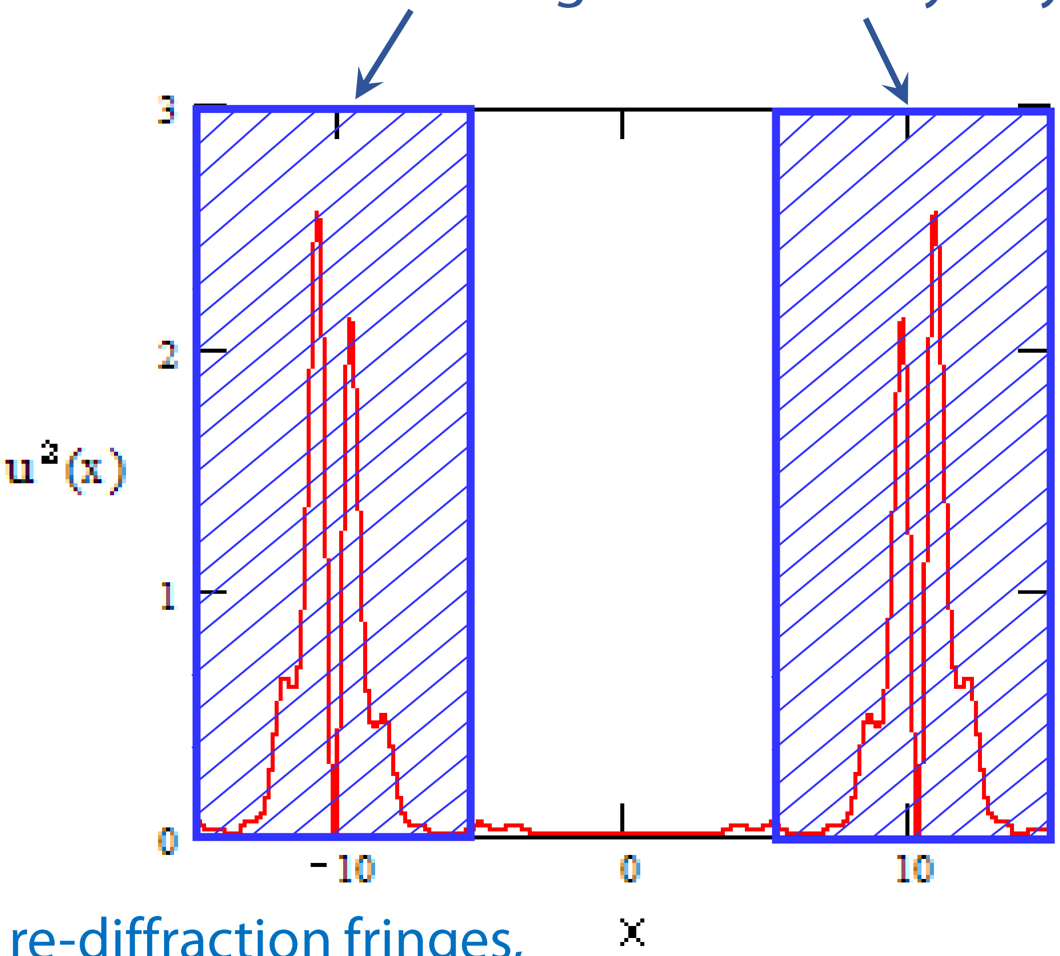


Expected double peaked diffraction pattern

Re-diffraction by a field lens



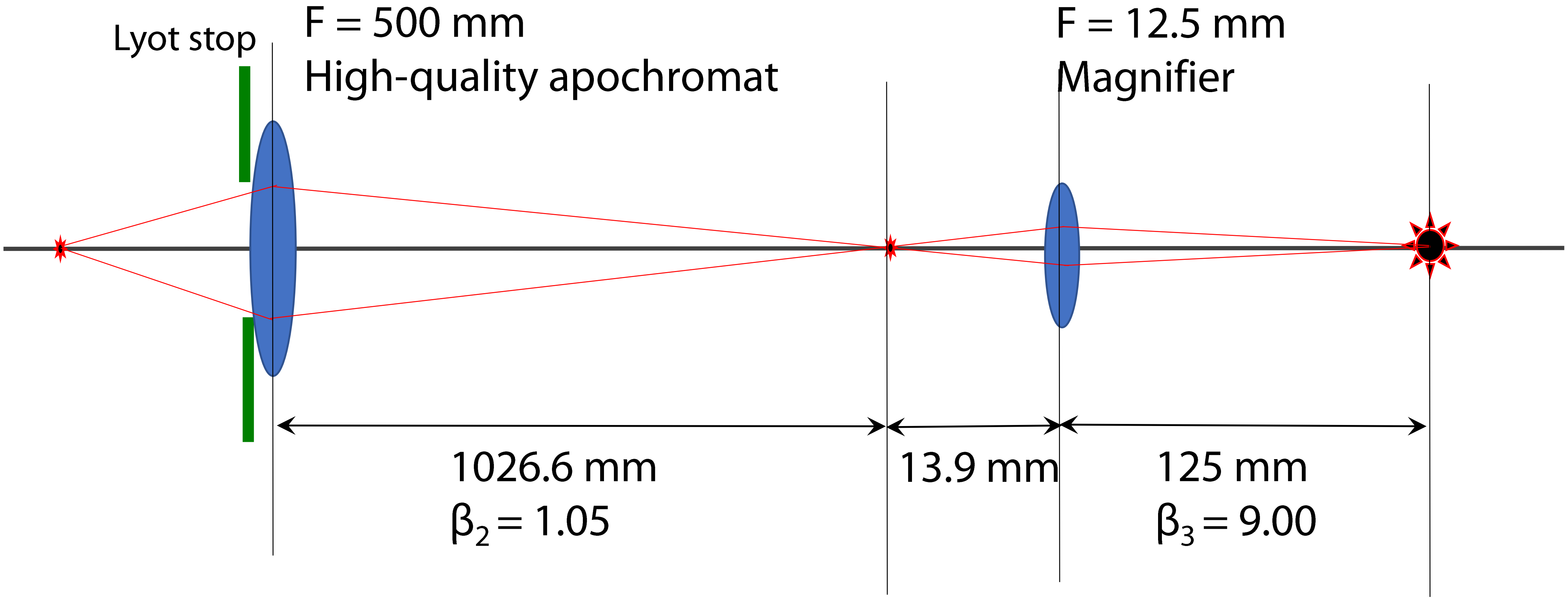
Re-diffraction fringes blocked by a Lyot stop



For efficiently blocking the re-diffraction fringes,
an opaque disk with large diameter is preferred.

