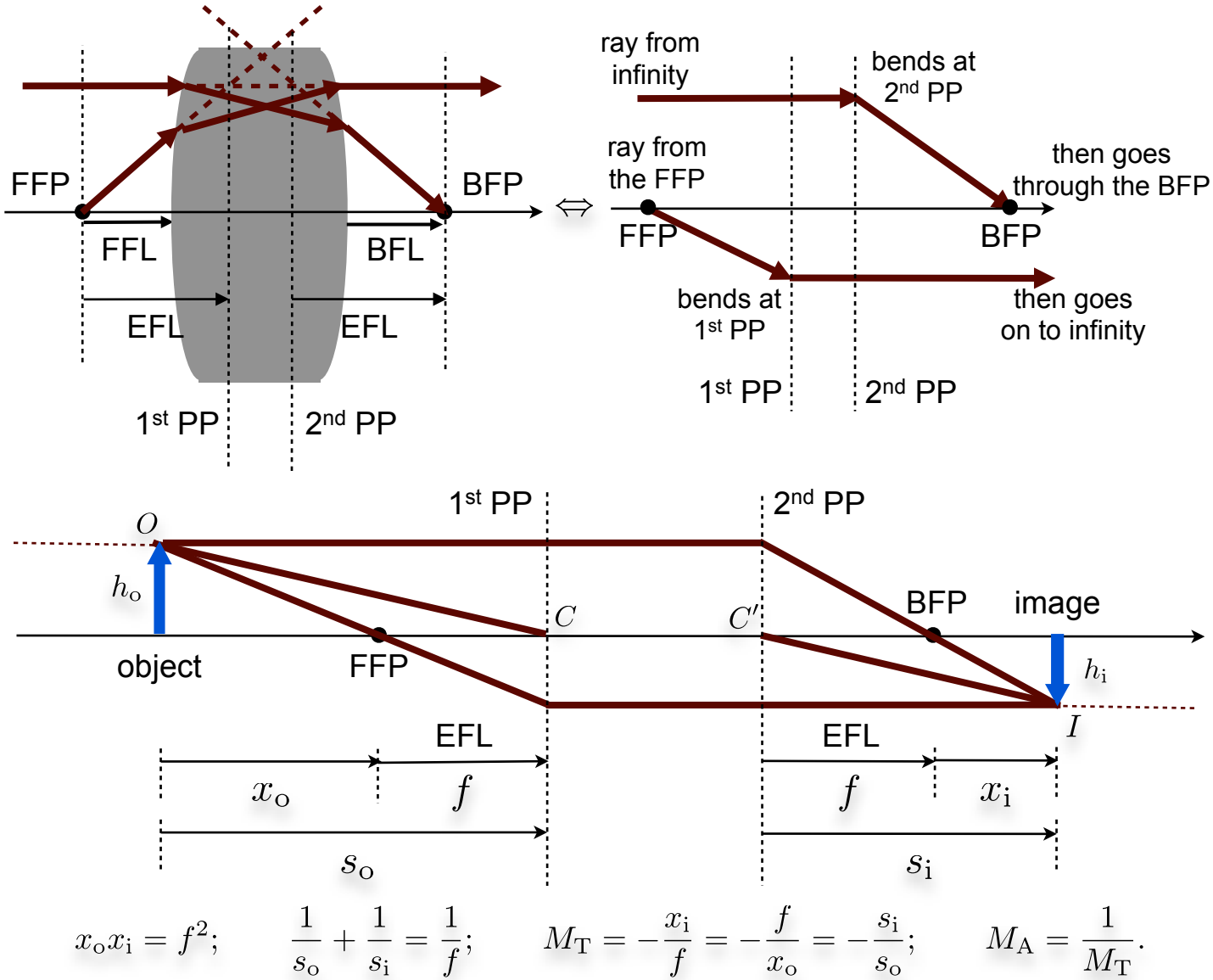
Overview: composite optical elements



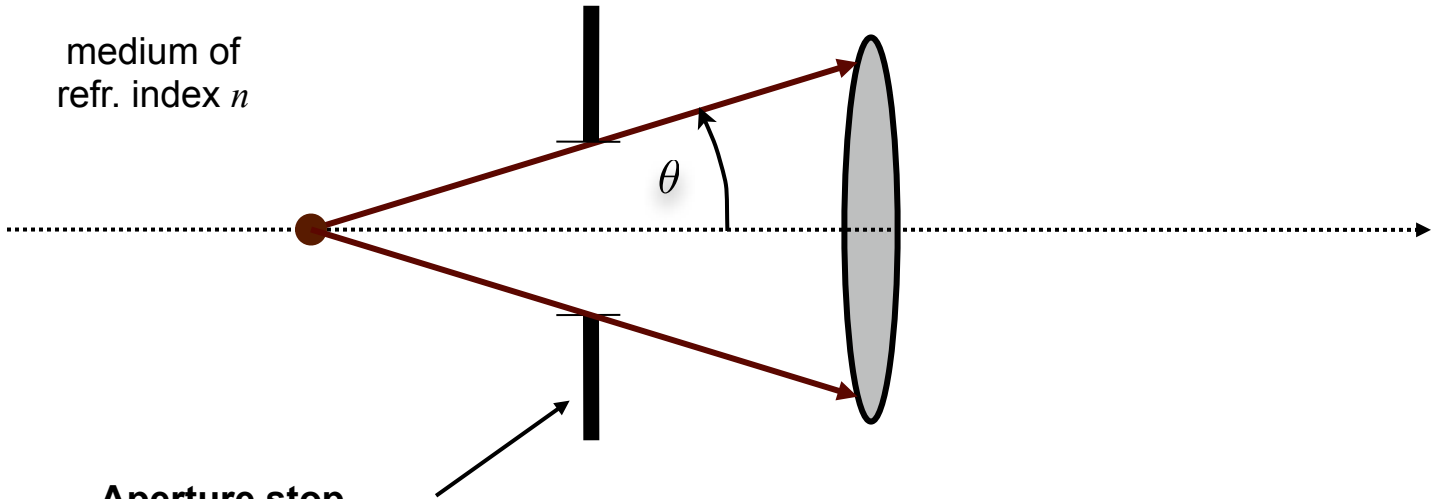
$$x_o x_i = f^2; \qquad \frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}; \qquad M_T = -\frac{x_i}{f} = -\frac{f}{x_o} = -\frac{s_i}{s_o}; \qquad M_A = \frac{1}{M_T}.$$

Today

- Apertures & Stops
  - Aperture
  - Entrance Pupil
  - Exit Pupil

  - Field Stop
  - Entrance Window
  - Exit Window

Aperture Stop and Numerical Aperture



Aperture stop
the physical element which limits the angle of acceptance of the imaging system

θ: half-angle subtended by the imaging system from an *axial* object

Numerical Aperture $(\mathrm{NA}) \equiv n \sin\theta$

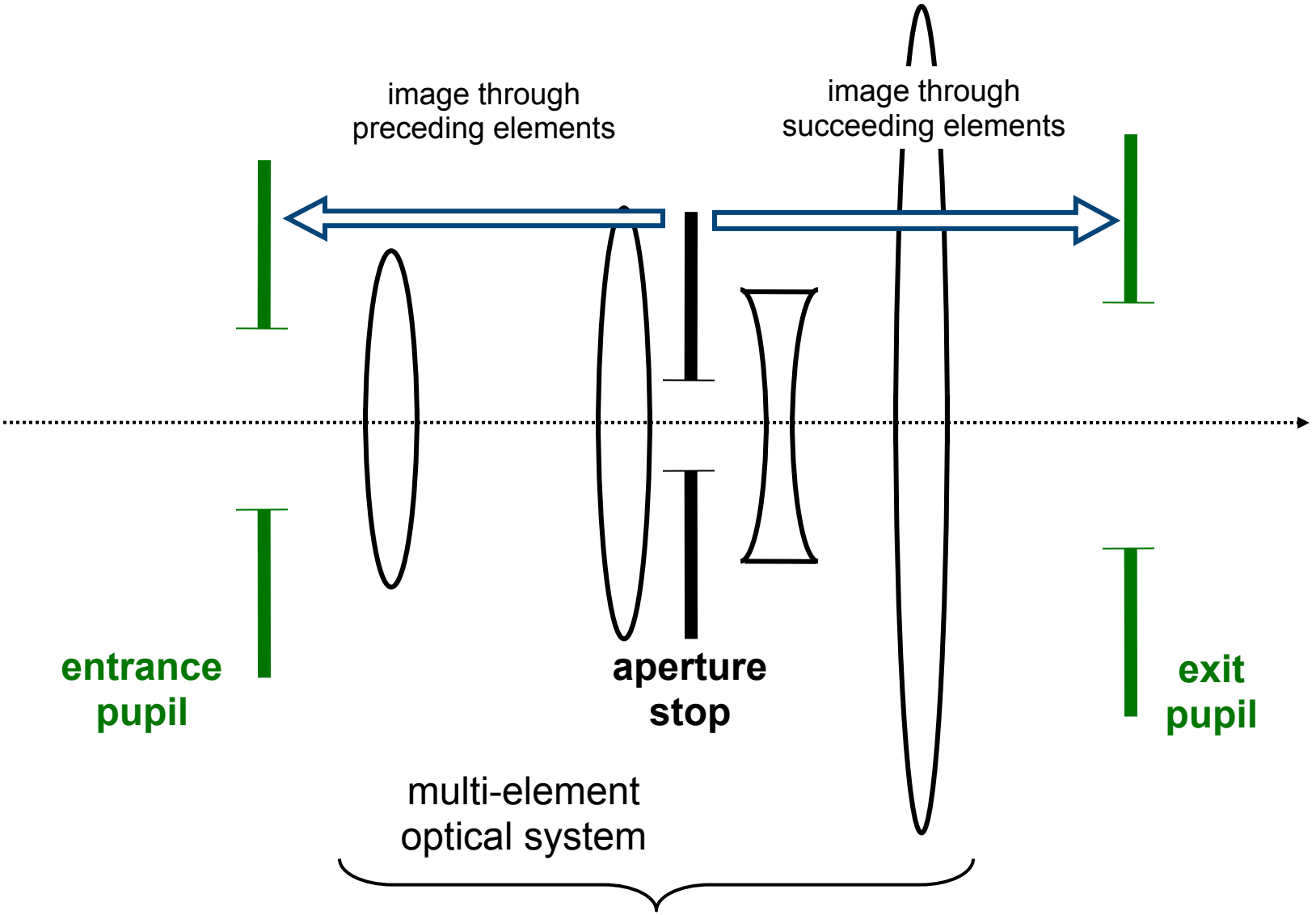
Speed
pronounced f-number, e.g. f/8 means (f/#)=8.

