

## Beam Based Characterization of 5-Pass Accelerator Transport October-November 2005

In the following pages analysis of global transport data taken in October & November 2005, as performed by the program OTAM<sup>1</sup>, is presented. This is not the final analysis, but aims to address issues of more immediate concern, such as raised in the 12 GeV beam physics meeting.

The quality of data, to the extent that they are used in this analysis, is quite good. This is reflected in the results below, showing cross-comparison between data & optical model, and between evaluated empirical transport model and data itself. A special characteristic of OTAM is the multiple screening criteria it applies to the data in order to ensure highly reliable matching results. Most of the data cleared all the tight baseline cutoffs<sup>2</sup> without need of tweaking. There are a few cases where the criteria had to be relaxed. These will be noted where appropriate in the following.

The picture that emerges points to what has been relatively well-known about the global CEBAF transport. Namely, after the machine is nominally tuned, the transport from 60 MeV to the end of the 5<sup>th</sup> pass, on an arc-to-arc scale, is short on surprises. There are a few minor sources of error such as skew field or localized focusing errors. But the matching situation on the arc-to-arc scale is quite good. The only place where we are not doing any matching, namely between 60 MeV and Arc 1, can present a very different picture. It has been shown in 2003 that even this part of the machine can be well within spec, leading to a near-perfect 60 MeV-to-3 GeV transport as measured then. But this is not guaranteed by any procedure in the standard tune-up repertory. This time the situation is seen to be quite different. Since the only things guaranteed by the current matching doctrine are the adherence to design of the beam spot at 60 MeV and that of the transport from Arc 1 to the halls in a Courant Snyder sense<sup>3</sup>, this uncertainty can in principle explain any amount of deviation from design of the beam spot in the halls. How much in reality this is the case would have to be answered by the current analysis in conjunction with more refined FOPT data already taken but yet to be analyzed, and emittance measurements being planned.

For this reason the transport from 60 MeV (OR) to Arc 1 is of particular importance, which also appears to be the most aberrant of all sections measured this time. The following 4 pages are thus devoted to a detailed account of the analysis of FOPT taken in this section. This is followed by a more condensed section-by-section description of the analysis outcome containing key information on data quality, measured transport and its quality, comparison with model, and matching scenario indicating how far the section in question is off design. The section OR-1A is also included with the same information presented in the common format again. For complete detail of analysis of all sections, refer to the more comprehensive [complete detail of FOPT analysis](#).

It should be noted that except for the section OR-1A, the Courant Snyder mismatch factors for all sections are less than 1.7 (square root of 3). This means the machine from Arc 1 to AT has been remarkably well-matched. Again we should emphasize this is true on the arc-to-arc scale and does not take into account problems occurring at a smaller scale. Also we should note that in the case of XY-coupling, minor errors can result in significant emittance blowup if the optics is sufficiently mismatched local to this source, if the coupling is not redressed later (which is almost certain the case). Thus until a complete analysis of all data taken and being planned is done, one cannot securely conclude if or how we can (cannot) produce the beam spot as designed all the way to the halls in the real machine.

Despite the predominance of good data, a few FOPT runs produced unusable data not realized until time of analysis. It is the hope that these can be repeated under closer scrutiny while the Oct-Nov optics is still in the machine, together with the emittance data.

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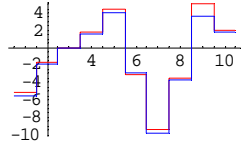
<sup>1</sup>. [Optical Transport Analysis & Matching](#) This link gives more detail on correct interpretation of the results, especially plots, presented below.

<sup>2</sup> The empirical quadrupole offsets (Roblin & Tiefenback) in Arcs 3, 4 and 5 were needed for this purpose.

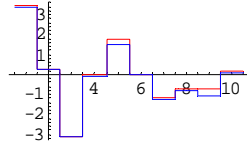
<sup>3</sup> Namely, disregarding phase.

## Measured trajectories (red) and fit to model (blue) in X (left) & Y(right) – Up/Downstream section

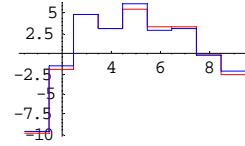
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TrajFit\_05oct091523MIX0\_0to1.dat  
X1-UP DATA (R) & FIT (B)



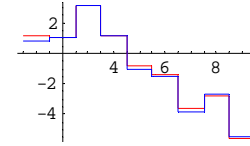
AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
X2-UP DATA (R) & FIT (B)



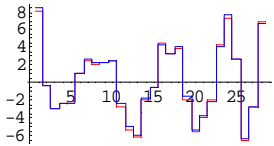
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Y1-UP DATA (R) & FIT (B)



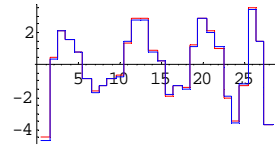
AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
Y2-UP DATA (R) & FIT (B)



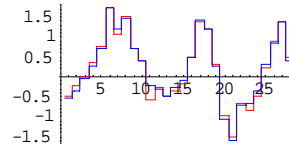
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X1-DN DATA (R) & FIT (B)



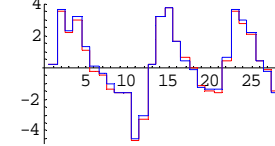
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TrajFit\_05oct091523MIX0\_0to1.dat  
X2-DN DATA (R) & FIT (B)



AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
Y1-DN DATA (R) & FIT (B)



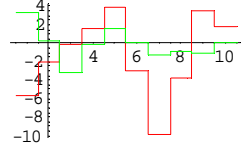
AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
Y2-DN DATA (R) & FIT (B)



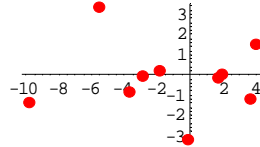
## Orthogonalized trajectory correlations (red dots) in X (left) & Y(right) – Up/Downstream section

Normalized Correlation:  
-0.0102597

AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
X1-UP FIT (R) & X2-UP FIT (G)

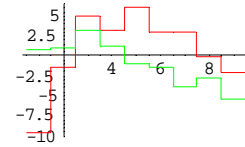


AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
X1/2-UP FIT CORR.

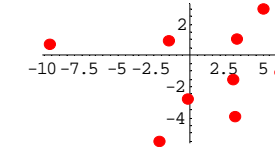


-0.00021316

AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
Y1-UP FIT (R) & Y2-UP FIT (G)

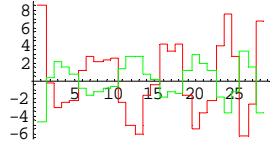


AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
Y1/2-UP FIT CORR.

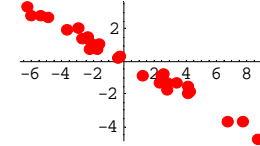


Normalized Correlation:  
-0.989341

AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
X1-DN FIT (R) & X2-DN FIT (G)

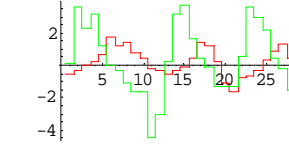


AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
X1/2-DN FIT CORR.

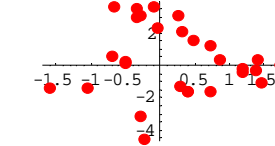


-0.0407571

AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024  
TrajFit\_05oct091523MIX0\_0to1.dat  
Y1/2-DN FIT CORR.



Near-singular transport in X from 0R to 1A is apparent in above plot.



# 4D symplectified

## 4D Symplectified Matrix:

$$\begin{pmatrix} 0.579616 & -6.79483 & -0.366287 & 2.52046 \\ 0.0652463 & -0.585896 & -0.0338818 & 0.237244 \\ 0.117093 & 0.812005 & 1.0862 & -4.01718 \\ 0.00532482 & 0.0241013 & 0.0130097 & 0.0473953 \end{pmatrix}$$

## 4D Symplectic Condition:

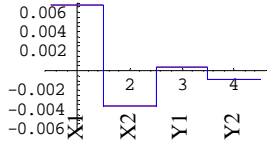
$$\begin{pmatrix} 0 & 0.102241 & 0 & 0 \\ -0.102241 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.102241 \\ 0 & 0 & -0.102241 & 0 \end{pmatrix}$$

## Performance of 4D symplectified matrix w.r.t. real data

ΔMLOGDec12011024

tandard2G\_05oct091523MIX0\_0to1

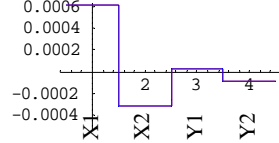
[-POS Measured (R) & Matrix Propagated (B)]



AMLOGDec12011024

standard2G\_05oct091523MIX0\_0to1

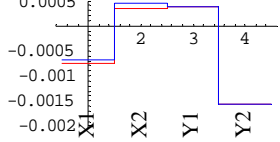
[+ANG Measured (R) & Matrix Propagated (B)]



ΔMLOGDec12011024

tandard2G\_05oct091523MIX0\_0to1

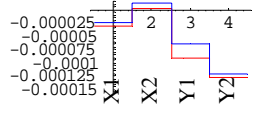
[-POS Measured (R) & Matrix Propagated (B)]



