

A telescopic periscope for beam positioning on the DarkLight scintillator

Part 1

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We are going to be running the experiment for ~1000 hours of beam time

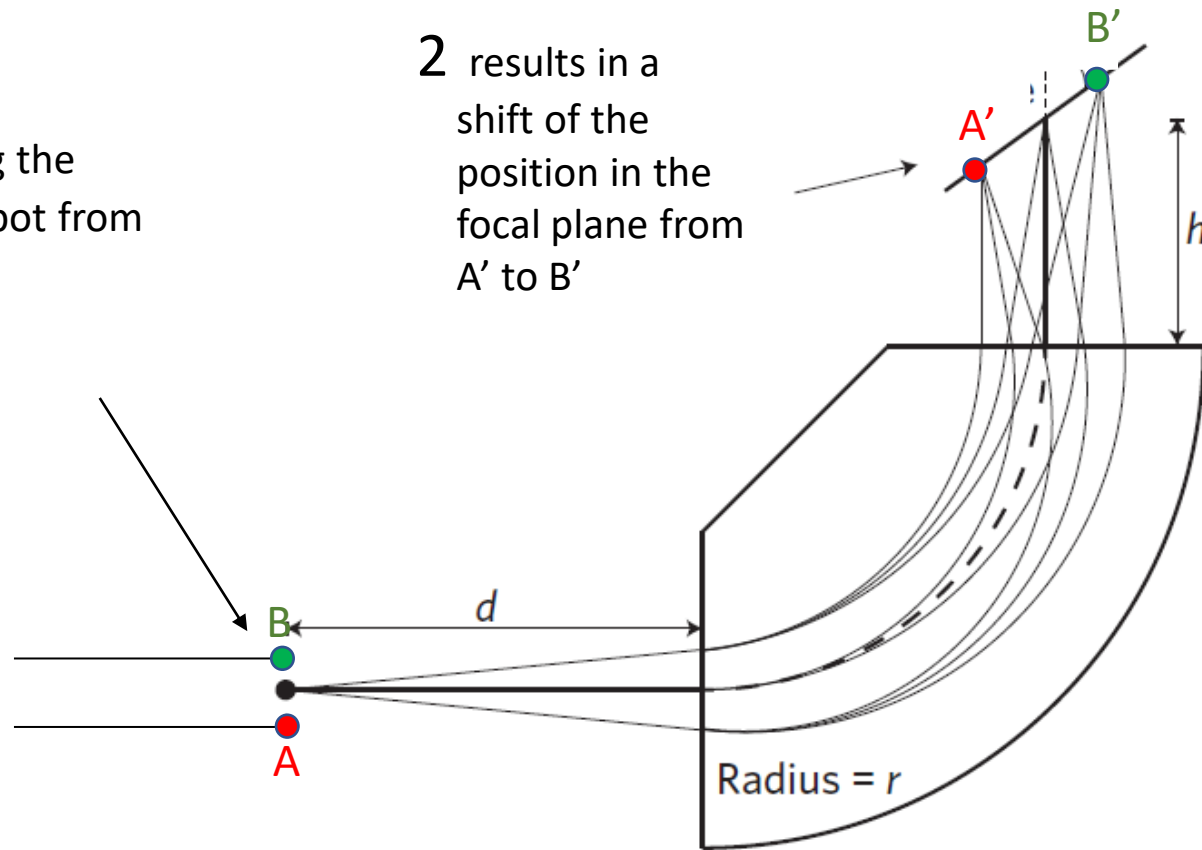
This will mean multiple runs, with breaks in between where the accelerator may be down, or retuned to different energies for other experiments.

It will be important to place the beamspot in exactly the same place each time we run, because if you view the spectrometer as a focusing lens system, a shift in the beamspot position on target (= shift in the object position) results in a shift in the position in the focal plane of each spectrometer, (=shift in the image position) and hence a shift in the energy of the putative resonance peak that the DarkLight experiment is searching for.

1 Shifting the beamspot from A to B

2 results in a shift of the position in the focal plane from A' to B'

3 and hence a shift in the energy of the lepton detected by each spectrometer



How well do we need to reproduce the beamspot position?

This is estimated in the appendix.

In the 50 MeV experiment, if the beam position on target shifts by 1 mm, the invariant mass of the detected dilepton pair shifts by ~ 52 keV.

This is to be compared to the ~ 150 keV invariant mass resolution from the TDR (Oct 18, 2022).

If these are random errors which add in quadrature, a 1 mm random shift results in worsening the invariant mass resolution by about 10%.

The present setup:

