On Possible Improvements for the BGC

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Initial Requirements for the BGC Optics

- Good transmission in the visible and **near UV** mainly because of the N_2^+ line at 391.4 nm;
- Good resolution, well corrected geometrical and chromatic aberrations;
- A reproduction scale of about 1 due to the relatively low resolution of the double MCP stack of at most 20 lp/mm;
- Relatively large working distance allows the placement of the detector system at d > 400 mm from the beam axis;
- Large acceptance, a solid angle of about $4\pi \cdot 10^{-4}$ sr desirable;
- Total depth of field up to 15 mm with reasonable blur;
- Reproduction scale chosen to see the background outside the window due to ionizing radiation and dark counts and to distinguish from synchrotron radiation.

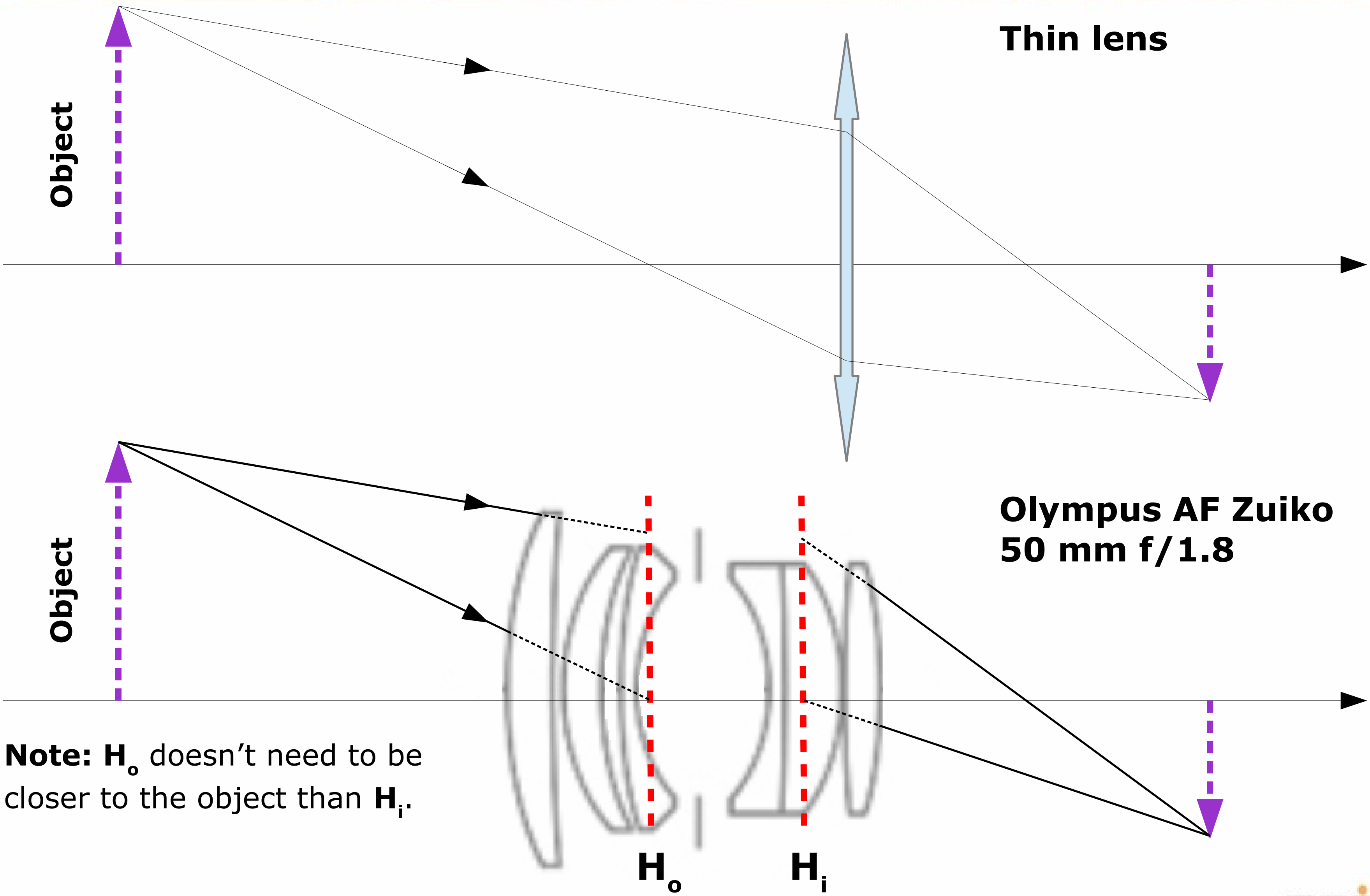
Note: Initially the hollow electron beam was expected to have an outer diameter of ≈ 3.6 mm.