AMLOGDec12011024

standard2G\_05oct091523MIX0\_0to1

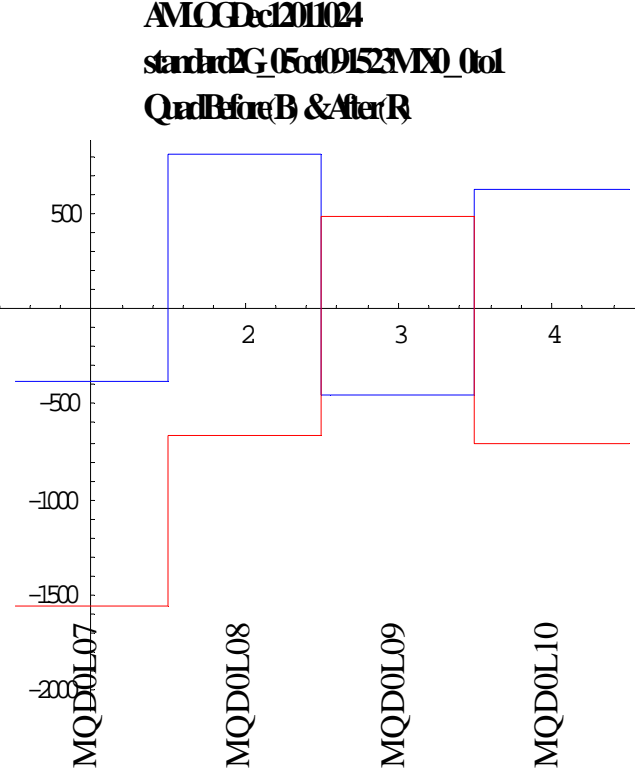
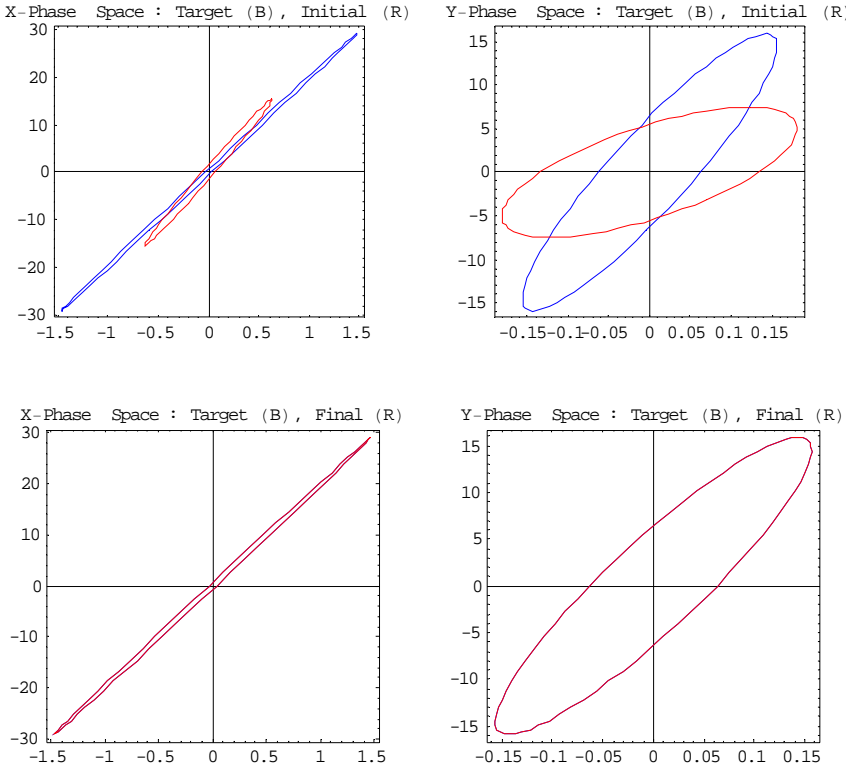
[+ANG Measured (R) & Matrix Propagated (B)]



# Mismatch, Courant Snyder, and Matching quad changes needed to achieve 100% matching

Left: Projected design phase ellipse at matching point before & after matching

Right: Matching quad changes (blue: before; red after)



## Courant Snyder mismatch factor (squared) before & after

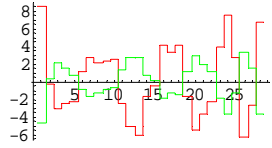
Maximum X & Y CS Parameter Ratios (Before):  
 22.152237      5.333192

Maximum X & Y CS Parameter Ratios (After):  
 1.000543      1.000117

# IPM0R07 to IPM1R01

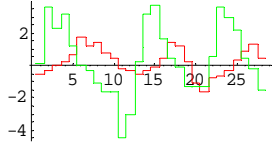
AMLOGDec12011024

TrajFit\_05oct091523MIX0\_0to1.dat  
X1-DNFIT (R) & X2-DNFIT (G)



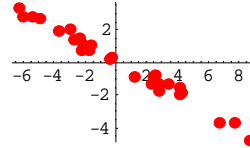
AMLOGDec12011024

TrajFit\_05oct091523MIX0\_0to1.dat  
Y1-DNFIT (R) & Y2-DNFIT (G)



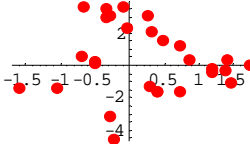
AMLOGDec12011024

TrajFit\_05oct091523MIX0\_0to1.dat  
X1/2-DNFIT CORR.



AMLOGDec12011024

TrajFit\_05oct091523MIX0\_0to1.dat  
Y1/2-DNFIT CORR.



Damping Factor, Determinants of X & Y Fitted:  
0.319752                      0.304142                      0.361601

Damping Factor, Determinants of 4 by 4 Fitted:  
0.319752                      0.334484

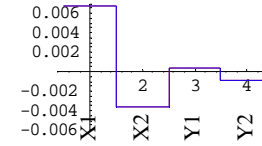
4D Symplectified Matrix:

$$\begin{pmatrix} 0.579616 & -6.79483 & -0.366287 & 2.52046 \\ 0.0652463 & -0.585896 & -0.0338818 & 0.237244 \\ 0.117093 & 0.812005 & 1.0862 & -4.01718 \\ 0.00532482 & 0.0241013 & 0.0130097 & 0.0473953 \end{pmatrix}$$

AMLOGDec12011024

standard2G\_05oct091523MIX0\_0to1

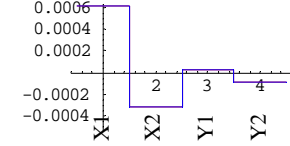
Z-POS Measured (R) & Matrix Propagated (B)



AMLOGDec12011024

standard2G\_05oct091523MIX0\_0to1

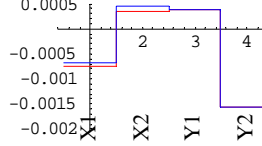
Z-ANG Measured (R) & Matrix Propagated (B)



AMLOGDec12011024

standard2G\_05oct091523MIX0\_0to1

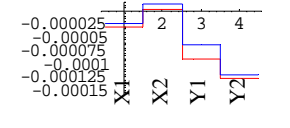
Z-POS Measured (R) & Matrix Propagated (B)



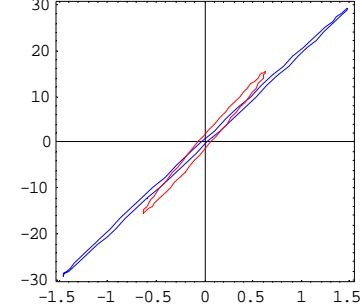
AMLOGDec12011024

standard2G\_05oct091523MIX0\_0to1

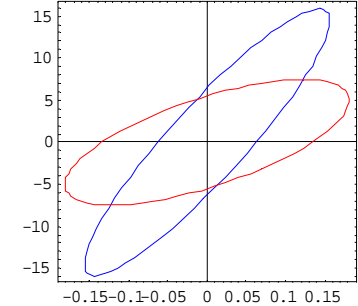
Z-ANG Measured (R) & Matrix Propagated (B)



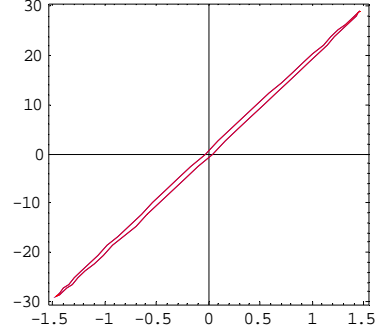
X-Phase Space : Target (B), Initial (R)



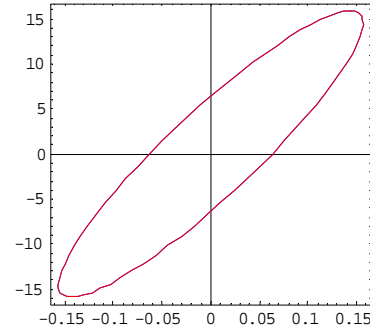
Y-Phase Space : Target (B), Initial (R)



X-Phase Space : Target (B), Final (R)



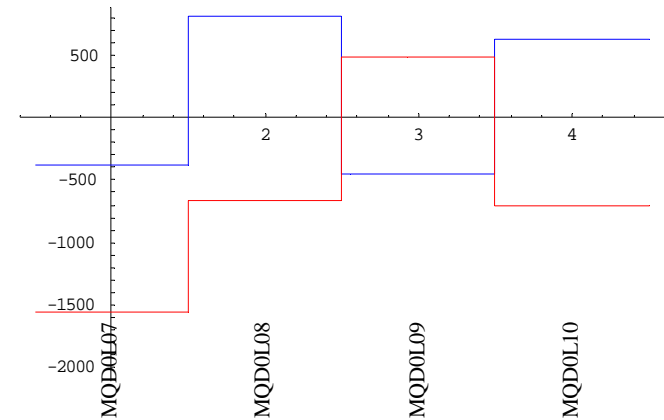
Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024

standard2G\_05oct091523MIX0\_0to1

Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):  
22.152237                      5.333192

Maximum X & Y CS Parameter Ratios (After):  
1.000543                      1.000117

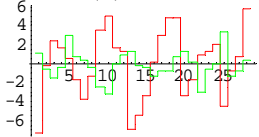
## Comments:

- Obviously near singular transport in X, not in keeping with design
- Significant XY coupling
- Non-trivial quad changes needed to re-match

# IPM1R01 to IPM2R01

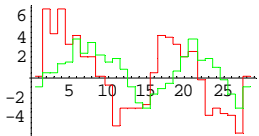
AMLOGDec12011024

TrajFit\_05oct091646MIX1\_1to2.dat  
X1-DN FIT (R) & X2-DN FIT (G)



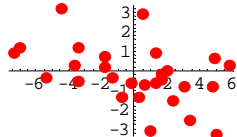
AMLOGDec12011024

TrajFit\_05oct091646MIX1\_1to2.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



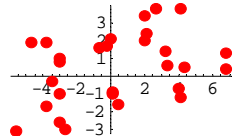
AMLOGDec12011024

TrajFit\_05oct091646MIX1\_1to2.dat  
X1/2-DN FIT CORR.



