15. MENISCUS OPTICS

Nikola Illášová

TASK

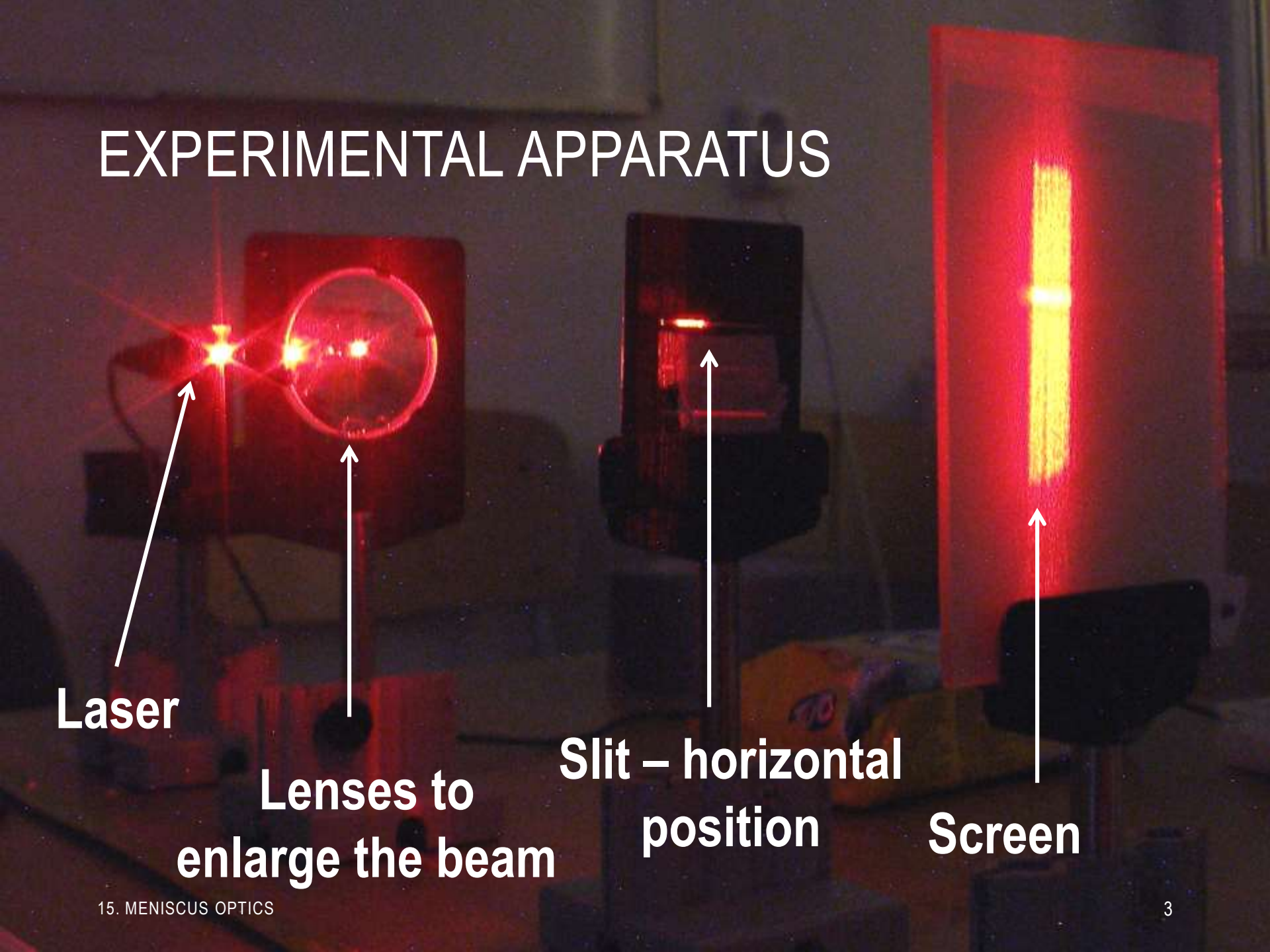
Cut a **narrow slit** in a thin sheet of opaque material.

Immerse the sheet in a **liquid** such as water.

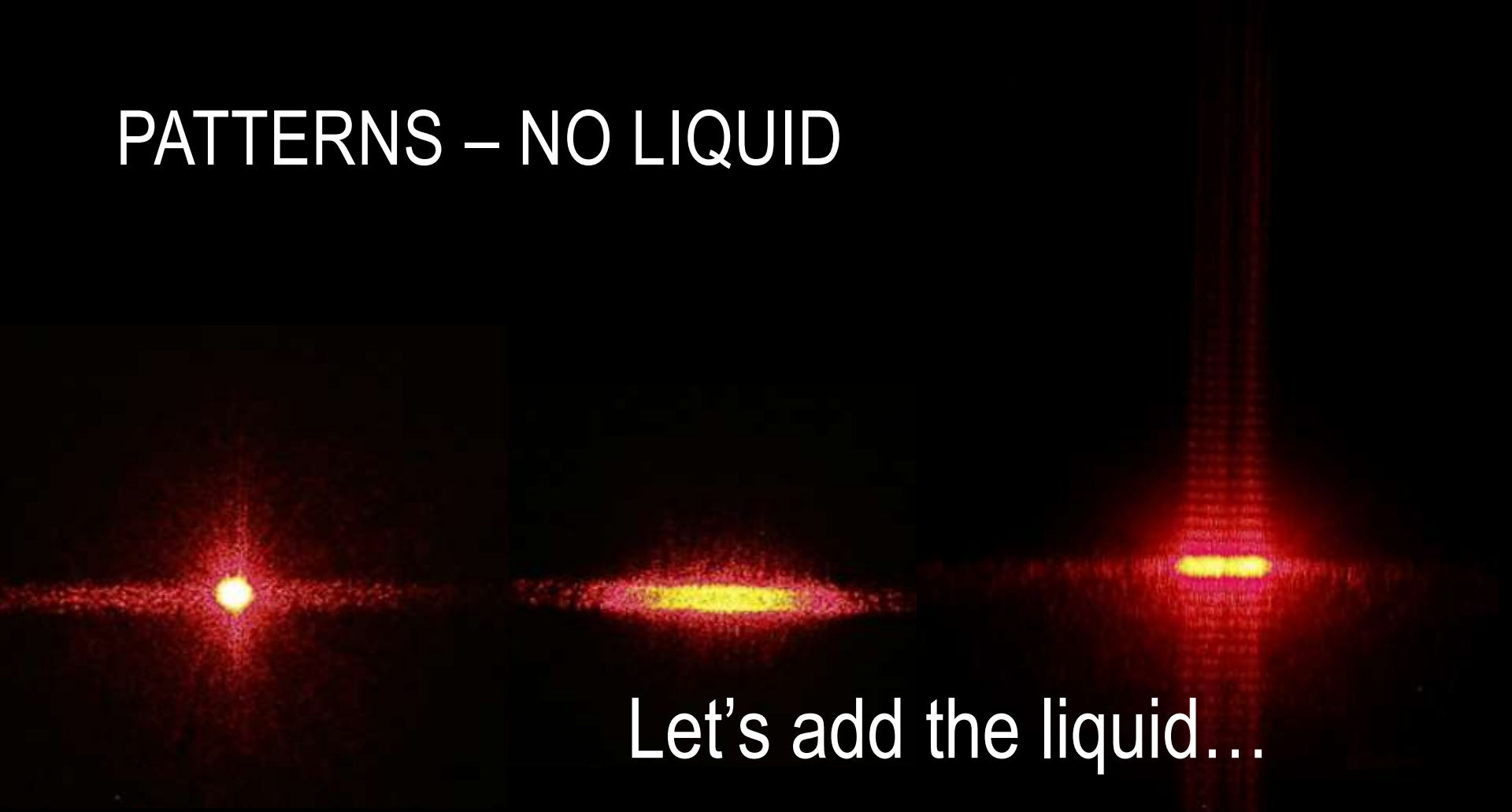
After removing the sheet from the liquid, you will see a liquid film in the slit.

Illuminate the slit and study the resulting pattern.

EXPERIMENTAL APPARATUS



PATTERNS – NO LIQUID



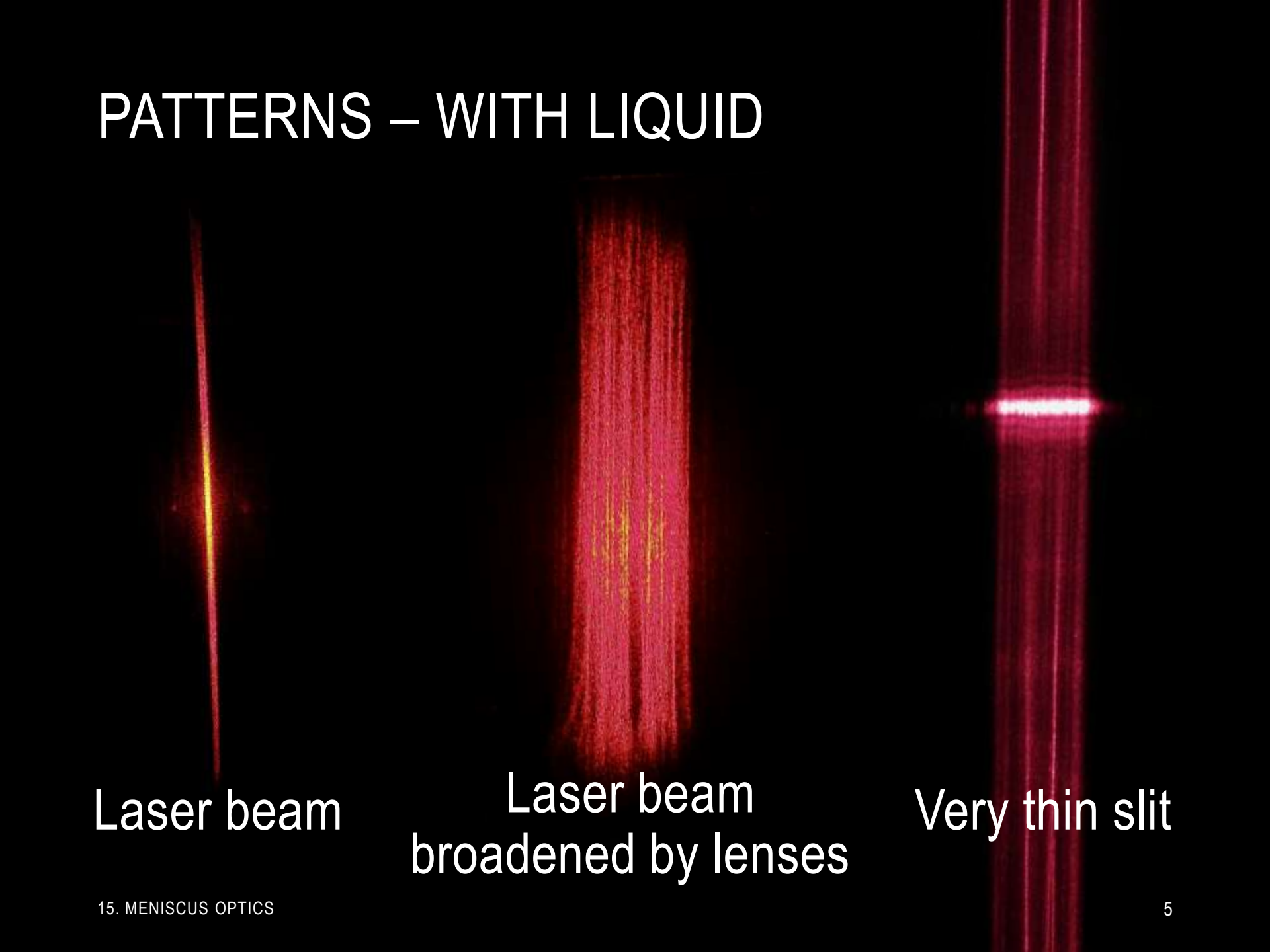
Let’s add the liquid…

Laser beam

Laser beam broadened by lenses

Very thin slit

PATTERNS – WITH LIQUID

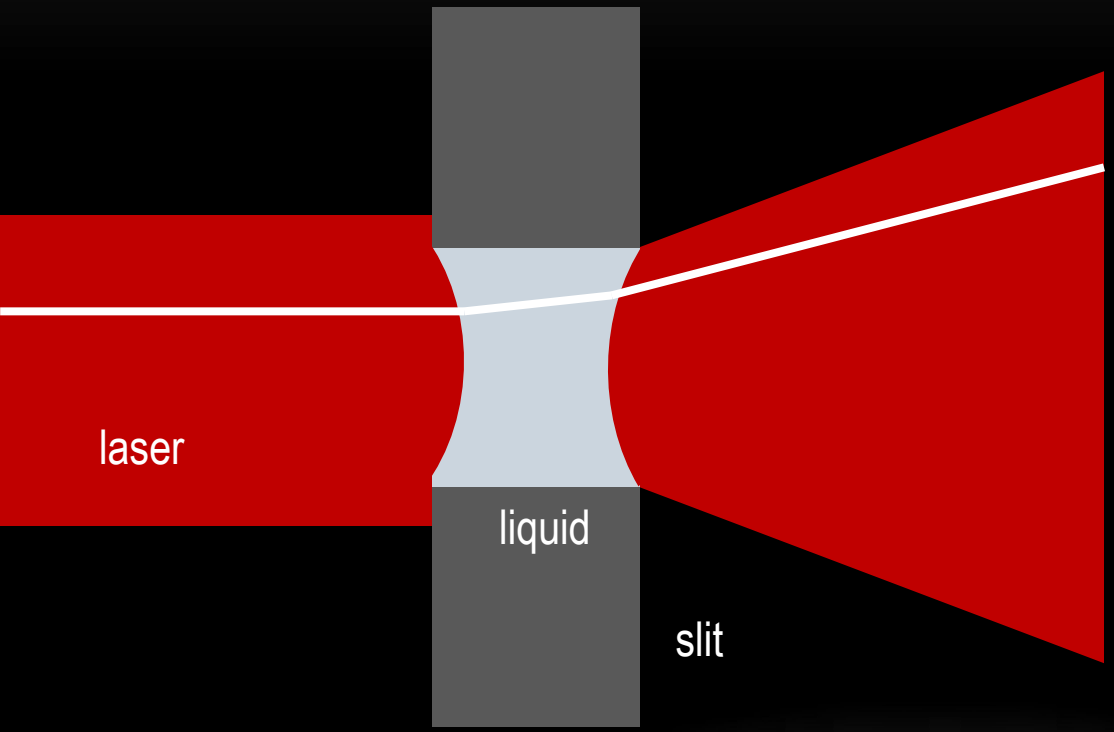


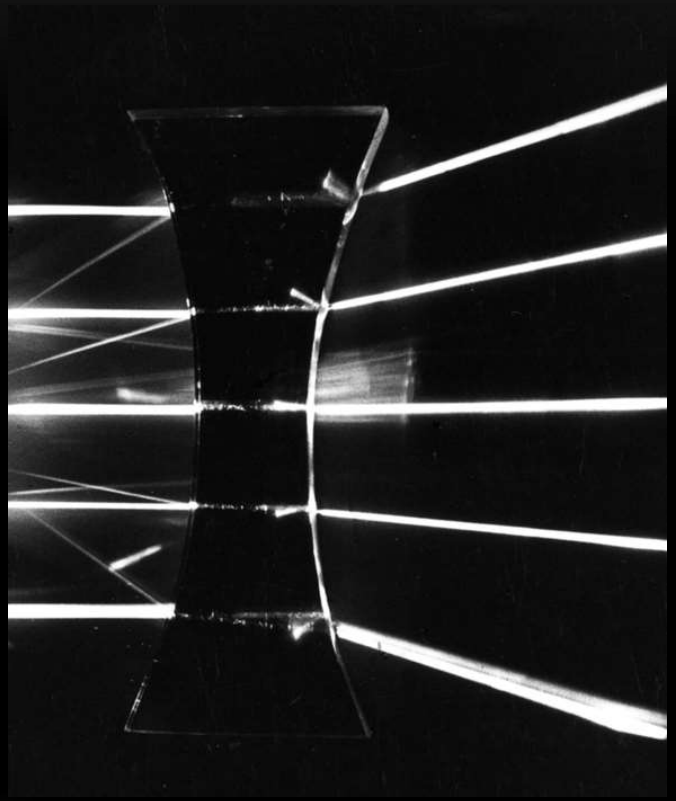
Laser beam

Laser beam
broadened by lenses

Very thin slit

LIQUID – DIVERGING LENS





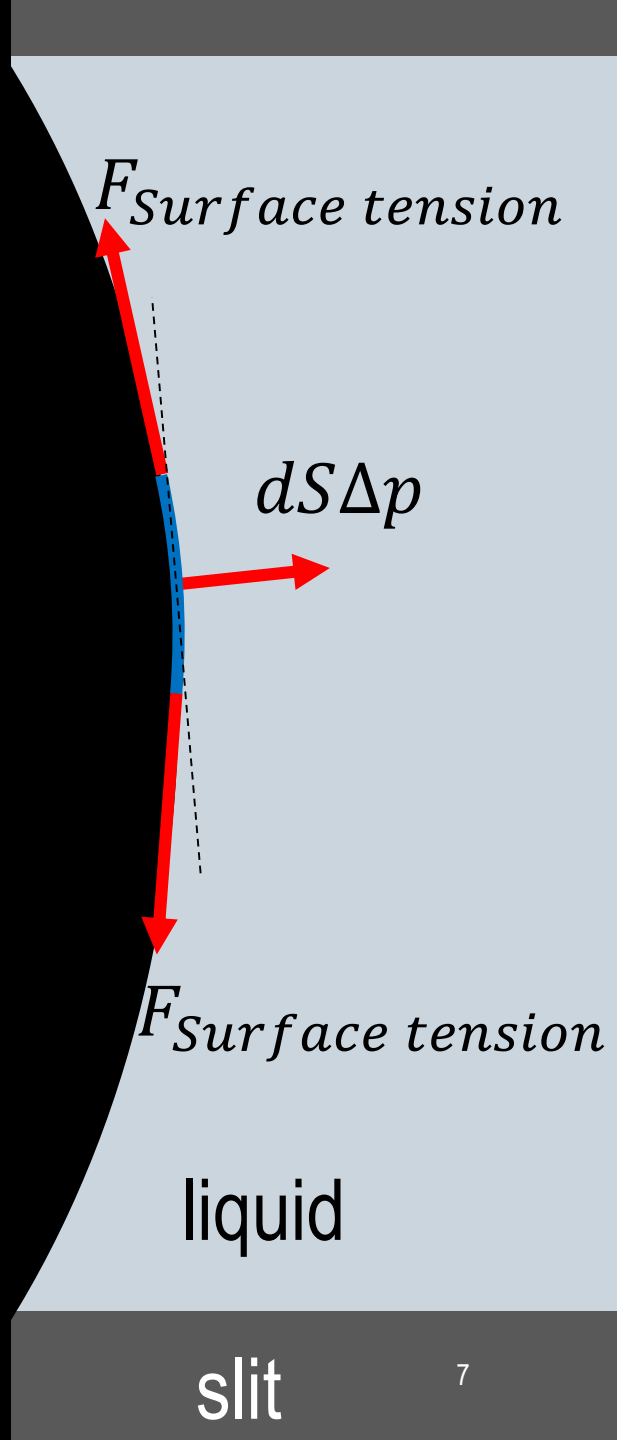
This could explain the patterns…**is it the real shape?**

SHAPE OF THE LIQUID FILM

Determined by:

