Focussing Light Guide Optimisation

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last changes to TeX-file July 9, 2006

1 Curved Light Guide

Simulation macros `curvedlightguide26.pcm` and `curvedlightguide25.pcm` combined. Use PHYSICA from TRIUMF to run these macro programs.

Both macros together simulate a focussing lightguide and optimise the curvature to minimise the spread of the focal lines.

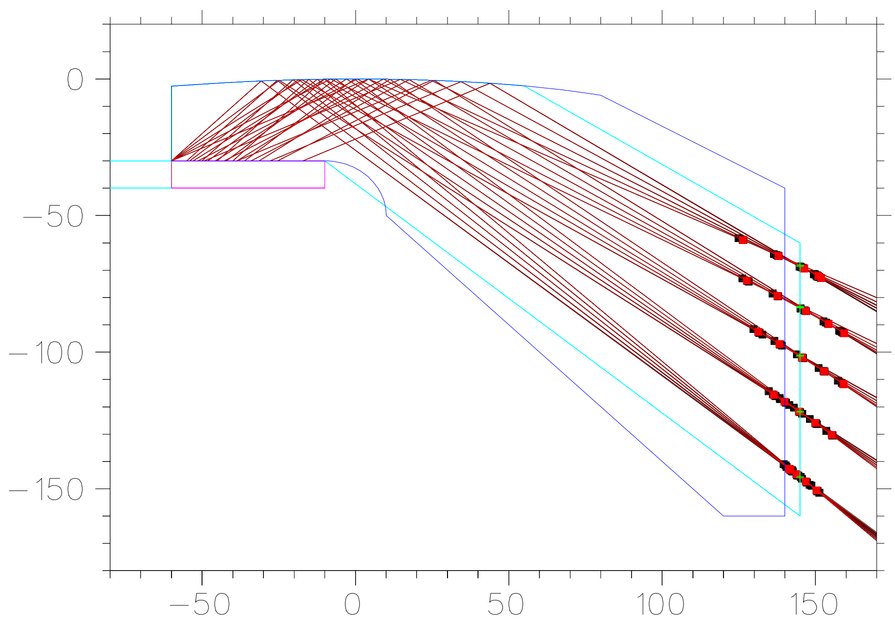

Figure 1: File `fit_proofofconceptc.eps` with lightguide shape as given to workshop in Edinburgh end of June 2006. Polynomial coefficients a2=-7.90925198e-4 a3=1.99383464E-02e-6 a4=-1.49911701E-01e-8 a5=-2.71815083e-10.

The focussing light guides simulated are to sit on the rim of a glass plate. In the visualisation the glass plate is light blue to the left, the magenta rectangle is a LiF plate to correct for chromatic effects, but is not part of this simulation. The light rays start on a plane currenly hard-wired to be at –30, units are thought to be millimetres but the design may be scaled. The simulation restricts itself to the 2-dimension x-y-plane, as all surfaces being parallel or perpendicular to the z-axis the z coordinate does not influence the x and y ray shapes.

The simulation is not a comprehensive raytrace simulation as it assumes that the light ray paths are predetermined, they are totally reflected on the curved surface and then hit the focal plane. The lines continue unrefracted outside the lightguide to show the focussing quality.

For each ray a focussing point is calculated based on the curvature, it gives an idea on how well the focussing can be done. Ideally all these square-shaped blobs are sitting on the focal plane line.

The (in this plot) vertical part of the light blue line at the right is the focal plane assumed for the optimisation. The dark blue line is a partially hard-coded shape with coordinates to go to the computer-controlled workshop machinery. The right edge stops short of the focal plane to allow for photomultiplier window thickness with the focus ideally being on the photocathode. In case of a thinner window this distance of 5mm should be padded with thin glass pieces.

2 Simulation macro 26 description

Macro `curvedlightguide26.pcm` is the outer shell. It asks to input some geometry quantities and start values for the polynome descibing the curvature. One may start with reasonably random values but then should do another iteration.

