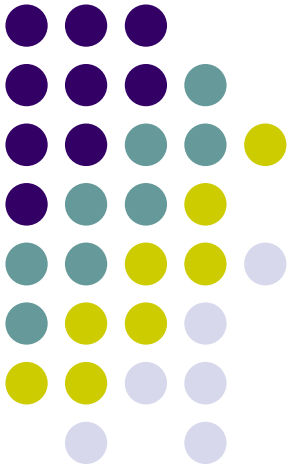
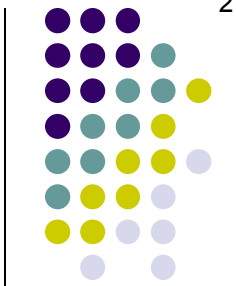
Ray Tracing

Basic Optics, Chapter 19

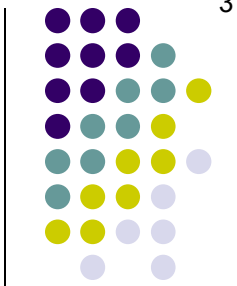


Ray Tracing



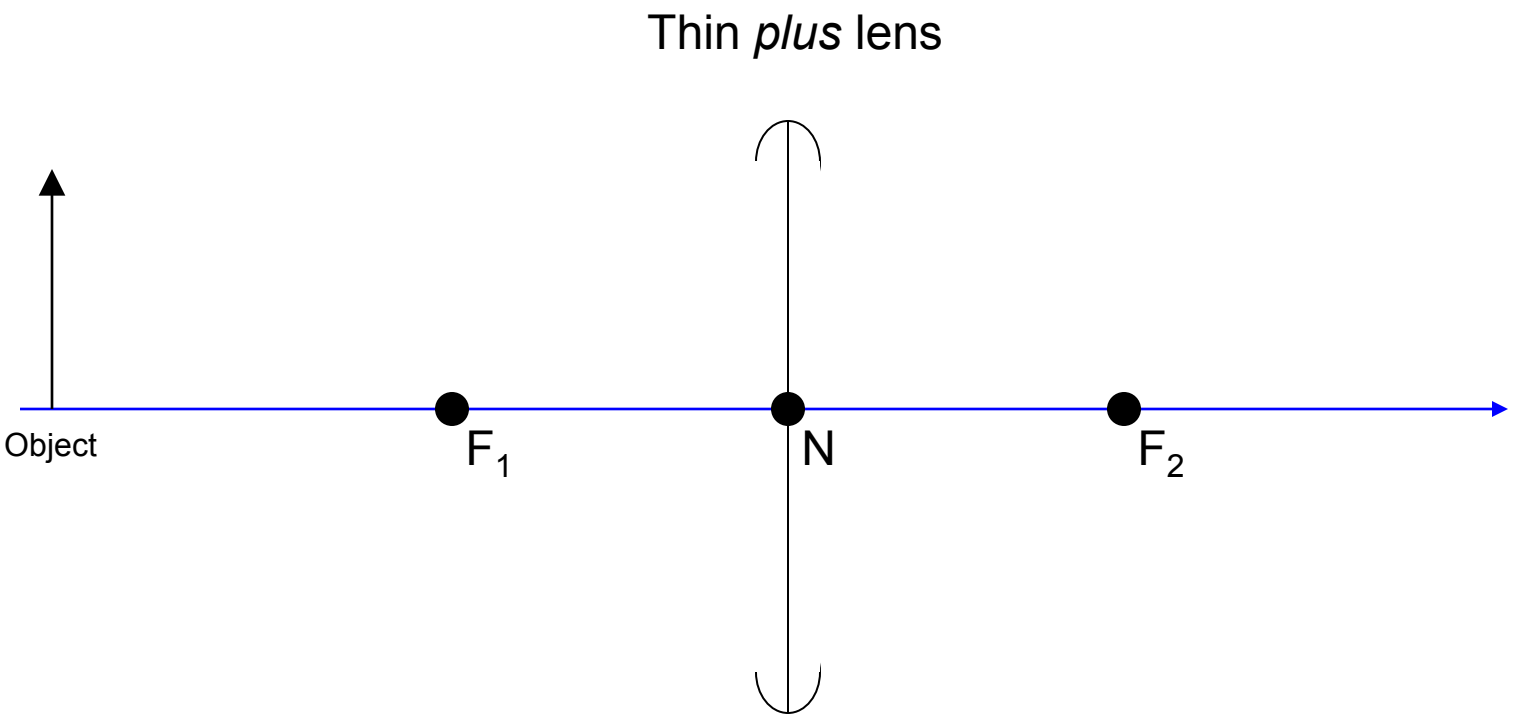
- In this lecture we will discuss ***ray tracing*** in greater detail
  - Ray tracing is a useful skill because it allows you to determine important properties of an optical system (and answer questions about them on the OKAP)

Ray Tracing



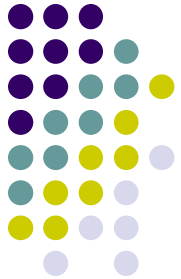
- In this lecture we will discuss ***ray tracing*** in greater detail
  - Ray tracing is a useful skill because it allows you to determine important properties of an optical system (and answer questions about them on the OKAP)
  - Specifically, we will look more closely at the rules governing the passage of rays through lenses—rules that determine:
    - The ***location*** of an image
    - Whether an image is ***upright*** or ***inverted***
    - The ***real*** vs ***virtual*** status of objects and images
    - The ***magnification*** of an image

Ray Tracing

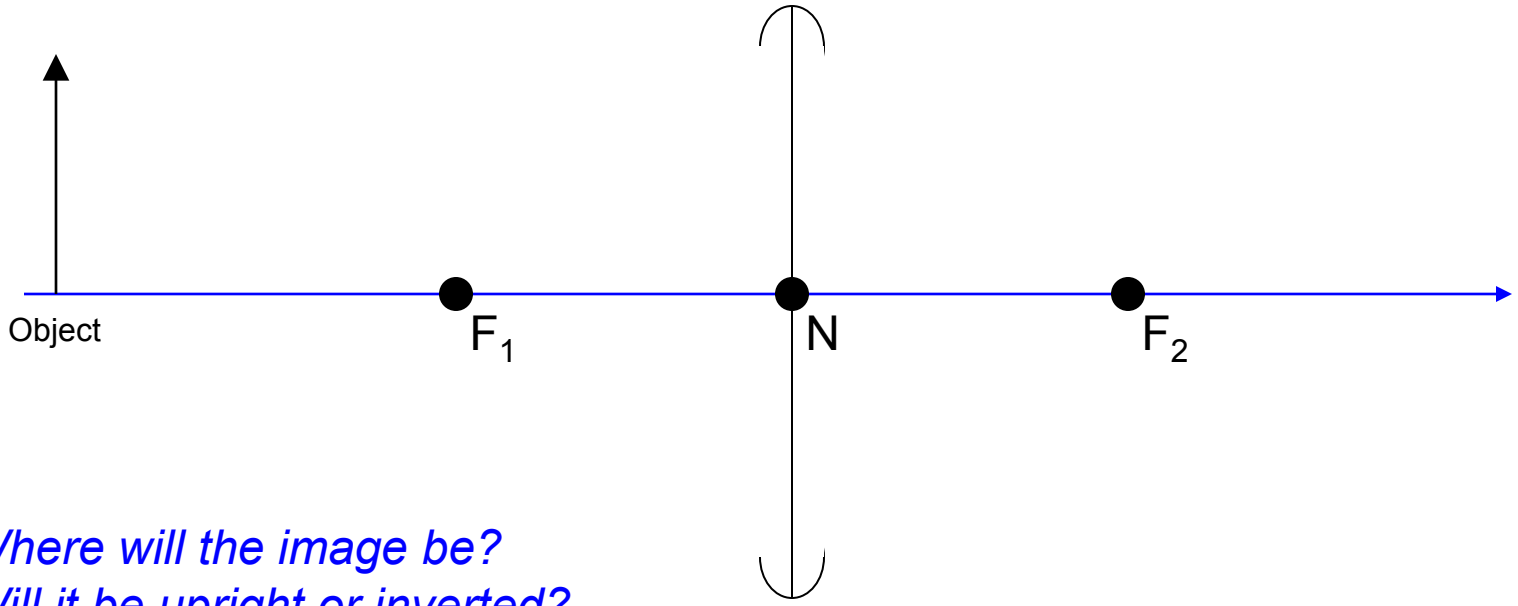


With regard to this object and its relationship with this optical system…

Ray Tracing



Thin *plus* lens

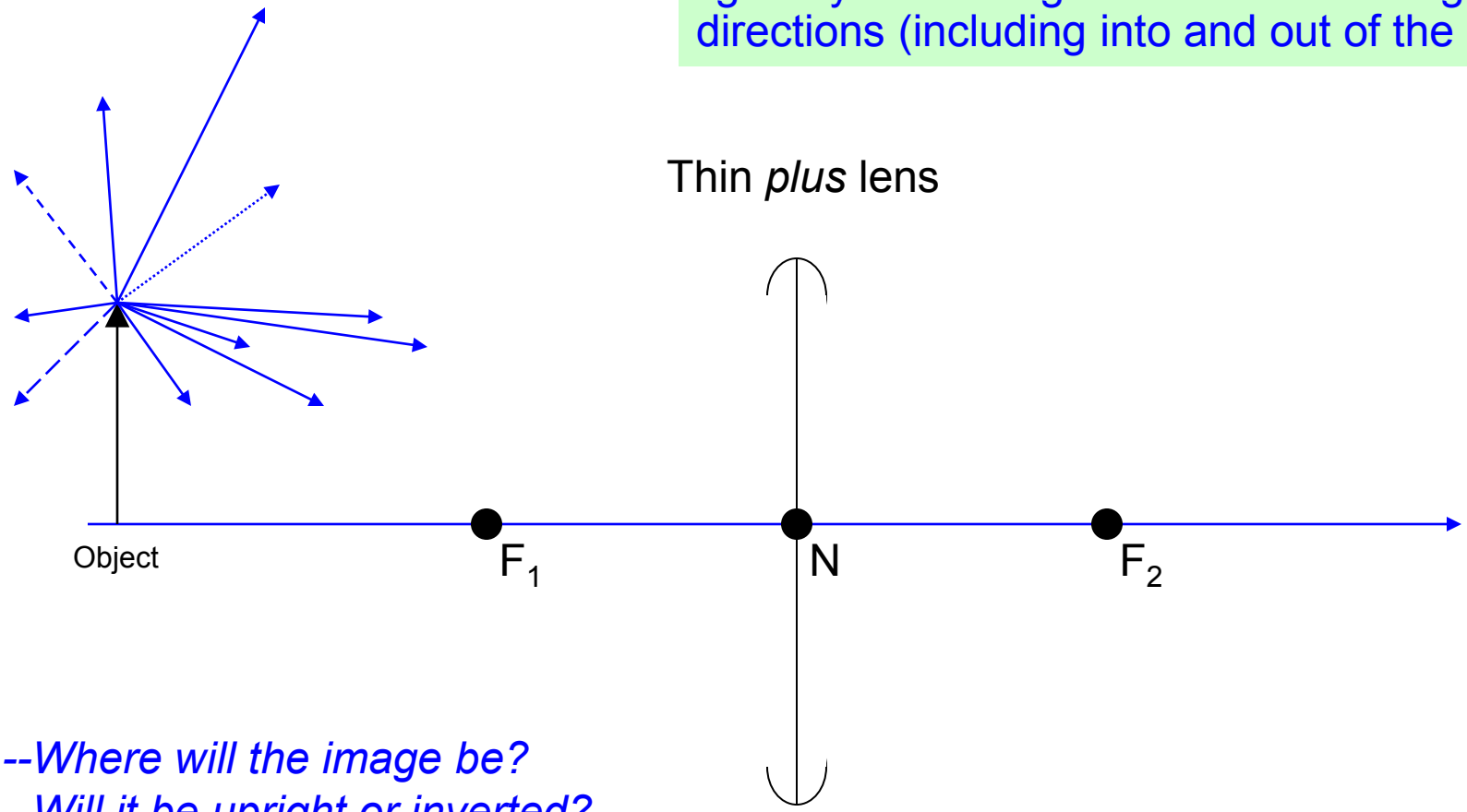


--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing

Consider the tip of the object: It has an infinity of light rays bouncing off of it and heading in all directions (including into and out of the screen).



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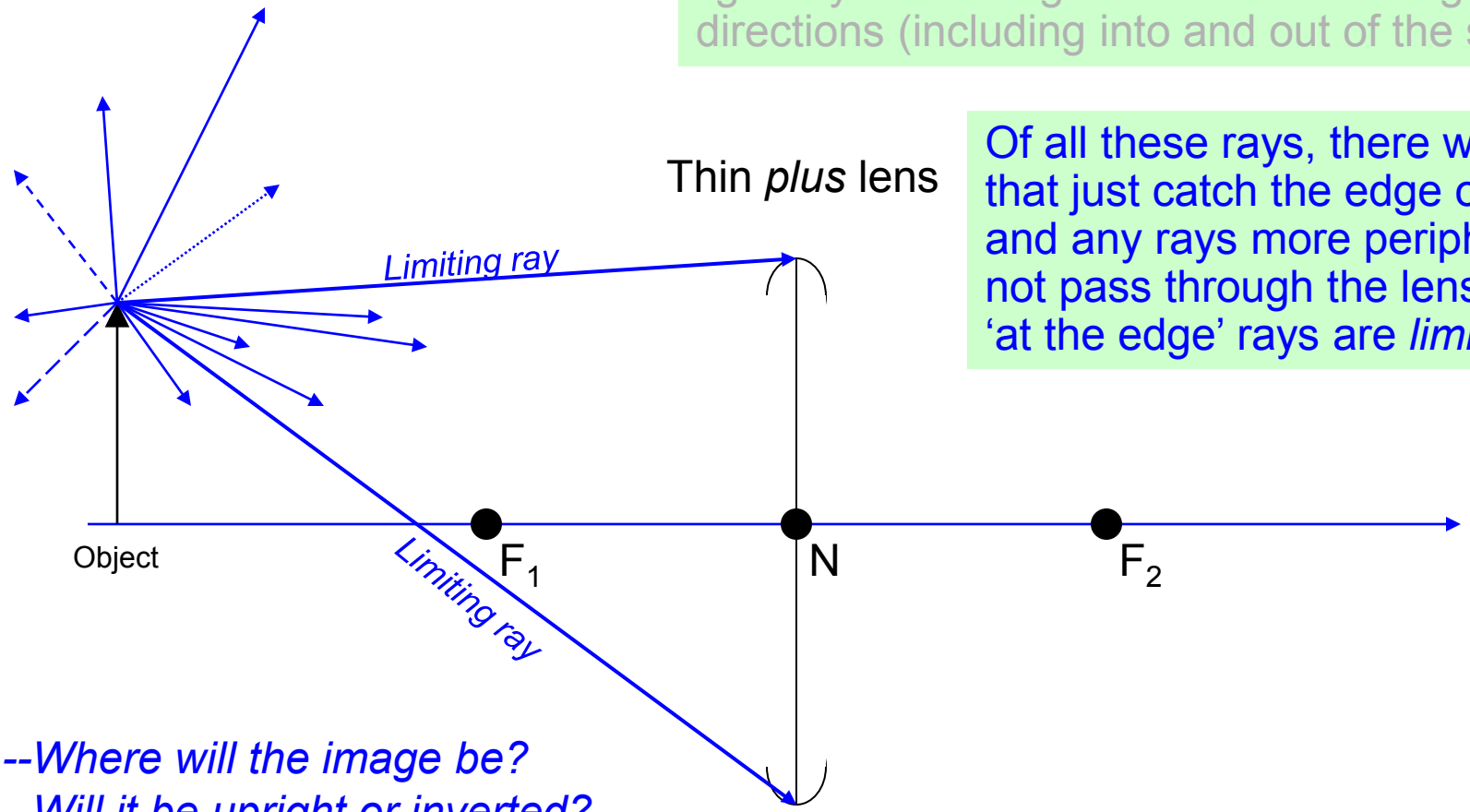
With regard to this object and its relationship with this optical system…

Ray Tracing

Consider the tip of the object: It has an infinity of light rays bouncing off of it and heading in all directions (including into and out of the screen).

Of all these rays, there will be some that just catch the edge of the lens, and any rays more peripheral will not pass through the lens. These 'at the edge' rays are *limiting rays.*



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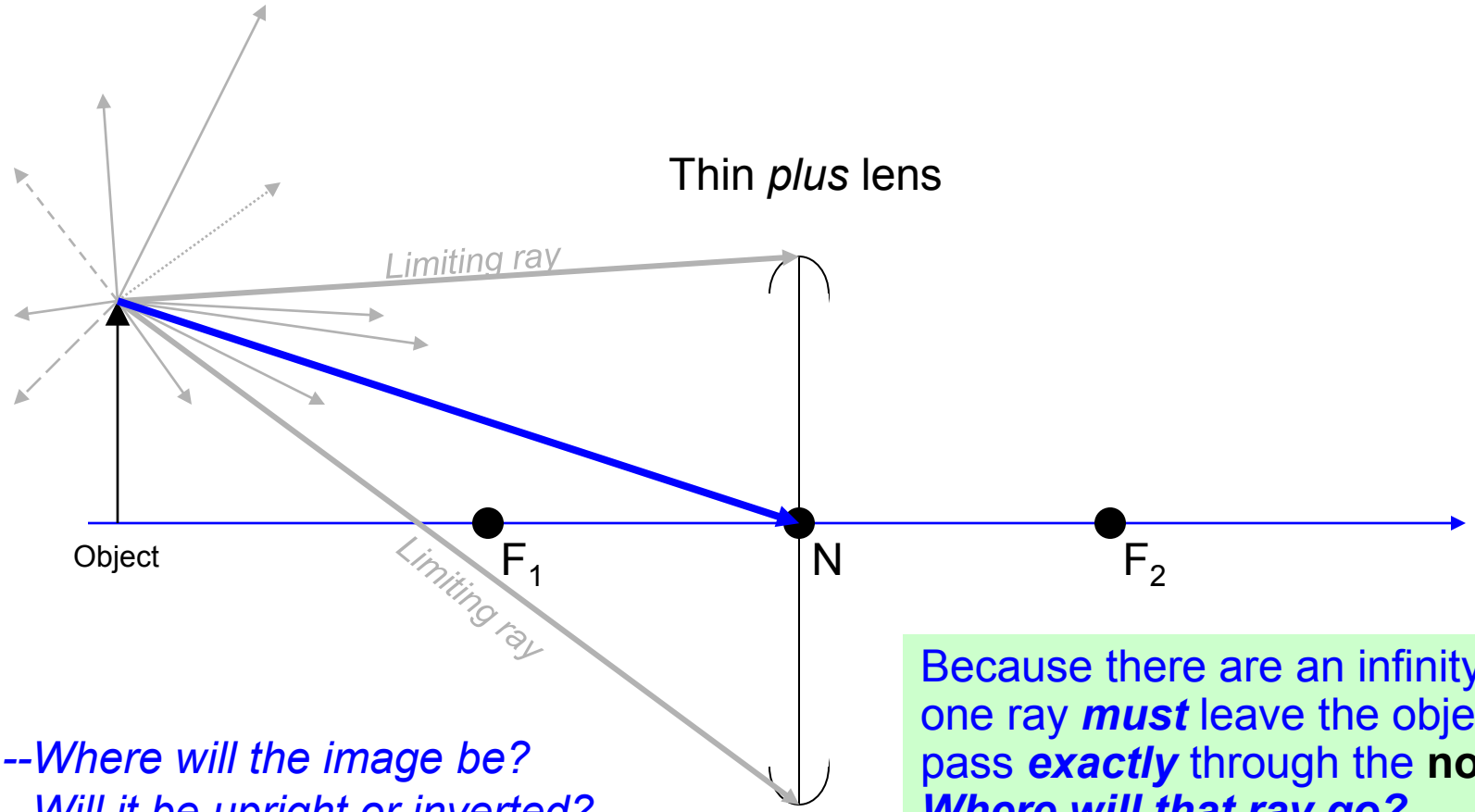
With regard to this object and its relationship with this optical system…

Ray Tracing

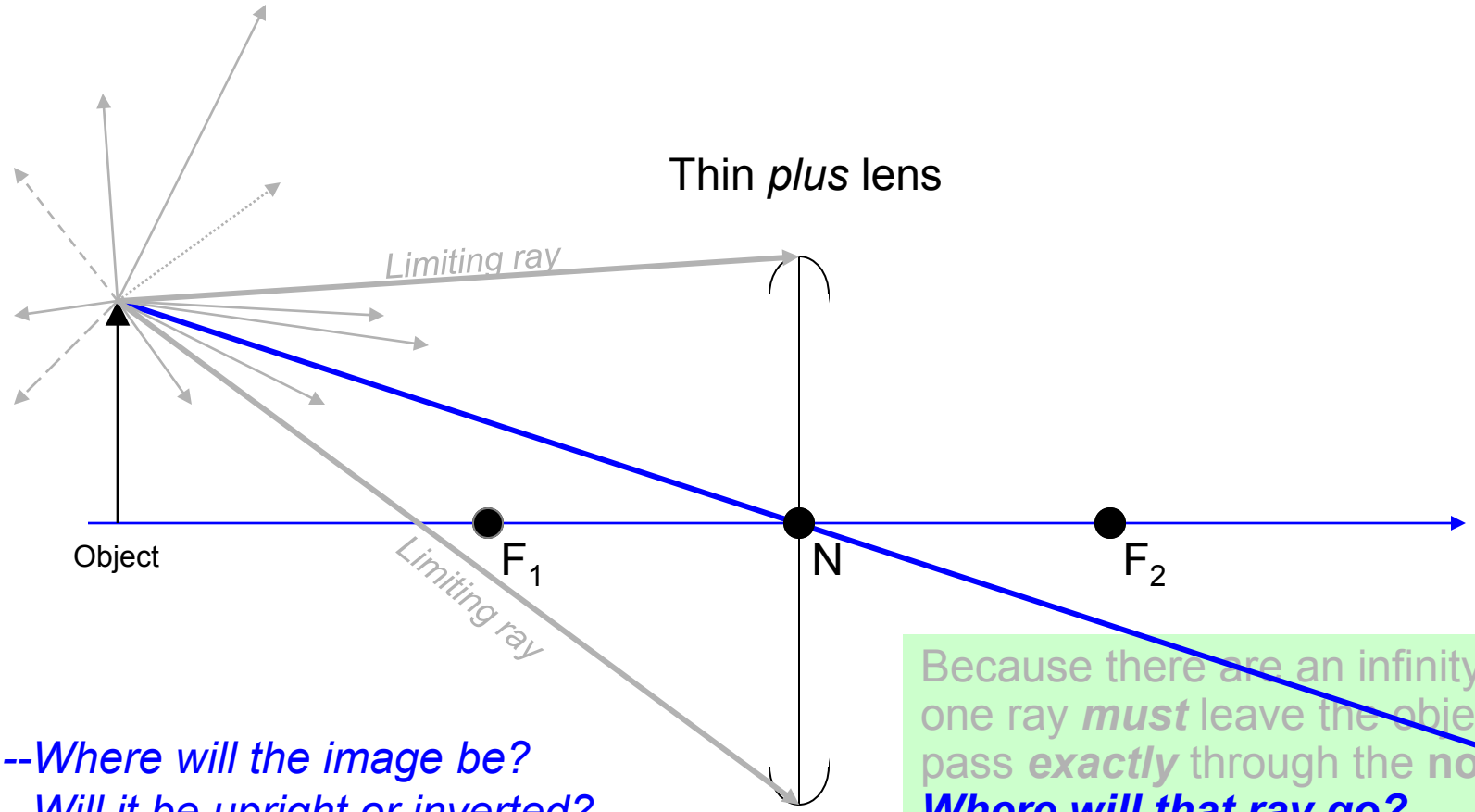


--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

Because there are an infinity of rays, one ray ***must*** leave the object tip and pass ***exactly*** through the **nodal point**. ***Where will that ray go?***

With regard to this object and its relationship with this optical system…

Ray Tracing



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--Are the object and image real or virtual?
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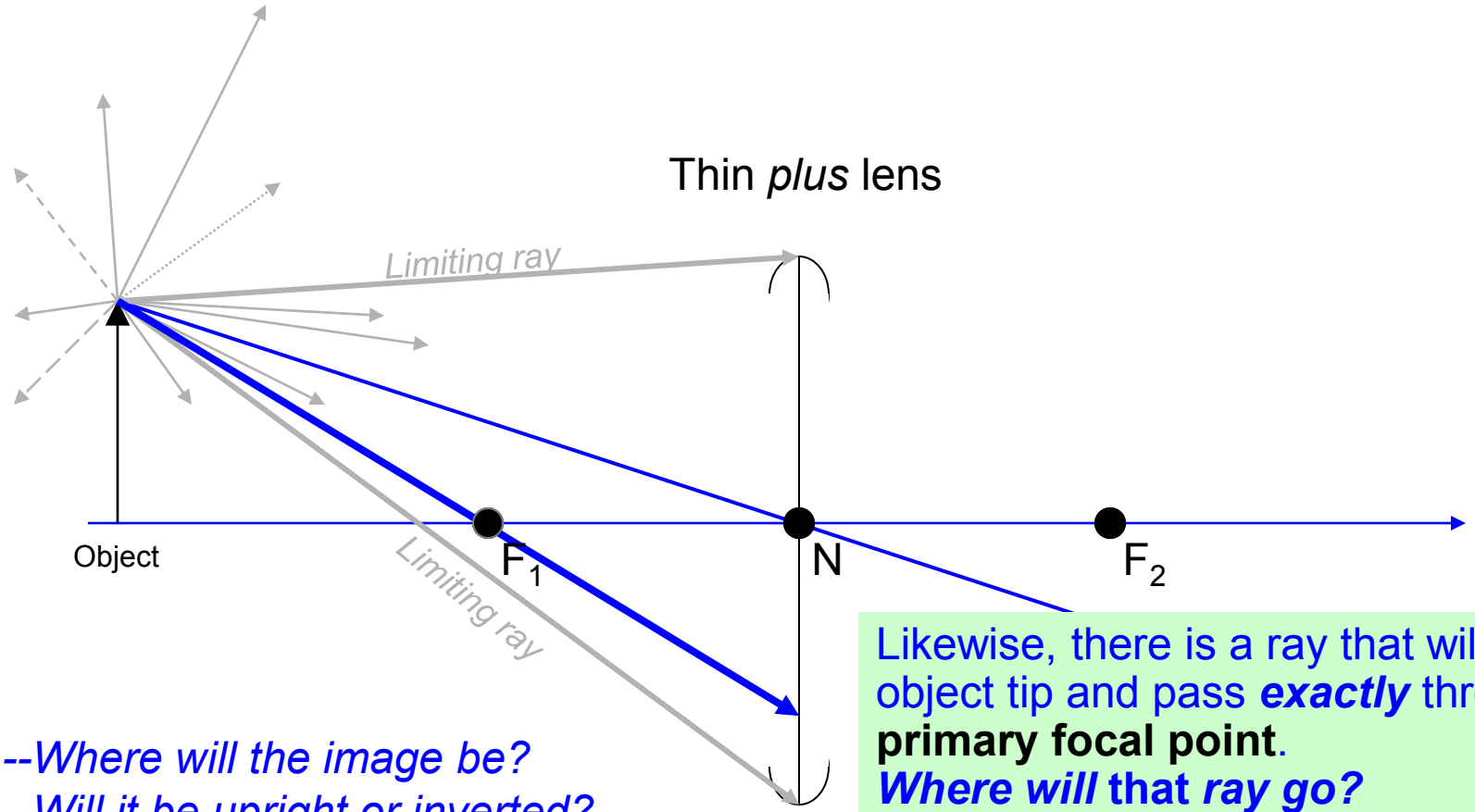
Because there are an infinity of rays, one ray ***must*** leave the object tip and pass ***exactly*** through the **nodal point**.
Where will that ray go?
By definition, a nodal ray must continue undeviated by the lens.