Status and Possible Improvements (1)

- Working with Ne at 581 nm eliminates the requirement for good transmission in the near UV; much easier to find a commercially available lens, if needed.
- The correction of chromatic aberrations also leads to the correction of the spherical aberration, thus it is useful beyond it's main purpose.
- For measurements of the proton beam transverse profile at LHC a reproduction scale larger than 1 is needed. This can be eventually achieved with a macro lens. A macro lens can be also useful at the HEL test stand, if reproduction scales larger than ≈ 1/10 are to be used.
- The working distance limitations need reassessment.
- Especially the acceptance of the lens at the LHC has to be maximized.
- For proton beam profile measurements the depth of field of 5 mm should be sufficient, however the visualization of a large hollow electron beam may need a Scheimpflug set-up to reduce blur due to insuffcient depth of field.
- The observation of the background outside the window is not needed anymore.

Some General Comments Regarding Optics

The Principal Planes (part 1)



Note: H$_o$ doesn't need to be closer to the object than **H$_i$**.

The Principal Planes (part 2)

- For an object at the so called object space principal plane ($\mathbf{H_o}$) the optical system creates an (upright) image identical to the object at the so called image space principal plane ($\mathbf{H_i}$). Magnification is exactly 1!
- One can apply everything learned about thin lenses by considering the object space to end at $\mathbf{H_o}$ and the image space to start at $\mathbf{H_i}$. See next slide.
- Optical systems are made of several simple lenses to mainly achieve two goals: limit the effects of aberrations neglected within the paraxial approximation, adjust the positions of the principal planes and focal points as needed.

Entrance Pupil, Aperture Stop, f-number

- The aperture stop limits the amount of light passing through a lens and affects the depth of field and the strength of aberrations. A stop with a smaller opening implies less light, weaker aberrations and an increased depth of field.

- The entrance pupil is the image of the aperture stop through the lenses in front of it (as looking from the object). An undeflected ray must pass through the opening of the entrance pupil to pass through the opening of the aperture stop.

- The **f-number** is the ratio between the **focal length** and the diameter of the **entrance pupil**.

