Virtual image displays

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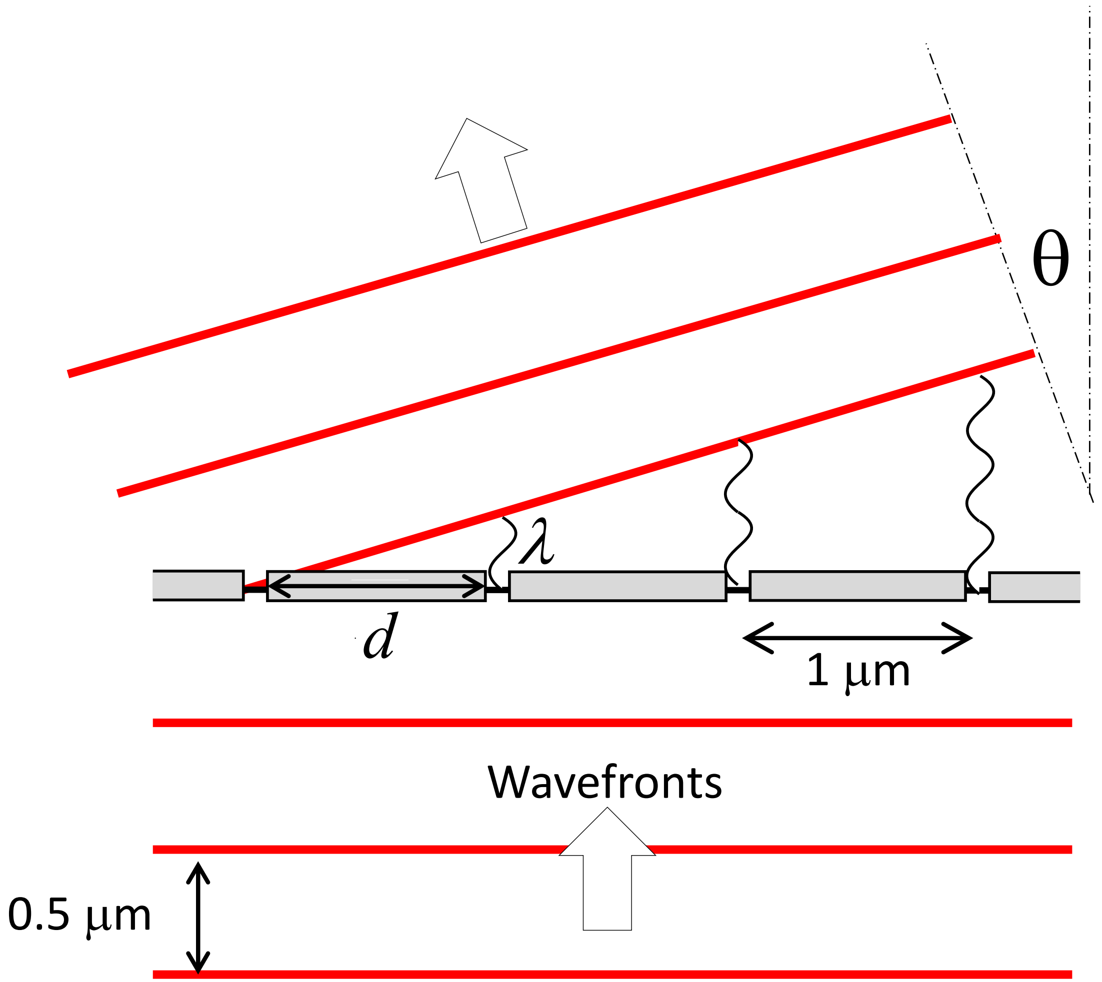
’88-07 Cambridge University
’07-18 Microsoft Research
’18-20 Facebook
‘20- Travoptics

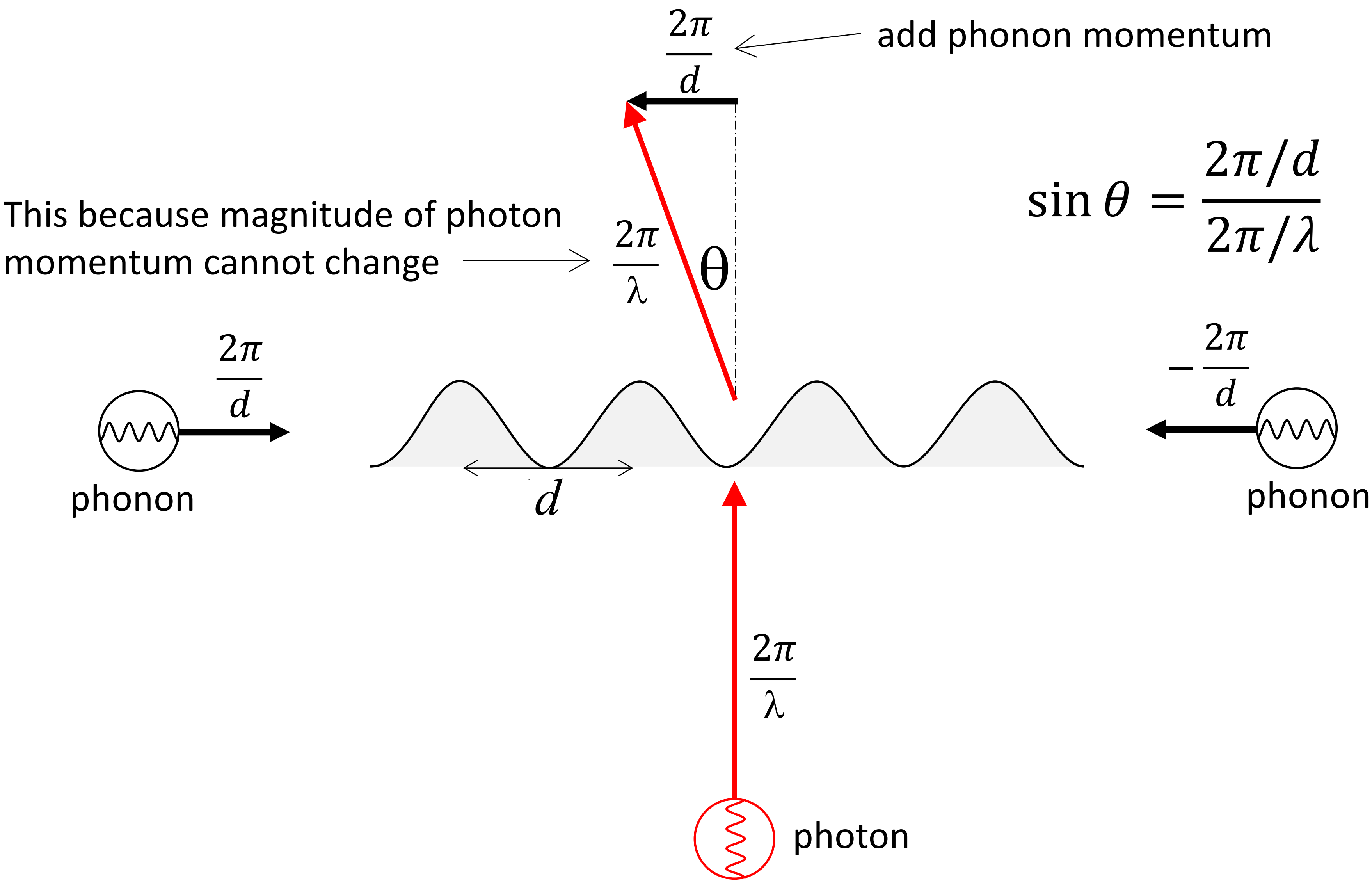
By what angle is the wave diffracted?



$$\lambda = d \sin\theta$$

$$\theta = \sin^{-1}\left(\frac{0\cdot 5}{1}\right)$$

We can also think of a grating as a standing wave of two phonons



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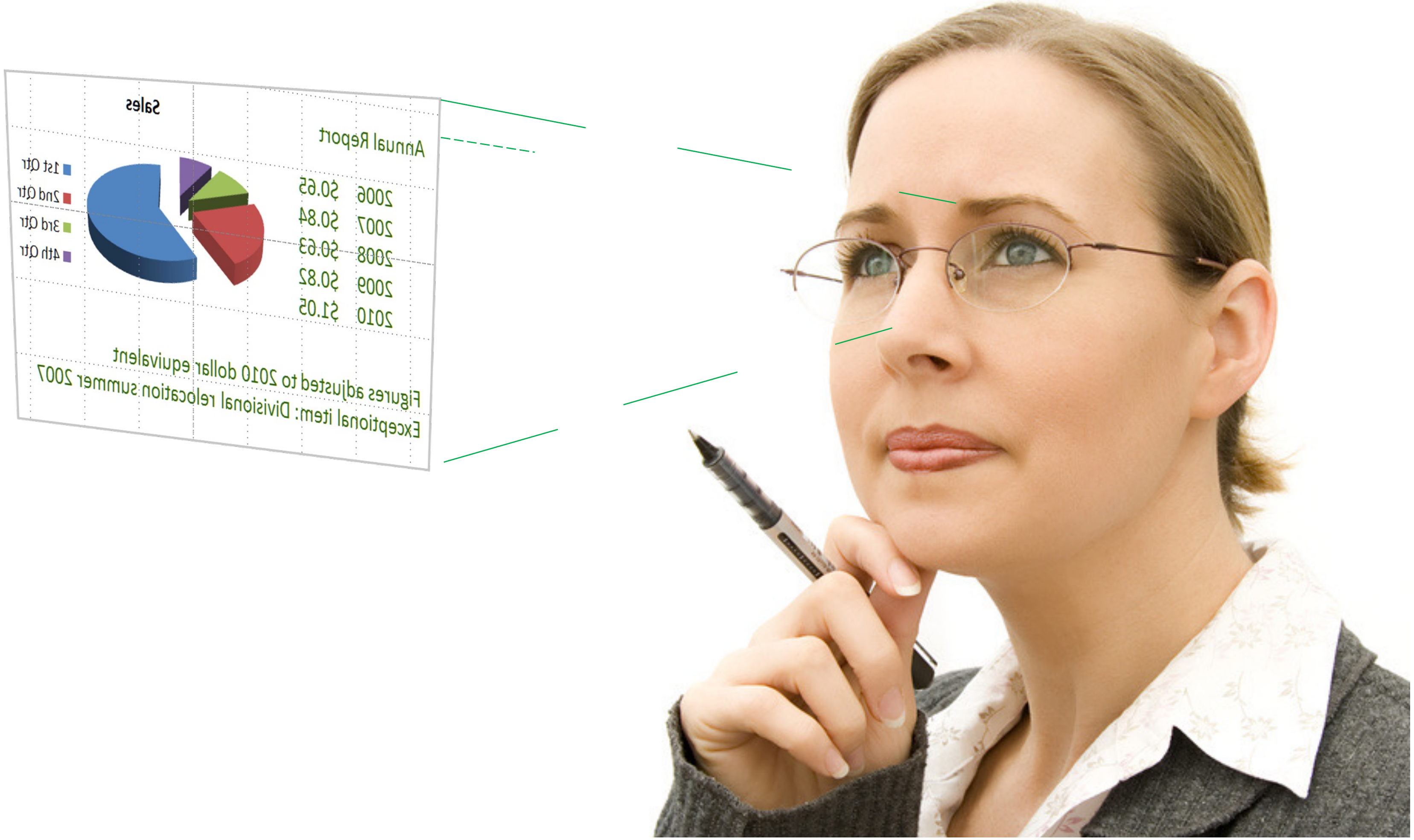
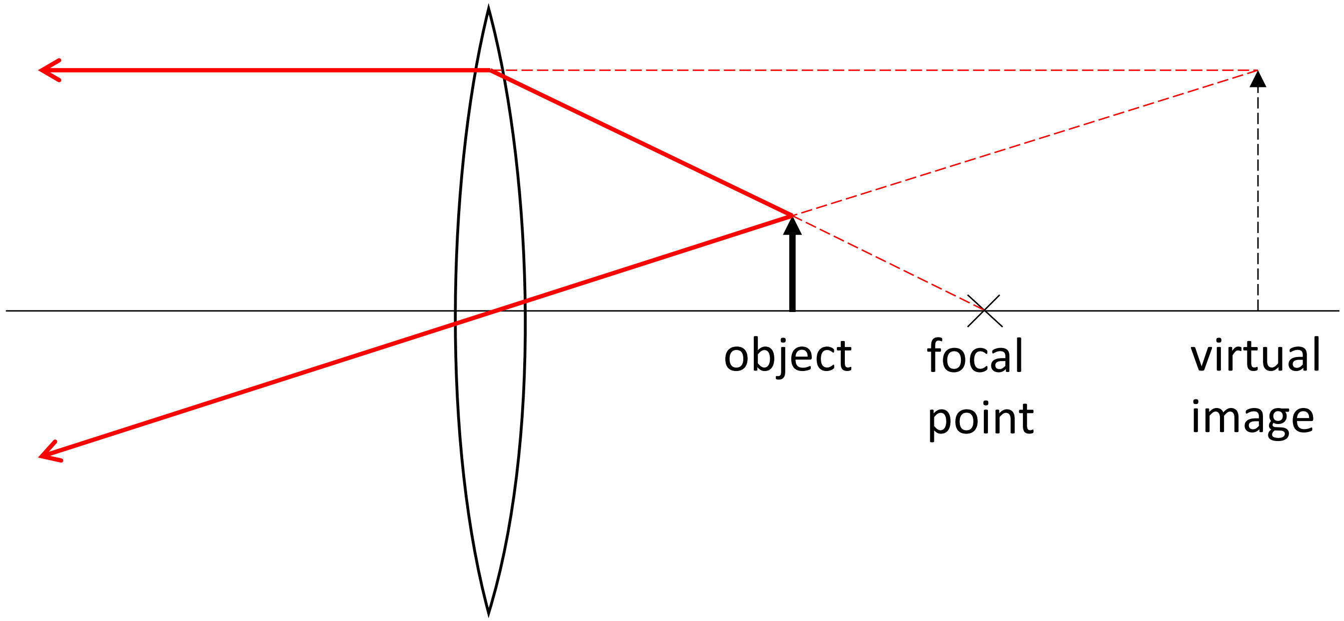
- We want the Web without pocket hassle
- Use a guide embossed with a grating
- How to design the gratings
- Why it is not so easy

After smart phones, transparent virtual image displays may be next.