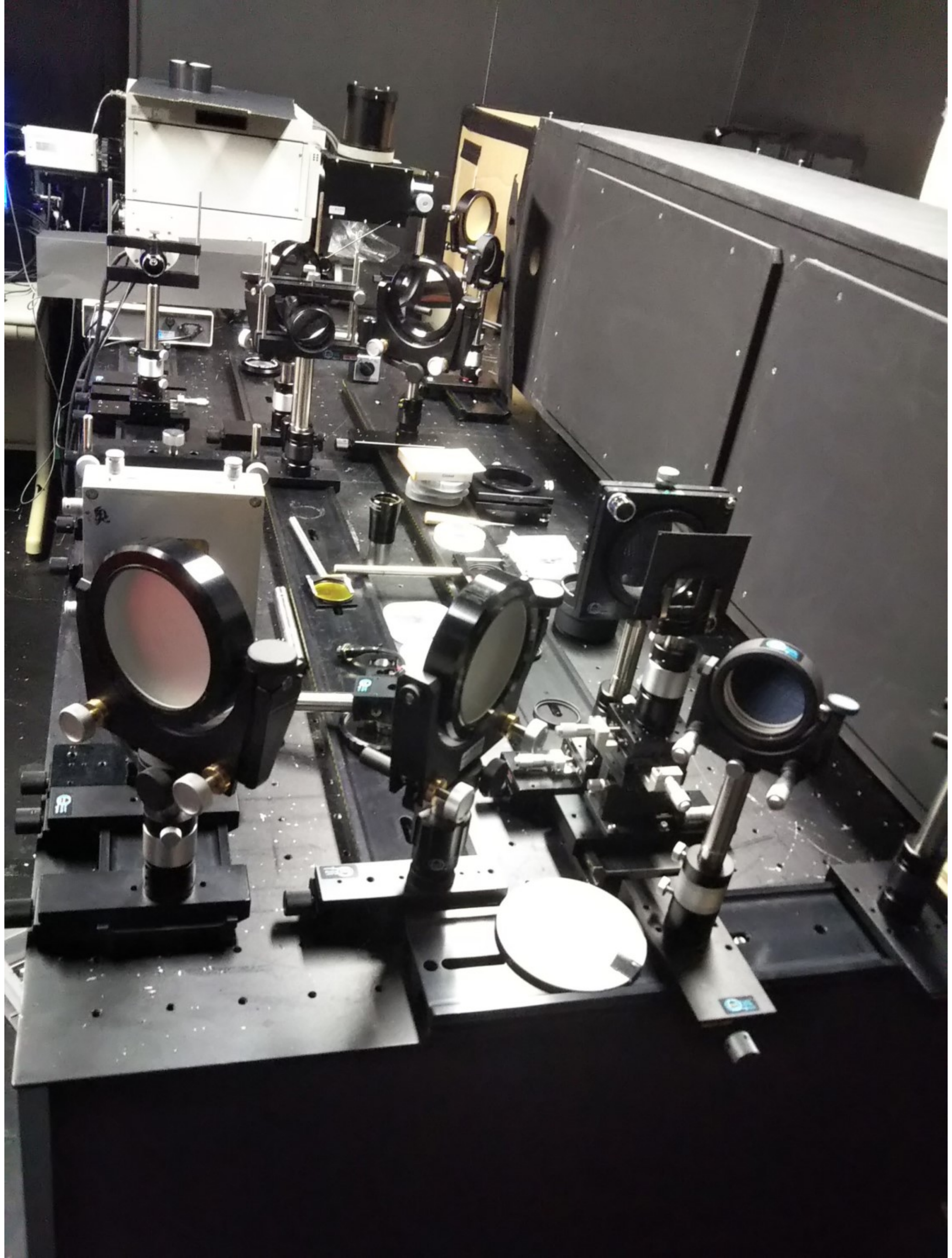
→ Reason why a large magnification in the 1st stage is essential!

3rd stage: Kepler-type relay system



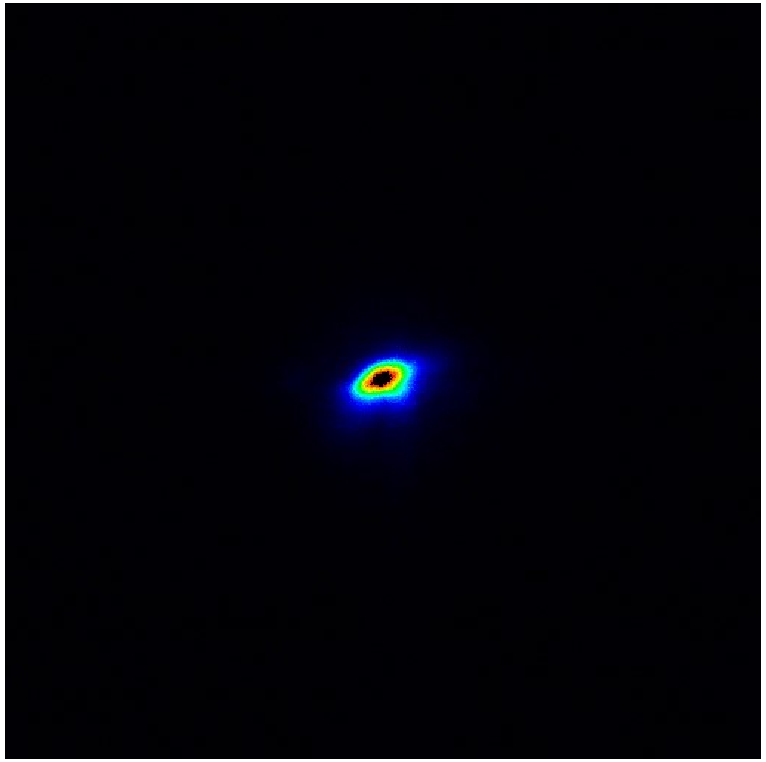
Final magnification to the beam image at final stage