DL target chamber

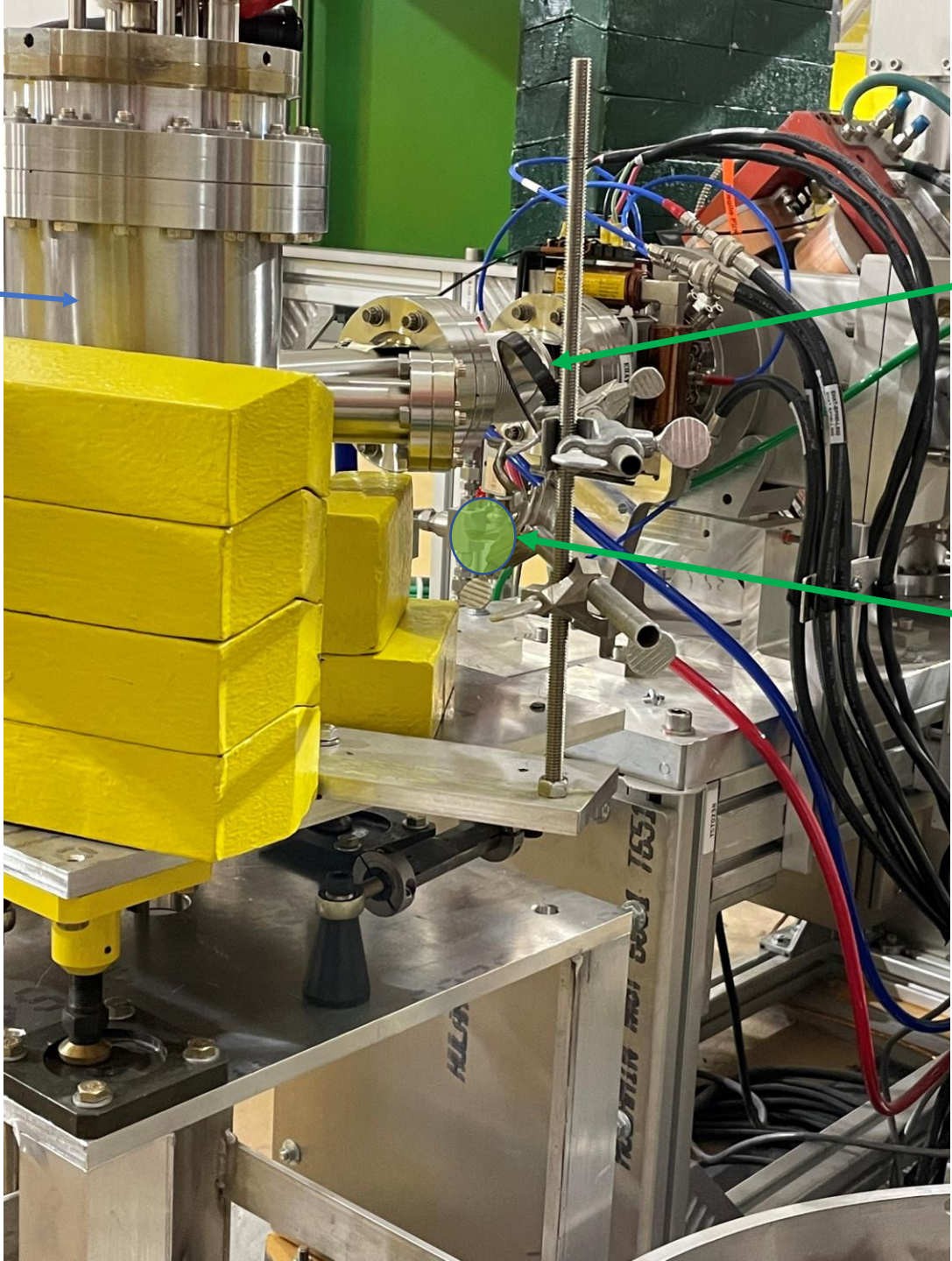


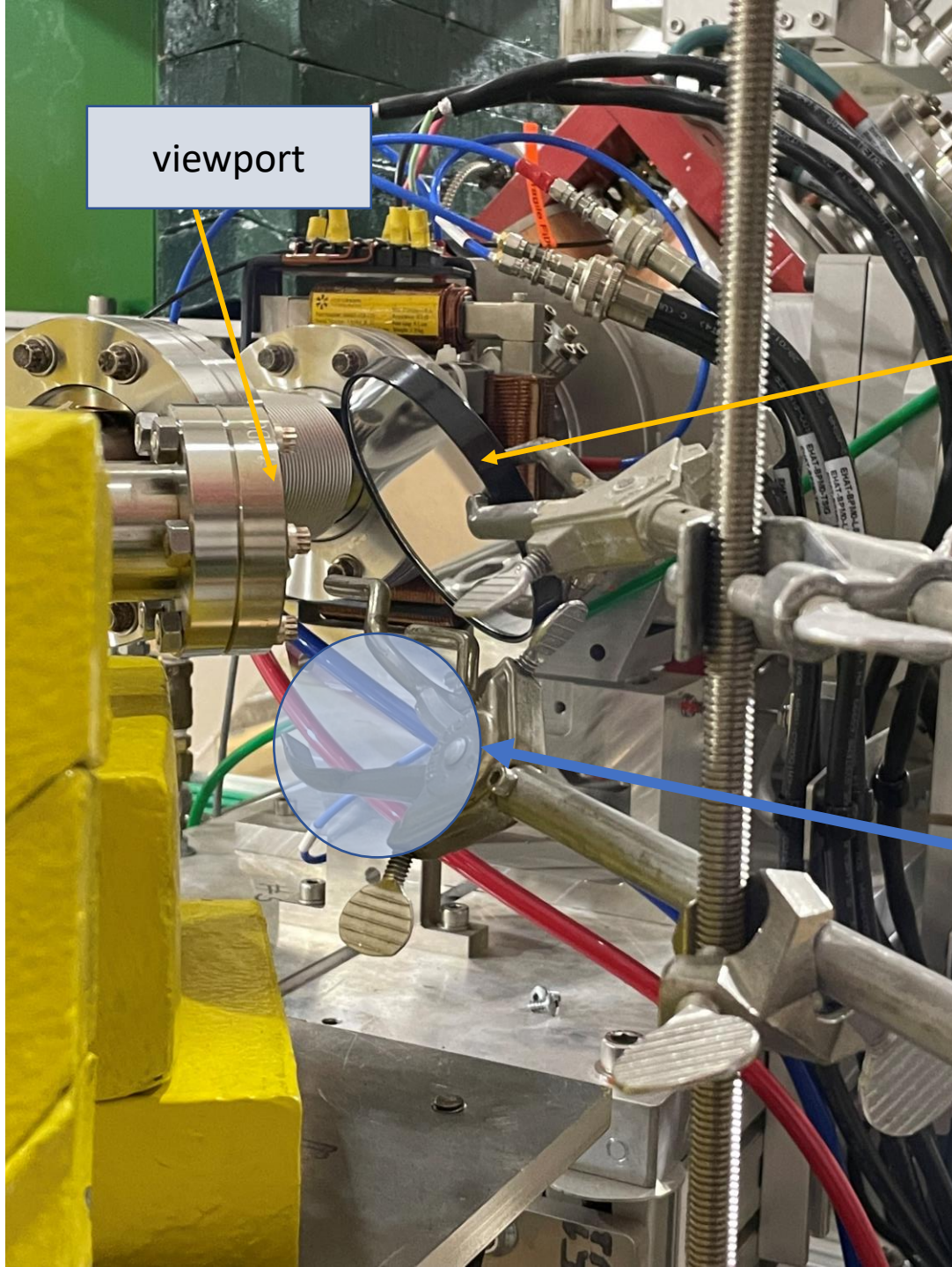
Beam direction

Magnifying mirror



Webcam sits here



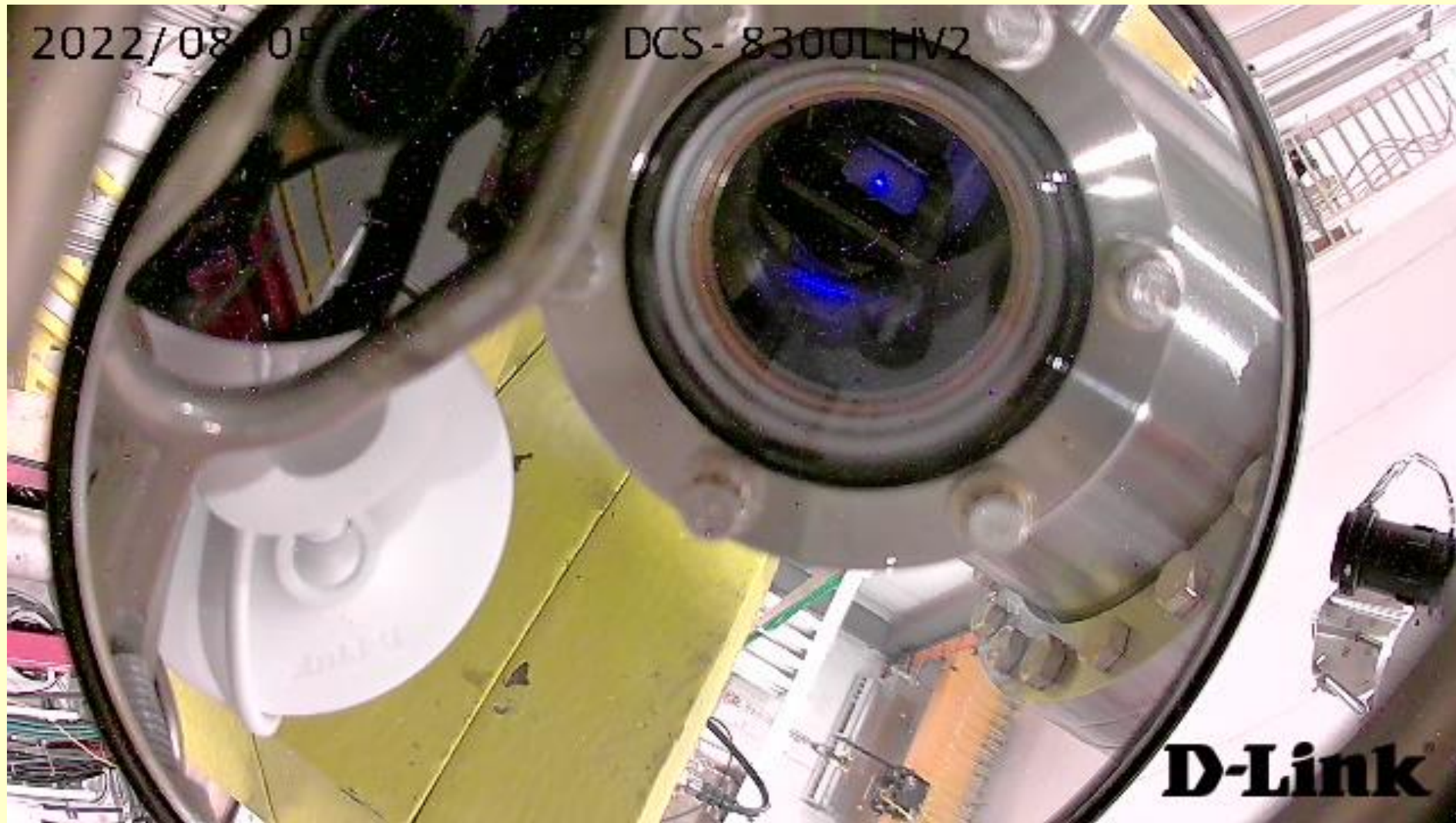