$$(f/\#) = \frac{1}{2\,(\mathrm{NA})}$$

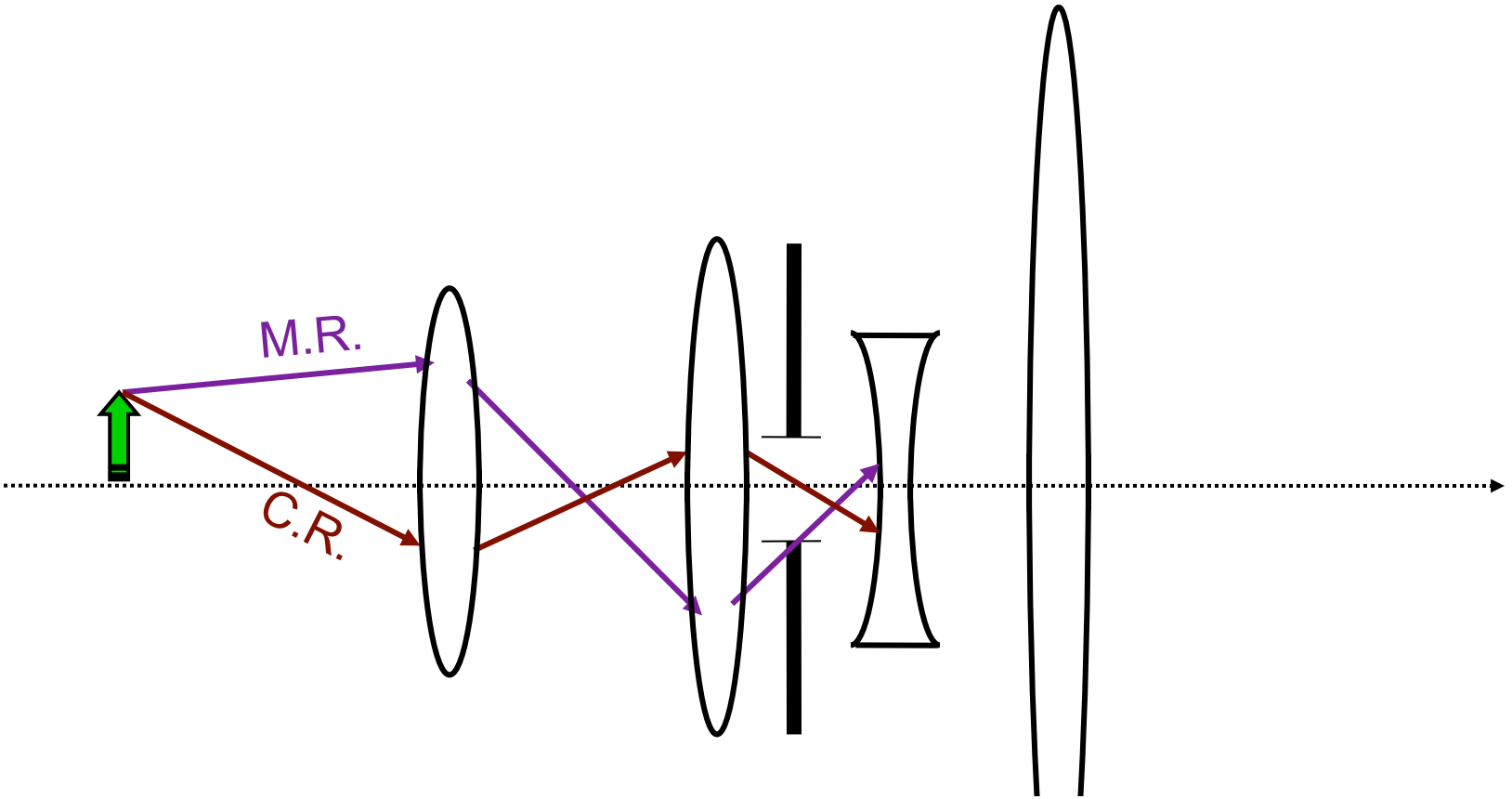
The **Aperture Stop** limits the optical *energy* that is admitted through the system

Later we will also learn that the NA also defines the *resolution* (or *resolving power*) of the optical system

Entrance & exit pupils



The Chief & Marginal Rays

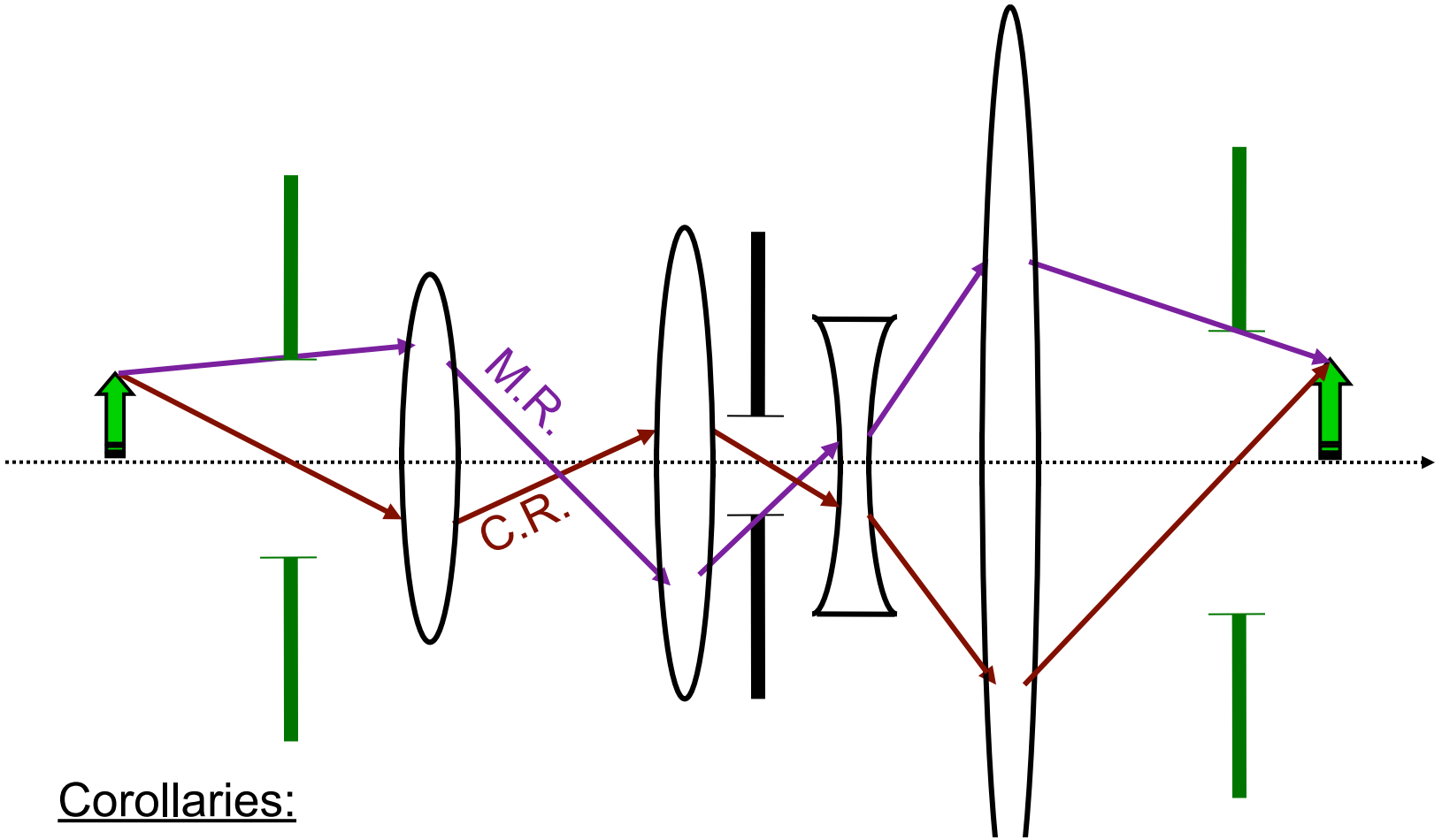


Chief Ray: Starts from off-axis object, goes through the *center* of the Aperture

Marginal Ray: Starts from off-axis object, goes through the *edge* of the Aperture

Together, the C.R. and M.R. define the angular acceptance of spherical ray bundles originating from an off-axis object.