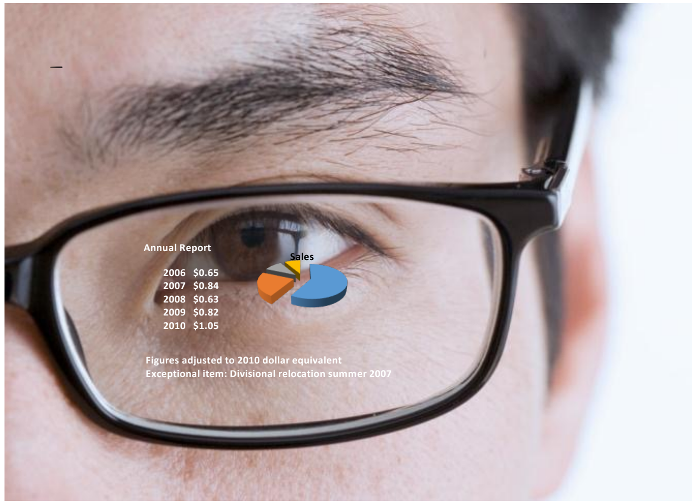


In *displays* an image is virtual if it appears to form behind the *display*



But most head-mounted displays are so ugly that no-one will wear them

We want slim virtual displays, for spectacles & for digital windows



What do we want?

- ***It has to look good***
- lets others see your eyes (for Skype)
- has unlimited field of view (120° x 90°)
- >2000 pixels per radian
- variable focal depth
- fits without adjustment
- spills no light (so eyes don't glow)
- wearable with optician's spectacles

Source: pinterest.com

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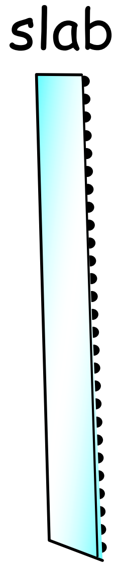
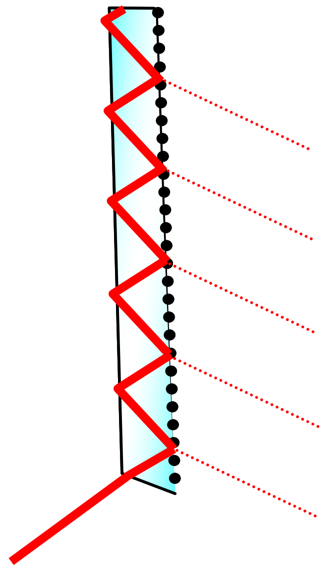
How do we get a virtual image from a guide?

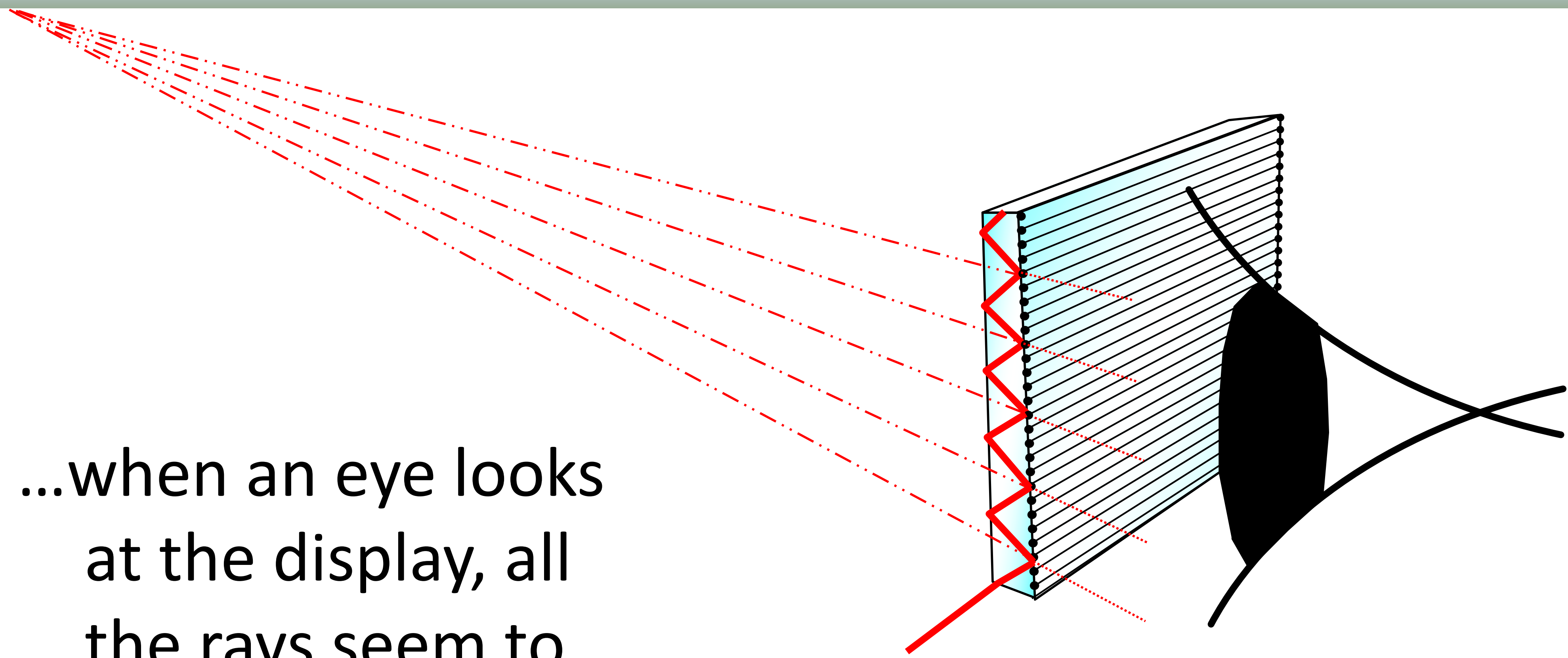


1. Shine a ray into a slab with parallel sides

2. Slightly emboss one side with a grating

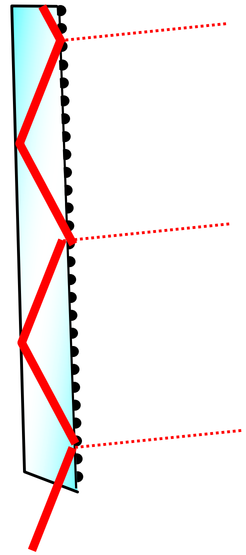
3. At each grating reflection, part of the ray diffracts out. The diffracted parts all travel in the same direction

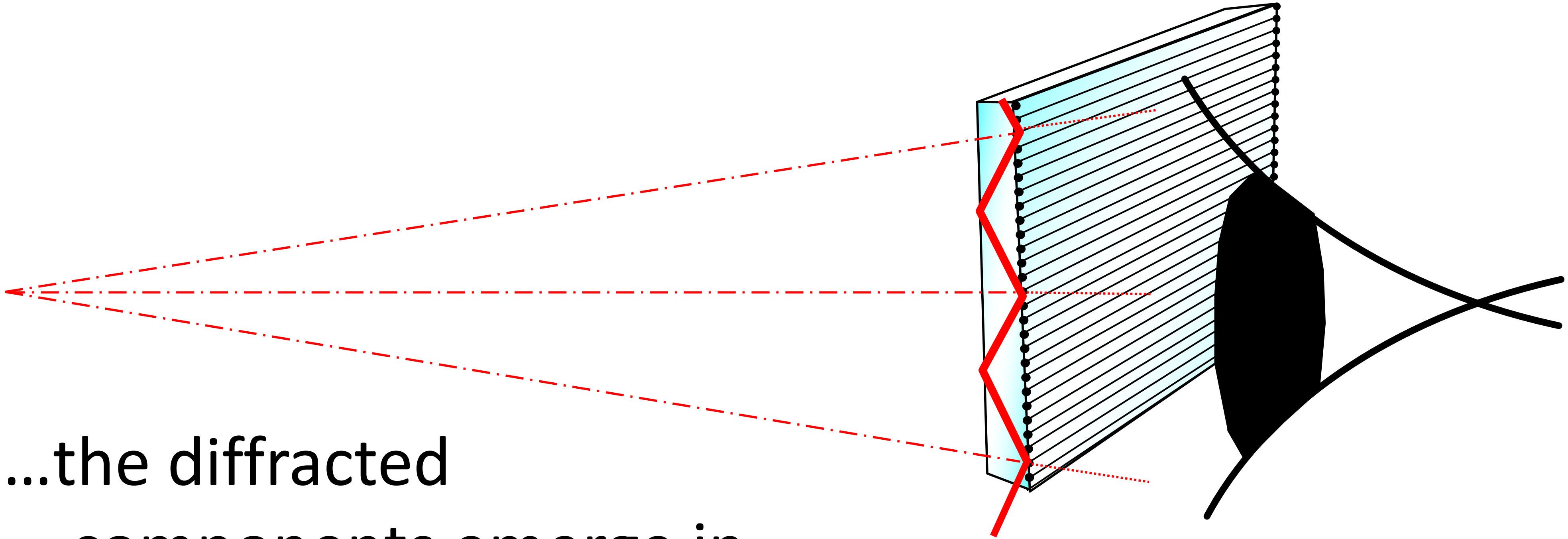




...when an eye looks at the display, all the rays seem to come from a point far behind the slab

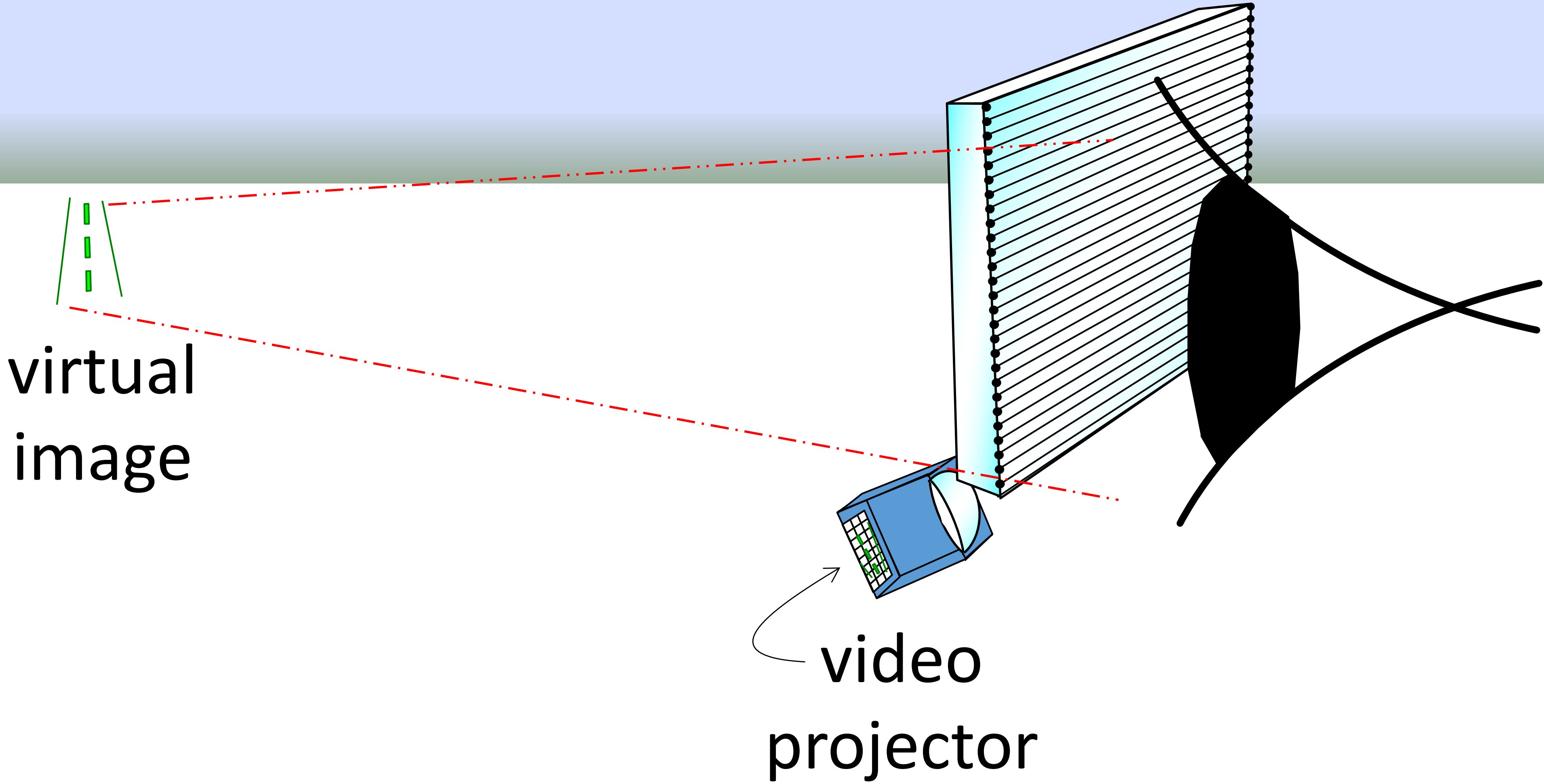
4. Inject a ray at a different angle into the slab