With regard to this object and its relationship with this optical system…

Ray Tracing

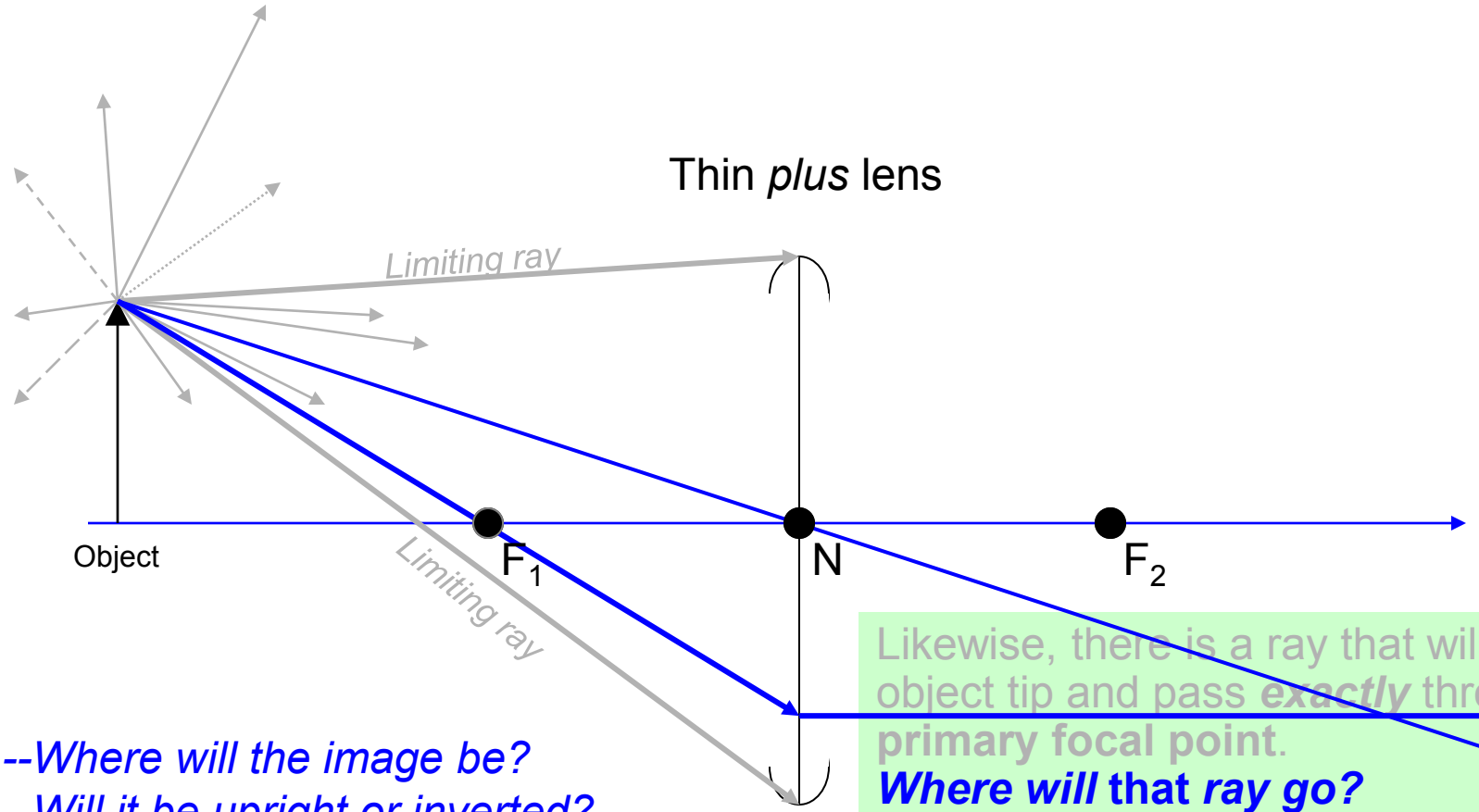


Likewise, there is a ray that will leave the object tip and pass ***exactly*** through the **primary focal point**.
Where will* that *ray go?

--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing

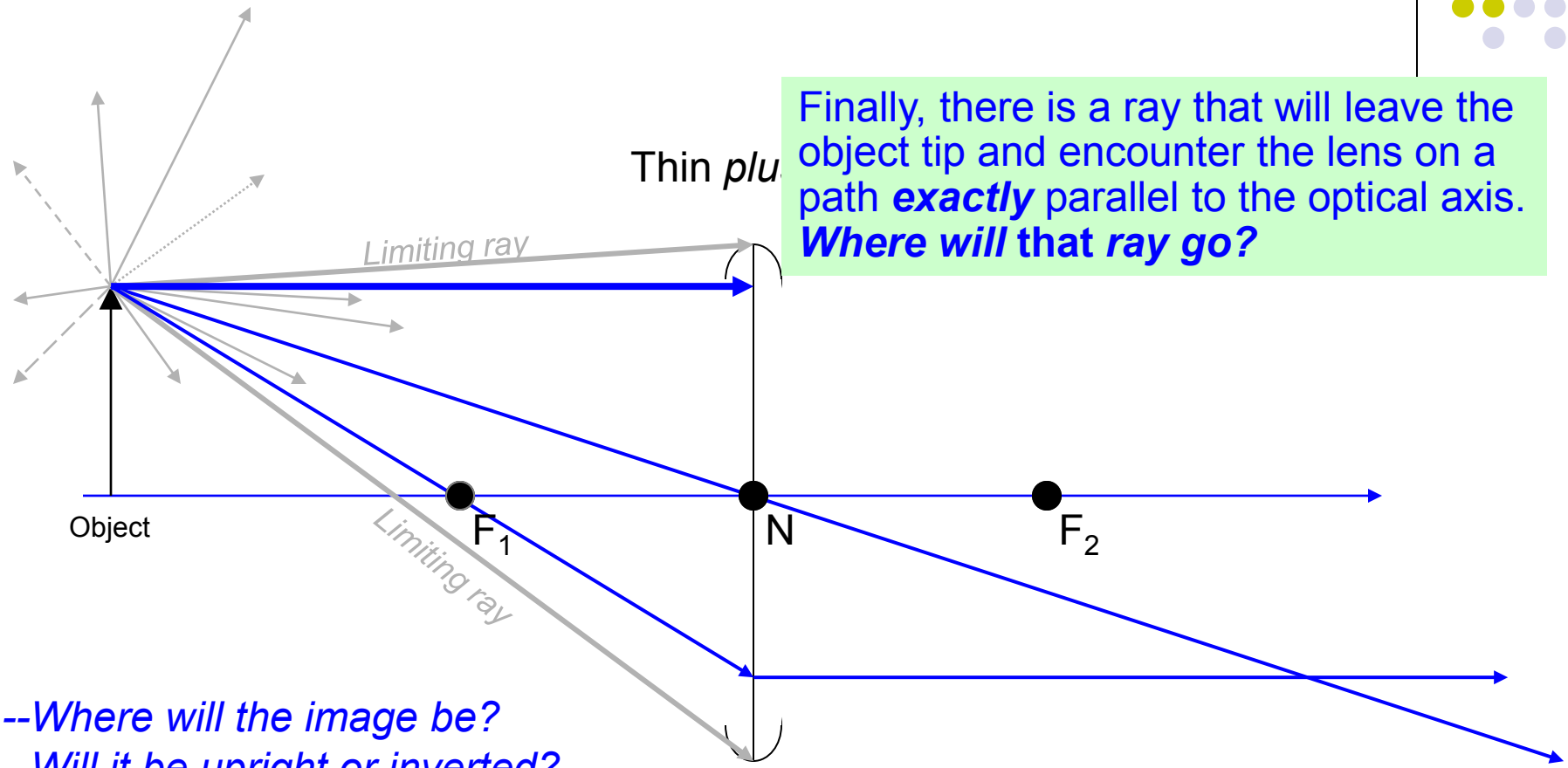


--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

Likewise, there is a ray that will leave the object tip and pass ***exactly*** through the **primary focal point**.
Where will* that *ray go?
By definition, a ray passing through the primary focal point will exit the lens parallel to the optical axis.

With regard to this object and its relationship with this optical system…

Ray Tracing

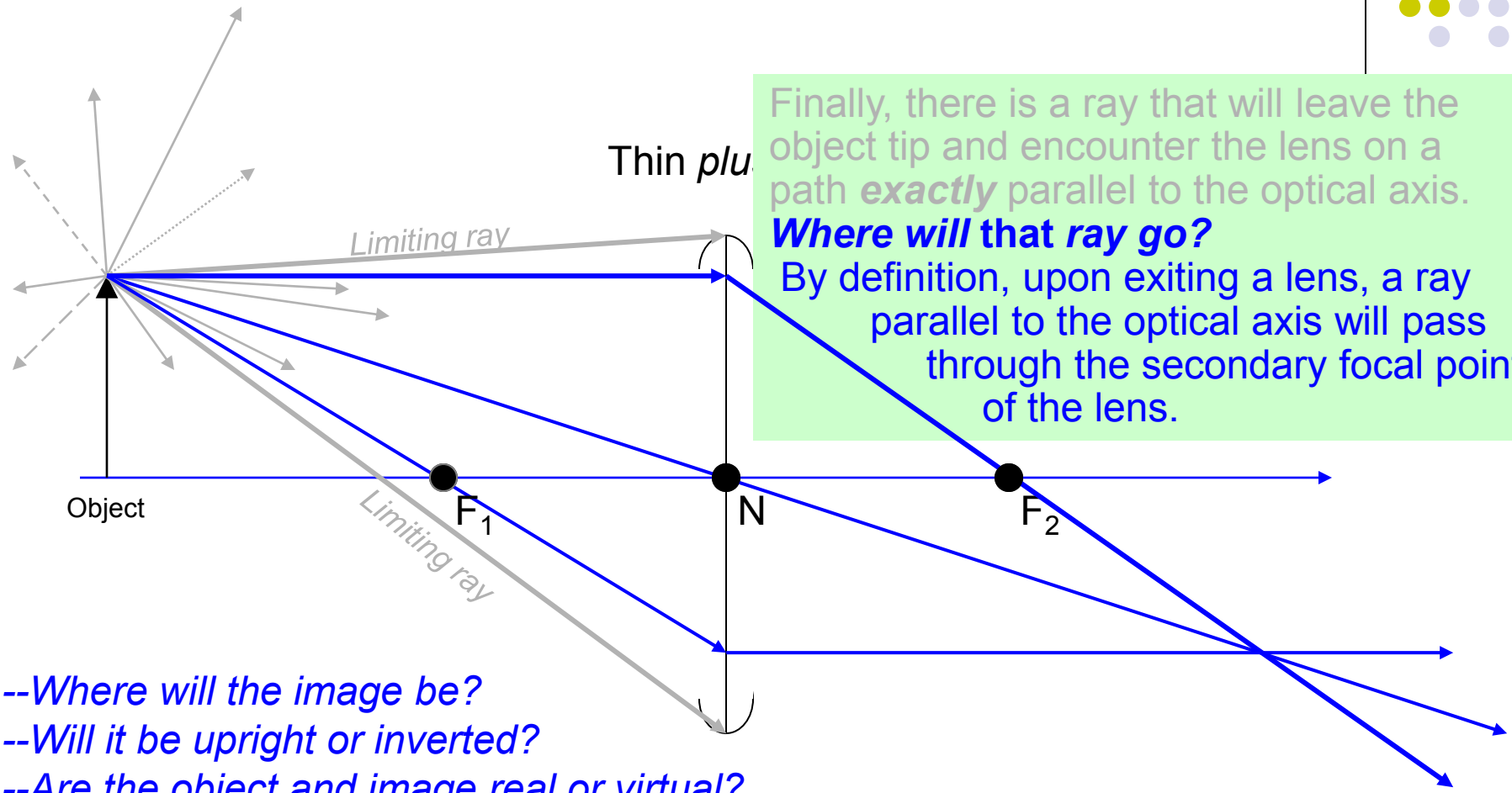


Finally, there is a ray that will leave the object tip and encounter the lens on a path ***exactly*** parallel to the optical axis. ***Where will* that *ray go?***

--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing



Finally, there is a ray that will leave the object tip and encounter the lens on a path ***exactly*** parallel to the optical axis.

Where will* that *ray go?

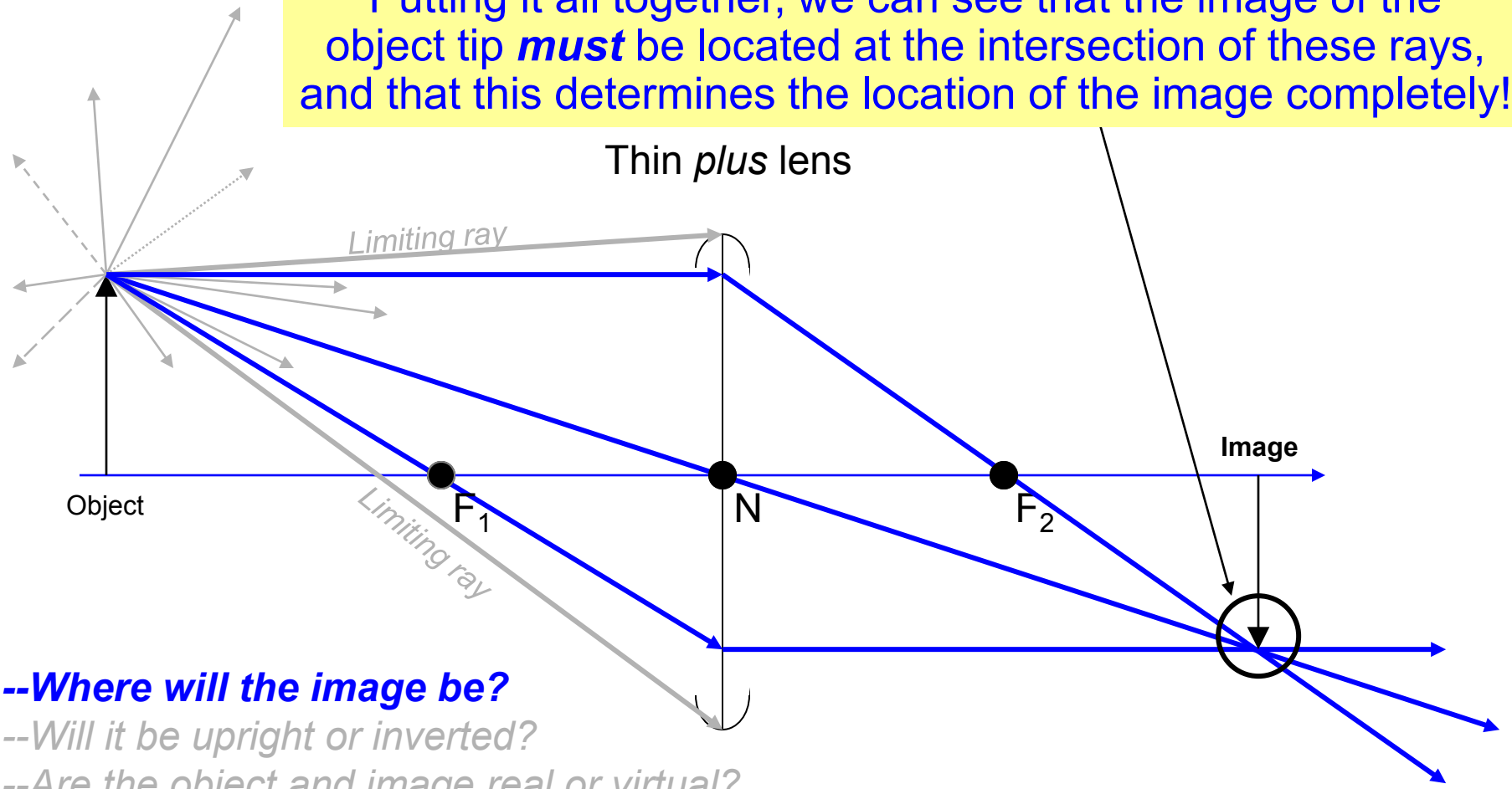
By definition, upon exiting a lens, a ray parallel to the optical axis will pass through the secondary focal point of the lens.

--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing

Putting it all together, we can see that the image of the object tip ***must*** be located at the intersection of these rays, and that this determines the location of the image completely!



--Where will the image be?

--Will it be upright or inverted?

--Are the object and image real or virtual?

--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing

In fact, any *two* of these rays would suffice to determine location

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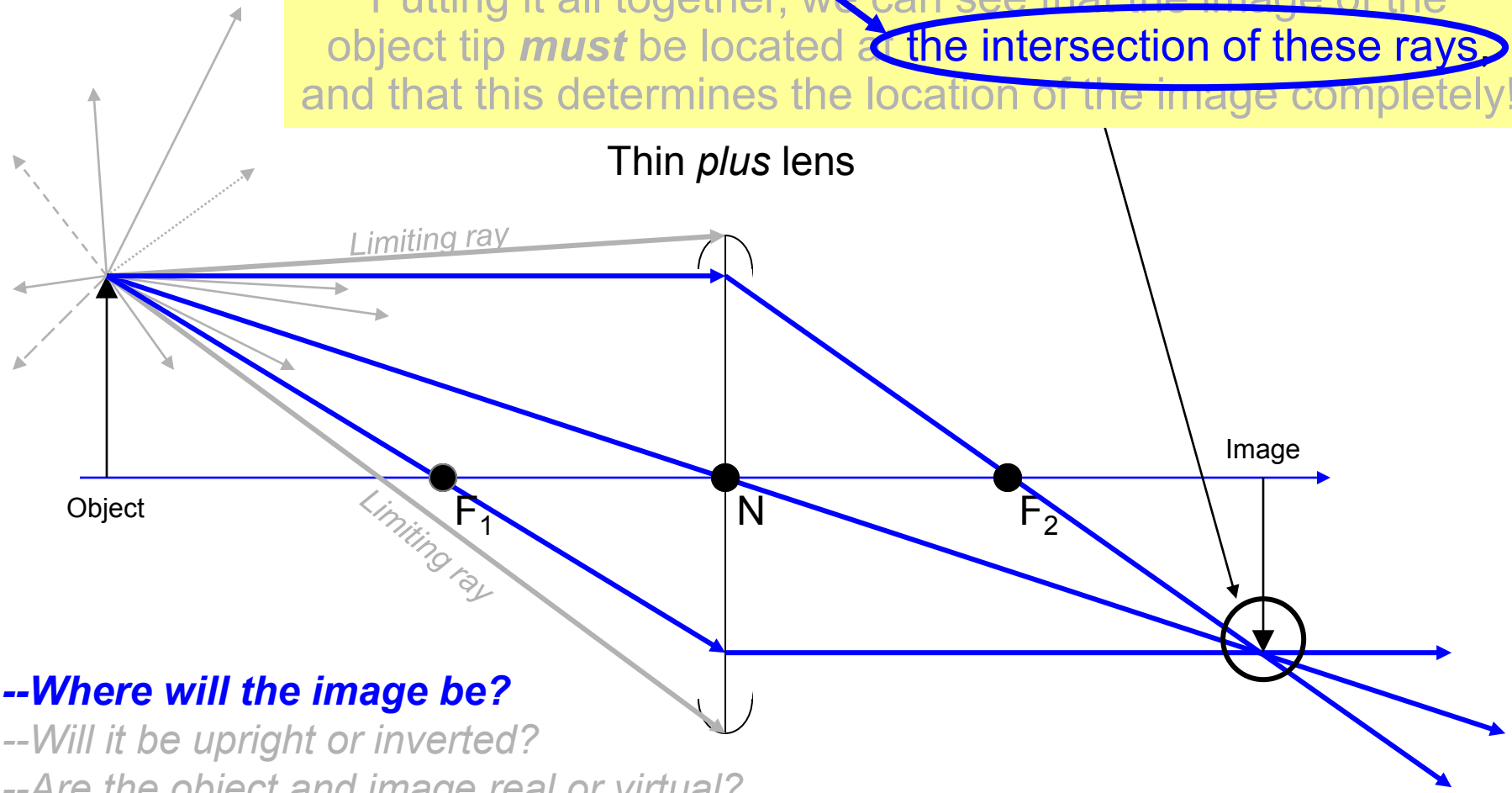

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With regard to this object and its relationship with this optical system…

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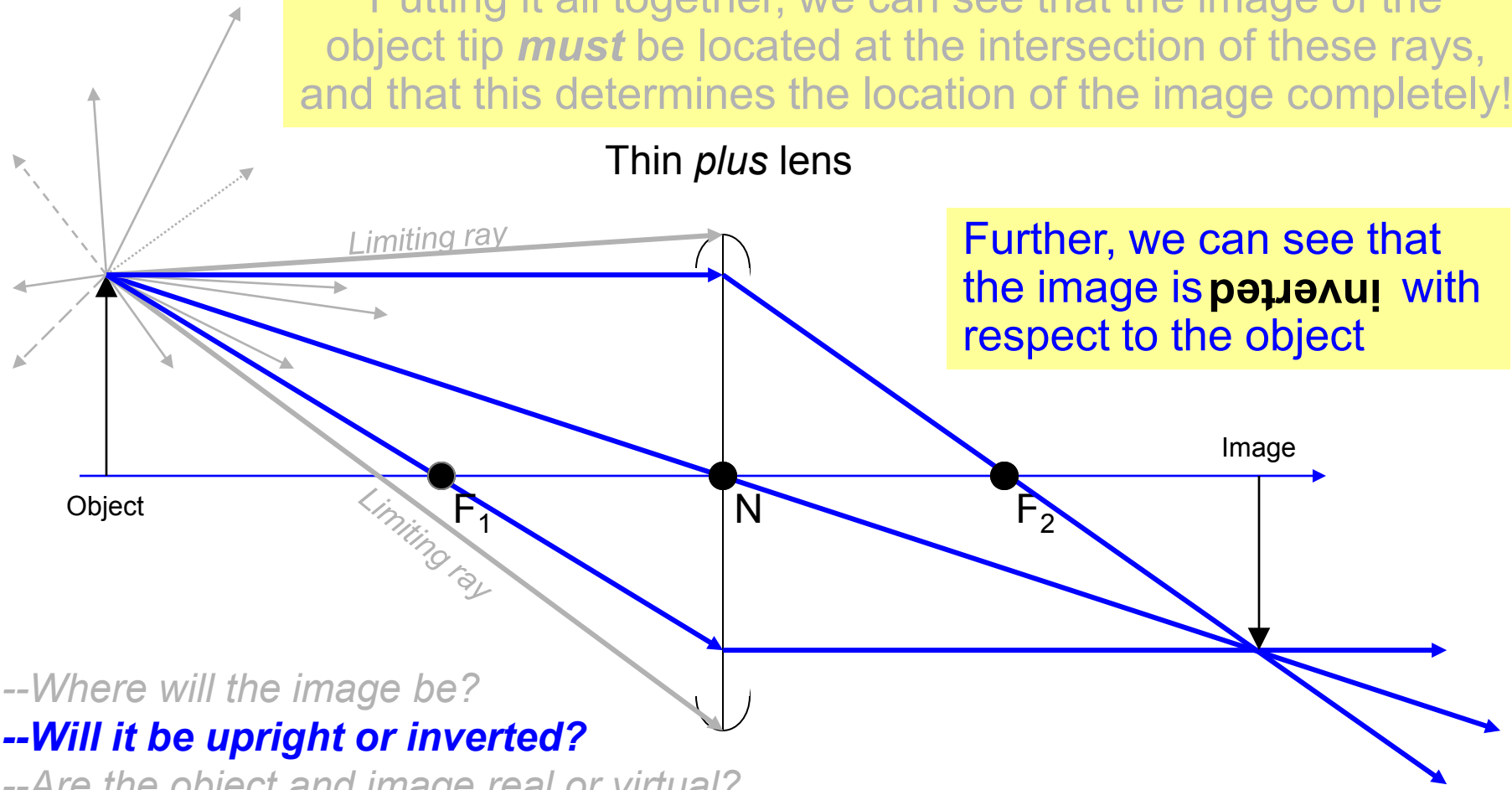


Further, we can see that the image is **inverted** with respect to the object

--Where will the image be?