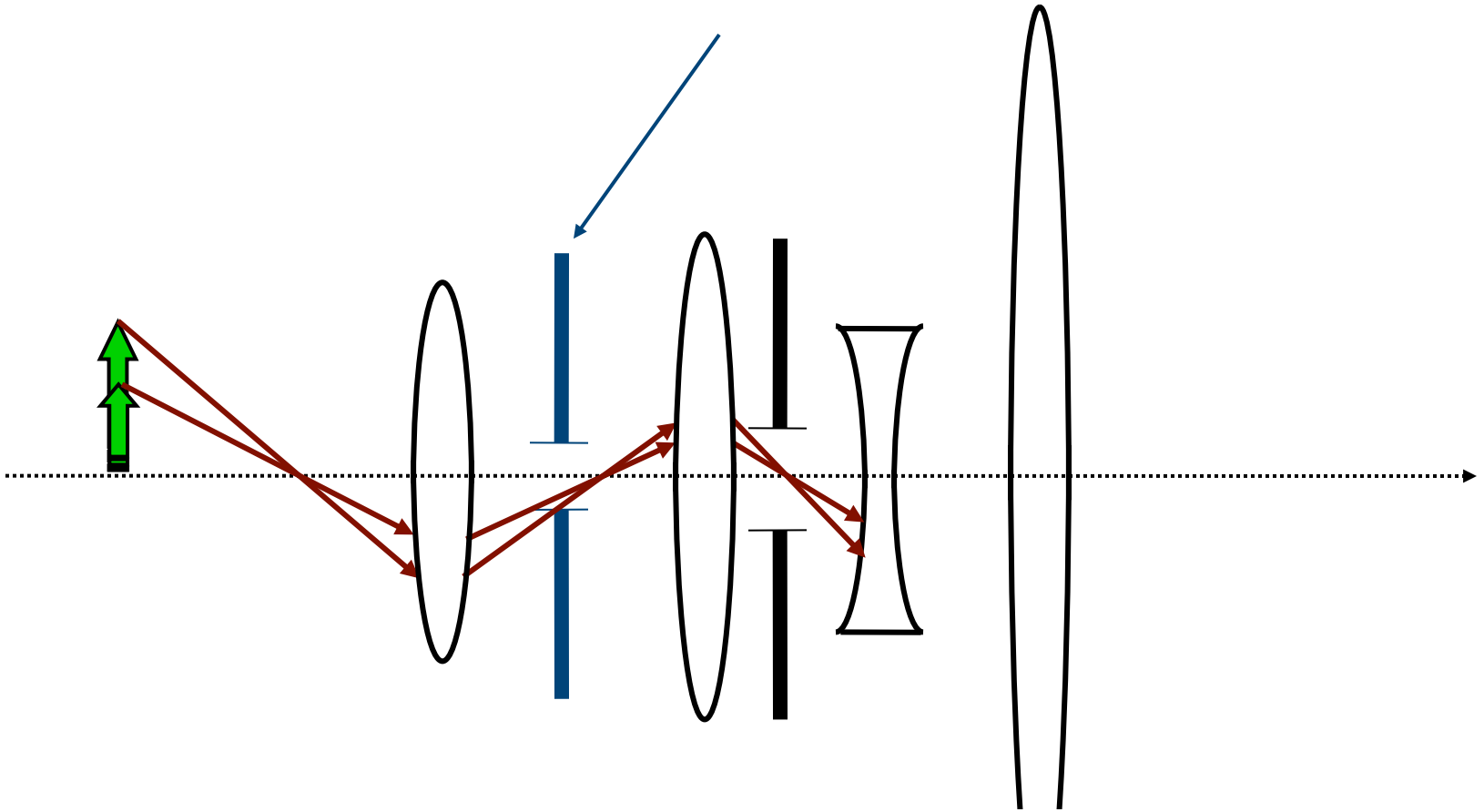
The Chief & Marginal Rays



Corollaries:

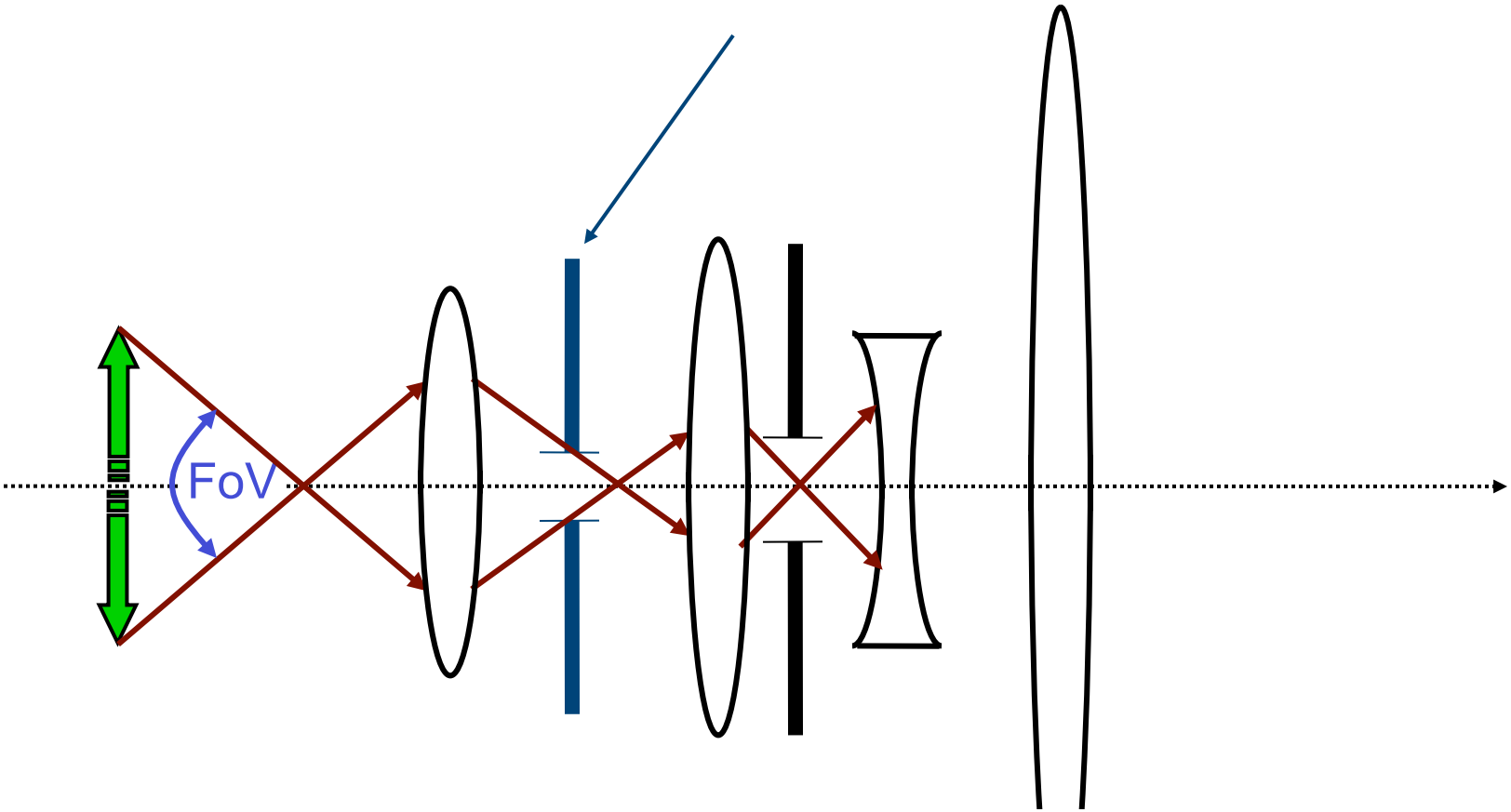
Chief Ray also goes through the *center* of the Entrance & Exit Pupils
Marginal Ray also goes through the *edge* of the Entrance & Exit Pupils
The Chief and Marginal Rays meet again at the image