AMLOGDec12011024

TrajFit\_05oct091646MIX1\_1to2.dat  
Y1/2-DN FIT CORR.



Damping Factor, Determinants of X & Y Fitted:  
0.725842                      0.722903                      0.712343

Damping Factor, Determinants of 4 by 4 Fitted:  
0.725842                      0.718015

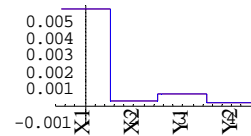
4D Symplectified Matrix:

$$\begin{pmatrix} 0.574712 & -16.4033 & 0.0911107 & -0.127128 \\ 0.076348 & -1.26524 & 0.0111795 & 0.00232281 \\ 0.0104175 & 0.394734 & -0.306107 & -3.93834 \\ -0.00337874 & 0.0287167 & 0.150264 & 0.217494 \end{pmatrix}$$

MLOGDec12011024

andard2G\_05oct091646MIX1\_1to2

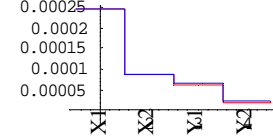
-POS Measured (R) & Matrix Propagated (G)



AMLOGDec12011024

standard2G\_05oct091646MIX1\_1to2

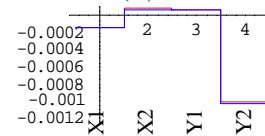
-BANG Measured (R) & Matrix Propagated (G)



MLOGDec12011024

andard2G\_05oct091646MIX1\_1to2

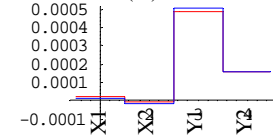
-POS Measured (R) & Matrix Propagated (G)



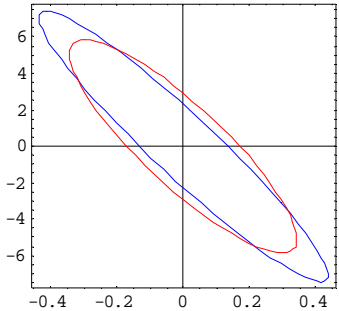
AMLOGDec12011024

standard2G\_05oct091646MIX1\_1to2

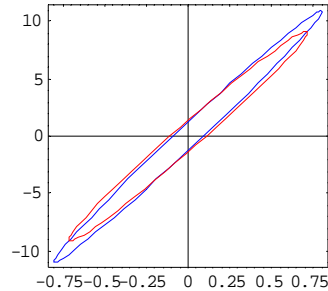
-BANG Measured (R) & Matrix Propagated (G)



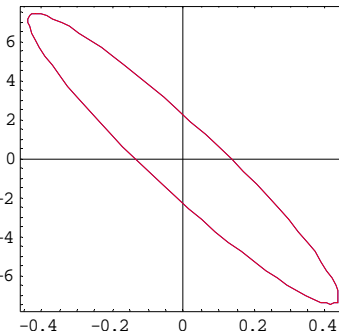
X-Phase Space : Target (B), Initial (R)



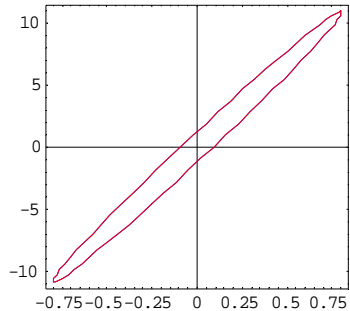
Y-Phase Space : Target (B), Initial (R)



X-Phase Space : Target (B), Final (R)



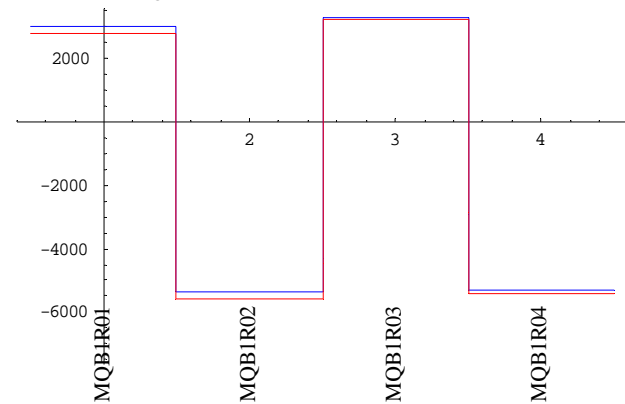
Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024

standard2G\_05oct091646MIX1\_1to2

Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):  
1.690660                      1.743886

Maximum X & Y CS Parameter Ratios (After):  
1.000527                      1.000626



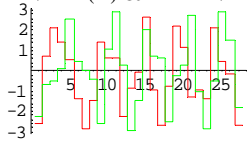
## Comments:

- Good data. Good transport

# IPM2R01 to IPM3R01

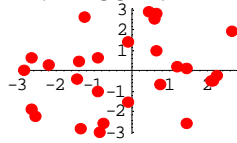
AMLOGDec12011024

TrajFit\_05oct091738MIX2\_2to3.dat  
X1-DN FIT (R) & X2-DN FIT (G)



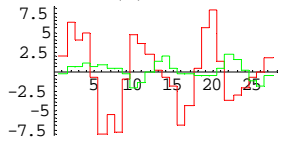
AMLOGDec12011024

TrajFit\_05oct091738MIX2\_2to3.dat  
X1/2-DN FIT CORR.



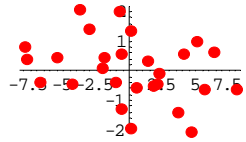
AMLOGDec12011024

TrajFit\_05oct091738MIX2\_2to3.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024

TrajFit\_05oct091738MIX2\_2to3.dat  
Y1/2-DN FIT CORR.



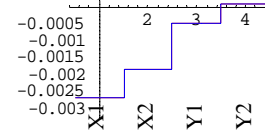
4D Symplectified Matrix:

$$\begin{pmatrix} -0.770058 & 0.806503 & 0.118927 & 0.782094 \\ -0.0399919 & -0.839841 & 0.0169313 & 0.109966 \\ -0.0828323 & 1.15181 & -0.822824 & 1.48523 \\ 0.00983674 & -0.134804 & -0.00227019 & -0.821085 \end{pmatrix}$$

MLOGDec12011024

andard2G\_05oct091738MIX2\_2to3

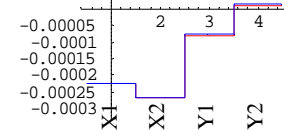
-POS Measured (R) & Matrix Propagated (B)



AMLOGDec12011024

standard2G\_05oct091738MIX2\_2to3

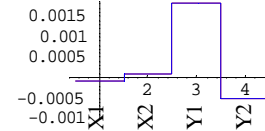
-ANG Measured (R) & Matrix Propagated (B)



MLOGDec12011024

andard2G\_05oct091738MIX2\_2to3

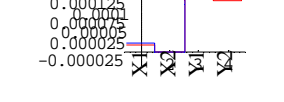
-POS Measured (R) & Matrix Propagated (B)



AMLOGDec12011024

standard2G\_05oct091738MIX2\_2to3

-ANG Measured (R) & Matrix Propagated (B)



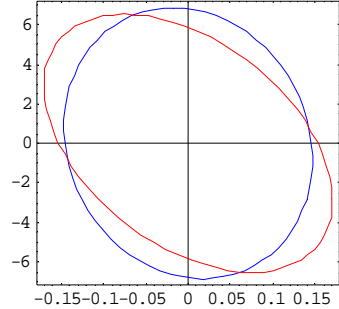
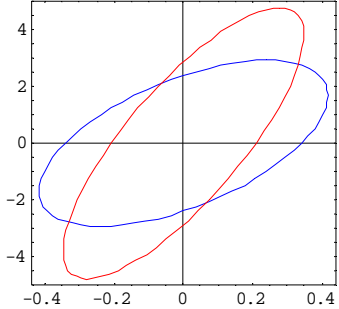
Damping Factor, Determinants of X & Y Fitted:

0.823903                      0.825096                      0.811388

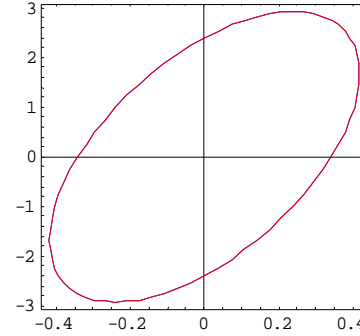
Damping Factor, Determinants of 4 by 4 Fitted:

0.823903                      0.818454

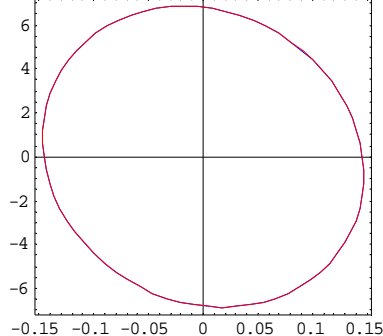
X-Phase Space : Target (B), Initial (R)    Y-Phase Space : Target (B), Initial (R)



X-Phase Space : Target (B), Final (R)



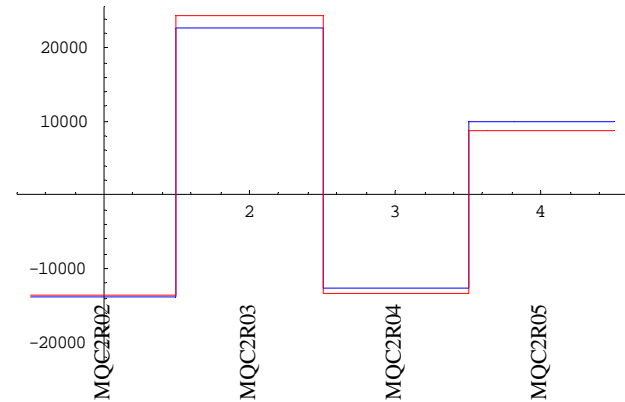
Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024

standard2G\_05oct091738MIX2\_2to3

Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):

2.791488                      1.507399

Maximum X & Y CS Parameter Ratios (After):

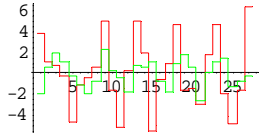
1.000083                      1.000064

## Comments:

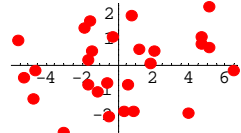
- Good data. Reasonable transport

# IPM3R01 to IPM4R01

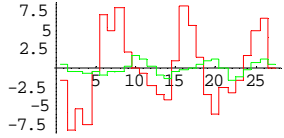
AMLOGDec12011024  
TrajFit\_05oct091810MIX3\_3to4.dat  
X1-DN FIT (R) & X2-DN FIT (G)



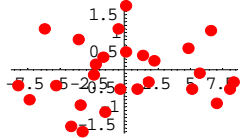
AMLOGDec12011024  
TrajFit\_05oct091810MIX3\_3to4.dat  
X1/2-DN FIT CORR.