The optimisation is based on a set of light rays, currently 25 forming 5 bundles of 5 parallel rays each. ttt is the angle in degrees (hence the use of sind, cosd, tand instead of sin, cos, tan functions), xxx the offset relative to (–60,–30). $xxxx/tan(\theta)$ is meant to cover the length where light emerges from the purple plate (beware possible refraction). The disc thickness of originally 10mm is now the input parameter dd.

v01 to v05 are index vectors, one for each ray bundle, and needed to allow the fit to determine the focal point for each bundle.

The curvature is given by a polynomial with coefficients a2 to a5, making the curve horizontal in (0,0). The values entered are scaled with 0.01^n to keep the order of magnitude at unity. The focal plane is assumed to be flat but can be oriented arbitrarily.

The optimisation computes the focal plane positions for the start polynomial coeffients as reference and then extra sets with each coefficient in turn being offset by $(-0.1) \times 0.01^n$. From the reference plus the differences scaled with fit parameters one subtracts the assumed focal plane positions (fit variables as well), for this quantity for all 25 rays the fit then performs a least-squares optimisation.

There is no explicit weight in the fitting equation, an implicit weight comes from the choice of light rays.

At the end of the macro the light guide shape is drawn and the coordinates saved to file contour.dat, this light guide shape is a little bit arbitrary.

3 Simulation macro 25 description

Macro `curvedlightguide25.pcm` is subroutine to 26 and mainly computes the reflection position and angle on the curved surface, and then returns the focal plane positions in vector yf80. It also draws the ray lines and the square focus blobs.

A set of x coordinates from –60 to +110 is generated. To find the x intersection value the inverse function is interpolated at x(y=0), y being the (curve minus light ray). Slope and curvature are then computed analytically from the polynomial coefficients. The interpolation requires a mononically increasing function, for unusual polynomial values this may fail. Plot y versus x to check the shape. When going from forth to fifth order polynomials, it was necessary at one point to narrow down the range, previously it was from –60 to +120. But is was found that the focus spot size did barely improve from this extra degree of freedom.

If one wanted to really improve on the focussing quality, a second reflection on a curved surface at around y=–40 to –50 could be a way to go as the bundles of initially parallel rays are better separated here and the focussing could be tweaked individually for each bundle (range).

4 Results

Different x coordinates for the focal plane allow the range of ray angles (somewhere from 25 to 45 degrees) to different lengths on the focal plane, depending on photo detector availability and granularity. One try was to get this length smaller than 50mm or 45mm, at the cost of larger relative defocussing.

Probably the best focal plane orientation is around 80 degrees (slightly depending on position) as it best approximates the the circle (cylinder) on which the focal points (lines) of a cylindrical mirror are located.

The magnetic field may force an orientation on the photon detectors and in consequence require a specific orientation of the focal plane.