The Field Stop



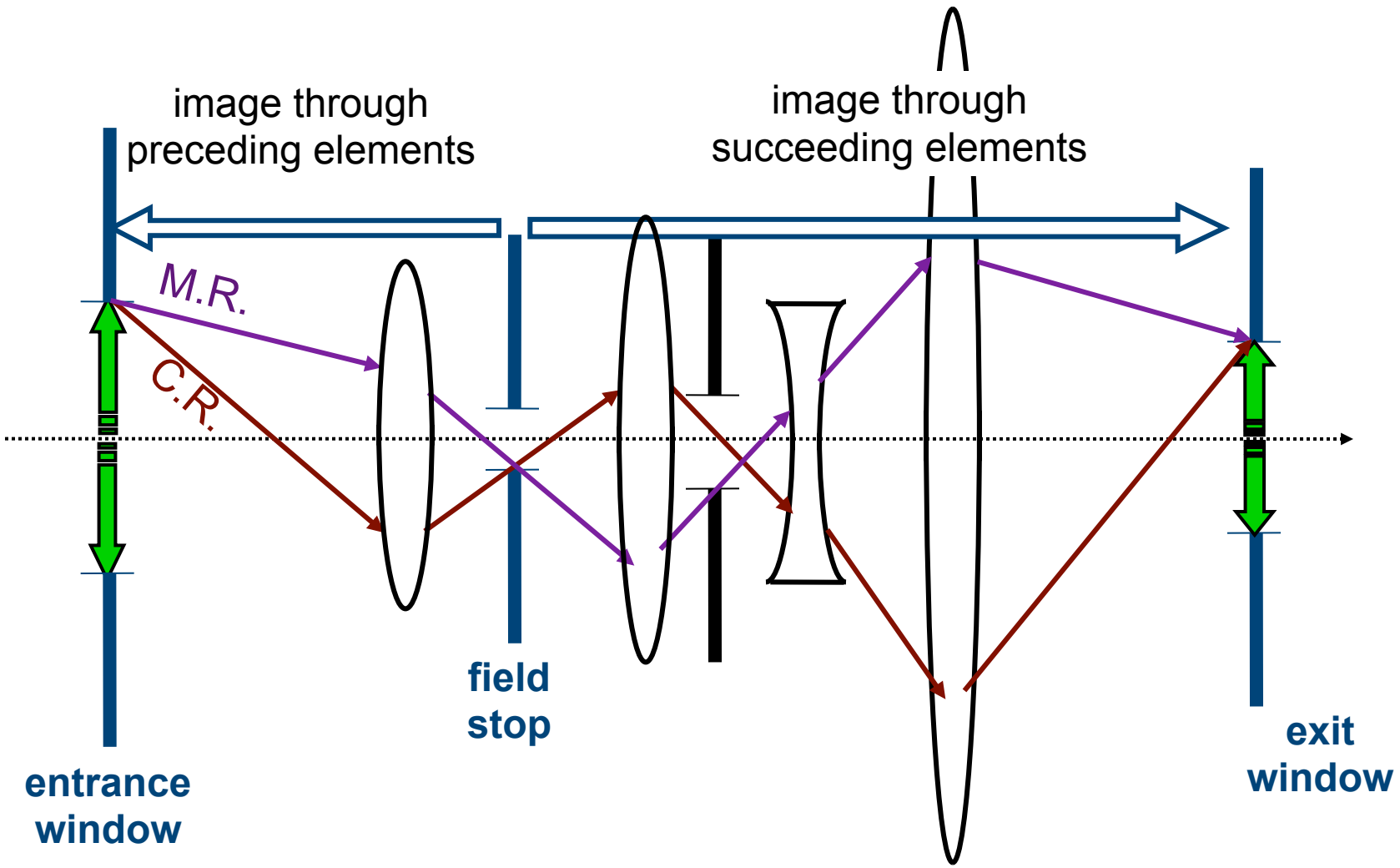
Limits the angular acceptance of Chief Rays

The Field Stop

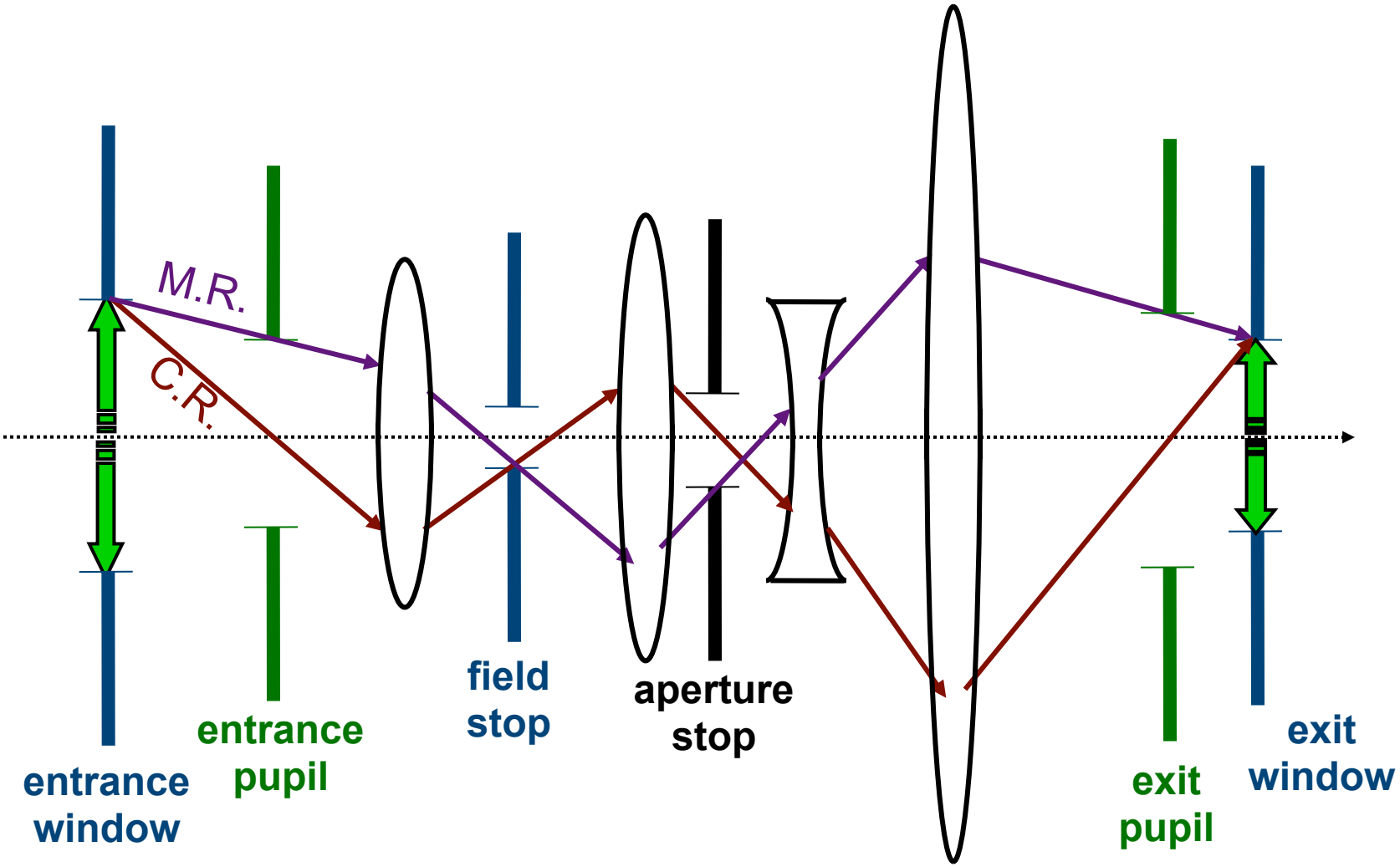


Defines the Field of View (FoV)