--Will it be upright or inverted?

--Are the object and image real or virtual?

--Will the image be magnified or minified?

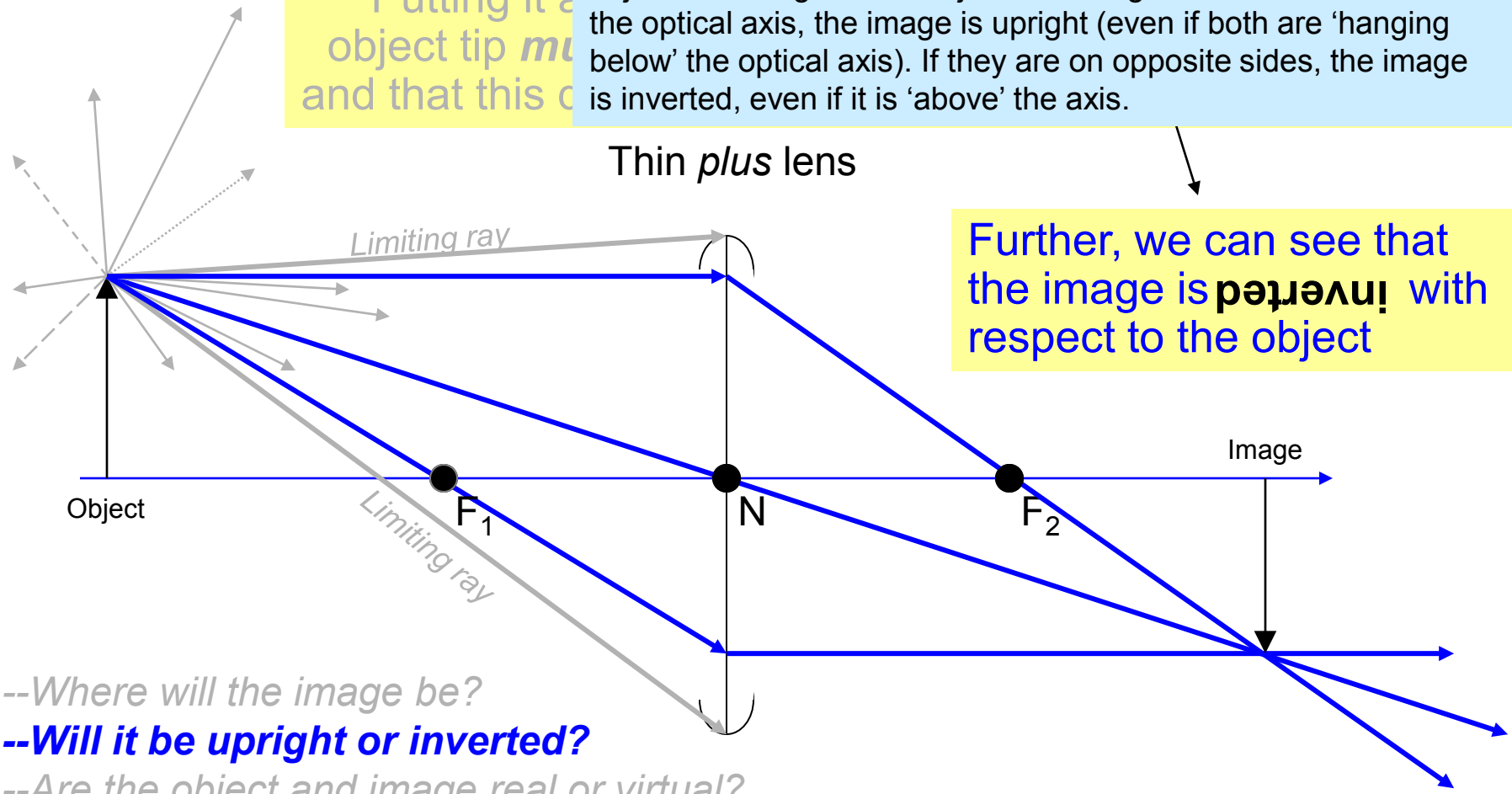
With regard to this object and its relationship with this optical system…

Ray Tracing

Putting it a
object tip ***mu***
and that this c

A quick word about upright vs inverted images:
The determining factor is the relative, not absolute, positions of the object and image. If the object and image are on the same side of the optical axis, the image is upright (even if both are 'hanging below' the optical axis). If they are on opposite sides, the image is inverted, even if it is 'above' the axis.

Thin *plus* lens



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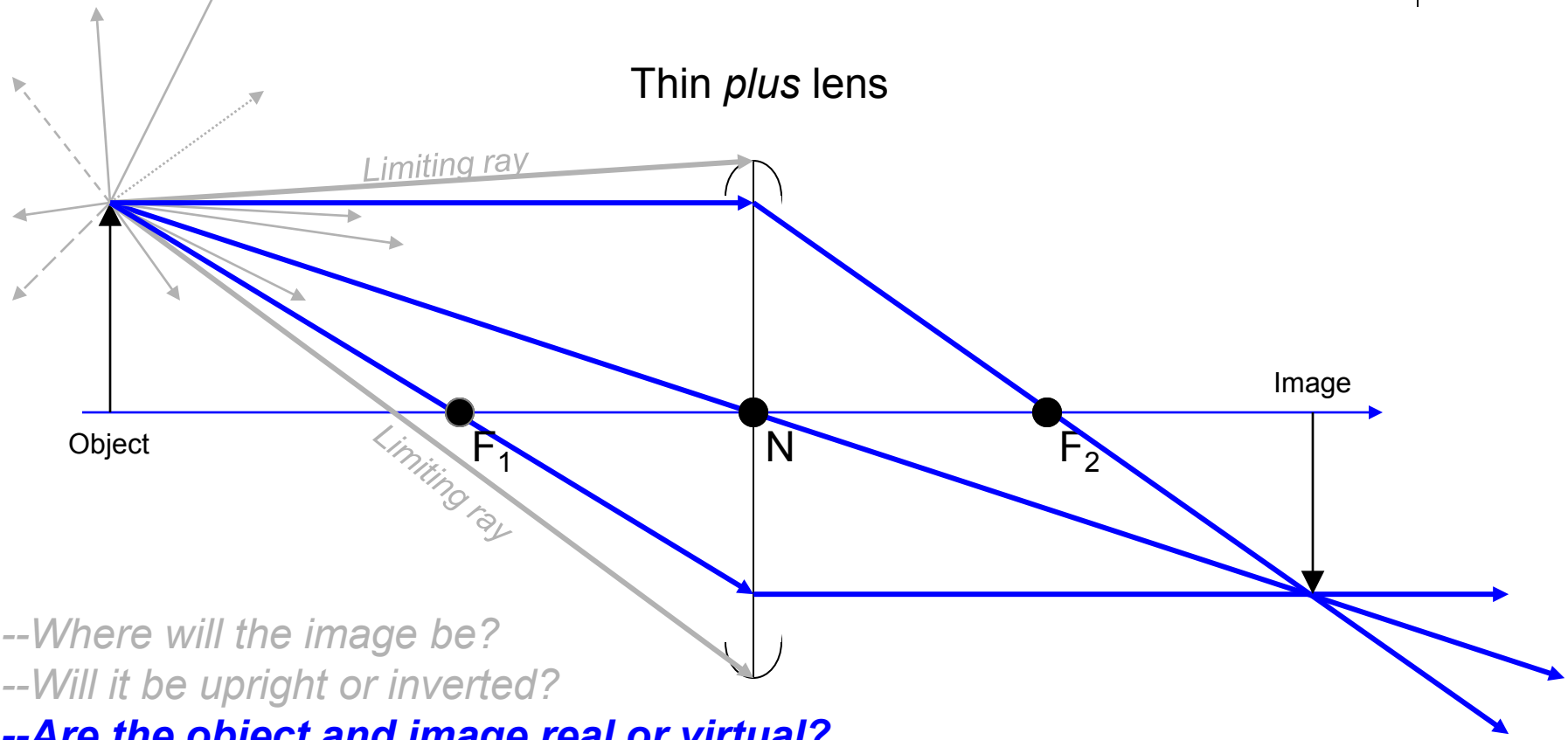
--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing

As for whether the image and object are real vs virtual…



--Where will the image be?
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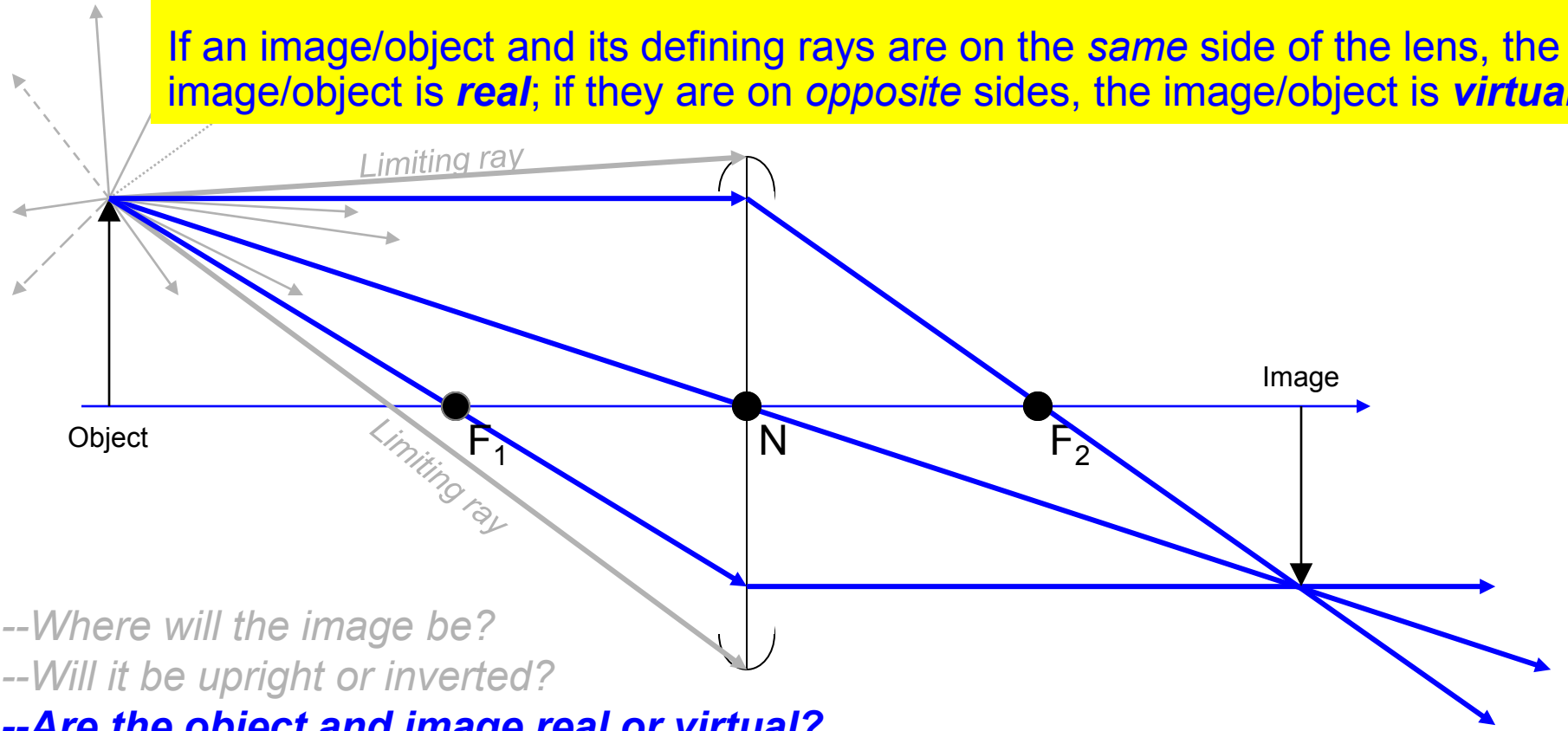
With regard to this object and its relationship with this optical system…

Ray Tracing

What determines the ***real vs virtual*** status of an object and image is the *relationship between the image/object and the rays that define it:*

If an image/object and its defining rays are on the *same* side of the lens, the image/object is ***real***; if they are on *opposite* sides, the image/object is ***virtual***.



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With regard to this object and its relationship with this optical system…

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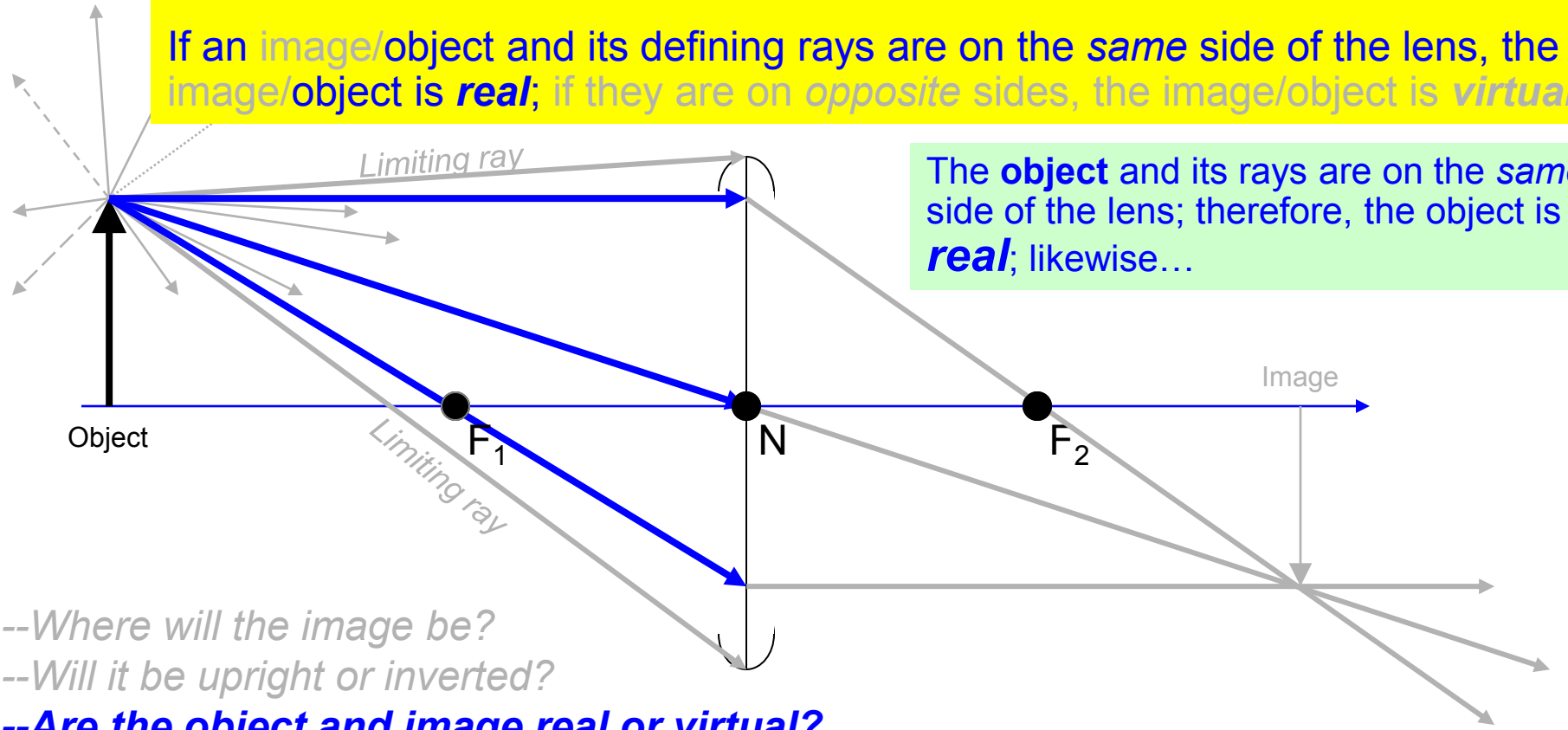

The **object** and its rays are on the *same* side of the lens; therefore, the object is ***real***; likewise…

--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
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With regard to this object and its relationship with this optical system…

Ray Tracing

What determines the ***real vs virtual*** status of an object and image is the *relationship between the image/object and the rays that define it:*

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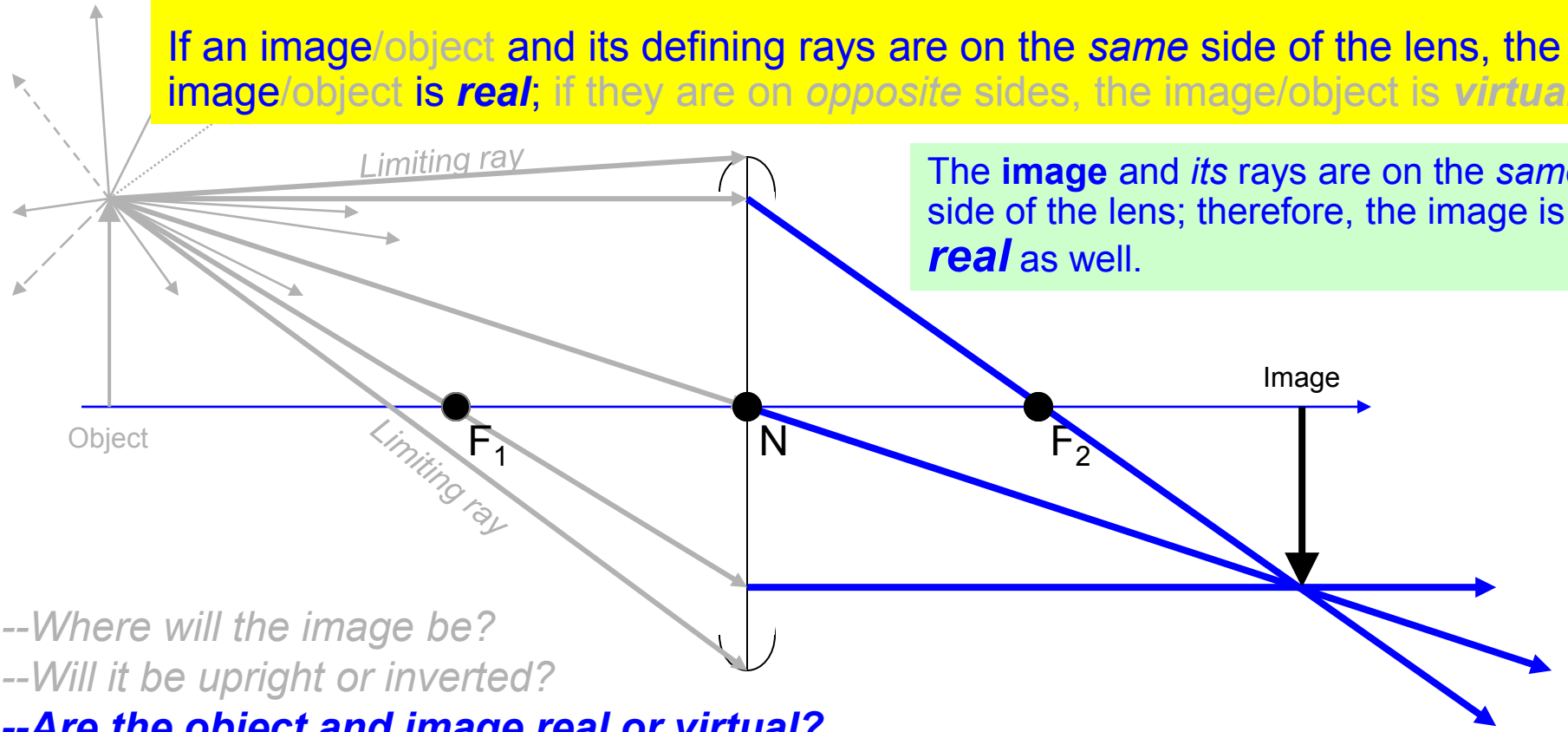


The **image** and *its* rays are on the *same* side of the lens; therefore, the image is ***real*** as well.

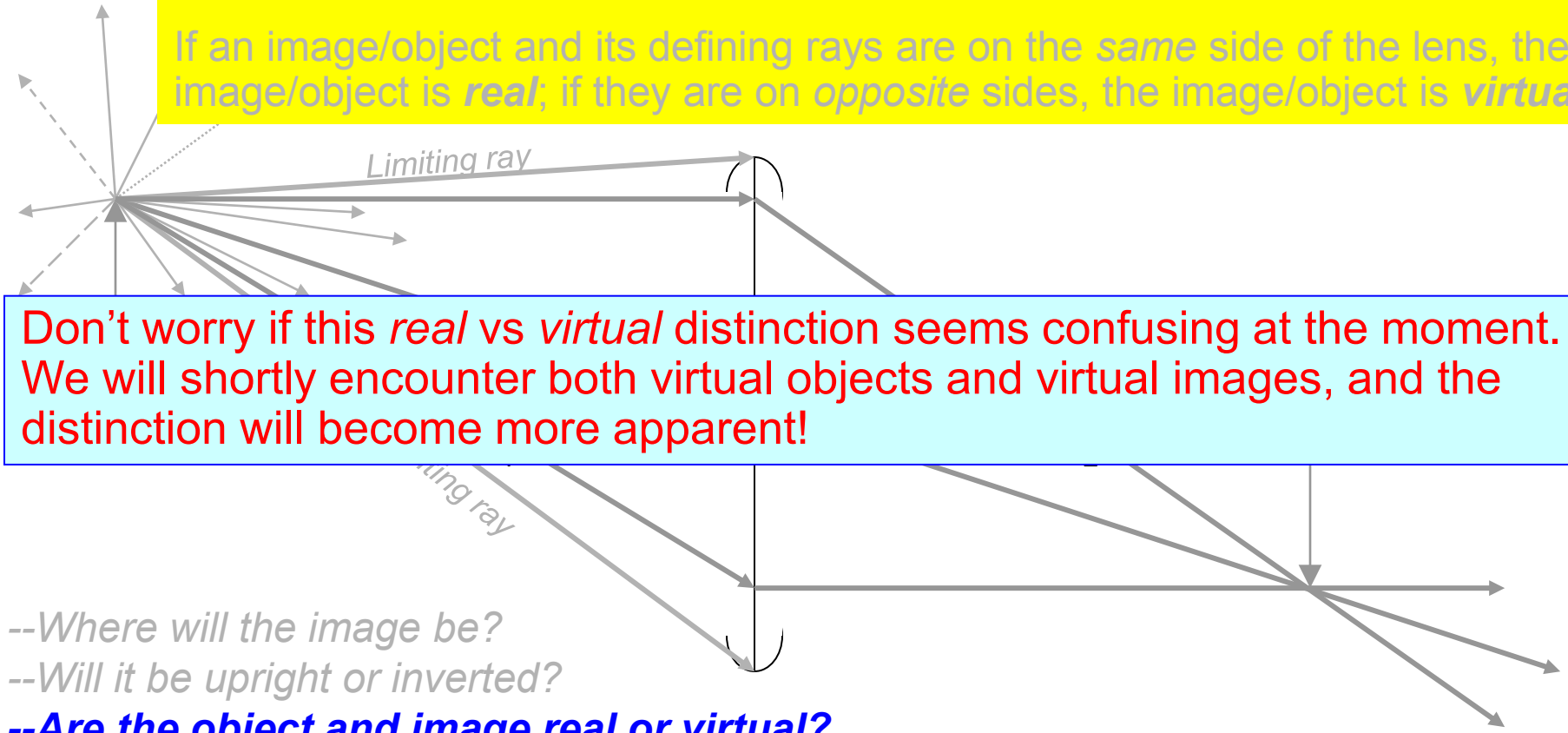
--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing

What determines the ***real vs virtual*** status of an object and image is the *relationship between the image/object and the rays that define it:*

If an image/object and its defining rays are on the *same* side of the lens, the image/object is ***real***; if they are on *opposite* sides, the image/object is ***virtual***.



