T1000717-v6
ETM HWS imaging solution - (distances pulled from G1100873). Full ETM distancs

Data from T0900385 - v06 and G1100873. [Lab book 13 - page 5 & page 10]

Telescope parabolic T1 RoC		4000 mm
Telescope parabolic T2 RoC		-200 mm
Telescope M1 to M2		1902.6 mm
Distance from ETM to Telescope		1429 mm
ETM curvature		2245 m
ETM thickness		20cm
ITM curvature		1934 m
Arm Length		3995 m
Lambda		532 nm
ETM substrate: Fused silica:		n = 1.46089

Imaging solution

M2 to f0	(distance)	[5273, 4314]mm
[M2 to in-vac PM]		= 762mm + 604mm = 1366mm (D1002460)
[in-vac periscope mirror to ALS table]		= 1858mm (D0900435, D0902168, D0900436, D0902163)
[ALS input to top periscope]		= 101mm (D1201448)
[top periscope mirror to bottom]		= 419mm (D1201448)
[BPM to f0] - X		= 1529mm (D1201448)
[BPM to f0] - Y		= 570mm (D1100607)
f0	(focal length)	2236.1 mm [CVI PLCX-50.8-1030.2-UV-532]
f0 to f1:	(distance)	610 mm
f1	(focal length)	2236.1 mm [CVI PLCX-25.4-1030.2-UV-532]
f1 to f2	(distance)	[928.3, 1079.0] mm
f2	(focal length)	-0.5589 mm [CVI PLCC-25.4-257.2-

```
UV-532]
f2 to HWS    (distance)                [1308, 903.6] mm
```

Y - Arm

Start with the CVI Lenses and determine all solutions based on the nominal lens positions : Y

In[104]:=
```
XorYDist = 4.314
L0Dist = 0.61
```

Out[104]= 4.314

Out[105]= 0.61

Load CVI Lenses

In[106]:=
```
CVILenses1 = {-279.6, -335.4, -391.3, -448.4, -558.9, -670.9, -1118.1, -1677, 670.9,
    782.7, 1118.1, 1677, 2236.1, 3353.5, 4471.4, 5589.2, 8384.9, 11180.6} / 1000.;
```

In[107]:=
```
(*CVILenses1 =
  {-1000,-600,-625,-500,-400,-350,-300,-250,-175,-175,-150,-125,-125,-125,-100,
    -100,-100,-75,-75,-75,-62.5,-50,-50,-40,-37.5,-30,-25,-25,-20,-15,-12.5,
    -10,10,10,10,12.5,12.5,15,15,20,20,25,25,25,25,30,30,37.5,37.5,
    40,40,50,50,50,50,50,50,62.5,62.5,75,75,75,75,100,100,100,125,125,
    125,150,150,175,175,175,200,200,250,250,250,250,300,300,350,375,
    500,500,600,625,750,800,1000,1000,1500,1500,2000,2000}/1000.0;*)
```

In[108]:=
```
Length[CVILenses1]
```

Out[108]= 18

Determine ABCD matrices

In[109]:=
$$\text{ABCDList} = \begin{pmatrix} 1 & L2 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ -1/f2 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & L1 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ -1/f1 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & L0 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ -1/f0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & T2toISCT \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ -2/T2RoC & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & T1toT2 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ -2/T1RoC & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & ETMtoT1 \\ 0 & 1 \end{pmatrix};$$

ABCD with distances substituted in

In[110]:=
```
CVILenses2 = Union[CVILenses1, CVILenses1];
ABCDSub = Simplify[ABCDList /. {ETMtoT1 → 1.429, T1RoC → 4.0,
      T1toT2 → 1.9026, T2RoC → -0.2, T2toISCT → XorYDist, L0 → L0Dist}];

s1 = Solve[{ABCDSub[[1]][[2]] == 0}, L2];
ABCDSub2 = Simplify[ABCDSub /. s1[[1]]];
s2 =  Solve[{ABCDSub2[[2]][[2]] == -20.5}, L1];
ABCDSub3 = Simplify[ABCDSub2 /. s2[[1]]];


resultN = Table[0, {ii, Length[CVILenses2]^3}];
countN = 1;
resultGood = {};
For[ii = 1, ii ≤ Length[CVILenses2], ii++, {

   For[jj = 1, jj ≤ Length[CVILenses2], jj++, {
     For[kk = 1, kk ≤ Length[CVILenses2], kk++, {
        For[mm = 1, mm ≤ 1, mm++, {
           f0A = CVILenses2[[ii]];
           f1A =  CVILenses2[[jj]];
           f2A =  CVILenses2[[kk]];


           ABCDOut = ABCDSub /. {f0 → f0A, f1 → f1A, f2 → f2A};
           ABCDSub3A = ABCDSub3 /. {f0 → f0A, f1 → f1A, f2 → f2A};


           L2A = ((L2 /. s1[[1]]) /. s2[[1]]) /.  {f0 → f0A, f1 → f1A, f2 → f2A};
           L1A = (L1 /. s2[[1]]) /. {f0 → f0A, f1 → f1A, f2 → f2A};

           If[(L1A > 0.7)  && (L2A > 0.7) && (L1A < 1.5) && (L2A < 1.5), {
             resultGood = Append[resultGood,
                 {ii, jj, kk, L1A, L2A, ABCDSub3A[[2]][[1]]}];
            }];
           countN = countN + 1;




         }];
      }];

    }];
   Print[{ii, Length[CVILenses2], Length[resultGood]}]
  }];
```

```
{1, 18, 4}
{2, 18, 8}
{3, 18, 9}
{4, 18, 10}
{5, 18, 10}
{6, 18, 10}
{7, 18, 10}
{8, 18, 10}
{9, 18, 10}
{10, 18, 12}
{11, 18, 12}
{12, 18, 27}
{13, 18, 38}
{14, 18, 45}
{15, 18, 51}
{16, 18, 57}
{17, 18, 63}
{18, 18, 68}
```

In[120]:=
```
CList = Table[
   {Abs[resultGood[[ii]][[6]]], resultGood[[ii]][[4]], resultGood[[ii]][[5]],
    CVILenses2[[resultGood[[ii]][[1]]]], CVILenses2[[resultGood[[ii]][[2]]]],
    CVILenses2[[resultGood[[ii]][[3]]]]}, {ii, Length[resultGood]}];
CList2 = Sort[CList];
CList3 = Table[
   {Abs[If[CVILenses2[[resultGood[[ii]][[1]]]] == CVILenses2[[resultGood[[ii]][[
            2]]]] || CVILenses2[[resultGood[[ii]][[3]]]] == CVILenses2[[
          resultGood[[ii]][[2]]]] || CVILenses2[[resultGood[[ii]][[1]]]] ==
         CVILenses2[[resultGood[[ii]][[3]]]], 25, 1] *
      (1 / Abs[resultGood[[ii]][[6]]]) * CVILenses2[[resultGood[[ii]][[1]]]] *
      CVILenses2[[resultGood[[ii]][[2]]]] * CVILenses2[[resultGood[[ii]][[3]]]]],
    resultGood[[ii]][[6]], resultGood[[ii]][[4]],
    resultGood[[ii]][[5]],
    CVILenses2[[resultGood[[ii]][[1]]]],
    CVILenses2[[resultGood[[ii]][[2]]]],
    CVILenses2[[resultGood[[ii]][[3]]]]},
   {ii, Length[resultGood]}];
CList4 = Sort[CList3];
```

In[124]:=
```
solnF = CList4[[Length[CList4] - 1]]
L1S = solnF[[3]];
L2S = solnF[[4]];
f0S = solnF[[5]];
f1S = solnF[[6]];
f2S = solnF[[7]];
```

Out[124]= {2008.28, -0.0347882, 1.07902, 0.903587, 2.2361, 2.2361, -0.5589}

In[130]:=
```
solnSimple =
 {f0 → f0S, f1 → f1S, f2 → f2S, L0 → L0Dist, L1 → L1S, L2 → L2S, M2tof0 → 4.314}
solnSimpleY = solnSimple
```

Out[130]= {f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 1.07902, L2 → 0.903587, M2tof0 → 4.314}

Out[131]= {f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 1.07902, L2 → 0.903587, M2tof0 → 4.314}