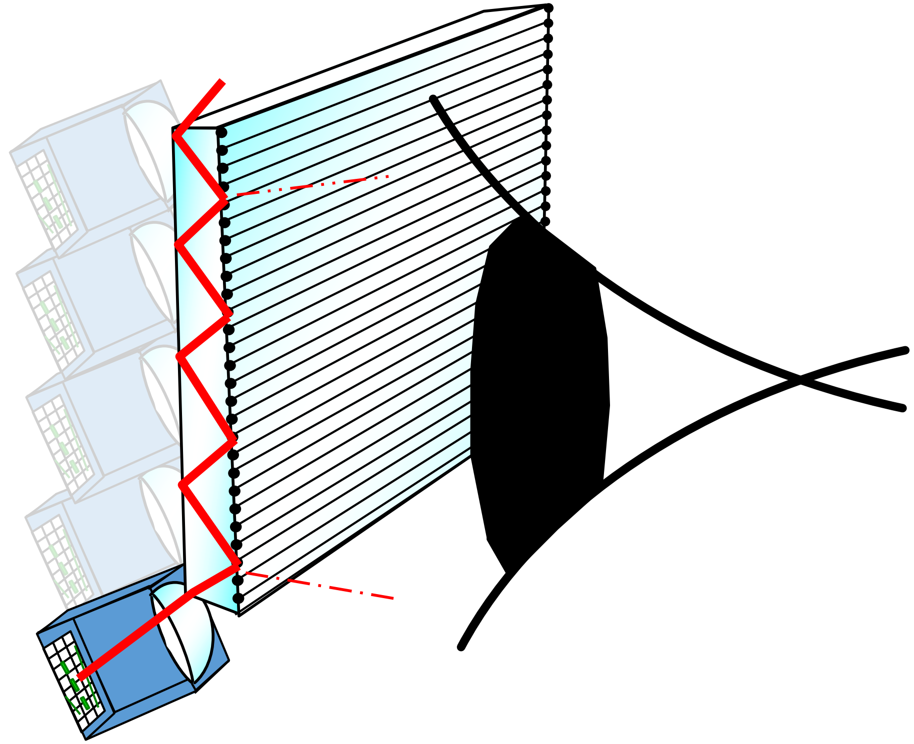


…the diffracted components emerge in a different direction, so seem to come from a different point

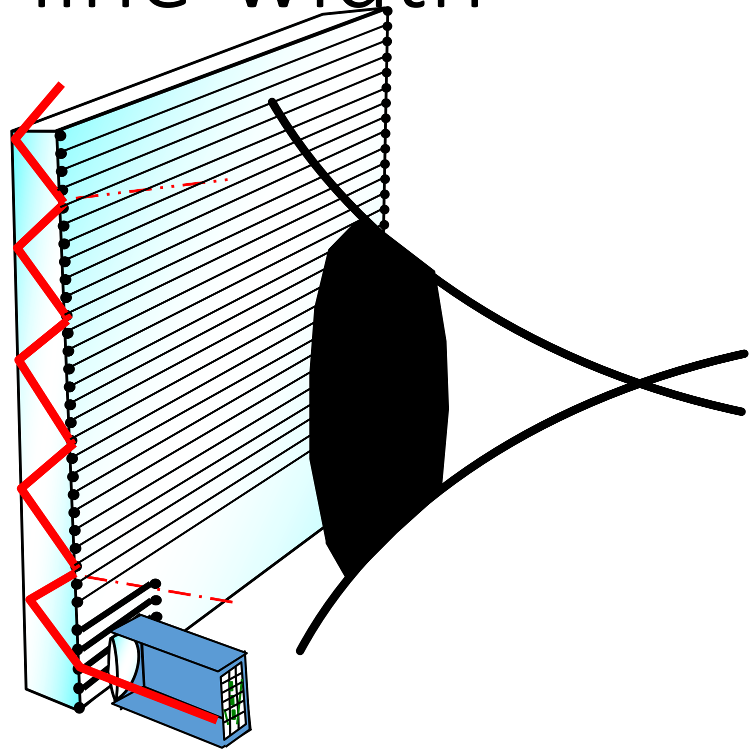
Add a projector and we can display a virtual image.



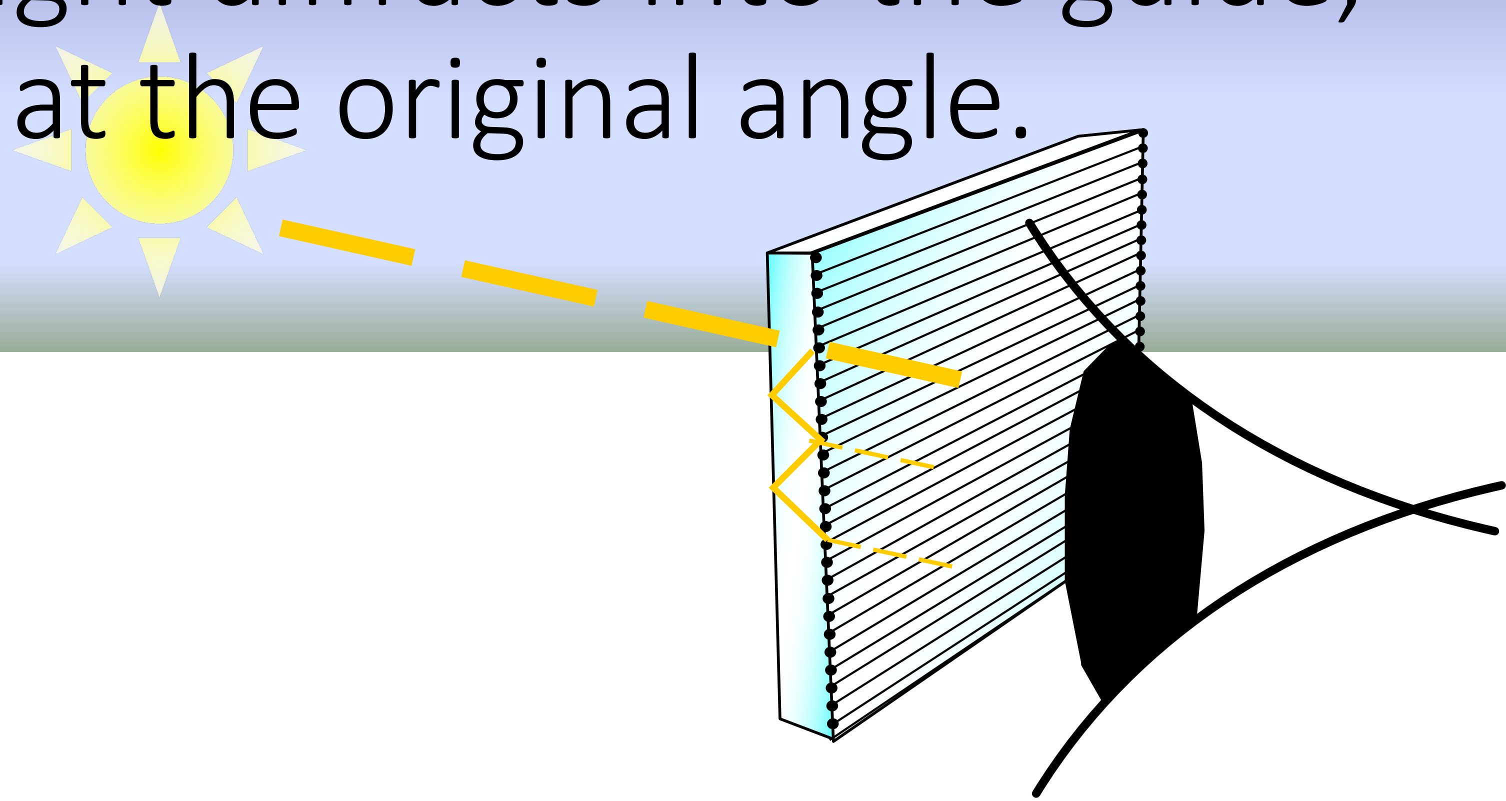
A projector is like a virtual display with a tiny pupil. The guide just expands the pupil.



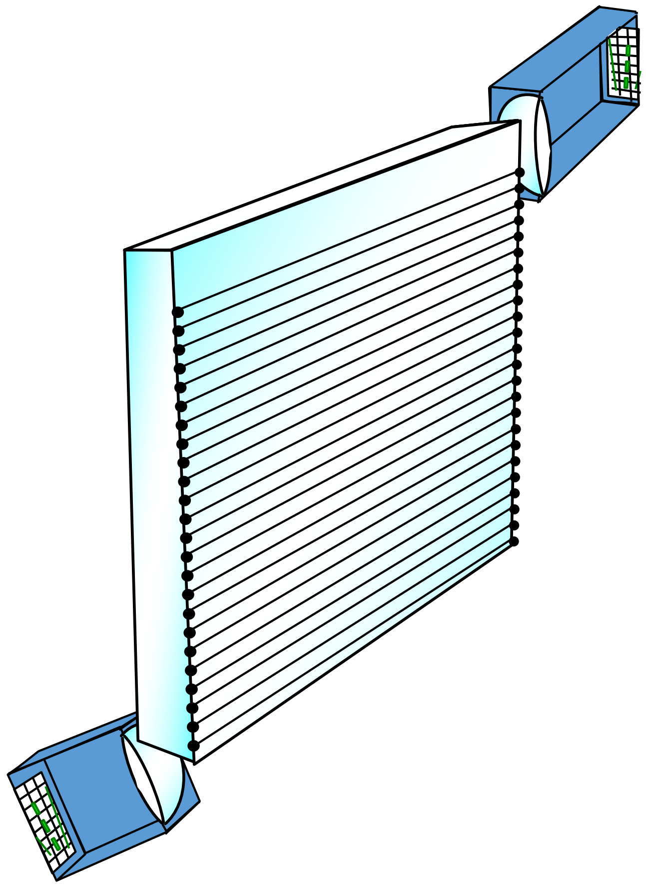
With LEDs, inject via a grating so as to cancel diffraction due to line-width



If any light diffracts into the guide, it exits at the original angle.



We need to expand the pupil horizontally as well as vertically. So add a 2nd grating



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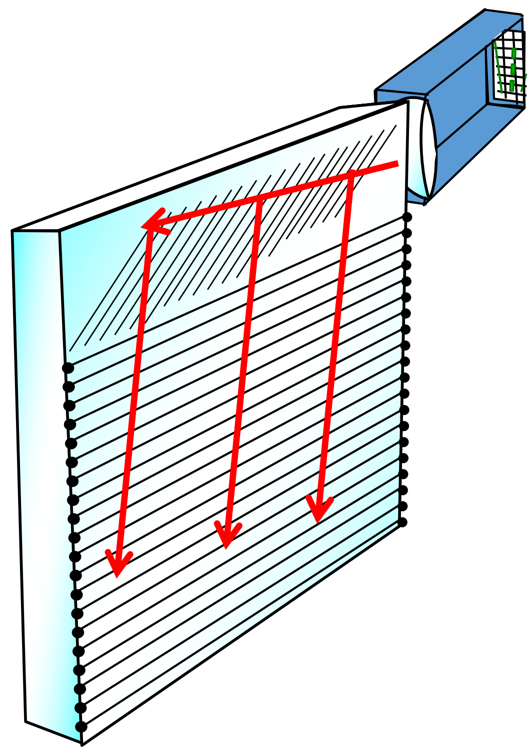
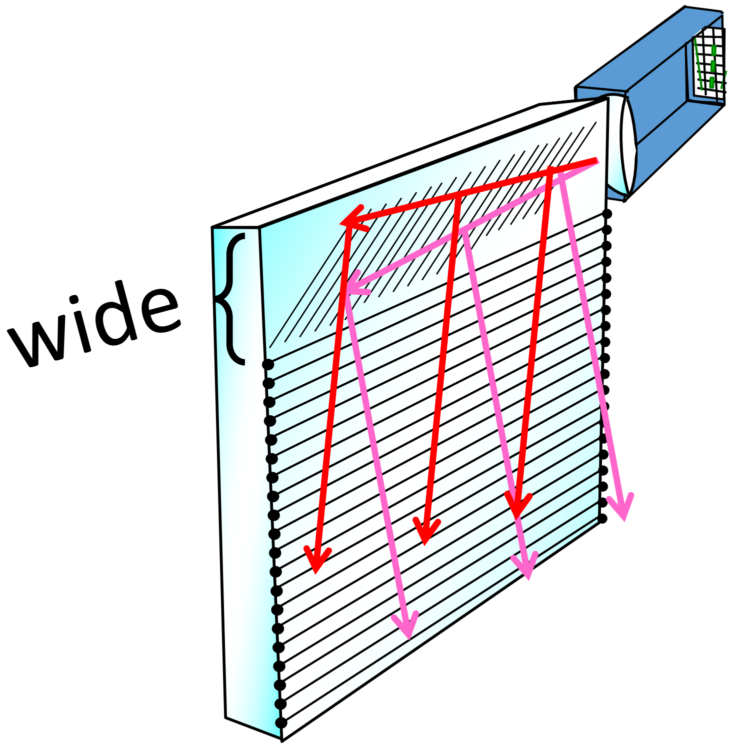
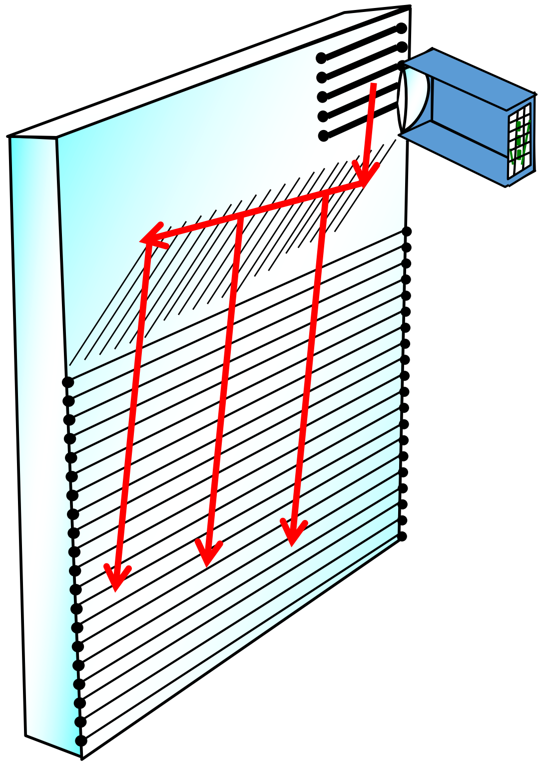