AMLOGDec12011024  
TrajFit\_05oct091810MIX3\_3to4.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024  
TrajFit\_05oct091810MIX3\_3to4.dat  
Y1/2-DN FIT CORR.



Damping Factor, Determinants of X & Y Fitted:

0.869998                      0.856107                      0.850912

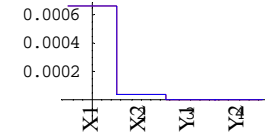
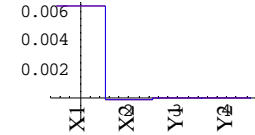
Damping Factor, Determinants of 4 by 4 Fitted:

0.869998                      0.853563

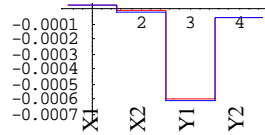
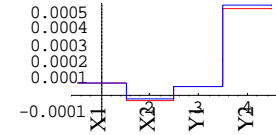
4D Symplectified Matrix:

$$\begin{pmatrix} -0.0101821 & -7.24385 & -0.0774518 & -0.860594 \\ 0.102179 & -1.64789 & -0.00988519 & -0.109147 \\ -0.0312888 & 0.218348 & -0.0556605 & -3.57353 \\ -0.0185217 & 0.130963 & 0.223201 & 0.730555 \end{pmatrix}$$

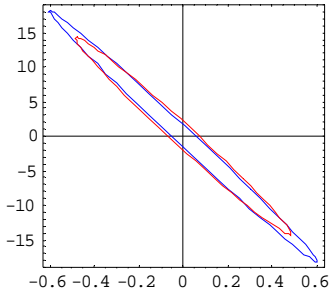
MLOGDec12011024                      AMLOGDec12011024  
andard2G\_05oct091810MIX3\_3to4      standard2G\_05oct091810MIX3\_3to4  
-POS Measured (R) & Matrix Propagated (G)      -POS Measured (R) & Matrix Propagated (G)



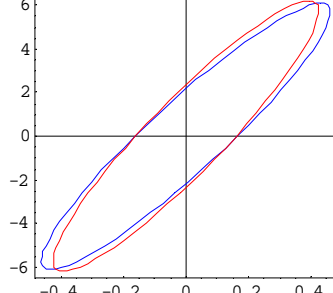
MLOGDec12011024                      AMLOGDec12011024  
andard2G\_05oct091810MIX3\_3to4      standard2G\_05oct091810MIX3\_3to4  
-POS Measured (R) & Matrix Propagated (G)      -POS Measured (R) & Matrix Propagated (G)



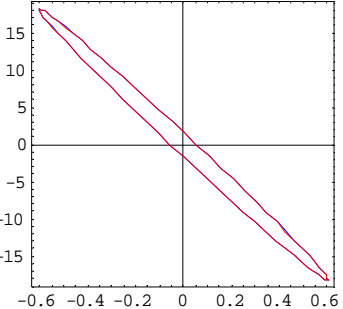
X-Phase Space : Target (B), Initial (R)



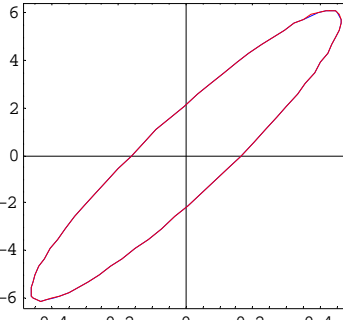
Y-Phase Space : Target (B), Initial (R)



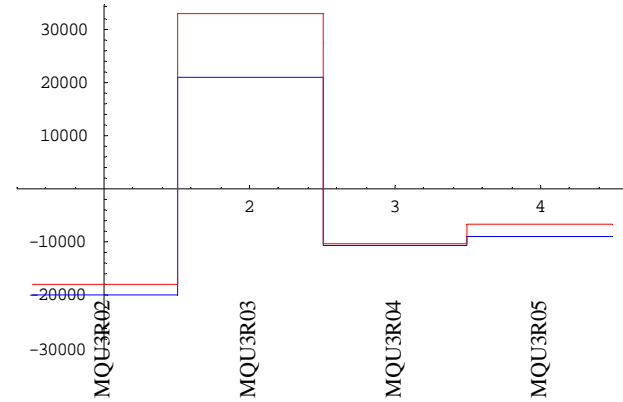
X-Phase Space : Target (B), Final (R)



Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024  
standard2G\_05oct091810MIX3\_3to4  
Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):  
1.665470                      1.326813

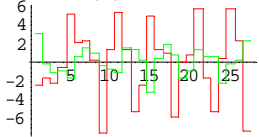
Maximum X & Y CS Parameter Ratios (After):  
1.000873                      1.001179

## Comments:

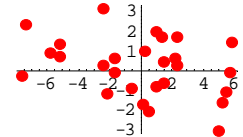
- Good data. Good transport

# IPM4R01 to IPM5R01

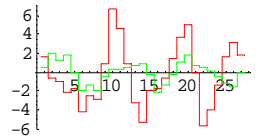
AMLOGDec12011024  
TrajFit\_05oct091831MIX4\_4to5.dat  
X1-DN FIT (R) & X2-DN FIT (G)



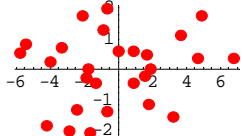
AMLOGDec12011024  
TrajFit\_05oct091831MIX4\_4to5.dat  
X1/2-DN FIT CORR.



AMLOGDec12011024  
TrajFit\_05oct091831MIX4\_4to5.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024  
TrajFit\_05oct091831MIX4\_4to5.dat  
Y1/2-DN FIT CORR.



Damping Factor, Determinants of X & Y Fitted:

0.896905                      0.912031                      1.054513

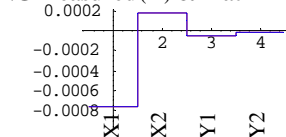
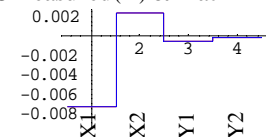
Damping Factor, Determinants of 4 by 4 Fitted:

0.896905                      0.985686

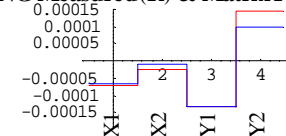
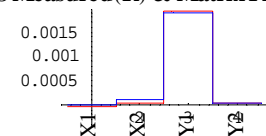
4D Symplectified Matrix:

$$\begin{pmatrix} 4.72584 & -48.5081 & 0.0501919 & 1.4315 \\ 0.447802 & -4.42853 & -0.00324221 & 0.12598 \\ 0.129804 & -1.46873 & -0.56985 & -3.41336 \\ 0.0229666 & -0.175397 & 0.190369 & -0.252129 \end{pmatrix}$$

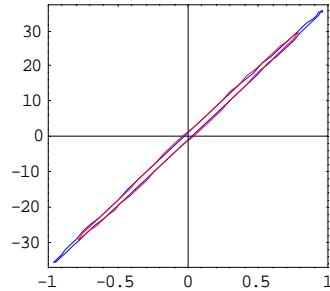
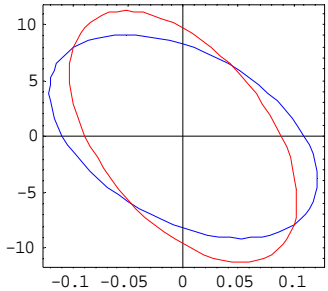
MLOGDec12011024                      AMLOGDec12011024  
andard2G\_05oct091831MIX4\_4to5      standard2G\_05oct091831MIX4\_4to5  
-POS Measured (R) & Matrix Propagated (G)      -BANG Measured (R) & Matrix Propagated (G)



MLOGDec12011024                      AMLOGDec12011024  
andard2G\_05oct091831MIX4\_4to5      standard2G\_05oct091831MIX4\_4to5  
-POS Measured (R) & Matrix Propagated (G)      -BANG Measured (R) & Matrix Propagated (G)

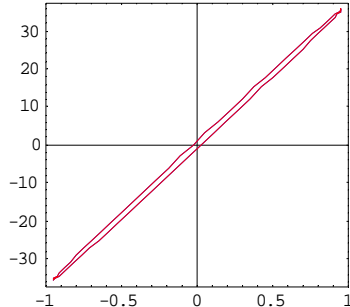
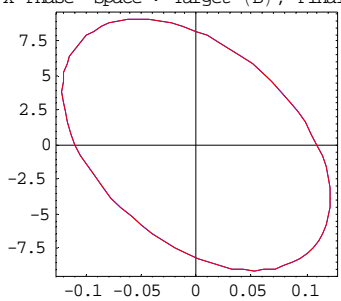


X-Phase Space : Target (B), Initial (R)      Y-Phase Space : Target (B), Initial (R)