Results as recorded in `results_varyang.txt` with mostly vertical focal planes.

```
optimised parameters for vertical focal plane, coefficients c2-c4
xxx=[0;5;10;15;20;0;5;10;15;20;24;28.56;0;10;20;30;42.89]
ttt=[45;45;45;45;45;35;35;35;35;35;35;35;25;25;25;25;25]
17 light beams as been used previously
disc thickness 10mm
focal plane at x=100mm
1st iteration  -11.4091419 -1.96648238 -2.09661912
2nd iteration  -11.409953  -1.96604649 -2.09008005
mean standard_deviation
-100.874031   1.38440532E-01
-69.8900198   1.7469115E-01
-47.4562082   3.42584691E-01

optimised parameters for vertical focal plane, coefficients c2-c5
17 light beams as been used previously
disc thickness 10mm
focal plane at x=100mm
1st iteration  -11.4023744 -0.611471194 -1.30958999 -7.5168204
2nd iteration  -11.4019704 -0.608574507 -1.32033042 -7.52195729
mean standard_deviation
-100.649677   4.13747015E-02
-69.7942928   2.36953667E-01
-47.2468397   1.76651104E-01
```

```
optimised parameters for vertical focal plane, coefficients c2-c5
17 light beams as been used previously
disc thickness 10mm
focal plane at x=80mm
1st iteration  -14.2160229 -1.977157 -3.52975162 -11.5561911
2nd iteration  -14.2166511 -1.98698916 -3.53486709 -11.506169
mean standard_deviation
-80.6929457   4.62185686E-02
-55.7887846   2.42138555E-01
-37.9139154   0.178501

optimised parameters for vertical focal plane, coefficients c2-c5
17 light beams as been used previously
disc thickness 10mm
focal plane at x=150mm
1st iteration  -7.62219412 4.23317714E-01 2.26925011E-01 -4.41376347
2nd iteration  -7.62002519 4.71789258E-01 8.66667183E-02 -4.38905782
mean standard_deviation
-150.58991   3.50580389E-02
-104.806505  2.31708222E-01
-70.5733376  6.0492674E-01


focal plane (100,-75,120deg) , coefficients c2-c5
17 light beams as been used previously
disc thickness 10mm
1st iteration  -12.2112474 -7.41645432 -7.08811661 -11.4724886
2nd iteration  -12.2910353 -7.58612919 -4.65915607 -2.56572906
3rd iteration  -12.308956  -7.66391093 -4.44973788 -1.5670303
mean standard_deviation
-61.7530075   5.93718553E-01
9.14683632    4.98498738E-01
44.5894267    2.21768406E-01

focal plane (100,-75,60deg) , coefficients c2-c5
17 light beams as been used previously
disc thickness 10mm
1st iteration  -10.9220199 1.78622266 -1.17752667 -8.91479266
2nd iteration  -10.9253377 1.77141554 -1.14151656 -8.76219409
3rd iteration
mean standard_deviation
-19.6444924   1.37836249E-01
4.41862829    3.40359863E-01
25.0366909    2.04221884E-01
```

```
-------------------------------------------------------------

focal plane (100,-75,90deg) , coefficients c2-c5
25 light beams
disc thickness 10mm
1st iteration
2nd iteration  -11.4423666 -1.17007125 -1.51520063 -4.96442295
3rd iteration  -11.442224 -1.17018959 -1.5169018 -4.96045582
mean standard_deviation
-25.7344558   7.17913173E-02
-9.11762099   1.4192901E-01
5.19313223   2.29860186E-01
17.4454699   2.70369926E-01
27.6154872   2.45654746E-01

focal plane (100,-75,100deg) , coefficients c2-c5
25 light beams
disc thickness 10mm
1st iteration  -11.6451254 -2.25969188 -1.78622243 -4.93158872
2nd iteration
3rd iteration
mean standard_deviation
-30.9390305   2.87115095E-02
-10.753952    7.9448721E-02
5.91603365    1.69396983E-01
19.6599725    2.10583479E-01
30.7186858    2.25919123E-01