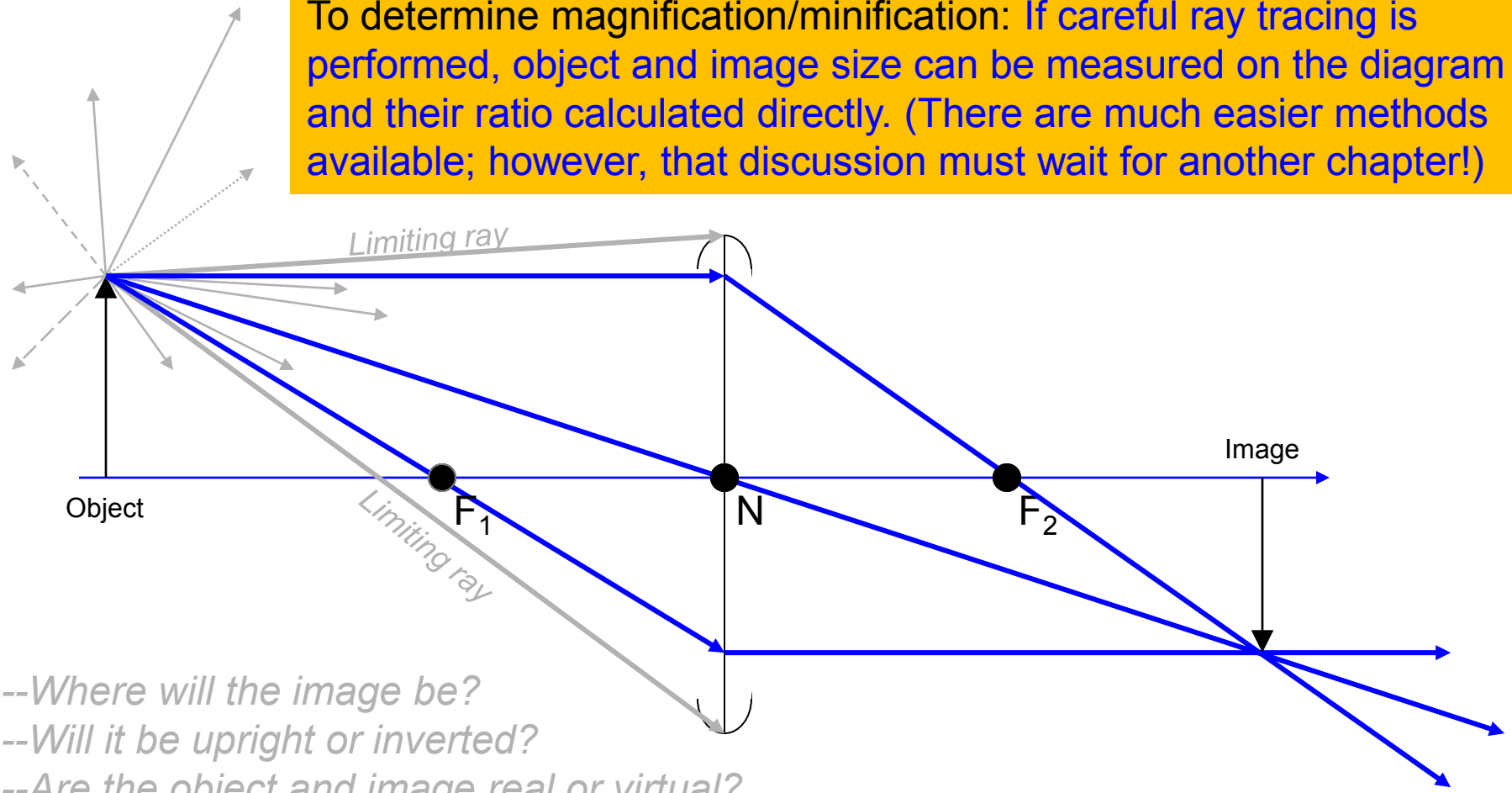
Don't worry if this *real* vs *virtual* distinction seems confusing at the moment. We will shortly encounter both virtual objects and virtual images, and the distinction will become more apparent!

--Where will the image be?
--Will it be upright or inverted?
--Are the object and image real or virtual?
--Will the image be magnified or minified?

With regard to this object and its relationship with this optical system…

Ray Tracing

To determine magnification/minification: If careful ray tracing is performed, object and image size can be measured on the diagram and their ratio calculated directly. (There are much easier methods available; however, that discussion must wait for another chapter!)



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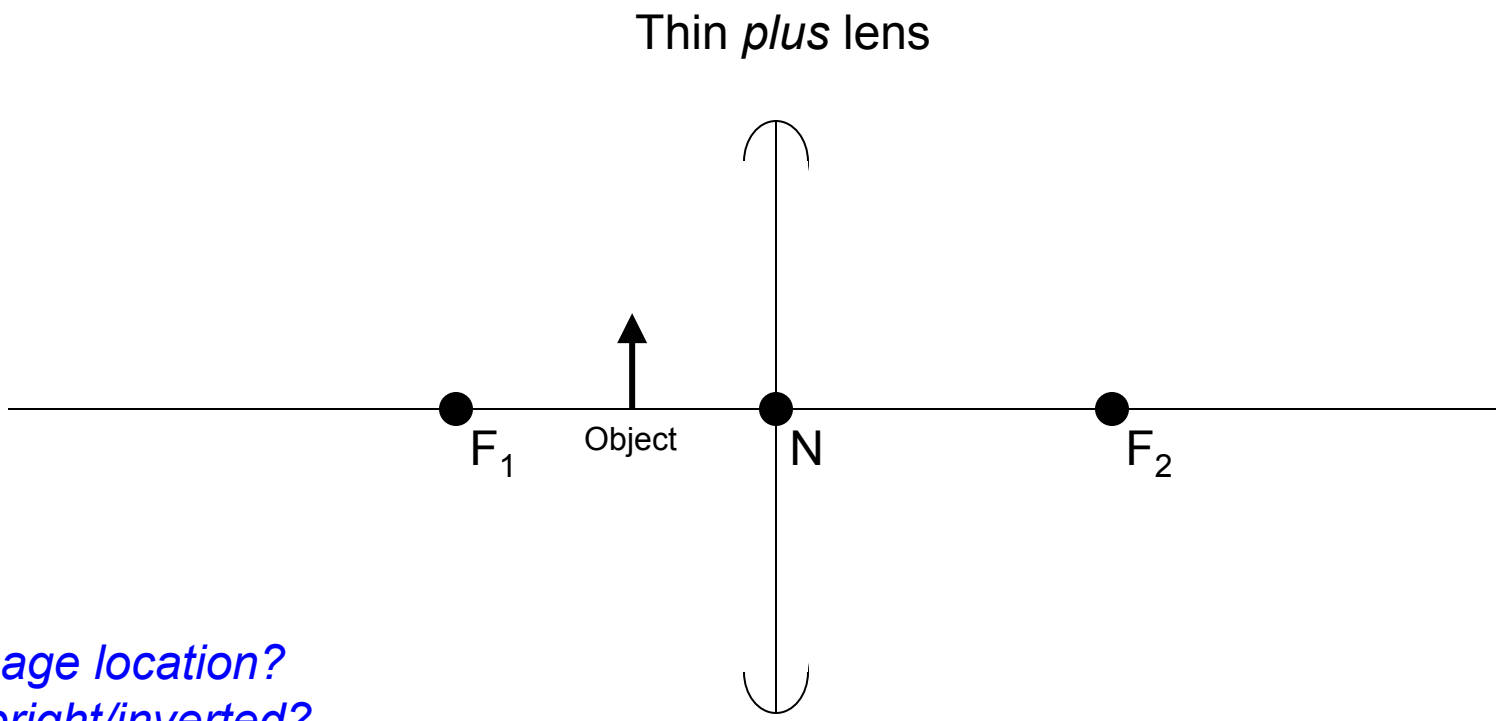
With regard to this object and its relationship with this optical system…

Ray Tracing



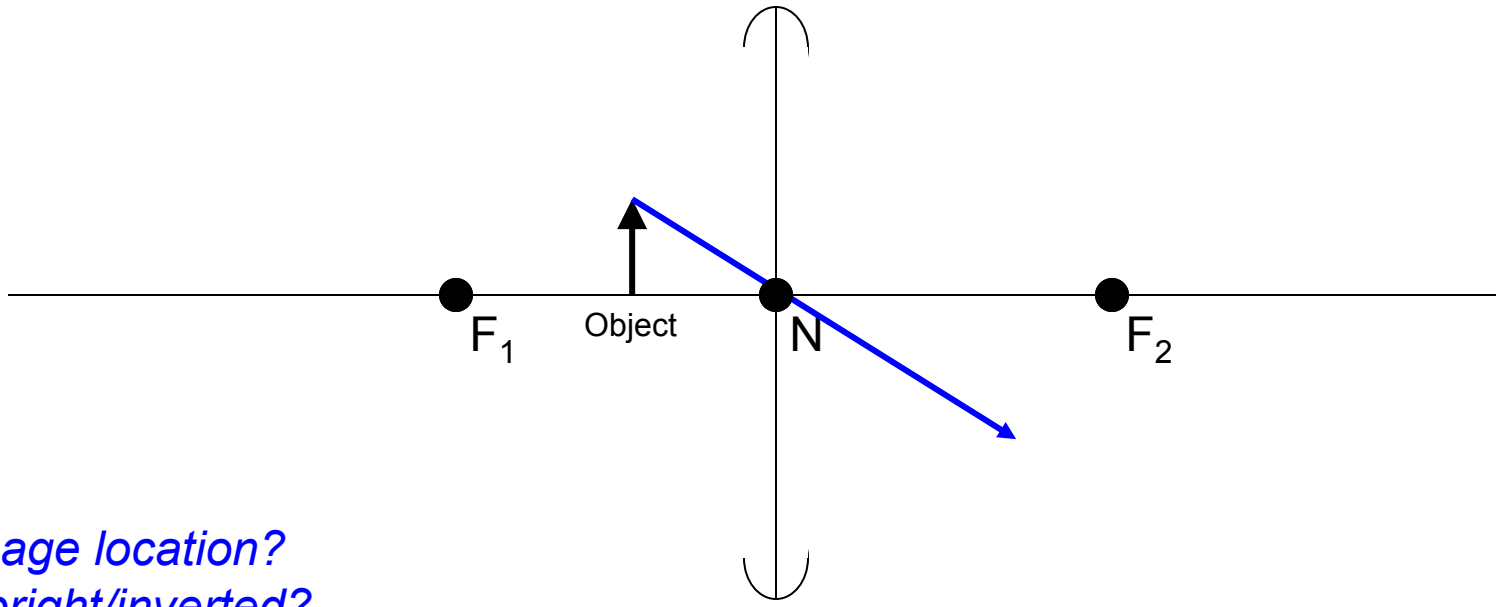
--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing

Trace the:
Nodal ray

Thin *plus* lens



--Image location?
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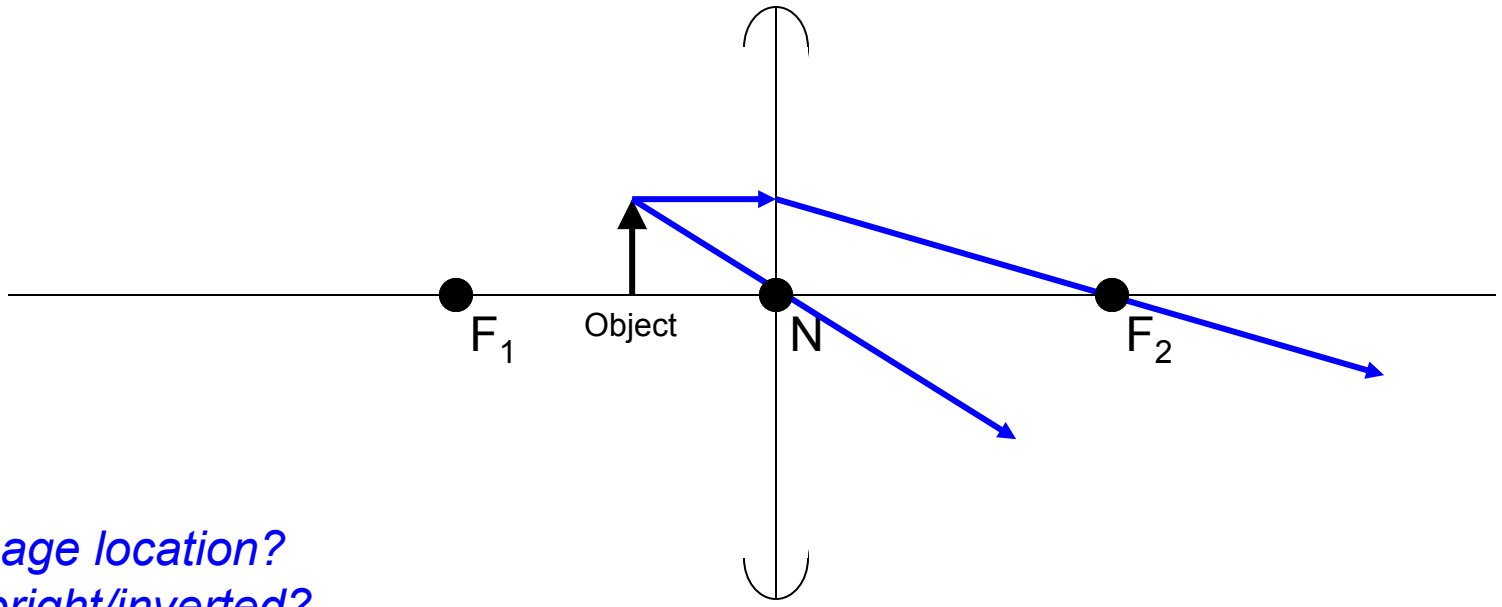
What about this object and its image?

Ray Tracing

Trace the:
Nodal ray
Secondary focal point ray

Thin *plus* lens



--Image location?
--Upright/inverted?
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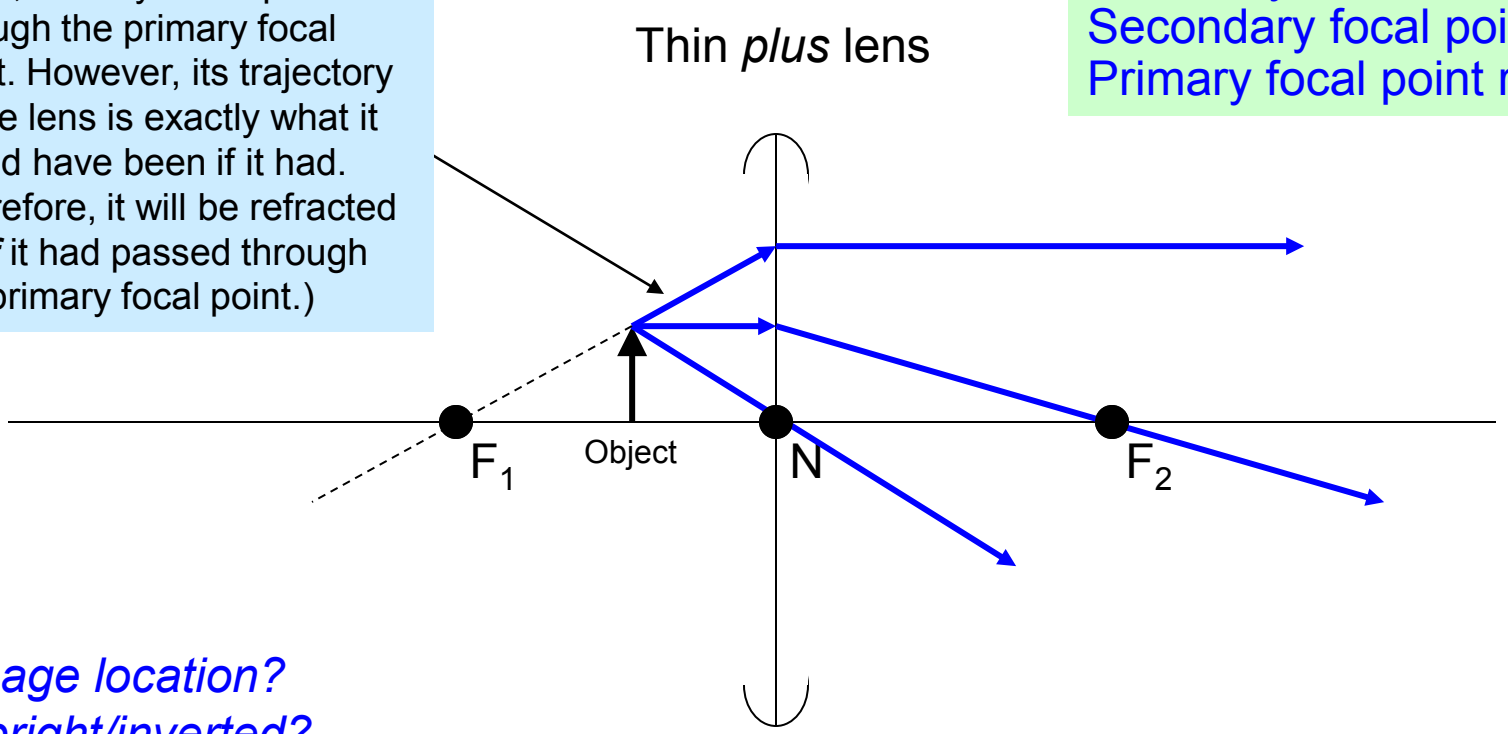
What about this object and its image?

Ray Tracing

(True, this ray didn't pass through the primary focal point. However, its trajectory to the lens is exactly what it would have been if it had. Therefore, it will be refracted ***as if*** it had passed through the primary focal point.)

Trace the:
Nodal ray
Secondary focal point ray
Primary focal point ray



--Image location?
--Upright/inverted?
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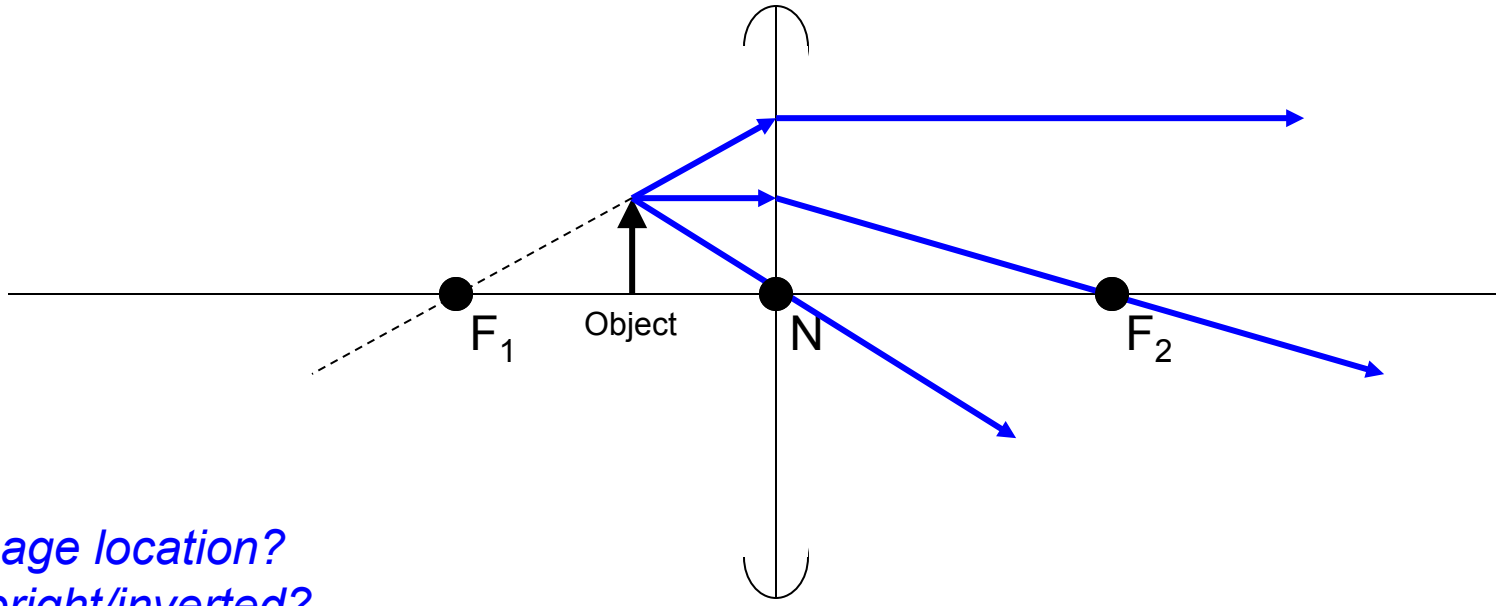
What about this object and its image?

Ray Tracing

But these rays don't intersect—
where's the image?

Trace the:
Nodal ray
Secondary focal point ray
Primary focal point ray

Thin *plus* lens



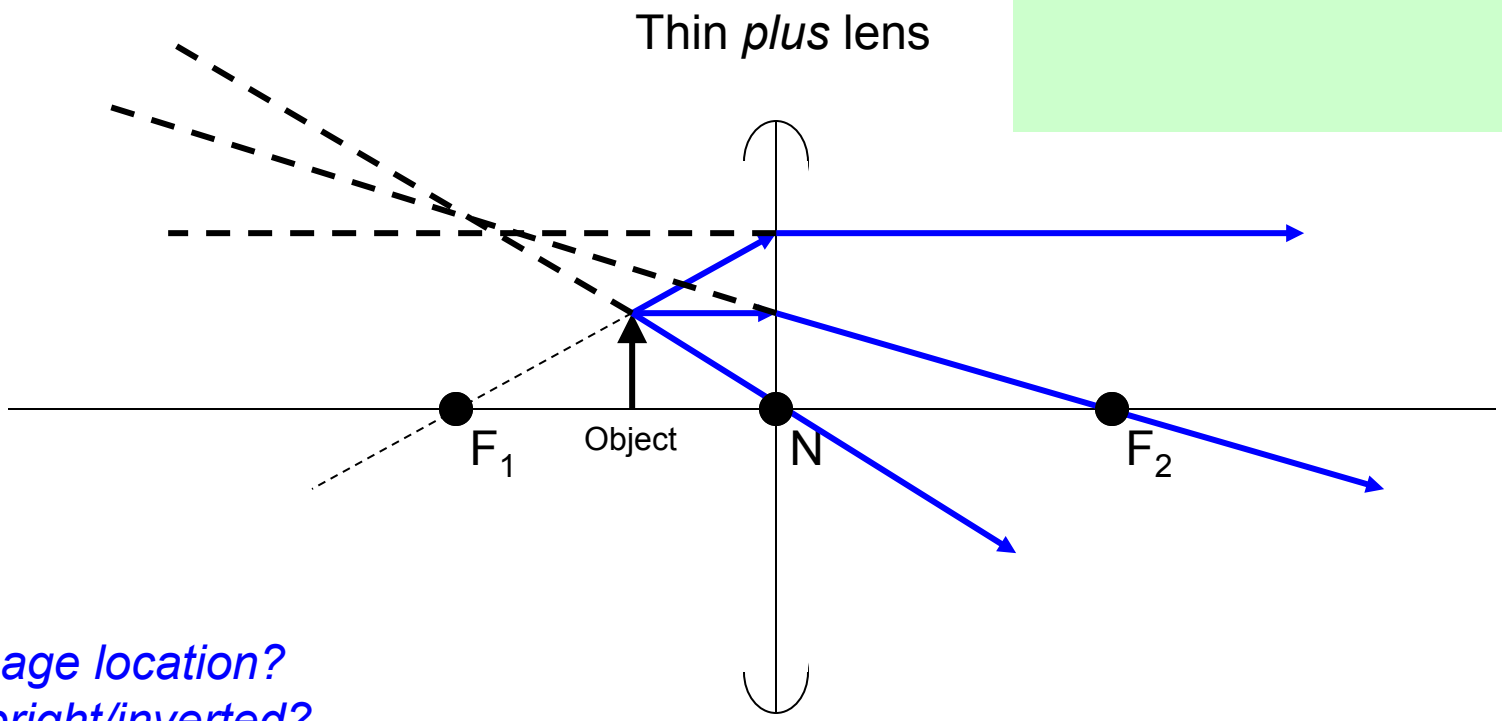
--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing

But these rays don't intersect—
where's the image?

Extend the rays to find the point of intersection…



--Image location?
--Upright/inverted?
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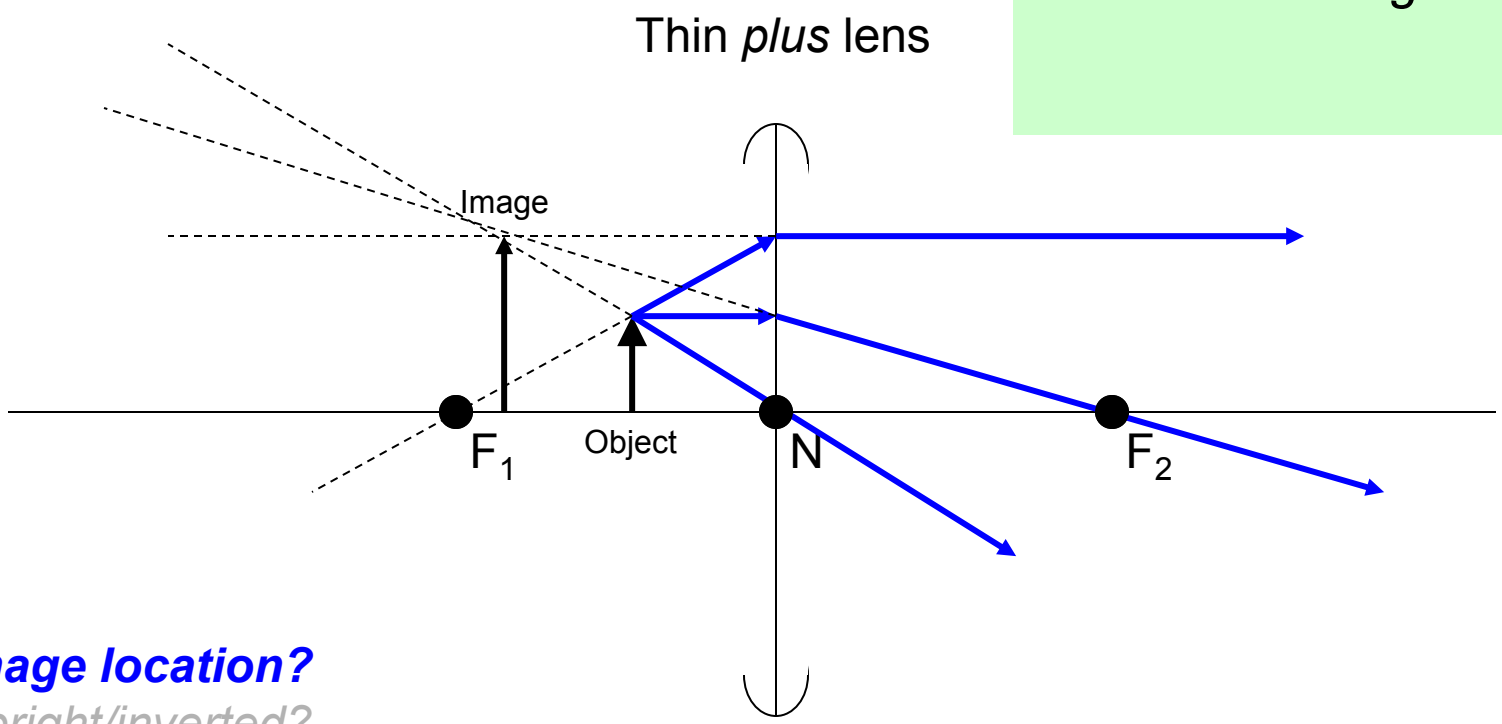
--Magnified/minified?