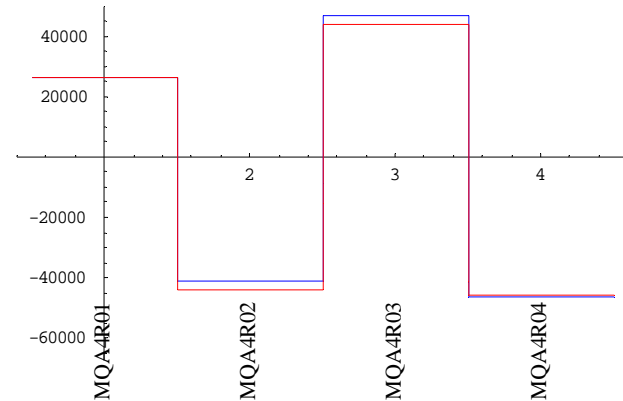


X-Phase Space : Target (B), Final (R)

Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024  
standard2G\_05oct091831MIX4\_4to5  
Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):

1.542005                      1.577799

Maximum X & Y CS Parameter Ratios (After):

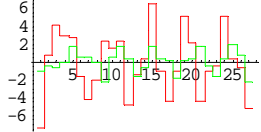
1.000076                      1.000592

## Comments:

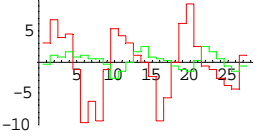
- Good data. Good transport

# IPM5R01 to IPM6R01

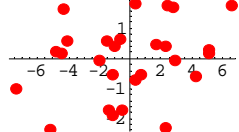
AMLOGDec12011024  
TrajFit\_05oct091858MIX5\_5to6.dat  
X1-DN FIT (R) & X2-DN FIT (G)



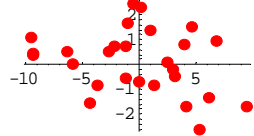
AMLOGDec12011024  
TrajFit\_05oct091858MIX5\_5to6.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024  
TrajFit\_05oct091858MIX5\_5to6.dat  
X1/2-DN FIT CORR.



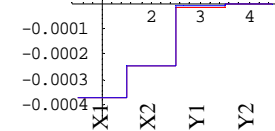
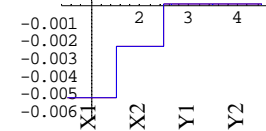
AMLOGDec12011024  
TrajFit\_05oct091858MIX5\_5to6.dat  
Y1/2-DN FIT CORR.



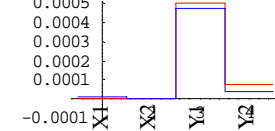
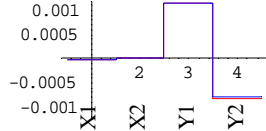
4D Symplectified Matrix:

$$\begin{pmatrix} 3.04245 & -23.4576 & 0.013361 & 0.130371 \\ 0.203524 & -1.29427 & 0.00204875 & 0.0189276 \\ 0.0419859 & -0.37129 & -0.911233 & 1.94162 \\ 0.000976422 & -0.00897305 & -0.104884 & -0.69444 \end{pmatrix}$$

MLOGDec12011024 AMLOGDec12011024  
andard2G\_05oct091858MIX5\_5to6 standard2G\_05oct091858MIX5\_5to6  
-POS Measured (R) & Matrix Propagated (G) -BANG Measured (R) & Matrix Propagated (G)



MLOGDec12011024 AMLOGDec12011024  
andard2G\_05oct091858MIX5\_5to6 standard2G\_05oct091858MIX5\_5to6  
-POS Measured (R) & Matrix Propagated (G) -BANG Measured (R) & Matrix Propagated (G)



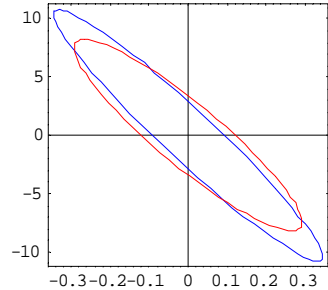
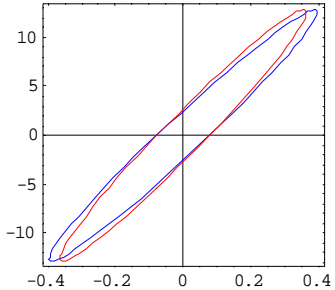
Damping Factor, Determinants of X & Y Fitted:

0.914564 0.894794 0.981841

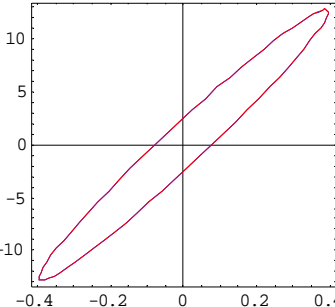
Damping Factor, Determinants of 4 by 4 Fitted:

0.914564 0.937342

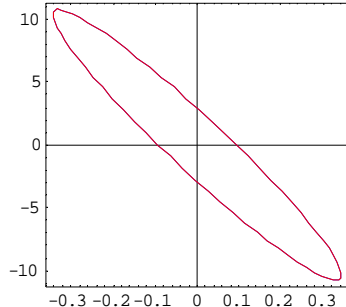
X-Phase Space : Target (B), Initial (R) Y-Phase Space : Target (B), Initial (R)



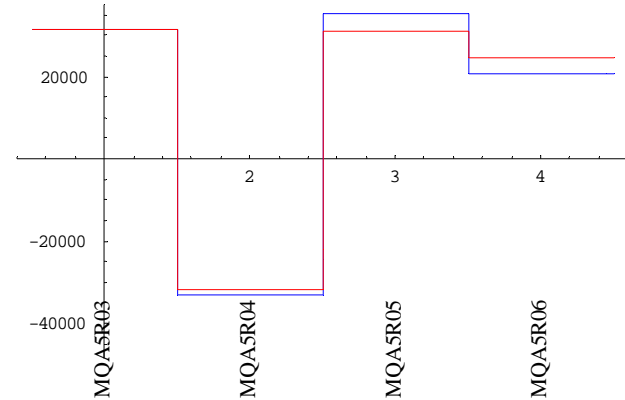
X-Phase Space : Target (B), Final (R)



Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024  
standard2G\_05oct091858MIX5\_5to6  
Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):

1.527178 1.743421

Maximum X & Y CS Parameter Ratios (After):

1.000055 1.000060

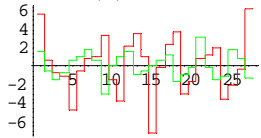


## Comments:

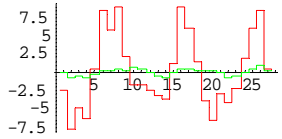
- Good data. Good transport

# IPM6R01 to IPM7R01

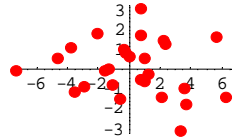
AMLOGDec12011024  
TrajFit\_05oct091919MIX6\_6to7.dat  
X1-DN FIT (R) & X2-DN FIT (G)



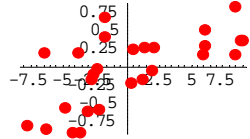
AMLOGDec12011024  
TrajFit\_05oct091919MIX6\_6to7.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024  
TrajFit\_05oct091919MIX6\_6to7.dat  
X1/2-DN FIT CORR.



AMLOGDec12011024  
TrajFit\_05oct091919MIX6\_6to7.dat  
Y1/2-DN FIT CORR.



Damping Factor, Determinants of X & Y Fitted:

0.927050                      0.929741                      0.880745

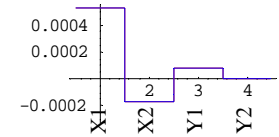
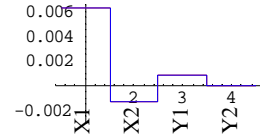
Damping Factor, Determinants of 4 by 4 Fitted:

0.927050                      0.908997

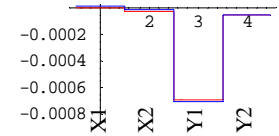
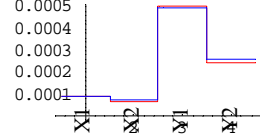
4D Symplectified Matrix:

$$\begin{pmatrix} -3.4427 & 29.2084 & -0.310041 & -0.624101 \\ -0.278014 & 2.11223 & -0.0229263 & -0.0811534 \\ -0.0459659 & 0.725482 & 0.548343 & -2.62159 \\ -0.0171684 & 0.0348697 & 0.0467046 & 1.32422 \end{pmatrix}$$

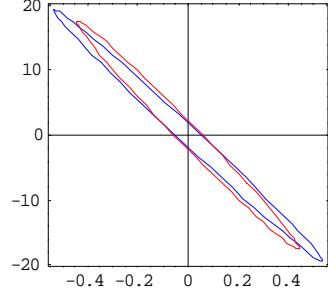
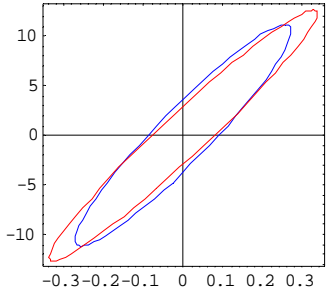
MLOGDec12011024                      AMLOGDec12011024  
andard2G\_05oct091919MIX6\_6to7                      standard2G\_05oct091919MIX6\_6to7  
-POS Measured (R) & Matrix Propagated (G)                      -POS Measured (R) & Matrix Propagated (G)



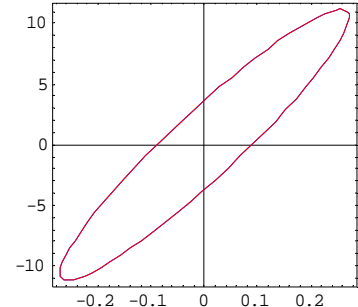
MLOGDec12011024                      AMLOGDec12011024  
andard2G\_05oct091919MIX6\_6to7                      standard2G\_05oct091919MIX6\_6to7  
-POS Measured (R) & Matrix Propagated (G)                      -POS Measured (R) & Matrix Propagated (G)