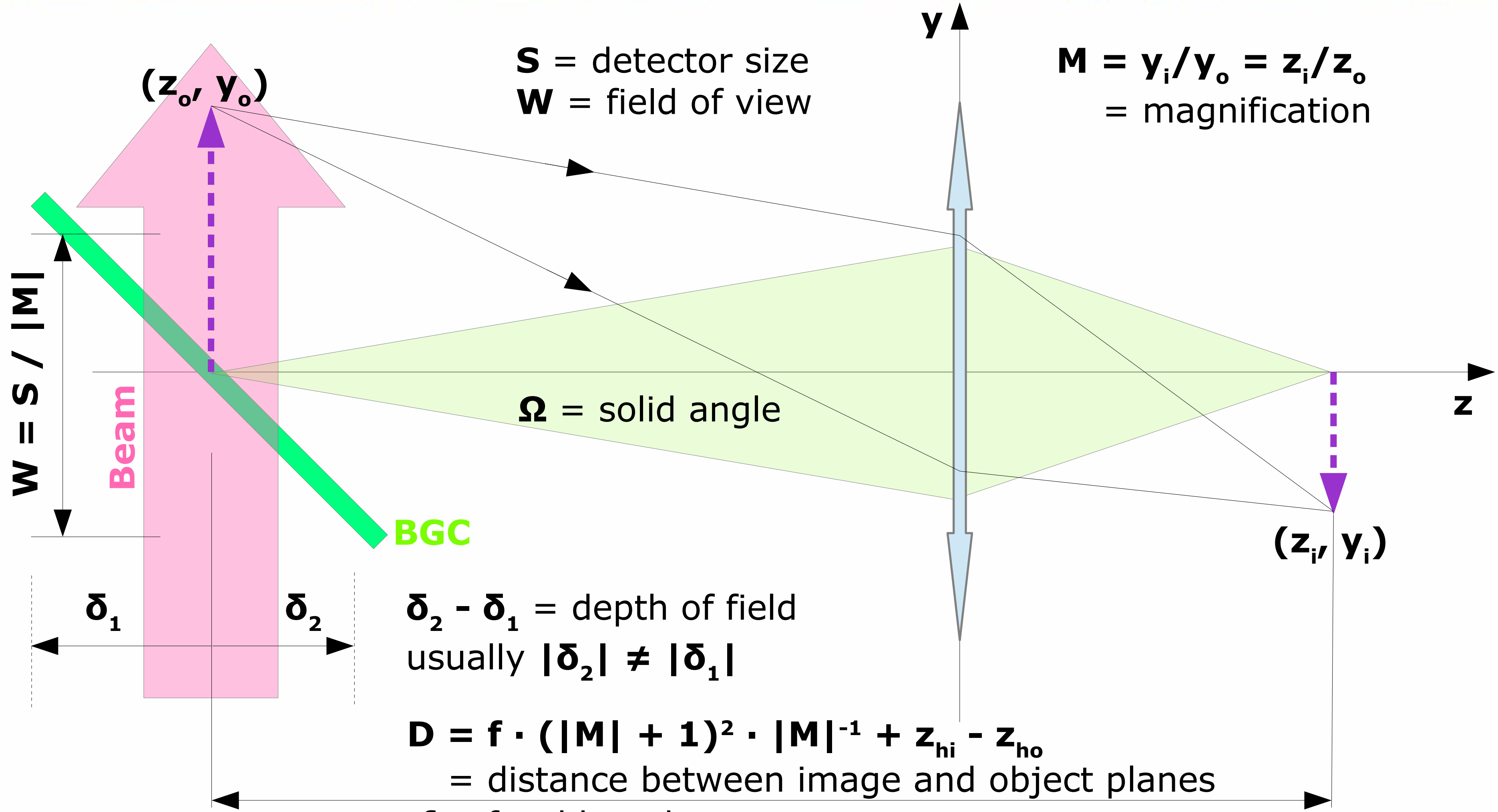
- Typically f-numbers are larger than unity. Example: the f-number of the lens presently used for the BGC is 4 (160 mm/40 mm).

- Sometimes low f-numbers may lead to vigneting, i.e. darkening of the image towards its edges.

More Often than Not

- For commercial lenses, one may not be readily given the position of the principal planes with respect to some easily accessible reference.
- The same applies to the position of the entrance pupil.
- The position of the entrance pupil is important if one has to determine the solid angle defining the acceptance of the lens.
- Thus, there may be no way around determining these experimentally.