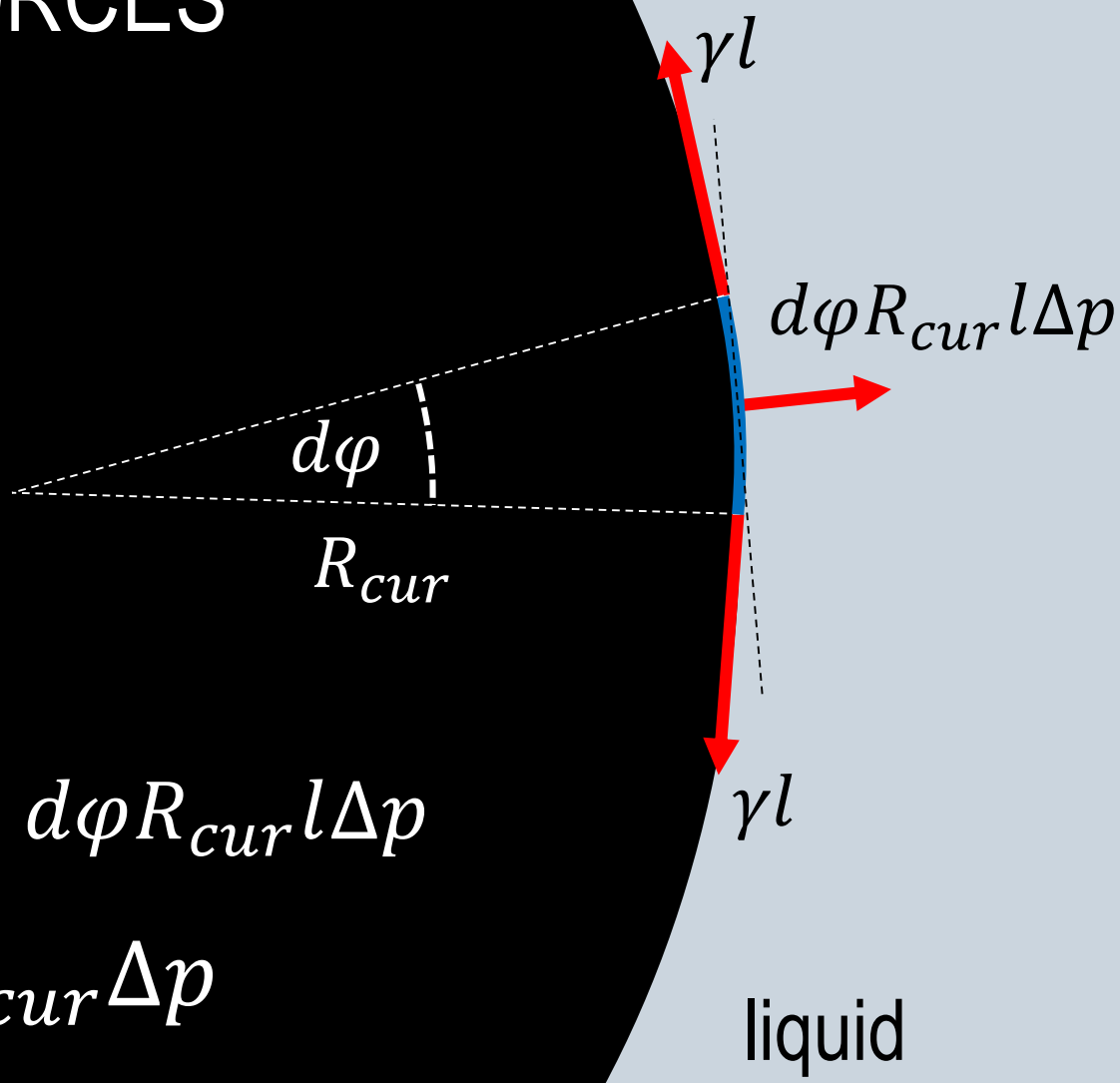
- Pressure difference
- Surface tension

In equilibrium



BALANCE OF FORCES

- Pressure difference
- Surface tension



- Forces equilibrium:

$$2\gamma l \sin\frac{d\varphi}{2} = d\varphi R_{cur} l \Delta p$$

$$\gamma = R_{cur}\Delta p$$

HEIGHT – CURVATURE RELATION

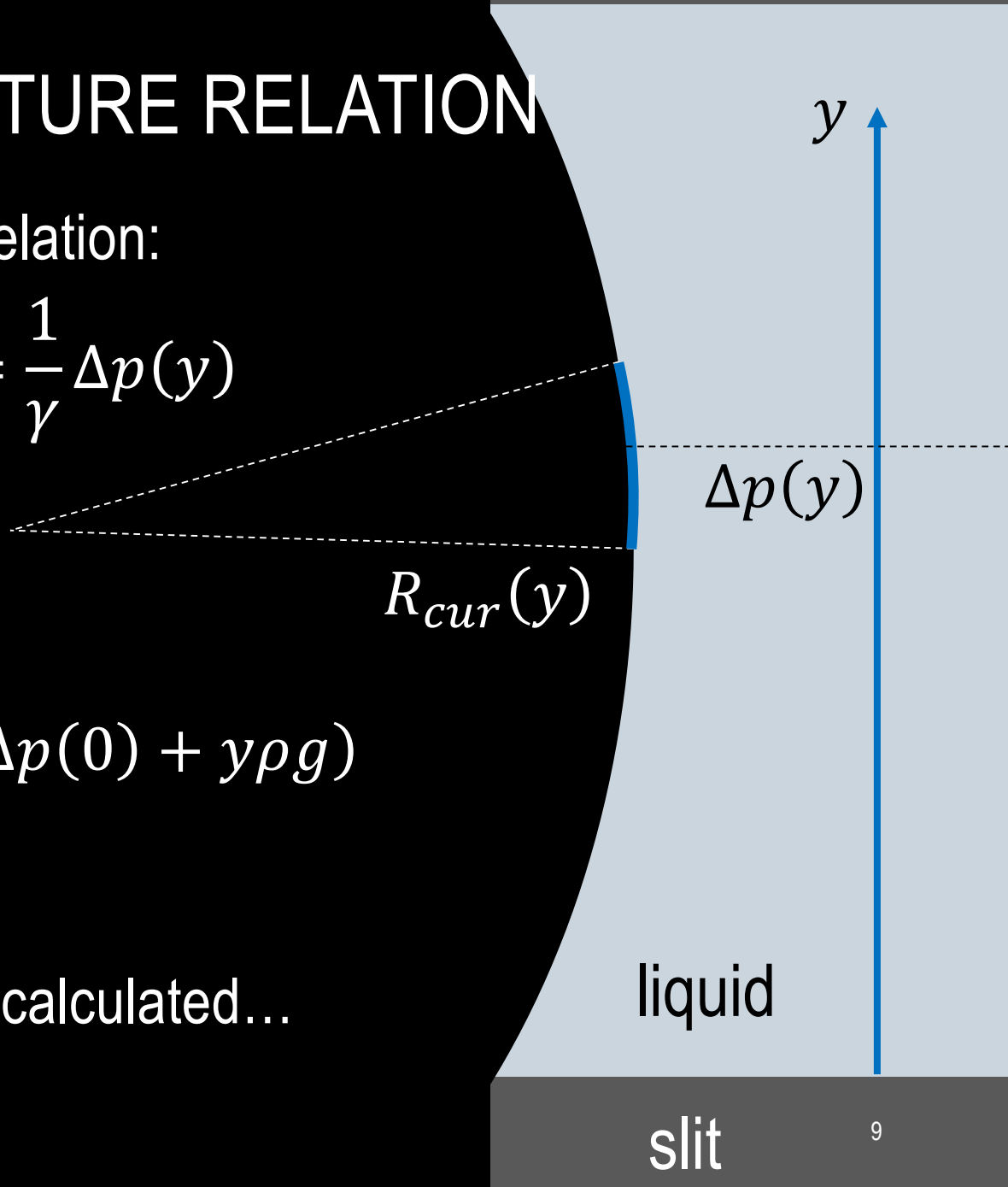
Curvature – pressure relation:

$$\frac{1}{R_{cur}(y)} = \frac{1}{\gamma}\Delta p(y)$$

Hydrostatic pressure:

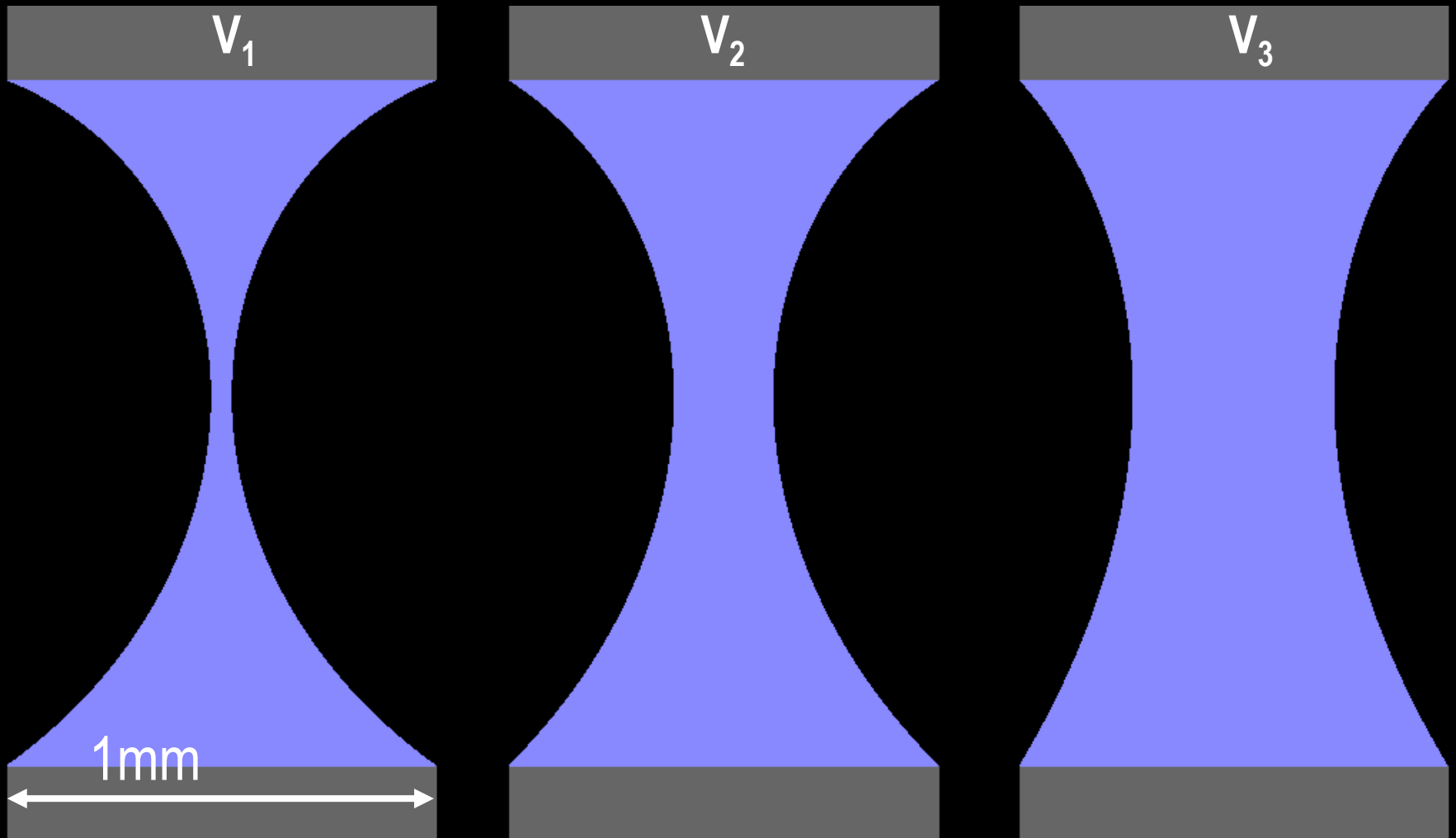
$$\frac{1}{R_{cur}(y)} = \frac{1}{\gamma}(\Delta p(0) + y\rho g)$$

Now the shape can be calculated…

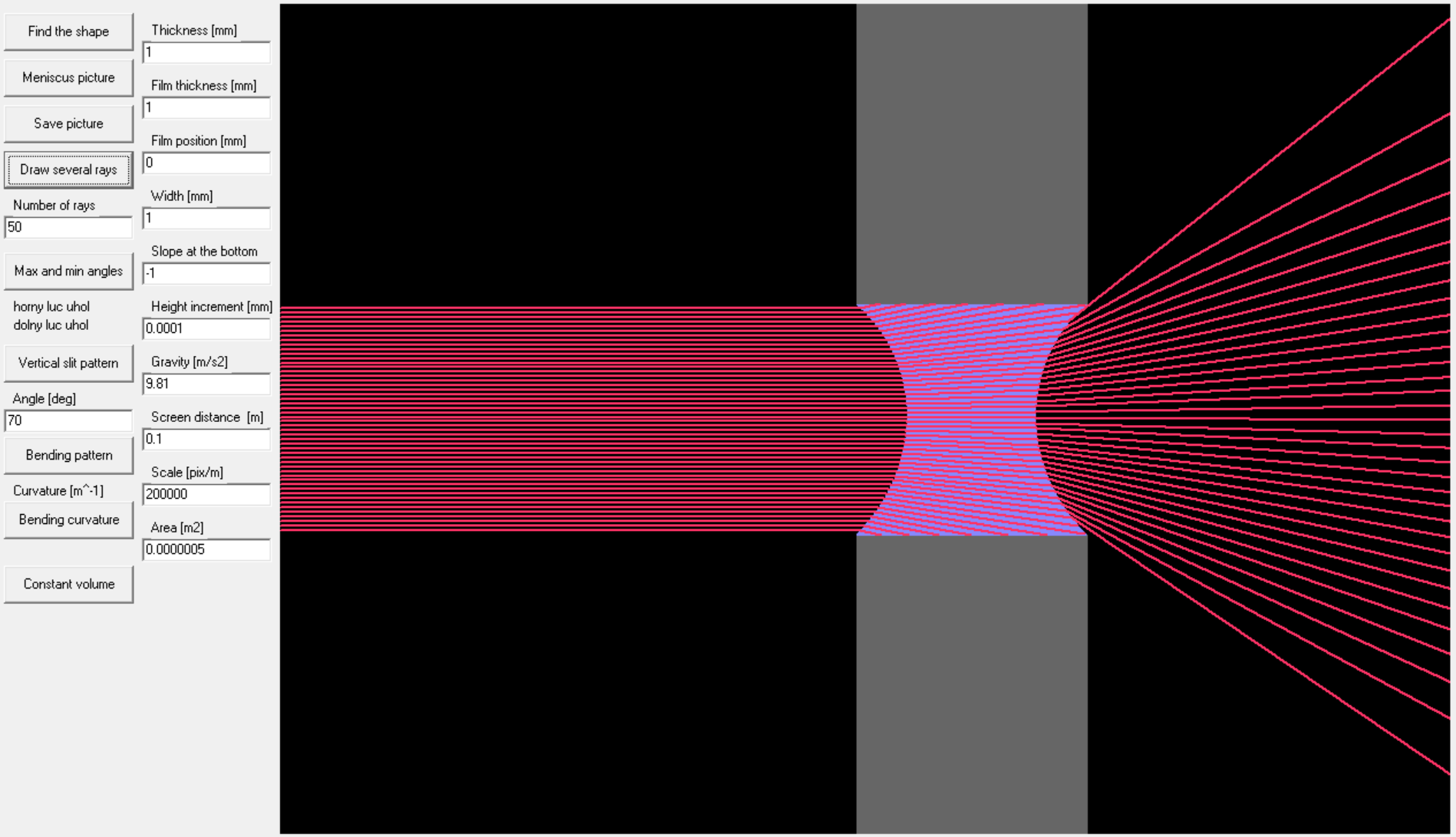


SHAPES DEPEND ON VOLUME OF LIQUID

FREE PARAMETER – unknown volume of liquid drains due to gravity

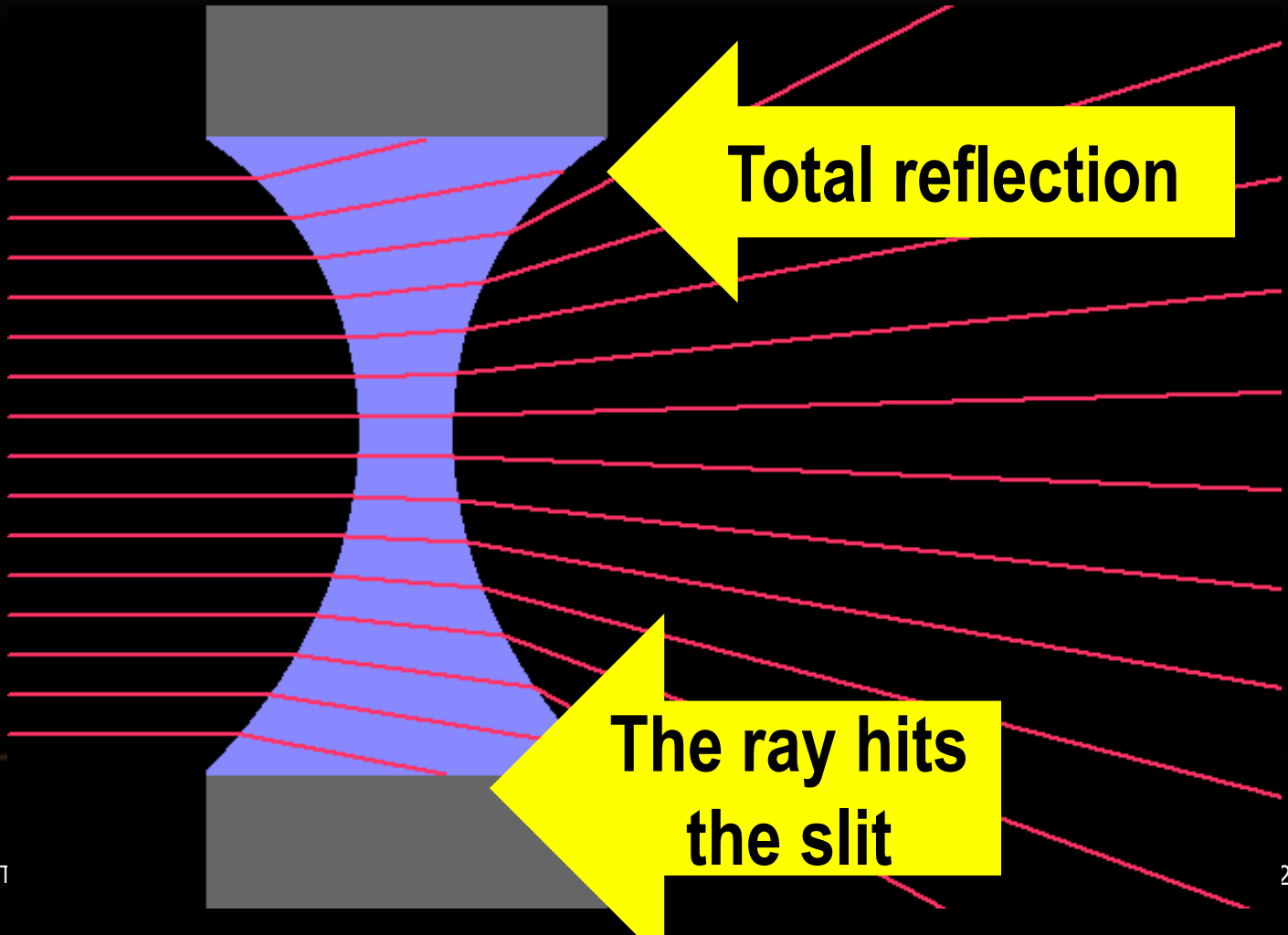


SIMULATION


Find the shape
Meniscus picture
Save picture
Draw several rays
Number of rays
50
Max and min angles
horny luc uhol
dolny luc uhol
Vertical slit pattern
Angle [deg]
70
Bending pattern
Curvature [m^-1]
Bending curvature
Constant volume
Thickness [mm]
1
Film thickness [mm]
1
Film position [mm]
0
Width [mm]
1
Slope at the bottom
-1
Height increment [mm]
0.0001
Gravity [m/s2]
9.81
Screen distance [m]
0.1
Scale [pix/m]
200000
Area [m2]
0.0000005