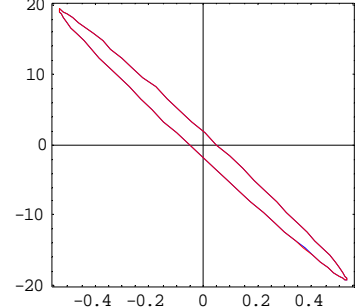
X-Phase Space : Target (B), Initial (R)      Y-Phase Space : Target (B), Initial (R)



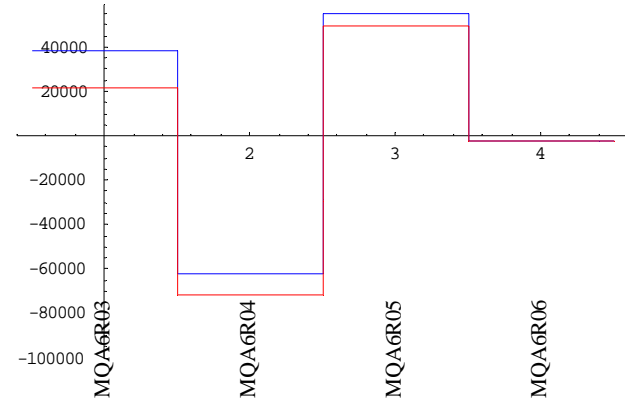
X-Phase Space : Target (B), Final (R)



Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024  
standard2G\_05oct091919MIX6\_6to7  
Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):

1.614295                      2.314827

Maximum X & Y CS Parameter Ratios (After):

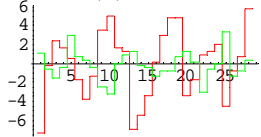
1.000074                      1.000019

## Comments:

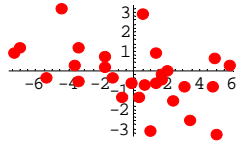
- Decent data. Good transport
- Arc 7 trajectory fit to model is not as good as other areas

# IPM7R01 to IPM8R01

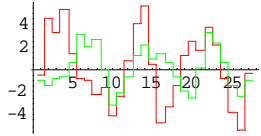
AMLOGDec12011024  
TrajFit\_05oct091646MIX1\_1to2.dat  
X1-DN FIT (R) & X2-DN FIT (G)



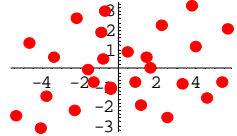
AMLOGDec12011024  
TrajFit\_05oct091646MIX1\_1to2.dat  
X1/2-DN FIT CORR.



AMLOGDec12011024  
TrajFit\_05oct092000MIX7\_7to8.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



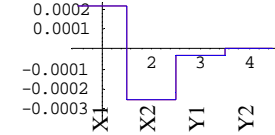
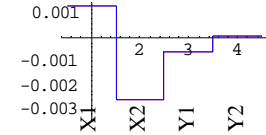
AMLOGDec12011024  
TrajFit\_05oct092000MIX7\_7to8.dat  
Y1/2-DN FIT CORR.



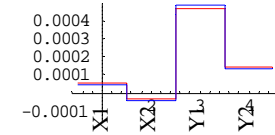
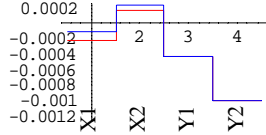
4D Symplectified Matrix:

$$\begin{pmatrix} -6.48987 & 68.5573 & 0.29218 & -0.10701 \\ -0.650101 & 6.73086 & 0.015657 & -0.0402838 \\ 0.561141 & -5.78453 & -0.966176 & 3.53503 \\ -0.104683 & 1.06113 & 0.0228239 & -1.0014 \end{pmatrix}$$

MLOGDec12011024 standard2G\_05oct092000MIX7\_7to8  
-POS Measured (R) & Matrix Propagated (G) BANG Measured (R) & Matrix Propagated (G)



MLOGDec12011024 standard2G\_05oct092000MIX7\_7to8  
-POS Measured (R) & Matrix Propagated (G) BANG Measured (R) & Matrix Propagated (G)



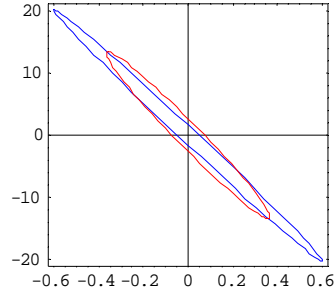
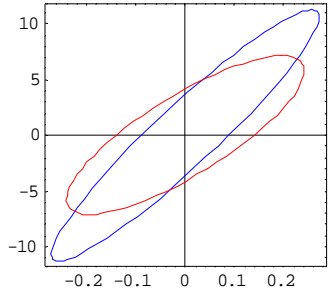
Damping Factor, Determinants of X & Y Fitted:

0.936348                      0.974863                      0.917420

Damping Factor, Determinants of 4 by 4 Fitted:

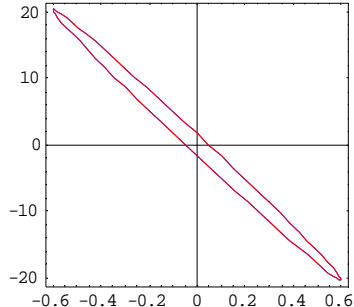
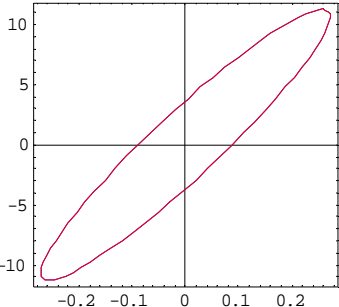
0.936348                      0.940212

X-Phase Space : Target (B), Initial (R)      Y-Phase Space : Target (B), Initial (R)

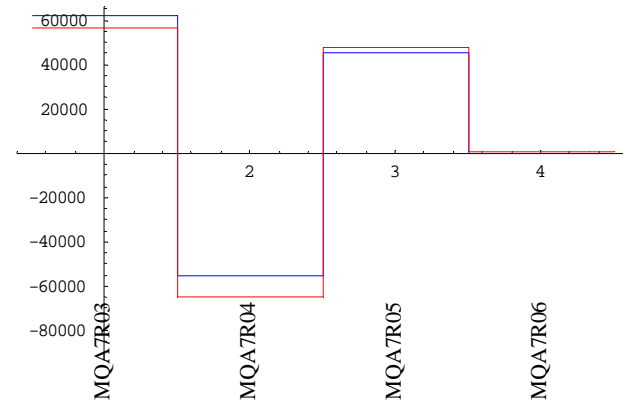


X-Phase Space : Target (B), Final (R)

Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024  
standard2G\_05oct092000MIX7\_7to8  
Quad Before(B) & After(R)



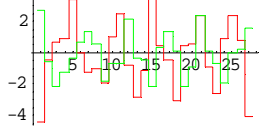
Maximum X & Y CS Parameter Ratios (Before):  
2.672206                      2.968609  
Maximum X & Y CS Parameter Ratios (After):  
1.000055                      1.000067

## Comments:

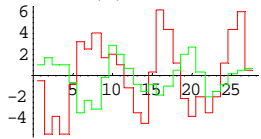
- Good transport
- Significant XY coupling from 7A to 8A. Data from 7R to 8A will be analyzed next.

# IPM8R01 to IPM9R01

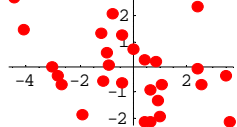
AMLOGDec12011024  
TrajFit\_05oct092000MIX8\_8to9.dat  
X1-DN FIT (R) & X2-DN FIT (G)



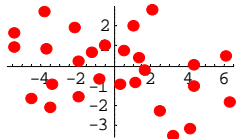
AMLOGDec12011024  
TrajFit\_05oct092000MIX8\_8to9.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024  
TrajFit\_05oct092000MIX8\_8to9.dat  
X1/2-DN FIT CORR.



AMLOGDec12011024  
TrajFit\_05oct092000MIX8\_8to9.dat  
Y1/2-DN FIT CORR.



Damping Factor, Determinants of X & Y Fitted:

0.943542

0.921718

0.953112

Damping Factor, Determinants of 4 by 4 Fitted:

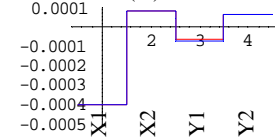
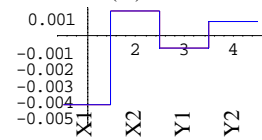
0.943542

0.964333

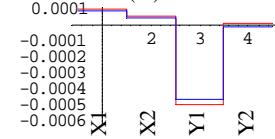
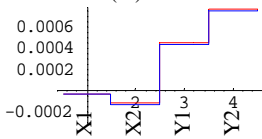
4D Symplectified Matrix:

$$\begin{pmatrix} -0.209292 & 11.8446 & -0.920198 & -2.07897 \\ -0.101954 & 1.78588 & -0.0896835 & -0.263942 \\ -0.135472 & 0.395557 & -0.868958 & -0.309399 \\ 0.0786099 & -0.646076 & -0.049748 & -0.977302 \end{pmatrix}$$

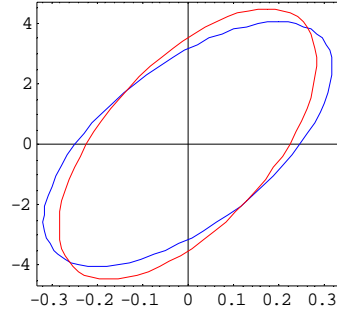
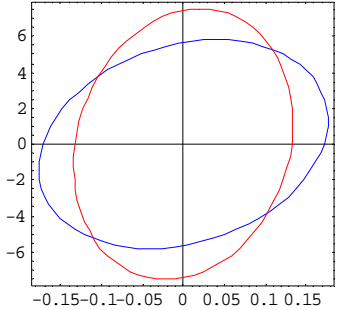
MLOGDec12011024 standard2G\_05oct092000MIX8\_8to9  
-POS Measured (R) & Matrix Propagated (G) BANG Measured (R) & Matrix Propagated (G)



MLOGDec12011024 standard2G\_05oct092000MIX8\_8to9  
-POS Measured (R) & Matrix Propagated (G) BANG Measured (R) & Matrix Propagated (G)