Optics, Simplified Overview

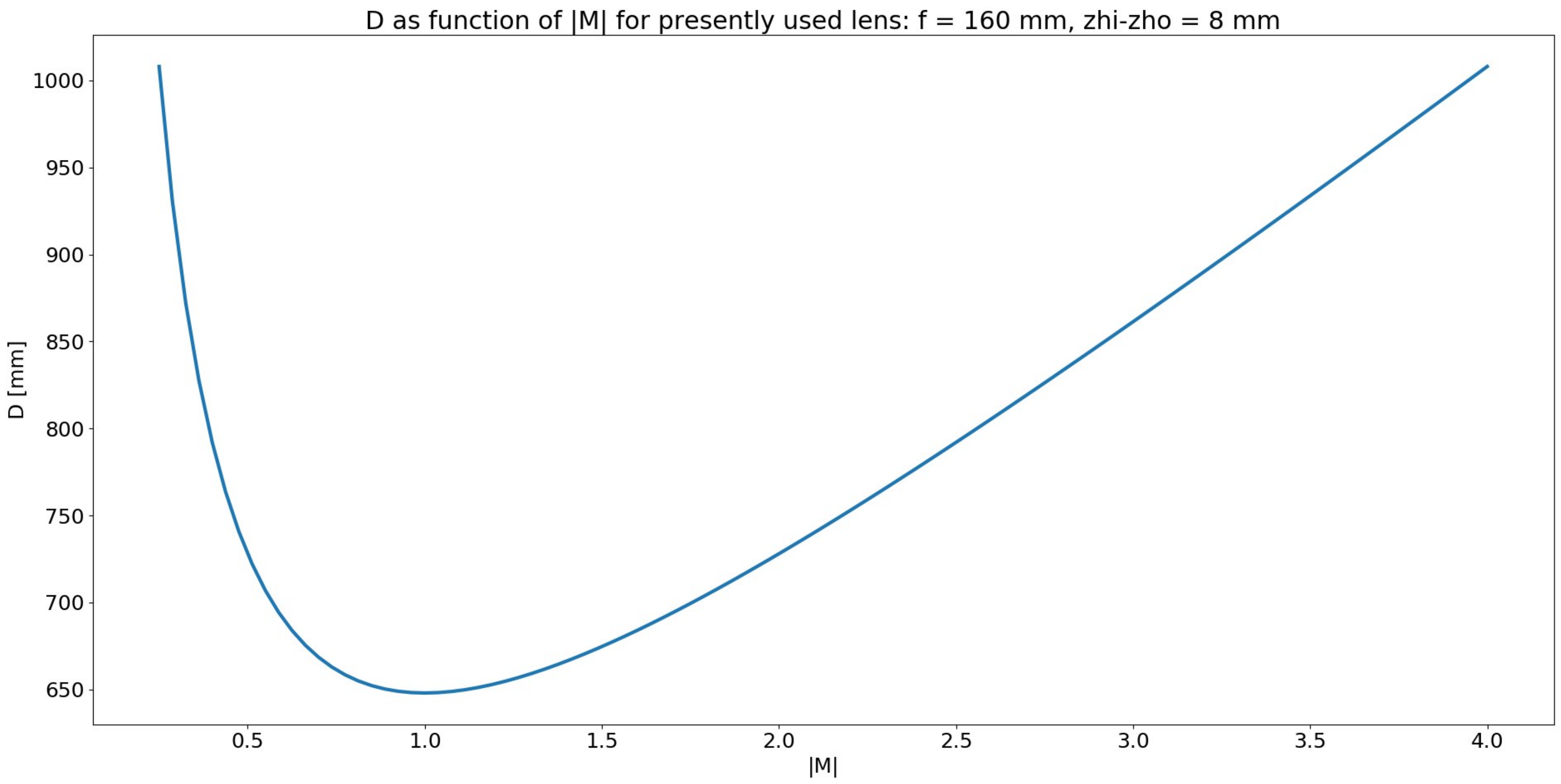


f = focal length
z_{hi}, z_{ho} = coordinates of the principal image and object planes*

(*) Not shown here for simplicity.

Magnification and Object to Image Distance

The minimum distance between the object and its real image is achieved for $\mathbf{M = -1}$, i.e. $|M| = 1$. This distance is $\mathbf{D_{min} = 4f + z_{hi} - z_{ho}}$. For any larger distance two different magnifications are possible, such that $\mathbf{M_1 \cdot M_2 = 1}$.