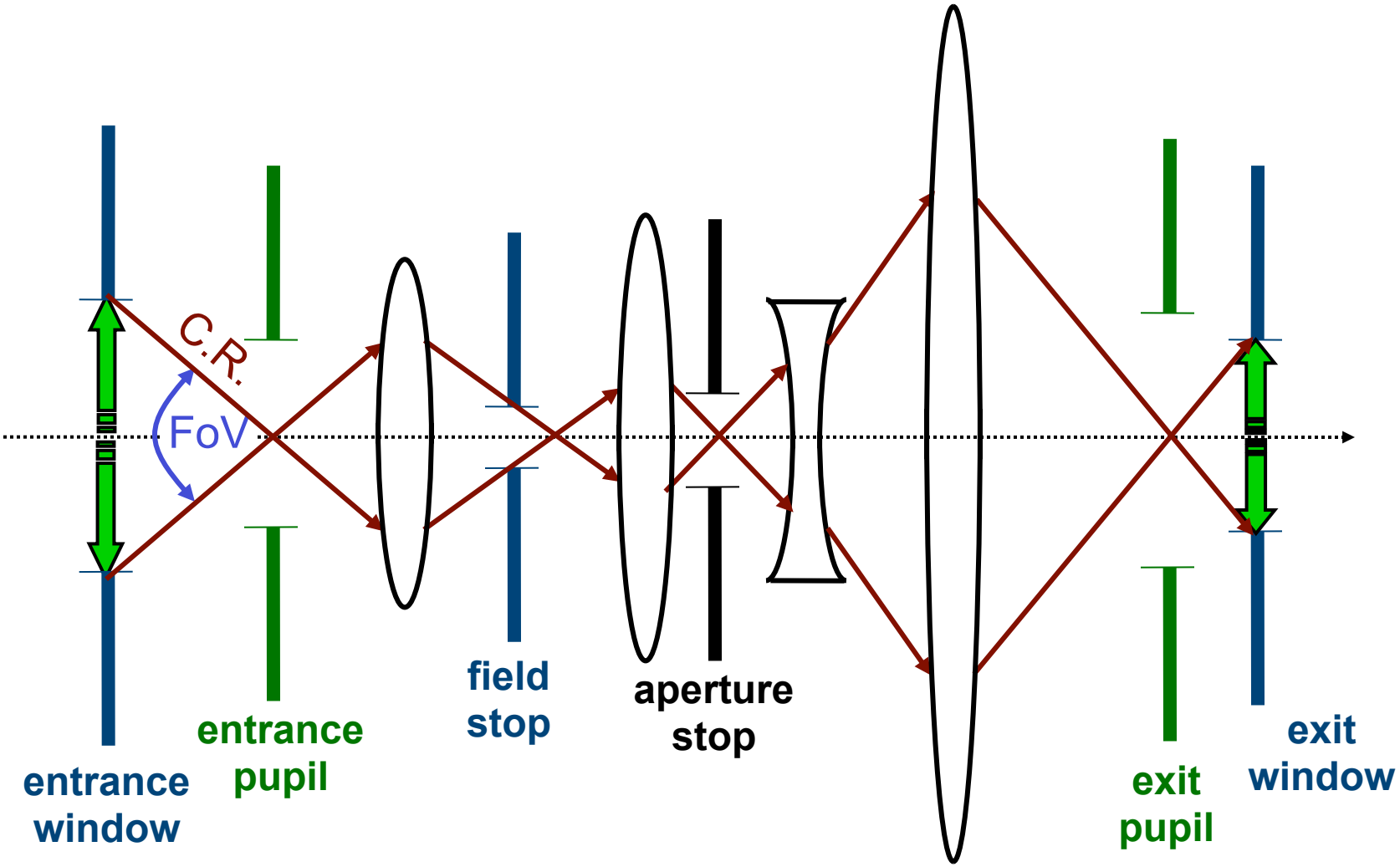
Entrance & Exit Windows



All together

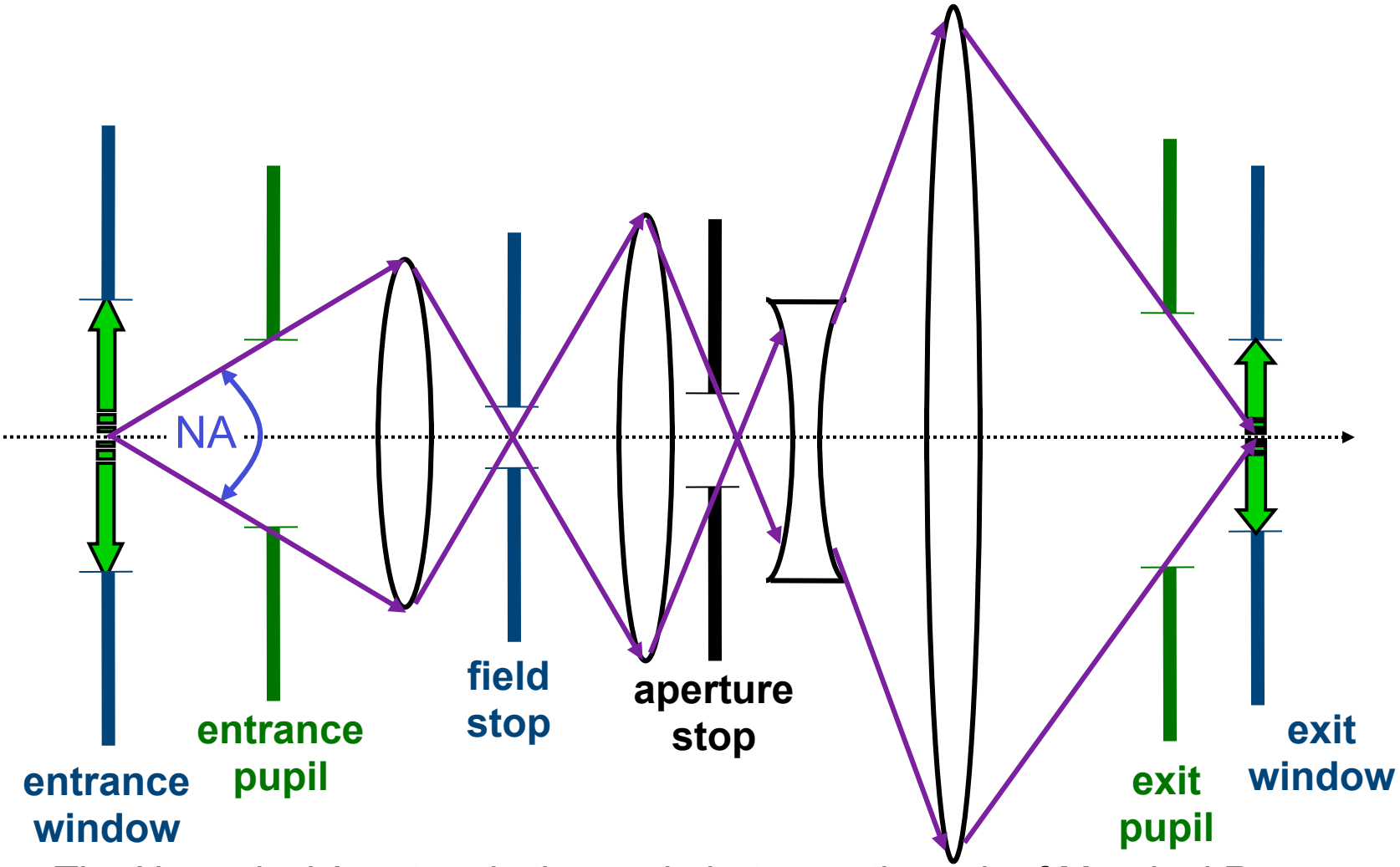


All together



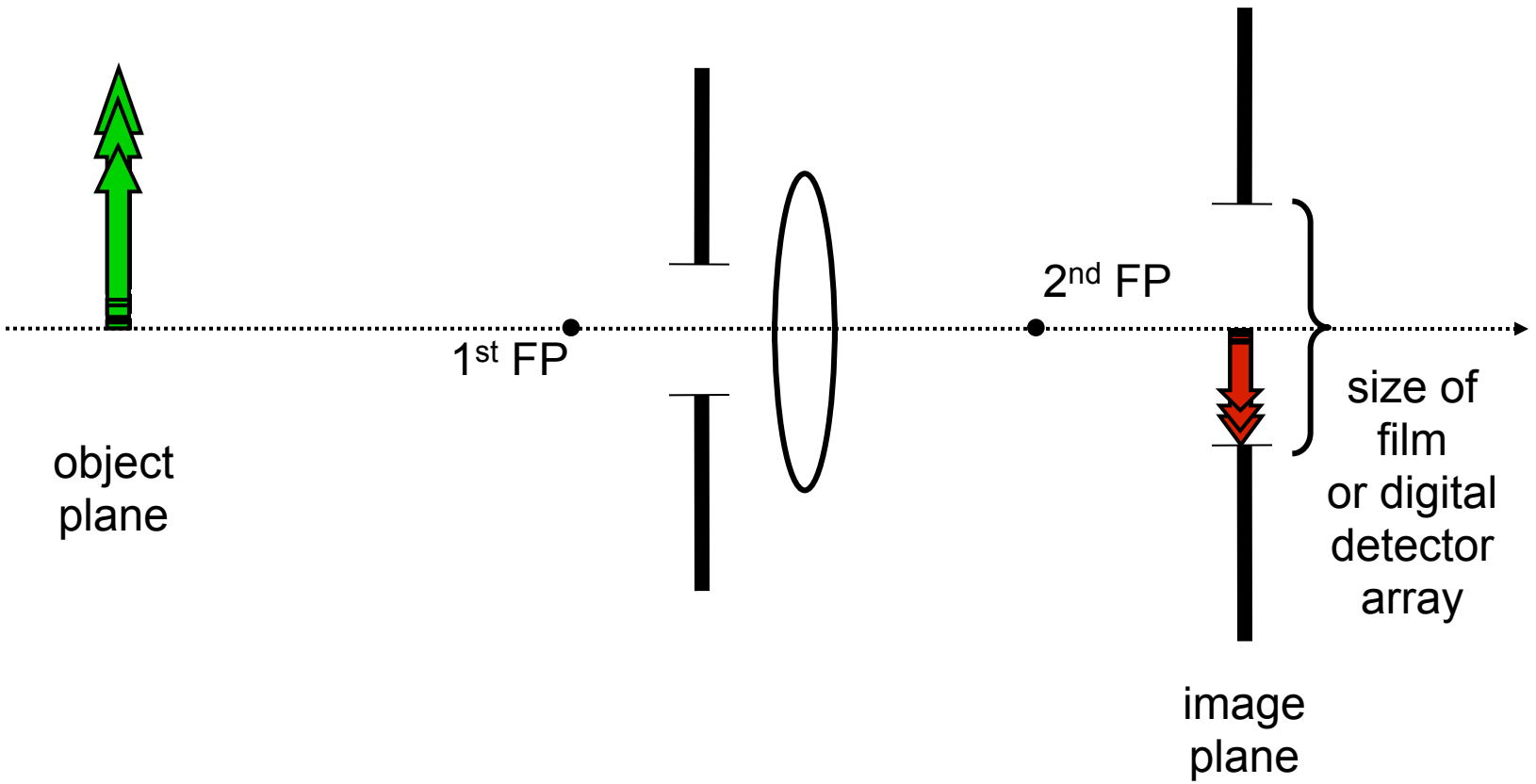
The Field of View is the angle between the pair of Chief Rays that just make it through the edges of the Field Stop