What about this object and its image?

Ray Tracing

Extend the rays to find the point of intersection… Here is the *image location*



--Image location?

--Upright/inverted?

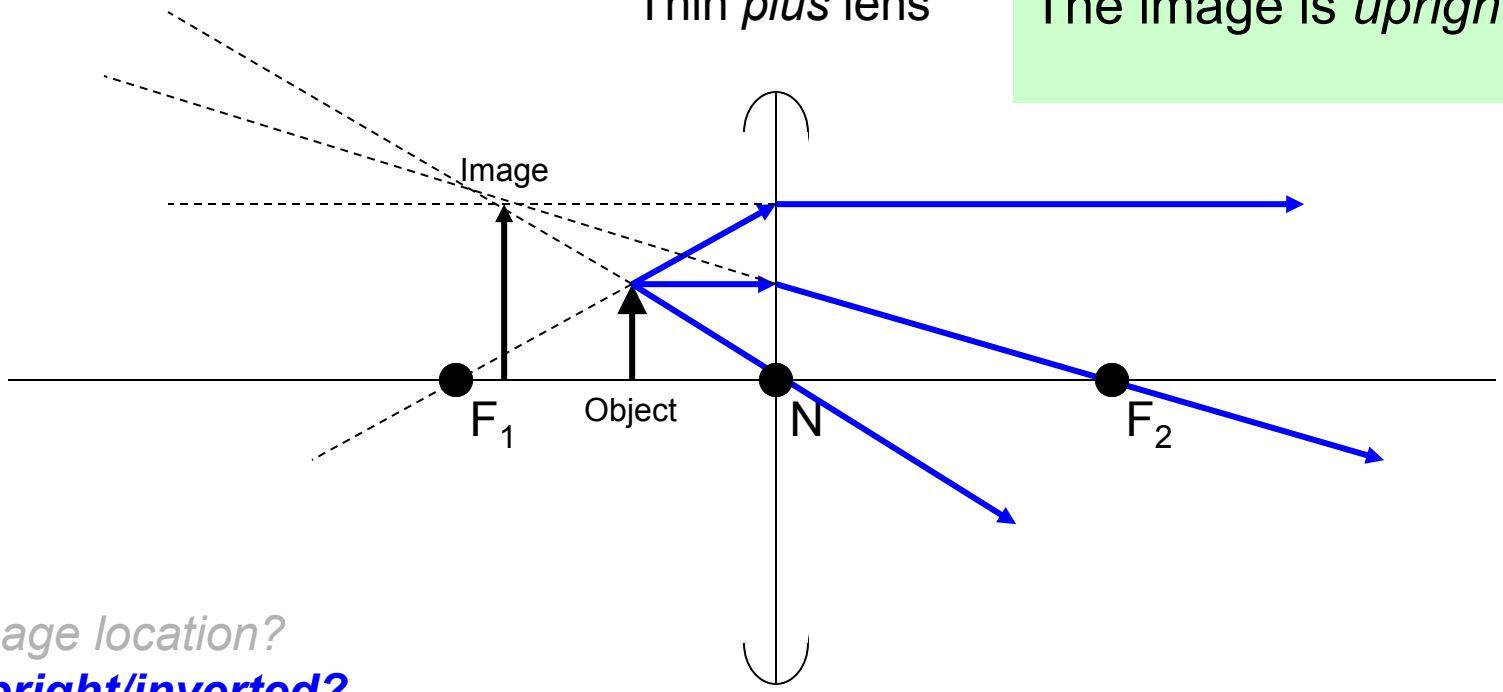
--Object and image real/virtual?

--Magnified/minified?

What about this object and its image?

Ray Tracing

Extend the rays to find the point of intersection…
Here is the *image location*
The image is *upright*

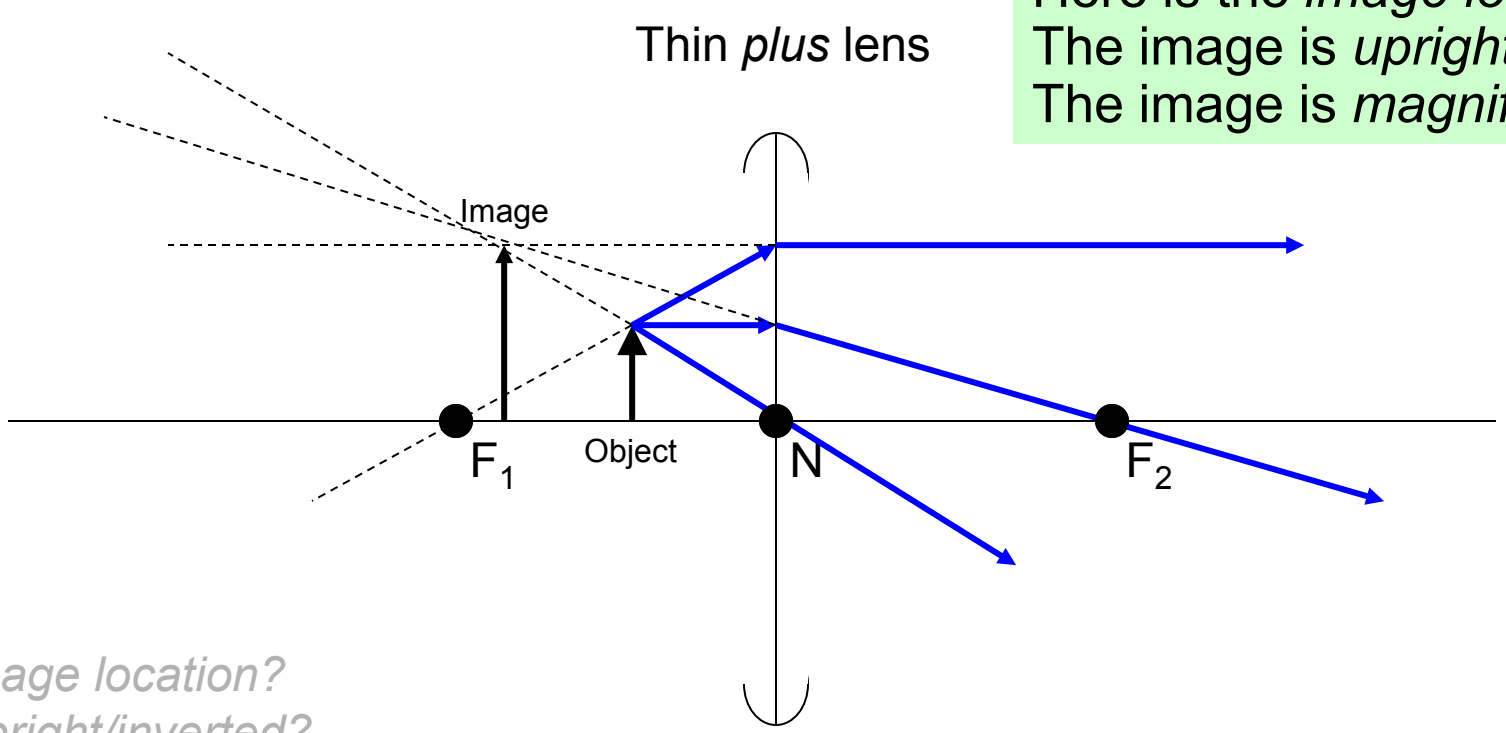


--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing

Extend the rays to find the point of intersection…
Here is the *image location*
The image is *upright*
The image is *magnified*

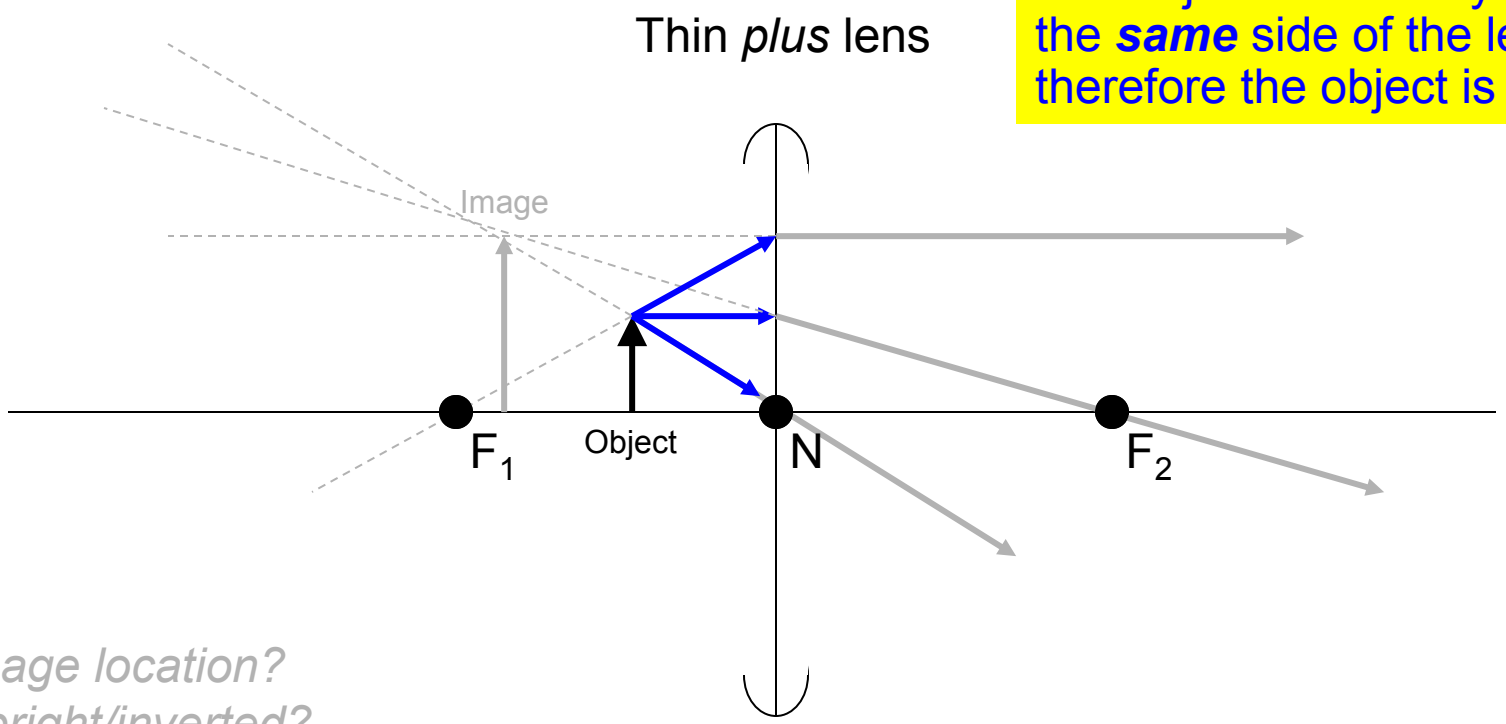


--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing

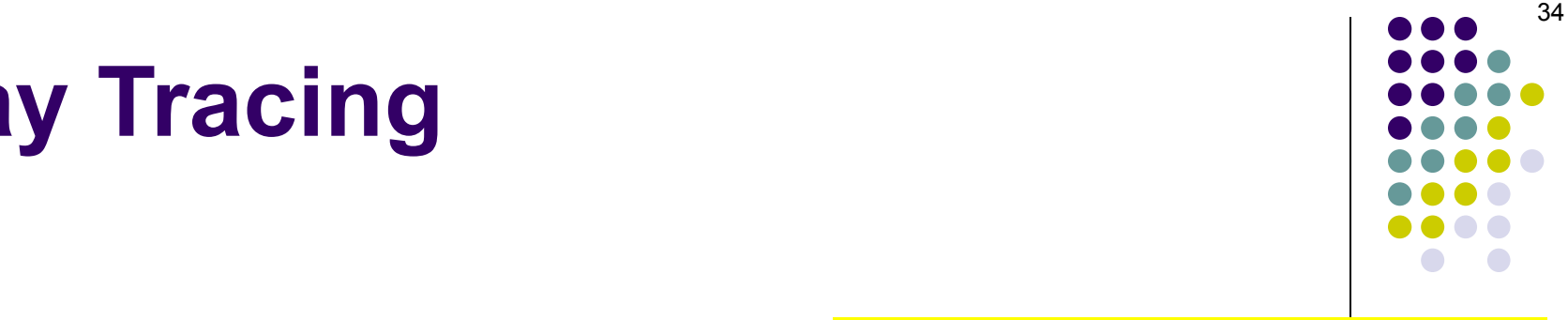
The object and its rays are on the ***same*** side of the lens, therefore the object is ***real***



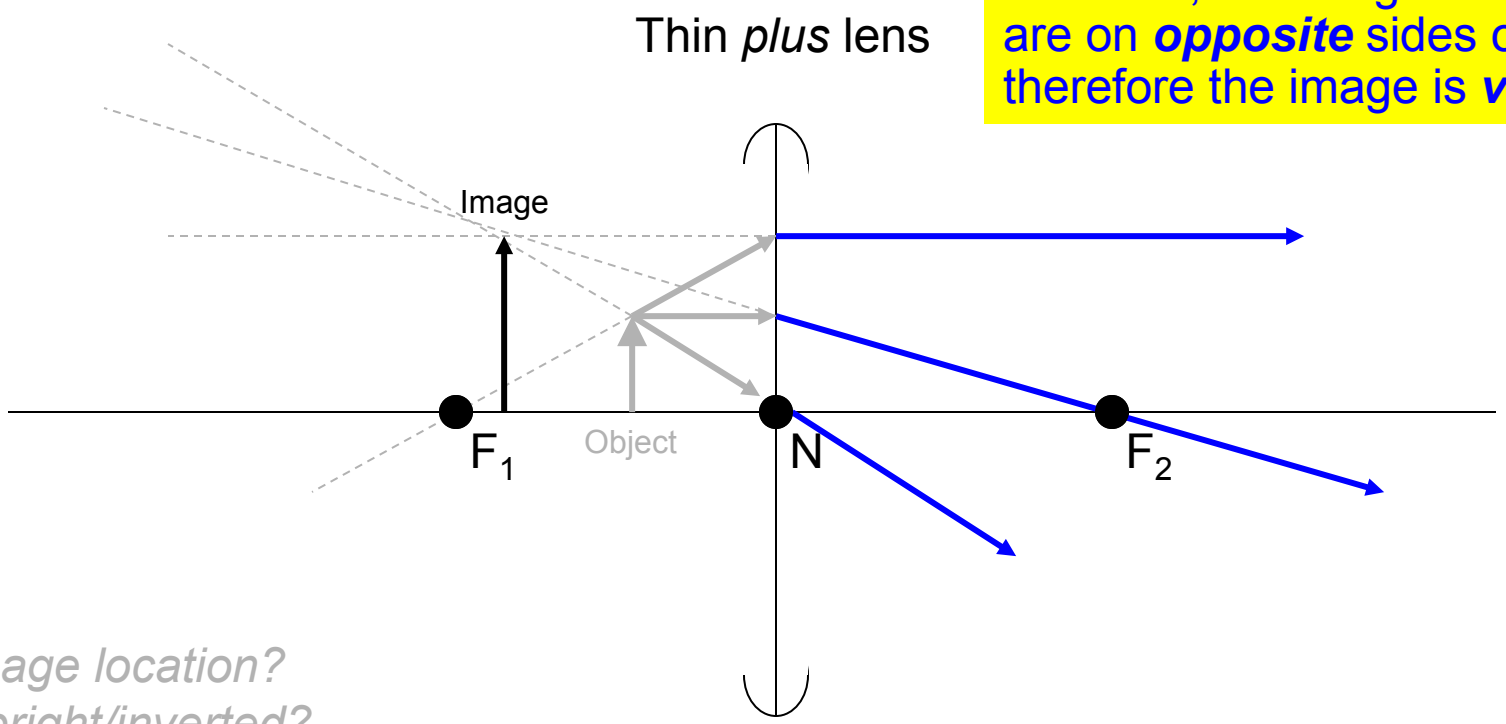
--Image location?
--Upright/inverted?
--Object** and image **real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing



However, the image and its rays are on ***opposite*** sides of the lens, therefore the image is ***virtual***

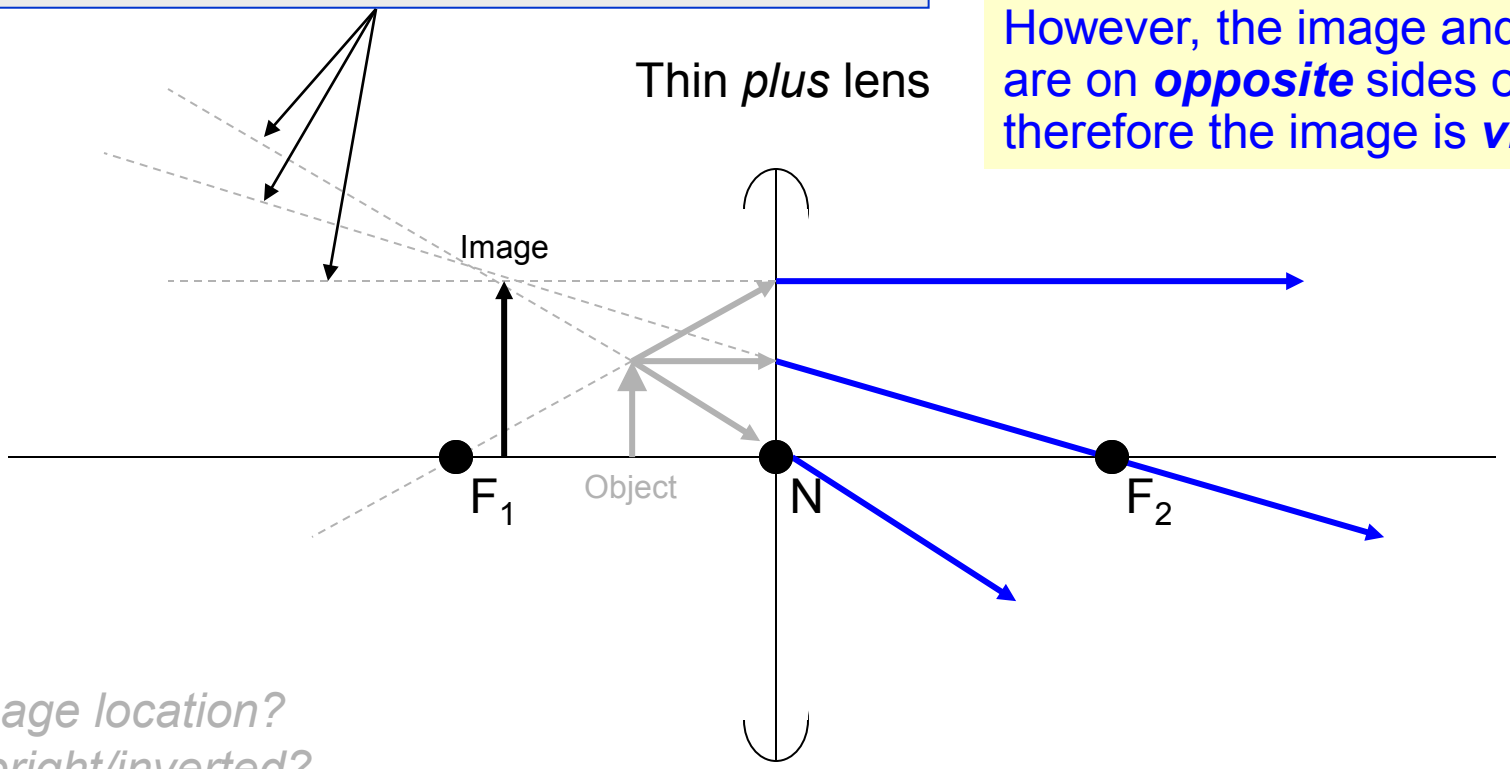


--Image location?
--Upright/inverted?
*--Object and **image real/virtual?***
--Magnified/minified?

What about this object and its image?

Ray Tracing

Rule of thumb**: If you have to use dashed lines to define an object or image, it's probably **virtual



However, the image and its rays are on ***opposite*** sides of the lens, therefore the image is ***virtual***

--Image location?
--Upright/inverted?
*--Object and **image real/virtual?***
--Magnified/minified?

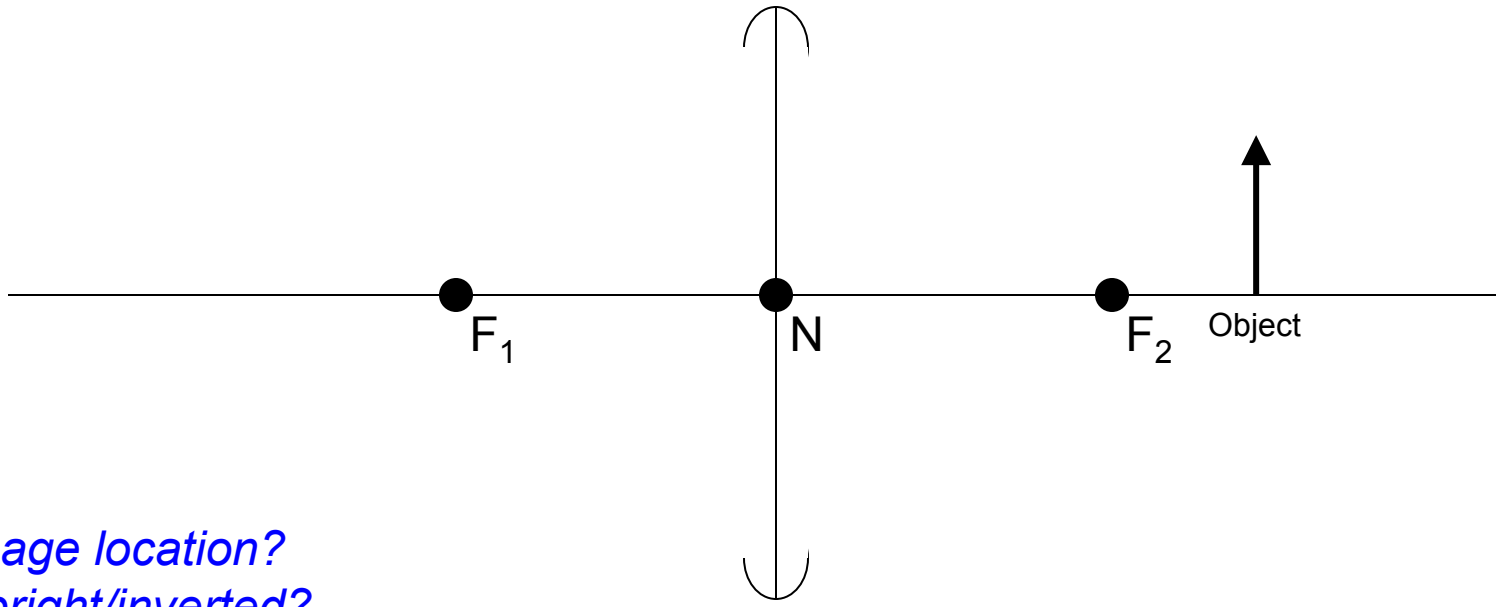
What about this object and its image?

Ray Tracing

Now try this one…

Remember: In Optics problems, the light is always going in* this *direction!

Thin *plus* lens



--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

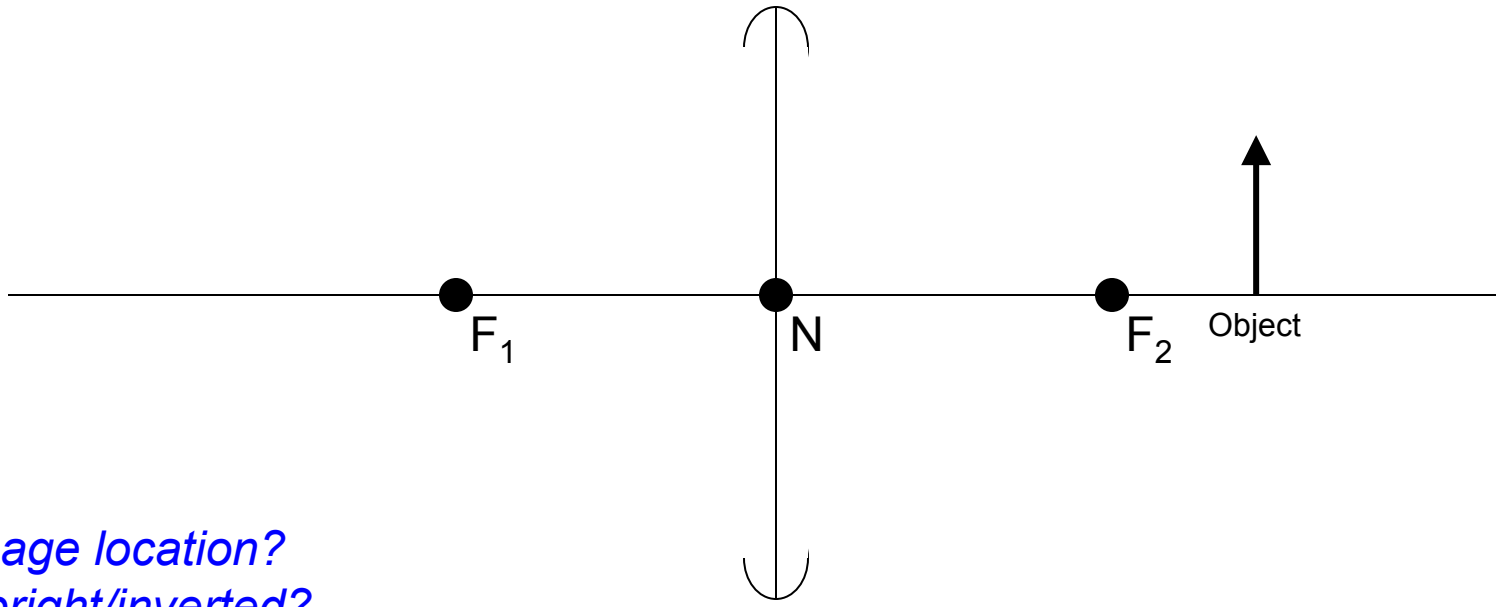
What about this object and its image?