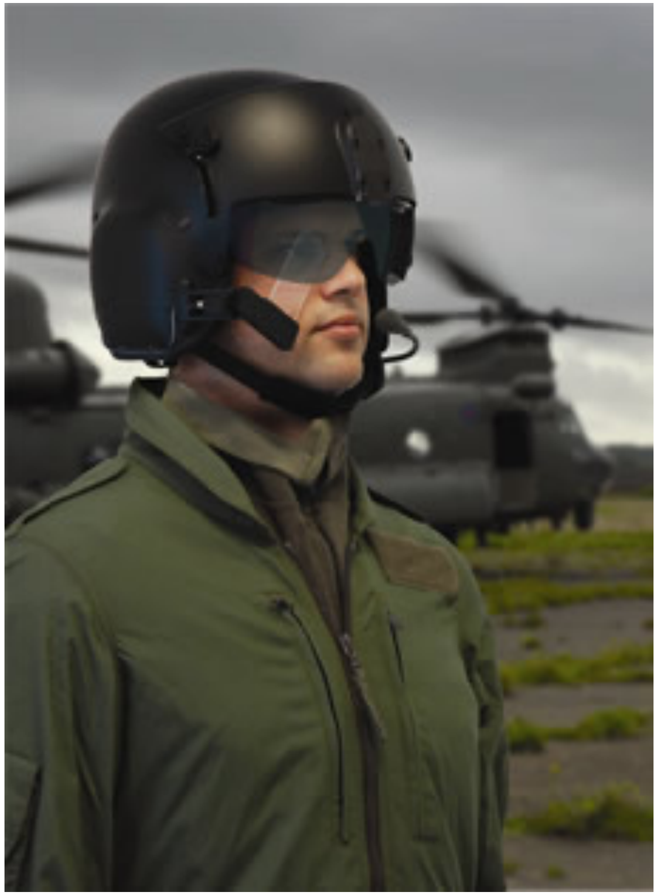
The second grating must be wide because rays fan-out from the projector

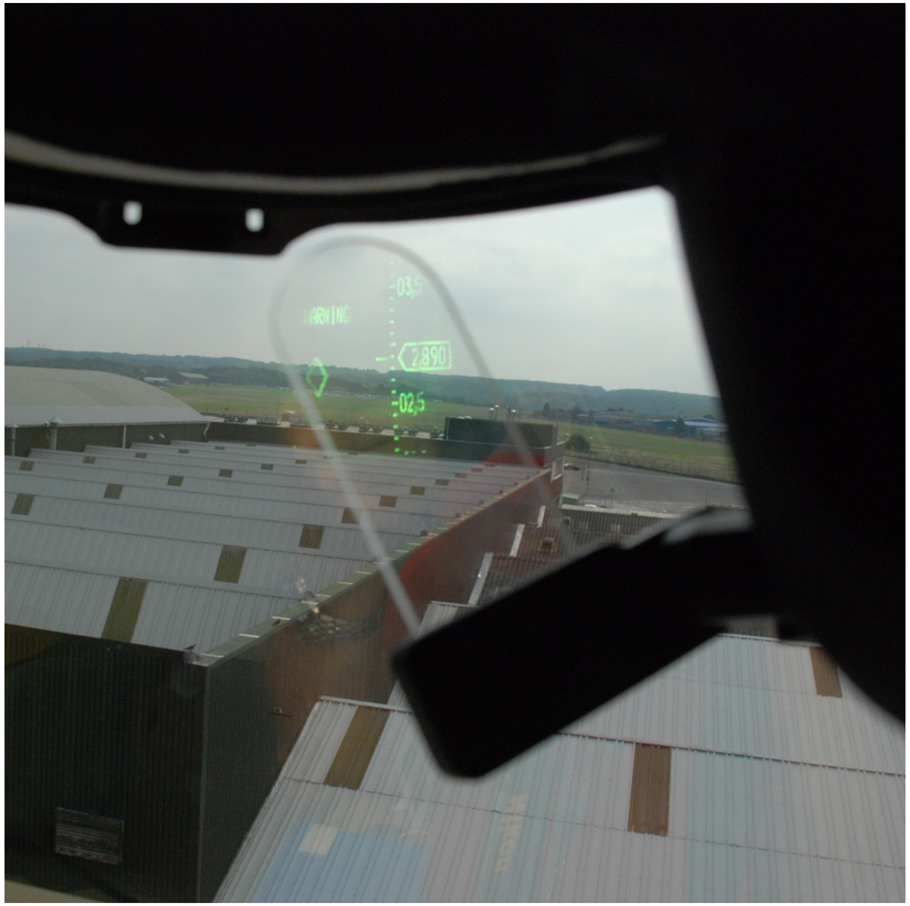


With LEDs, diffract twice off expansion grating so as to cancel line-width effects



This concept is used in aircraft: 40° by 30° field of view & 1920x1080 resolution





baesystems.com

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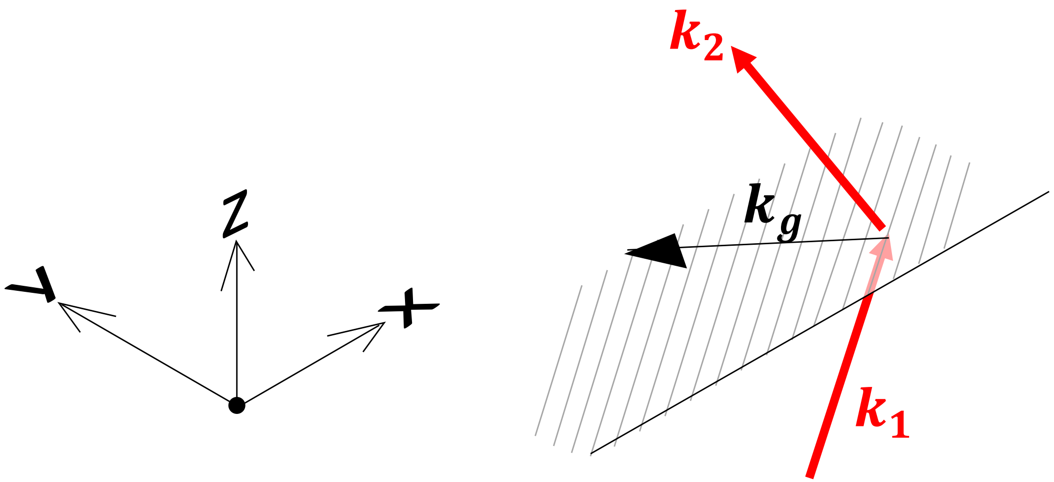
In 3D, we express diffraction using vectors.
Let the grating be in the x, y plane:

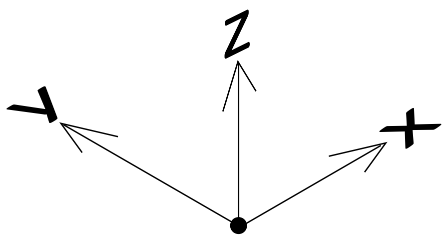


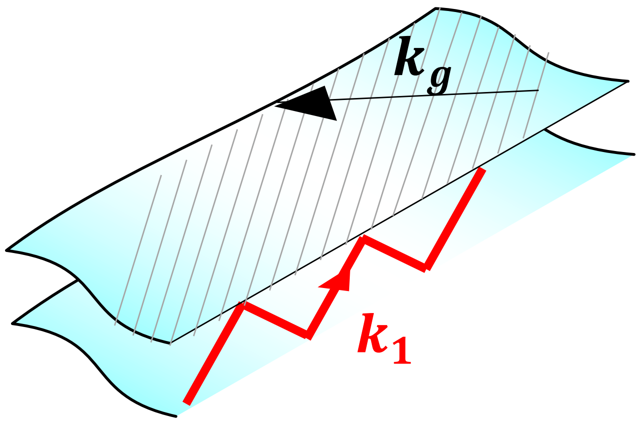
To find $\boldsymbol{k}_2$, add the grating vector to the wave vector then normalise

$$\boldsymbol{k}_2 = \left[\frac{\begin{matrix} \boldsymbol{k}_1.\boldsymbol{i} & +k_g\cos\phi \\ \boldsymbol{k}_1.\boldsymbol{j} & +k_g\sin\phi \end{matrix}}{\sqrt{|\boldsymbol{k}_1|^2 - \left(\boldsymbol{k}_1.\boldsymbol{j}\ +k_g\cos\phi\right)^2 - \left(\boldsymbol{k}_1.\boldsymbol{i}\ +k_g\sin\phi\ \right)^2}}\right]$$