$\beta_1 \times \beta_2 \times \beta_3 = 1.10$

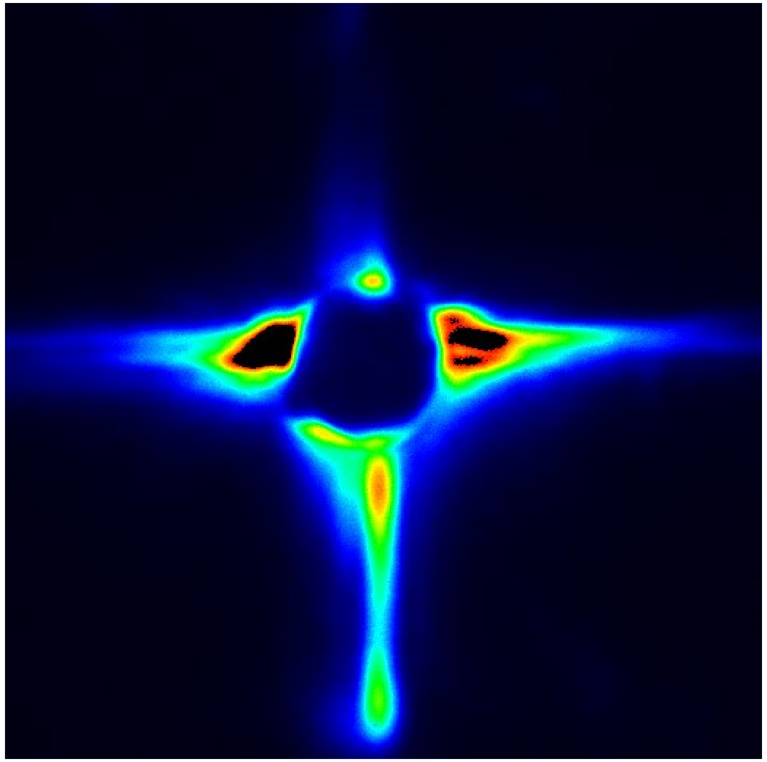


First shot with a gated