REFRACTION OF LIGHT

- We know the shape, Snell's law of refraction



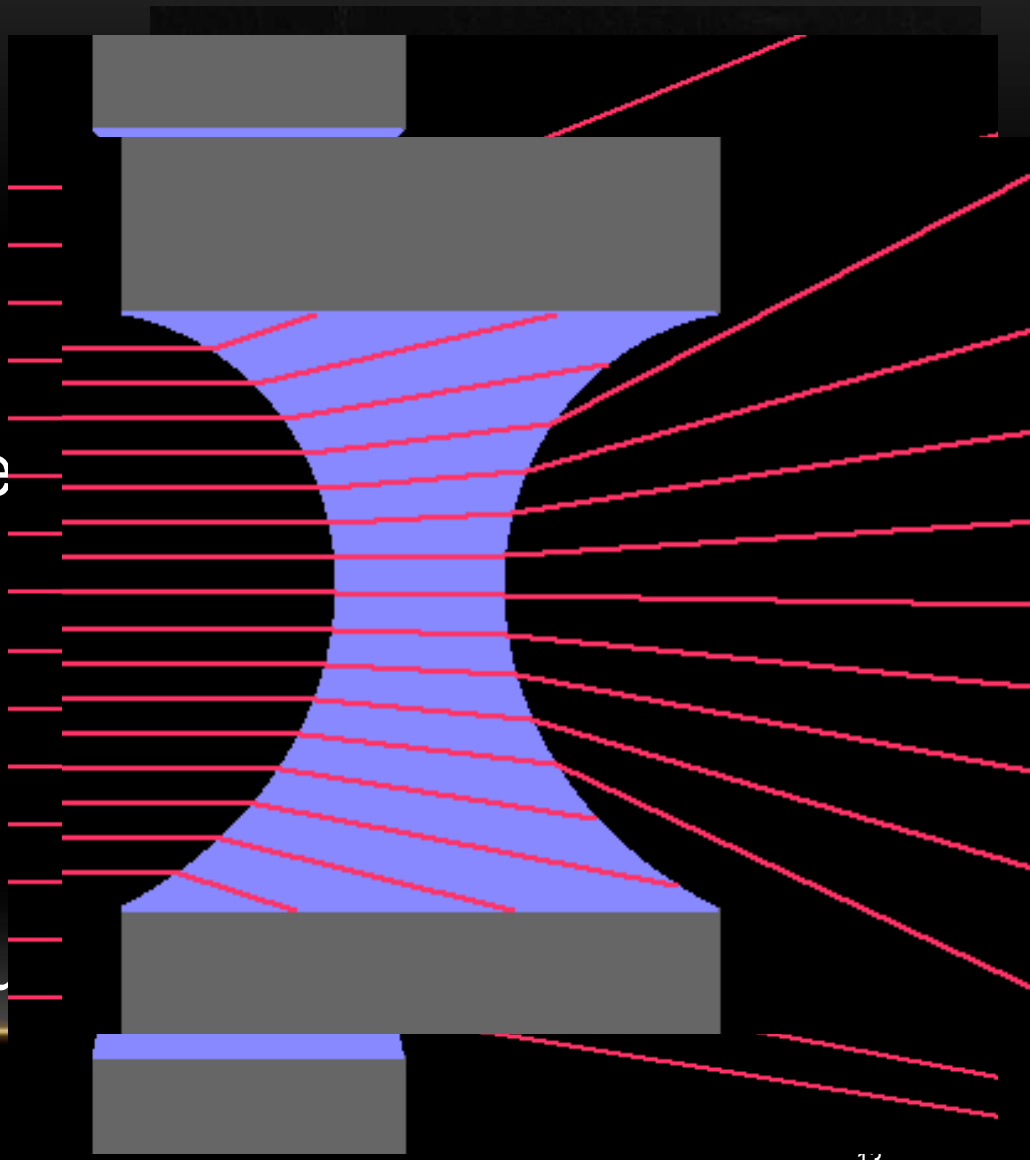
MENISCUS VS. LENS

Lenses are…

- Thin
- Horizontally symmetrical
- Radius of curvature >> size

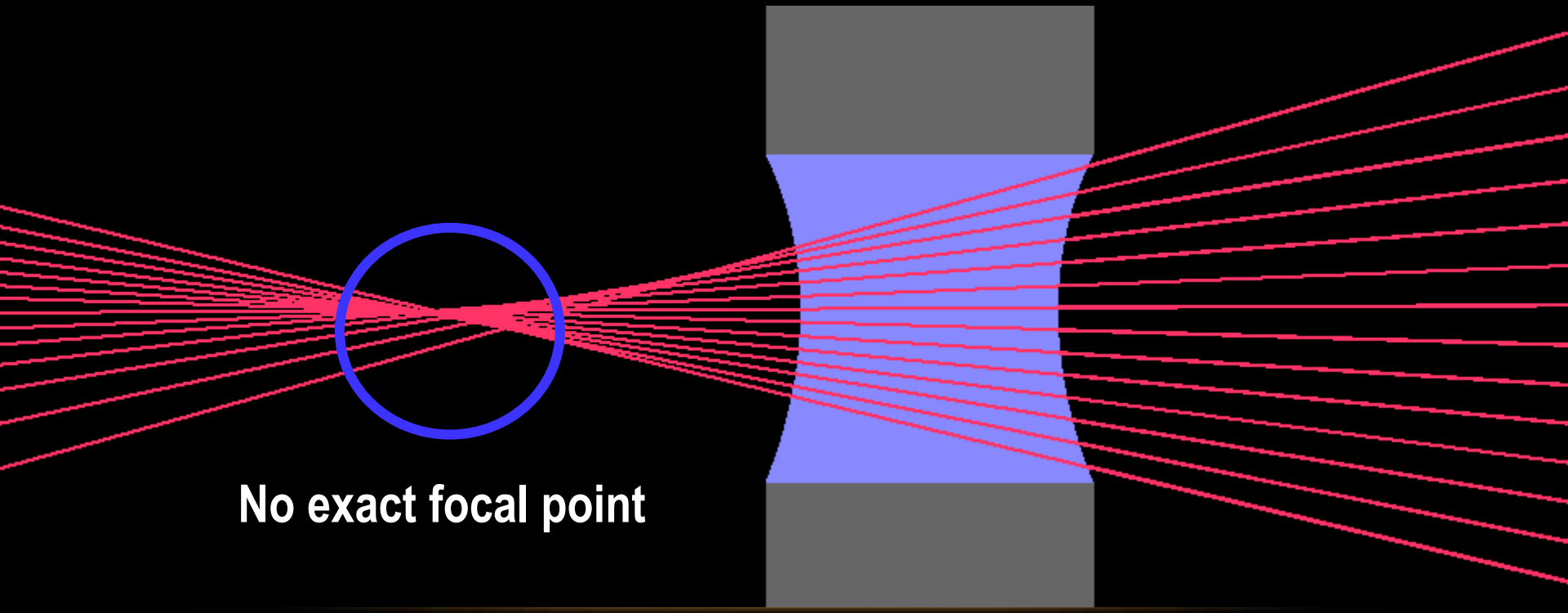
Meniscus may be…

- Thick
- Asymmetrical
- With small radius of curvatu



MENISCUS VS. LENS

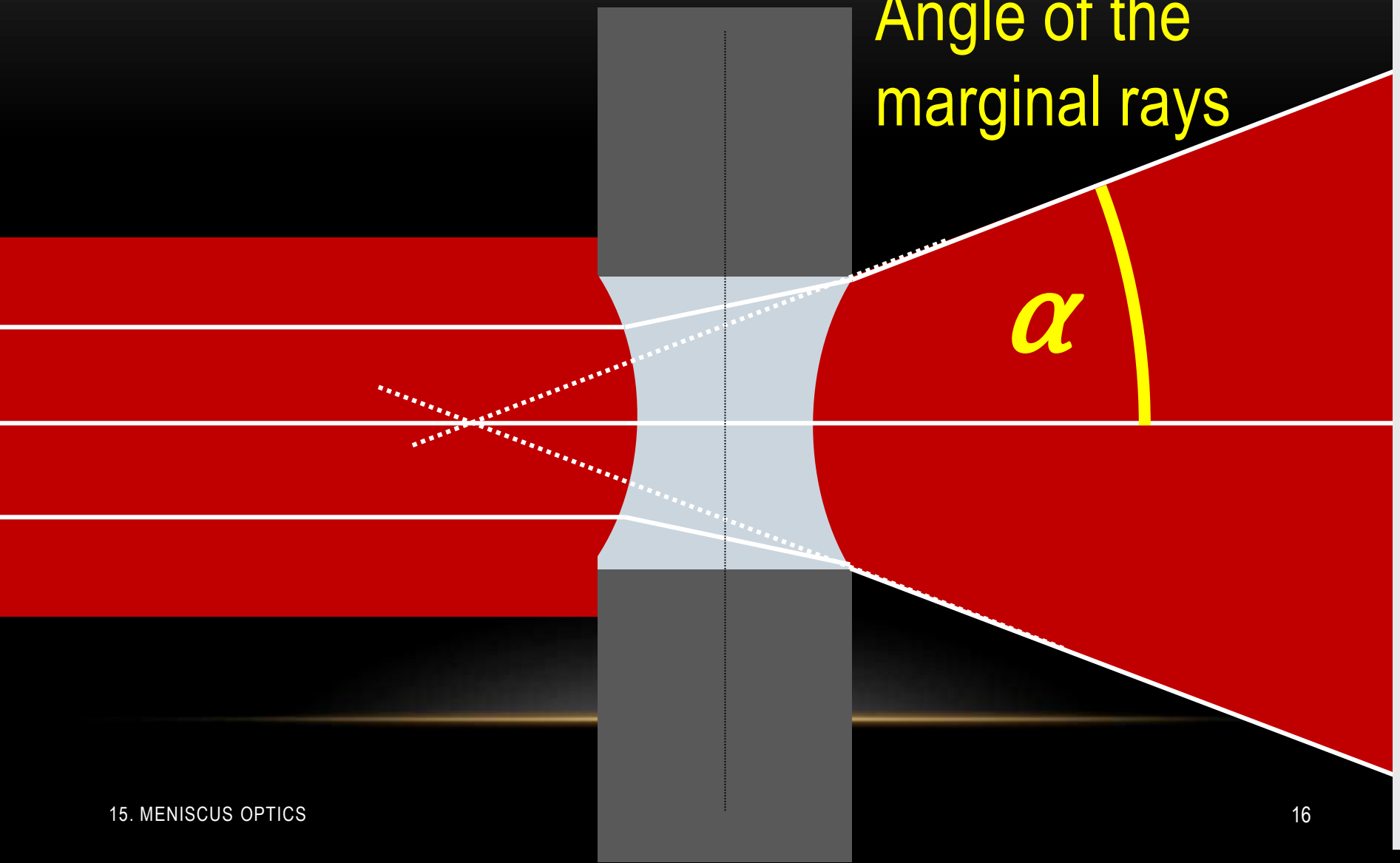
- Can still sometimes behave like a lens
  - With some aberration, though



Horizontal slit

EXPERIMENTS

RELEVANT QUANTITY TO MEASURE:

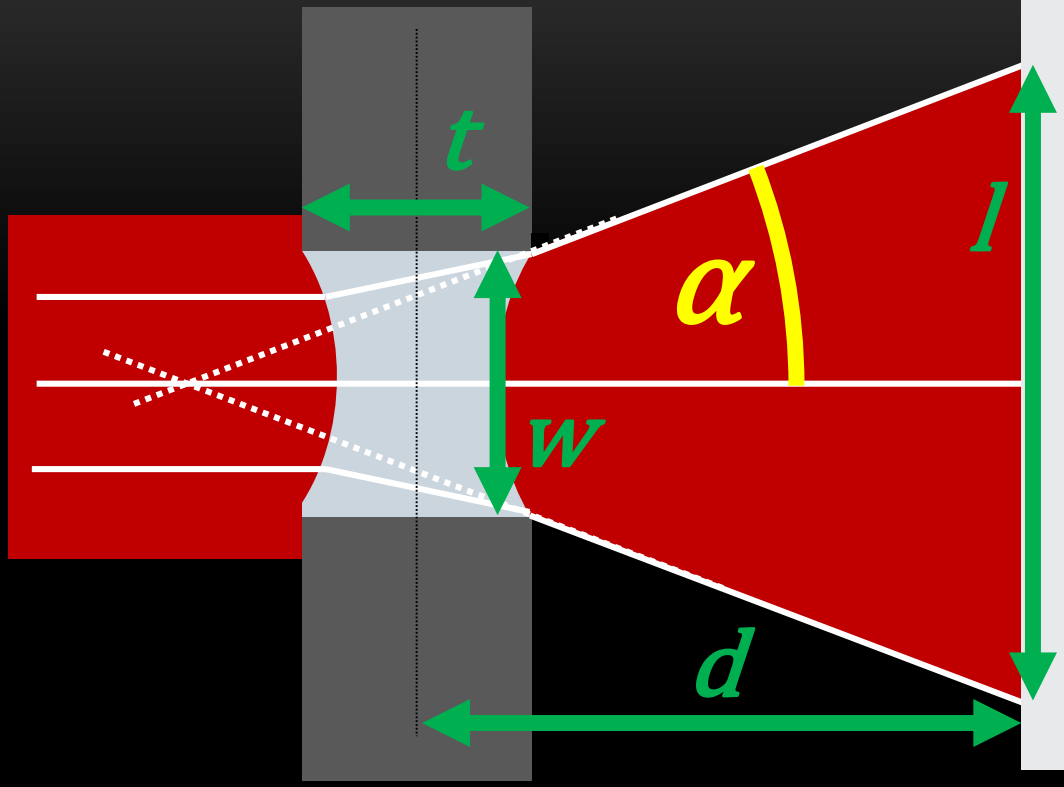


MEASUREMENTS

Set parameters ***t, w, d***

Measuring ***l***

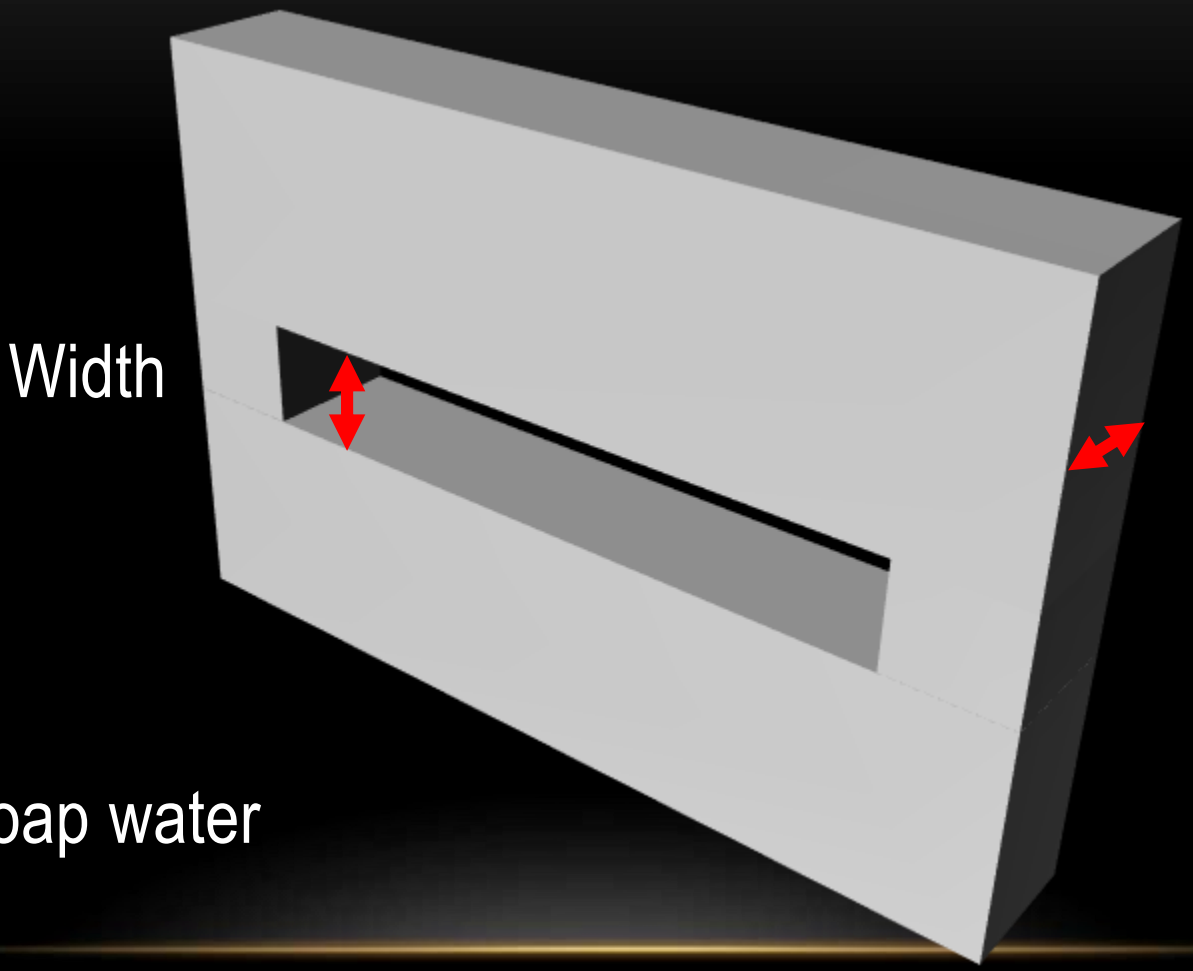
Calculating ***α***



$$\tan\alpha = \frac{\frac{l}{2} - \frac{w}{2}}{d - \frac{t}{2}}$$

$$\boldsymbol{\alpha = \arctan\left(\frac{l - w}{2d - t}\right)}$$

MEASUREMENTS

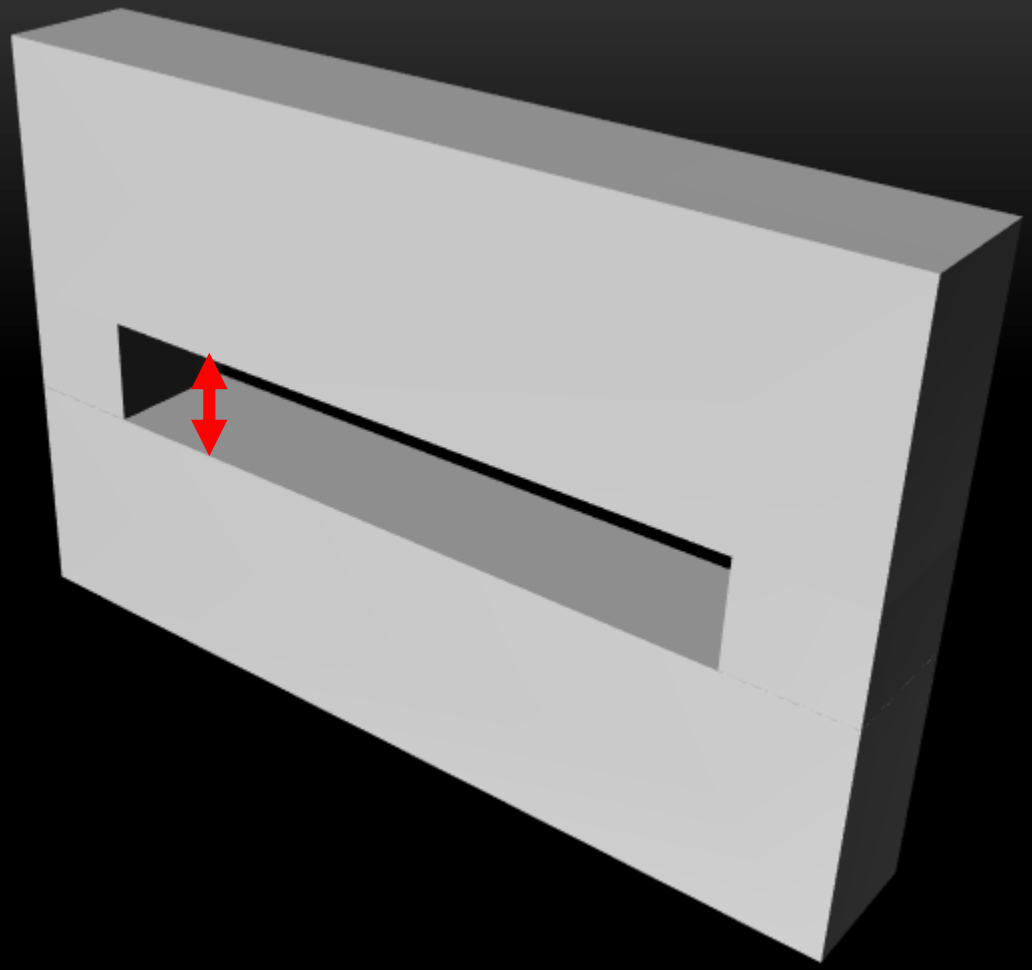


Liquid: soap water

OUR SLITS

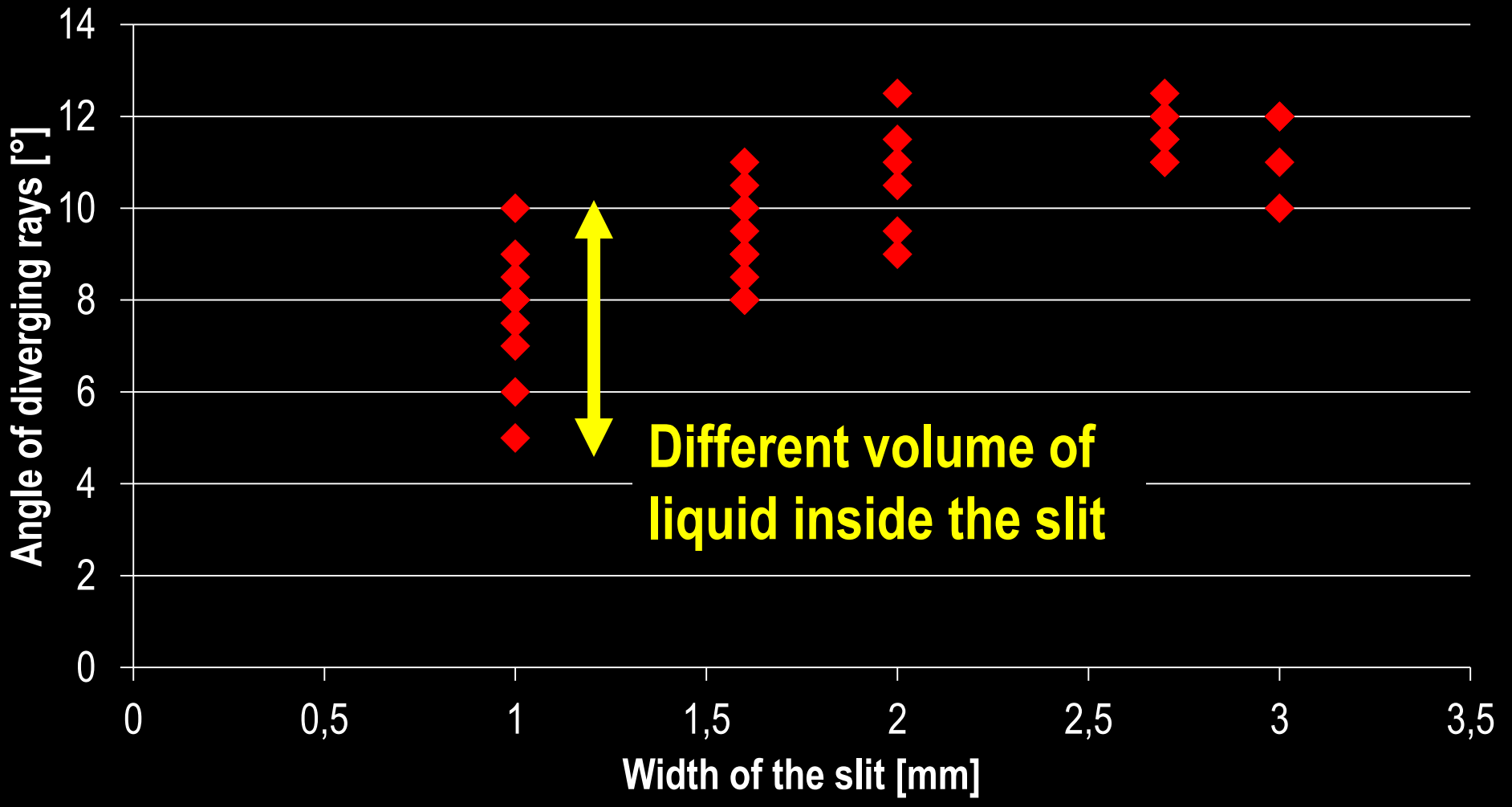
- 5 different thicknesses
- 5 different widths
- + Optical slit

