Preparation

In[1]:=
```
ppm = 10^-6;
```

In[2]:=
```
TE = 10 ppm;
LE = loss ppm / 2;
RE = 1 - TE - LE;
tE = √TE ;
rE = √RE ;

TF =.;
LF = loss ppm / 2;
RF = 1 - TF - LF;
tF = √TF ;
rF = √RF ;
```

In[12]:=
$$\text{rcav} = -\text{rF} + \frac{\text{tF}^2\ \text{rE}}{1 - \text{rF}\ \text{rE}};$$

In[13]:=
```
Rcav[TF_, loss_] = rcav^2;
```

In[14]:=
$$\text{F}[\text{TF\_}, \text{loss\_}] = \frac{\pi \sqrt{\text{rF}\ \text{rE}}}{1 - \text{rF}\ \text{rE}};$$

In[15]:=
```
FSRX = 3 897 627.1; (*MHz*)
FSRY = 3 878 678.;(*MHz*)
```

Before the wiping (Visibility: Oct 07, 2009 / fcav: Nov 10, 2009)

Data Preparation

In[17]:=
```
fcX = 1650;
dfcX = 70;(* from TF measurement. Error +/-70 Hz*)
```

In[19]:=
```
fcY = 1720;
dfcY = 70;(* from TF measurement. Error +/-70 Hz*)
```

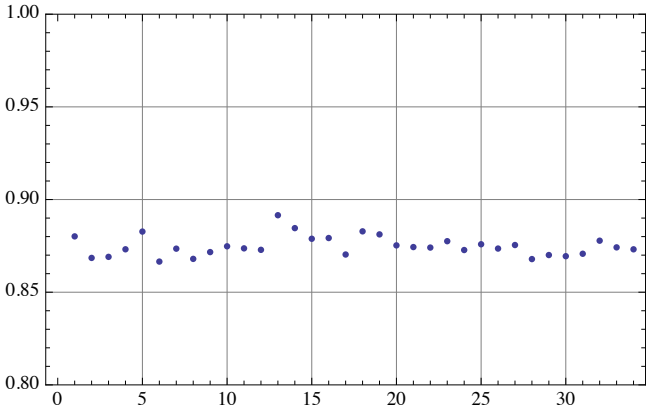
Loading the data files

In[21]:=
```
datX = ReadList[
   "/Users/karai/LIGO/09/09_40m/Upgrade09/IFO/loss-X-939008600.log", {Number, Number}];
```

In[22]:=
```
VdatX = Map[#[[1]] / #[[2]] &, datX];
```

In[23]:=
```
ListPlot[VdatX, PlotRange → {0.8, 1}, Frame → True, GridLines → Automatic]
```

Out[23]=



In[24]:=
```
X = {Mean[VdatX], StandardDeviation[VdatX], Length[VdatX]}
```

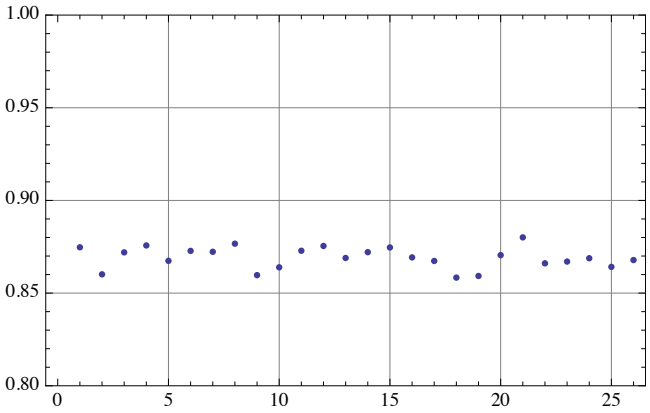
Out[24]=
```
{0.87486, 0.0054449, 34}
```

In[25]:=
```
datY = ReadList[
    "/Users/karai/LIGO/09/09_40m/Upgrade09/IFO/loss-Y-939010178.log", {Number, Number}];
```

In[26]:=
```
VdatY = Map[#[[1]] / #[[2]] &, datY];
```

In[27]:=
```
ListPlot[VdatY, PlotRange → {0.8, 1}, Frame → True, GridLines → Automatic]
```