In[132]:=
```
MatrixForm[CList4]
```

Out[132]//MatrixForm=

3.55979	-0.0294513	1.47528	1.29483	-0.5589	0.6709	-0.2796
4.36702	-0.0288182	1.30312	1.32748	-0.6709	0.6709	-0.2796
6.41049	-0.03817	1.41773	0.960976	-1.1181	0.7827	-0.2796
7.59134	-0.0276285	0.979589	1.39264	-1.1181	0.6709	-0.2796
9.28034	-0.0316282	1.37451	1.15276	-1.1181	0.7827	-0.3354
10.258	-0.0357767	1.14999	1.04017	-1.677	0.7827	-0.2796
11.6219	-0.0270677	0.827104	1.42522	-1.677	0.6709	-0.2796
12.7086	-0.0269455	1.33121	1.34489	-1.1181	0.7827	-0.3913
14.8592	-0.0296275	1.10602	1.24776	-1.677	0.7827	-0.3354
20.3607	-0.0252258	1.06196	1.45571	-1.677	0.7827	-0.3913
24.2219	-0.043282	0.82221	0.836488	3.3535	1.1181	-0.2796
27.1047	-0.0464027	0.945164	0.728628	2.2361	1.677	-0.3354
31.0709	-0.0449891	0.914935	0.795694	4.4714	1.1181	-0.2796
34.923	-0.0360106	0.780389	1.00343	3.3535	1.1181	-0.3354
35.457	-0.041384	0.817236	0.815333	1.677	2.2361	-0.3913
36.8187	-0.0398534	0.906884	0.850066	2.2361	1.677	-0.3913
37.9215	-0.0460768	0.97402	0.77122	5.5892	1.1181	-0.2796
44.7848	-0.0374418	0.873644	0.954492	4.4714	1.1181	-0.3354
46.4034	-0.036236	0.778653	0.93431	1.677	2.2361	-0.4484
47.6277	-0.0308056	0.738493	1.17066	3.3535	1.1181	-0.3913
48.2497	-0.0348494	0.867783	0.974111	2.2361	1.677	-0.4484
54.6494	-0.0383538	0.933067	0.925133	5.5892	1.1181	-0.3354
55.0588	-0.047609	1.05724	0.738578	8.3849	1.1181	-0.2796
57.4084	-0.043926	1.01443	0.711449	1.677	3.3535	-0.4484
61.0592	-0.0320393	0.83228	1.11357	4.4714	1.1181	-0.3913
62.6508	-0.0402504	1.20382	0.791029	3.3535	1.677	-0.4484
63.8521	-0.0107256	1.03803	0.94728	0.7827	-0.3913	2.2361
71.6258	-0.029261	0.703988	1.16455	1.677	2.2361	-0.5589
72.1983	-0.0484123	1.10088	0.72226	11.1806	1.1181	-0.2796
74.4954	-0.0328254	0.892041	1.07932	5.5892	1.1181	-0.3913
74.6659	-0.0280696	0.792115	1.21416	2.2361	1.677	-0.5589
79.328	-0.0396383	1.01677	0.885977	8.3849	1.1181	-0.3354
80.3168	-0.0279115	0.790027	1.27607	4.4714	1.1181	-0.4484
88.264	-0.0356108	0.946647	0.886773	1.677	3.3535	-0.5589
96.8045	-0.0324691	1.1333	0.985964	3.3535	1.677	-0.5589
97.9731	-0.0286015	0.850134	1.23682	5.5892	1.1181	-0.4484
104.01	-0.0403118	1.06065	0.866402	11.1806	1.1181	-0.3354
105.297	-0.0398009	1.10677	0.747795	1.677	4.4714	-0.5589
107.163	-0.0234767	0.715419	1.45747	2.2361	1.677	-0.6709
108.111	-0.0339328	0.976218	1.03364	8.3849	1.1181	-0.3913
119.071	-0.0351969	1.34485	0.871793	4.4714	1.677	-0.5589
125.86	-0.0299778	0.877946	1.06448	1.677	3.3535	-0.6709
132.205	-0.0380539	1.46265	0.712058	2.2361	3.3535	-0.6709

138.725	-0.0271978	1.06182	1.18354	3.3535	1.677	-0.6709
141.382	-0.037053	1.48878	0.803297	5.5892	1.677	-0.5589
141.732	-0.0345134	1.02036	1.0108	11.1806	1.1181	-0.3913
142.149	-0.0295734	0.934798	1.18447	8.3849	1.1181	-0.4484
149.864	-0.0335689	1.04268	0.897649	1.677	4.4714	-0.6709
170.506	-0.029505	1.2766	1.04649	4.4714	1.677	-0.6709
174.122	-0.0361149	1.15947	0.797562	1.677	5.5892	-0.6709
186.333	-0.030083	0.979191	1.1583	11.1806	1.1181	-0.4484
202.363	-0.0310748	1.42273	0.964272	5.5892	1.677	-0.6709
221.396	-0.023667	0.854643	1.47636	8.3849	1.1181	-0.5589
271.327	0.00189298	1.44896	0.710428	0.7827	-0.3913	1.677
290.145	-0.0240804	0.899529	1.44375	11.1806	1.1181	-0.5589
350.135	-0.0239461	1.23239	1.18669	2.2361	3.3535	-1.1181
374.16	-0.0224085	1.31747	1.28588	3.3535	2.2361	-1.1181
396.781	-0.0211303	0.786754	1.49599	1.677	4.4714	-1.1181
401.033	-0.0490189	0.729911	0.721633	1.677	1.677	-0.2796
459.077	-0.0228285	0.916585	1.32919	1.677	5.5892	-1.1181
616.801	-0.0254898	1.12004	1.10672	1.677	8.3849	-1.1181
761.642	-0.0206424	1.39163	1.42426	8.3849	1.677	-1.1181
775.584	-0.0270302	1.23781	0.995507	1.677	11.1806	-1.1181
835.028	-0.0200801	1.35307	1.3139	2.2361	4.4714	-1.677
1303.29	-0.0430078	1.14729	0.724939	2.2361	2.2361	-0.4484
1625.95	-0.0193385	0.974568	1.49313	1.677	11.1806	-1.677
2008.28	-0.0347882	1.07902	0.903587	2.2361	2.2361	-0.5589
2870.12	-0.02922	1.00982	1.08466	2.2361	2.2361	-0.6709

Rest

Create Function to Determine Output Radius and Beam Size and to plot the Beam

Arm cavity parameters

ETM as a Lens

In[155]:=
```
ETMOutmatrix = {{1, 0}, {0, nFusedSilica532/1}}.{{1, ETMthick}, {0, 1}}.{{1, 1 - nFusedSilica532}, {-RETM nFusedSilica532, 1/nFusedSilica532}};
RETMn = -RETM / nFusedSilica532;
ETMAsMirror = {{1, 0}, {-2 / RETMn, 1}};
OutRW[OutModeFromCavityRW[[2]],
  OutModeFromCavityRW[[1]], λg, {{1, 100.0}, {0, 1}}.ETMOutmatrix];
OutModeFromETMRW = OutRW[OutModeFromCavityRW[[2]],
  OutModeFromCavityRW[[1]], λg, ETMOutmatrix]
```

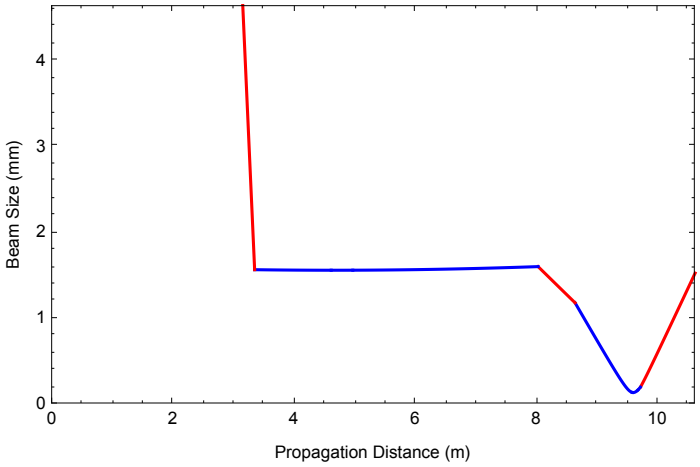
Out[159]= {1579.5, 0.0314198}

Plot the output

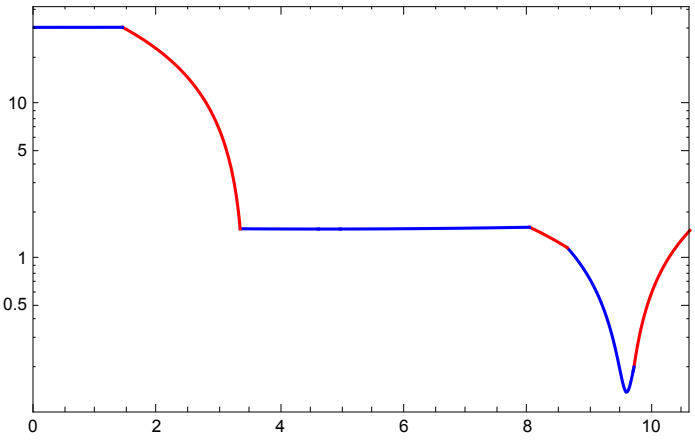
In[160]:=
```
ABCDList = Reverse[ {{{1, L2}, {0, 1}}, {{1, 0}, {-1/f2, 1}}, {{1, L1}, {0, 1}},
    {{1, 0}, {-1/f1, 1}}, {{1, L0}, {0, 1}}, {{1, 0}, {-1/f0, 1}}, {{1, T2toISCT}, {0, 1}}, {{1, 0}, {-2/T2RoC, 1}},
    {{1, T1toT2}, {0, 1}}, {{1, 0}, {-2/T1RoC, 1}}, {{1, ETMtoT1}, {0, 1}}}] /. solnSimple ;

plot1 = PlotTheBeamPropagation[ABCDList, OutModeFromETMRW, λg]
plot2 = LogPlotTheBeamPropagation[ABCDList, OutModeFromETMRW, λg]
```