All together

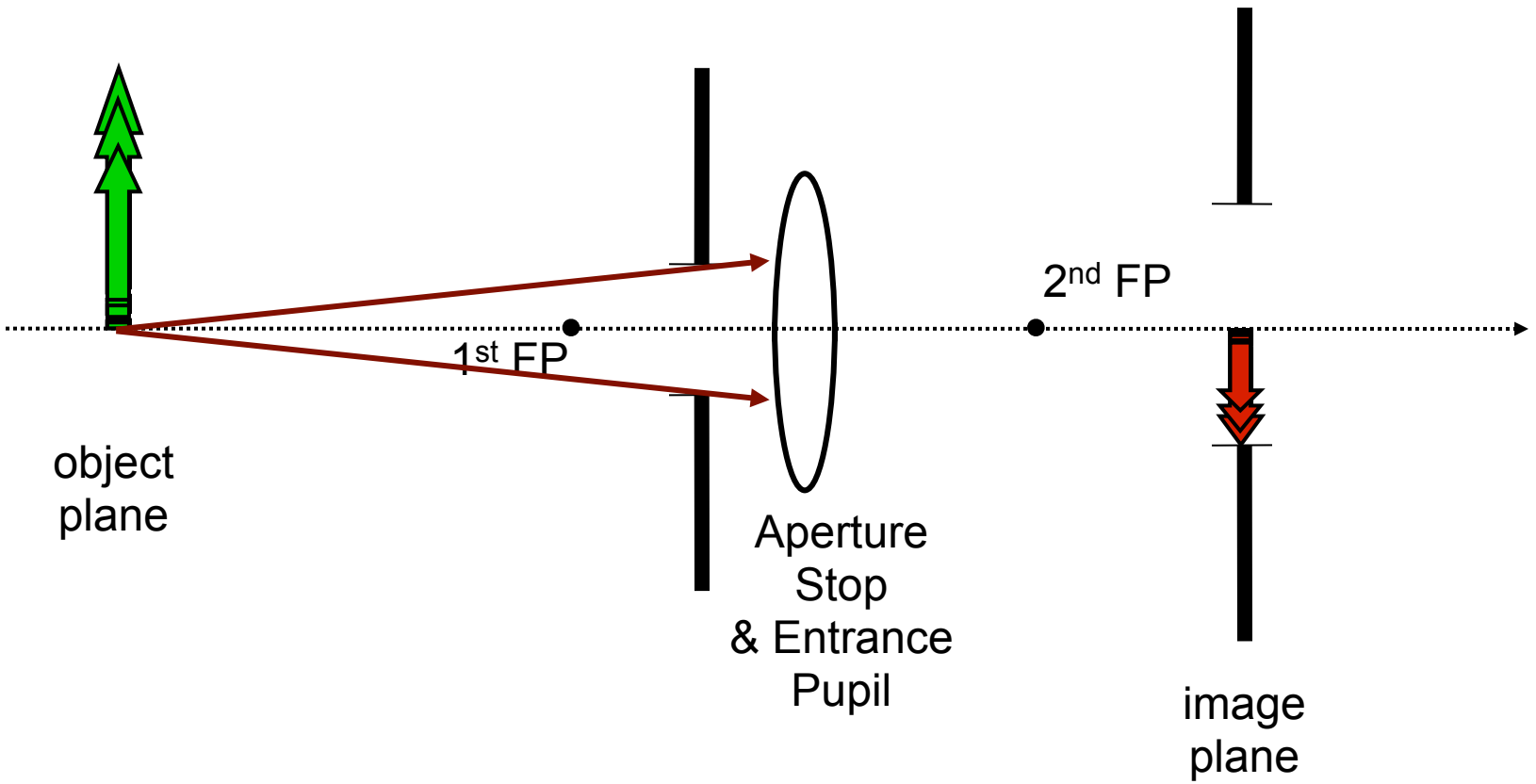


The Numerical Aperture is the angle between the pair of Marginal Rays that just make it through the edges of the Aperture Stop