Width



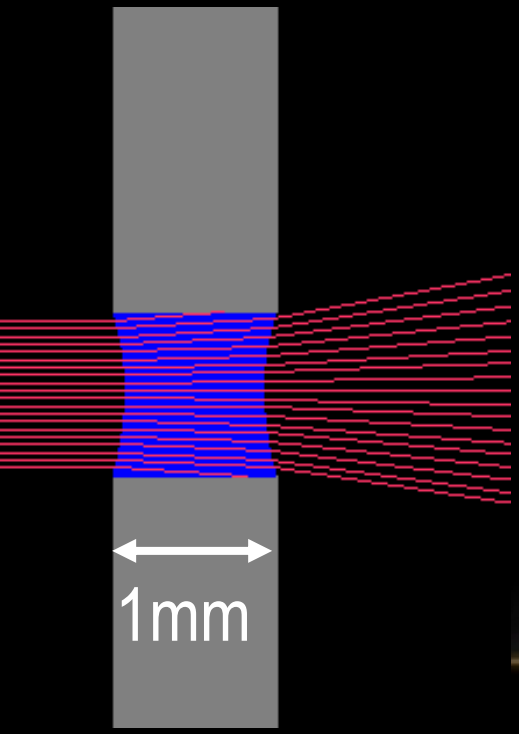
CHANGING WIDTH

CHANGING WIDTH



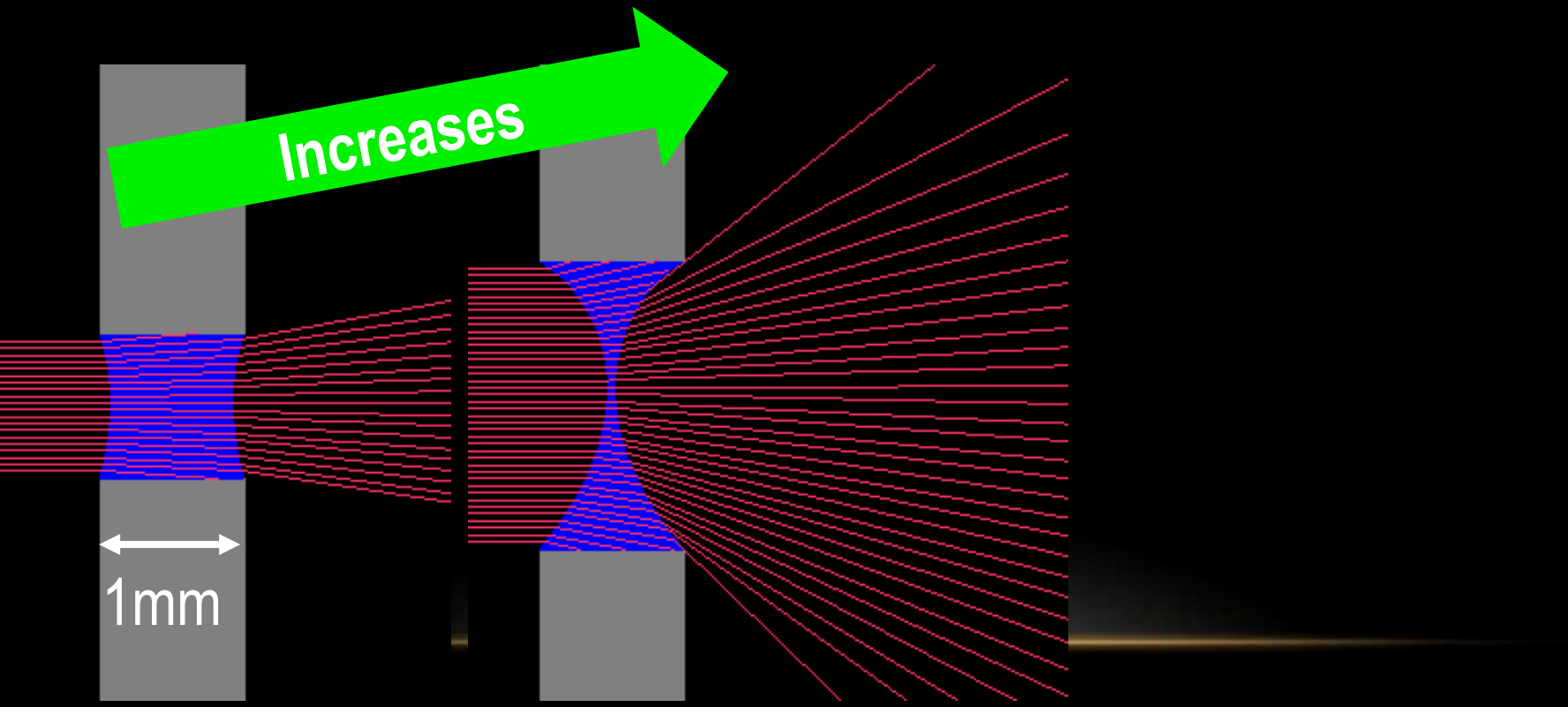
CHANGING WIDTH OF THE SLIT

- **Very narrow slits** – hold relatively large amount of liquid
  - Low curvature → low optical power



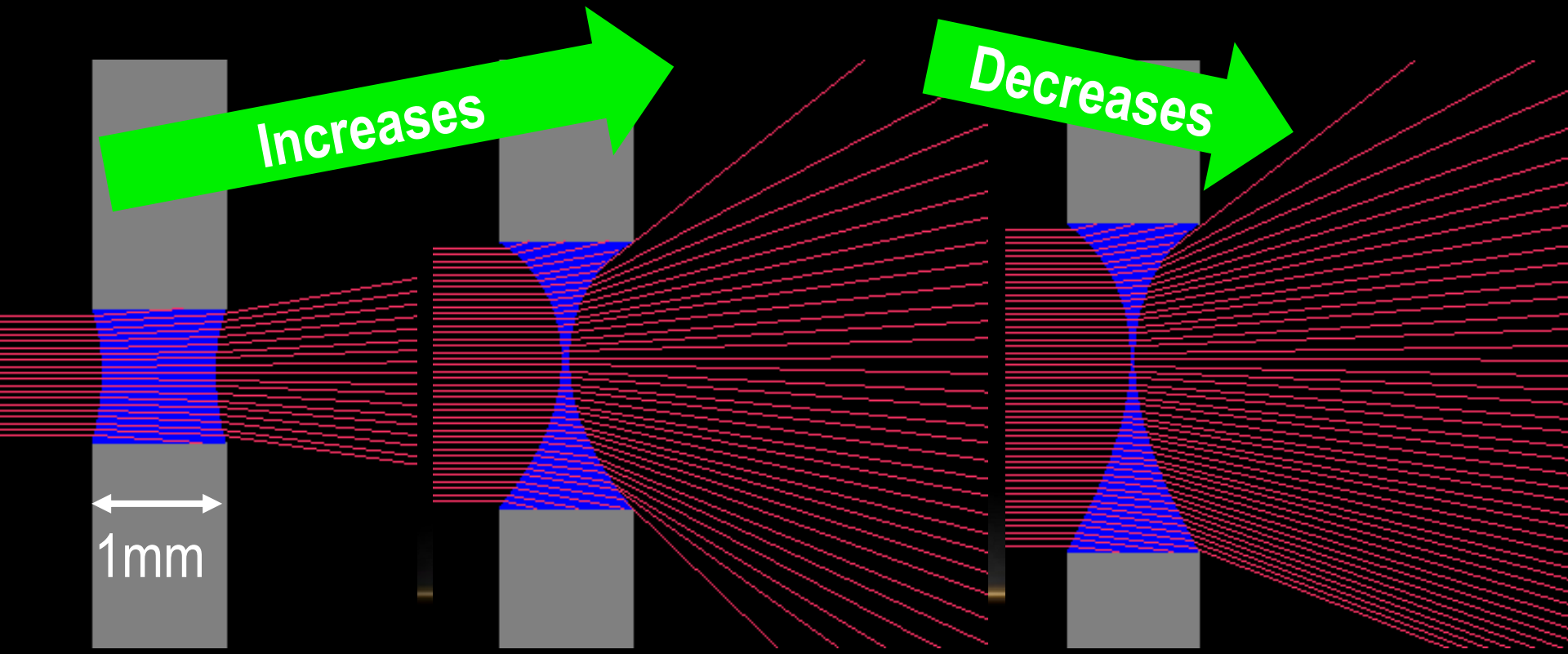
CHANGING WIDTH OF THE SLIT

- **Wider slits** – liquid drains down, leaving thinner meniscus
  - Higher curvature → more diverging

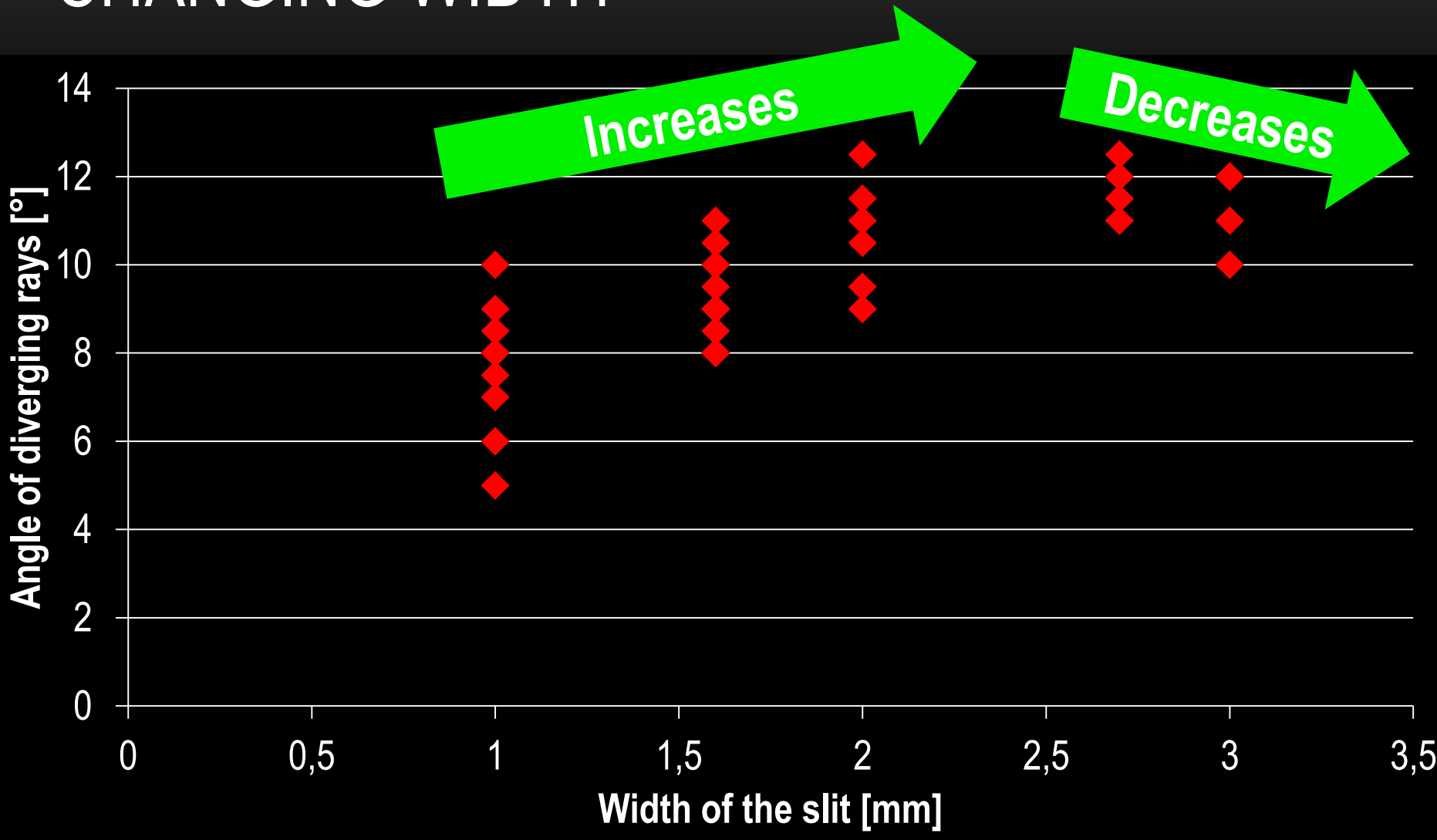


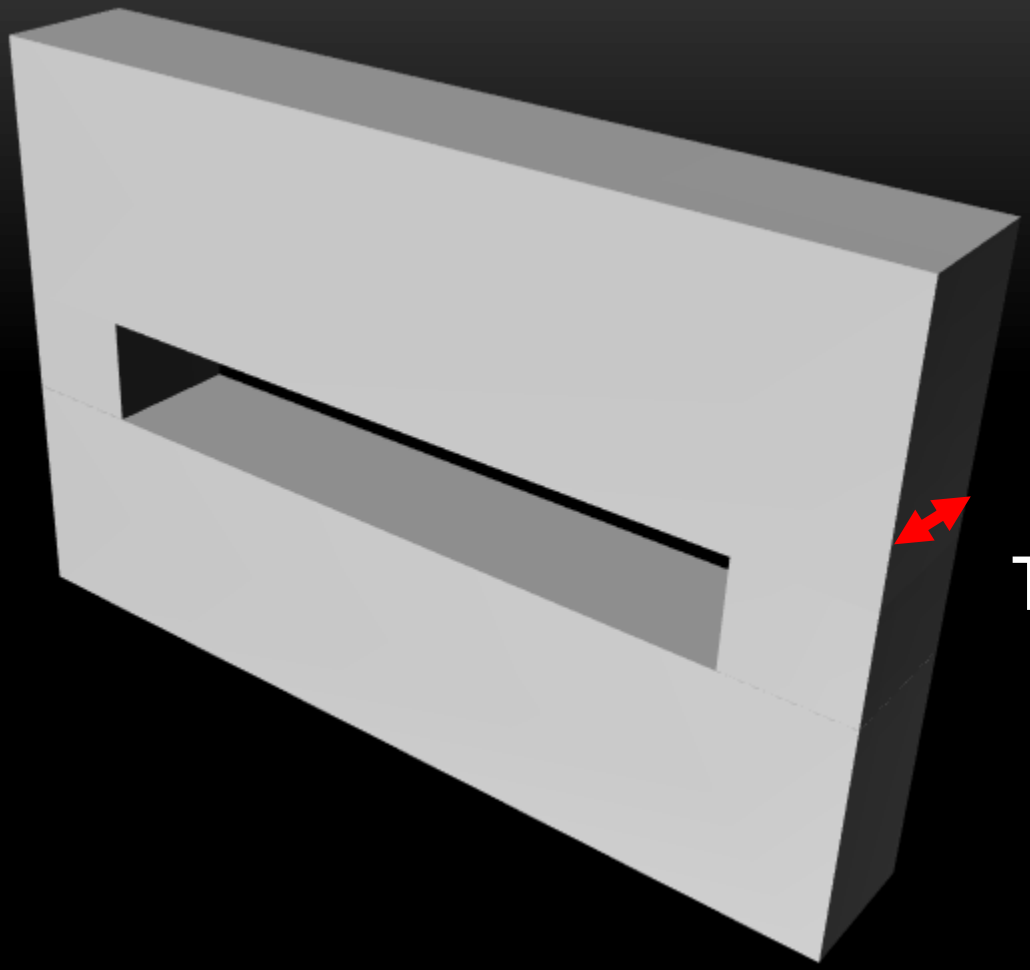
CHANGING WIDTH OF THE SLIT

- **Too wide slits** – film must have non-zero thickness
  - Curvature is limited → divergence falls again