Out[161]=

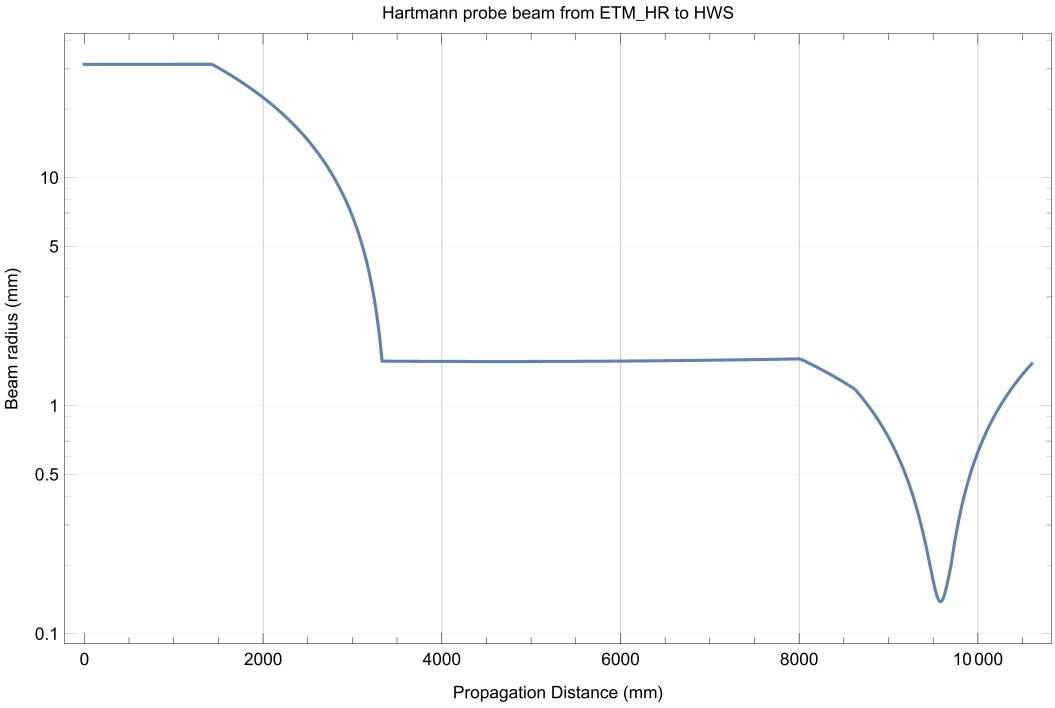


Out[162]=

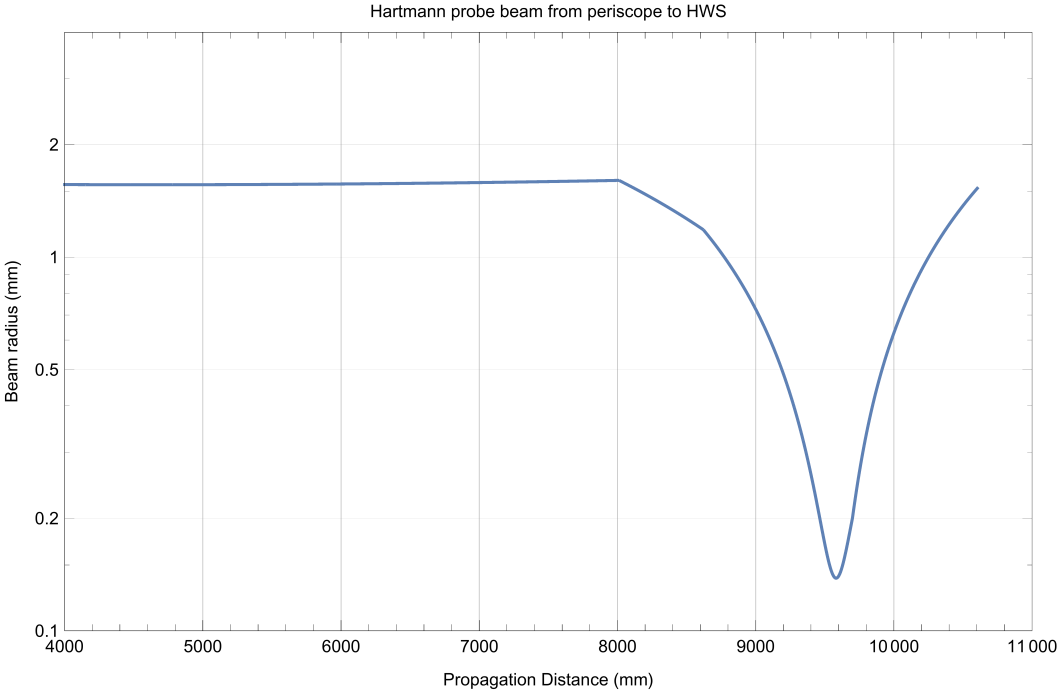


In[163]:=
```
ListLogPlot[tableOut, Joined → True, Frame → True,
 GridLines → Automatic, FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from ETM_HR to HWS"}]
ListLogPlot[tableOut, Joined → True, Frame → True, GridLines → Automatic,
 FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from periscope to HWS"},
 PlotRange → {{4000, 11000}, {0.1, 4}}]
```

Out[163]=



Out[164]=



In[165]:=
```
M1 = {{1, L2}, {0, 1}} . {{1, 0}, {-1/f2, 1}} . {{1, L1}, {0, 1}} . {{1, 0}, {-1/f1, 1}} . {{1, L0}, {0, 1}} . {{1, 0}, {-1/f0, 1}} . {{1, T2toISCT}, {0, 1}} .
 {{1, 0}, {-2/T2RoC, 1}} . {{1, T1toT2}, {0, 1}} . {{1, 0}, {-2/T1RoC, 1}} . {{1, ETMtoT1}, {0, 1}} /. solnSimple ;
MatrixForm[Simplify[M1]]
```

Out[166]//MatrixForm=

$$\begin{pmatrix} -0.0441368 & -7.14677 \\ -0.0302085 & -27.5483 \end{pmatrix}$$

ETMY fiber launcher plot

Plot the output for ETMY

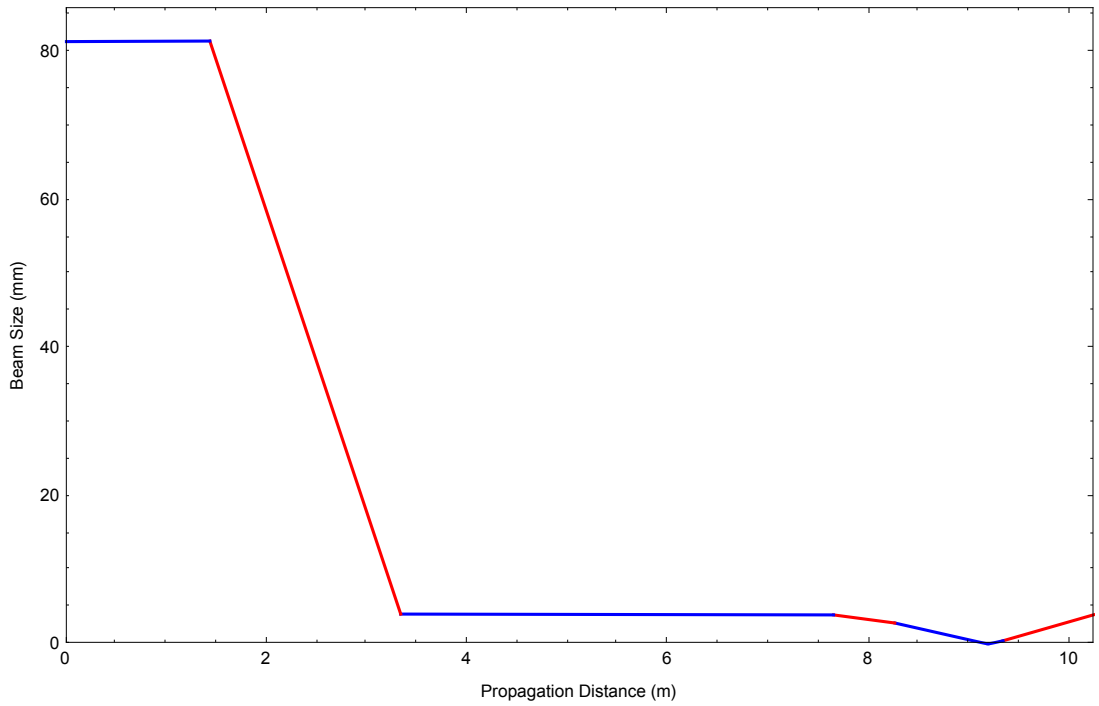
In[194]:=
```
solnSimple = solnSimpleY
```

Out[194]=
```
{f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 1.07902, L2 → 0.903587, M2tof0 → 4.314}
```

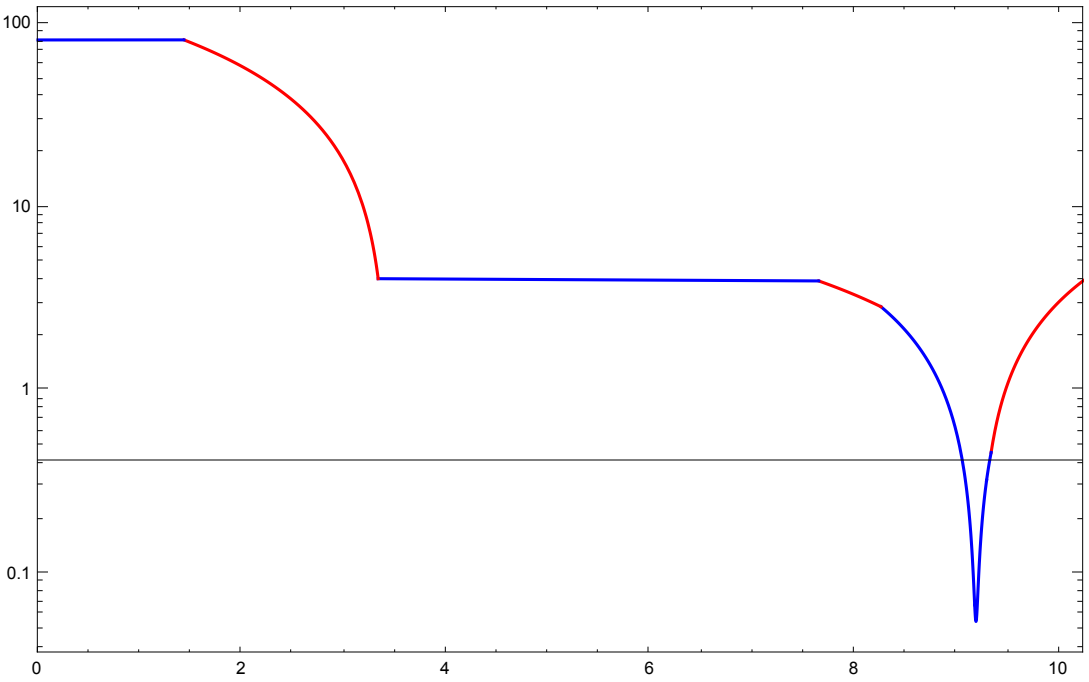
In[195]:=
```
ABCDList = Reverse[
    {{{1, L2}, {0, 1}}, {{1, 0}, {-1/f2, 1}}, {{1, L1}, {0, 1}}, {{1, 0}, {-1/f1, 1}}, {{1, L0}, {0, 1}}, {{1, 0}, {-1/f0, 1}}, {{1, M2tof0}, {0, 1}},
     {{1, 0}, {-2/T2RoC, 1}}, {{1, T1toT2}, {0, 1}}, {{1, 0}, {-2/T1RoC, 1}}, {{1, ETMtoT1}, {0, 1}}}] /. solnSimple ;
OutModeFromETMRW = {1579.4958047124749`, 0.08141979105529595`}
plot1 = PlotTheBeamPropagation[ABCDList, OutModeFromETMRW, λg]
plot2 = LogPlotTheBeamPropagation[ABCDList, OutModeFromETMRW, λg]
```