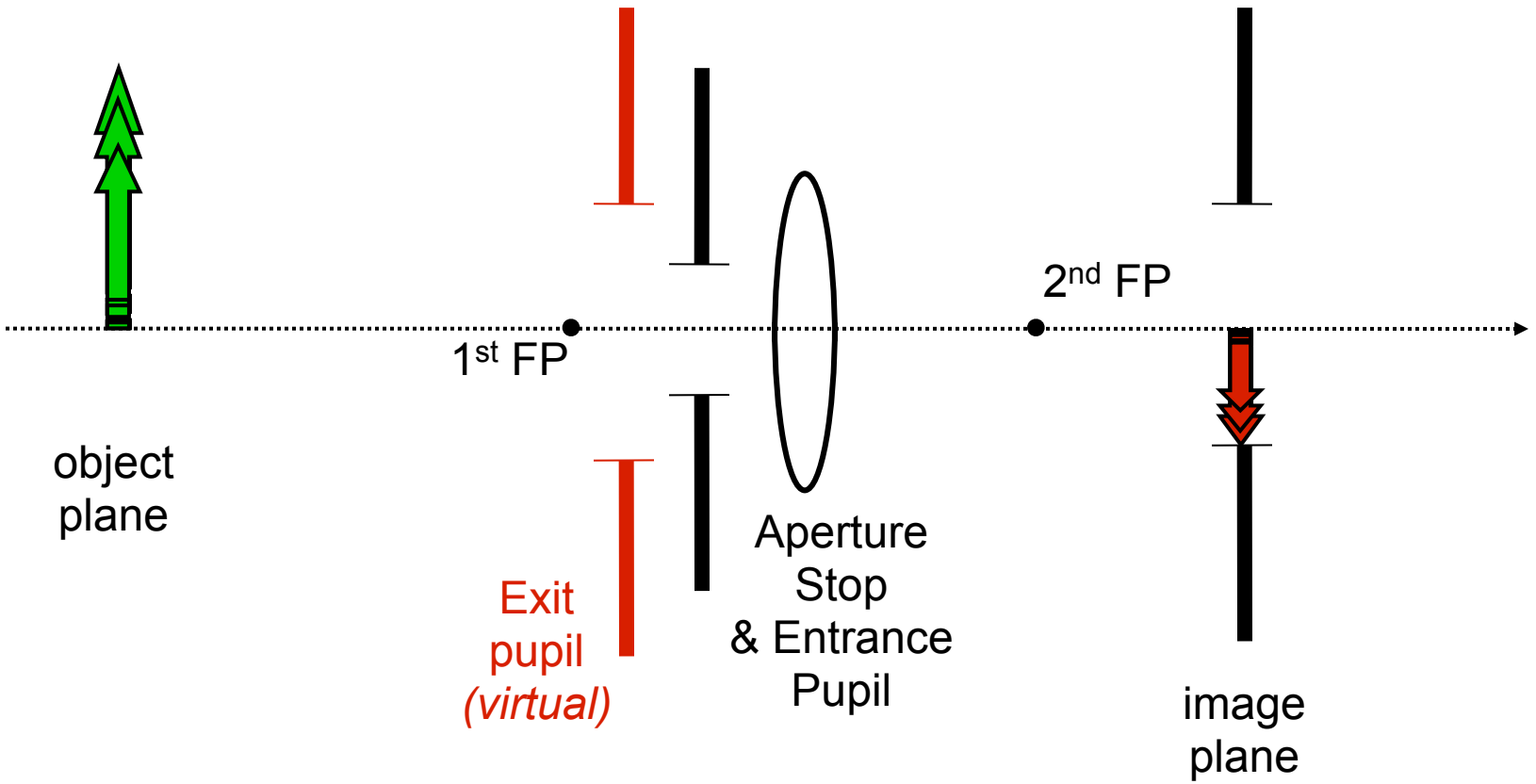
Example: single-lens camera



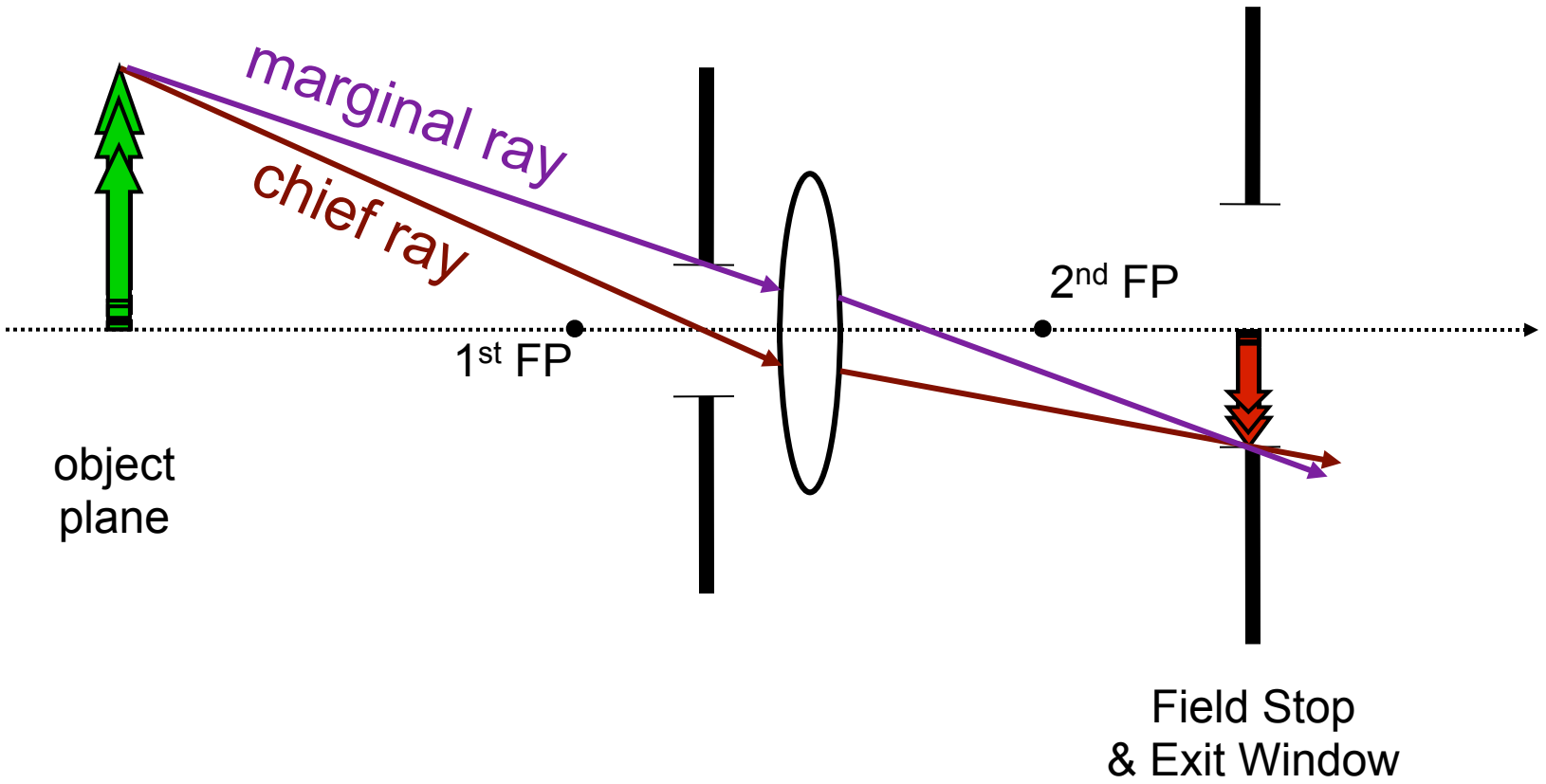
Example: single-lens camera



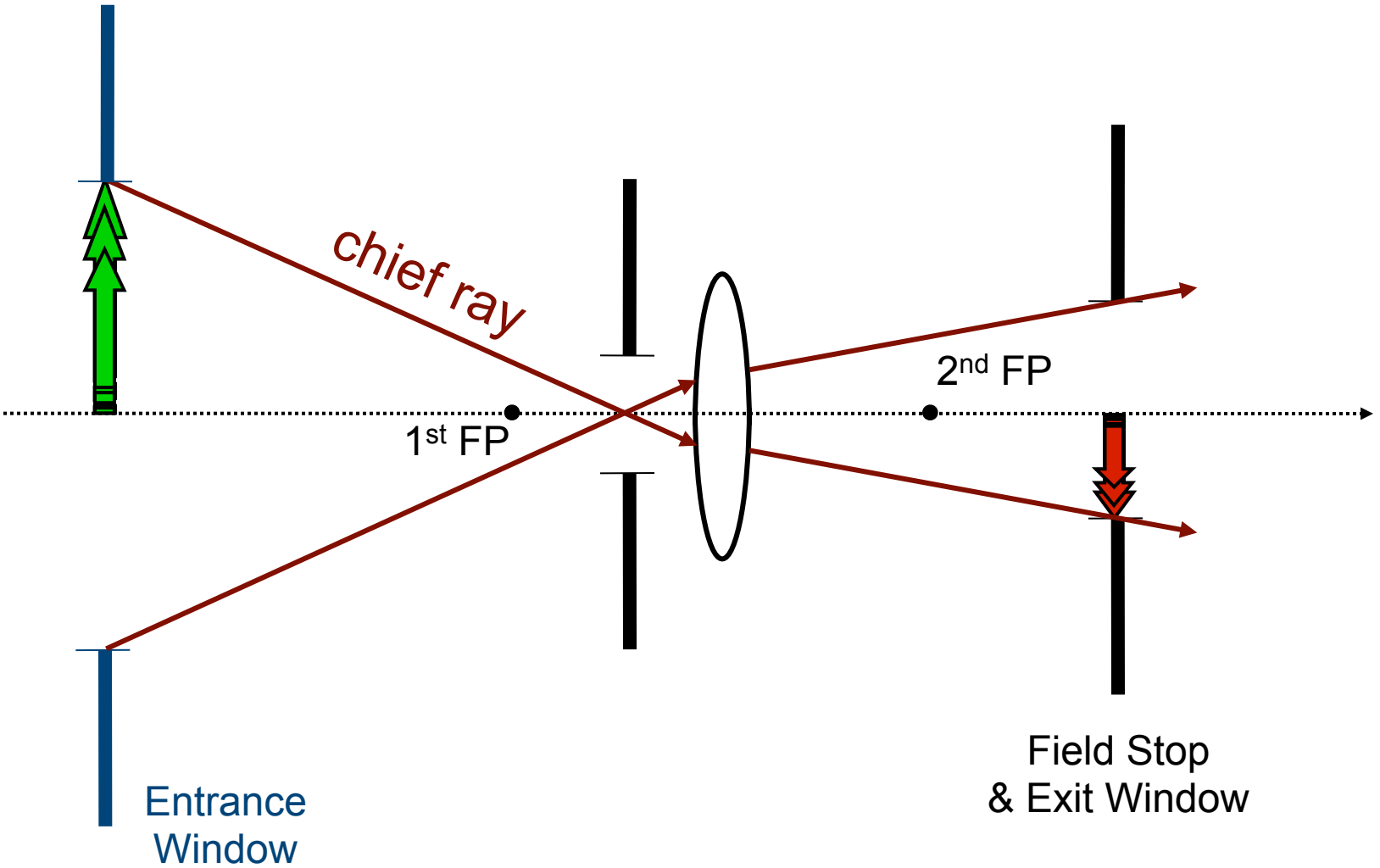
Example: single-lens camera



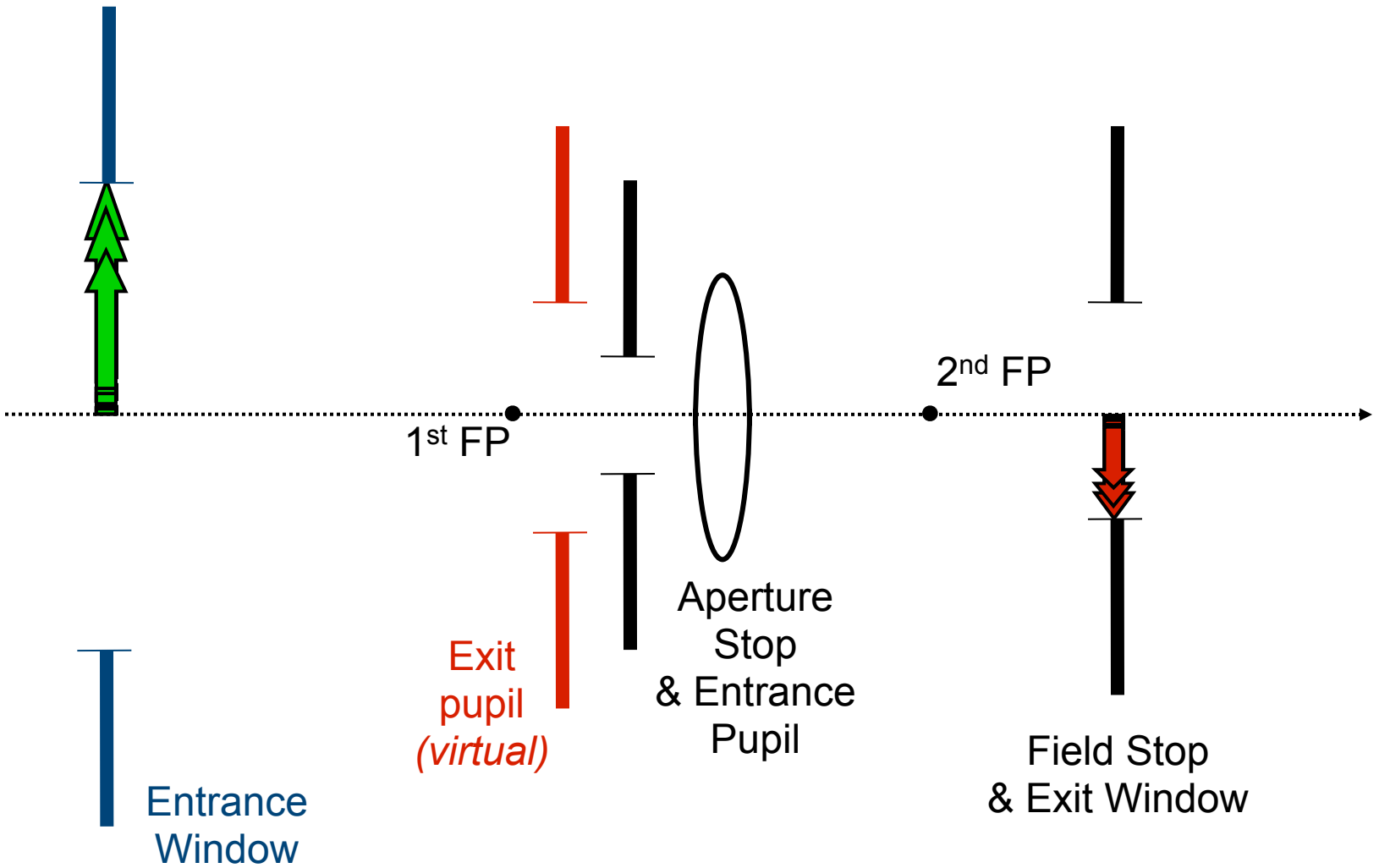
Example: single-lens camera



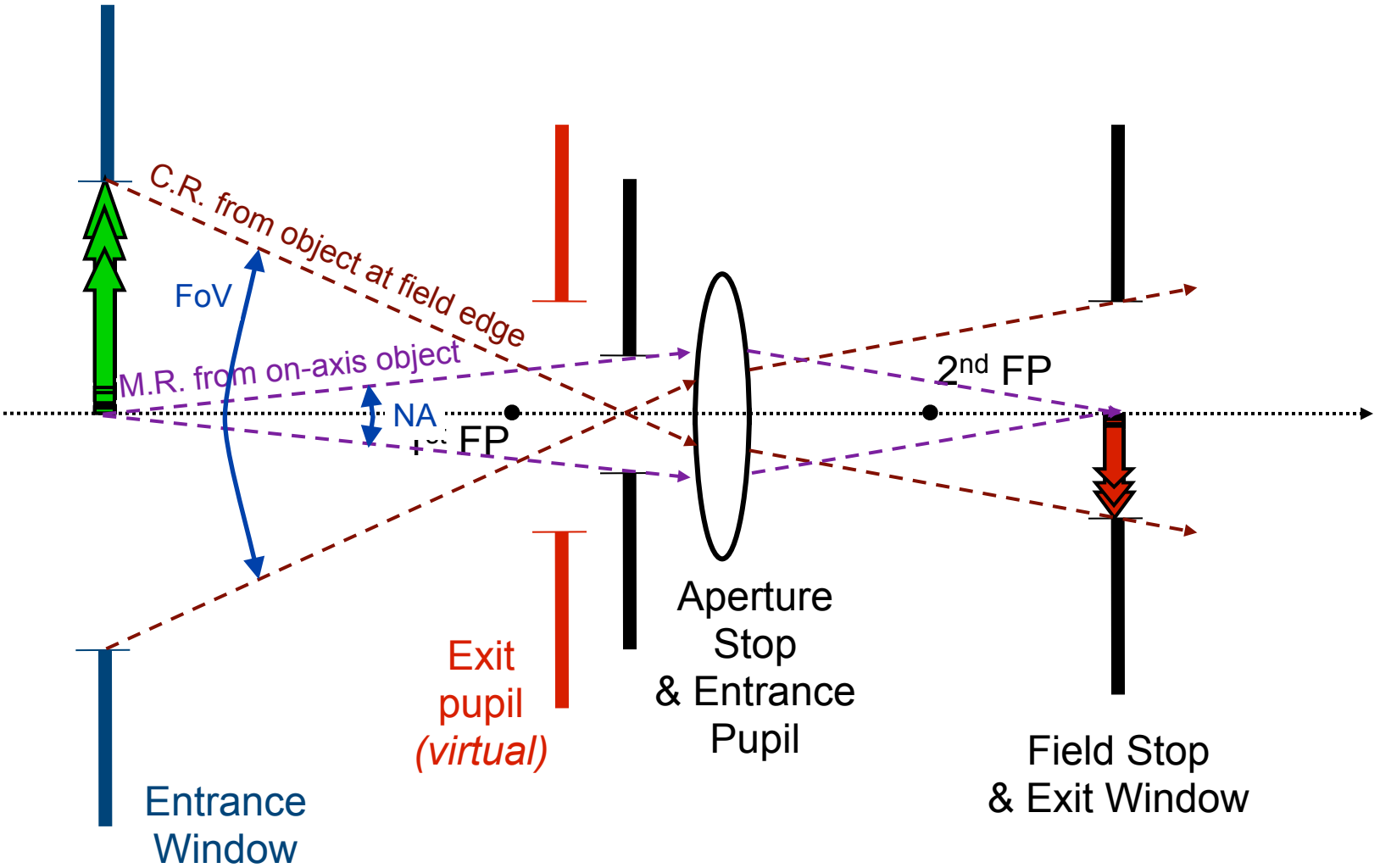
Example: single-lens camera



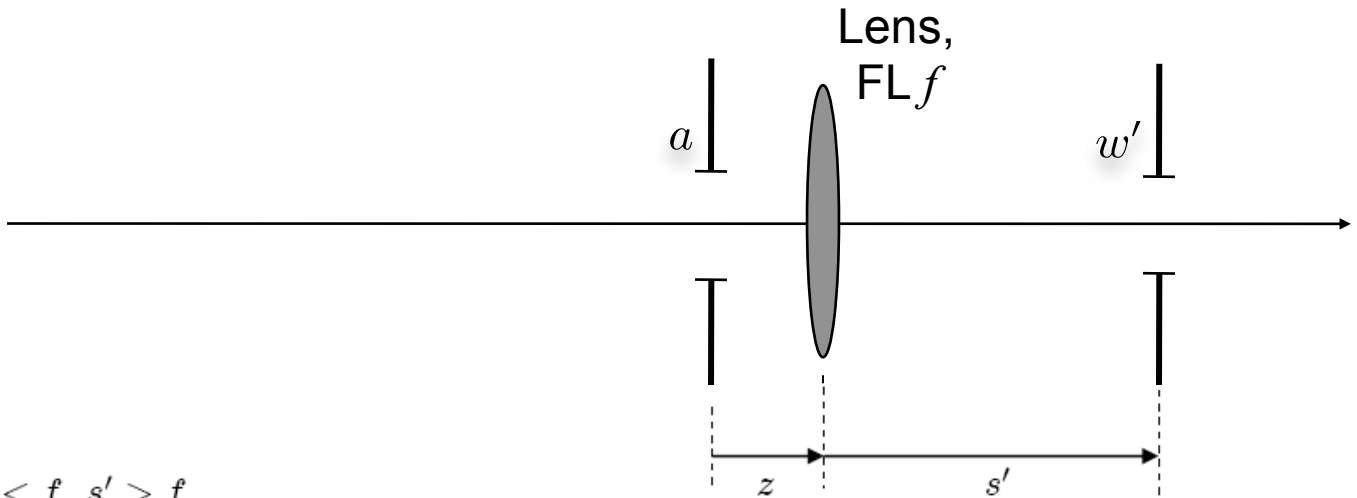
Example: single-lens camera



Example: single-lens camera



Example: single-lens camera



Given: $z < f$, $s' > f$.

Angular acceptance wrt *axial* point object: limited by a, so a is the aperture.
There are no optical elements to the left of a, so a is also the Entrance Pupil.

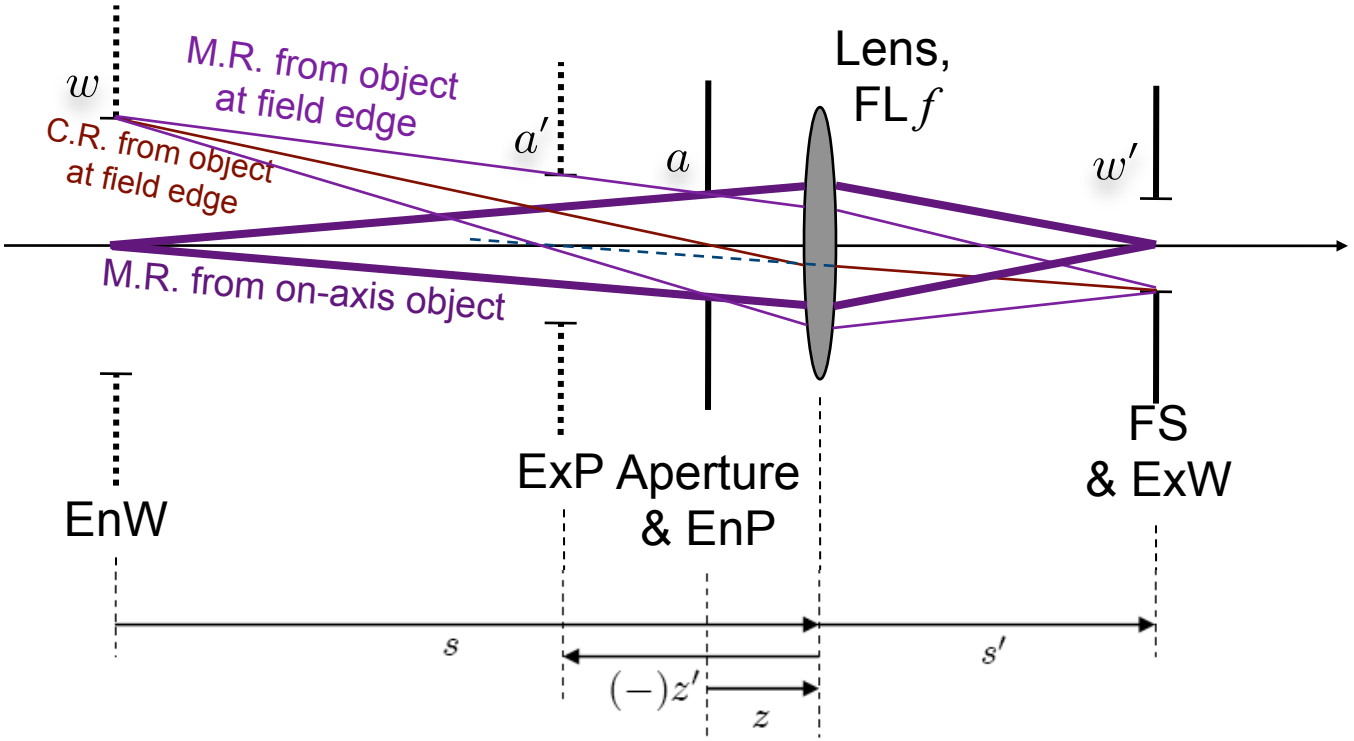
Location of Exit Pupil: $\frac{1}{z'} + \frac{1}{z} = \frac{1}{f} \Rightarrow z' = \frac{zf}{z-f} (< 0)$. Exit Pupil size: $a' = -\frac{z'}{z} a = -\frac{af}{z-f}$.

Marginal ray cut–off wrt *off–axis* point object: limited by w', so w' is the field stop.
There are no optical elements to the right of w', so w' is also the Exit Window.

Location of Entrance Window: $\frac{1}{s'} + \frac{1}{s} = \frac{1}{f} \Rightarrow s = \frac{s'f}{s'-f} (> 0)$.
(Note: this is also the location of the in–focus object.)

Entrance Window size: $w = -\frac{s}{s'} w' = -\frac{w'f}{s'-f}$.

Example: single-lens camera



Note: The angular acceptance of rays emanating from an off–axis point object is *smaller* than the angular acceptance of rays from an on–axis point object. This phenomenon is called "vignetting." Vignetting is generally undesirable; if it is allwoed, the image off-axis appears to be *dimmer* than the image on–axis.

2.71 / 2.710 Optics
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