Out[27]=



In[28]:=
```
Y = {Mean[VdatY], StandardDeviation[VdatY], Length[VdatY]}
```

Out[28]=
```
{0.869147, 0.00577788, 26}
```

■ X arm

■ FWHM

In[29]:=
```
(*
fc={1615.38,1558.21,1620.97,1616.46,1646.69};
Mean[fc]
*)
(* numbers from abs length measurement *)
```

In[30]:=
```
FWHM = fcX * 2;
FSR = FSRX;
FinesseX = FSR / FWHM
```

Out[32]= 1181.1

In[33]:=
```
dFinesseX = Abs[D[FSR / (FC * 2), FC] * dfcX /. FC → fcX]
```

Out[33]= 50.1072

In[34]:=
```
{FinesseX, dFinesseX}
```

Out[34]= {1181.1, 50.1072}

loss

In[35]:=
```
solX = FindRoot[{Rcav[TF, loss] == X[[1]], F[TF, loss] == FinesseX},
  {{loss, 0, 200}, {TF, 0.001, 0.01}}]
```

Out[35]= {loss → 161.882, TF → 0.00513424}

In[36]:=
```
lossX = loss /. solX;
TFX = TF /. solX;
```

Error

In[38]:=
```
solXdX1 = FindRoot[{Rcav[TF, loss] == X[[1]] + X[[2]], F[TF, loss] == FinesseX},
    {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[39]:=
```
solXdX2 = FindRoot[{Rcav[TF, loss] == X[[1]] - X[[2]], F[TF, loss] == FinesseX},
    {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[40]:=
```
solXdF1 = FindRoot[{Rcav[TF, loss] == X[[1]], F[TF, loss] == FinesseX + dFinesseX},
    {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[41]:=
```
solXdF2 = FindRoot[{Rcav[TF, loss] == X[[1]], F[TF, loss] == FinesseX - dFinesseX},
    {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[42]:=
$$\text{dlossX} = \sqrt{\left(\frac{(\text{loss /. solXdX2}) - (\text{loss /. solXdX1})}{2}\right)^2 + \left(\frac{(\text{loss /. solXdF1}) - (\text{loss /. solXdF2})}{2}\right)^2}$$

Out[42]= 10.6373

In[43]:=
$$\text{dTFX} = \sqrt{\left(\frac{(\text{TF /. solXdX2}) - (\text{TF /. solXdX1})}{2}\right)^2 + \left(\frac{(\text{TF /. solXdF1}) - (\text{TF /. solXdF2})}{2}\right)^2}$$

Out[43]= 0.000217768

Y arm

FWHM

In[44]:=
```
(*
fc={1649.9,1662.6,1652.0,1619.1,1650.3,1644.4,1636.9,1646.3,1647.3,1633.2};
Mean[fc]
*)
(* numbers from abs length measurement *)
```

In[45]:=
```
FWHM = fcY * 2;
FSR = FSRY;
FinesseY = FSR / FWHM
```

Out[47]= 1127.52

In[48]:=
```
dFinesseY = Abs[D[FSR / (FC * 2), FC] * dfcY /. FC → fcY]
```

Out[48]= 45.8876

In[49]:=
```
{FinesseY, dFinesseY}
```

Out[49]= {1127.52, 45.8876}

■ loss

In[50]:=
```
solY = FindRoot[{Rcav[TF, loss] == Y[[1]], F[TF, loss] == FinesseY},
  {{loss, 0, 200}, {TF, 0.001, 0.01}}]
```

Out[50]= {loss → 178.56, TF → 0.00536904}

In[51]:=
```
lossY = loss /. solY;
TFY = TF /. solY;
```

■ Error

In[53]:=
```
solYdY1 = FindRoot[{Rcav[TF, loss] == Y[[1]] + Y[[2]], F[TF, loss] == FinesseY},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[54]:=
```
solYdY2 = FindRoot[{Rcav[TF, loss] == Y[[1]] - Y[[2]], F[TF, loss] == FinesseY},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[55]:=
```
solYdF1 = FindRoot[{Rcav[TF, loss] == Y[[1]], F[TF, loss] == FinesseY + dFinesseY},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[56]:=
```
solYdF2 = FindRoot[{Rcav[TF, loss] == Y[[1]], F[TF, loss] == FinesseY - dFinesseY},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[57]:=
$$\text{dlossY} = \sqrt{\left(\frac{(\text{loss} /. \text{solYdY2}) - (\text{loss} /. \text{solYdY1})}{2}\right)^2 + \left(\frac{(\text{loss} /. \text{solYdF1}) - (\text{loss} /. \text{solYdF2})}{2}\right)^2}$$