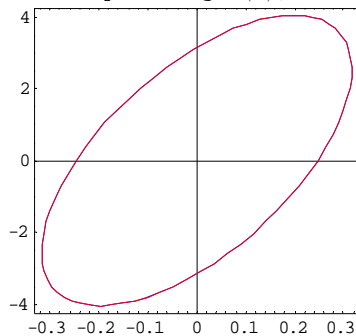
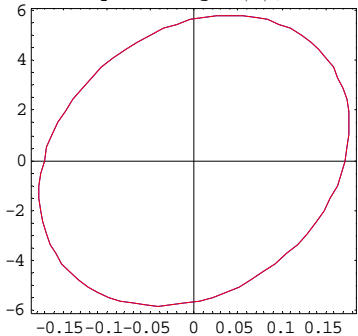


X-Phase Space : Target (B), Initial (R) Y-Phase Space : Target (B), Initial (R)

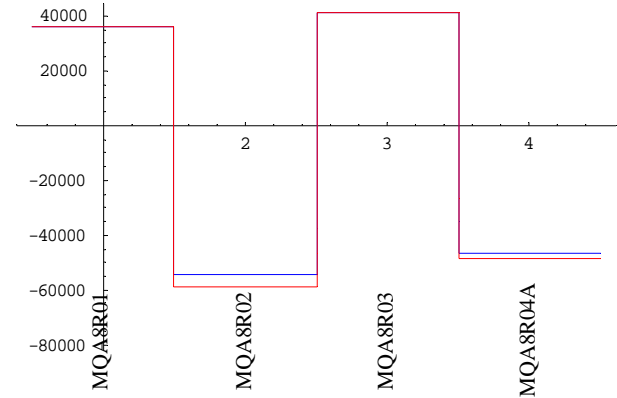


X-Phase Space : Target (B), Final (R)

Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024  
standard2G\_05oct092000MIX8\_8to9  
Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before):

1.734374 1.319642

Maximum X & Y CS Parameter Ratios (After):

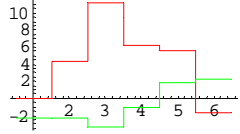
1.000106 1.000037

## Comments:

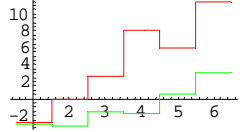
- Used 7A-9A FOPT data, as 8A-9A data had beam loss in entire 9A.
- The input orbit in 8A however is still very orthogonal as can be seen in the correlation plots, so this result should be quite reliable.
- Good match.

**IPM9R01 to IPMAT07**

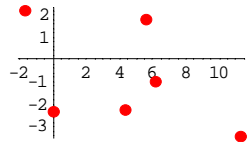
AMLOGDec12011024  
TrajFit\_05oct100627MIX9\_9to10.dat  
X1-DN FIT (R) & X2-DN FIT (G)



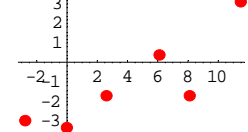
AMLOGDec12011024  
TrajFit\_05oct100627MIX9\_9to10.dat  
Y1-DN FIT (R) & Y2-DN FIT (G)



AMLOGDec12011024  
TrajFit\_05oct100627MIX9\_9to10.dat  
X1/2-DN FIT CORR.



AMLOGDec12011024  
TrajFit\_05oct100627MIX9\_9to10.dat  
Y1/2-DN FIT CORR.

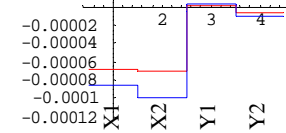
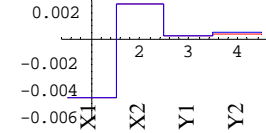


Damping Factor, Determinants of X & Y Fitted: 0.949274 0.822302 0.967738  
Damping Factor, Determinants of 4 by 4 Fitted: 0.949274 0.890407

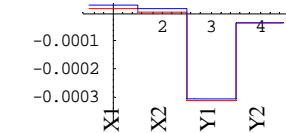
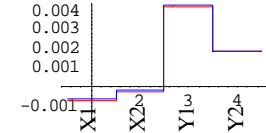
4D Symplectified Matrix:

$$\begin{pmatrix} 3.19148 & -37.3208 & -0.085953 & -2.01176 \\ -0.0191107 & 0.508537 & -0.00413838 & 0.00359388 \\ 0.157693 & -0.984895 & -1.92513 & -13.1578 \\ -0.00251642 & -0.0390375 & 0.124892 & 0.381037 \end{pmatrix}$$

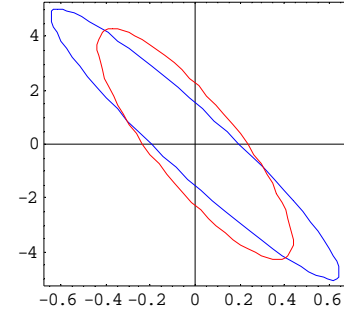
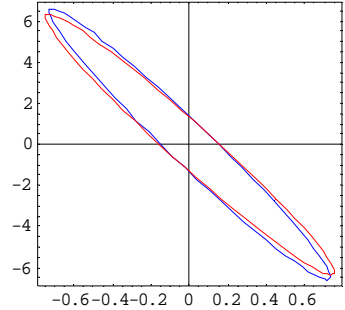
MLOGDec12011024 AMLOGDec12011024  
andard2G\_05oct100627MIX9\_9to10 standard2G\_05oct100627MIX9\_9to10  
-POS Measured (R) & Matrix Propagated (G) BANG Measured (R) & Matrix Propagated (G)



MLOGDec12011024 AMLOGDec12011024  
andard2G\_05oct100627MIX9\_9to10 standard2G\_05oct100627MIX9\_9to10  
-POS Measured (R) & Matrix Propagated (G) BANG Measured (R) & Matrix Propagated (G)

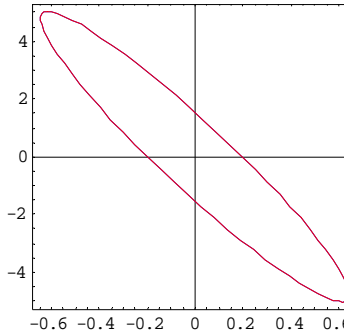
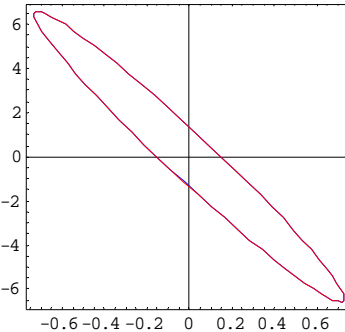


X-Phase Space : Target (B), Initial (R) Y-Phase Space : Target (B), Initial (R)

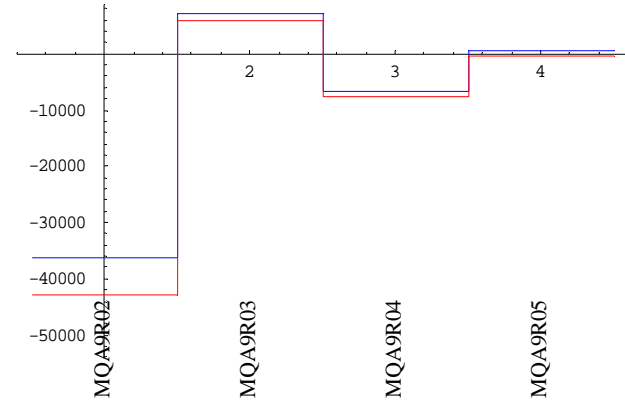


X-Phase Space : Target (B), Final (R)

Y-Phase Space : Target (B), Final (R)



AMLOGDec12011024  
standard2G\_05oct100627MIX9\_9to10  
Quad Before(B) & After(R)



Maximum X & Y CS Parameter Ratios (Before): 1.367427 2.278977  
Maximum X & Y CS Parameter Ratios (After): 1.000160 1.000455



## Comments:

- Decent transport
- Vertical trajectory fit to AT model not perfect, possibly due to too few BPM's.

## Propagation of Design Beam Using Measured Empirical 4D Matrices:

In the following pages the consequence of the empirical transport as measured on the beam spot propagation is studied. We present two cases below:

- 4D propagation of the DESIGN beam at IPM0R07, assuming no internal XY correlation at this point, by 4D empirical matrices from IPM0R07 to IPMNR01 (N=1, 2, .....9) and IPMAT07 based on concatenation of the section-by-section symplectified matrices presented in the preceding pages. The resulting **projections** of the beam distribution onto the X-X' space and Y-Y' space are plotted at these BPM's (Left: X; Right: Y) in **red**, against DESIGN phase ellipses at the corresponding BPM's properly damped by momentum ratio in **blue**. The ratio between projected emittances of the propagated beam and the theoretical beam, as well as the (normalized) maximum Courant Snyder mismatch parameter are also printed next to each plot.
- 4D propagation of the DESIGN beam at IPM1R01 by the same principle. This gives an entirely manageable case at the end of 5 pass, as opposed to the previous case. The contrast between these two sets of plots illustrates how much impact the error in transport from 0R to 1A can have on the delivery of DESIGN beam at the target, something we have no control over currently without going through measurement & analysis of this kind.
- Looks like on 10/09 I have a case of data coming out of my ears. I just discovered (a little too late) a gold mine of detailed FOPT/EZLOG data (for Injector matching, not 12 GeV) taken across the Chicane-NL boundary on 10/09 which I have not turned attention to, and was aimed at answering exactly this question. This should give a good picture across this boundary (presumably NL gradient CAL is better than last time), which is actually independent of the state of Injector matching.

The following are points I made in a previous email that are pertinent to the current discussion, and are included here for record. It is, based on these discussions, highly desirable to repeat the 0R-AT FOPT and get usable data for answer on how this area looks after Injector matching on 10/14.