Out[196]=
```
{1579.5, 0.0814198}
```

Out[197]=

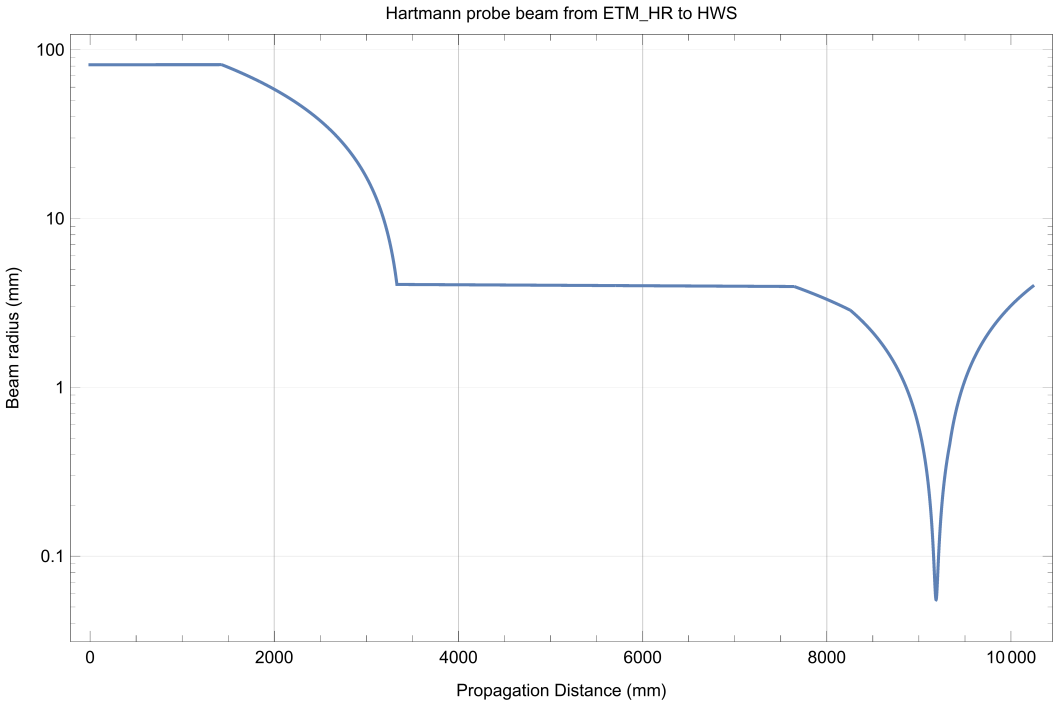


Out[198]=

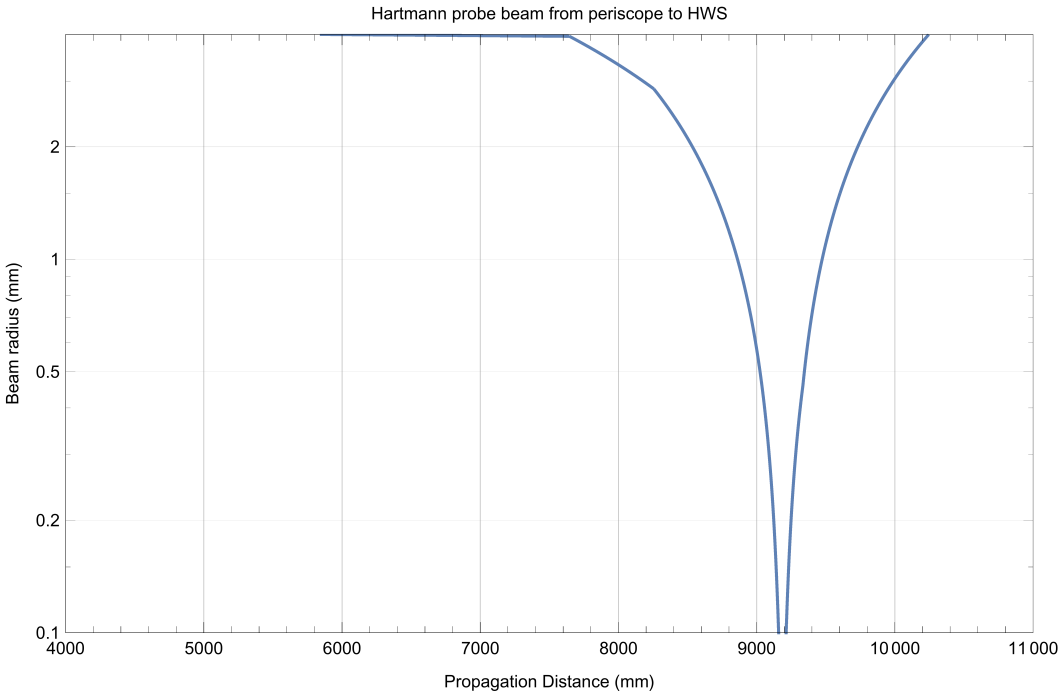


In[199]:=
```
ListLogPlot[tableOut, Joined → True, Frame → True,
 GridLines → Automatic, FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from ETM_HR to HWS"}]
ListLogPlot[tableOut, Joined → True, Frame → True, GridLines → Automatic,
 FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from periscope to HWS"},
 PlotRange → {{4000, 11000}, {0.1, 4}}]
ListPlot[tableOut, Joined → True, Frame → True,
 GridLines → Automatic, FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from periscope to HWS"},
 PlotRange → {{4000, 11000}, {0.1, 4}}]
```

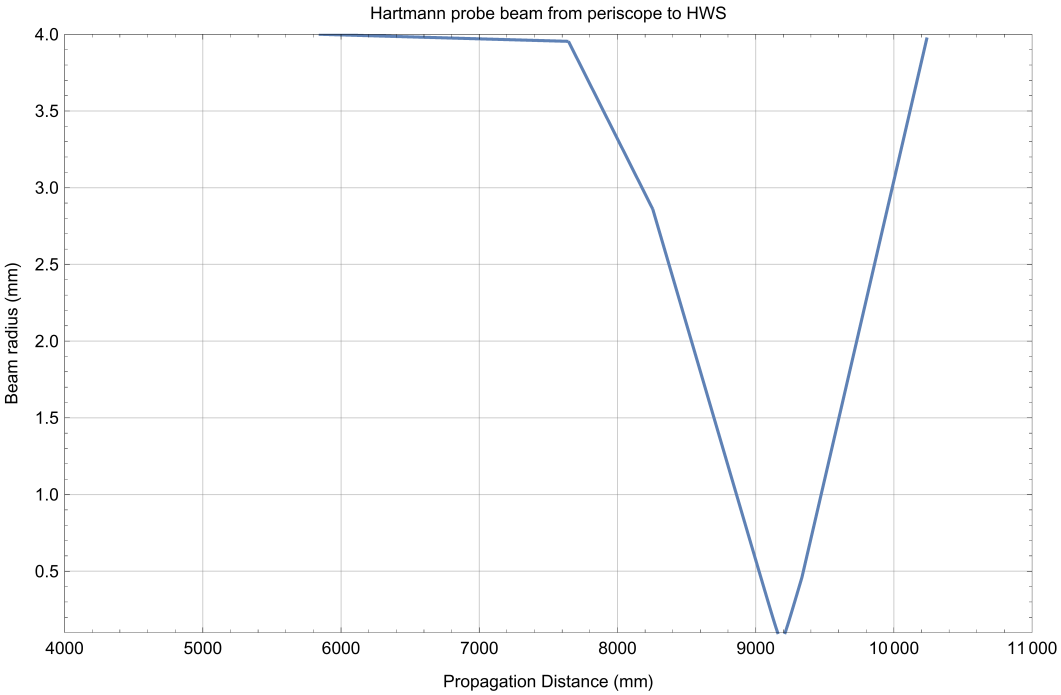
Out[199]=



Out[200]=



Out[201]=



In[202]:=
```
solnSimple
```

Out[202]=
```
{f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 1.07902, L2 → 0.903587, M2tof0 → 4.314}
```

In[203]:=
```
M1 = {{1, L2}, {0, 1}}.{{1, 0}, {-1/f2, 1}}.{{1, L1}, {0, 1}}.{{1, 0}, {-1/f1, 1}}.{{1, L0}, {0, 1}}.{{1, 0}, {-1/f0, 1}}.{{1, M2tof0}, {0, 1}}.
   {{1, 0}, {-2/T2RoC, 1}}.{{1, T1toT2}, {0, 1}}.{{1, 0}, {-2/T1RoC, 1}}.{{1, ETMtoT1}, {0, 1}} /. solnSimple
MatrixForm[Chop[Simplify[M1]]]
```

Out[203]=
```
{{-0.0487805, 2.57572 × 10^-14}, {-0.0347882, -20.5}}
```

Out[204]//MatrixForm=

$$\begin{pmatrix} -0.0487805 & 0 \\ -0.0347882 & -20.5 \end{pmatrix}$$

In[205]:=

In[206]:=
```
solnSimple
```

Out[206]=
```
{f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 1.07902, L2 → 0.903587, M2tof0 → 4.314}
```