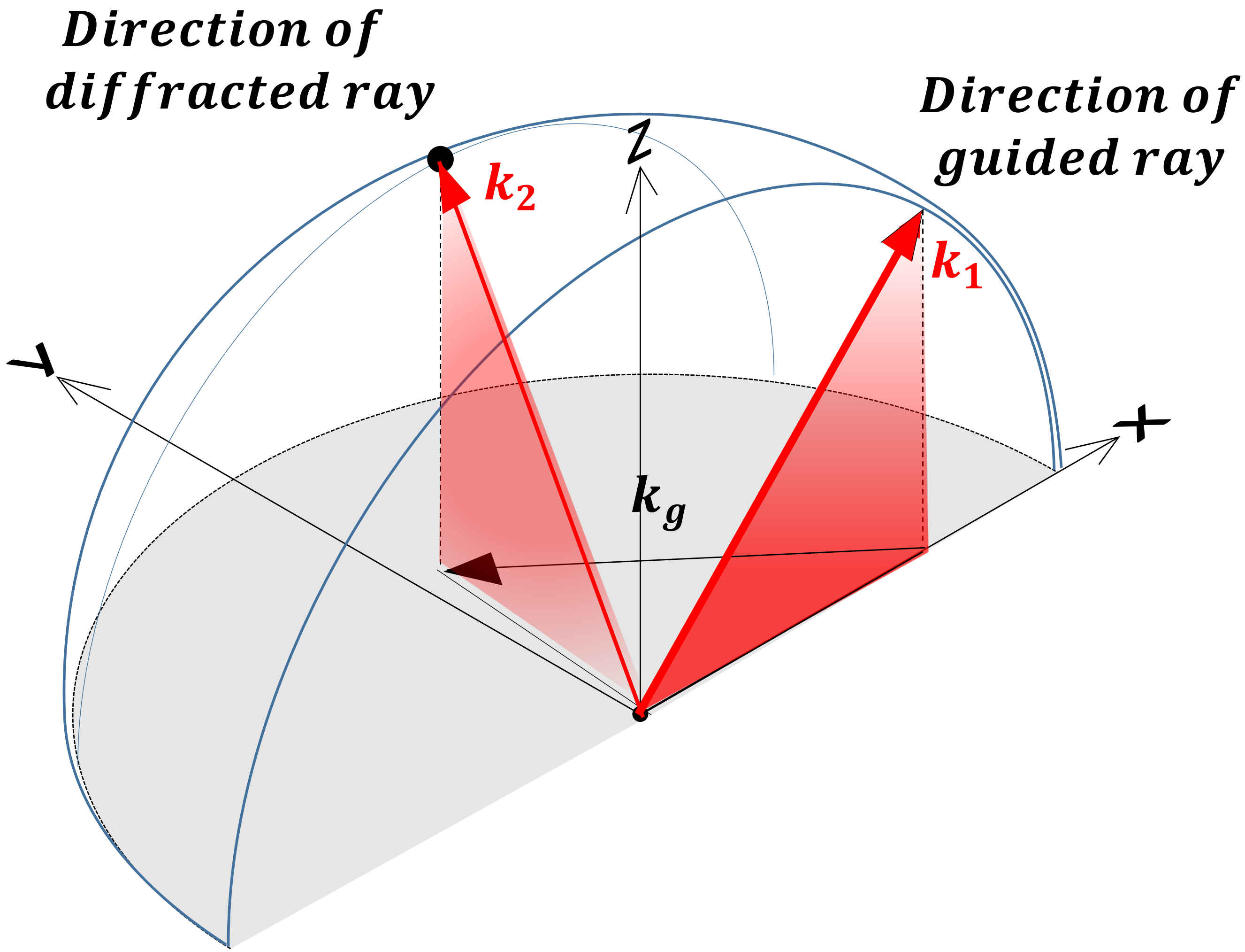
add grating vector

normalise

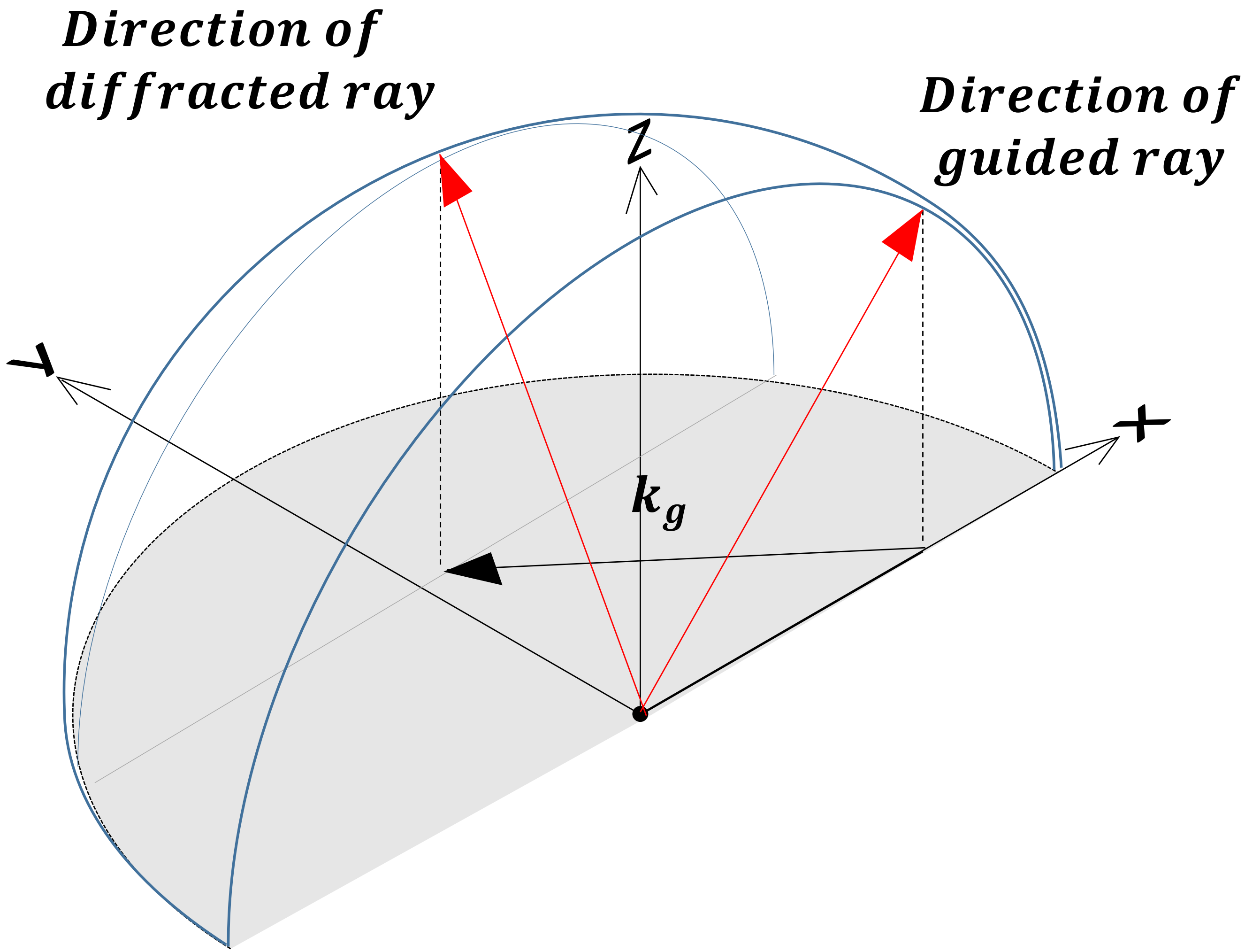




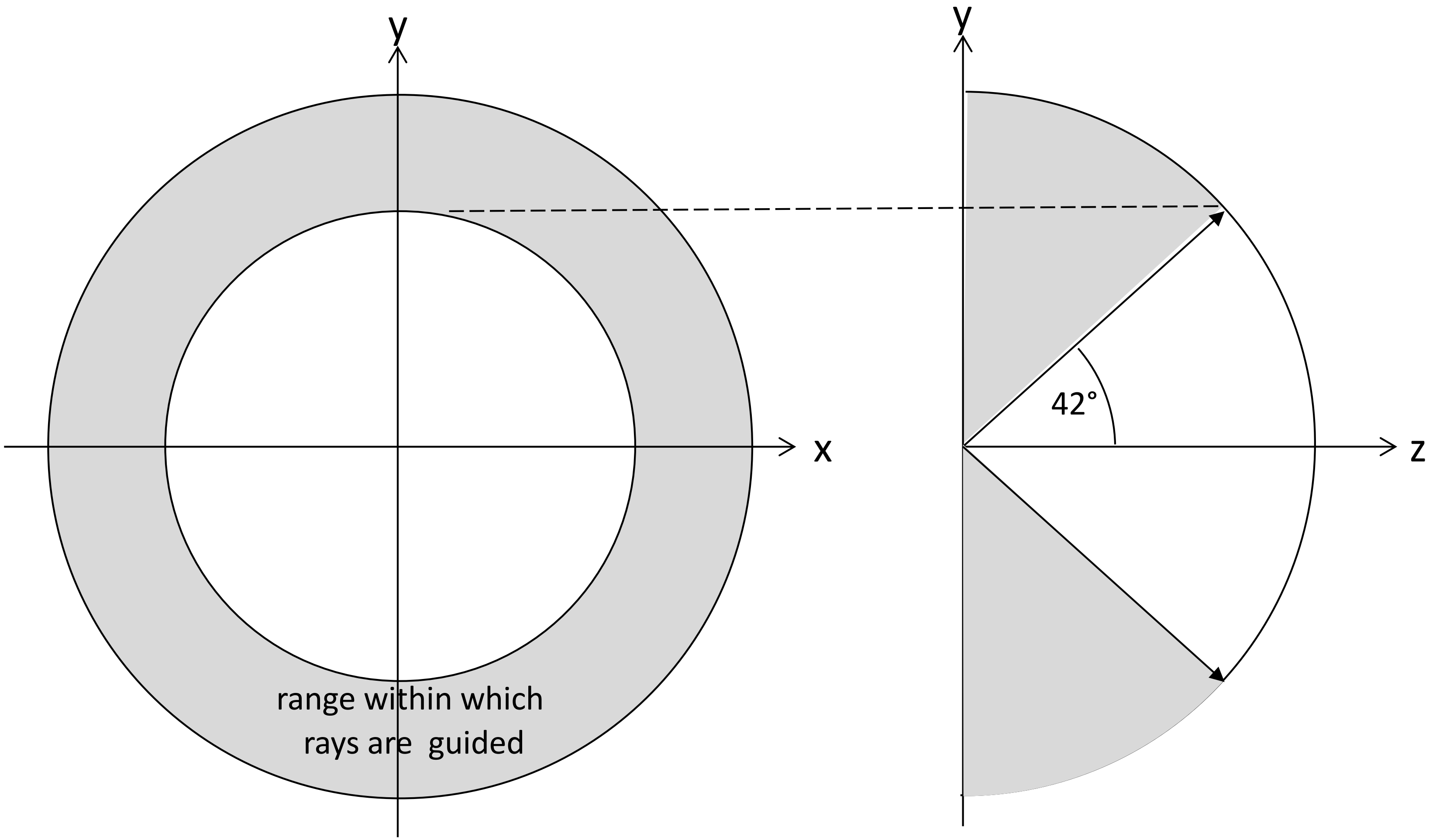
The effect of diffraction is to resolve k_1 in the plane of the grating (1), add k_g (2), then project the result onto a unit sphere (3).



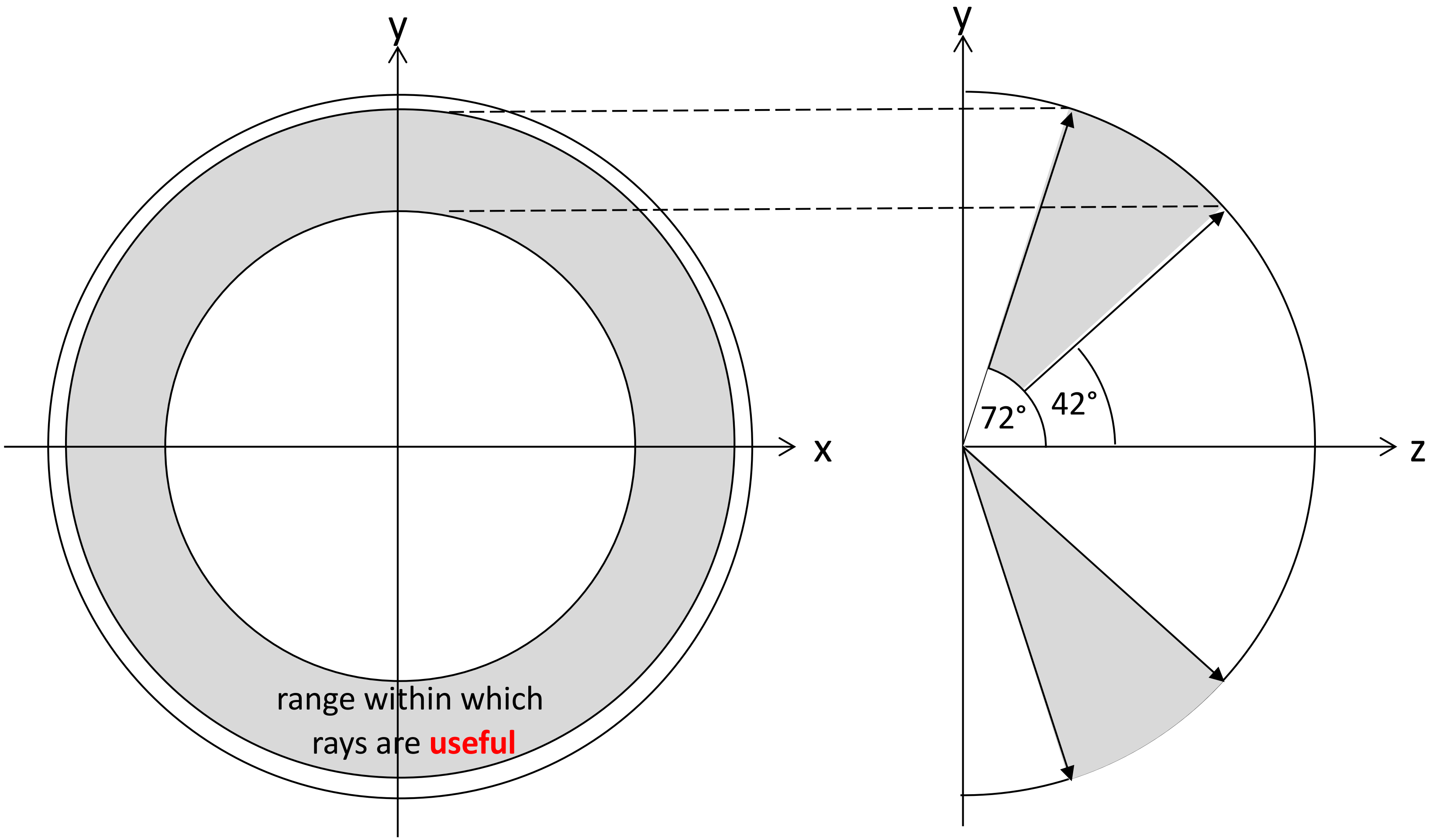
Scan about the y-axis and the diffracted ray rotates about the surface normal (z)