Out[57]= 11.5519

In[58]:=
$$\text{dTFY} = \sqrt{\left(\frac{(\text{TF} /. \text{solYdY2}) - (\text{TF} /. \text{solYdY1})}{2}\right)^2 + \left(\frac{(\text{TF} /. \text{solYdF1}) - (\text{TF} /. \text{solYdF2})}{2}\right)^2}$$

Out[58]= 0.000218433

Report

In[59]:=
```
Print["X Arm:"];
Print["Arm visibility (given): ", X[[1]], " +/- ", X[[2]], "  (", X[[3]], " pts)"];
Print["Cut off freq (given): ", fcX, " +/- ", dfcX];
Print["Finesse (derived): ", FinesseX, " +/- ", dFinesseX];
Print[""];
Print["Round Trip loss (estimated): ", lossX, " +/- ", dlossX];
Print["Front Mirror T (estimated): ", TFX, " +/- ", dTFX];
Print[""];
Print["Y Arm:"];
Print["Arm visibility (given): ", Y[[1]], " +/- ", Y[[2]], "  (", Y[[3]], " pts)"];
Print["Cut off freq (given): ", fcY, " +/- ", dfcY];
Print["Finesse (derived): ", FinesseY, " +/- ", dFinesseY];
Print[""];
Print["Round Trip loss (estimated): ", lossY, " +/- ", dlossY];
Print["Front Mirror T (estimated): ", TFY, " +/- ", dTFY];
```

```
X Arm:

Arm visibility (given): 0.87486 +/- 0.0054449  (34 pts)

Cut off freq (given): 1650 +/- 70

Finesse (derived): 1181.1 +/- 50.1072


Round Trip loss (estimated): 161.882 +/- 10.6373

Front Mirror T (estimated): 0.00513424 +/- 0.000217768


Y Arm:

Arm visibility (given): 0.869147 +/- 0.00577788  (26 pts)

Cut off freq (given): 1720 +/- 70

Finesse (derived): 1127.52 +/- 45.8876


Round Trip loss (estimated): 178.56 +/- 11.5519

Front Mirror T (estimated): 0.00536904 +/- 0.000218433
```

After the wiping (Visibility: Dec 14, 2009 / fcav: Dec 14, 2009)

Data Preparation

In[74]:=
```
fcX = 1616;
dfcX = 14;
(* from TF measurement. error +/-14 *)
```

In[76]:=
```
fcY = 1590;
dfcY = 4;
(* from TF measurement. error +/-4 *)
```

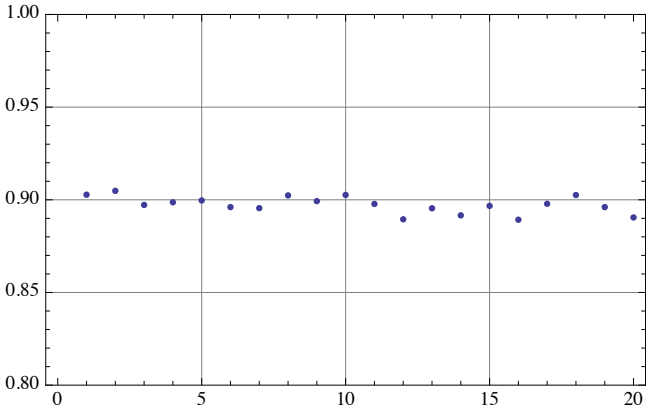
Loading the data files

In[78]:=
```
datX = ReadList[
    "/Users/karai/LIGO/09/09_40m/Upgrade09/IFO/loss-X-944865946.log", {Number, Number}];
```