Plot the output from Fiber Launcher - ETMY

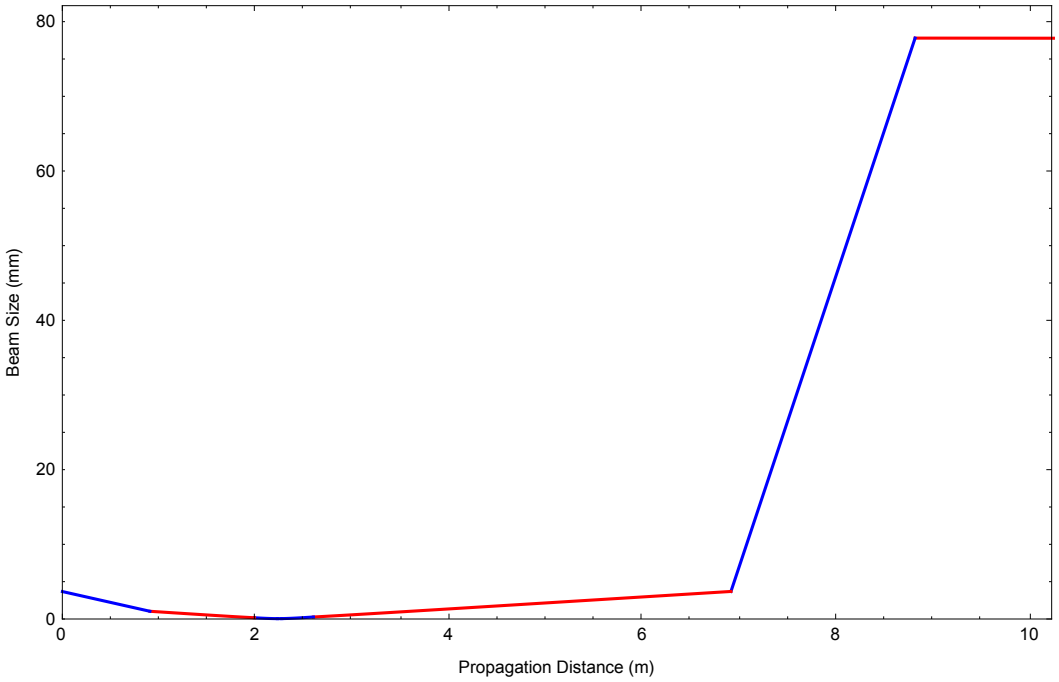
In[207]:=
```
solnSimple
```

Out[207]=
```
{f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 1.07902, L2 → 0.903587, M2tof0 → 4.314}
```

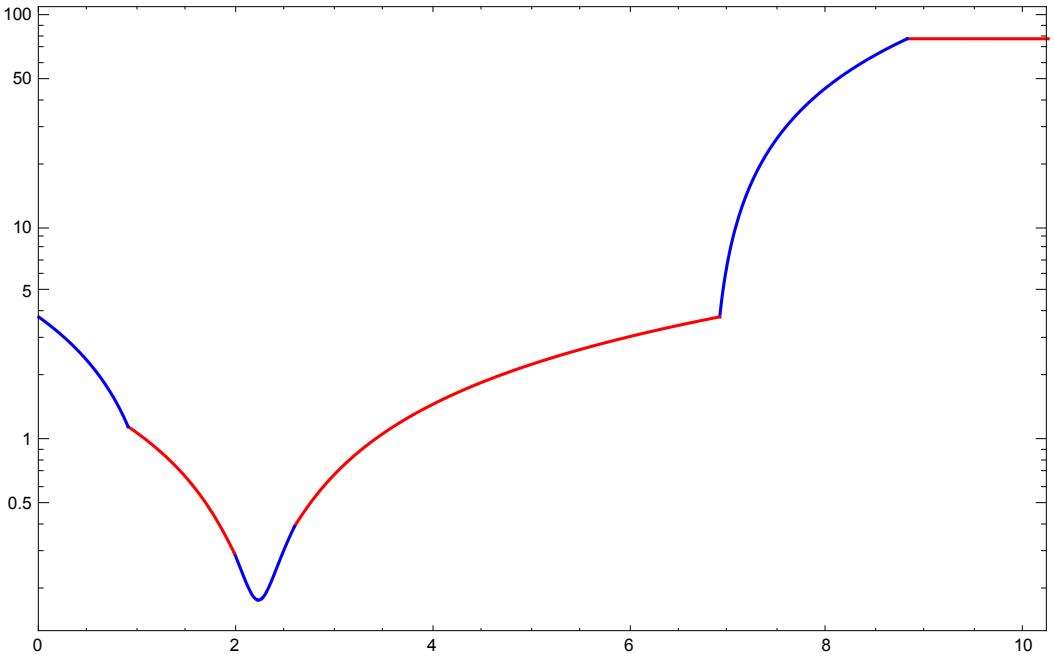
In[213]:=
```
ABCDList =
 {{{1, L2}, {0, 1}}, {{1, 0}, {-1/f2, 1}}, {{1, L1}, {0, 1}}, {{1, 0}, {-1/f1, 1}}, {{1, L0}, {0, 1}}, {{1, 0}, {-1/f0, 1}}, {{1, M2tof0}, {0, 1}},
  {{1, 0}, {-2/T2RoC, 1}}, {{1, T1toT2}, {0, 1}}, {{1, 0}, {-2/T1RoC, 1}}, {{1, ETMtoT1}, {0, 1}}} /. solnSimple;
OutModeFromFiberRW = {-1.3 + 0.0, 3.8*^-3}
plot1 = PlotTheBeamPropagation[ABCDList, OutModeFromFiberRW, λg]
plot2 = LogPlotTheBeamPropagation[ABCDList, OutModeFromFiberRW, λg]
```

Out[214]= {−1.3, 0.0038}

Out[215]=

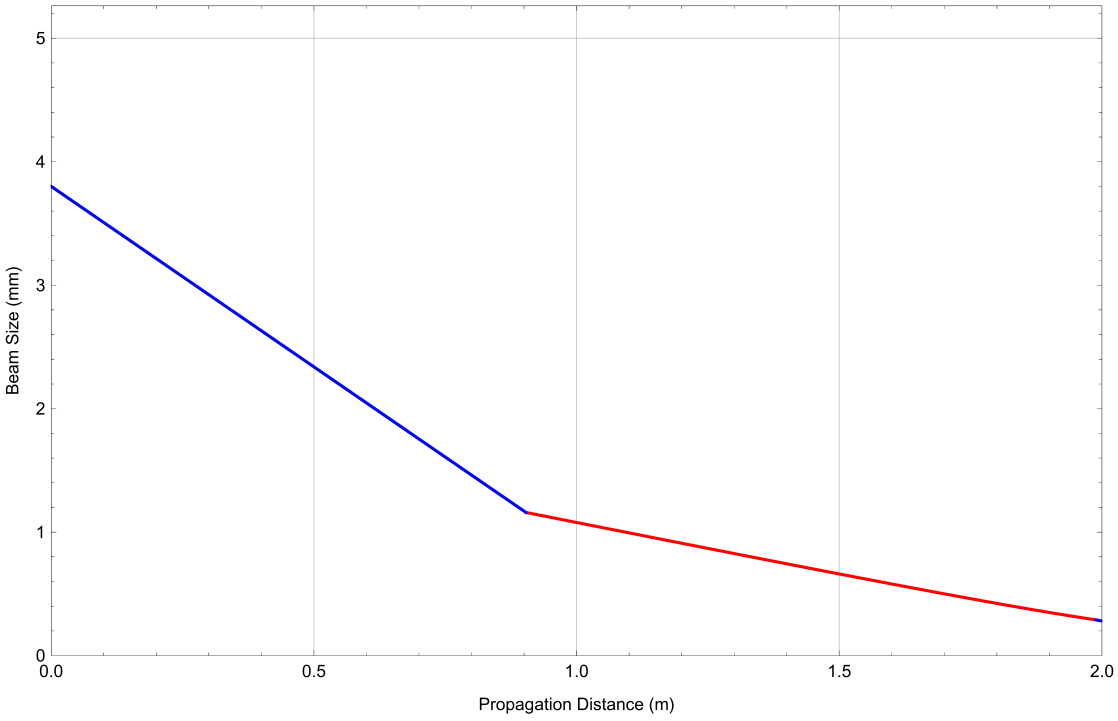


Out[216]=



In[217]:=
```
Show[plot1, GridLines → {Automatic, Table[ii * 5, {ii, 12}]},
 PlotRange → {{0, 2}, {0, 5}}]
```

Out[217]=



Real System Analysis

X - Arm

Start with the CVI Lenses and determine all solutions based on the nominal lens positions : X

In[91]:=
```
XorYDist = 5.273
LODist = 0.61
```

Out[91]= 5.273

Out[92]= 0.61

Load CVI Lenses

In[93]:=
```
CVILenses1 = {-279.6, -335.4, -391.3, -448.4, -558.9, -670.9, -1118.1, -1677, 670.9,
    782.7, 1118.1, 1677, 2236.1, 3353.5, 4471.4, 5589.2, 8384.9, 11180.6} / 1000.;
```

In[94]:=
```
(*CVILenses1 =
  {-1000,-600,-625,-500,-400,-350,-300,-250,-175,-175,-150,-125,-125,-125,-100,
    -100,-100,-75,-75,-75,-62.5,-50,-50,-40,-37.5,-30,-25,-25,-20,-15,-12.5,
    -10,10,10,10,12.5,12.5,15,15,20,20,25,25,25,25,30,30,37.5,37.5,
    40,40,50,50,50,50,50,50,62.5,62.5,75,75,75,75,100,100,100,125,125,
    125,150,150,175,175,175,200,200,250,250,250,250,300,300,350,375,
    500,500,600,625,750,800,1000,1000,1500,1500,2000,2000}/1000.0;*)
```

In[95]:=
```
Length[CVILenses1]
```

Out[95]= 18

Determine ABCD matrices

In[96]:=
```
ABCDList = {{1, L2}, {0, 1}}.{{1, 0}, {-1/f2, 1}}.{{1, L1}, {0, 1}}.{{1, 0}, {-1/f1, 1}}.{{1, L0}, {0, 1}}.{{1, 0}, {-1/f0, 1}}.
  {{1, T2toISCT}, {0, 1}}.{{1, 0}, {-2/T2RoC, 1}}.{{1, T1toT2}, {0, 1}}.{{1, 0}, {-2/T1RoC, 1}}.{{1, ETMtoT1}, {0, 1}};
```