camera in HER at 7 GeV

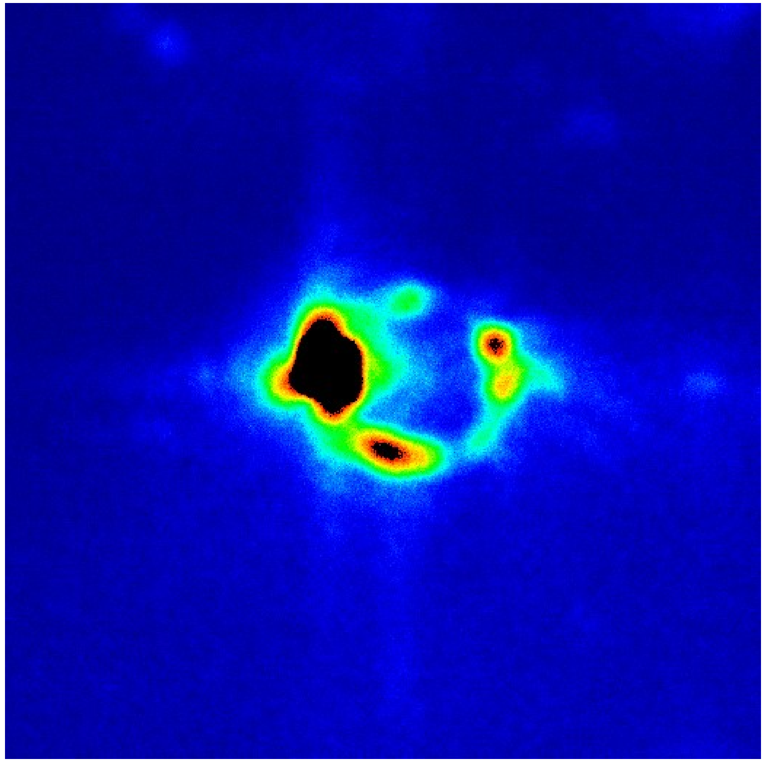
Beam core



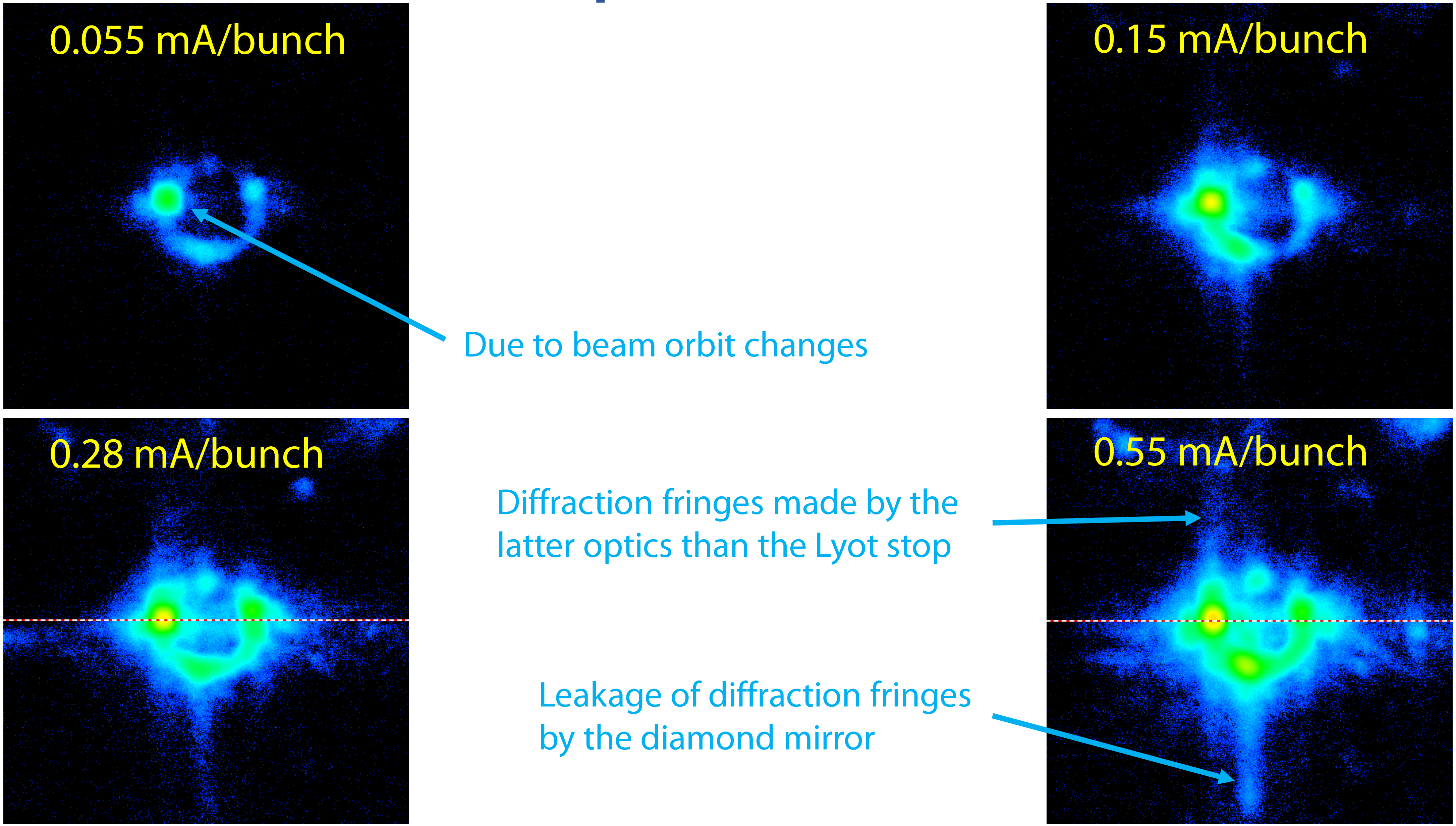