viewport

Magnifying mirror

Webcam sits here





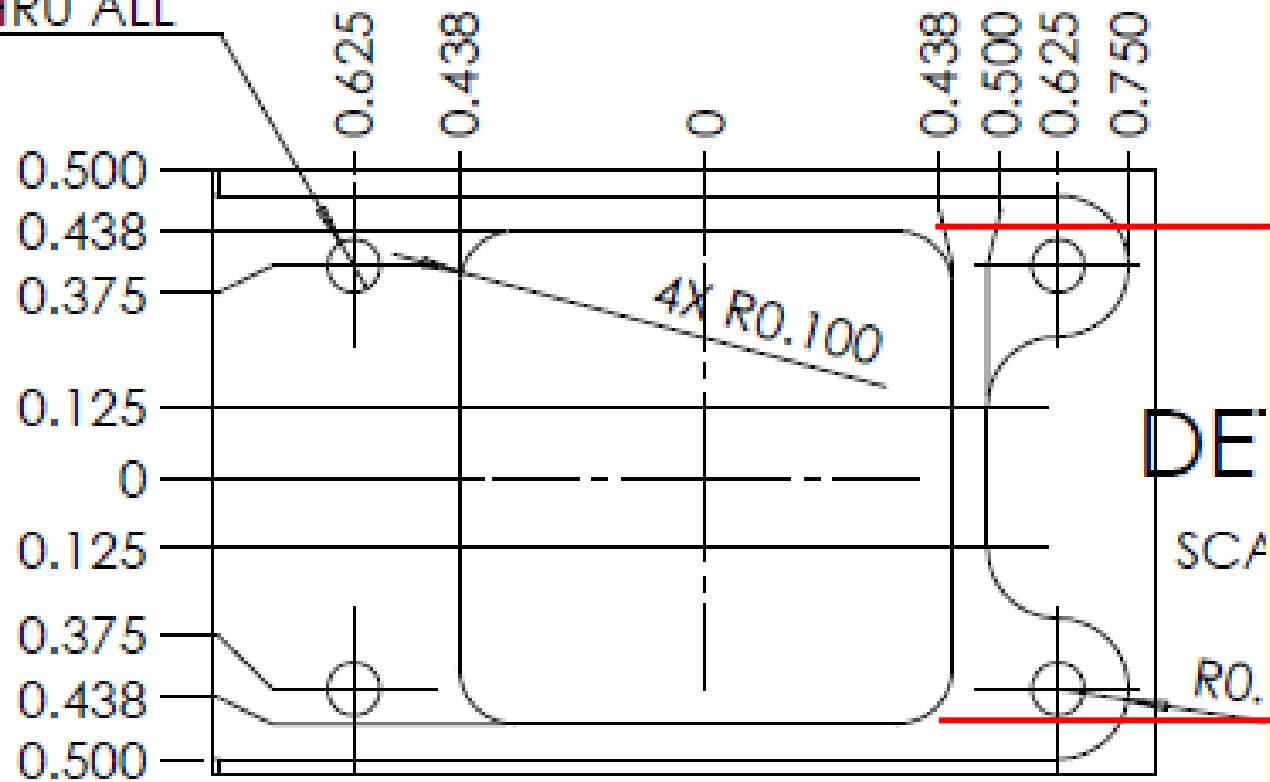
Presently, this is what the webcam viewing the target scintillation screen sees.