ABCD with distances substituted in

In[97]:=
```
CVILenses2 = Union[CVILenses1, CVILenses1];
ABCDSub = Simplify[ABCDList /. {ETMtoT1 → 1.429, T1RoC → 4.0,
      T1toT2 → 1.9026, T2RoC → -0.2, T2toISCT → XorYDist, L0 → L0Dist}];

s1 = Solve[{ABCDSub[[1]][[2]] == 0}, L2];
ABCDSub2 = Simplify[ABCDSub /. s1[[1]]];
s2 =  Solve[{ABCDSub2[[2]][[2]] == -20.5}, L1];
ABCDSub3 = Simplify[ABCDSub2 /. s2[[1]]];


resultN = Table[0, {ii, Length[CVILenses2]^3}];
countN = 1;
resultGood = {};
For[ii = 1, ii ≤ Length[CVILenses2], ii++, {

   For[jj = 1, jj ≤ Length[CVILenses2], jj++, {
     For[kk = 1, kk ≤ Length[CVILenses2], kk++, {
        For[mm = 1, mm ≤ 1, mm++, {
           f0A = CVILenses2[[ii]];
           f1A =  CVILenses2[[jj]];
           f2A =  CVILenses2[[kk]];


           ABCDOut = ABCDSub /. {f0 → f0A, f1 → f1A, f2 → f2A};
           ABCDSub3A = ABCDSub3 /. {f0 → f0A, f1 → f1A, f2 → f2A};


           L2A = ((L2 /. s1[[1]]) /. s2[[1]]) /.  {f0 → f0A, f1 → f1A, f2 → f2A};
           L1A = (L1 /. s2[[1]]) /. {f0 → f0A, f1 → f1A, f2 → f2A};

           If[(L1A > 0.7)  && (L2A > 0.7) && (L1A < 1.5) && (L2A < 1.5), {
             resultGood = Append[resultGood,
                 {ii, jj, kk, L1A, L2A,  ABCDSub3A[[2]][[1]]}];
            }];
           countN = countN + 1;




        }];
      }];

    }];
   Print[{ii, Length[CVILenses2], Length[resultGood]}]
  }];
```

```
{1, 18, 1}
{2, 18, 3}
{3, 18, 3}
{4, 18, 3}
{5, 18, 3}
{6, 18, 3}
{7, 18, 3}
{8, 18, 3}
{9, 18, 3}
{10, 18, 4}
{11, 18, 5}
{12, 18, 25}
{13, 18, 38}
{14, 18, 47}
{15, 18, 54}
{16, 18, 62}
{17, 18, 66}
{18, 18, 69}
```

In[107]:=
```
CList = Table[
   {Abs[resultGood[[ii]][[6]]], resultGood[[ii]][[4]], resultGood[[ii]][[5]],
    CVILenses2[[resultGood[[ii]][[1]]]], CVILenses2[[resultGood[[ii]][[2]]]],
    CVILenses2[[resultGood[[ii]][[3]]]]}, {ii, Length[resultGood]}];
CList2 = Sort[CList];
CList3 = Table[
   {Abs[If[CVILenses2[[resultGood[[ii]][[1]]]] == CVILenses2[[resultGood[[ii]][[
            2]]]] || CVILenses2[[resultGood[[ii]][[3]]]] == CVILenses2[[
          resultGood[[ii]][[2]]]] || CVILenses2[[resultGood[[ii]][[1]]]] ==
         CVILenses2[[resultGood[[ii]][[3]]]], 25, 1] *
      (1 / Abs[resultGood[[ii]][[6]]]) * CVILenses2[[resultGood[[ii]][[1]]]] *
      CVILenses2[[resultGood[[ii]][[2]]]] * CVILenses2[[resultGood[[ii]][[3]]]]],
    resultGood[[ii]][[6]], resultGood[[ii]][[4]],
    resultGood[[ii]][[5]],
    CVILenses2[[resultGood[[ii]][[1]]]],
    CVILenses2[[resultGood[[ii]][[2]]]],
    CVILenses2[[resultGood[[ii]][[3]]]]},
   {ii, Length[resultGood]}];
CList4 = Sort[CList3];
```

In[111]:=
```
solnF = CList4[[Length[CList4]]]
L1S = solnF[[3]];
L2S = solnF[[4]];
f0S = solnF[[5]];
f1S = solnF[[6]];
f2S = solnF[[7]];
```

Out[111]= {2866.35, -0.0243741, 0.928255, 1.30764, 2.2361, 2.2361, -0.5589}

In[117]:=
```
solnSimple =
 {f0 → f0S, f1 → f1S, f2 → f2S, L0 → L0Dist, L1 → L1S, L2 → L2S, M2tof0 → 5.273}
solnSimpleX = solnSimple
```

Out[117]= {f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 0.928255, L2 → 1.30764, M2tof0 → 5.273}

Out[118]= {f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 0.928255, L2 → 1.30764, M2tof0 → 5.273}

Rest

Create Function to Determine Output Radius and Beam Size and to plot the Beam

Arm cavity parameters

ETM as a Lens

In[141]:=
$$\text{ETMOutmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & \frac{\text{nFusedSilica532}}{1} \end{pmatrix} \cdot \begin{pmatrix} 1 & \text{ETMthick} \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ \frac{1 - \text{nFusedSilica532}}{-\text{RETM}\,\text{nFusedSilica532}} & \frac{1}{\text{nFusedSilica532}} \end{pmatrix};$$

```
RETMn = -RETM / nFusedSilica532;
ETMAsMirror = {{1, 0}, {-2 / RETMn, 1}};
OutRW[OutModeFromCavityRW[[2]],
  OutModeFromCavityRW[[1]], λg, {{1, 100.0}, {0, 1}}.ETMOutmatrix];
OutModeFromETMRW = OutRW[OutModeFromCavityRW[[2]],
  OutModeFromCavityRW[[1]], λg, ETMOutmatrix]
```

Out[145]= {1579.5, 0.0314198}

ETMX fiber launcher plot

Plot the output for ETMX

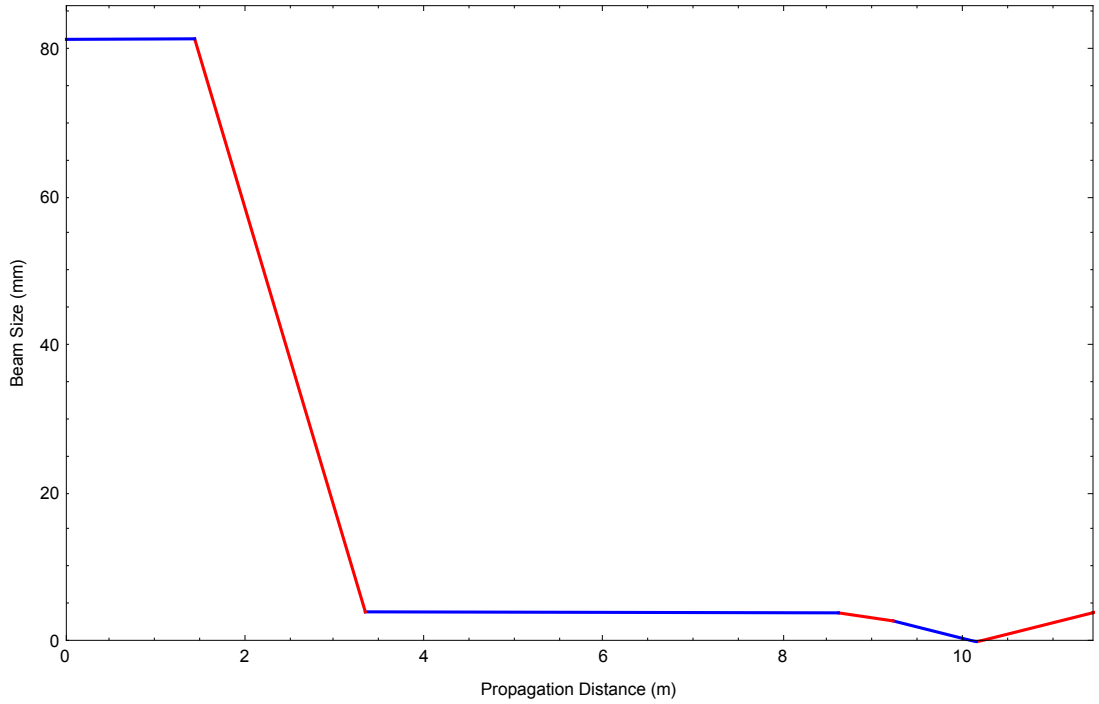
In[146]:=
```
solnSimple
```

Out[146]= {f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 0.928255, L2 → 1.30764, M2tof0 → 5.273}