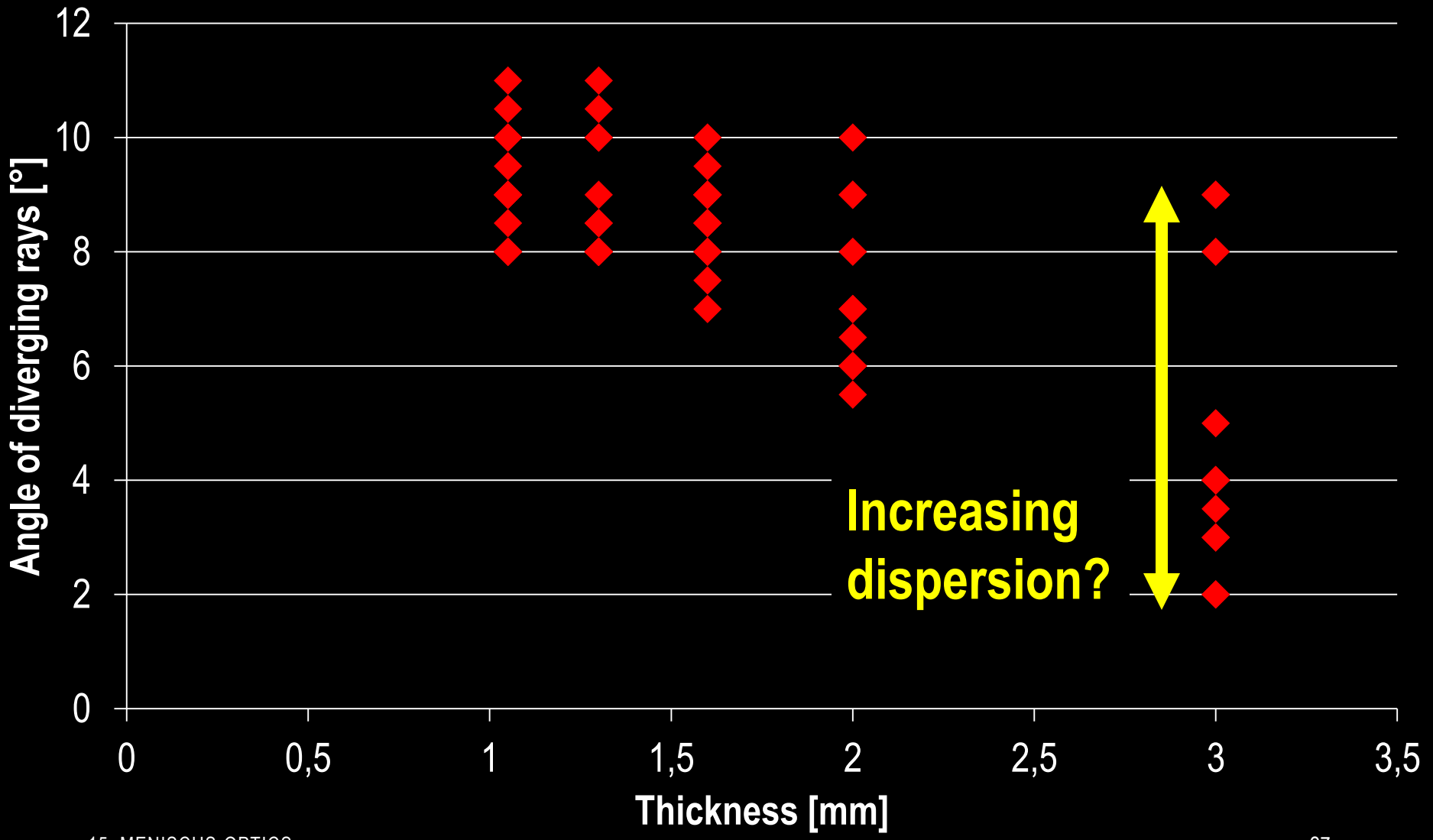
CHANGING WIDTH





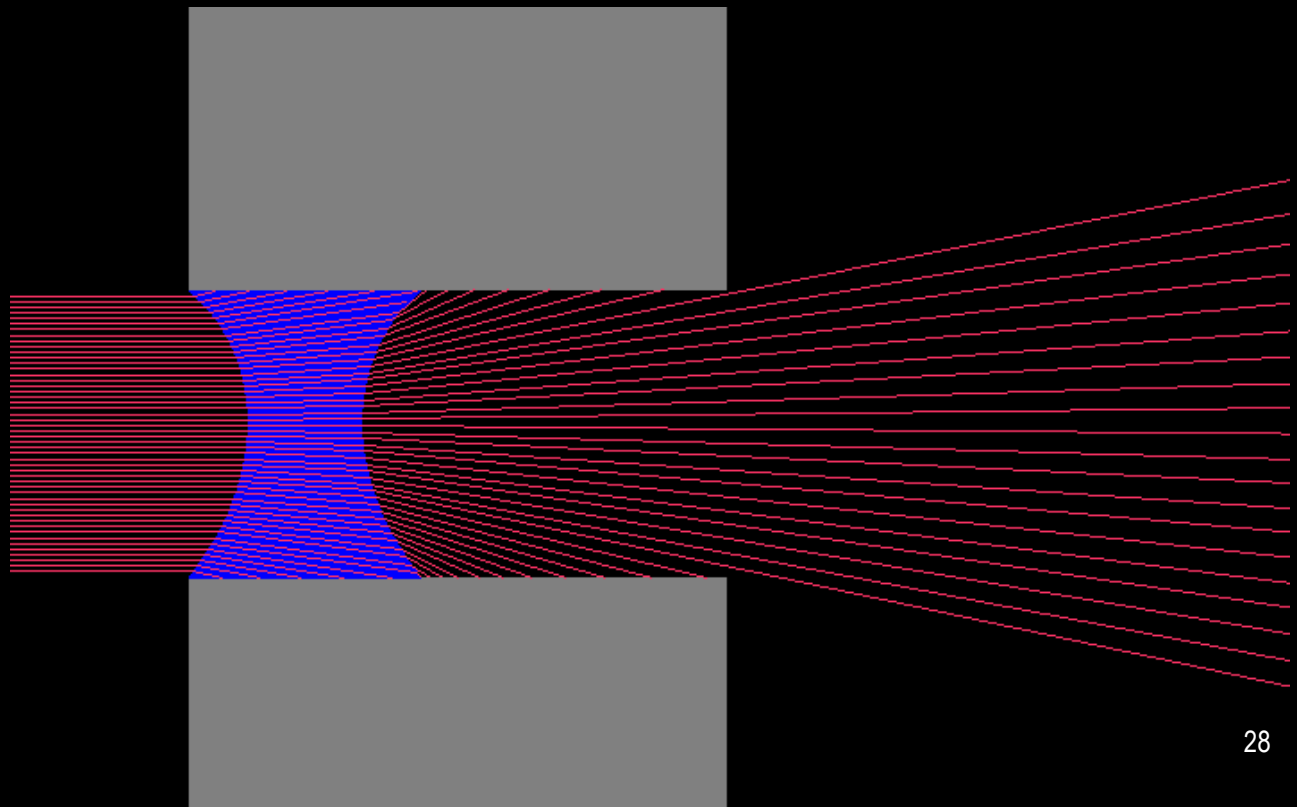
CHANGING THICKNESS

CHANGING THICKNESS

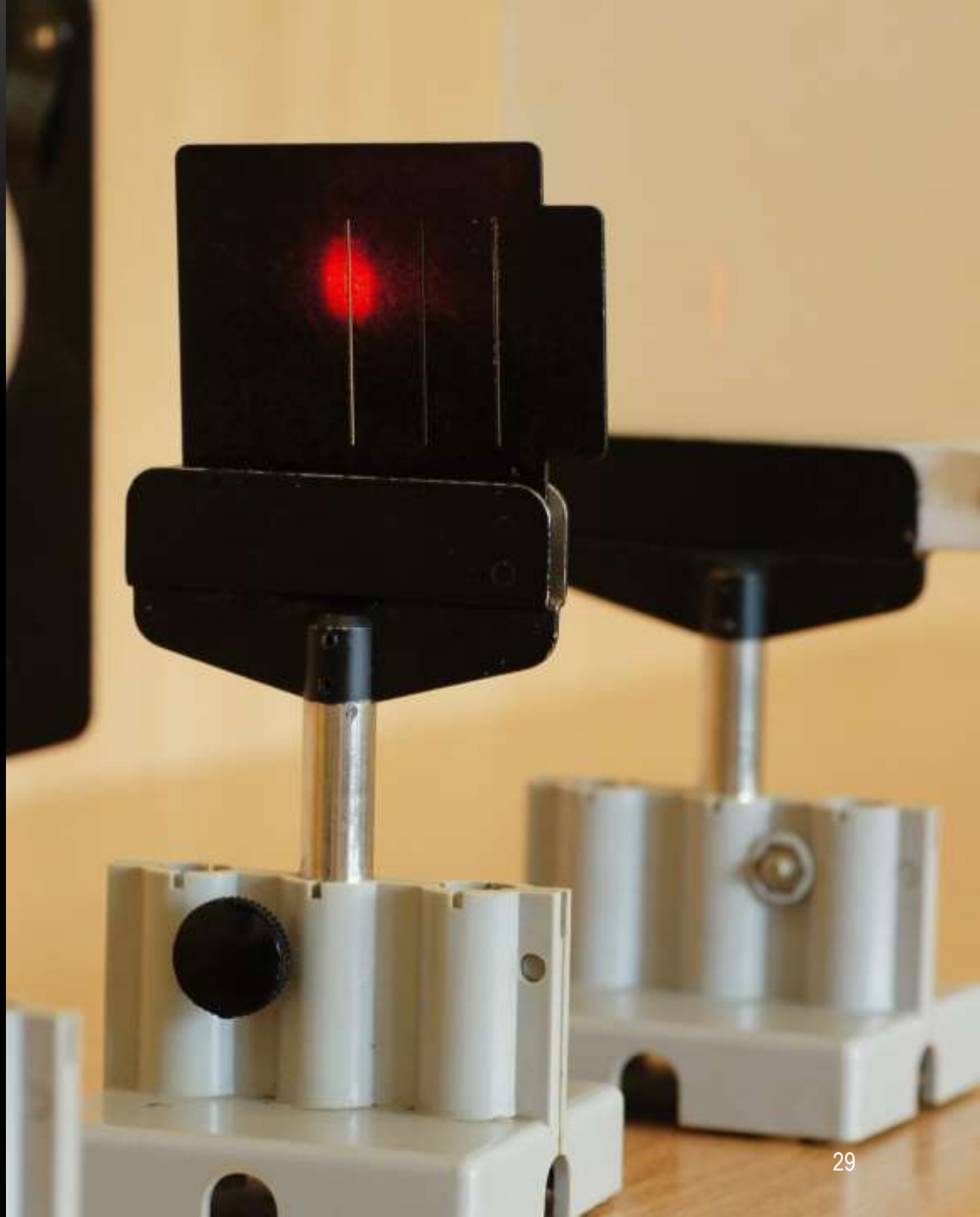


LARGE DISPERSION

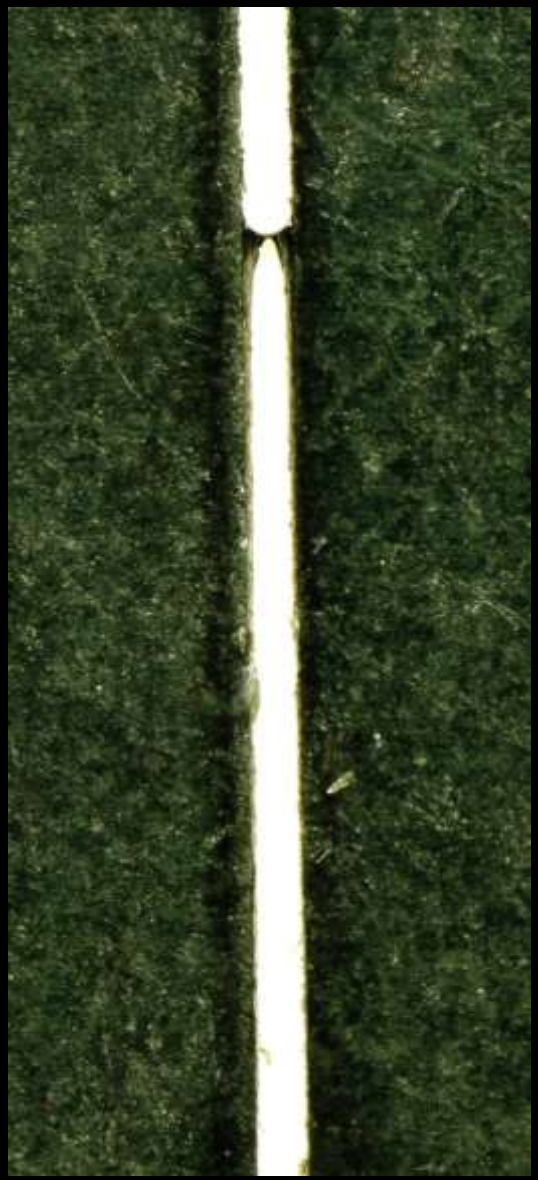
- The film doesn't always fill the entire slit
  - Film closer to the screen – more diverging
  - Film further from the screen – less diverging



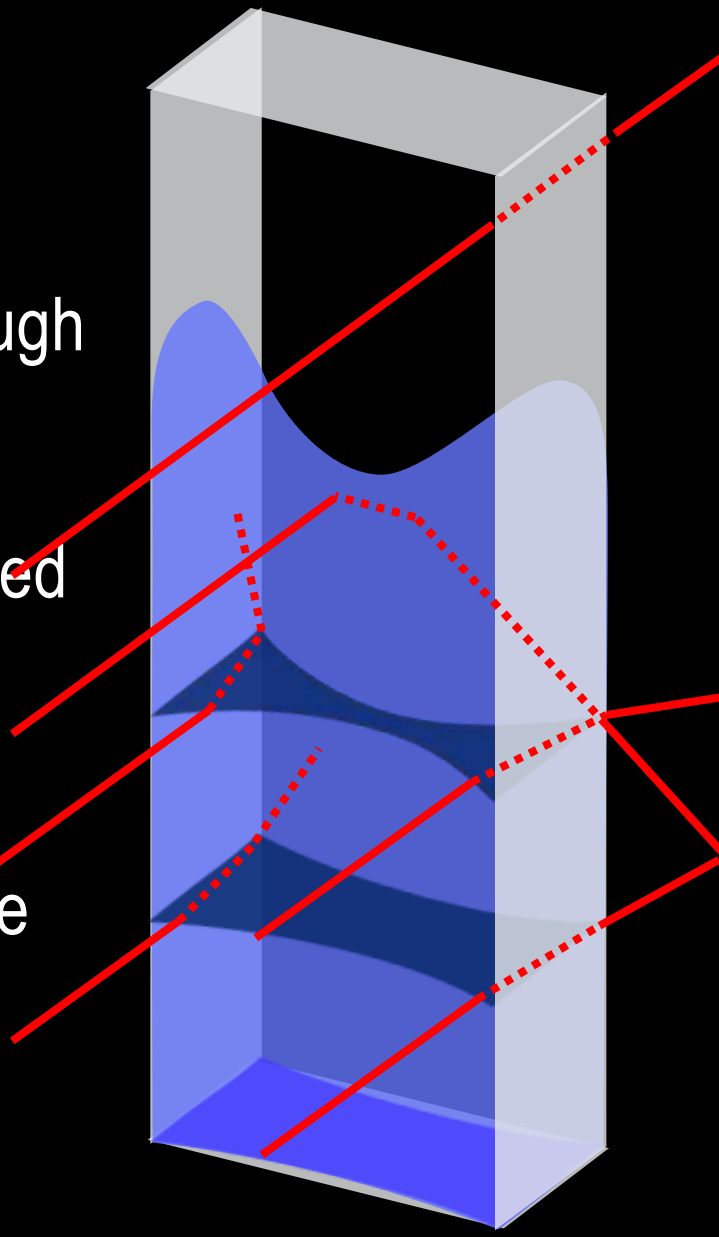
VERTICALLY PLACED SLIT



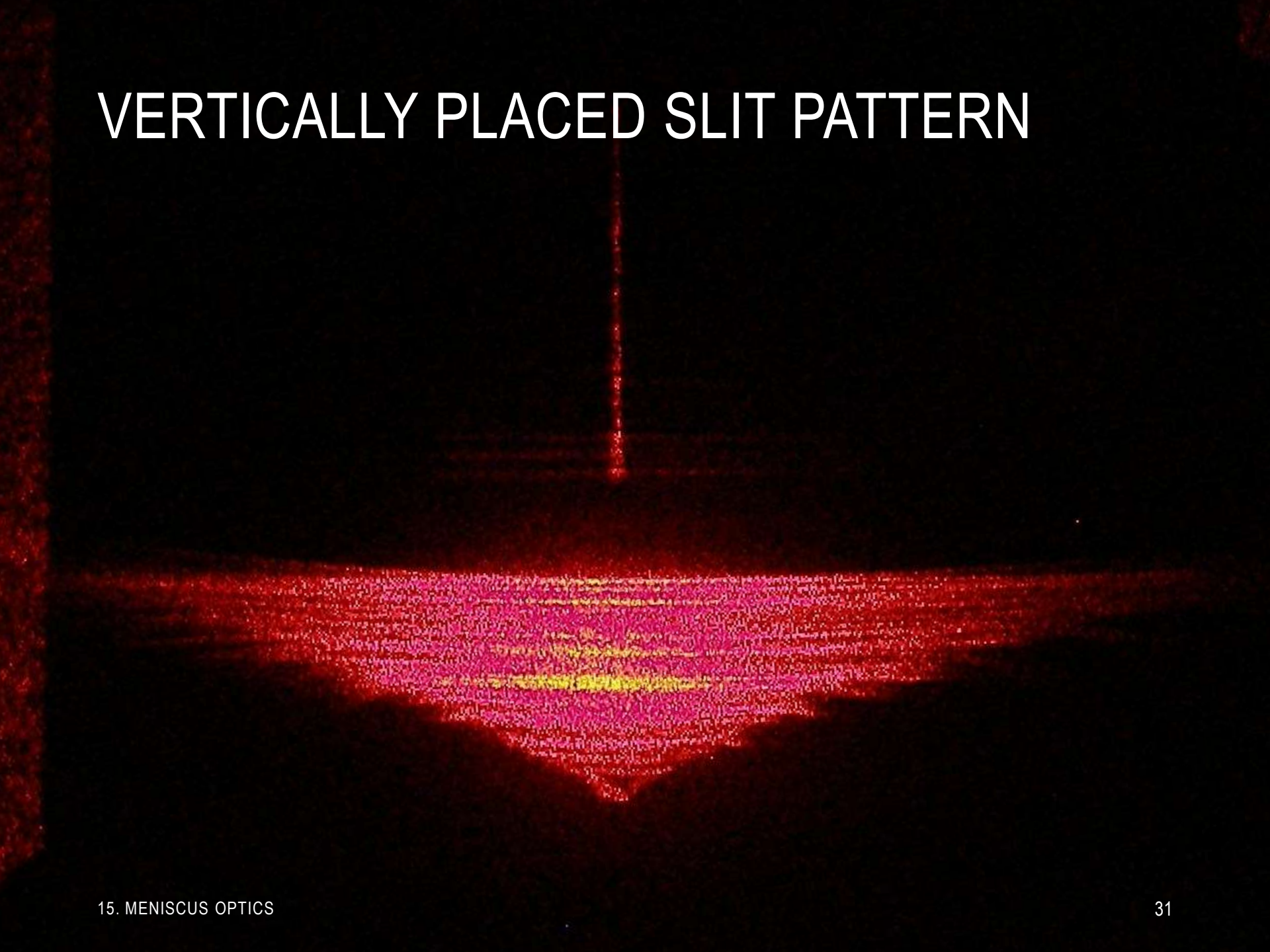
LIQUID IN A VERTICAL SLIT



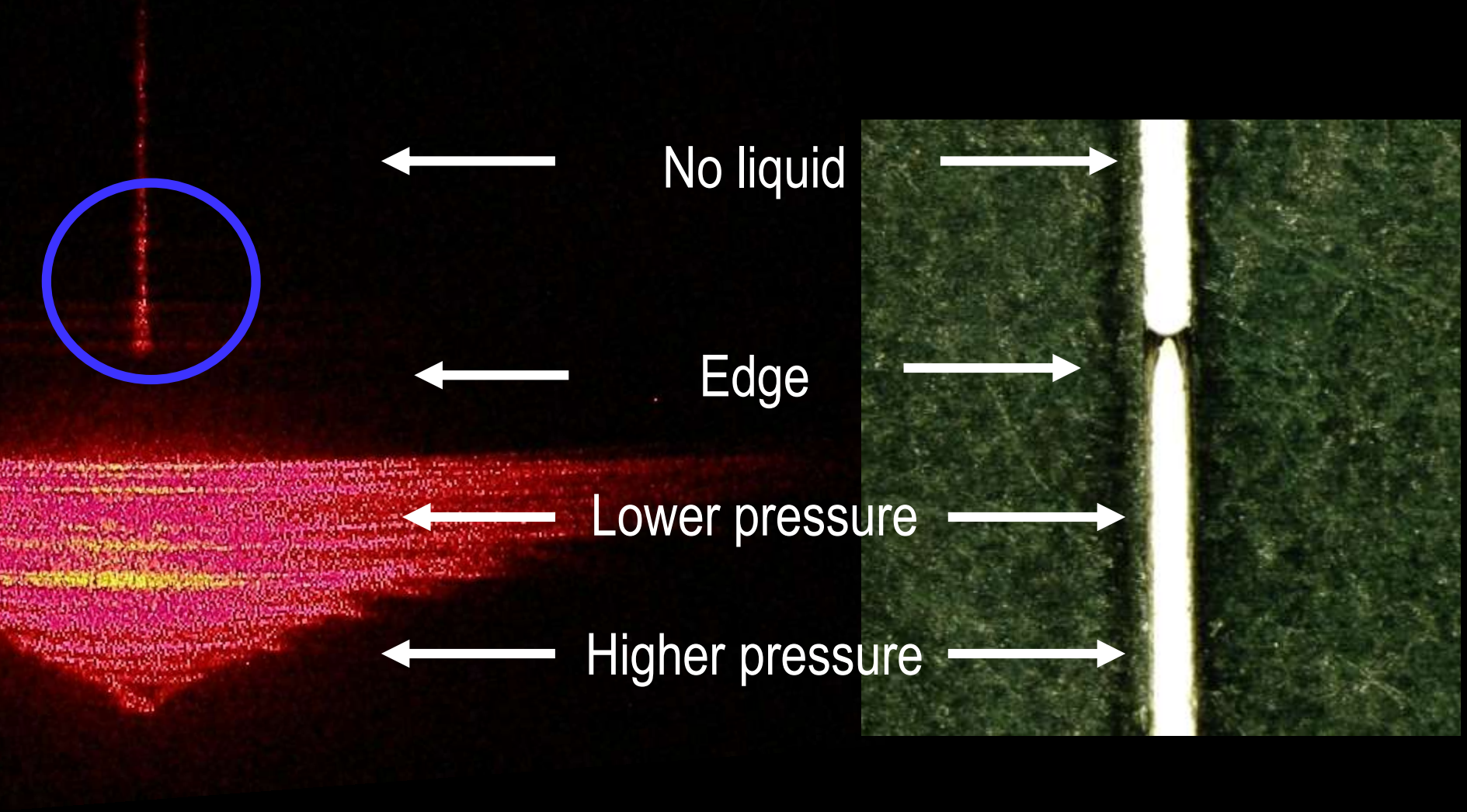
- No liquid at the top
  - Light passes trough
- The edge
  - Refracted/reflected away
- Lens-like shape
- Hydrostatic pressure
  - Less diverging at the bottom



VERTICALLY PLACED SLIT PATTERN



VERTICALLY PLACED SLIT – PATTERN

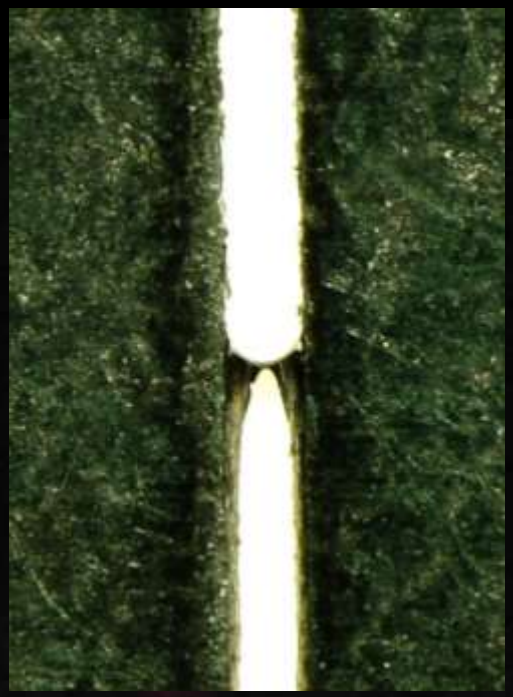


DIFFRACTION AT THE EDGE – CLOSE-UP

Liquid wetting the slit

→ effectively thinner slit at the edge

→ wider diffraction maxima

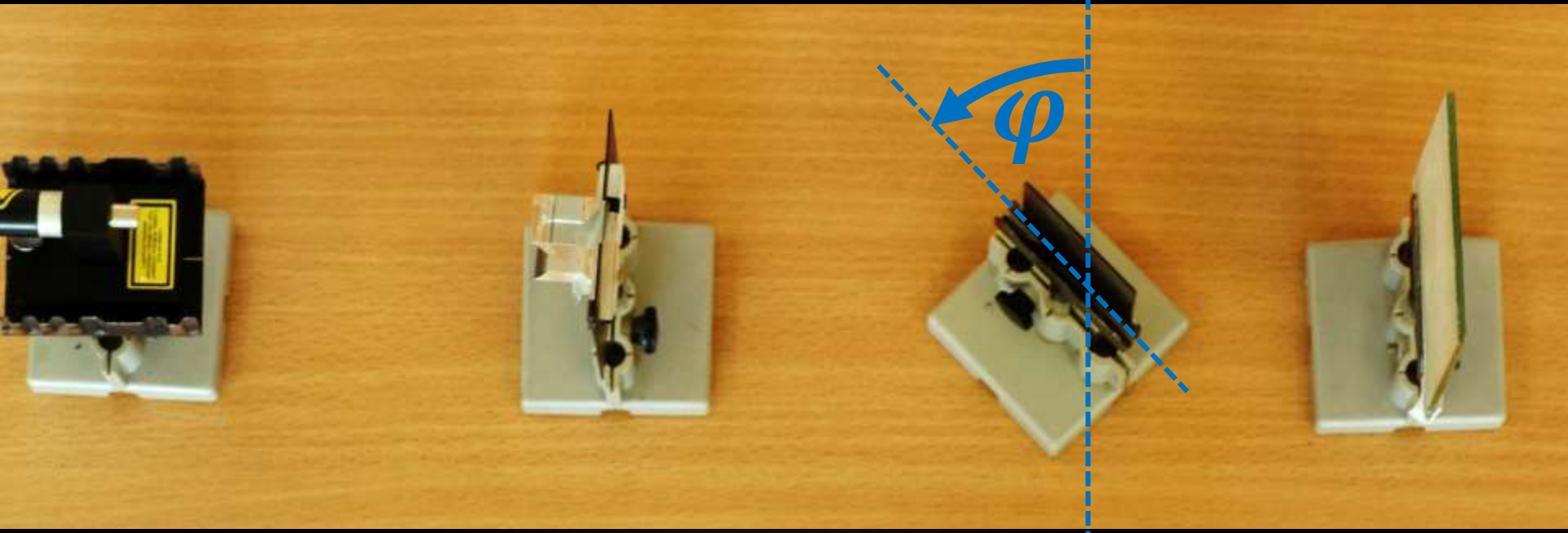


Interesting phenomenon:

BENDING OF THE PATTERN

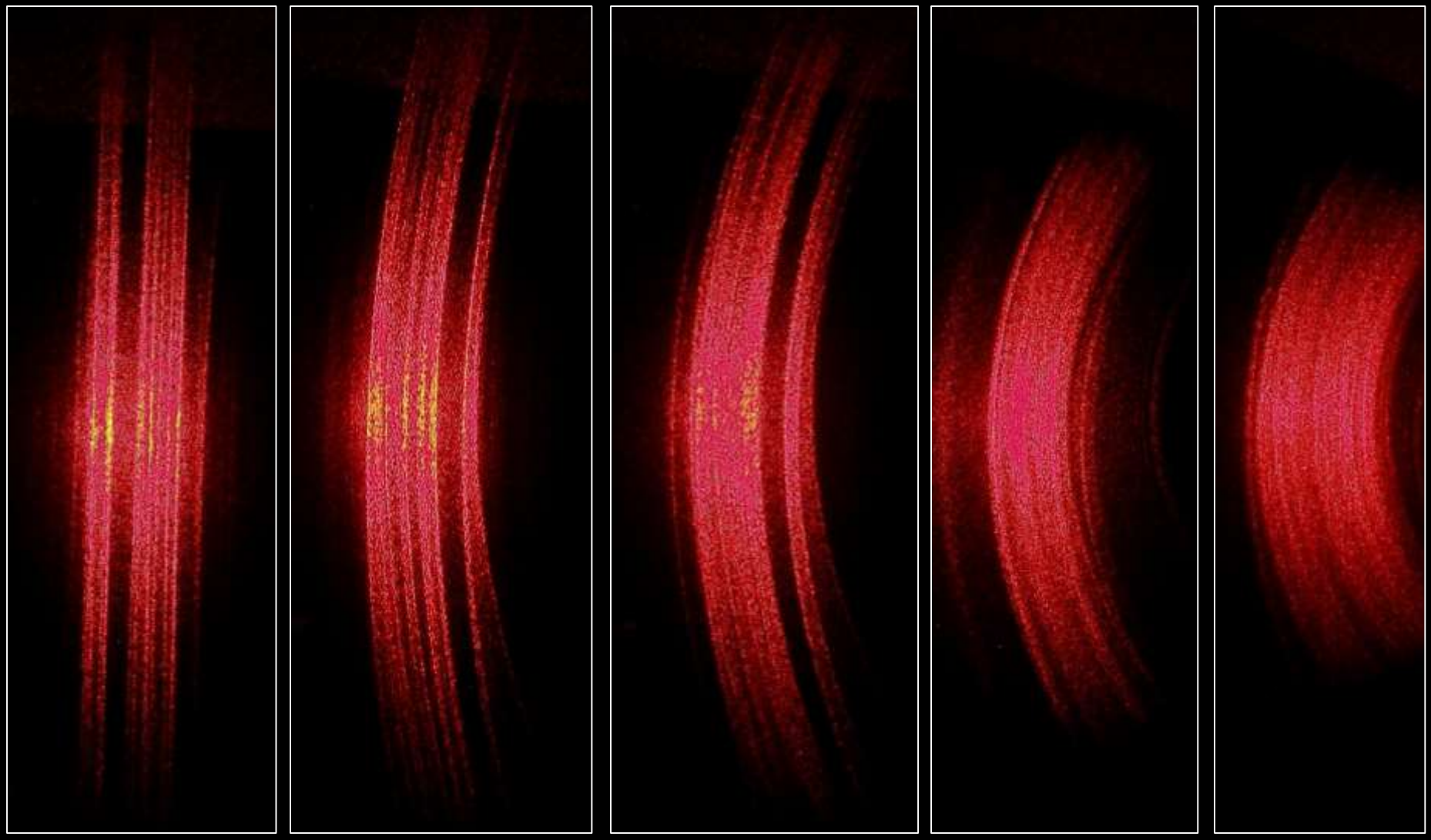
ROTATING THE SLIT

- Horizontal slit
- Turning around the vertical axis



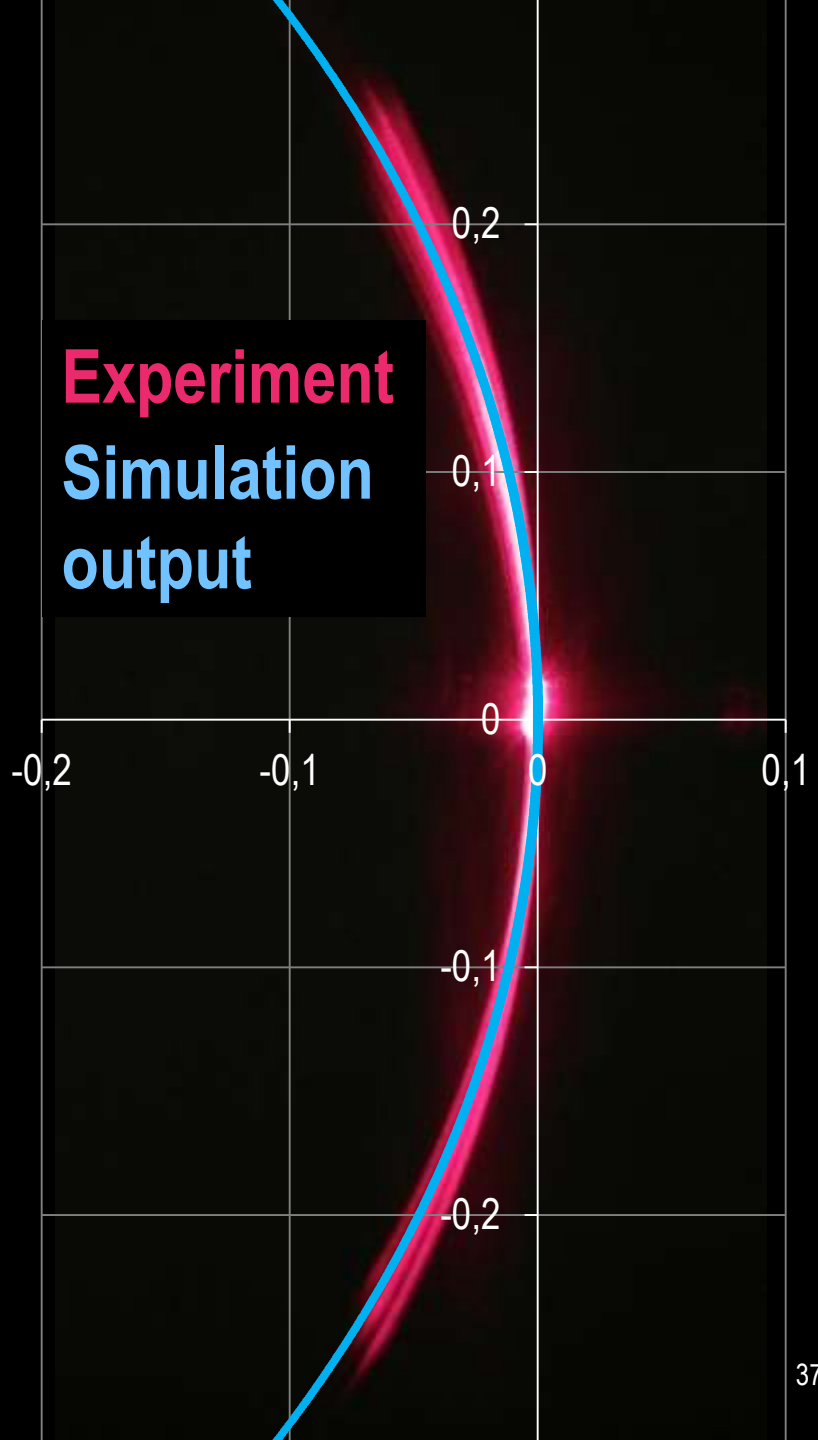
Laser Lenses Slit Screen

INCREASING THE ANGLE

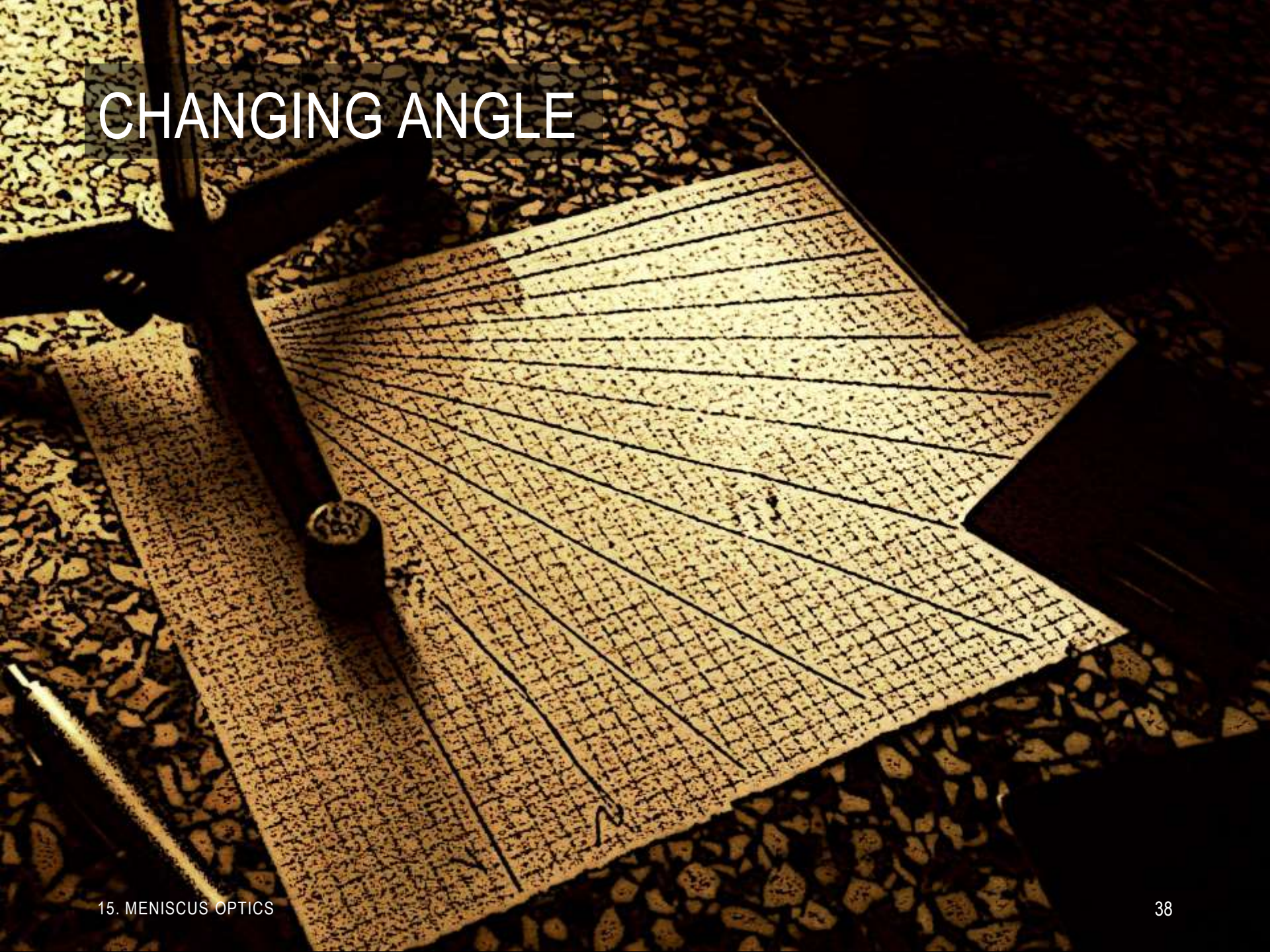


BENDING PATTERN

- Picture – angle of tilt: 54.5°
- Measuring:
  Curvature = 1/radius

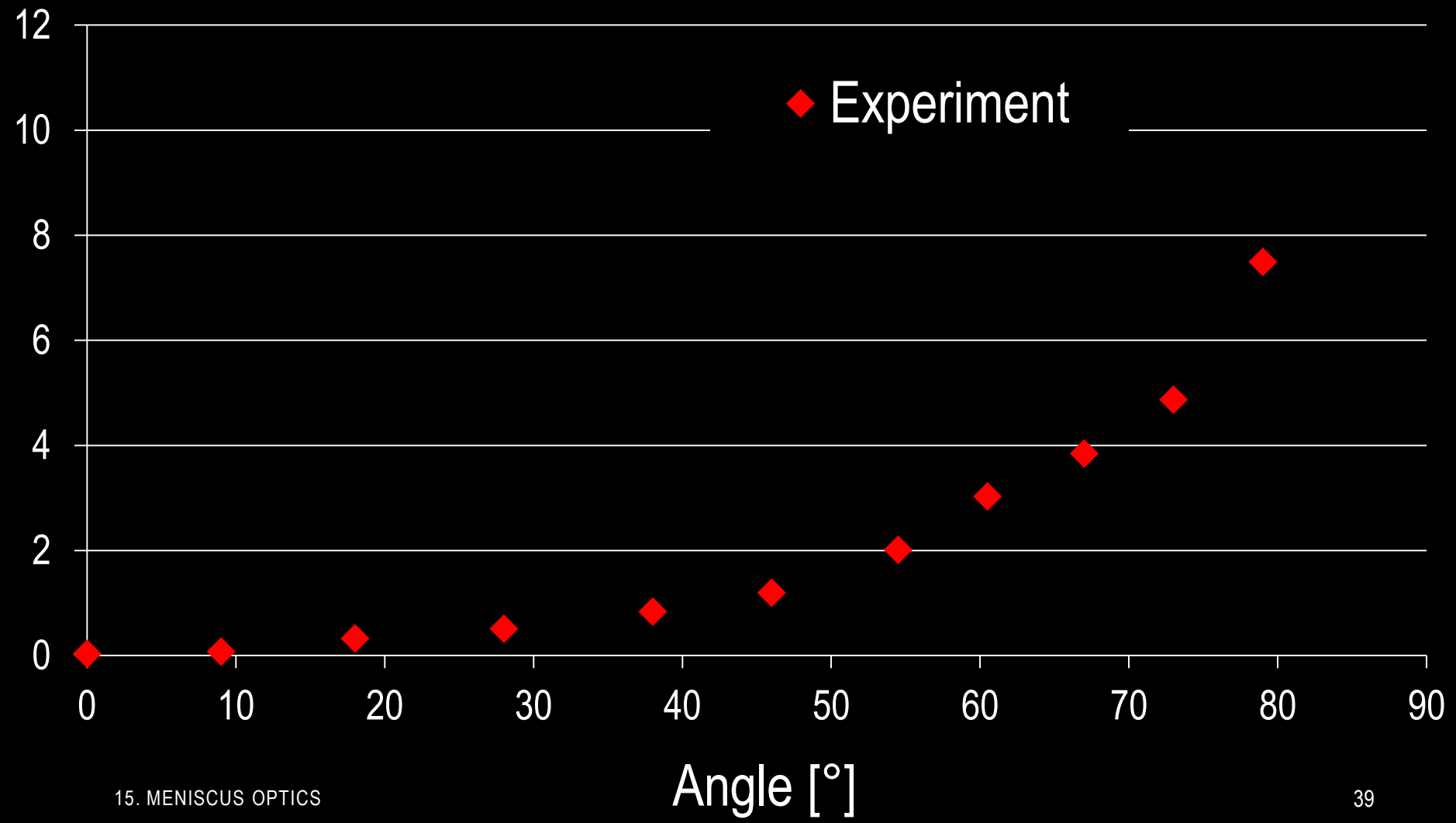


CHANGING ANGLE



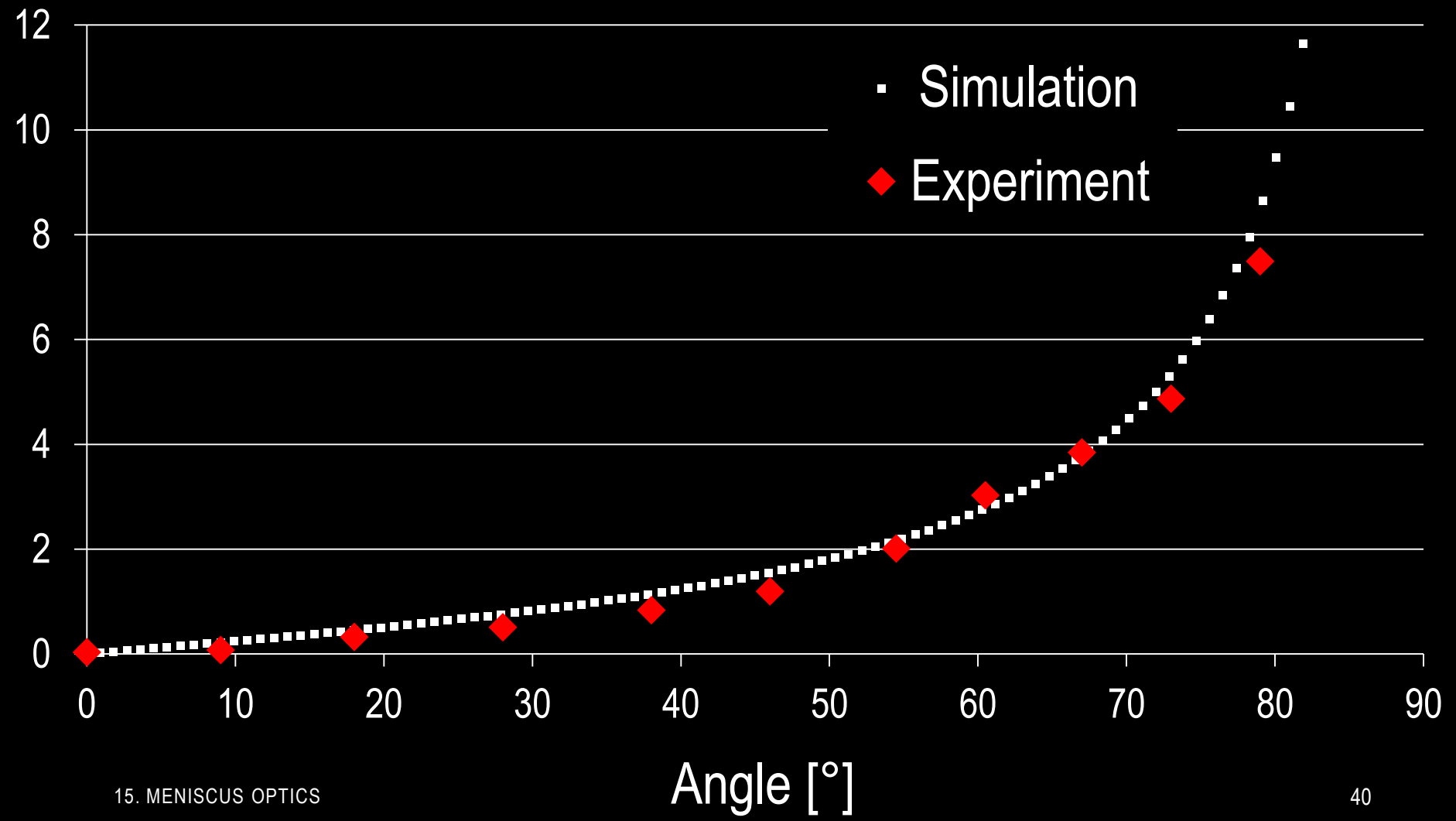
CURVATURE DEPENDING ON ANGLE

Curvature = 1/radius [m^{-1}]