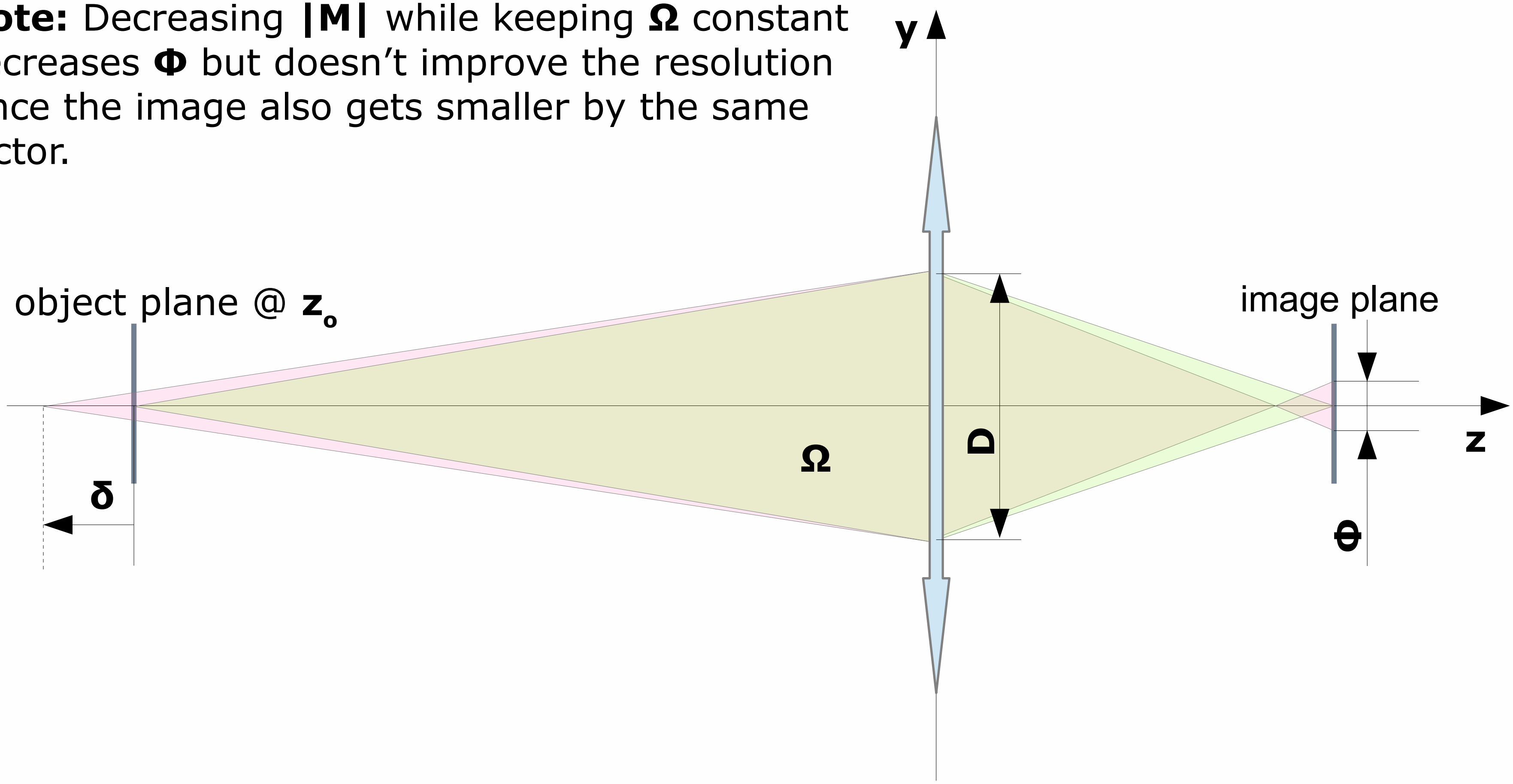


Depth of Field

$$\Phi \approx 2 \cdot |\delta| \cdot (\Omega/\pi)^{0.5} \cdot |M|, \quad |\delta|/(|z_o| - f) << 1 \;\&\; \Omega \leq 2.5 \cdot 10^{-2}$$