The scintillator is only a small fraction of the total field of view, making it hard to see misplacement of the beamspot by only 1 mm



We can digitally zoom in and crop the image, but now the image is starting to get grainy. It would be better to have more magnification in the first place, so that the scintillation screen fills up most of the viewing area.

THRU ALL



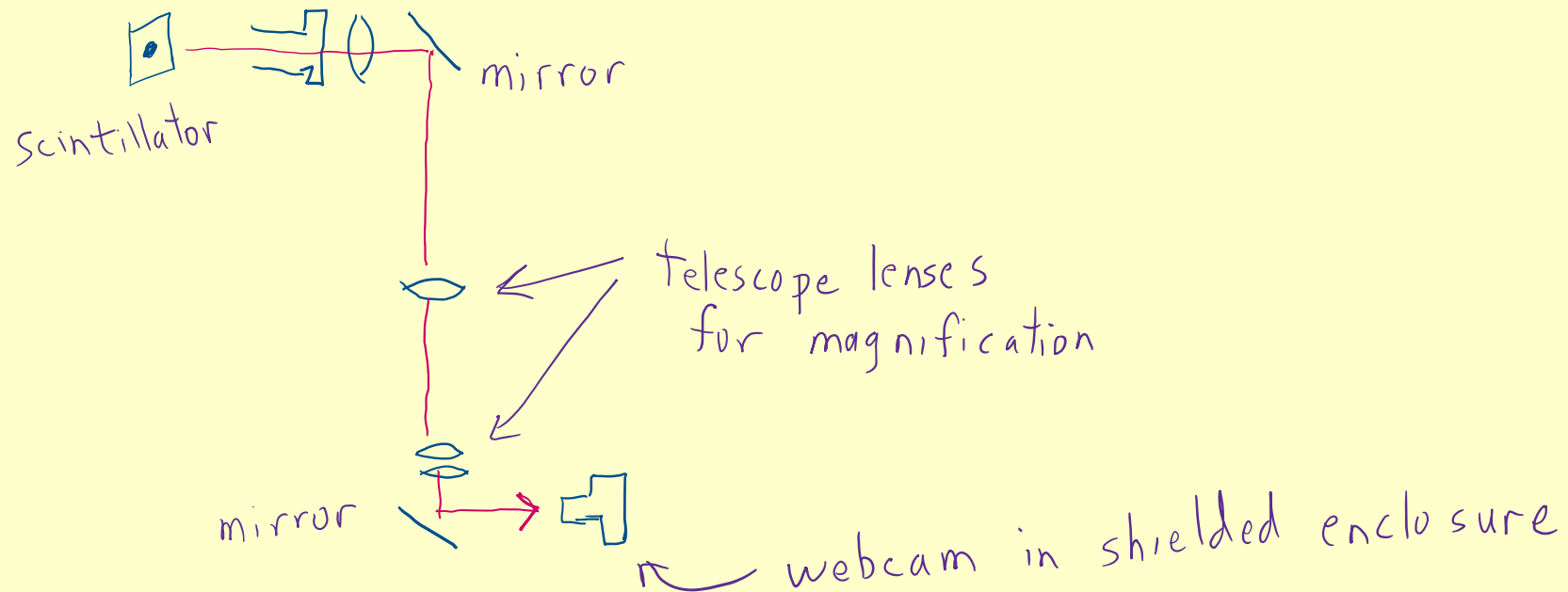
Active area of BeO scintillator screen

2 x 0.438 inch
= 22.25 mm

Problems with current setup:

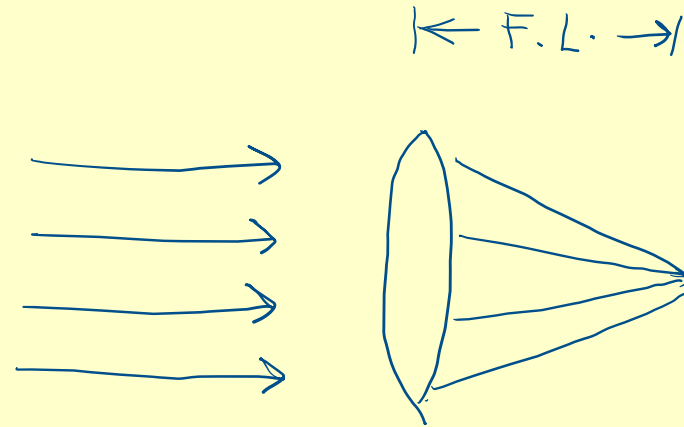
1. Scintillator screen too small on the monitor – we need more magnification, to zoom into the scintillator itself
2. Webcam is close to the beamline and is exposed to radiation, which will kill it over time.
3. Optical components are not rigidly mounted, can easily fall out of alignment.