focal plane (100,-75,80deg) , coefficients c2-c5
25 light beams
disc thickness 10mm
1st iteration  -11.2738418 -3.49726983E-01 -1.40262682 -5.01649447
2nd iteration  -11.2727987 -3.48690033E-01 -1.41263109 -5.0125
3rd iteration
mean standard_deviation
-22.6334971   1.19407535E-01
-8.13654169   1.8040845E-01
4.75242357    2.68794746E-01
16.1194761    3.08172866E-01
25.8000344    2.60256954E-01

focal plane (145,-100,90deg) , coefficients c2-c5
25 light beams
disc thickness 10mm
1st iteration  -7.9128119 -4.42802927E-02 -1.16079834E-02 -2.74545232
```

```
2nd iteration  -7.90924085 2.00163459E-02 -1.49946043E-01 -2.7184356
3rd iteration
mean standard_deviation
-35.6765332   5.95755254E-02
-11.8701133   1.30368622E-01
8.68029057    2.23128997E-01
26.4658436    2.83957069E-01
41.6055835    2.55100342E-01

 Minimum =            -35.7195257       | Maximum =            -35.5720938
 Index of minimum =  [3]                | Index of maximum = [5]
 Sum  =               -178.382674       |
 Mean =               -35.6765348       | Geometric mean unavailable
 Median not requested                   | Variance =           3.54859744E-03
 Standard deviation = 5.95701052E-02    | Average deviation = 4.17763792E-02
 Skewness =           9.67968827E-01    | Kurtosis =           -1.04037182
 Minimum =            -12.0075805       | Maximum =            -11.6926763
 Index of minimum =  [3]                | Index of maximum = [5]
 Sum  =               -59.3506019       |
 Mean =               -11.8701204       | Geometric mean unavailable
 Median not requested                   | Variance =           1.69974503E-02
 Standard deviation = 1.3037427E-01     | Average deviation = 1.08306168E-01
 Skewness =           2.89473937E-01    | Kurtosis =           -1.98646521
 Minimum =            8.44231417        | Maximum =            8.96235003
 Index of minimum =  [3]                | Index of maximum = [5]
 Sum  =               43.4014327        |
 Mean =               8.68028655        | Geometric mean =     8.67800256
 Median not requested                   | Variance =           4.9786502E-02
 Standard deviation = 2.23128891E-01    | Average deviation = 1.87952278E-01
 Skewness =           2.19591245E-01    | Kurtosis =           -2.09575785
 Minimum =            26.1644983        | Maximum =            26.813012
 Index of minimum =  [3]                | Index of maximum = [5]
 Sum  =               132.329201        |
 Mean =               26.4658401        | Geometric mean =     26.4646234
 Median not requested                   | Variance =           8.06284668E-02
 Standard deviation = 2.83951522E-01    | Average deviation = 2.3832153E-01
 Skewness =           1.81822771E-01    | Kurtosis =           -2.12832733
 Minimum =            41.3761555        | Maximum =            42.0304518
 Index of minimum =  [3]                | Index of maximum = [1]
 Sum  =               208.027882        |
 Mean =               41.6055765        | Geometric mean =     41.6049532
 Median not requested                   | Variance =           6.5078555E-02
 Standard deviation = 2.55104988E-01    | Average deviation = 1.82636898E-01
 Skewness =           7.4213213E-01     | Kurtosis =           -1.3132542
 -7.90923204
```

```
 1.9987148E-02
 -1.5003795E-01
 -2.71818946
```

