P. Kitching

We propose to use a semiconductor laser to produce an expanded parallel beam illuminating a circular aperture (pinhole) attached to the detector. The light passing through the pinhole falls on a small CCD camera with the lens removed. Four sets of such an apparatus are envisioned, which will overdetermine the position and orientation of the detector in the x-y plane. The detector position in z can be fixed by a stop on the track in the solenoid, or by a variation of the technique proposed here.

1 Apparatus

The lasers are mounted on the downstream endplug of the magnet yoke. They will then move with the endplug when the detector package is withdrawn from the solenoid.

Two pinholes are mounted on the upstream, two on the downstream G10 endplates of detector stack. The CCD cameras are attached to the upstream endplug of the yoke

1.1 Layout of detector and alignment system

Shown below are two figures. The first Figure shows the layout of the G10 endplates of the detector, with four possible locations for the pinholes at the ends of the four protruding "arms".The second depicts the layout of the E614 experiment with one laser-pinhole-CCD camera set of alignment tools.

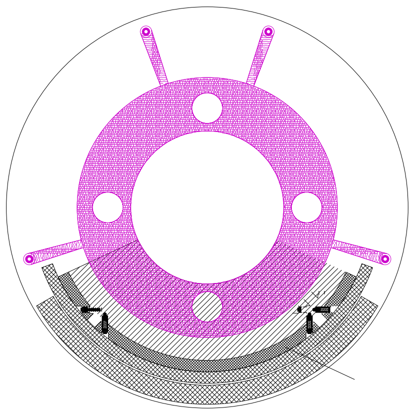


Figure 1: G10 End-plate.

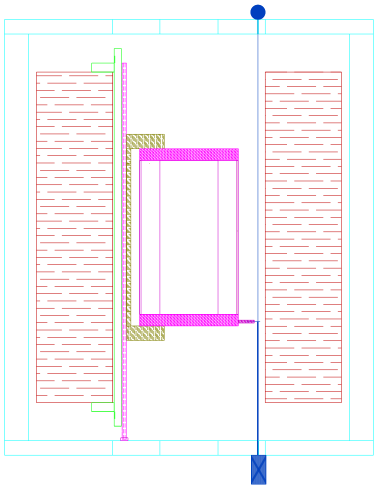


Figure 2: Layout of detector with single laser alignment set.

1.1.1 Dimensions of E614 system

```
> Laser_CCD :=3000;
```

$$Laser\_CCD := 3000$$

```
> Det_stack :=1060;
```

$$Det\_stack := 1060$$

```
> Laser_targ_down :=(Laser_CCD-Det_stack)/2;
```

$$Laser\_targ\_down := 970$$

```
> CCD_targ_down := Laser_CCD-Laser_targ_down;
```

$$CCD\_targ\_down := 2030$$

```
> CCD_targ_up :=(Laser_CCD-Det_stack)/2;
```

$$CCD\_targ\_up := 970$$

```
> Laser_targ_up := Laser_CCD-Laser_targ_down;
```

$$Laser\_targ\_up := 2030$$

```
> data_list:=[[CCD_targ_up,2.4e+6],[CCD_targ_up,0],[CCD_targ_down,0],[CCD_targ_down,2.4e+6]];
```

$$data\_list := [[970, .24\,10^7], [970, 0], [2030, 0], [2030, .24\,10^7]]$$

1.2 Laser:

With the use of a beam expander a semiconductor laser can produce beam a few m in extent with a wavelength typically 630 nm and a divergence of less than 1 mr.

```
> lambda :=630*10^(-6);
```

$$\lambda := \frac{63}{100000}$$

1.3 CCD Camera:

We propose to use the "QuickCam" model,which has a 3.2 mm by 2.4 mm CCD with 320 by 240 pixels and a pixel size of 10 microns.

2 Theory of light intensity from a circular aperture

We assume parallel light from the laser falling perpendicular to a small circular aperture of radius "a".From Fresnel diffraction theory, one can show

2.1 Intensity distribution along z-axis, perpendicular to aperture

A circular aperture of radius a gives rise to an intensity distribution along the z-axis of

```
> Intensity:=z -> (1-cos(Pi*a^2/(z*lambda)))/(2*lambda**2);
```

$$Intensity := z \to \frac{1}{2}\,\frac{1-\cos(\frac{\pi\,a^2}{z\,\lambda})}{\lambda^2}$$

2.2 Radial intensity distribution

The theoretical prediction for the intensity in the diffraction pattern formed by a circular aperture is given by the function Fresnel(x), where,if r is the radial distance from the z-axis through the centre of the aperture, then

```
> x:=r -> 2*Pi*a*r/(lambda*z);
```

$$x := r \to 2\,\frac{\pi\,a\,r}{\lambda\,z}$$

```
> Fresnel:=x -> (2*BesselJ(1,x)/x)^2;
```

$$Fresnel := x \to 4\,\frac{\mathrm{BesselJ}(1,\,x)^2}{x^2}$$

3 Results for E614 Detector Setup

```
> focus:=a -> a^2/lambda;
```

$$focus := a \to \frac{a^2}{\lambda}$$

```
> a_down :=sqrt(lambda*CCD_targ_down);
```