We want this instead:



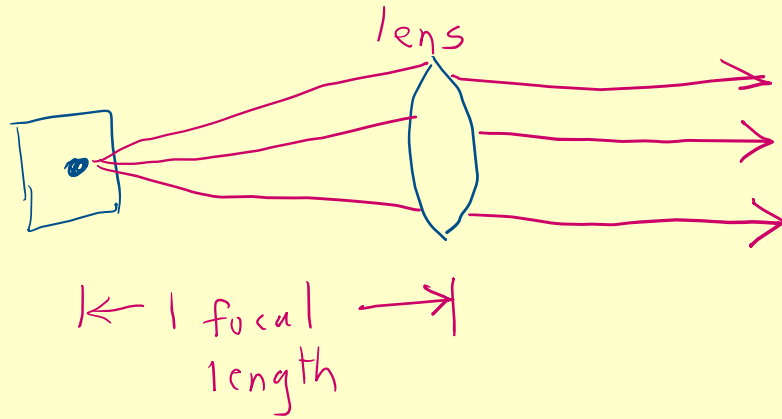
Optical design:

Recall that parallel light rays from an object at infinity (e.g. a star) passing through a focusing lens will converge at one point; this distance is by definition the focal length of the lens:



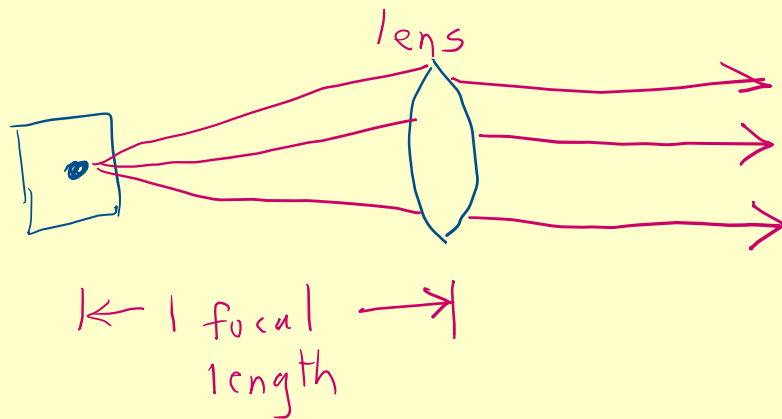
We can also run the light rays in the above diagram backwards.

If we place a lens one focal length away from the beamspot on the scintillator, the light rays from that beamspot will emerge as parallel rays after passing through the lens

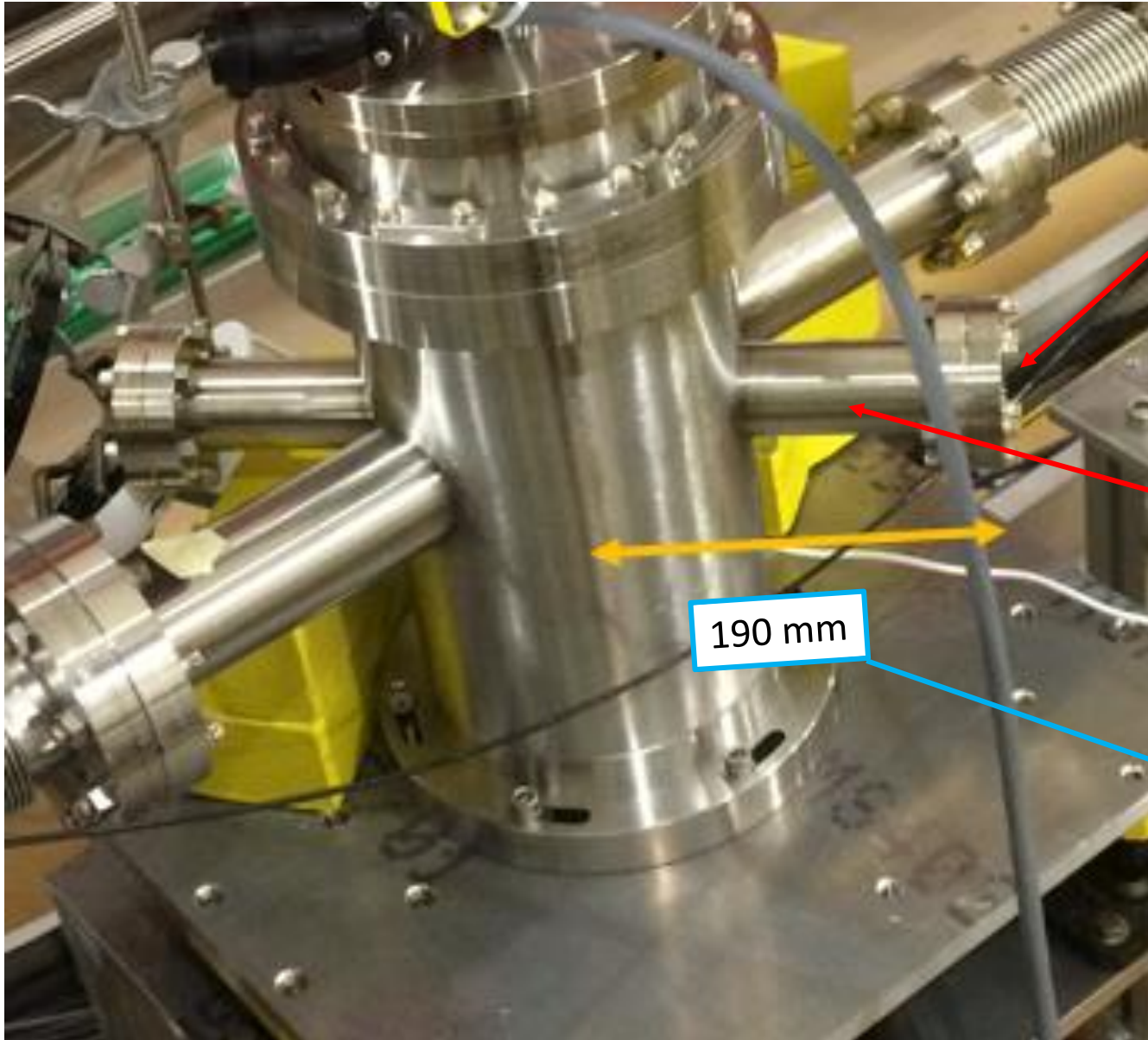


i.e. that beamspot will look like a star at infinity!