In[79]:=
```
VdatX = Map[#[[1]] / #[[2]] &, datX];
```

In[80]:=
```
ListPlot[VdatX, PlotRange → {0.8, 1}, Frame → True, GridLines → Automatic]
```

Out[80]=



In[81]:=
```
X = {Mean[VdatX], StandardDeviation[VdatX], Length[VdatX]}
```

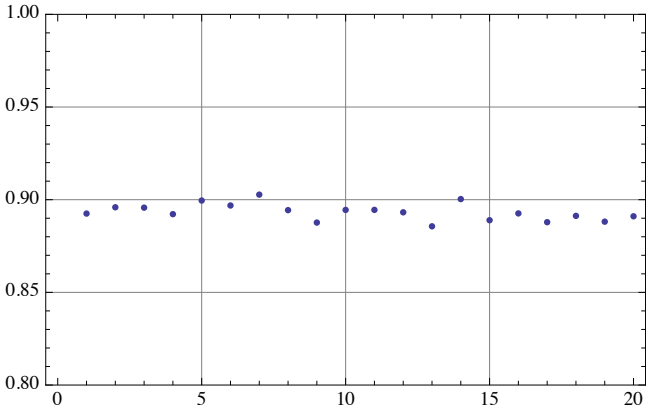
Out[81]=
```
{0.897312, 0.00456015, 20}
```

In[82]:=
```
datY = ReadList[
    "/Users/karai/LIGO/09/09_40m/Upgrade09/IFO/loss-Y-944865071.log", {Number, Number}];
```

In[83]:=
```
VdatY = Map[#[[1]] / #[[2]] &, datY];
```

In[84]:=
```
ListPlot[VdatY, PlotRange → {0.8, 1}, Frame → True, GridLines → Automatic]
```

Out[84]=



In[85]:=
```
Y = {Mean[VdatY], StandardDeviation[VdatY], Length[VdatY]}
```

Out[85]=
```
{0.893277, 0.00449546, 20}
```

X arm

FWHM

In[86]:=
```
FWHM = fcX * 2;
FSR = FSRX;
FinesseX = FSR / FWHM
```

Out[88]= 1205.95

In[89]:=
```
dFinesseX = Abs[D[FSR / (FC * 2), FC] * dfcX /. FC → fcX]
```

Out[89]= 10.4476

In[90]:=
```
{FinesseX, dFinesseX}
```

Out[90]= {1205.95, 10.4476}

loss

In[91]:=
```
solX = FindRoot[{Rcav[TF, loss] == X[[1]], F[TF, loss] == FinesseX},
  {{loss, 0, 200}, {TF, 0.001, 0.01}}]
```

Out[91]= {loss → 127.295, TF → 0.00505969}

In[92]:=
```
lossX = loss /. solX;
TFX = TF /. solX;
```

Error

In[94]:=
```
solXdX1 = FindRoot[{Rcav[TF, loss] == X[[1]] + X[[2]], F[TF, loss] == FinesseX},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[95]:=
```
solXdX2 = FindRoot[{Rcav[TF, loss] == X[[1]] - X[[2]], F[TF, loss] == FinesseX},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[96]:=
```
solXdF1 = FindRoot[{Rcav[TF, loss] == X[[1]], F[TF, loss] == FinesseX + dFinesseX},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[97]:=
```
solXdF2 = FindRoot[{Rcav[TF, loss] == X[[1]], F[TF, loss] == FinesseX - dFinesseX},
   {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

In[98]:=
$$\text{dlossX} = \sqrt{\left(\frac{(\text{loss} /. \text{solXdX2}) - (\text{loss} /. \text{solXdX1})}{2}\right)^2 + \left(\frac{(\text{loss} /. \text{solXdF1}) - (\text{loss} /. \text{solXdF2})}{2}\right)^2}$$

Out[98]= 6.37812

In[99]:=
$$\text{dTFX} = \sqrt{\left(\frac{(\text{TF} /. \text{solXdX2}) - (\text{TF} /. \text{solXdX1})}{2}\right)^2 + \left(\frac{(\text{TF} /. \text{solXdF1}) - (\text{TF} /. \text{solXdF2})}{2}\right)^2}$$