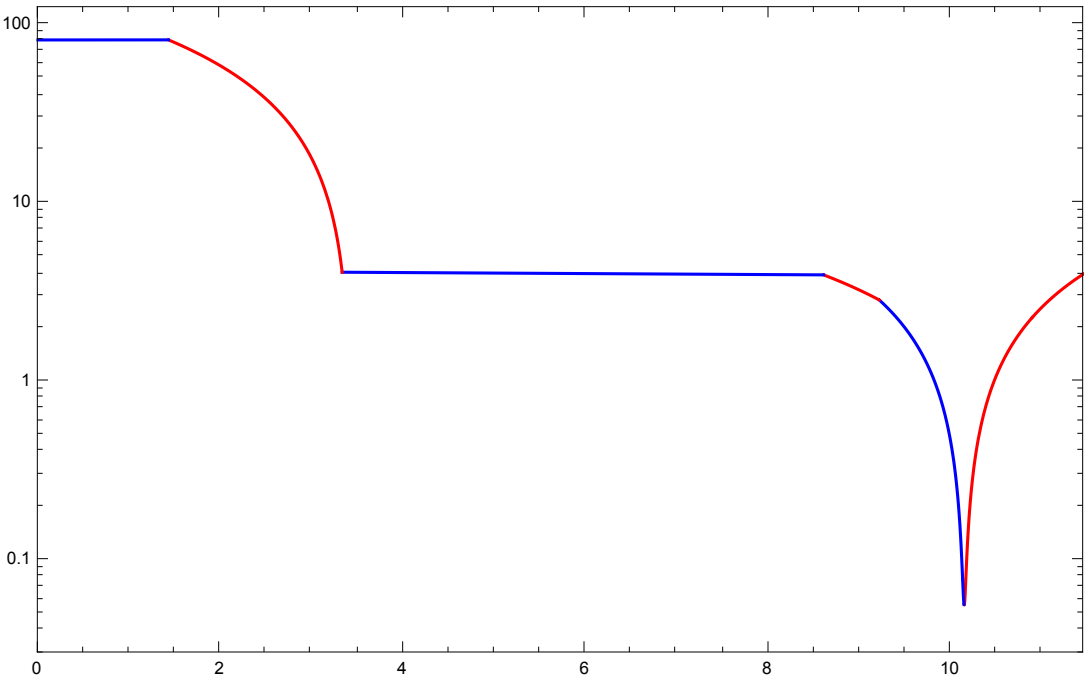
In[147]:=
```
ABCDList = Reverse[
    {{{1, L2}, {0, 1}}, {{1, 0}, {-1/f2, 1}}, {{1, L1}, {0, 1}}, {{1, 0}, {-1/f1, 1}}, {{1, L0}, {0, 1}}, {{1, 0}, {-1/f0, 1}}, {{1, M2tof0}, {0, 1}},
     {{1, 0}, {-2/T2RoC, 1}}, {{1, T1toT2}, {0, 1}}, {{1, 0}, {-2/T1RoC, 1}}, {{1, ETMtoT1}, {0, 1}}}] /. solnSimple;
OutModeFromETMRW = {1579.4958047124749`, 0.08141979105529595`}
plot1 = PlotTheBeamPropagation[ABCDList, OutModeFromETMRW, λg]
plot2 = LogPlotTheBeamPropagation[ABCDList, OutModeFromETMRW, λg]
```

Out[148]= {1579.5, 0.0814198}

Out[149]=

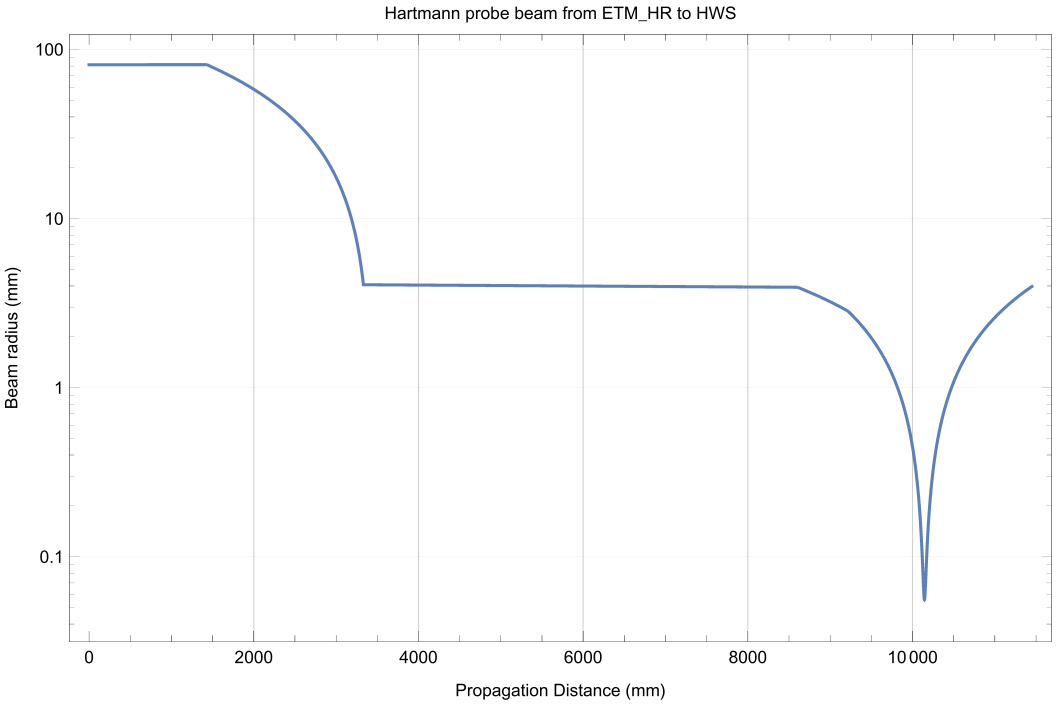


Out[150]=

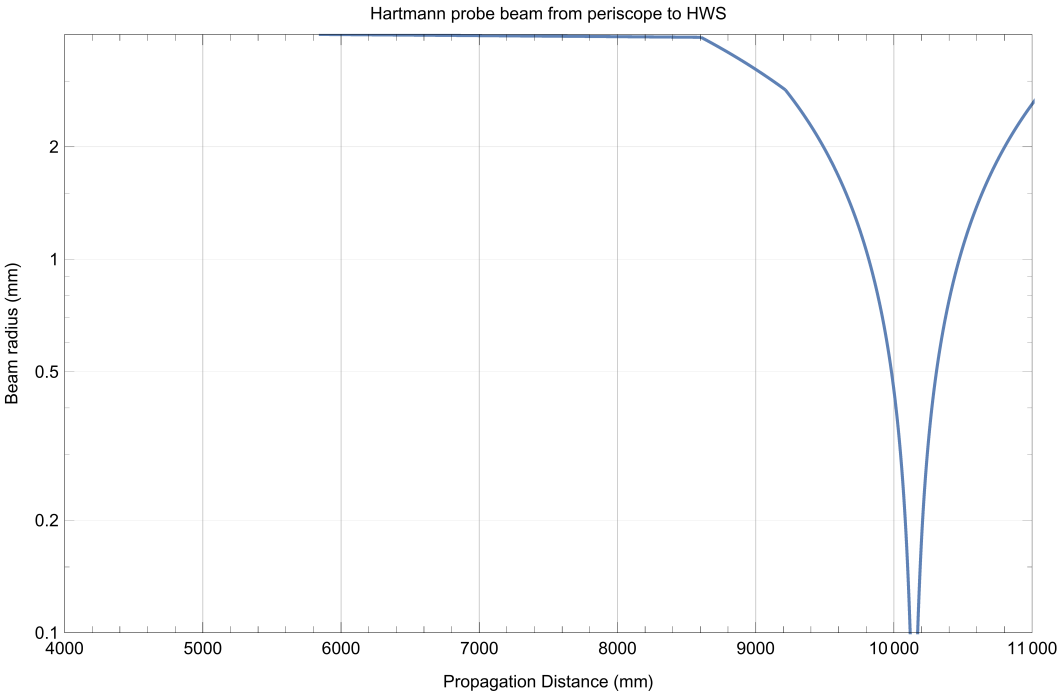


In[151]:=
```
ListLogPlot[tableOut, Joined → True, Frame → True,
 GridLines → Automatic, FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from ETM_HR to HWS"}]
ListLogPlot[tableOut, Joined → True, Frame → True, GridLines → Automatic,
 FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from periscope to HWS"},
 PlotRange → {{4000, 11000}, {0.1, 4}}]
ListPlot[tableOut, Joined → True, Frame → True,
 GridLines → Automatic, FrameLabel → {"Propagation Distance (mm)",
   "Beam radius (mm)", "Hartmann probe beam from periscope to HWS"},
 PlotRange → {{4000, 11000}, {0.1, 4}}]
```

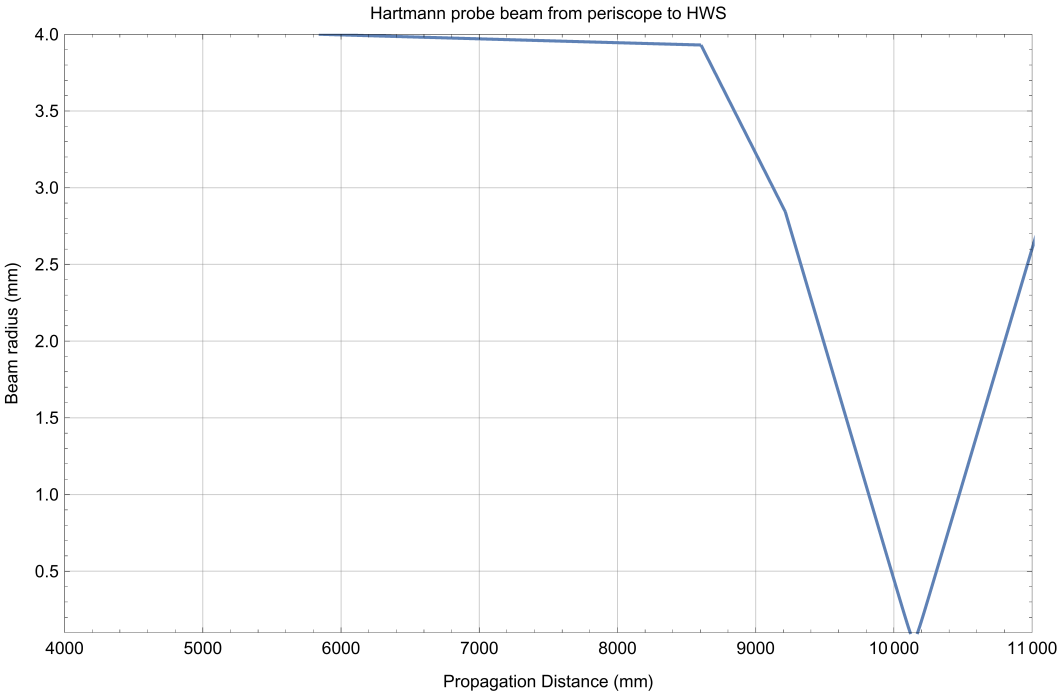
Out[151]=



Out[152]=



Out[153]=



In[154]:=
```
solnSimple
```

Out[154]=
```
{f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 0.928255, L2 → 1.30764, M2tof0 → 5.273}
```