Core blocked by a Φ3mm disk



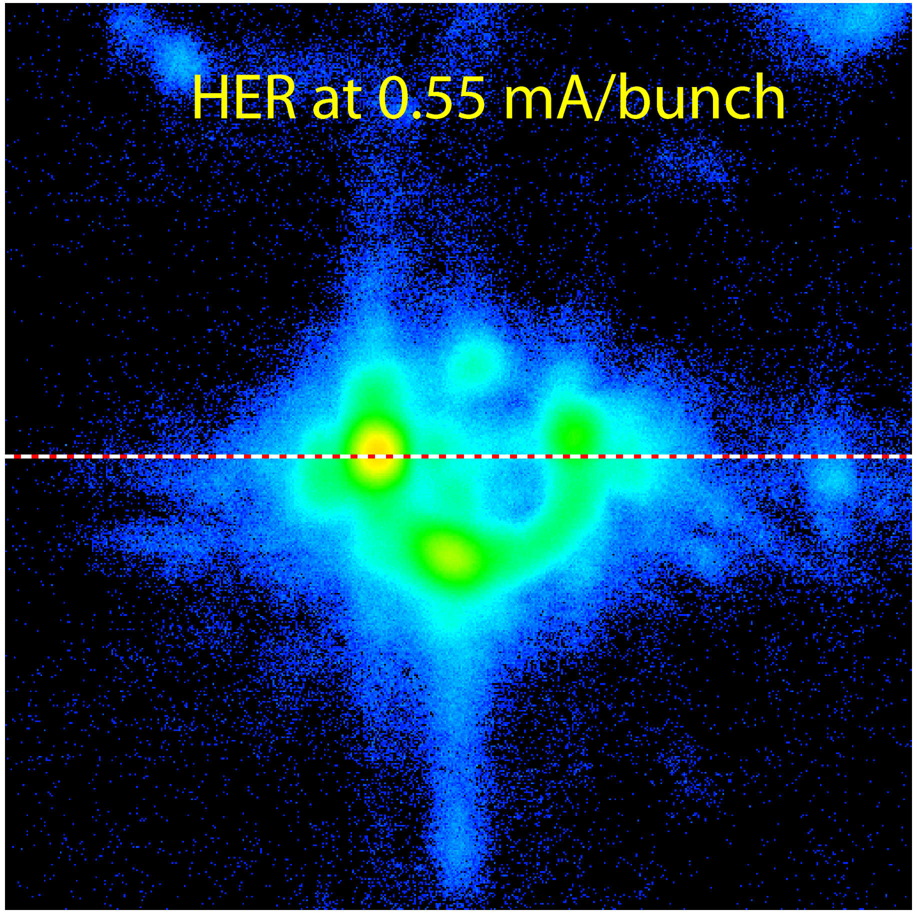
Re-diffraction fringes
blocked by the Lyot stop