Ray Tracing

Now try this one…

Trace the:

Thin *plus* lens



--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

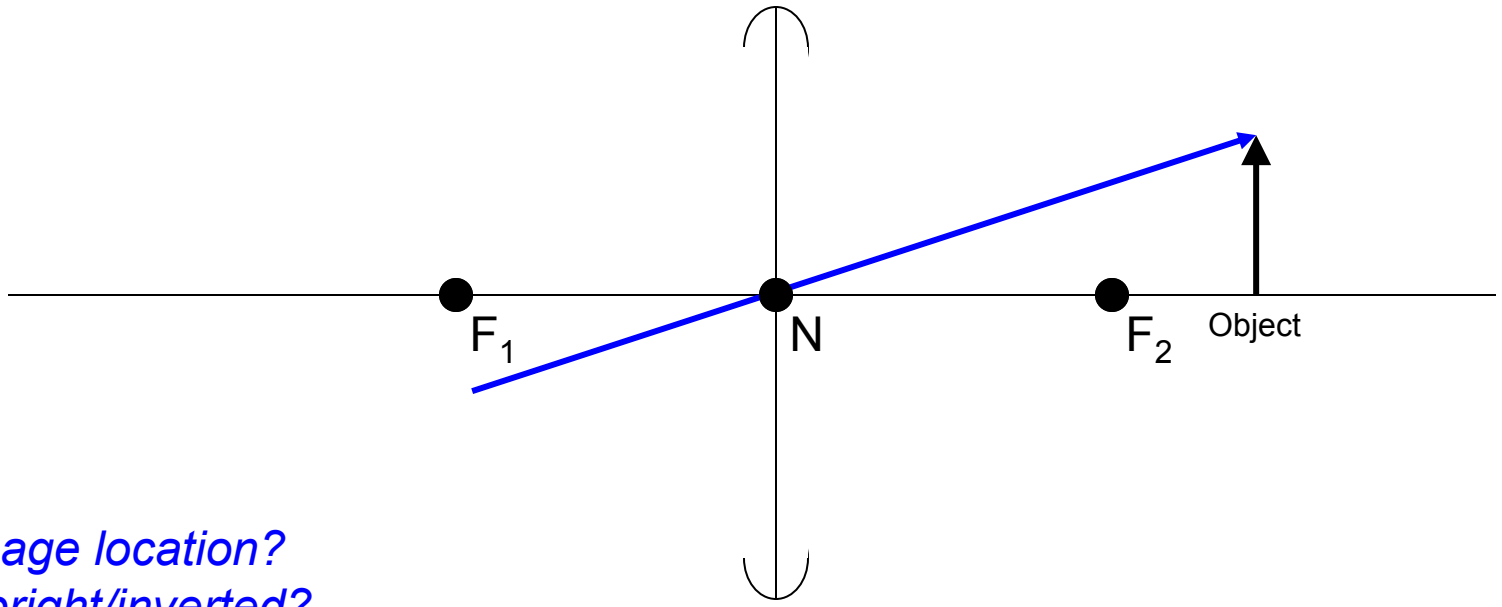
What about this object and its image?

Ray Tracing

Now try this one…

Trace the:
Nodal ray

Thin *plus* lens



--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

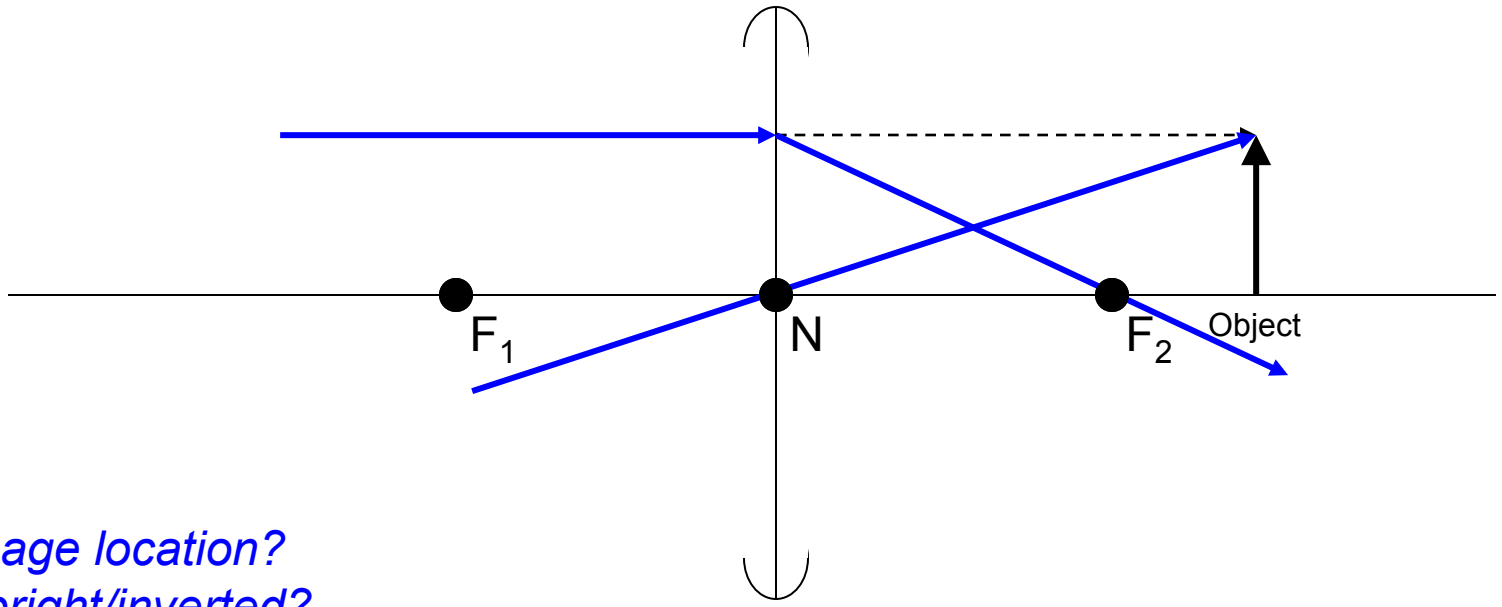
What about this object and its image?

Ray Tracing

Now try this one…

Trace the:
Nodal ray
Secondary focal point ray

Thin *plus* lens



--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

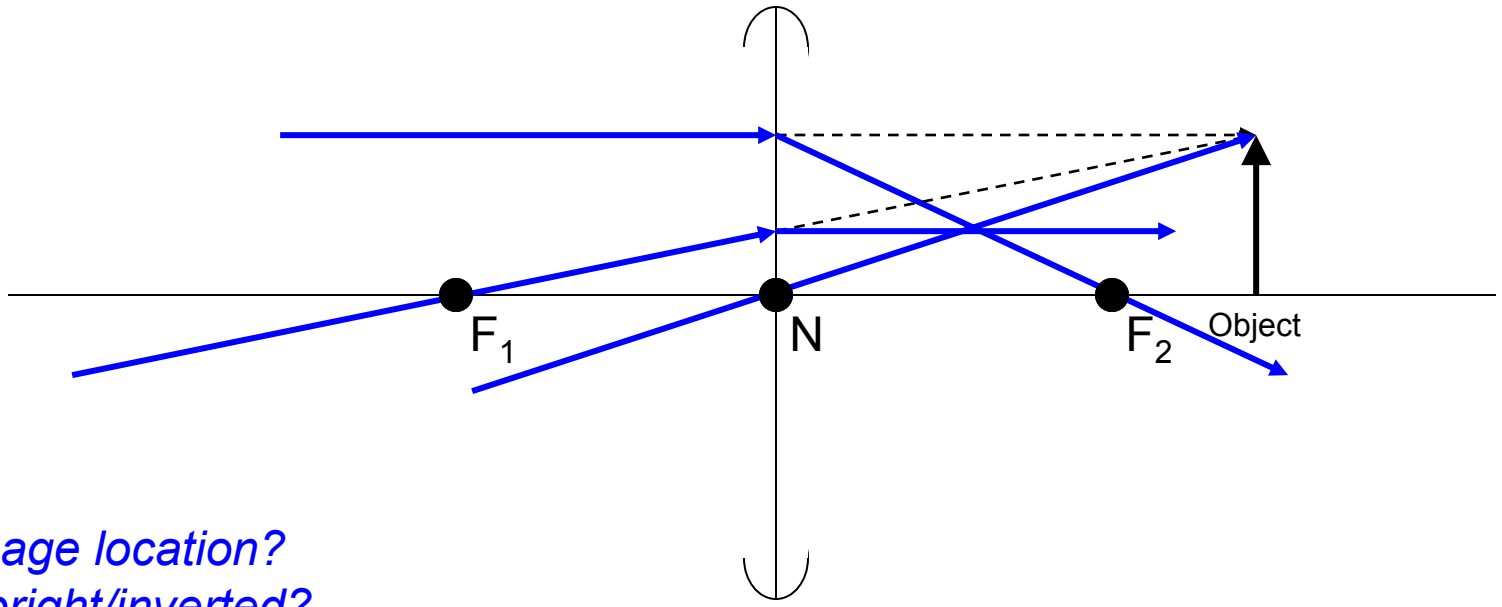
What about this object and its image?

Ray Tracing

Now try this one…

Trace the:
Nodal ray
Secondary focal point ray
Primary focal point ray

Thin *plus* lens



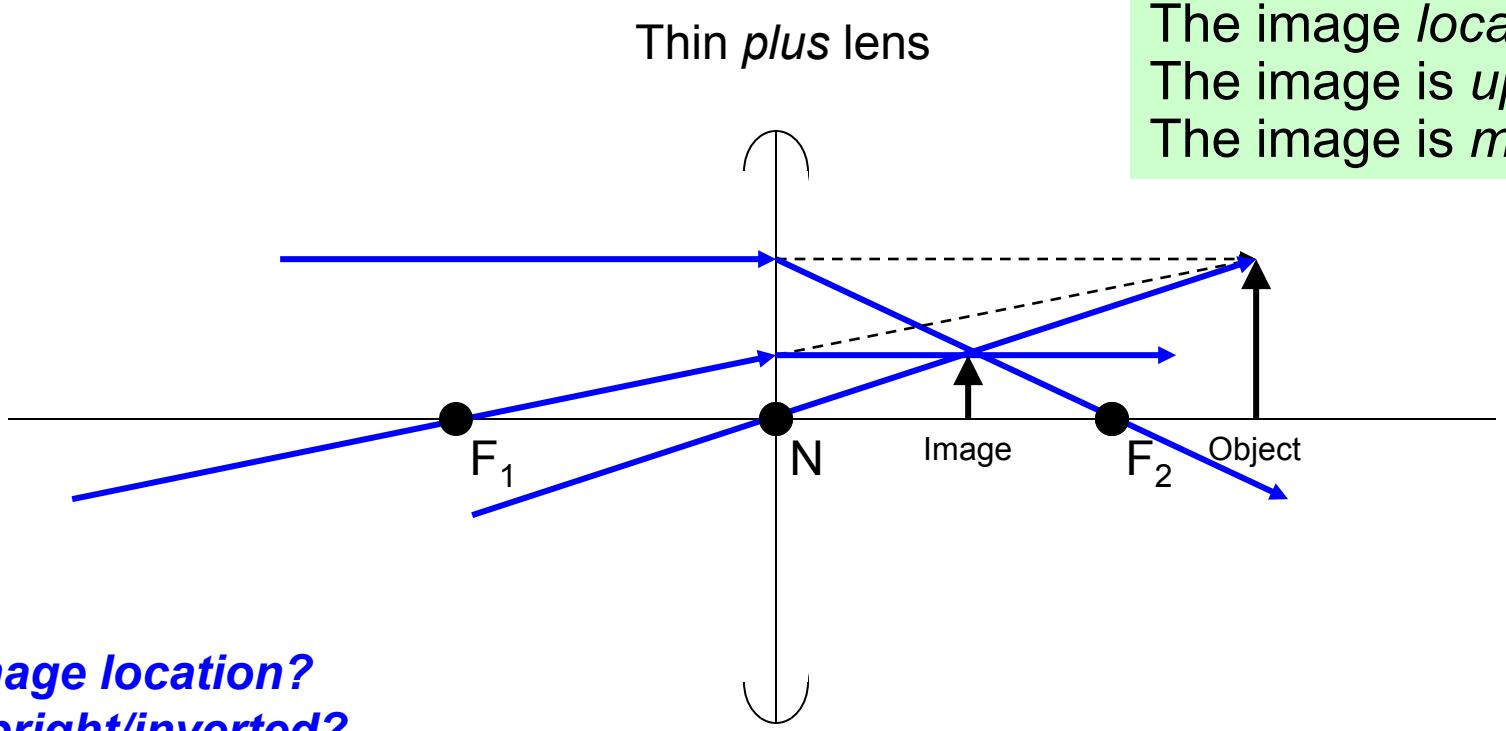
--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing

Now try this one…

Here is…
The image *location*
The image is *upright*
The image is *minified*



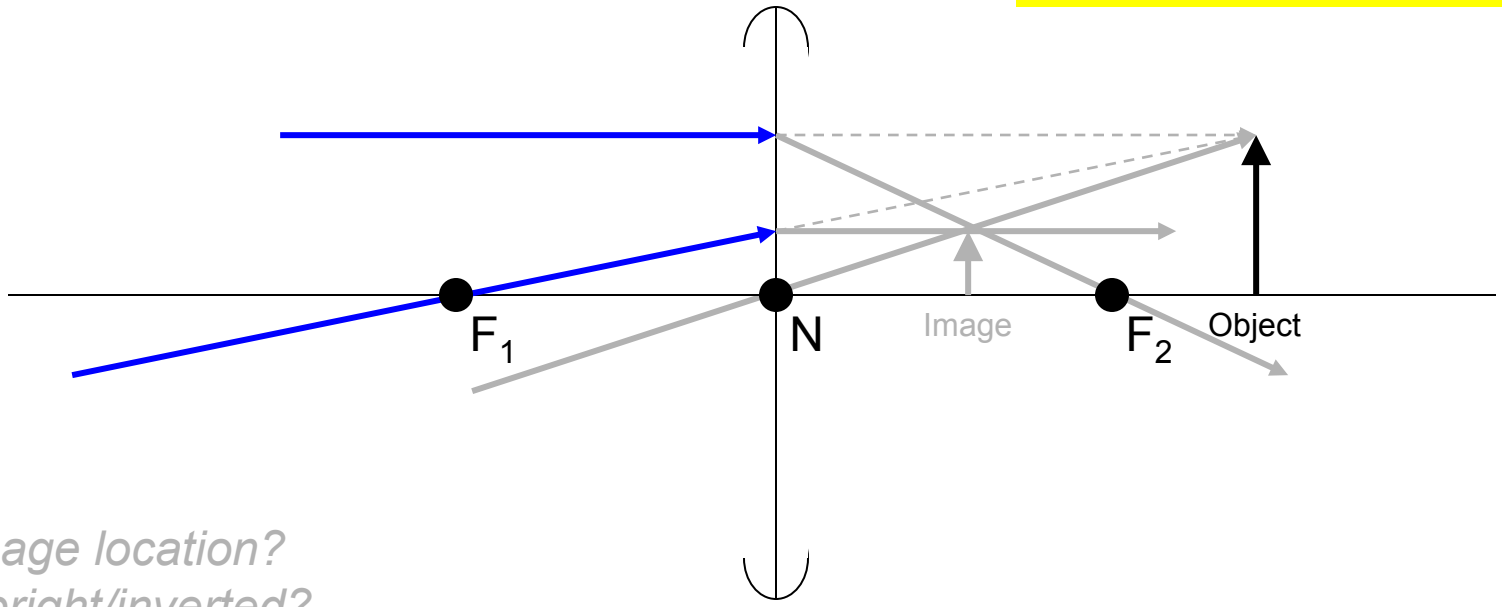
--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing

Now try this one…

The object and its rays are on **opposite** sides of the lens, therefore the object is ***virtual***



--Image location?
--Upright/inverted?
--Object** and image **real/virtual?
--Magnified/minified?

What about this object and its image?

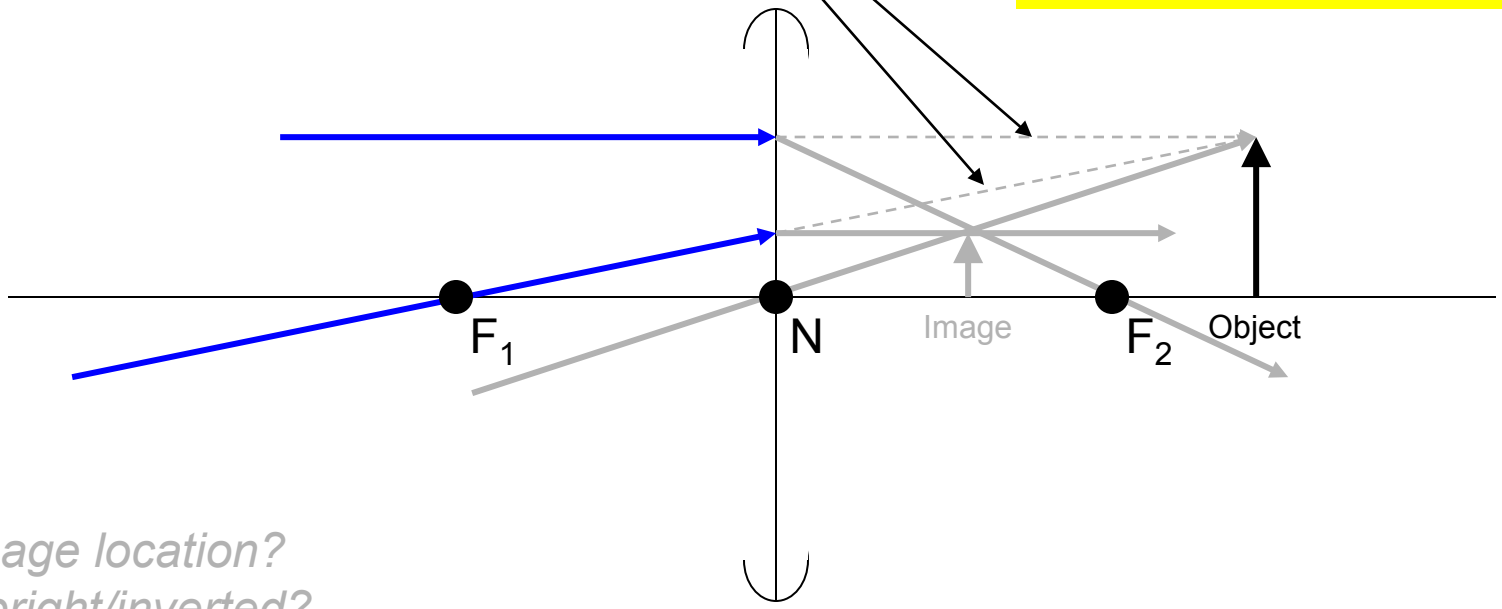
Ray Tracing

Now try this one…

There are those dashed lines again…

Thin *plus* lens

The object and its rays are on **opposite** sides of the lens, therefore the object is ***virtual***



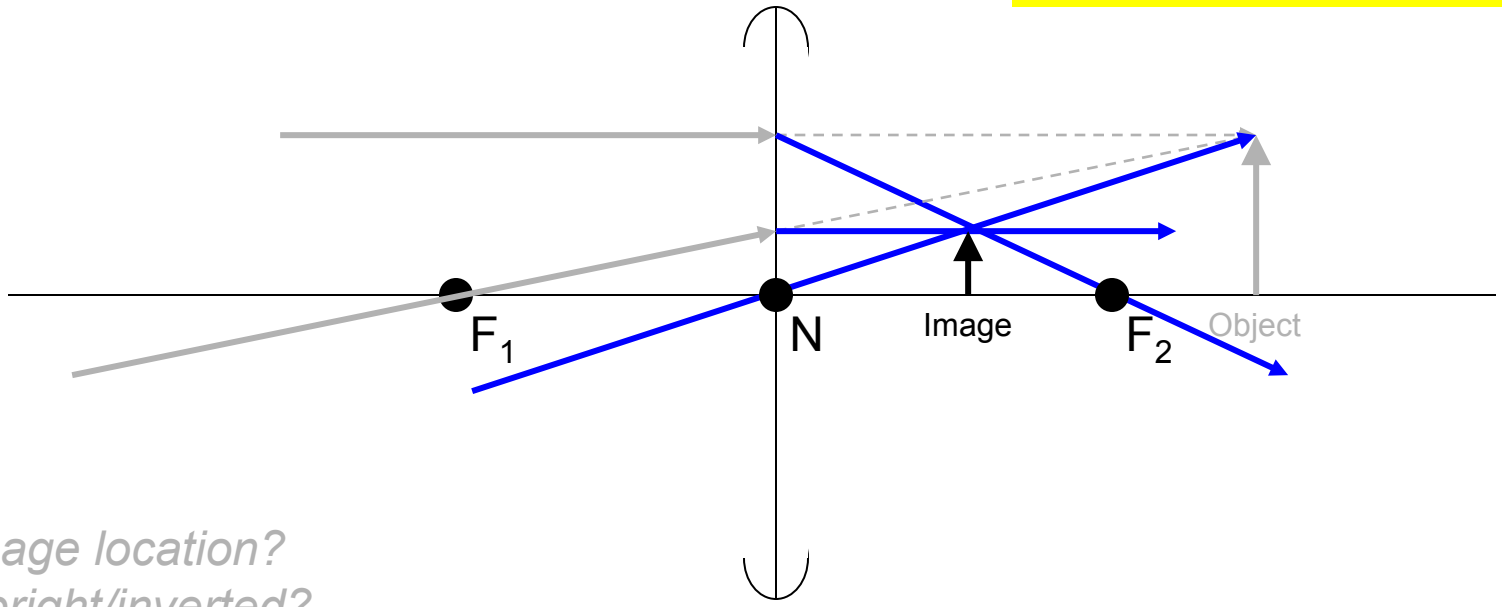
--Image location?
--Upright/inverted?
--Object** and image **real/virtual?
--Magnified/minified?

What about this object and its image?

Ray Tracing

Now try this one…

Thin *plus* lens



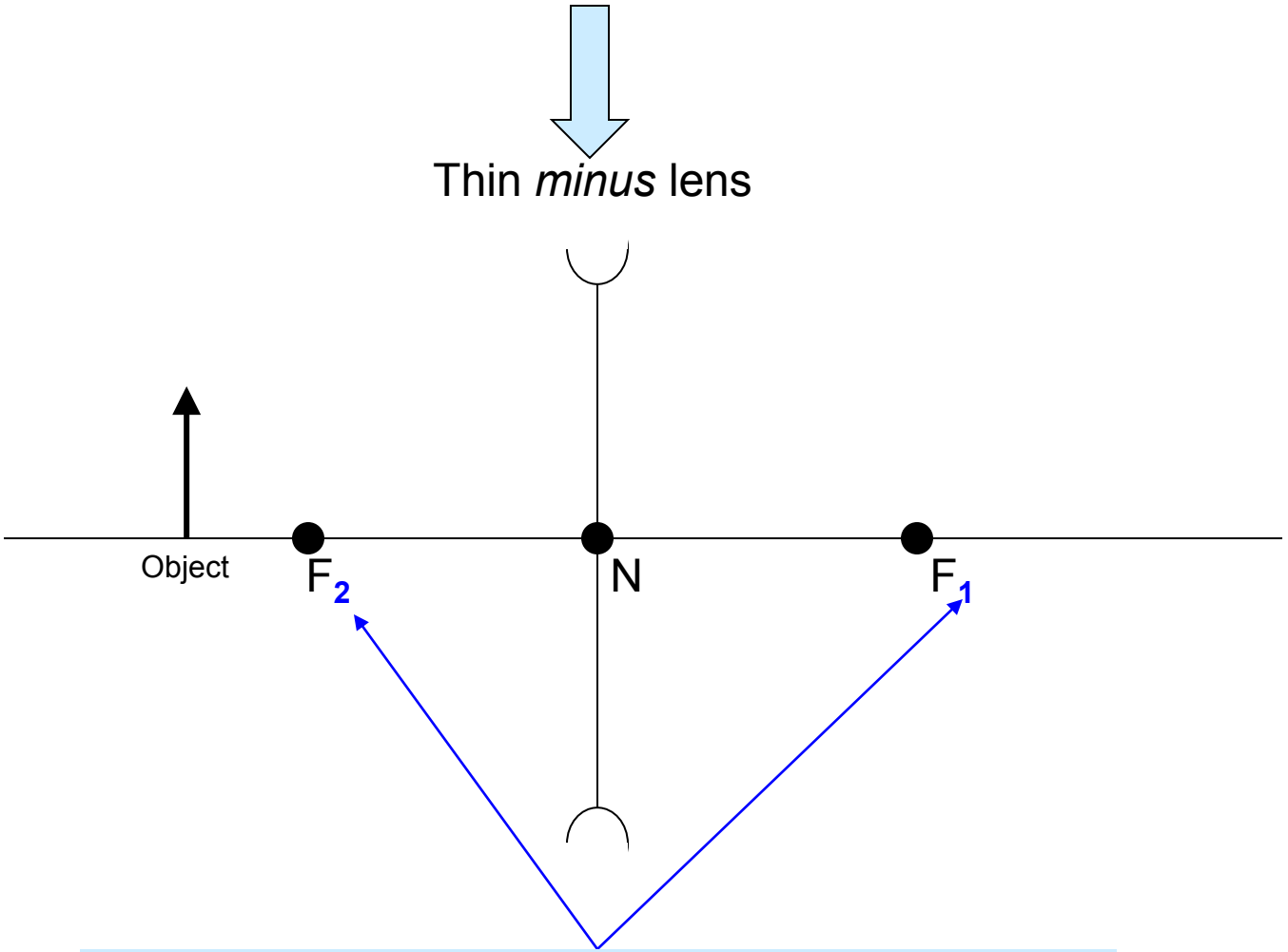
However, the image and its rays are on the ***same*** side of the lens, therefore the image is ***real***

--Image location?
--Upright/inverted?
*--Object and **image real/virtual?***
--Magnified/minified?