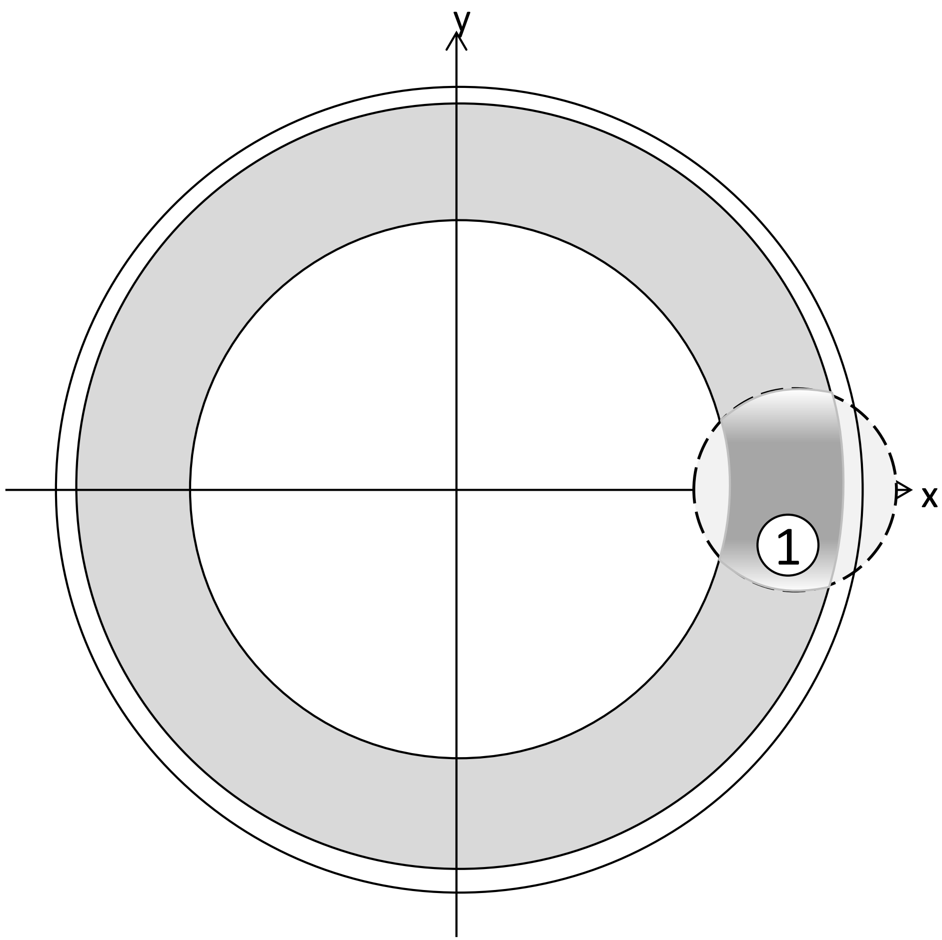
Only rays at greater than the critical angle (42°) will propagate within a guide

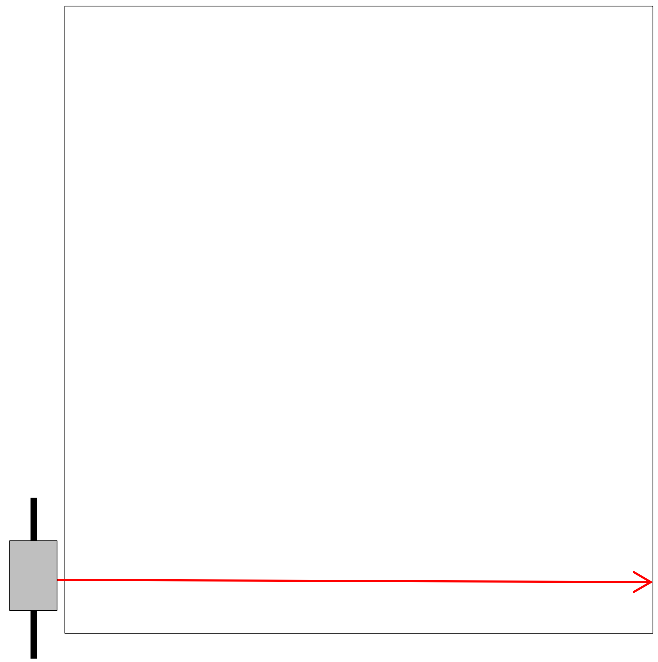


Rays at ~90° rarely hit the grating. Let us choose 72° as the other limit.

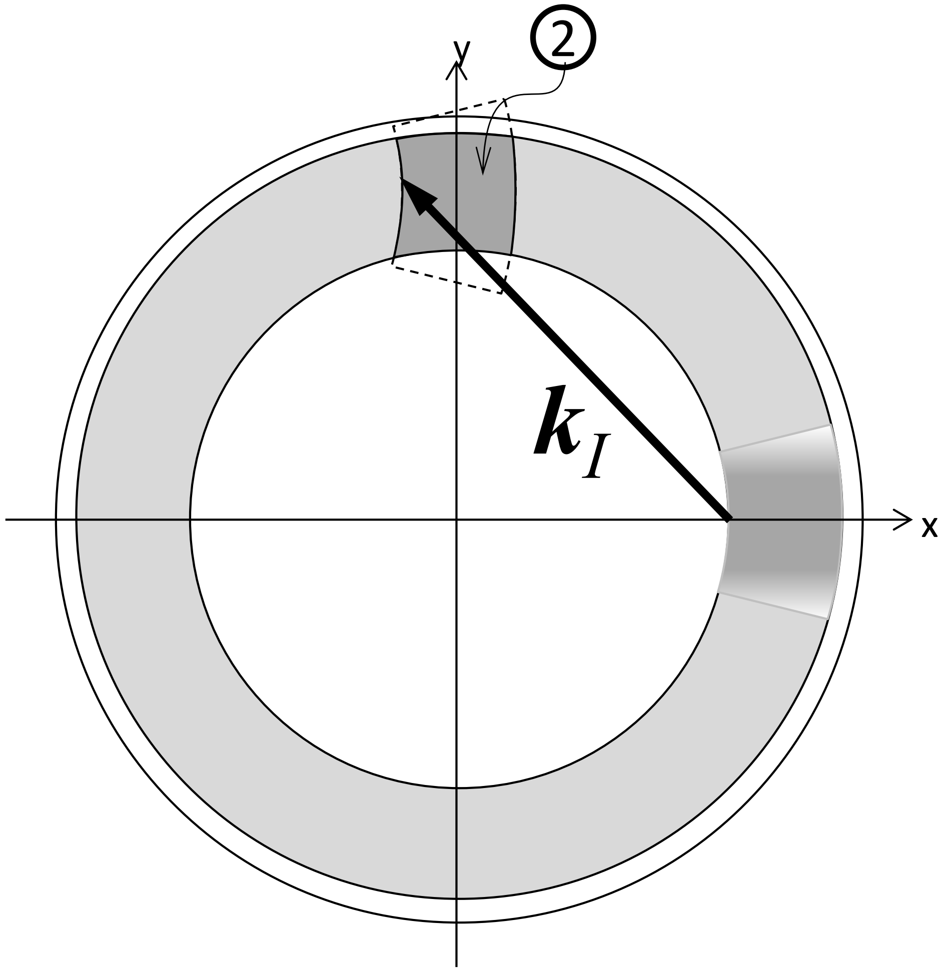


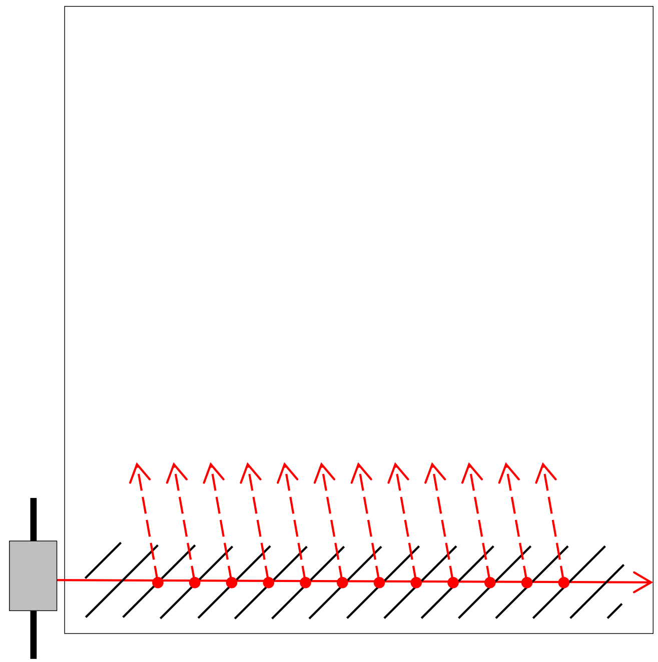
(1) Point a projector into a guide and only some rays will be guided



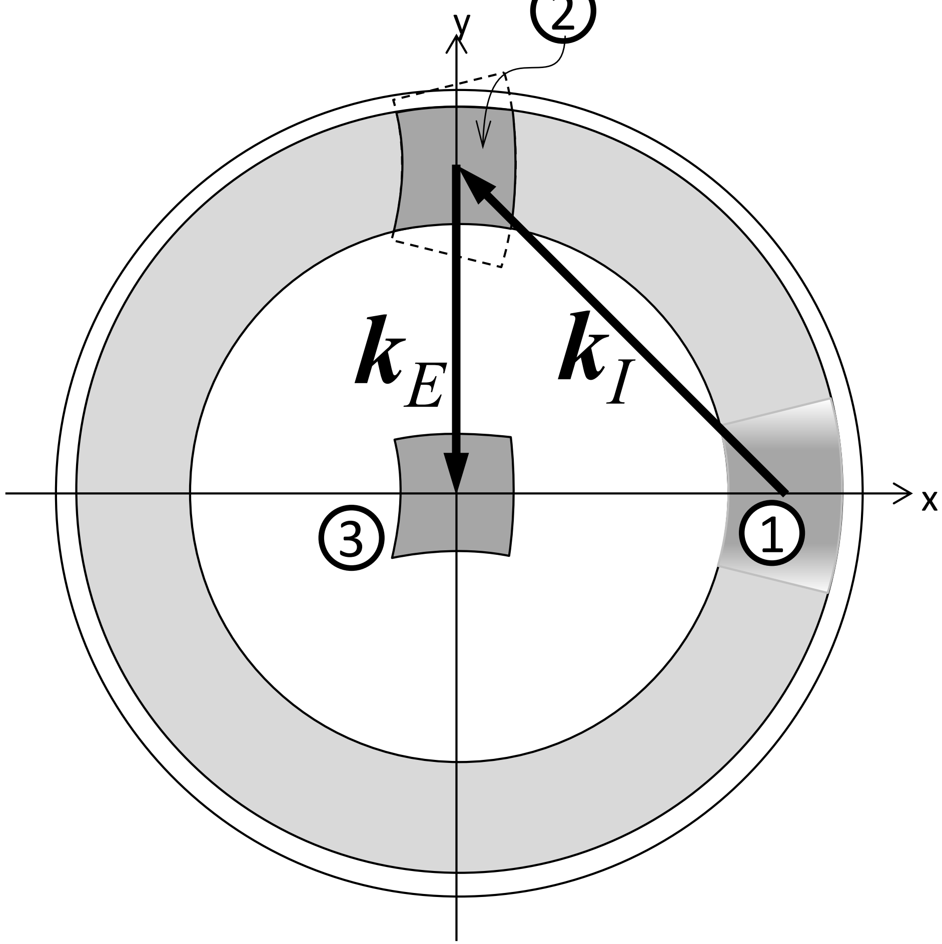


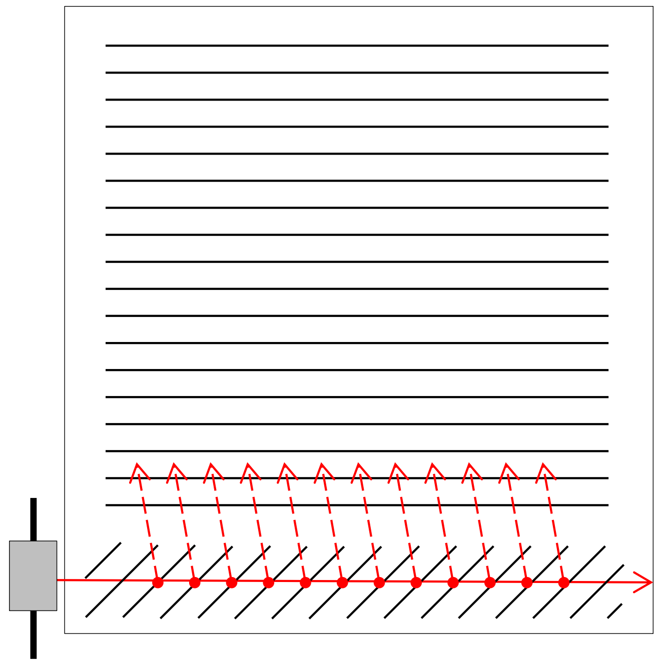
(2) Add k_I, intermediate grating vector & only some rays are guided to exit grating