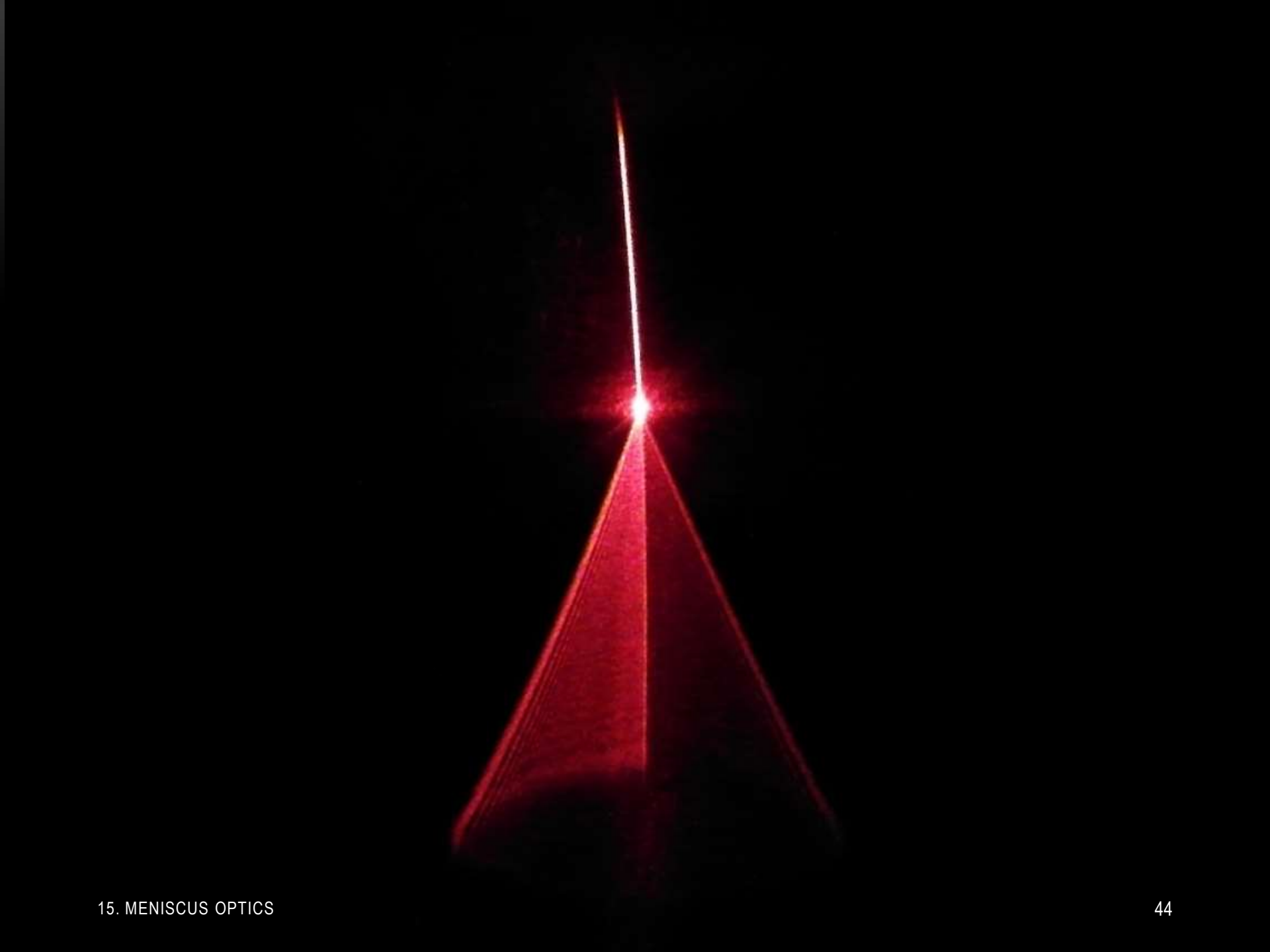
CURVATURE DEPENDING ON ANGLE

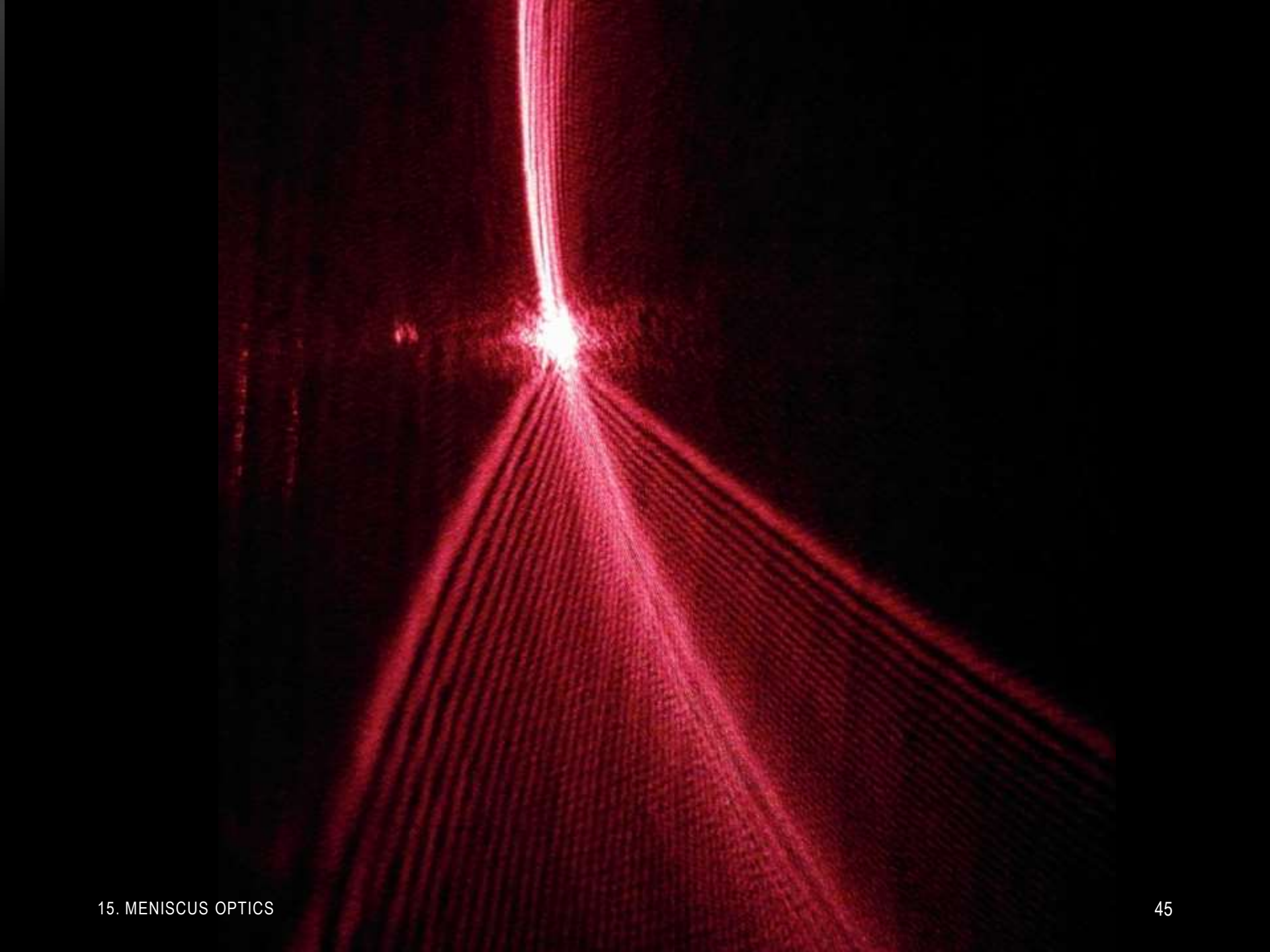
Curvature = 1/radius [m^{-1}]



Interesting patterns

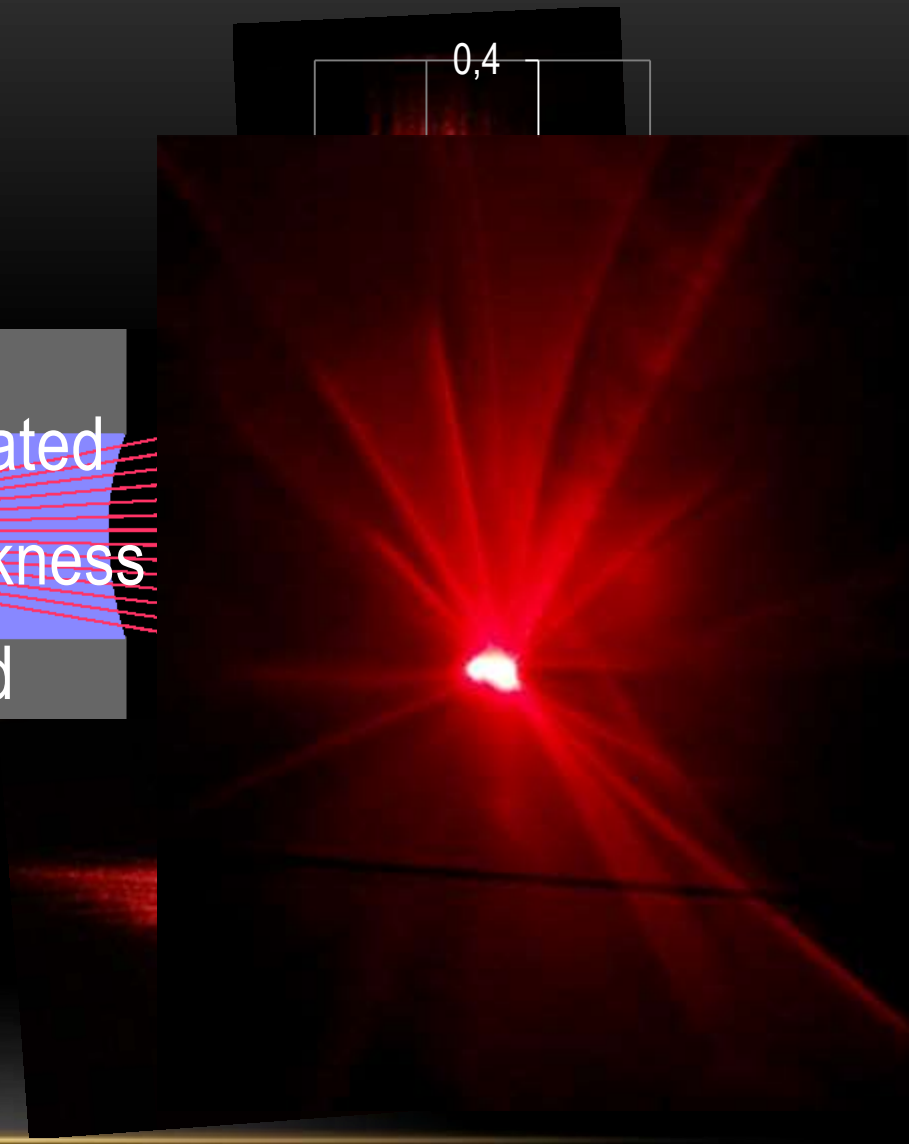
THE ARTISTIC POINT OF VIEW





SUMMARY

- Meniscus as a lens
  - Simulation used
- Horizontal slit pattern investigated
  - Dependence on width, thickness
- Vertical slit – pattern explained
- Bending of the pattern
  - Simulation
- Other interesting patterns



THANK YOU FOR YOUR ATTENTION

Nikola Illášová

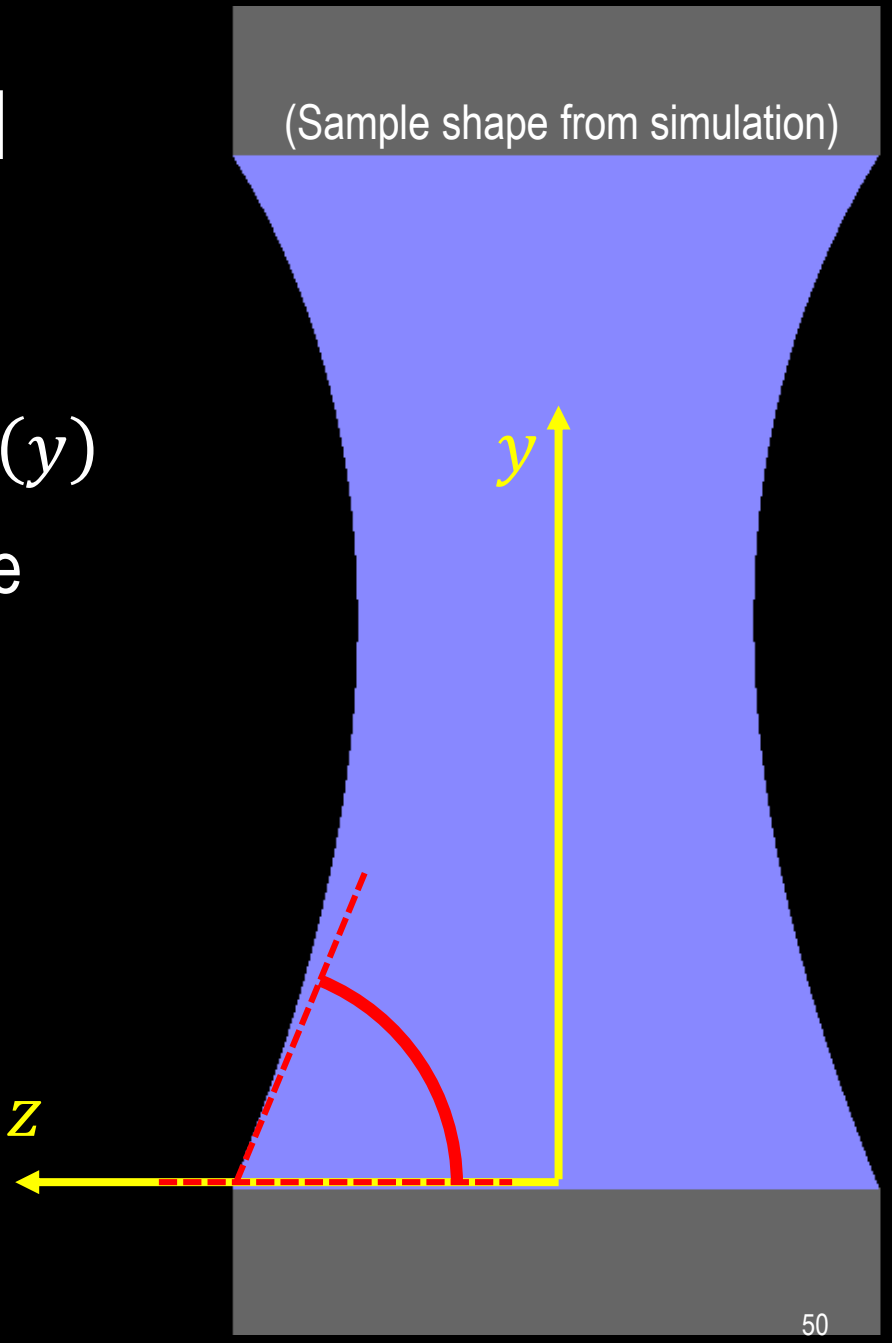
15. Meniscus optics

APPENDICES

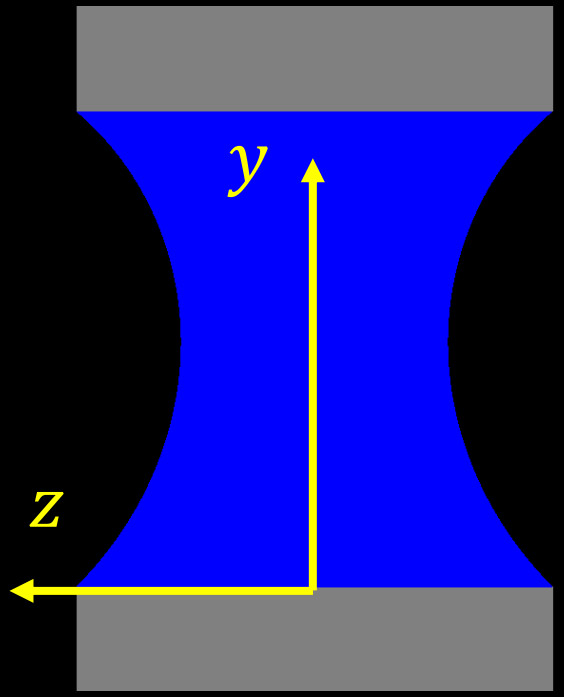
SHAPE CALCULATION

- **Euler's method; Delphi**
- Increments of $\frac{dz}{dy}(y)$ and $z(y)$ based on radius of curvature

- Boundary conditions:
  - Width, thickness
  - Slope at the bottom



SHAPE CALCULATION



Euler's method; Delphi

Forces equillibruim: $\frac{1}{R(y)} = \frac{1}{\gamma}(\Delta p(0) + y\rho g)$

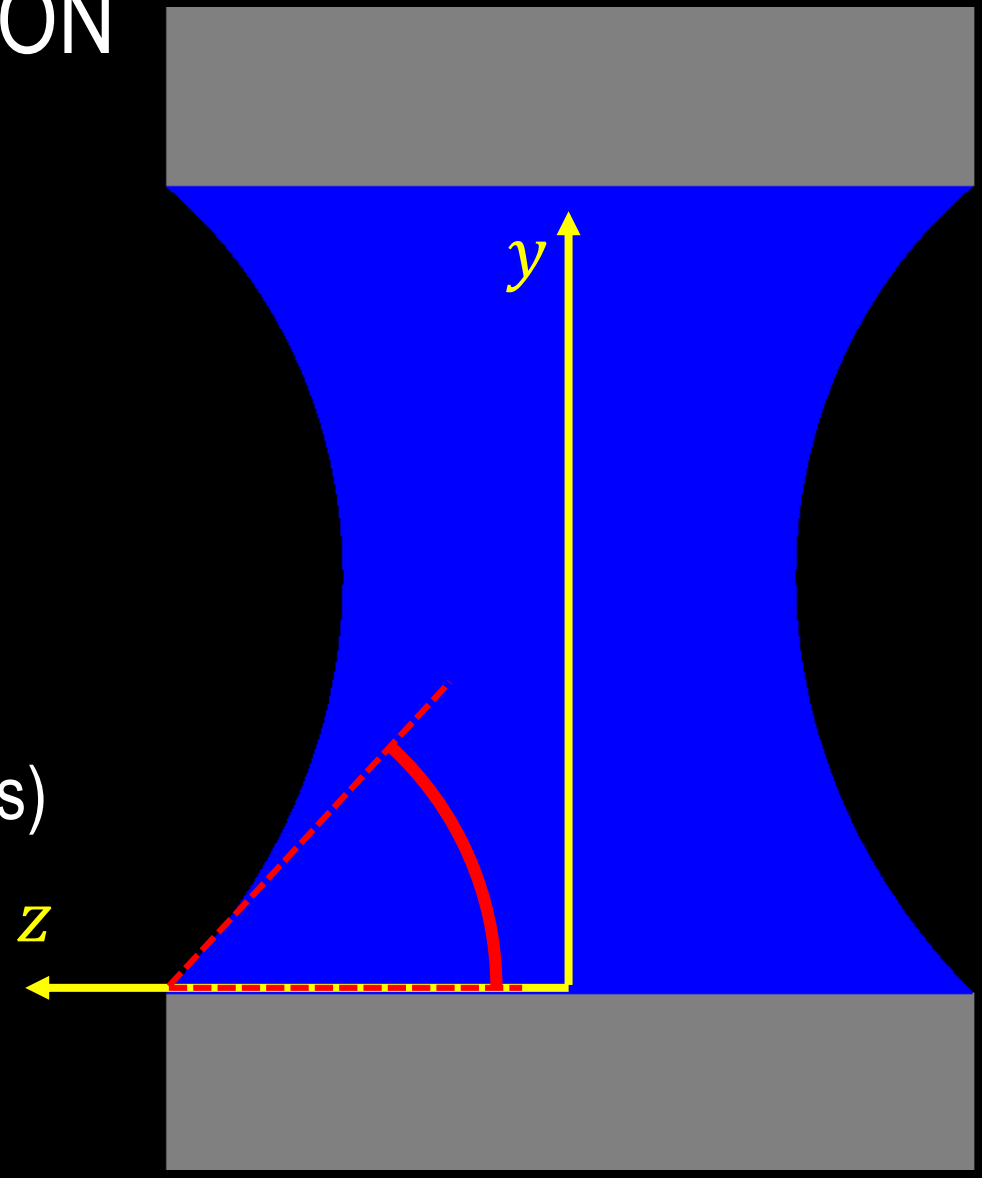
Second derivative $z''(y) = \frac{1}{R(y)}(z'(y)^2 + 1)^{\frac{3}{2}}$

First derivative $\Delta z'(y) = z''(y)\Delta y$

Increment $\Delta z = z'(y)\Delta y + \frac{1}{2}z''(y)\Delta y^2$

SHAPE CALCULATION

- Boundary conditions:
  - Width, thickness
  - Slope at the bottom
  - Symmetrical shape (with respect to y-axis)



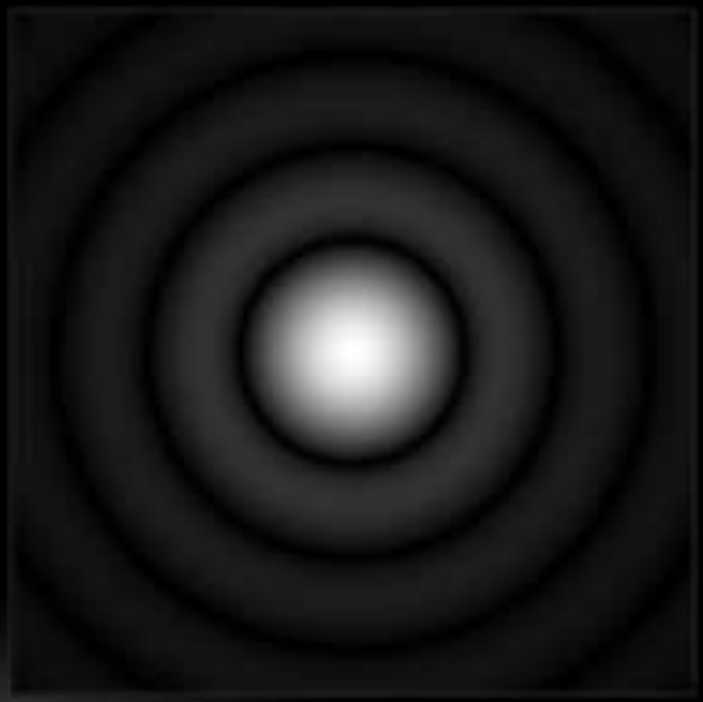
SLITS OVERVIEW

- Changing width, thickness = 1.0mm
  - 1.0mm, 2.0mm, 1.6mm, 2.7mm, 3.0mm
- Changing thickness, width = 1.6mm
  - 1.0mm, 1.3mm, 1.6mm, 2.0mm, 3.0mm