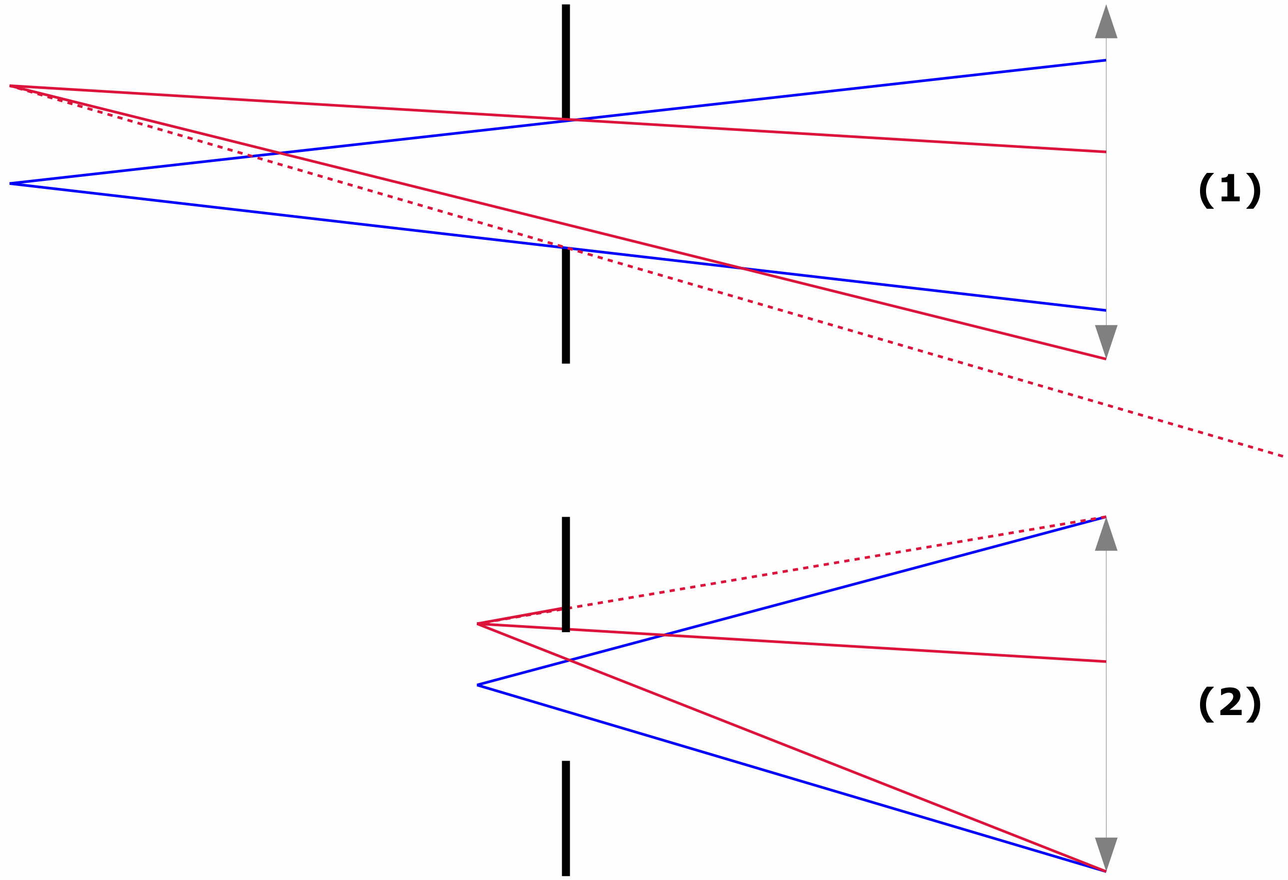
$$(\Omega/\pi)^{0.5} \approx (D / 2f) \cdot |M| / (|M| + 1)$$

Note: Decreasing **|M|** while keeping **Ω** constant decreases **Φ** but doesn't improve the resolution since the image also gets smaller by the same factor.