What about this object and its image?

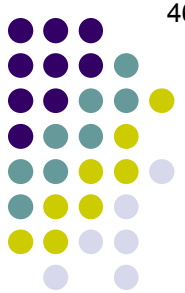
Ray Tracing

Note: Minus lens!

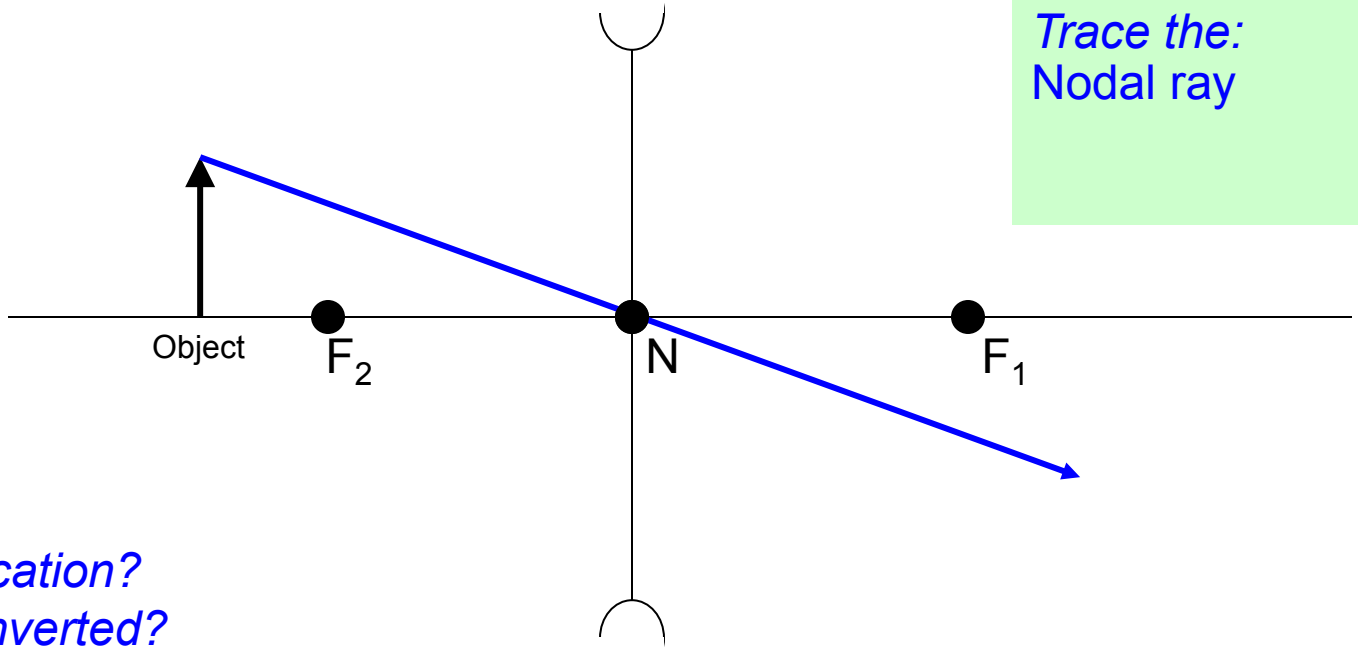


*Because it's a minus lens, the focal points have **changed sides***

Ray Tracing



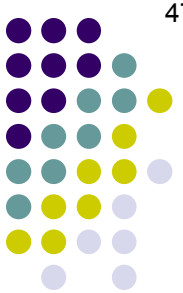
Thin *minus* lens

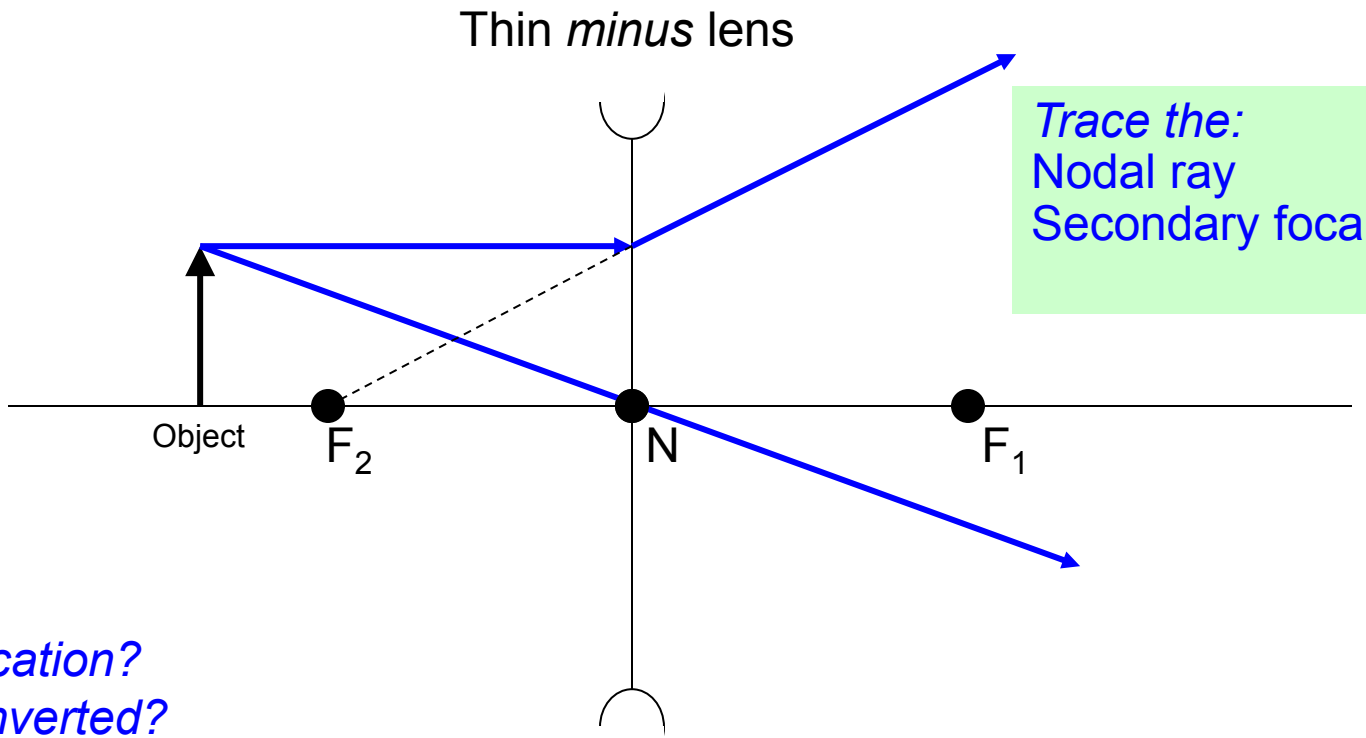


Trace the:
Nodal ray

--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

Ray Tracing

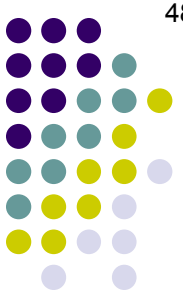


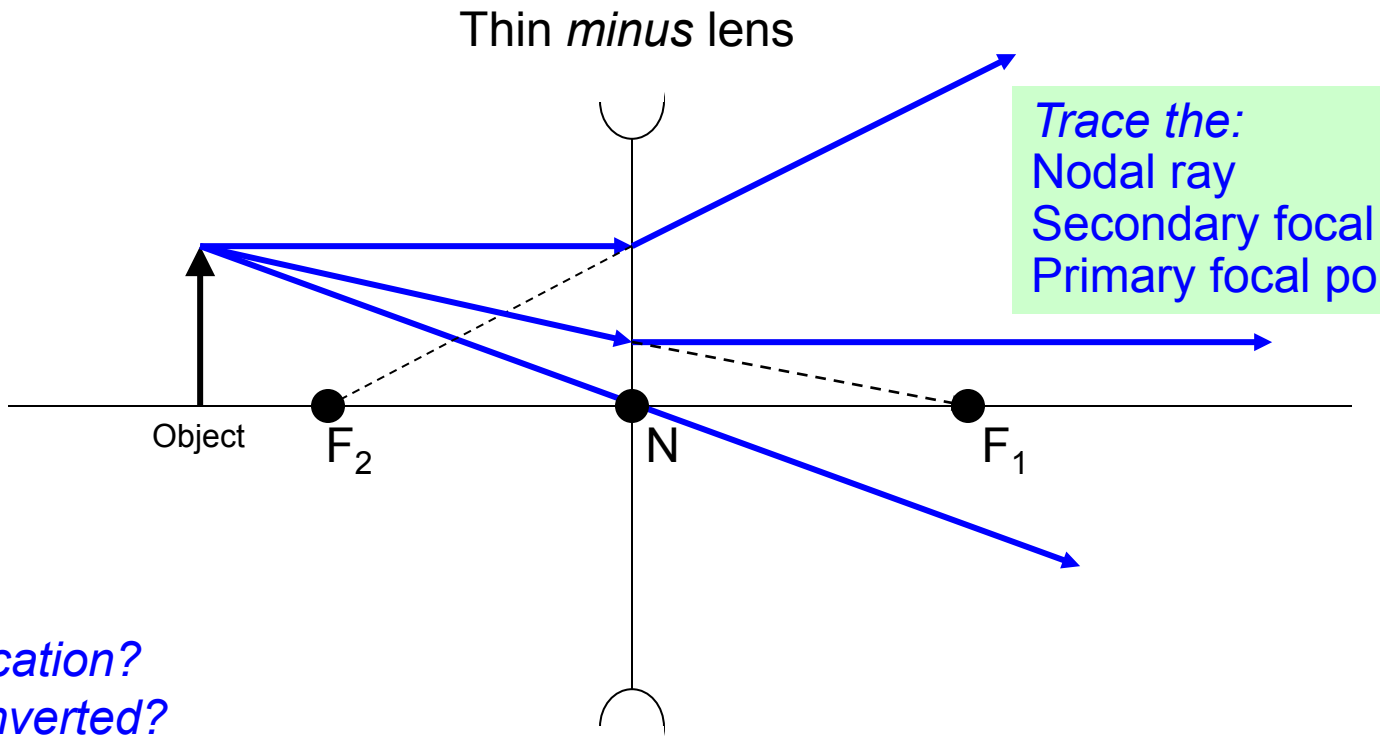


Trace the:
Nodal ray
Secondary focal point ray

--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

Ray Tracing





Trace the:
Nodal ray
Secondary focal point ray
Primary focal point ray

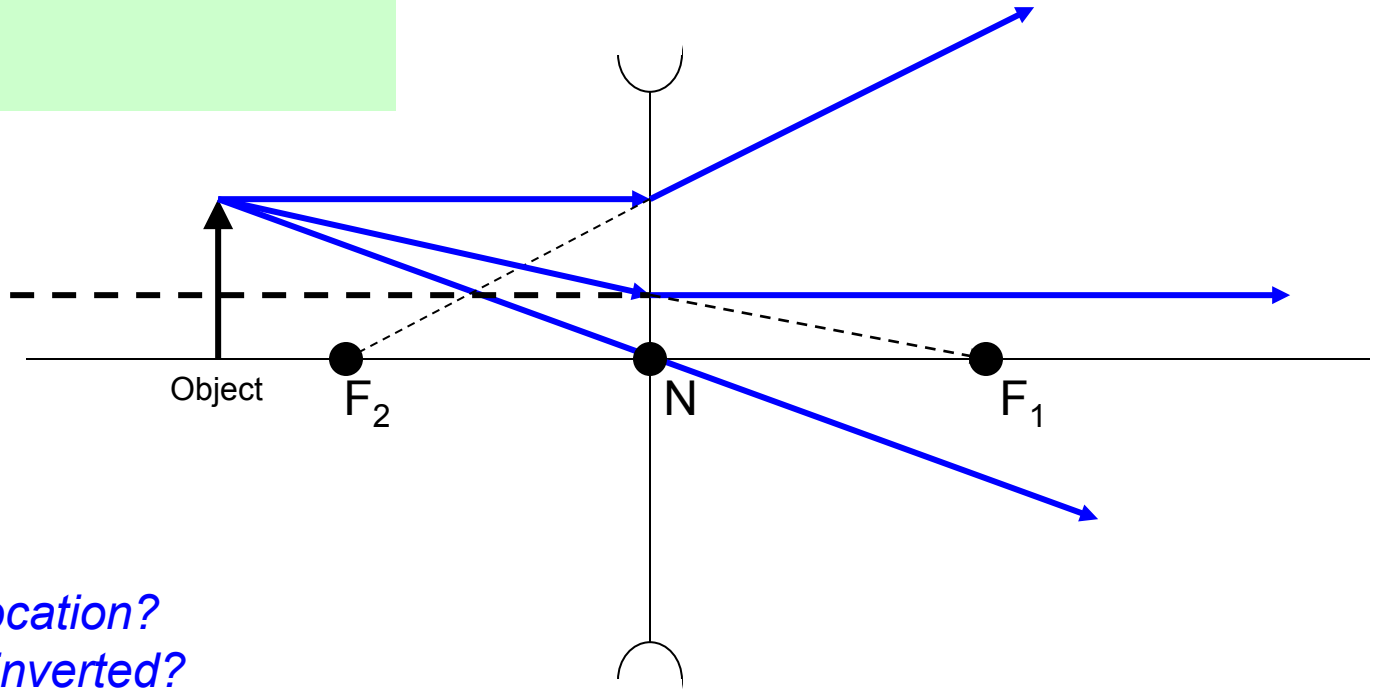
--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

Ray Tracing

Not actually necessary; we could have pegged the image with the other two rays

Extend the rays to find the point of intersection…

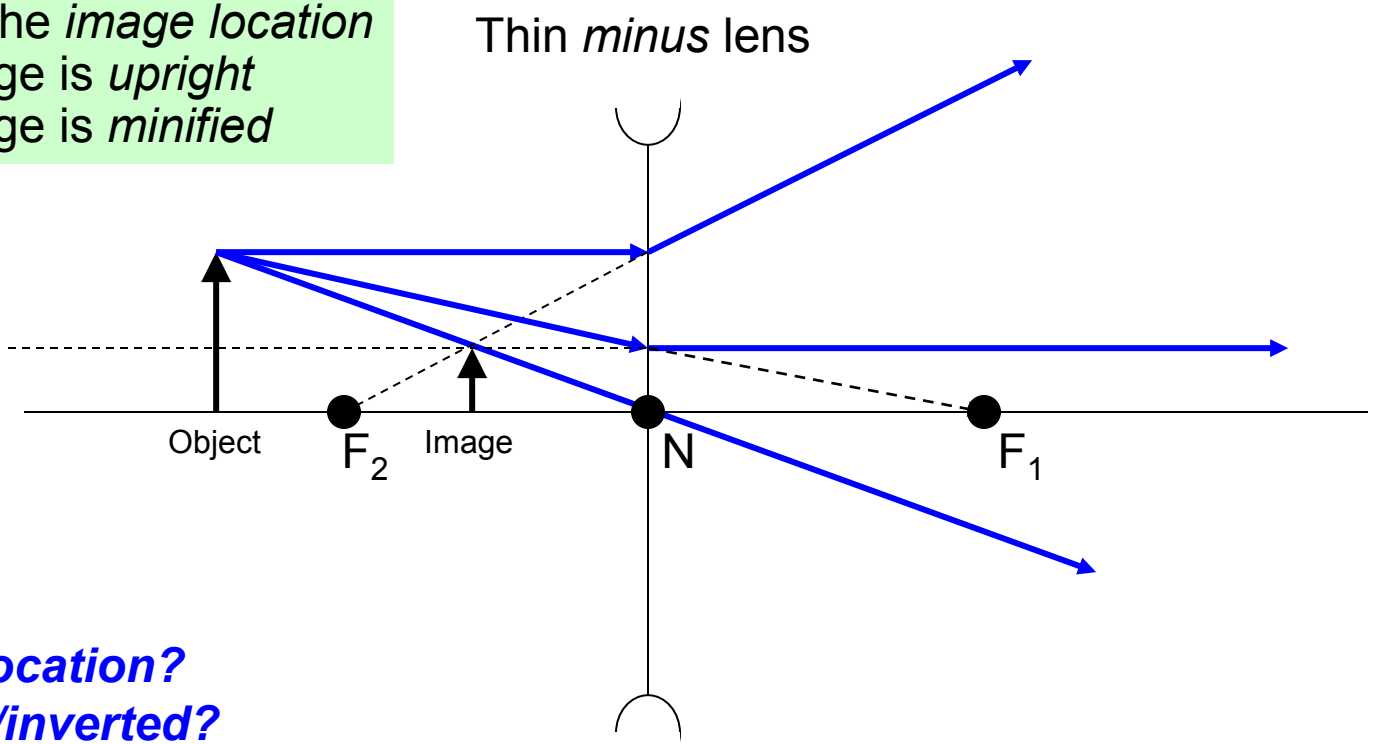
Thin *minus* lens



--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

Ray Tracing

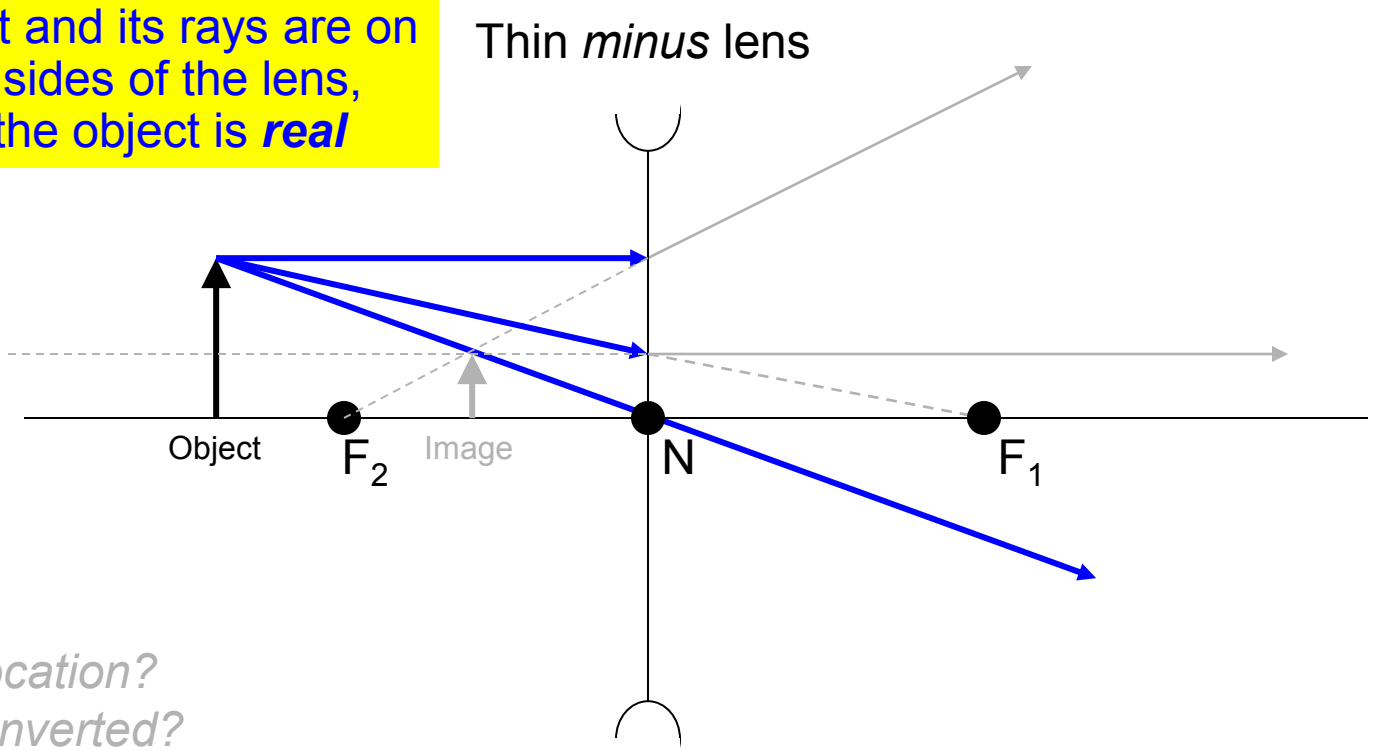
Extend the rays to find the point of intersection…
Here is the *image location*
The image is *upright*
The image is *minified*



--Image location?
--Upright/inverted?
--Object and image real/virtual?
--Magnified/minified?

Ray Tracing

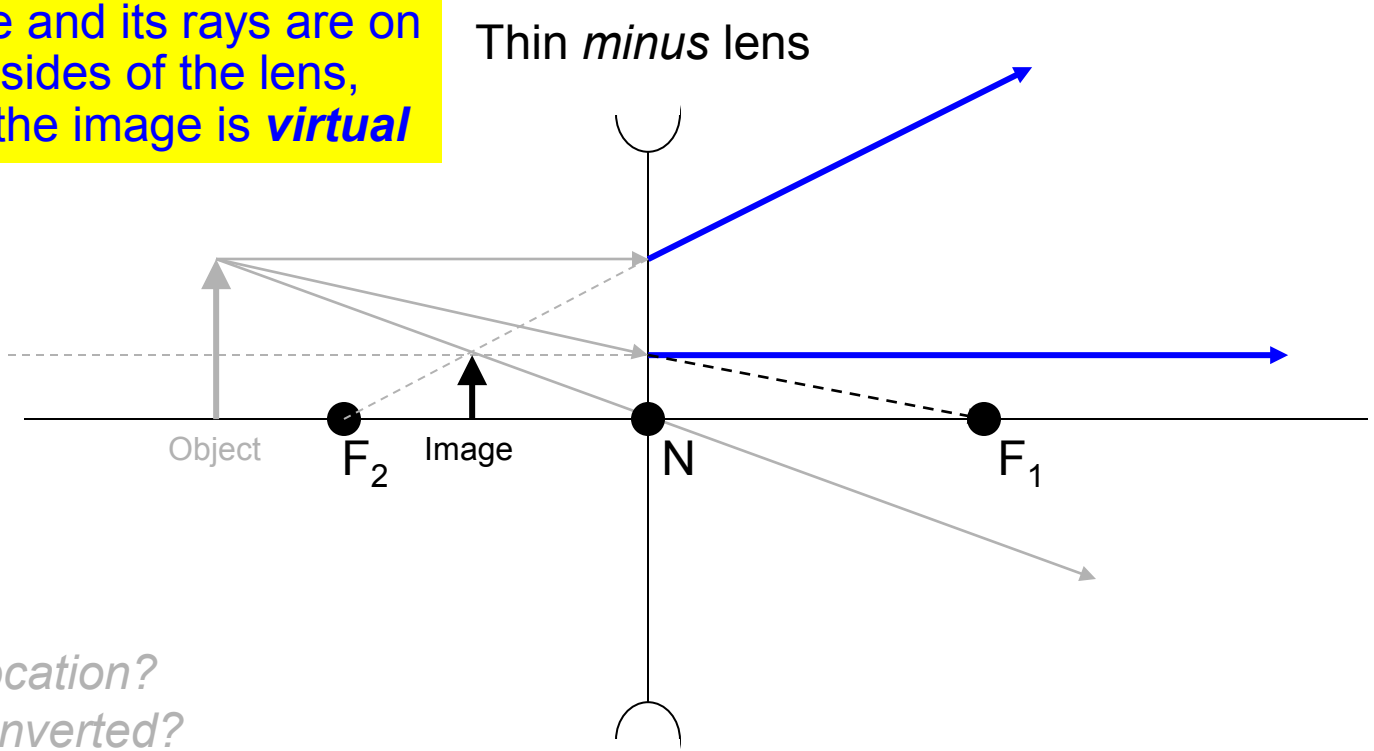
The object and its rays are on the ***same*** sides of the lens, therefore the object is ***real***



--Image location?
--Upright/inverted?
--Object** and image **real/virtual?
--Magnified/minified?