If we now take a telescope focused at infinity, and place it after the lens, we will see a magnified image of the beamspot through the telescope. As far as the telescope is concerned, it is looking at starlight coming from infinity.



We will replicate the above optical design for DarkLight.



40 mm clear aperture
glass viewport window

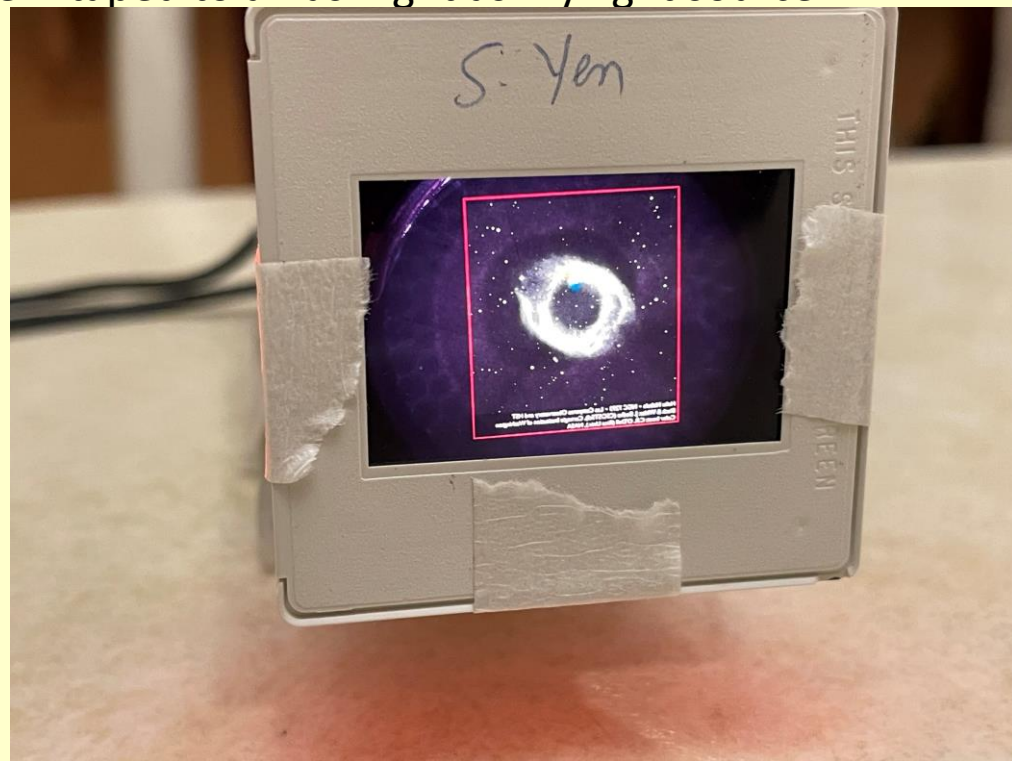
35 mm ID pipe

190 mm

Beam to viewport distance is 190 mm. If I were to mount a lens of 190 mm focal length right against the glass viewport window, The light from the beamspot on the target scintillator will emerge as parallel rays, as desired.

It so happens I'm an amateur astronomer, and I've got a bunch of surplus lenses lying around ... including one of close to 190 mm focal length!
I did some prototyping on my kitchen table.

The 22.25 mm size of the scintillator screen closely resembles the 24 x 35 mm area of a 35 mm slide of years gone by, so I used one of them taped to a flashlight as my light source.