$$a\_down := \frac{21}{100}\sqrt{29}$$

```
> evalf(a_down);
```

$$1.130884609$$

```
> a_up :=sqrt(lambda*CCD_targ_up);
```

$$a\_up := \frac{3}{100}\sqrt{679}$$

```
> evalf(a_up);
```

$$.7817288532$$

```
> a :=0.5*(a_up+a_down):
> evalf(a);
```

$$.9563067313$$

Average hole radius is 0.96 mm

3.1 Plots of intensity distributions

> With optimal hole radius, so that focus is at CCD,

```
> r_up:=a_up*x/(2*Pi);
```

$$r\_up := \frac{3}{200}\frac{\sqrt{679}\,x}{\pi}$$

```
> evalf(r_up);
```

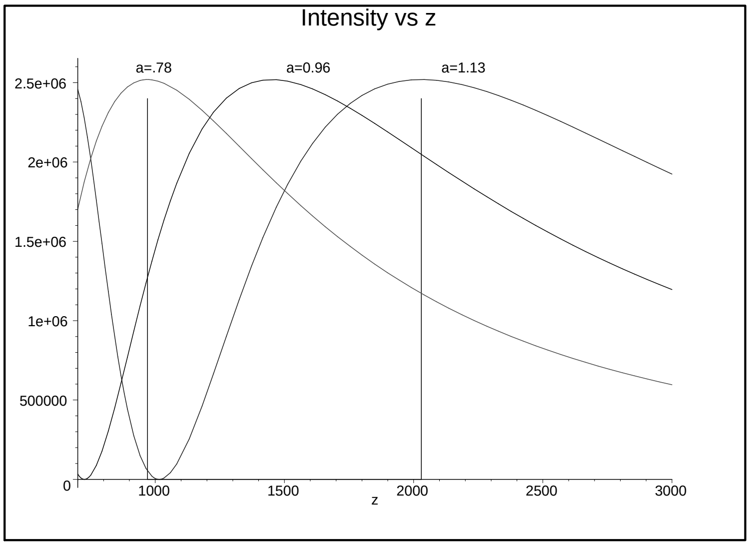
$$.1244160111\,x$$

```
> r_down:=a_down*x/(2*Pi);
> evalf(r_down);
```

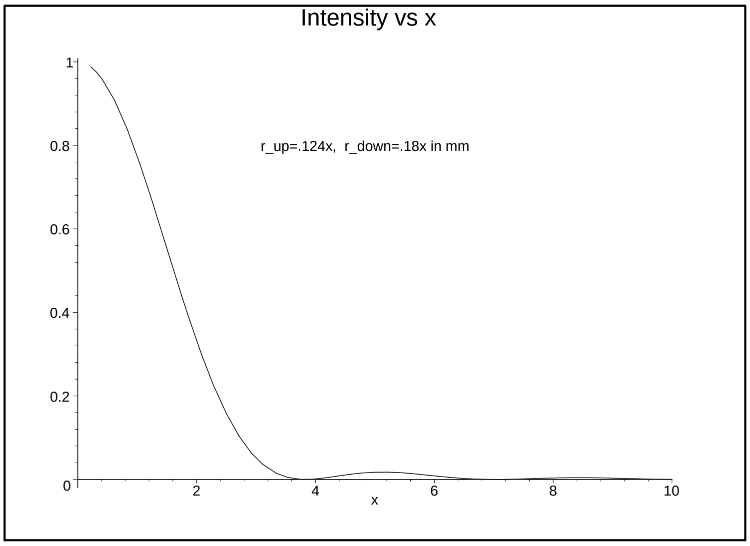
$$r\_down := \frac{21}{200}\frac{\sqrt{29}\,x}{\pi}$$

$$.1799858757\,x$$

```
> with(plots):
> p1:=plot(Intensity(z),z=700..3000,color=black):
> t1:=textplot([1600,2.6e+6,"a=0.96"]):
> a :=a_up:
> p2:=plot(Intensity(z),z=700..3000,color=red):
> t2:=textplot([1000,2.6e+6,"a=.78"]):
> a :=a_down:
> p3:=plot(Intensity(z),z=700..3000,color=blue):
> t3:=textplot([2200,2.6e+6,"a=1.13"]):
> p5:=pointplot(data_list,style=line):
> t6:=textplot([5,0.8,"r_up=.124x, r_down=.18x in mm"]):
> p6:=plot(Fresnel(x),x=0..10,color=black):
> display(p1,t1,p2,t2,p3,t3,p5,title="Intensity vs z");
```




```
>  display(p6,t6,title="Intensity vs x");
```



4 Test of Concept

We have studied a basic system consisting of a semiconductor laser, a 1mm circular aperture and a "QuickCam" CCD camera in a student project at the University of Alberta. The overall conclusions of this study were that

1) there is a one-to-one correlation between the position of the aperture and the diffraction pattern observed in the CCD camera

2) the position of the centroid of the diffraction pattern can be determined to better than 50 microns. Hence the location of the circular aperture in the X-Y plane can be determined to this kind of accuracy

5 Conclusions:

We propose an inexpensive laser-pinhole-CCD system for aligning the X-Y position of the E614 detector package. By using four such systems, two attached to the upstream end of the detector package, and two to the downstream end, we should be able to overdetermine the orientation of the detector and its X-Y location. Its position in z must be found by either using a stop, or by a variation of the system described here in which the laser beam impinges at an angle to one end face of the detector and is reflected by a mirror, after passing through a small circular aperture attached to the face. The diffraction patter is then detected by another CCD camera. One the design of detector support structure is finalised, we can proceed to detailed design of the alignment system