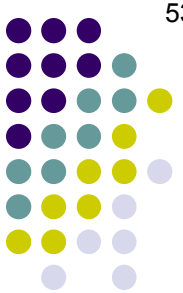
Ray Tracing

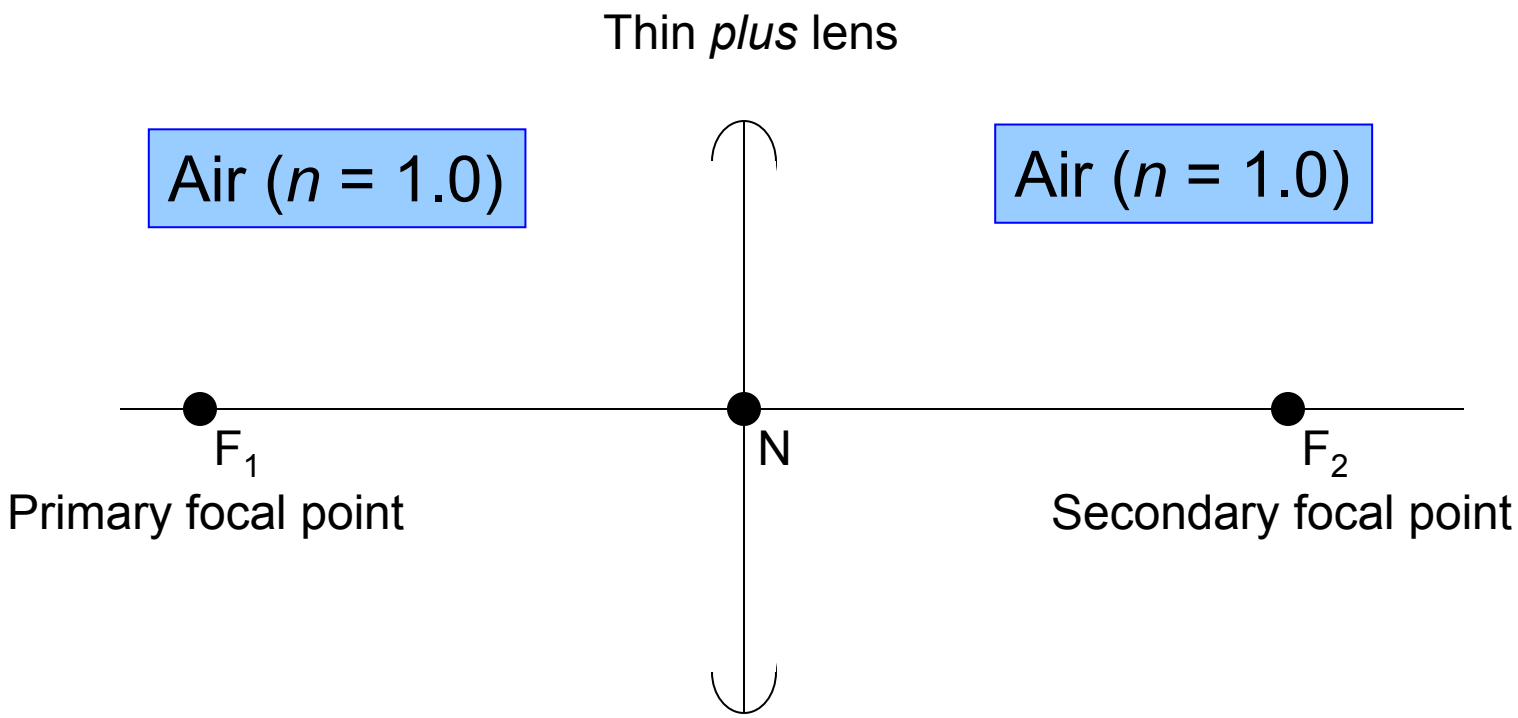
The image and its rays are on ***opposite*** sides of the lens, therefore the image is ***virtual***



--Image location?
--Upright/inverted?
*--Object and **image real/virtual?***
--Magnified/minified?

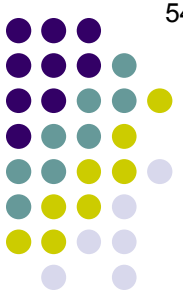
Ray Tracing

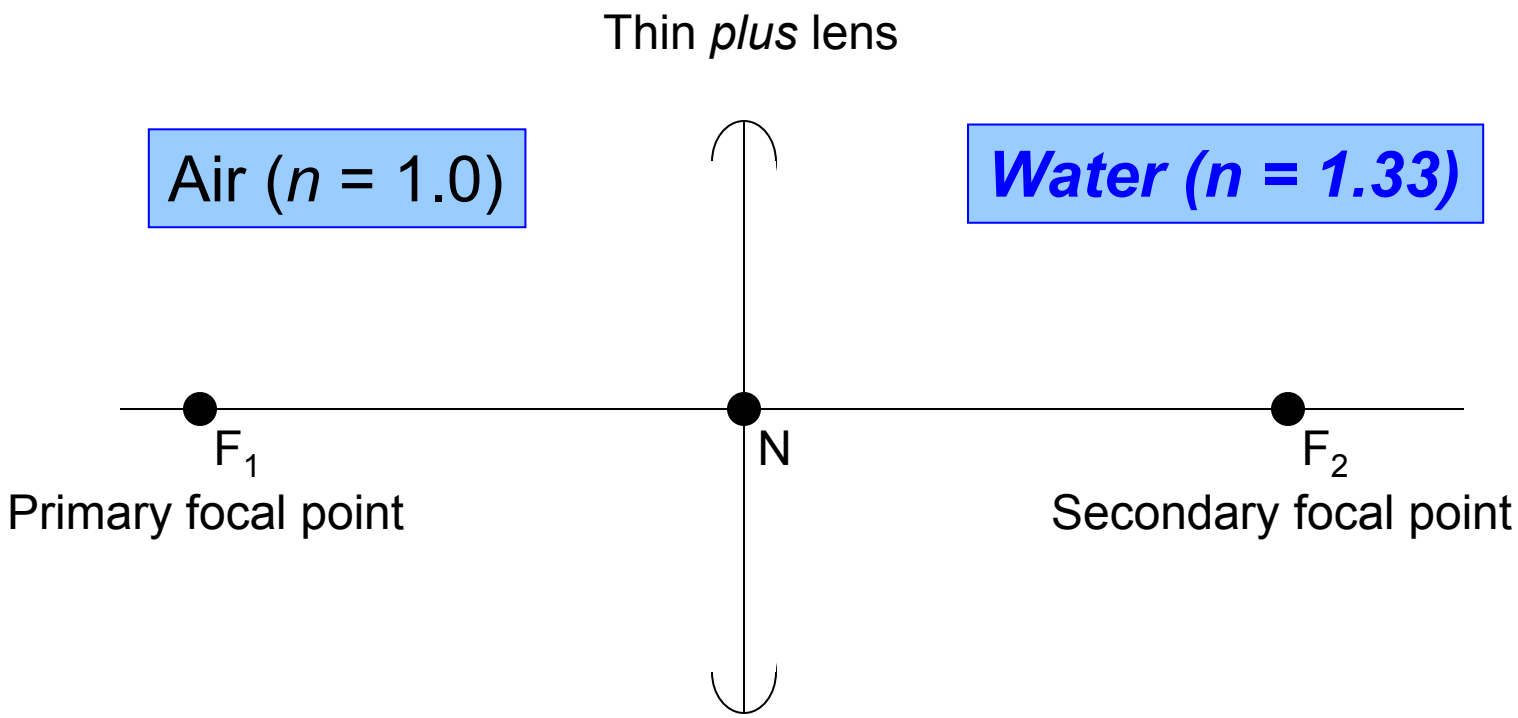




Note: In the discussion thus far, we have assumed the refractive index on either side of the lens is the same.

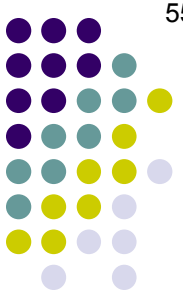
Ray Tracing

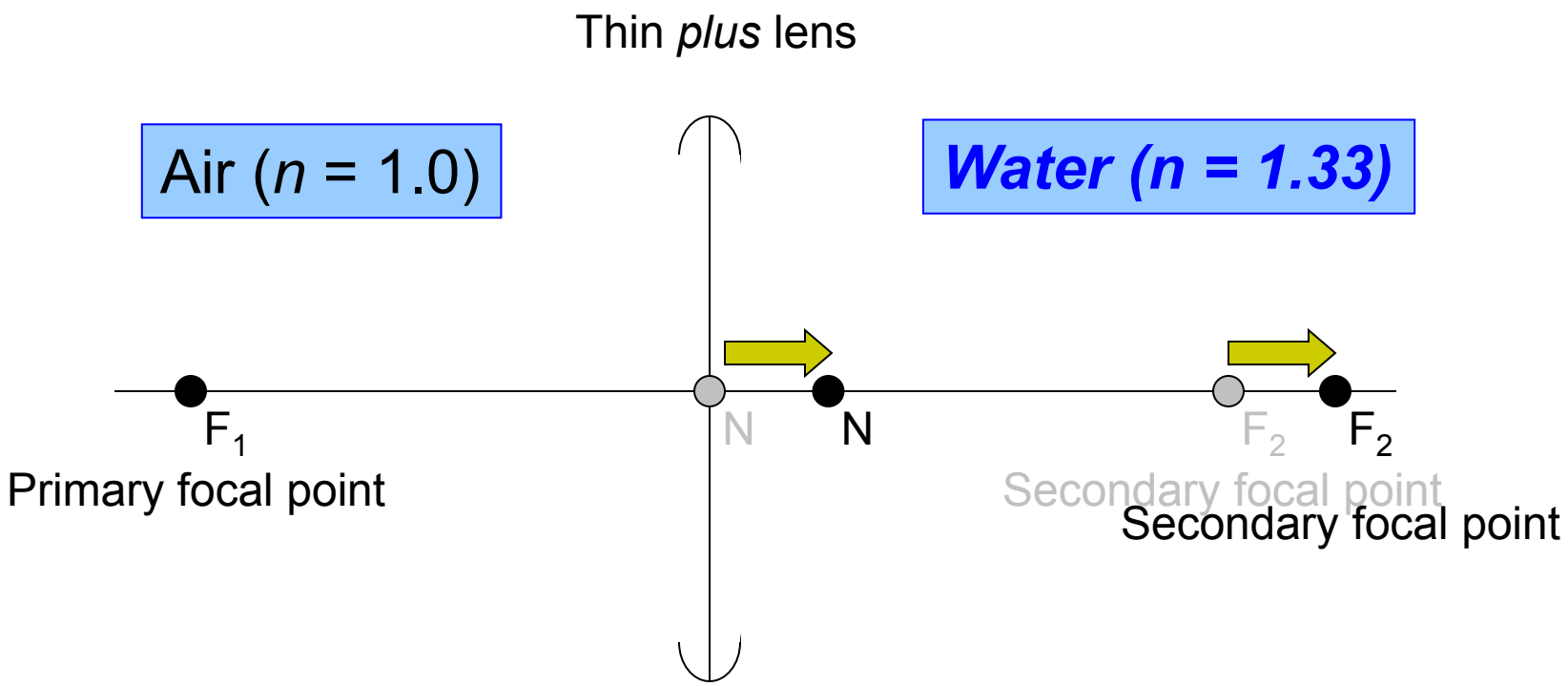




Note: In the discussion thus far, we have assumed the refractive index on either side of the lens is the same. ***What if it's not?***

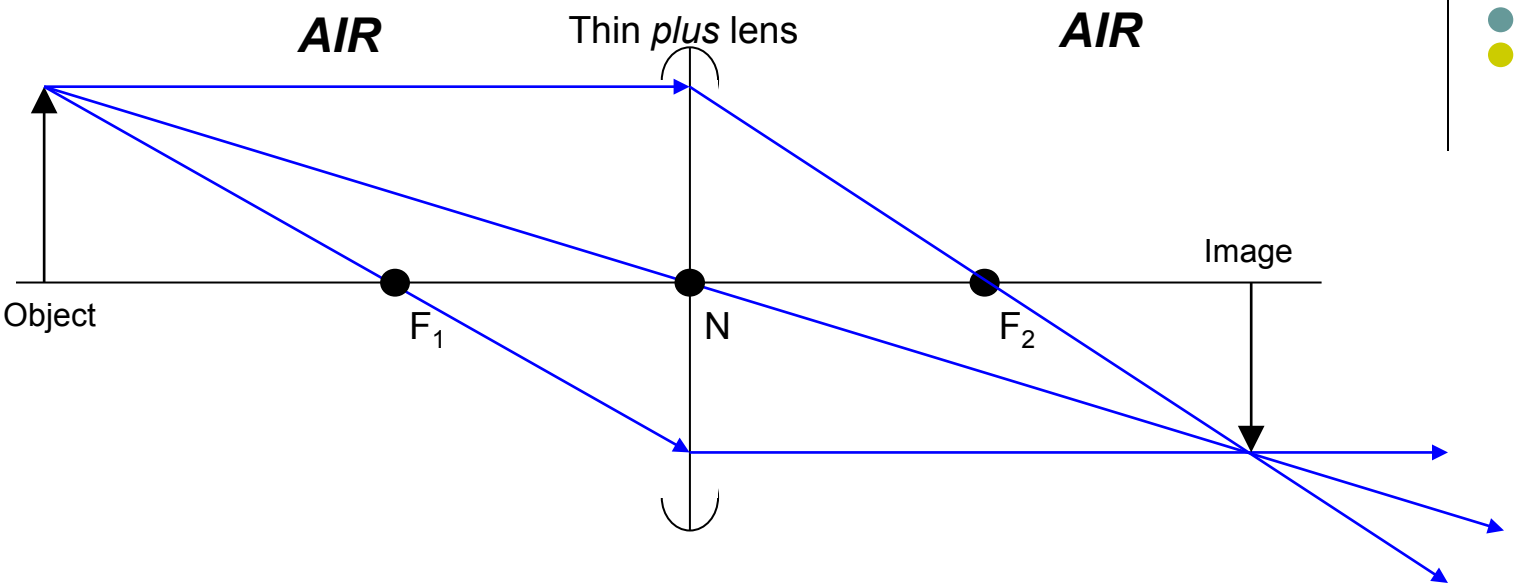
Ray Tracing





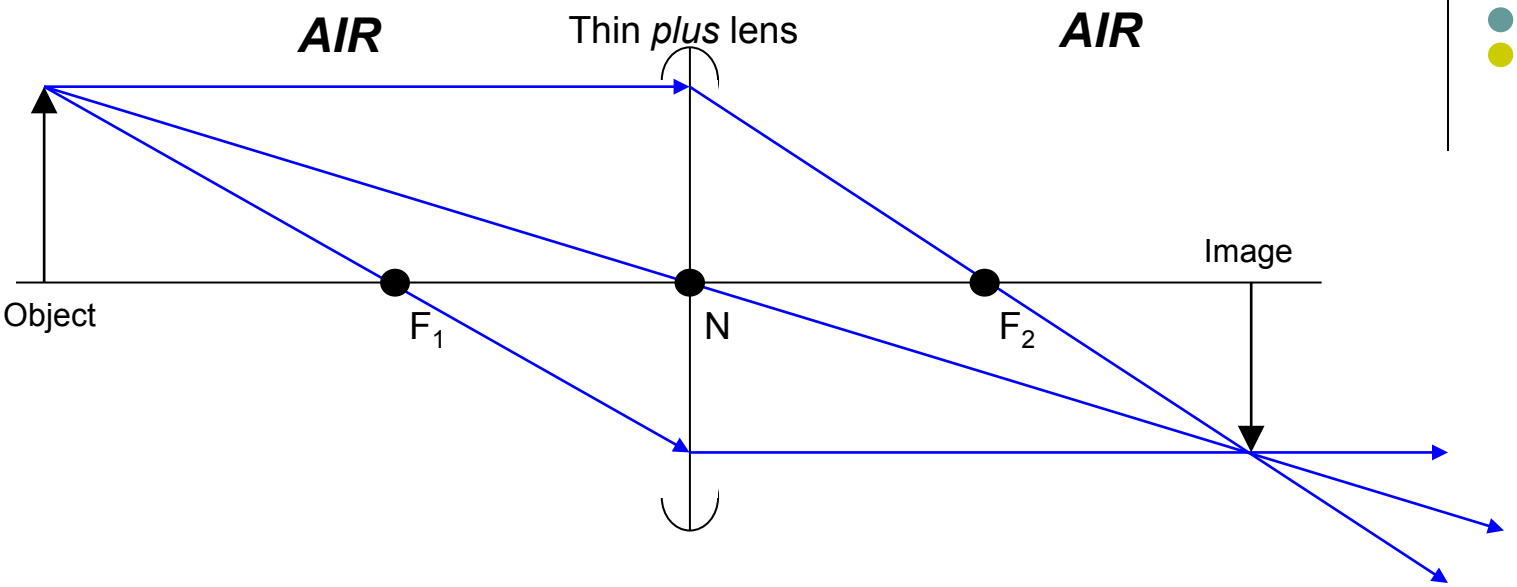
When *n* is not the same on both sides of the lens, the nodal point is pulled to the side with the higher *n*, and the focal length on that side becomes *l o n g e r*

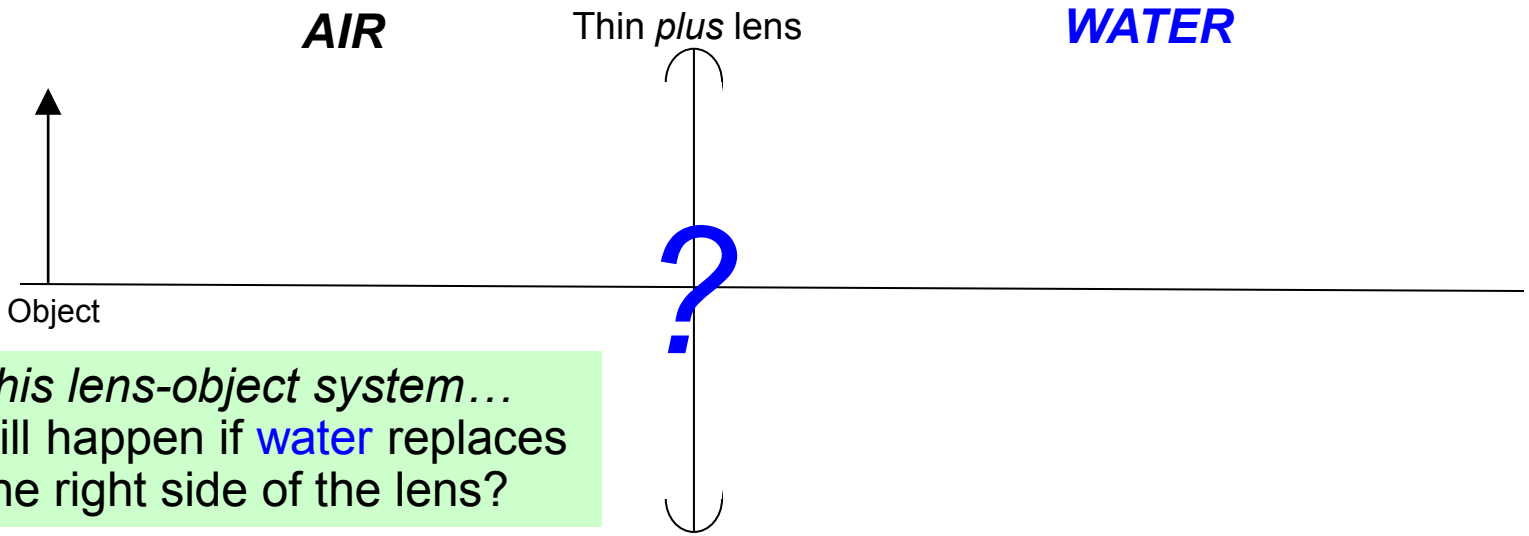
Ray Tracing



Given this lens-object system…

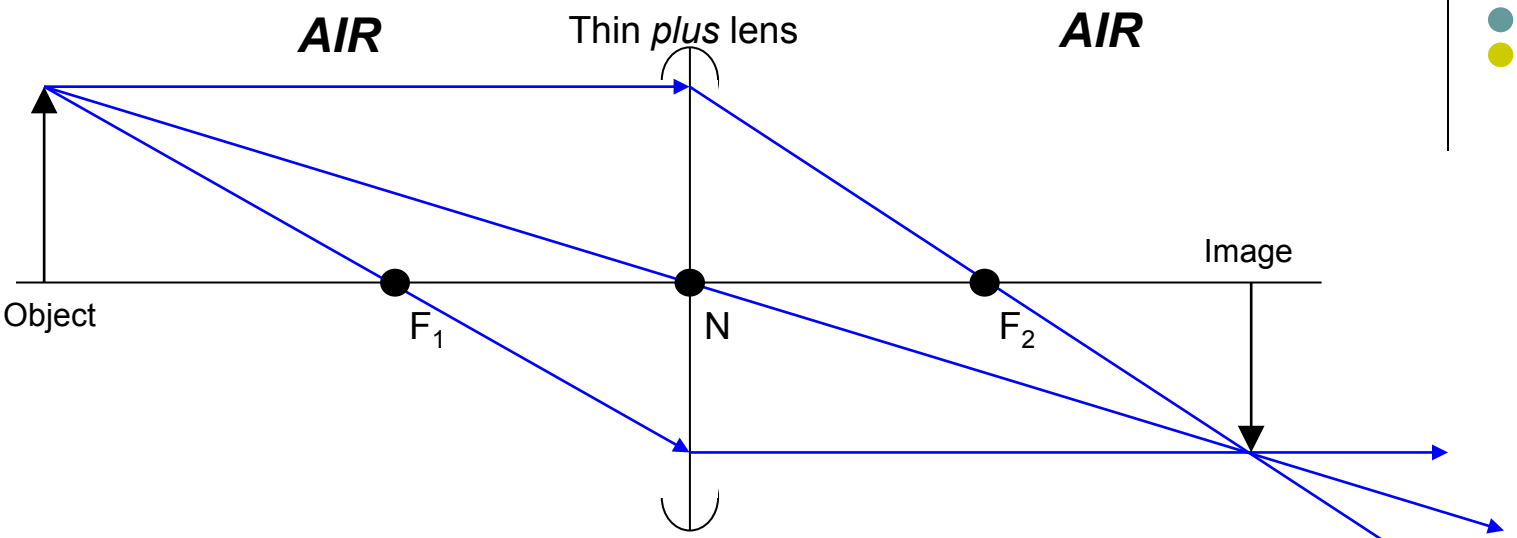
Ray Tracing

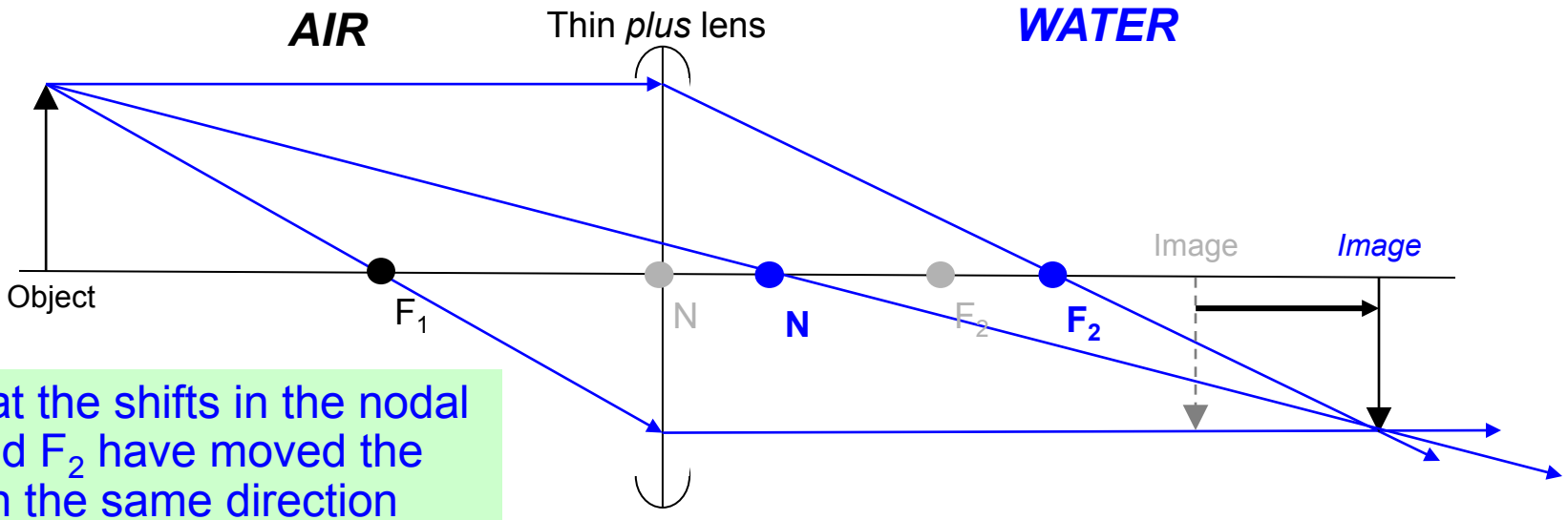




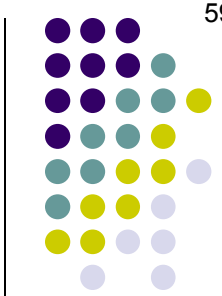
Given this lens-object system…
What will happen if water replaces air on the right side of the lens?

Ray Tracing





Note that the shifts in the nodal point and F_2 have moved the image in the same direction



At this juncture, you should assess your Optics knowledge by taking Quiz 4 *(slide-set* BO30*). After that, resume the tutorial with slide-set* BO20*.*