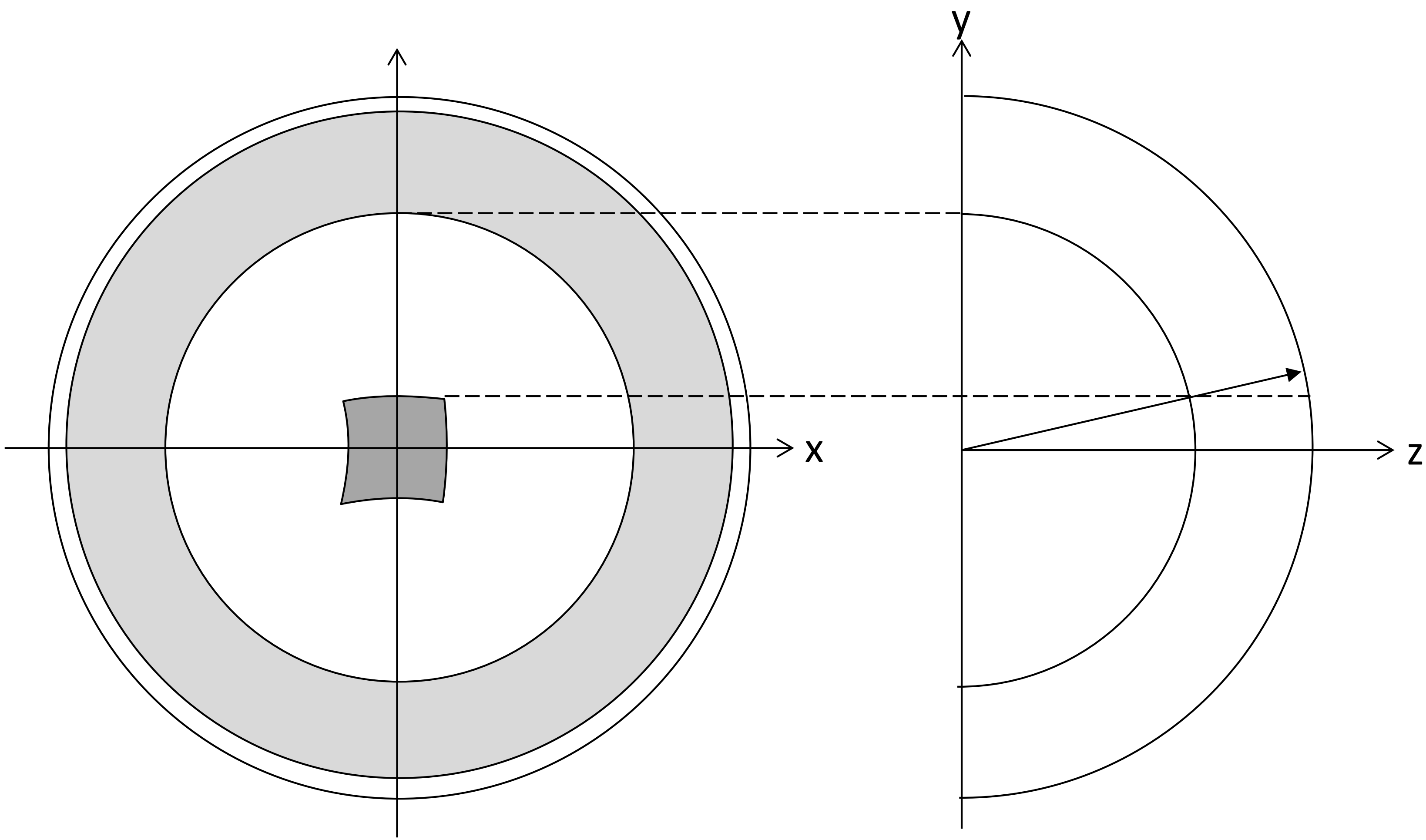


(3) Add $\boldsymbol{k}_E$, exit grating vector and rays emerge to viewer

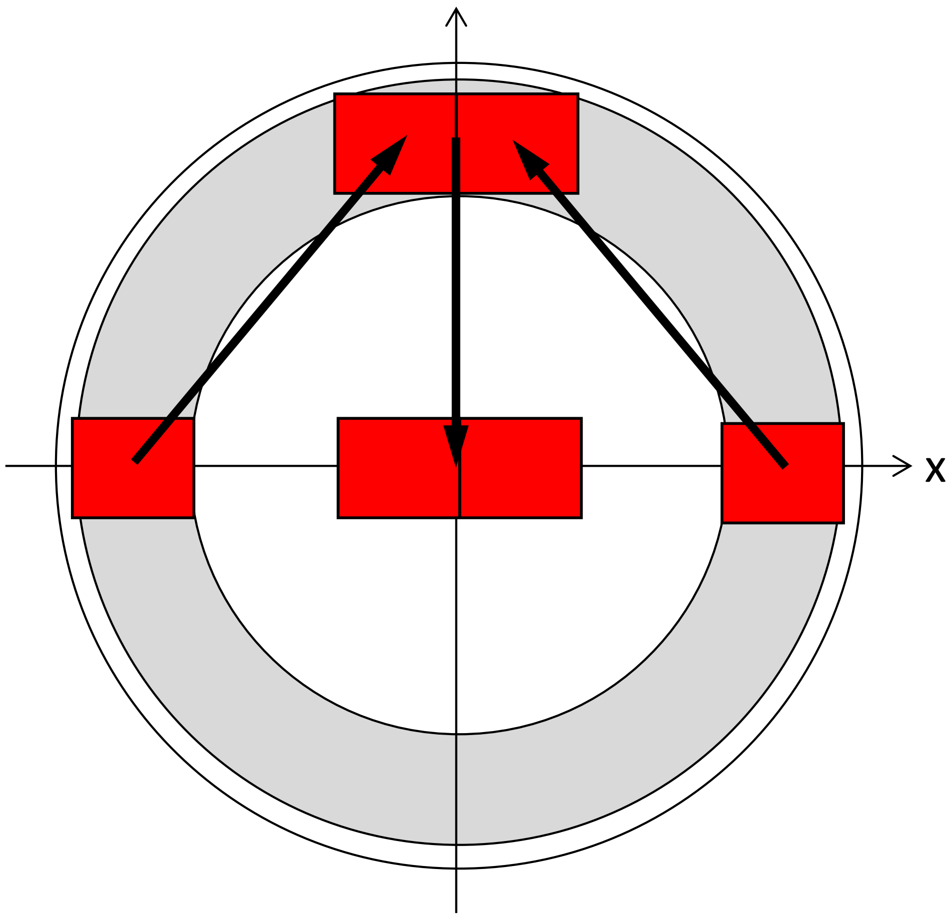


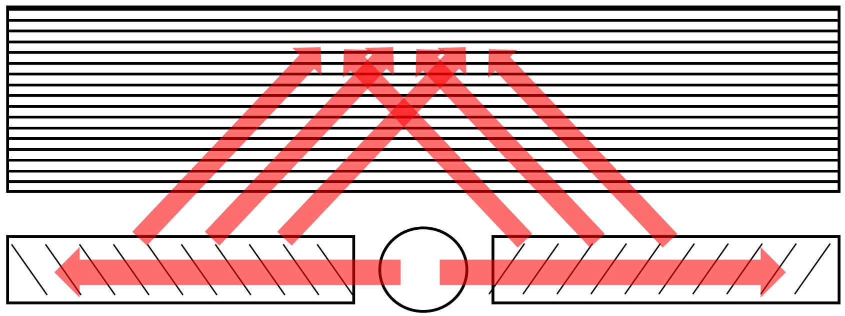


The field of view of the virtual image is limited by the critical angle.



Hololens v2 gets 43°x28° by splitting the input into 2 directions





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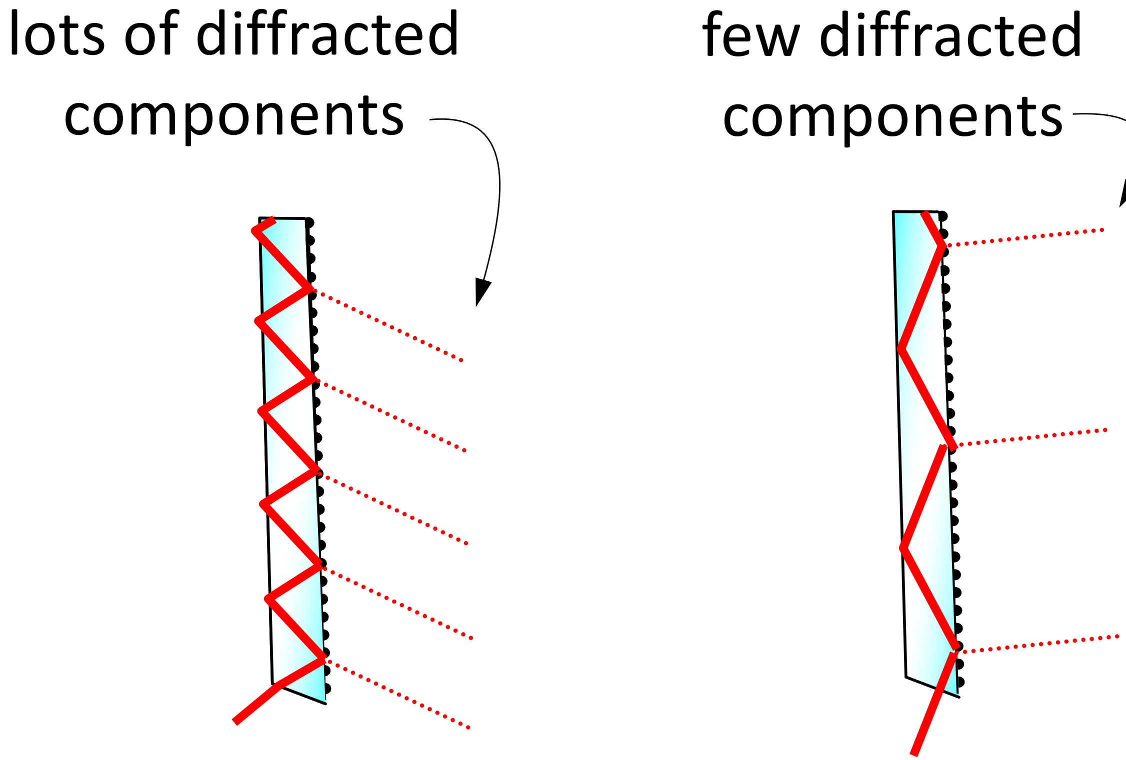
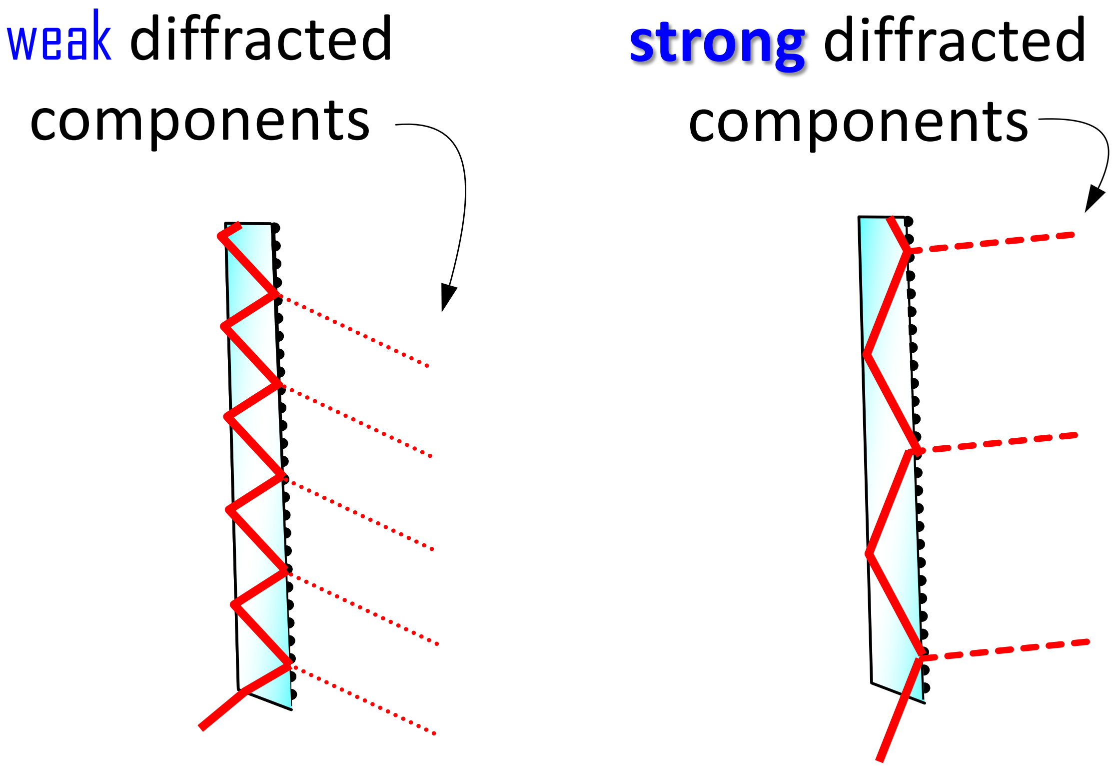
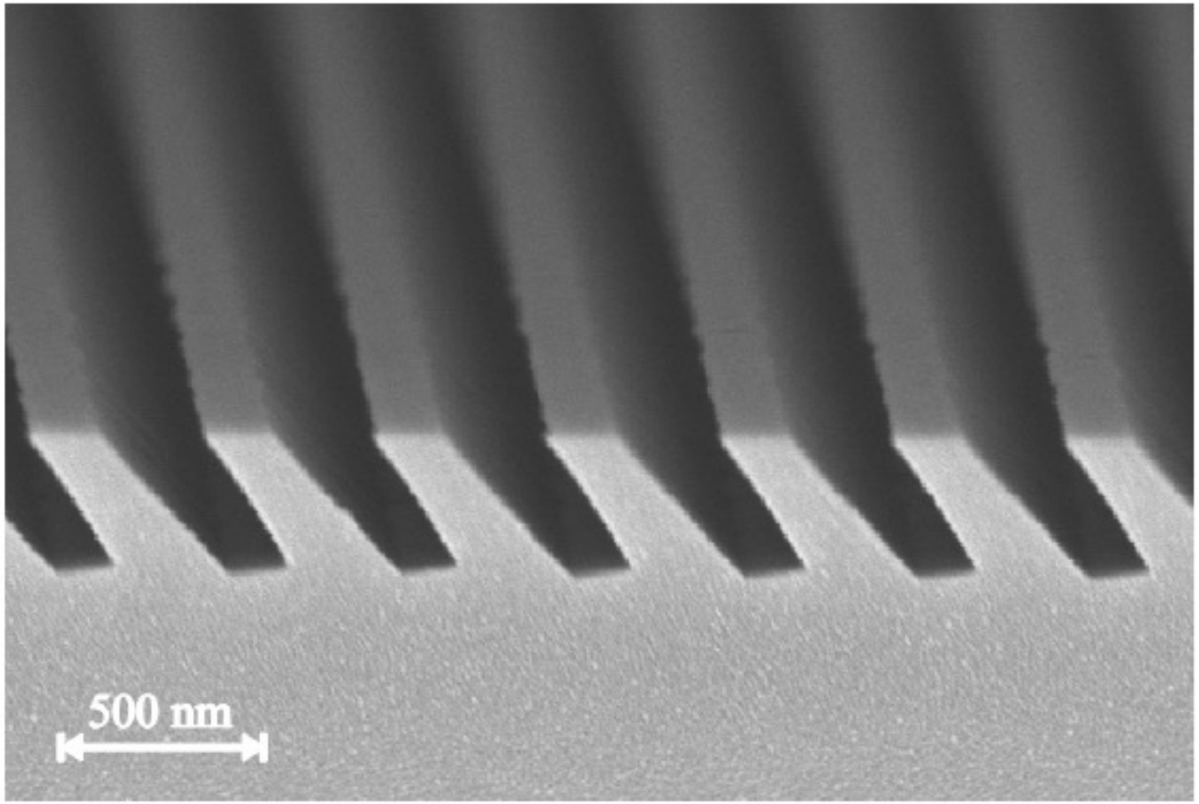
How do we get the same intensity for all ray angles?