5 Macro code lines

For the simulation macros for PHYSICA from TRIUMF are used.

5.1 curvedlightguide26.pcm

```
! version 26   keeping 24 stable for now
! version 24   calling 23  - together performing lightguide optimisation
!              allowing variable focal plane orientation
! version 22   calling 21  - together performing lightguide optimisation
!
! version 12 : shorten to (90mm x2=-4.5 x3=-0.5 x4=-0.3) 77mm -5.4 -0.9 -0.5
!    variant  n  -- no mirror (again)
! version 11 : only keeping 45, 35, 25 degrees , and changing 117->115...
! version 10 : adding hoizontal mirror to illustrate upstream-only lightguide
! version 09 : graphics elements for x=115 x2=-3.6 x3=-0.2 (60^-n)
! version 08 : get beta=1.00 and 0.99 entries for 45,35,25 degrees...
! version 07 : project onto x=165, seems to be ok for -2.5 0 0
! version 06 : making x2 a free parameter as well
! version 05 : no graphics yet, but focussing length (based on version 03)
! version 03->04 : adding graphic elements...not for 03 -> 05
!
!!! xxxand ttt hardcoded for the moment  - 10mm disc thickness
xxxx=[0;5;10;15;20]
tttt=[0;0;0;0;0]
xxx=xxxx
ttt=tttt+45
copy\app xxxx/tand(40) tttt+40 xxx ttt
copy\app xxxx/tand(35) tttt+35 xxx ttt
copy\app xxxx/tand(30) tttt+30 xxx ttt
copy\app xxxx/tand(25) tttt+25 xxx ttt
 v01=[1;1;1;1;1;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0]
 v02=[0;0;0;0;0;1;1;1;1;1;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0]
 v03=[0;0;0;0;0;0;0;0;0;0;1;1;1;1;1;0;0;0;0;0;0;0;0;0;0]
 v04=[0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;1;1;1;1;1;0;0;0;0;0]
 v05=[0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;1;1;1;1;1]
 v00=v01-v01
inquire ‘disc thickness [mm] dd=’ dd
xxx=xxx/10*dd
!
=len(xxx)
```

```
=len(ttt)
gen lll 1 1 len(xxx)
! inquire `x position right of LiF edge ' xlif
! inquire `angle [in deg] of light ray  ' tlif
 inquire `a2 (times 100^-2) [nominal value -3]=' a2
 x2=a2*0.0001
 inquire `a3 (times 100^-3) [0 or 0.1 or so  ]=' a3
 x3=a3*0.000001
 inquire `a4 (times 100^-4) [0 or 0.1 or so  ]=' a4
 x4=a4*0.00000001
 inquire `a5 (times 100^-5) [0 or 0.1 or so  ]=' a5
 x5=a5*0.0000000001
 inquire `focal plane point x [maybe +100(mm)]=' xfocal
 inquire `focal plane point y [maybe -100(mm)]=' yfocal
 inquire `focal plane angle   [90? 45? [deg] ]=' tfocal
!
@curvedlightguide25.pcm
y000=yf80
!
x2=(a2-0.1)*0.0001
@curvedlightguide25.pcm
x2=a2*0.0001
y002=yf80
!
x3=(a3-0.1)*0.000001
@curvedlightguide25.pcm
x3=a3*0.000001
y003=yf80
!
x4=(a4-0.1)*0.00000001
@curvedlightguide25.pcm
x4=a4*0.00000001
y004=yf80
!
x5=(a5-0.1)*0.0000000001
@curvedlightguide25.pcm
x5=a5*0.0000000001
y005=yf80
!
w002=y002-y000
w003=y003-y000
w004=y004-y000
w005=y005-y000
SCALAR\VARY c2 c3 c4 c5 c01 c02 c03 c04 c05
FIT v00=y000+w002*c2+w003*c3+w004*c4+w005*c5-(c01*v01+c02*v02+c03*v03+c04*v04+c05*v05)
```

```
COLOUR 2
x2=(a2-0.1*c2)*0.0001
x3=(a3-0.1*c3)*0.000001
x4=(a4-0.1*c4)*0.00000001
x5=(a5-0.1*c5)*0.0000000001
@curvedlightguide25.pcm
color 3
set pchar -4
gra\noax xfocal+yf80*cosd(tfocal) yfocal+yf80*sind(tfocal)
set pchar 0
!
stat yf80[1:5] sdev0105\sdev
stat yf80[6:10] sdev0610\sdev
stat yf80[11:15] sdev1115\sdev
stat yf80[16:20] sdev1620\sdev
stat yf80[21:25] sdev2125\sdev
=‘standard deviations of beam bundles:’
=sdev0105
=sdev0610
=sdev1115
=sdev1620
=sdev2125
=‘optimised polynomial coefficients (maybe try another iteration):’
=(a2-0.1*c2)
=(a3-0.1*c3)
=(a4-0.1*c4)
=(a5-0.1*c5)

!
destroy lx9 ly9
lx9[1]=-60
ly9[1]=-30
gen lx8 -60 0.5 80
ly8=lx8*(lx8*(x2+lx8*(x3+lx8*(x4+lx8*x5))))
copy\app lx8 ly8 lx9 ly9
lx8=[140;140;120;10]
ly8=[-40;-160;-160;-50]
copy\app lx8 ly8 lx9 ly9
gen la 0 3 90
lx8=-10+20*cosd(la)
ly8=-50+20*sind(la)
copy\app lx8 ly8 lx9 ly9
lx8=[-10;-60]
ly8=[-30;-30]
copy\app lx8 ly8 lx9 ly9
```

```
inquire ‘plot axes with scales? 0=no 1=yes ’ wat1
if (1-(wat1=1)) then goto schluss1
colour 1
gra\axes
schluss1:
inquire ‘plot dark blue shape and write file contour.dat? 0=no 1=yes ’ wat2
if (1-(wat2=1)) then goto schluss2

color 4
gra\noax lx9 ly9
write\format contour.dat (2F10.4) lx9 ly9

schluss2:
colour 1
```