Out[99]= 0.0000441683

Y arm

FWHM

```
In[100]:= FWHM = fcY * 2;
          FSR = FSRY;
          FinesseY = FSR / FWHM
Out[102]= 1219.71

In[103]:= dFinesseY = Abs[D[FSR / (FC * 2), FC] * dfcY /. FC → fcY]
Out[103]= 3.06845

In[104]:= {FinesseY, dFinesseY}
Out[104]= {1219.71, 3.06845}
```

loss

```
In[105]:= solY = FindRoot[{Rcav[TF, loss] == Y[[1]], F[TF, loss] == FinesseY},
            {{loss, 0, 200}, {TF, 0.001, 0.01}}]
Out[105]= {loss → 131.235, TF → 0.00499728}

In[106]:= lossY = loss /. solY;
          TFY = TF /. solY;
```

Error

```
In[108]:= solYdY1 = FindRoot[{Rcav[TF, loss] == Y[[1]] + Y[[2]], F[TF, loss] == FinesseY},
              {{loss, 0, 200}, {TF, 0.001, 0.01}}];

In[109]:= solYdY2 = FindRoot[{Rcav[TF, loss] == Y[[1]] - Y[[2]], F[TF, loss] == FinesseY},
              {{loss, 0, 200}, {TF, 0.001, 0.01}}];

In[110]:= solYdF1 = FindRoot[{Rcav[TF, loss] == Y[[1]], F[TF, loss] == FinesseY + dFinesseY},
              {{loss, 0, 200}, {TF, 0.001, 0.01}}];

In[111]:= solYdF2 = FindRoot[{Rcav[TF, loss] == Y[[1]], F[TF, loss] == FinesseY - dFinesseY},
              {{loss, 0, 200}, {TF, 0.001, 0.01}}];
```

$$\text{In[112]:= } \text{dlossY} = \sqrt{\left(\frac{(\text{loss} /. \text{solYdY2}) - (\text{loss} /. \text{solYdY1})}{2}\right)^2 + \left(\frac{(\text{loss} /. \text{solYdF1}) - (\text{loss} /. \text{solYdF2})}{2}\right)^2}$$

```
Out[112]= 6.13188
```

$$\text{In[113]:= } \text{dTFY} = \sqrt{\left(\frac{(\text{TF} /. \text{solYdY2}) - (\text{TF} /. \text{solYdY1})}{2}\right)^2 + \left(\frac{(\text{TF} /. \text{solYdF1}) - (\text{TF} /. \text{solYdF2})}{2}\right)^2}$$

```
Out[113]= 0.0000139474
```

Report

In[114]:=
```
Print["X Arm:"];
Print["Arm visibility (given): ", X[[1]], " +/- ", X[[2]], "  (", X[[3]], " pts)"];
Print["Cut off freq (given): ", fcX, " +/- ", dfcX];
Print["Finesse (derived): ", FinesseX, " +/- ", dFinesseX];
Print[""];
Print["Round Trip loss (estimated): ", lossX, " +/- ", dlossX];
Print["Front Mirror T (estimated): ", TFX, " +/- ", dTFX];
Print[""];
Print["Y Arm:"];
Print["Arm visibility (given): ", Y[[1]], " +/- ", Y[[2]], "  (", Y[[3]], " pts)"];
Print["Cut off freq (given): ", fcY, " +/- ", dfcY];
Print["Finesse (derived): ", FinesseY, " +/- ", dFinesseY];
Print[""];
Print["Round Trip loss (estimated): ", lossY, " +/- ", dlossY];
Print["Front Mirror T (estimated): ", TFY, " +/- ", dTFY];
```

```
X Arm:

Arm visibility (given): 0.897312 +/- 0.00456015  (20 pts)

Cut off freq (given): 1616 +/- 14

Finesse (derived): 1205.95 +/- 10.4476


Round Trip loss (estimated): 127.295 +/- 6.37812

Front Mirror T (estimated): 0.00505969 +/- 0.0000441683


Y Arm:

Arm visibility (given): 0.893277 +/- 0.00449546  (20 pts)

Cut off freq (given): 1590 +/- 4

Finesse (derived): 1219.71 +/- 3.06845


Round Trip loss (estimated): 131.235 +/- 6.13188

Front Mirror T (estimated): 0.00499728 +/- 0.0000139474
```