In[155]:=
```
M1 = {{1, L2}, {0, 1}}.{{1, 0}, {-1/f2, 1}}.{{1, L1}, {0, 1}}.{{1, 0}, {-1/f1, 1}}.{{1, L0}, {0, 1}}.{{1, 0}, {-1/f0, 1}}.{{1, M2tof0}, {0, 1}}.
   {{1, 0}, {-2/T2RoC, 1}}.{{1, T1toT2}, {0, 1}}.{{1, 0}, {-2/T1RoC, 1}}.{{1, ETMtoT1}, {0, 1}} /. solnSimple
MatrixForm[Chop[Simplify[M1]]]
```

Out[155]=
$$\left\{\left\{-0.0487805,\ -1.24345\times 10^{-14}\right\},\ \{-0.0243741,\ -20.5\}\right\}$$

Out[156]//MatrixForm=
$$\begin{pmatrix} -0.0487805 & 0 \\ -0.0243741 & -20.5 \end{pmatrix}$$

In[157]:=

In[158]:=
```
solnSimple
```

Out[158]=
```
{f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 0.928255, L2 → 1.30764, M2tof0 → 5.273}
```

Plot the output from Fiber Launcher - ETMX

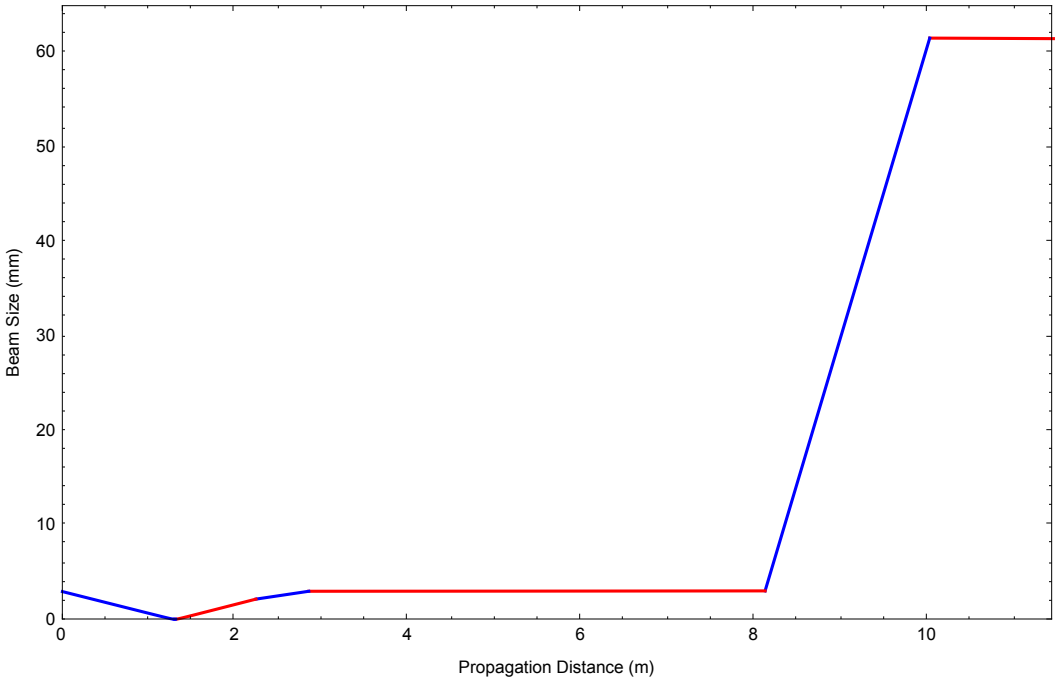
In[159]:=
```
solnSimple
```

Out[159]=
```
{f0 → 2.2361, f1 → 2.2361, f2 → -0.5589,
 L0 → 0.61, L1 → 0.928255, L2 → 1.30764, M2tof0 → 5.273}
```

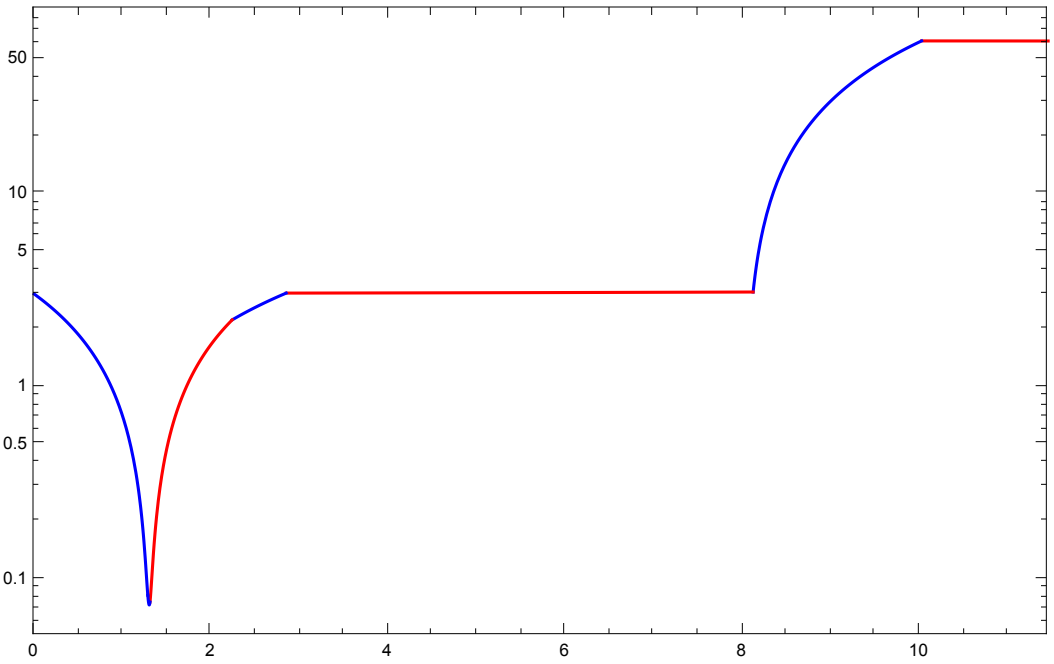
In[160]:=
```
ABCDList =
 {{{1, L2}, {0, 1}}, {{1, 0}, {-1/f2, 1}}, {{1, L1}, {0, 1}}, {{1, 0}, {-1/f1, 1}}, {{1, L0}, {0, 1}}, {{1, 0}, {-1/f0, 1}}, {{1, M2tof0}, {0, 1}},
  {{1, 0}, {-2/T2RoC, 1}}, {{1, T1toT2}, {0, 1}}, {{1, 0}, {-2/T1RoC, 1}}, {{1, ETMtoT1}, {0, 1}}} /. solnSimple;
OutModeFromFiberRW = {-1.3 + 0.0, 3.*^-3}
plot1 = PlotTheBeamPropagation[ABCDList, OutModeFromFiberRW, λg]
plot2 = LogPlotTheBeamPropagation[ABCDList, OutModeFromFiberRW, λg]
```

Out[161]= {-1.3, 0.003}

Out[162]=

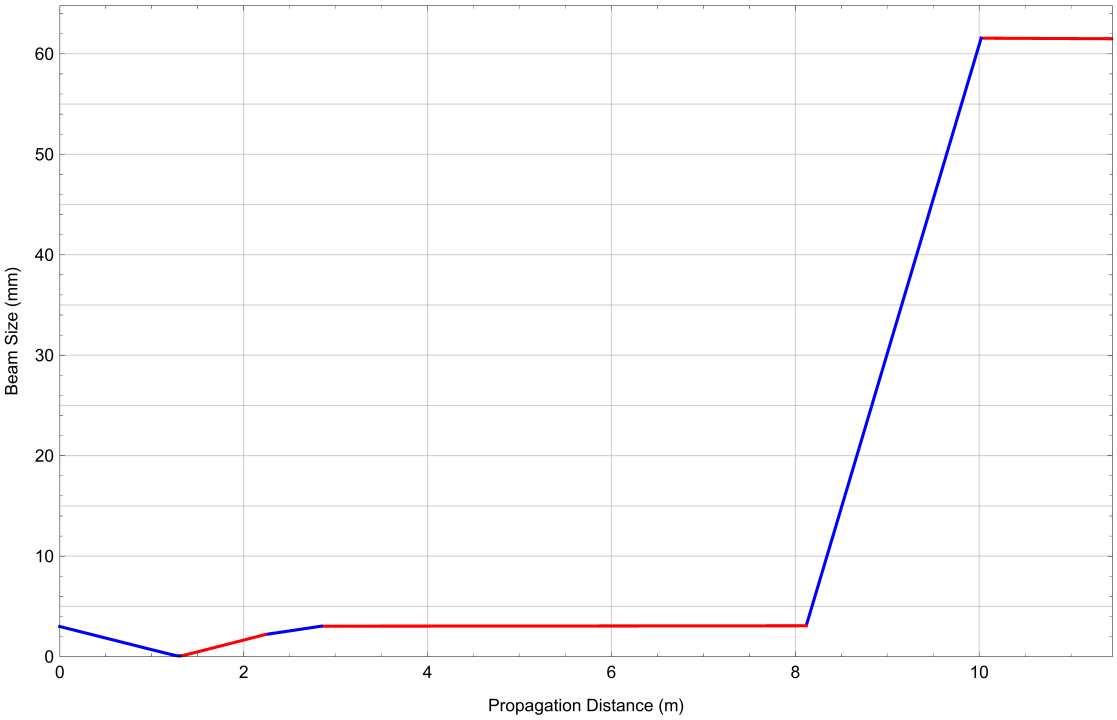


Out[163]=



In[164]:=
```
Show[plot1, GridLines → {Automatic, Table[ii * 5, {ii, 12}]}]
```

Out[164]=



Real System Analysis

Solutions