Light source



Achromatic lens
50mm diameter
X 190 mm focal length



190 mm

Home-made telescope
with 90° elbow,
magnification about 4x

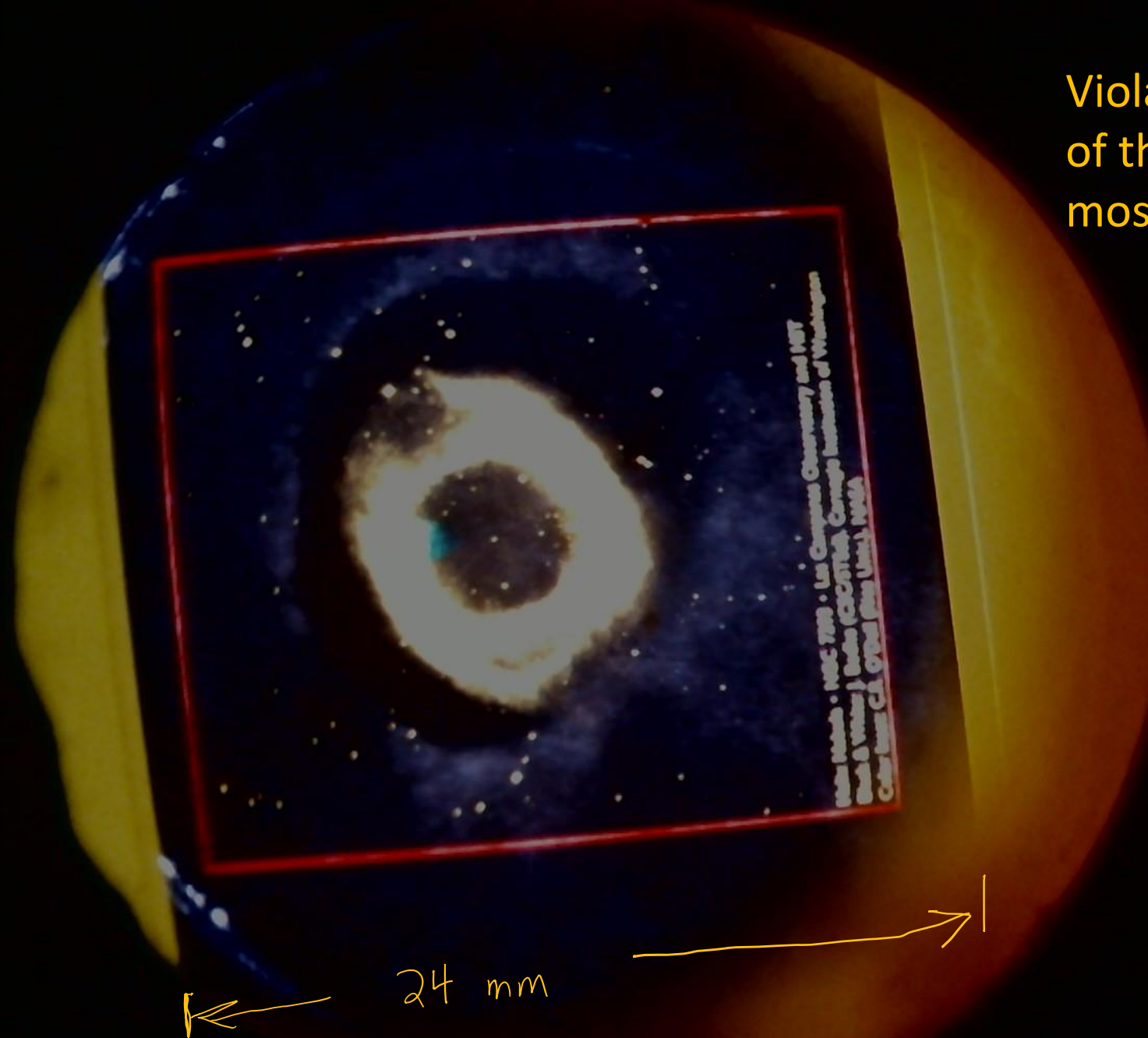


my optical bench

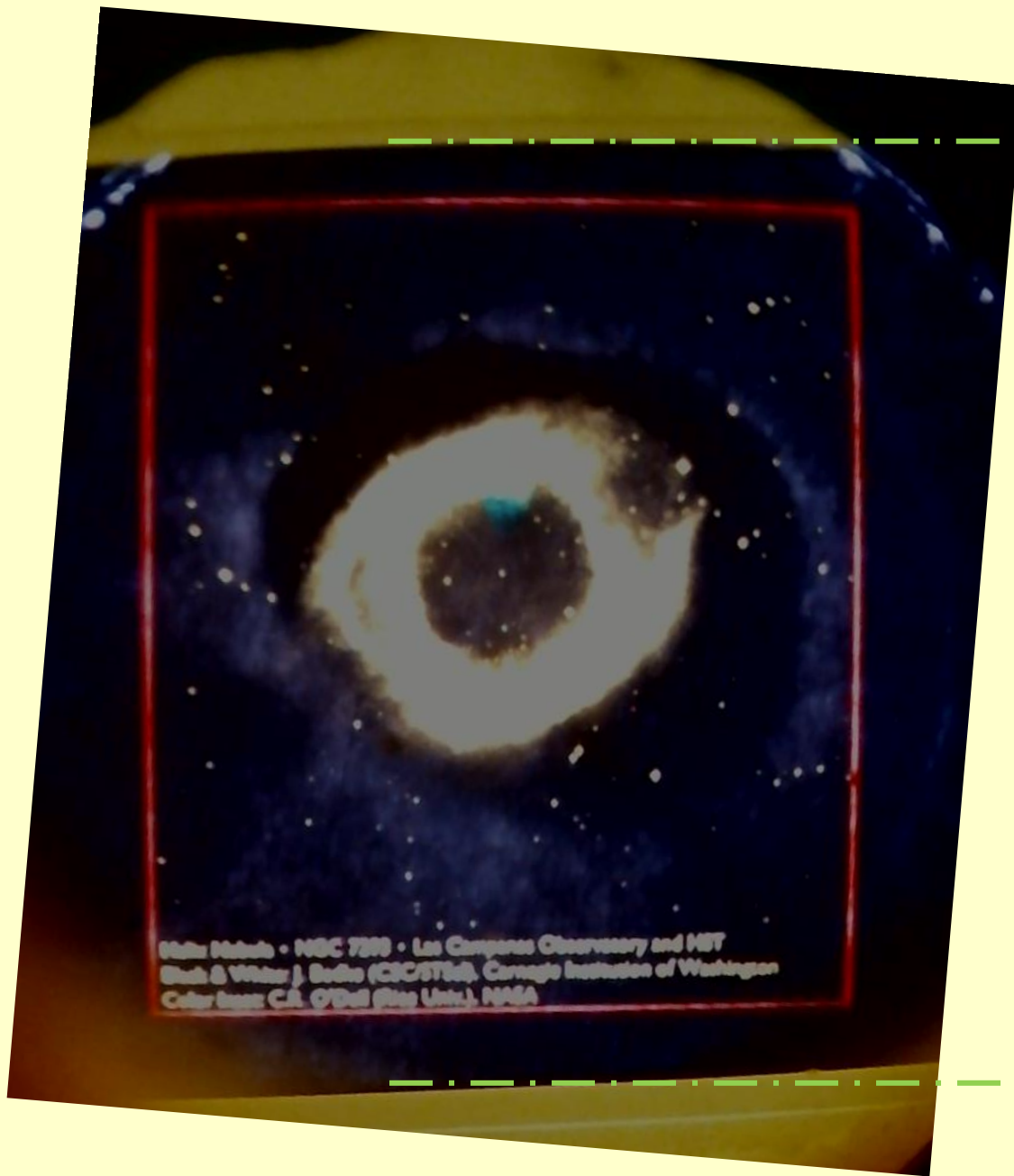
I couldn't get the D-link Webcam that we are using in the beam area to work on my phone or on my laptop computer, but my own webcam has similar optical specs, so I placed it behind the eyepiece of the telescope.



Viola ! The 24 mm dimension of the slide nicely fills up most of the monitor!