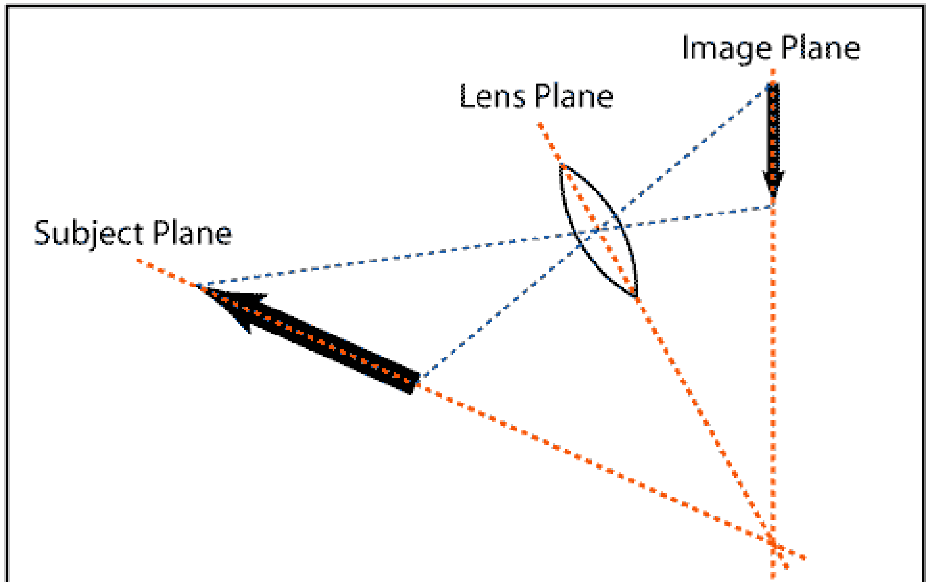


Solid Angle and Vignetting

The upper limit is imposed on the solid angle by the exit window. For (point) light sources off axis vignetting may appear at the lens (1) or at the window (2) and one has to consider these issues when trying to improve the signal by increasing the solid angle.