Use a grating which diffracts more of rays incident at shallow angles

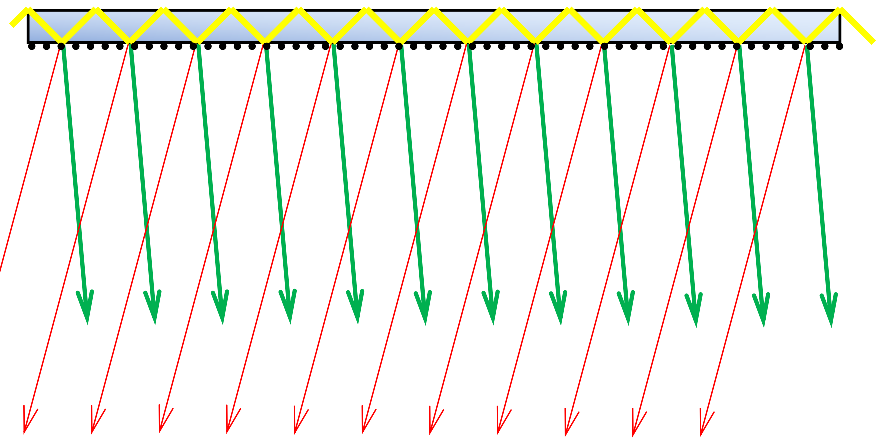


This grating ejects the same fraction per unit length, whatever the ray angle

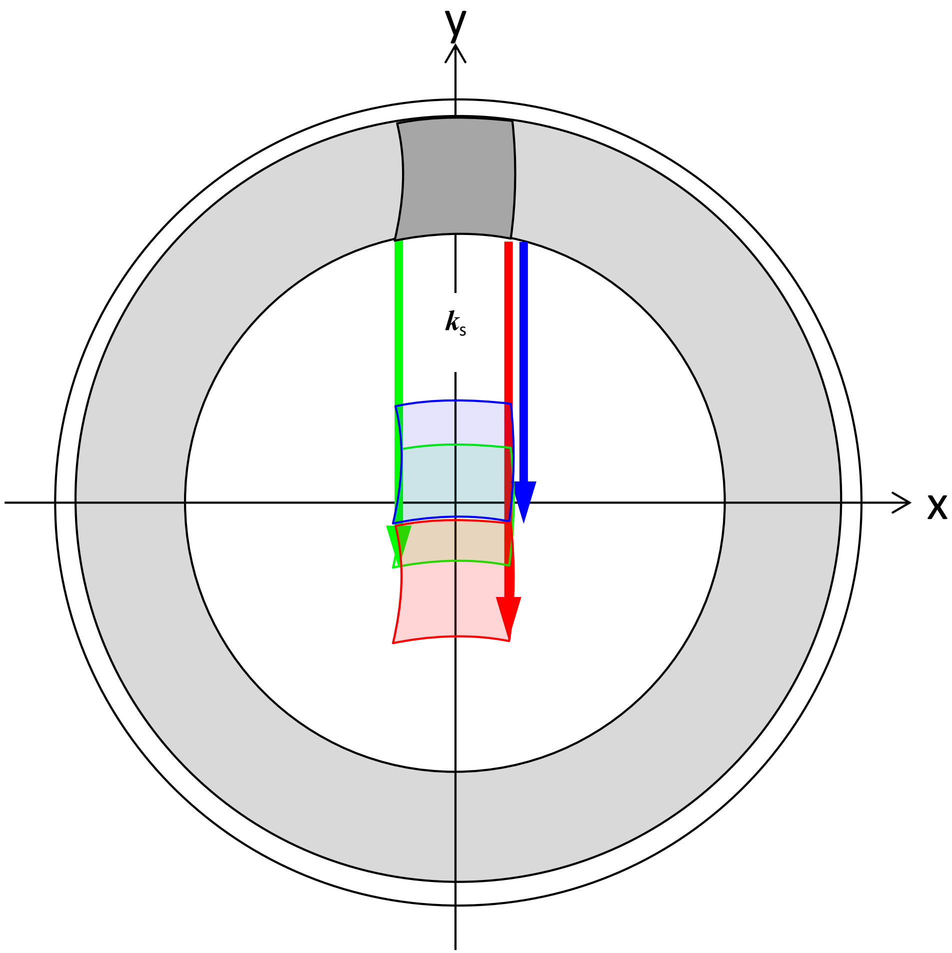


T. Levola http://www.opticsinfobase.org/oe/abstract.cfm?URI=oe-15-5-2067

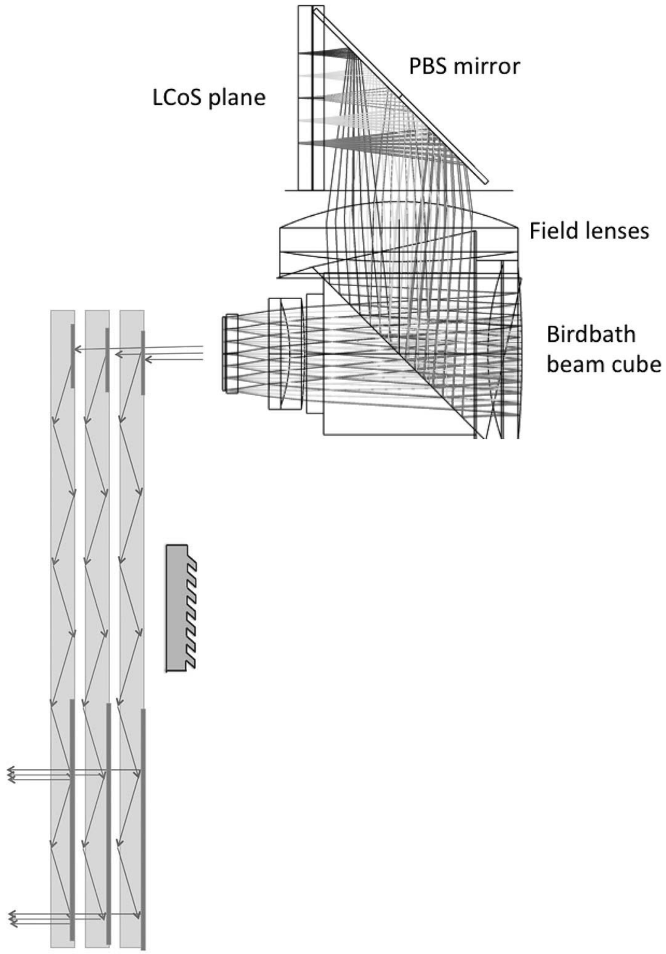
Red, green & blue have different diffraction angles. Can we predistort?

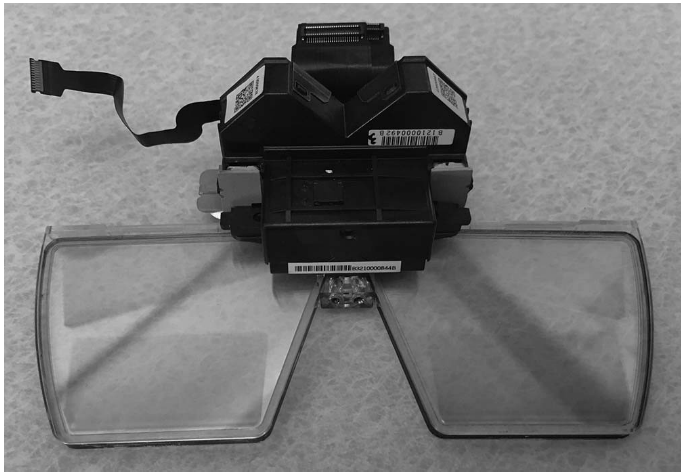


No, we cannot predistort unless the fields of view at least overlap!

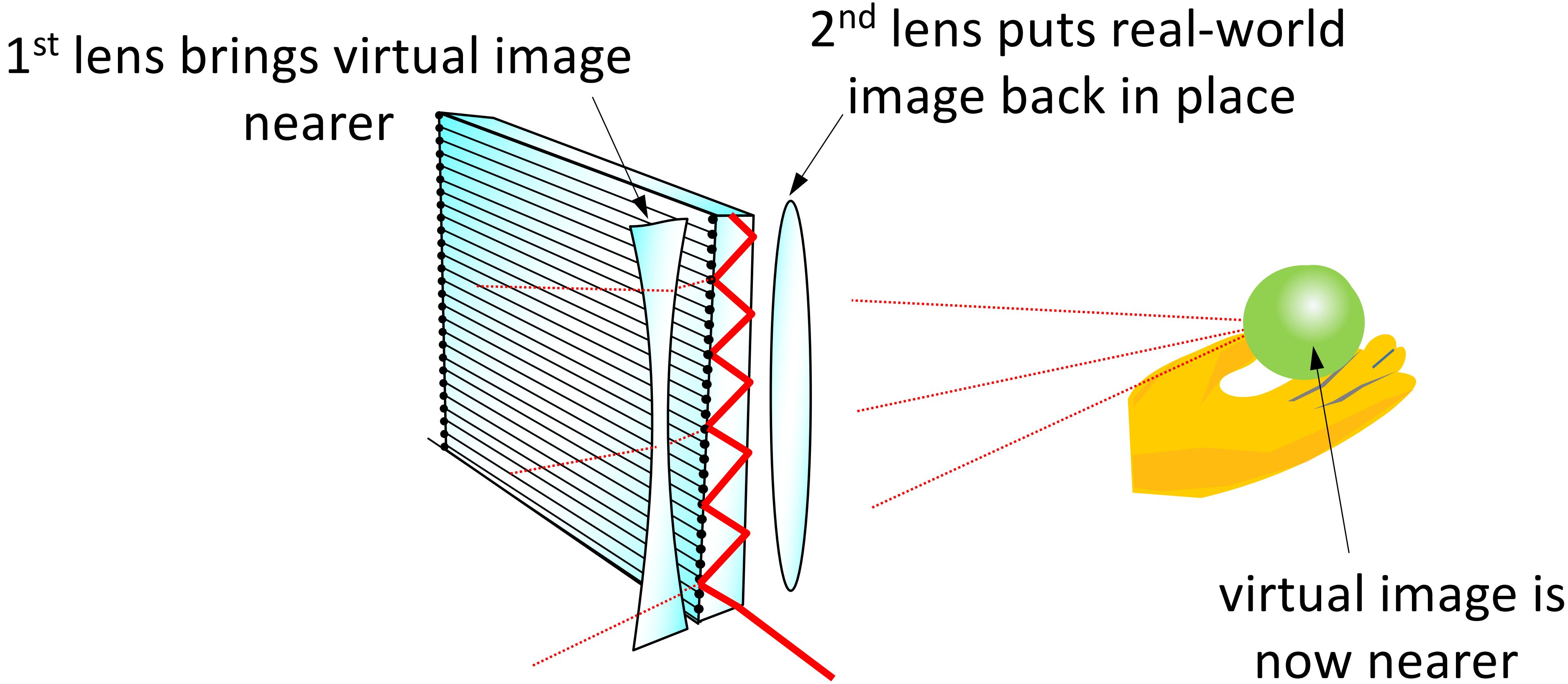


Hololens 1 used one guide each for red, green&blue.





Tiling means the image is focused at infinity but users want it at 2m (or better, variable)



Pupil expansion turns out to be bulky, lossy, heavy, with limited field of view....

Summary

- Point a projector into a guide embossed with a grating for a slim virtual display

- We calculate the field of view by adding grating vectors

- The image from a bare guide is monochrome and fixed at infinity

- Uniformity requires finite element analysis of grating teeth