- Optical slit
  - Width 0.5mm, thickness 1.0mm

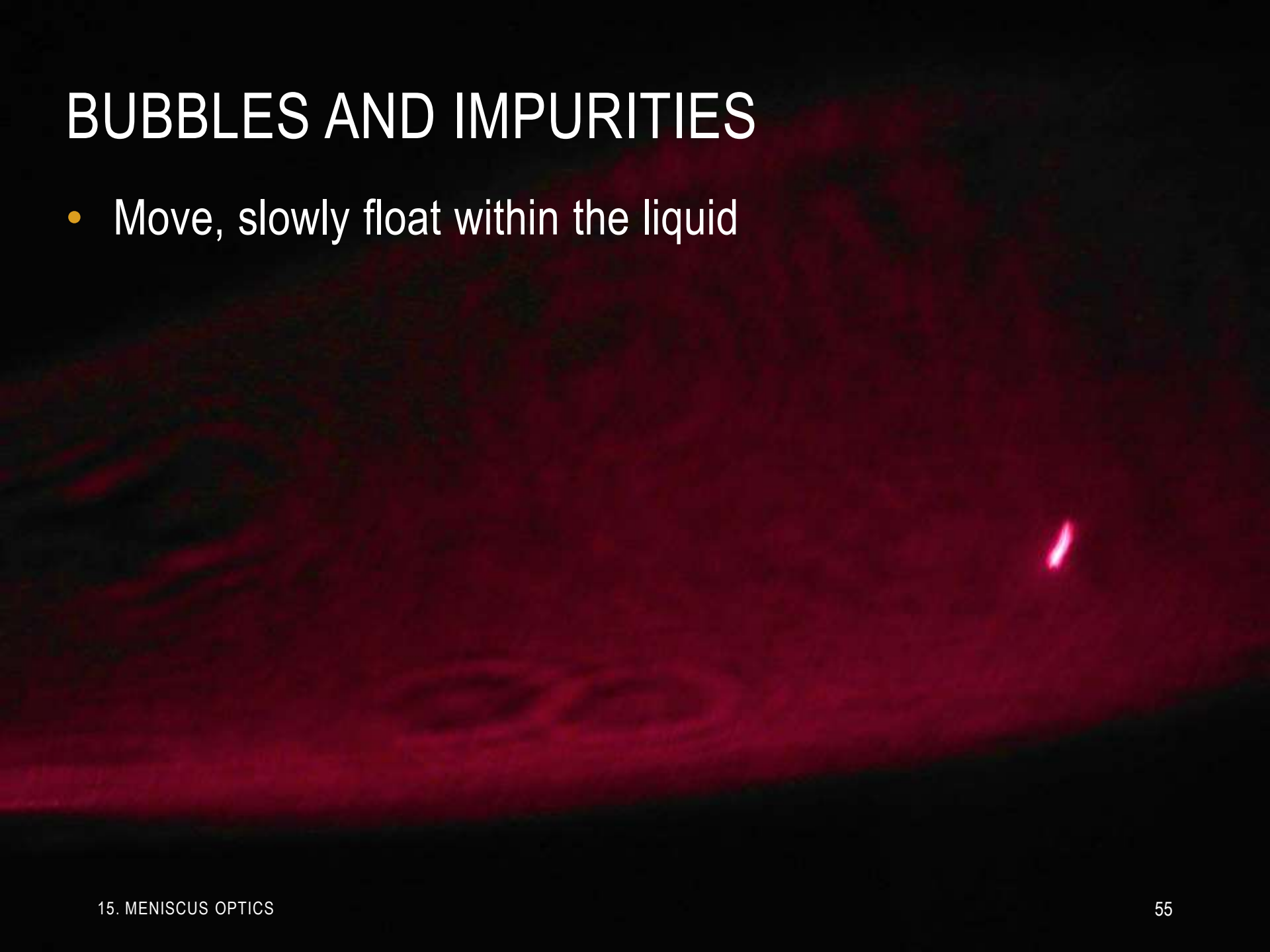
AIRY DISC

- Circular aperture
- Diffraction of light

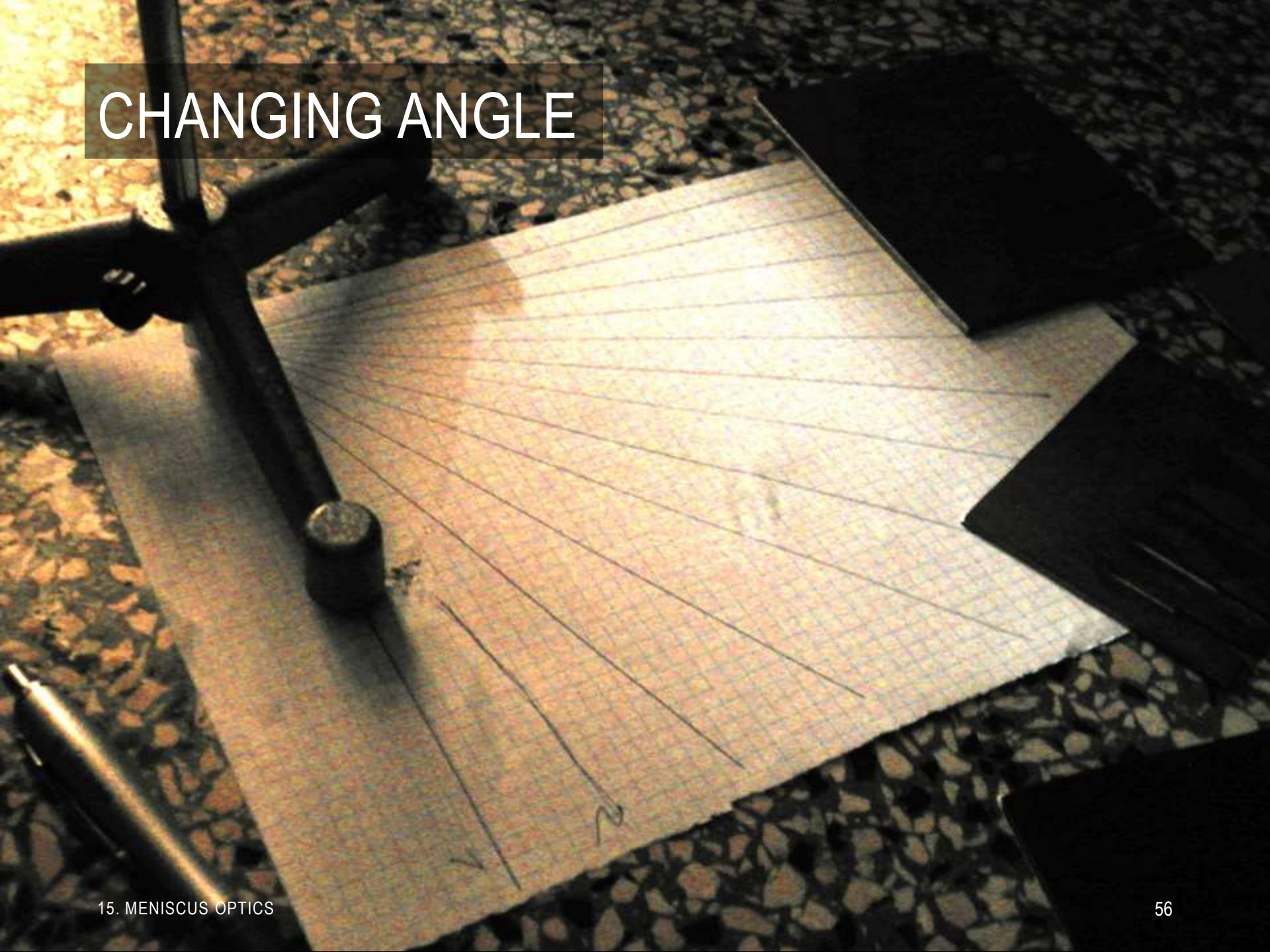


BUBBLES AND IMPURITIES

- Move, slowly float within the liquid



CHANGING ANGLE

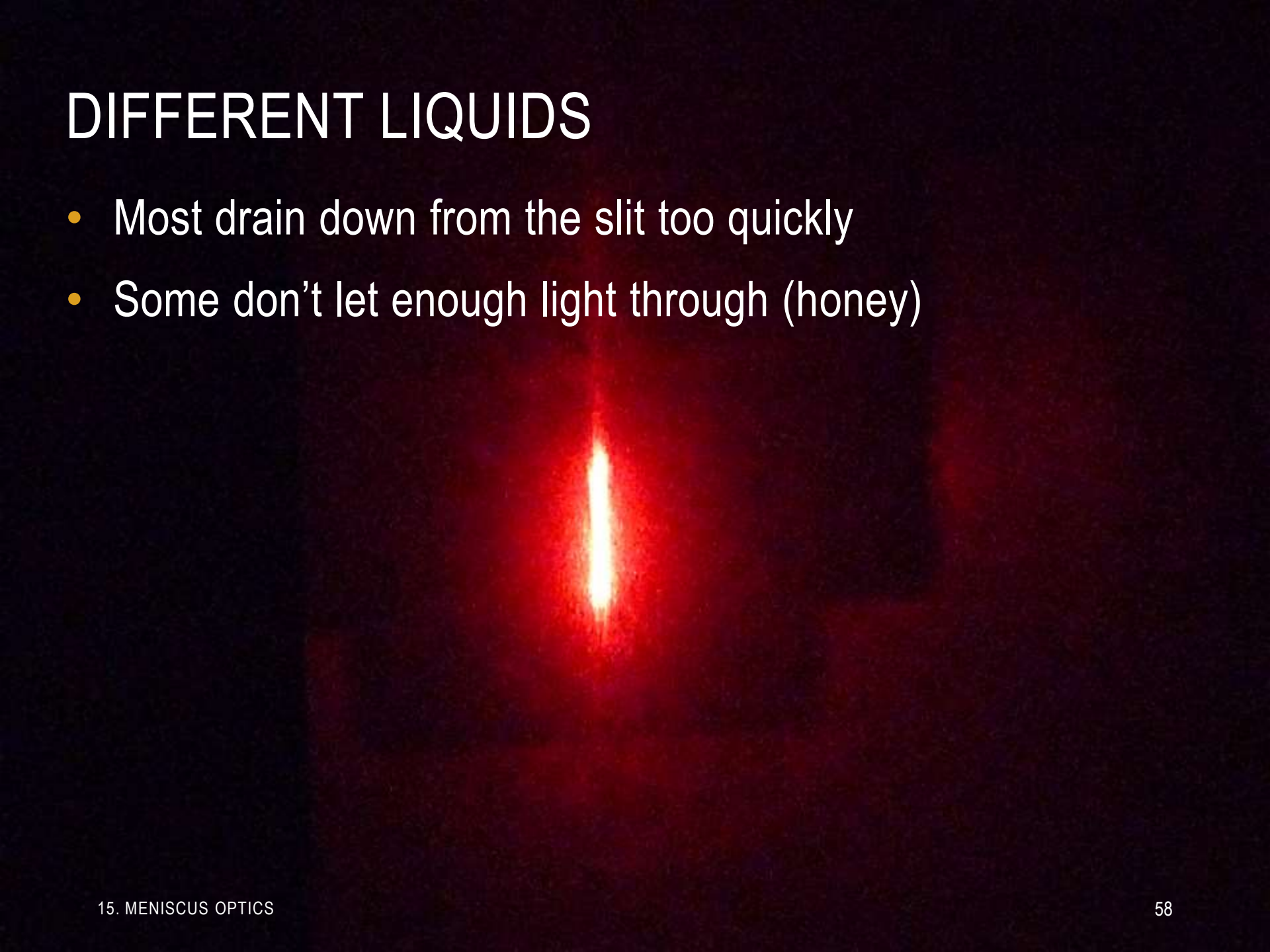


SLIT TOO WIDE

- Liquid either drains away, or forms a thin film
  - Low curvature → no special pattern created

DIFFERENT LIQUIDS

- Most drain down from the slit too quickly
- Some don’t let enough light through (honey)

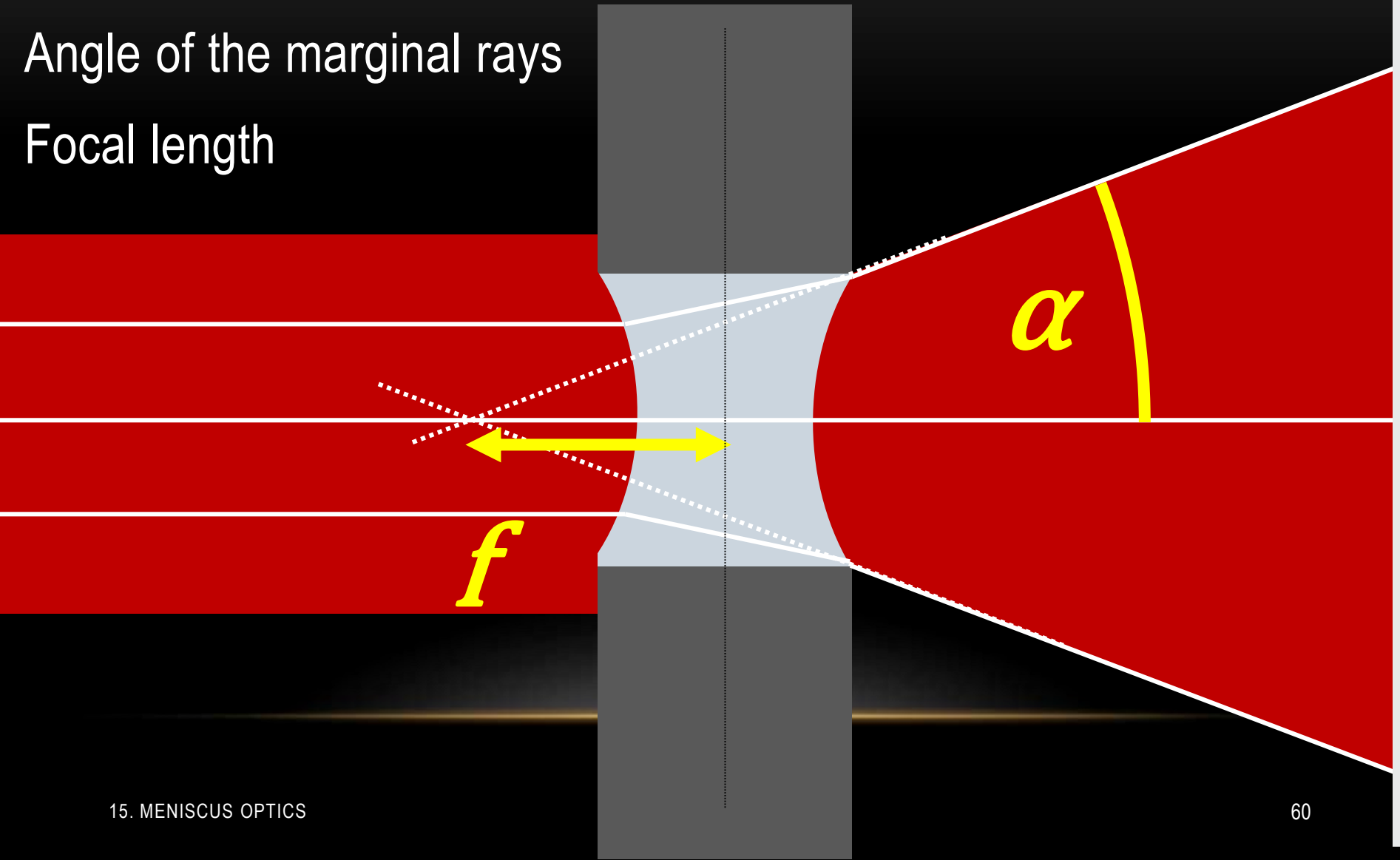


NEVYMAZANE

RELEVANT QUANTITIES TO MEASURE

Angle of the marginal rays

Focal length



MEASUREMENTS

Set parameters ***t, w, d***

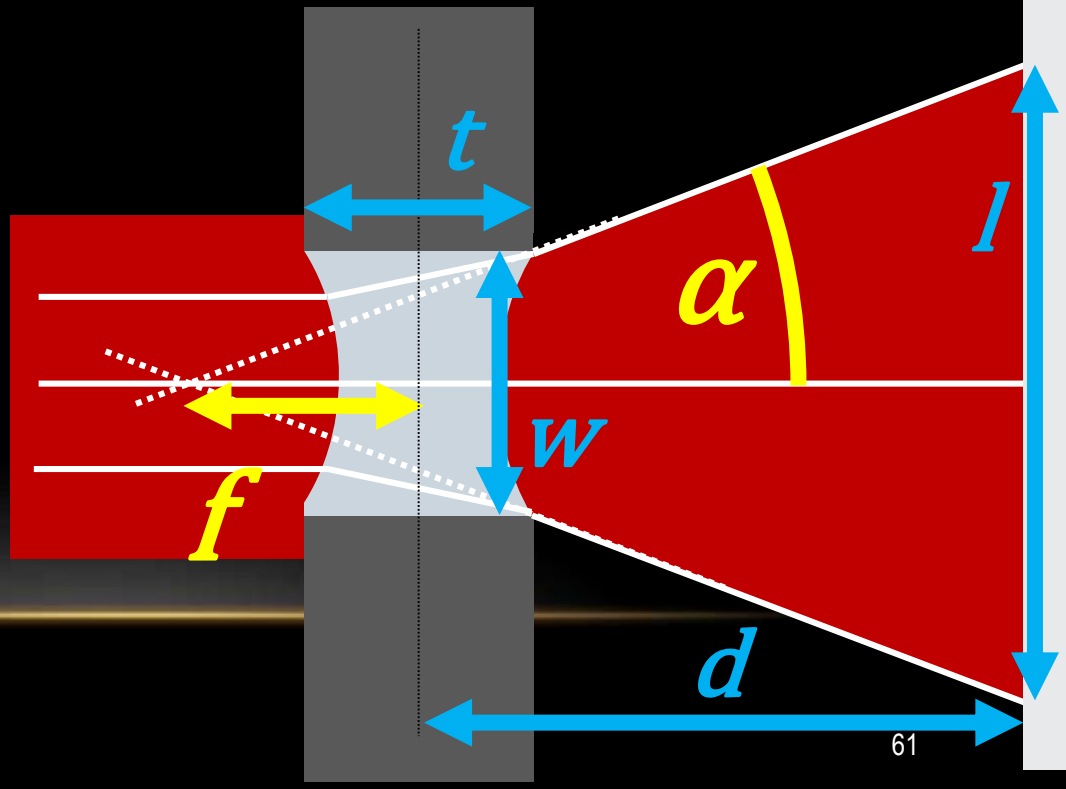
Measuring ***l***

Calculating ***α, f***

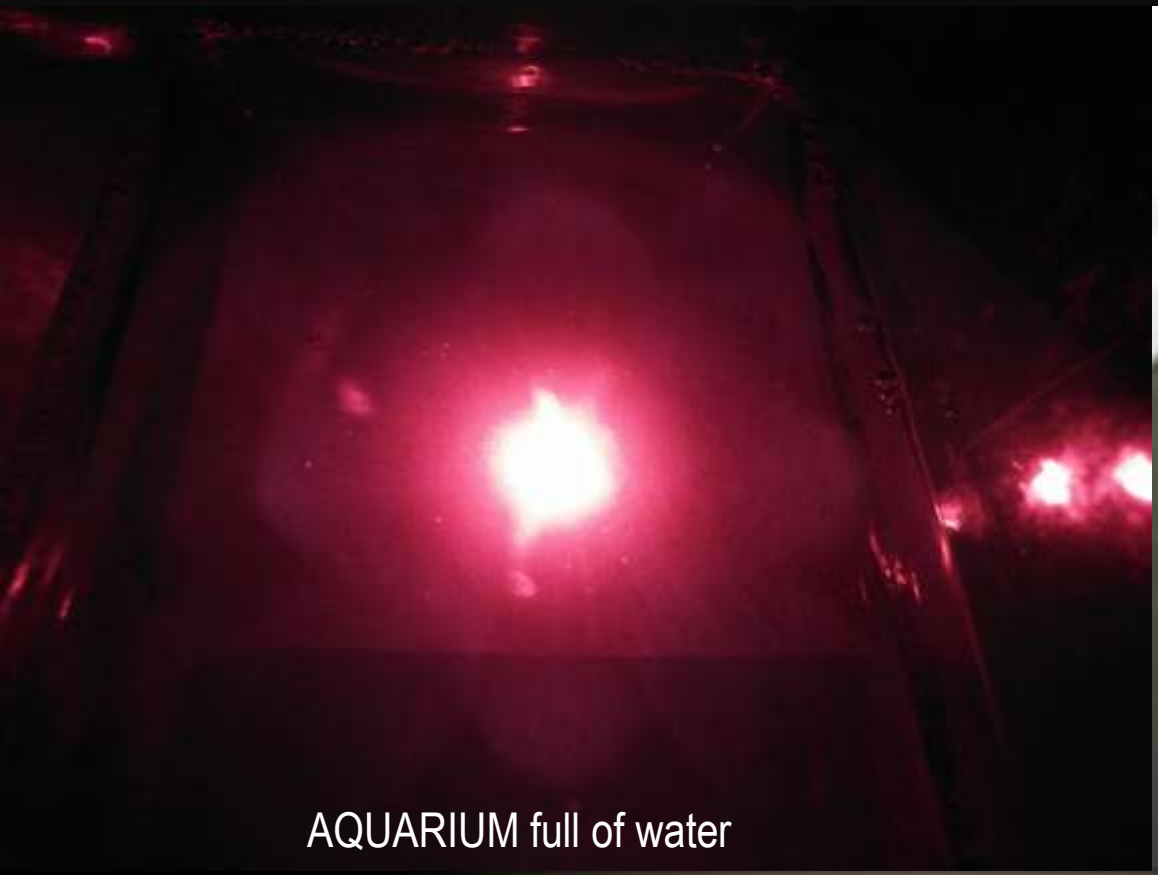
$$\tan\alpha = \frac{\frac{l}{2} - \frac{w}{2}}{d - \frac{t}{2}} = \frac{w}{f + \frac{t}{2}}$$

$$\alpha = \arctan\left(\frac{l - w}{2d - t}\right)$$

$$f = \frac{w}{\tan\alpha} - \frac{t}{2}$$



IS IT THE WATER, OR THE SHAPE?



AQUARIUM full of water

SOAP FILM