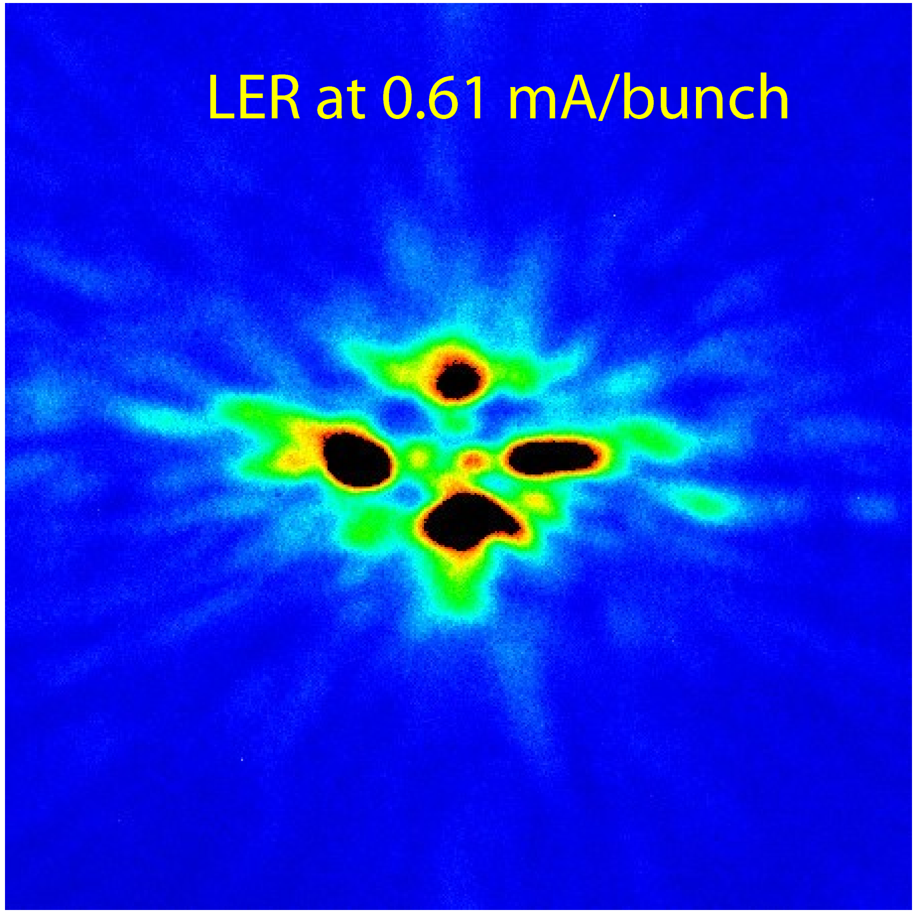


Bunch-current dependence in HER



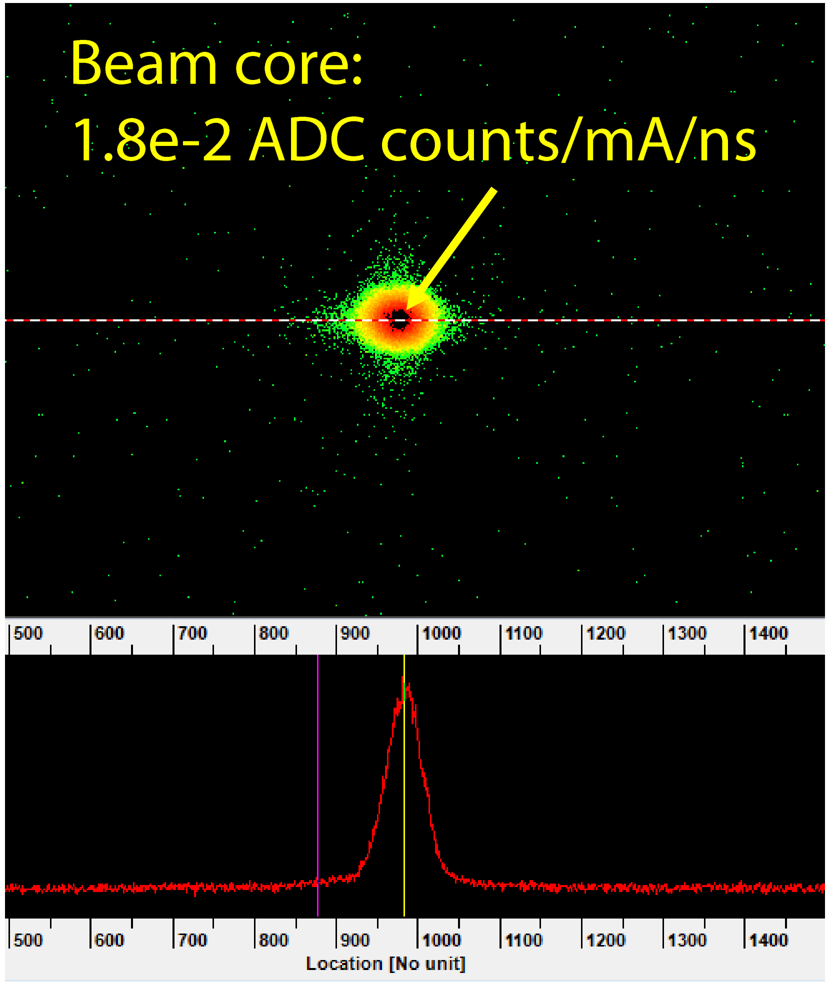
Comparison of halos between HER and LER



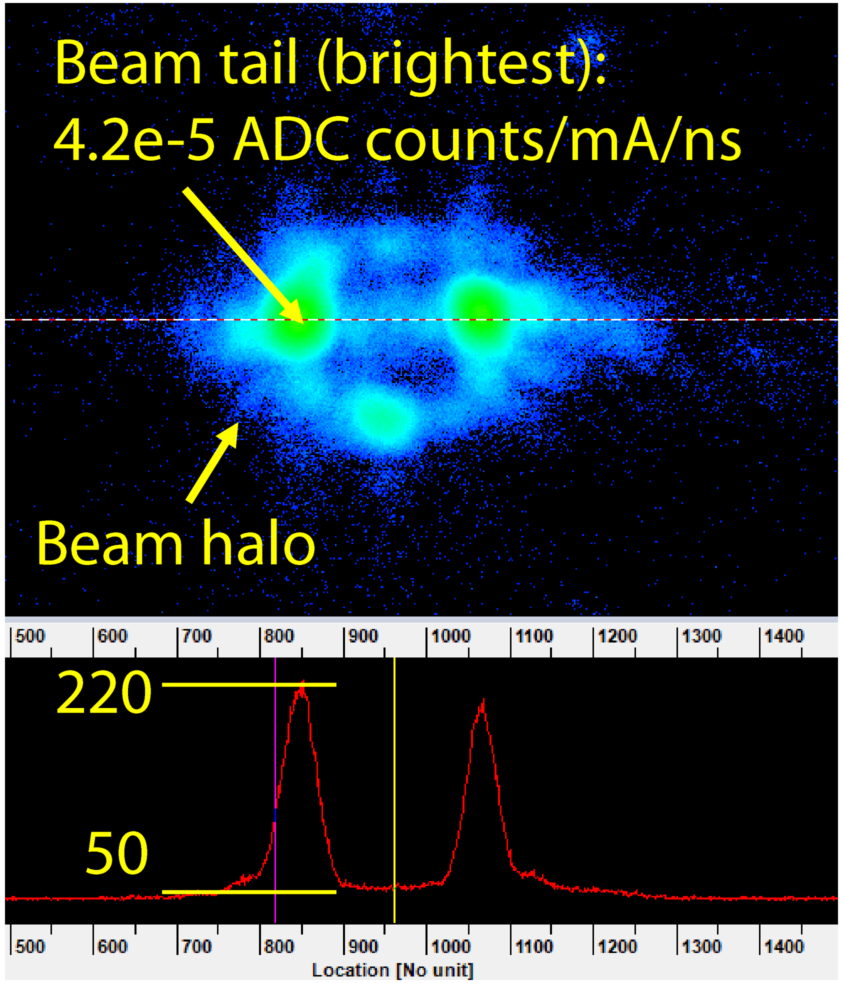


Sensitivity in beam halo measurement

τ = 10 ns



τ = 10 μs



Ratio of Brightest tail/Core
~ 2e-3

Extending the exposure τ to have a brightest spot 12 bit max. counts and looking at beam halo (few counts + ped.), the beam halo/brightest ratio
~ 4 ADC counts/12 bit counts
~ 2e-3

Ratio of beam halo/Core
~ 2e-3 x 2e-3 ~ O(1e-6)

Summary

- Understanding and hopefully lowering beam halo are required to get the best performance of various accelerators.
- We developed two coronagraphs in SuperKEKB enabling non-invasive and high-sensitivity measurements.
- Sensitivity was ~O(1e-6) compared with the beam core.
- Future prospects: feedback of optical axis and opaque disk movement, etc.

Thank you for your attention!