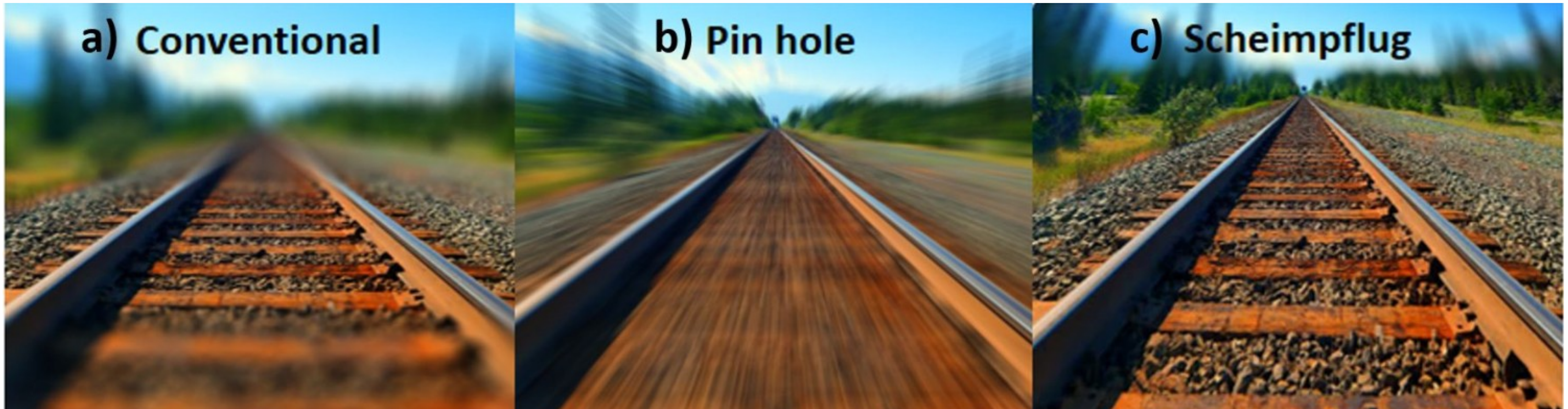


The Scheimpflug Set-Up



By Fil Hunter at English Wikipedia

Camera with Scheimpflug adapter



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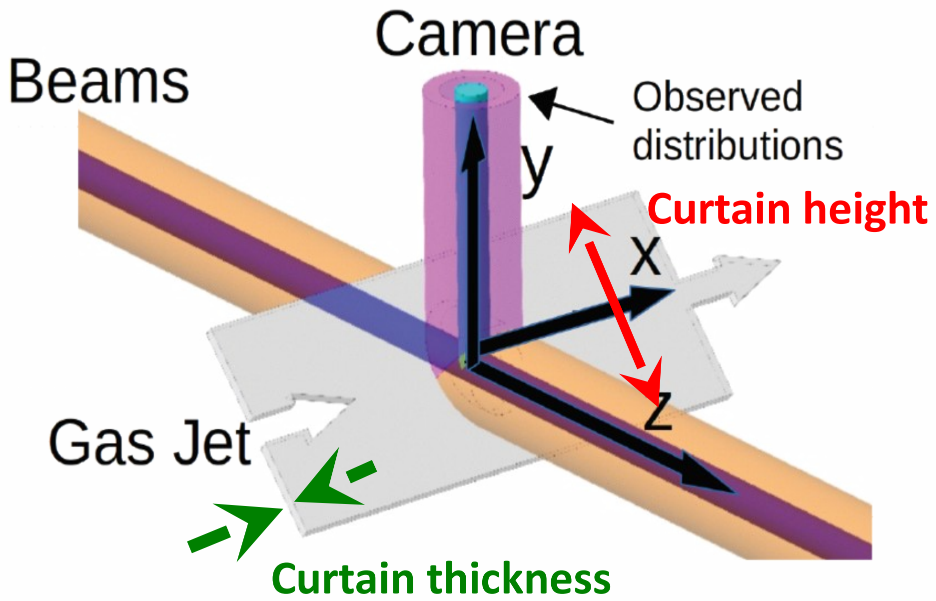
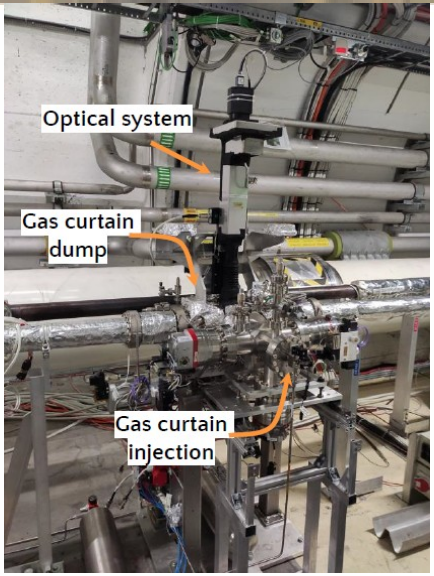
Status and Possible Improvements (2)

Further proposals for LHC:

- Reduction of curtain height as present one not needed
- Possible reduction of curtain thickness for better resolution
- Larger pressure for ***same*** gas load ⇒ higher **density**
  ⇒ **Simulation by Oliver should give some insight**



Status and Possible Improvements (3)



Actual status:

- No shielding of Image intensifier and CMOS camera
- Quite some background due to ionizing radiation
- Quite some destroyed camera pixels

Improvements:

- Shielding against **charged** particles
  - Less background from image intensifier, no 'comets' expected
    –> only 'thin' material needed e.g. ≈ 20 cm metal, heavy concrete or 40 cm plastics **(???)**
- Shielding against **neutrons**
  - Prolongation of CMOS camera lifetime expected, less background from image intensifier **(?)**
    –> 'thick' material needed e.g. ≈ 50 cm plastics **(???)**
- Shielding against γ
  - A bit less background from image intensifier **(?)**
    –> 'medium thick' material need e.g. ≈ 20 cm lead **(???)**

⇒ **FLUKA simulation required (or Geant4; whatever is suited)**