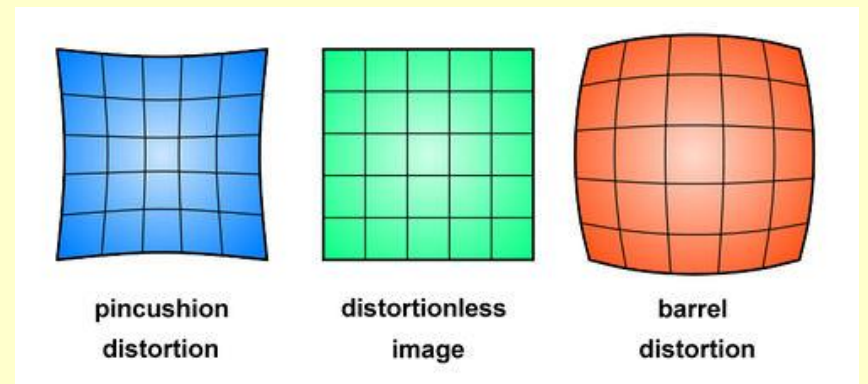


24 mm



24 mm

- Focus very good at centre, intrinsic resolution ~ 0.2 mm judging from the size of the star at the center
- should easily be able to reproduce beamspot position to better than 1 mm
- Some non-linear distortion visible

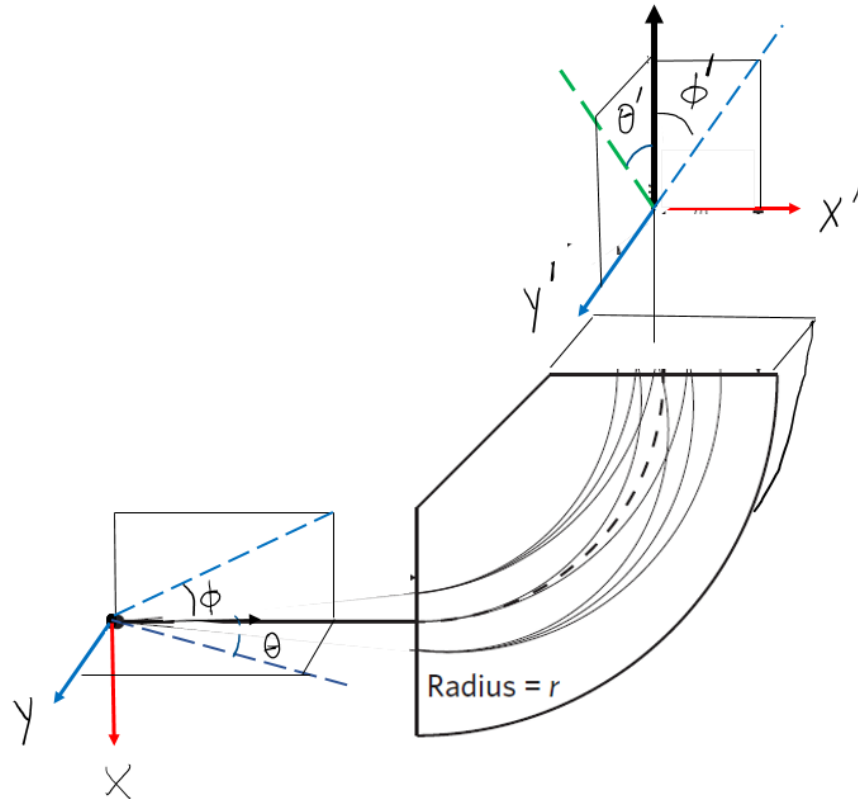


Next steps:

1. Try it with the D-Link webcam that we are using in the beam area
2. Order front-surface mirrors to fold the system into a periscope.
3. Design mechanical support system for the optical components.
4. Test it with beam!

Appendix:

Calculating the effect of a beam shift of 1 mm on the missing mass resolution



We use the coordinate system shown at the left, where the x, x' axes are in the bend plane of the spectrometer magnet.

Since we determine momentum deviation $\delta = \frac{P - P_0}{P_0}$

using $X_f = R_{16} \delta$

then the uncertainty in momentum $\Delta\delta = \frac{\Delta P}{P_0}$

is given by

$$\Delta X_f = R_{16} \frac{\Delta P}{P_0}$$

$$\text{or } \Delta P = P_0 \frac{\Delta X_f}{R_{16}} = P_0 \frac{R_{11}}{R_{16}} \Delta X_i$$

Beam transport notation:

$$R_{11} \equiv \frac{\partial X'}{\partial X} = \text{magnification}$$

$$R_{16} \equiv \frac{\partial X'}{\partial P} = \text{dispersion}$$

This tells us the momentum shift Δp in each spectrometer that results from a shift Δx_i of beam position on the target

From Harald Merkel's presentation at May 2022 collaboration meeting and private communications afterwards, $R_{11} = -0.77$

and $\frac{dP}{dx'} = 0.00172 /_{\text{mm}} = 0.172 \% / \text{mm}$

or $R_{16} = \frac{dx'}{dP} = 581.4 \text{ mm}$

so $\Delta p = p_0 \frac{R_{11}}{R_{16}} \Delta X_i = p_0 \frac{(0.77)}{581.4} \Delta X_i \leftarrow \text{in mm}$
 $= p_0 \ 0.00132 \ \Delta X_i \leftarrow \text{in mm}$

So 1 mm shift in $X_i \equiv$ momentum shift $\frac{\Delta p}{p_0} = 0.00132$
 $= 0.132\%$

in each of the two spectrometers.

For the experiment with 50 MeV beam, suppose that each spectrometer is at a central momentum of 20 MeV. The shift in the measured energy in each spectrometer would be

$$0.132\% \times 20 \text{ MeV} = 26 \text{ KeV}$$

and the shift in the invariant mass (measured with both spectrometers) is twice this, or 52 keV. This is to be compared to the estimated mass resolution of ~150 keV, from the TDR (Oct 18, 2022 revision).

Since these are assumed to be random Gaussian errors, which add in quadrature, 1 mm spread in the beam positions add about 10% to the missing mass resolution.