5.2 curvedlightguide25.pcm

```
! version 25   keeping 23 stable for now
! version 23   subroutine to 24 for lightguide fit optimisation
!              allowing variable focal plane orientation
! version 21   subroutine to 22 for lightguide fit optimisation
!
! version 12 : shorten to (90mm x2=-4.5 x3=-0.5 x4=-0.3) 77mm -5.4 -0.9 -0.5
!    variant  n  -- no mirror (again)
! version 11 : only keeping 45, 35, 25 degrees , and changing 117->115...
! version 10 : adding hoizontal mirror to illustrate upstream-only lightguide
! version 09 : graphics elements for x=115 x2=-3.6 x3=-0.2 (60^-n)
! version 08 : get beta=1.00 and 0.99 entries for 45,35,25 degrees...
! version 07 : project onto x=165, seems to be ok for -2.5 0 0
! version 06 : making x2 a free parameter as well
! version 05 : no graphics yet, but focussing length (based on version 03)
! version 03->04 : adding graphic elements...not for 03 -> 05
!
 GENERATE x -60 1 120
 GENERATE x -60 1 110
 do i=lll
 xlif=xxx[i]
 tlif=ttt[i]
 x1=tand(tlif)
 x0=-30-x1*(-60+xlif) ! LiF edge at -30,-60
 y=x0+x*(x1-x*(x2+x*(x3+x*(x4+x*x5))))
! GRAPH x y
 y2=x*(x*(x2+x*(x3+x*(x4+x*x5))))
 nl=[0;1] ! need a vector for interp()
```

```
 p=interp(y,x,nl)
 =p
 px=p[1] ! intersection with curved mirror
 py=px*(px*(x2+px*(x3+px*(x4+px*x5))))
 pyd=px*(2*x2+px*(3*x3+px*4*(x4+px*x5)))
 pydd=(2*x2+px*(6*x3+px*12*(x4+px*x5)))
 =px
 =py
 =pyd
 !!!=pyd*57.3 is slope not angle...
 =pydd
 m=tan(atan(-x1)+2*atan(pyd))
 =m
 yf=py+(250-px)*m ! focal plane vertical at 250
 =yf
! introducing horizonal mirror at y=-40
mx= px+(-py-30)/m


 tx[1]=-60+xlif
 tx[2]=px
 tx[3]=250
!! tx[3]=mx
!! tx[4]=250
 ty[1]=-30
 ty[2]=py
 ty[3]=yf
!! ty[3]=-30
!! ty[4]=-30-30-yf
 GRAPH\noax tx ty
 fff[i]=yf

! calculating focussing length from curvature...
!
 lff=0.5/pydd*sin(atan(-x1)+atan(pyd))
 lfl=lff/sqrt(1+m*m) ! the length projected onto x-axis
 lfx=px+lfl
 lfy=py+lfl*m
 set pchar -8
   gra\noax lfx lfy
 set pchar 0
!!! yf75[i]=py+(75-px)*m ! focal plane vertical at 75
!!! yf77[i]=py+(77-px)*m ! focal plane vertical at 77
!!! yf80[i]=py+(80-px)*m ! focal plane vertical at 80
!!!!yf80[i]=py+(fdistance-px)*m ! focal plane vertical at x=fdistance
```

```
yf80[i]=(m*px-m*xfocal+yfocal-py)/(m*cosd(tfocal)-sind(tfocal))
  enddo
 !!color 1
 !!gra\noax x y2

! drawing lightguides contour lines
!
!  SCALES\COMM -100 200 -200 20
 lx1=[-200;-60;-60;-200]
 ly1=[-30-dd;-30-dd;-30;-30]
 COLOUR 6
 GRAPH\NOAX lx1 ly1
 lx2=[-60;-10;-10;-60;-60]
 ly2=[-30-dd;-30-dd;-30;-30;-30-dd]
 COLOUR 7
 GRAPH\NOAXES lx2 ly2
 lx3=[-60;-60]
 ly3=[-30;-30]
 ly3[2]=y2[1]
 COLOUR 6
 GRAPH\NOAX lx3 ly3
 COPY x y2 mx my IFF (x<56) ! <=55
 GRAPH\NOAX mx my
 lx4=[55;xfocal+50*cosd(tfocal);xfocal-50*cosd(tfocal);-10]
 ly4=[0;yfocal+50*sind(tfocal);yfocal-50*sind(tfocal);-30]
 ly4[1]=y2[116]  ! 55 - (-60) + 1
 colour 6
 GRAPH\NOAX lx4 ly4
 colour 1
```