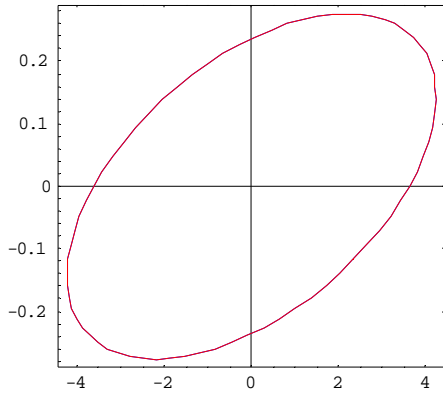
- The 0R-1A data shown was taken on 10/09, or before the Injector matching solution was implemented (10/14). There was a set of Special FOPT taken on 10/14 right AFTER Injector matching from 0R to AT, and then another one on 10/23. These would have been extremely interesting in shedding light on how the 0R-1A transport was impacted. Unfortunately both sets of data showed very poor match to the 0R optics (which was untouched by Injector matching) for reasons I am still struggling to understand. It appears that all trajectories were unphysical, although they fit the model nicely in 1A. In comparison the 10/09 data fit the model in 0R much better than it does on average. It is an unfortunate & puzzling state of matter. I hope I could try this FOPT myself again to see if I can catch something. I am submitting an Atlantis in the mean time.
- The Injector matching for Happex, on the other hand, is only indirectly related to what we are looking at here. It deals with the overall transport from the gun to say, 1A and beyond. We know there is not really sufficient damping from the gun to 60 MeV due to mismatch (after XY coupling is fixed). So Injector matching can be creating a mismatch to cancel this mismatch if necessary so that the overall transport is good. This does not automatically make the 0R-1A match good, which is more relevant to the spot matching problem since we do spot matching at 60 MeV, but it may be safe to assume it made the overall situation go in the right direction. This really goes back to the question of what to do if the spot & PZT occupy very different places in the phase space<sup>4</sup>. So far we do not have to answer this question and I hope we never do.

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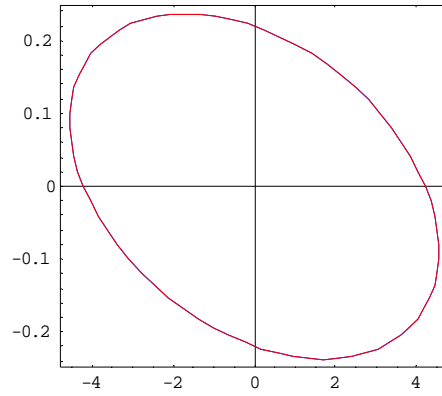
<sup>4</sup> There are indications that they are not too far apart.

# Propagation of Design Beam at IPM0R07 Using Measured Empirical 4D Matrices

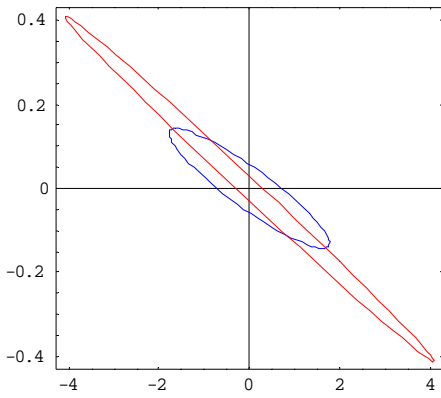
IPM0R07  
Emit. Ratio: 1.  
CS: 1.



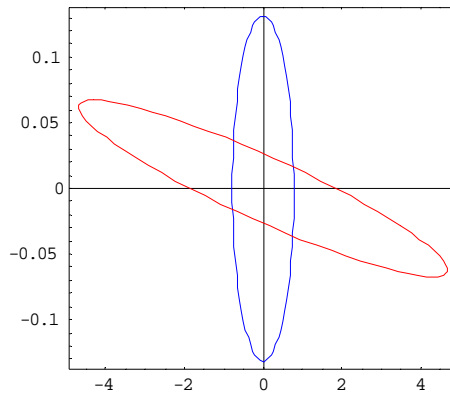
IPM0R07  
Emit. Ratio: 1.  
CS: 1.



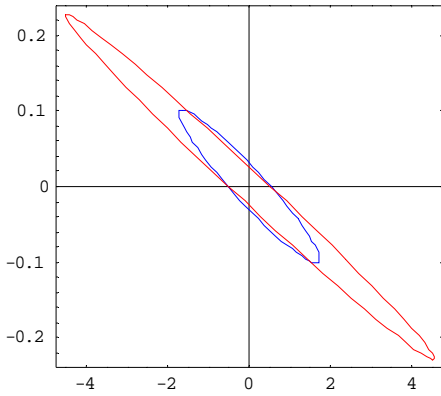
IPM1R01  
Emit. Ratio: 1.22  
CS: 3.839



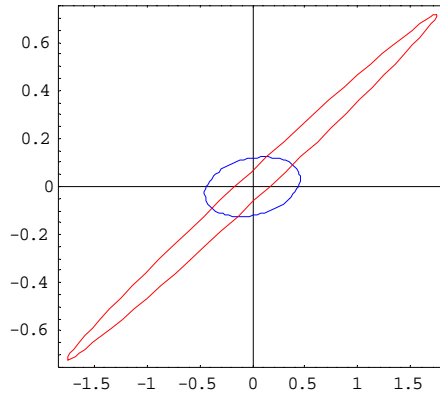
IPM1R01  
Emit. Ratio: 1.22  
CS: 15.029



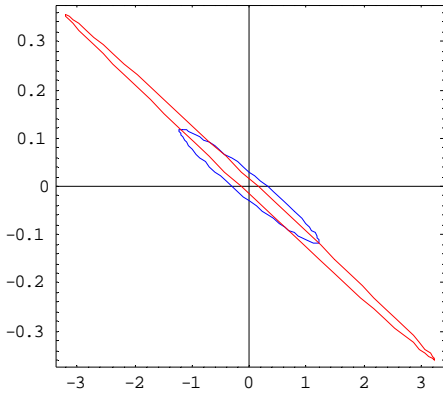
IPM2R01  
Emit. Ratio: 2.2  
CS: 1.865



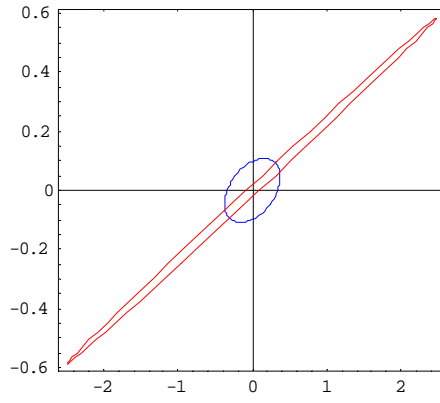
IPM2R01  
Emit. Ratio: 2.2  
CS: 9.132



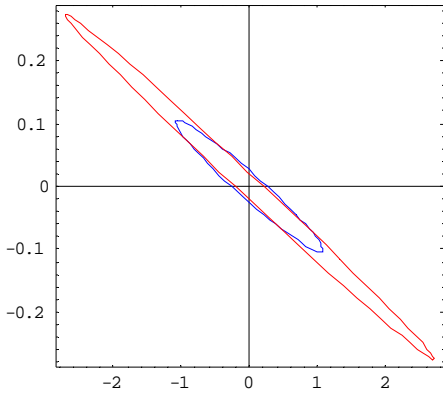
IPM3R01  
Emit. Ratio: 1.45  
CS: 3.708



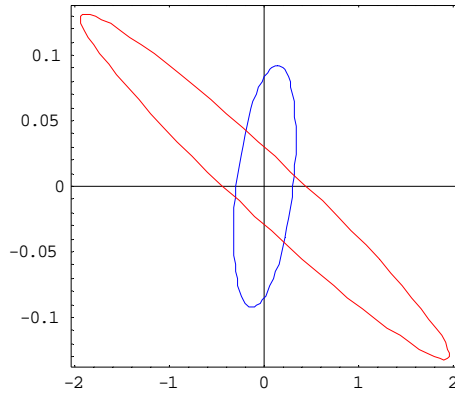
IPM3R01  
Emit. Ratio: 1.45  
CS: 18.109



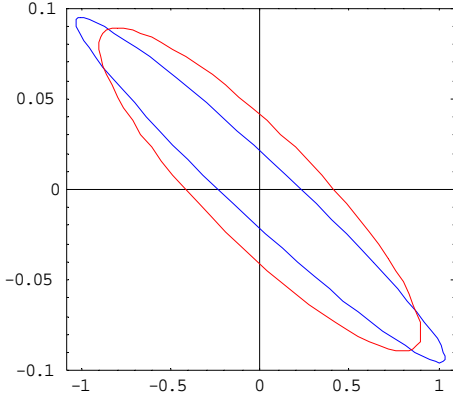
IPM4R01  
Emit. Ratio: 2.11  
CS: 1.803



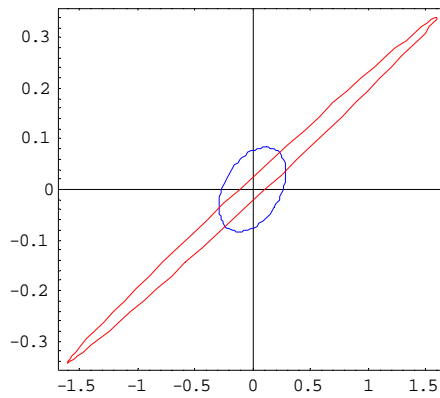
IPM4R01  
Emit. Ratio: 2.11  
CS: 12.605



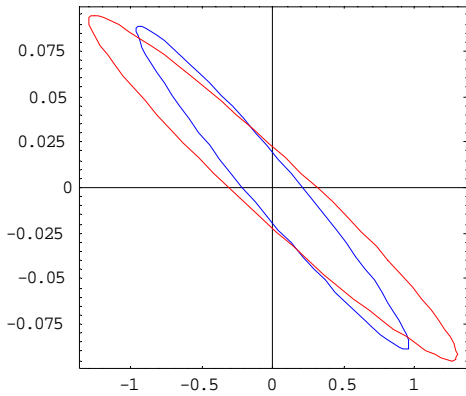
IPM5R01  
Emit. Ratio: 1.67  
CS: 1.324



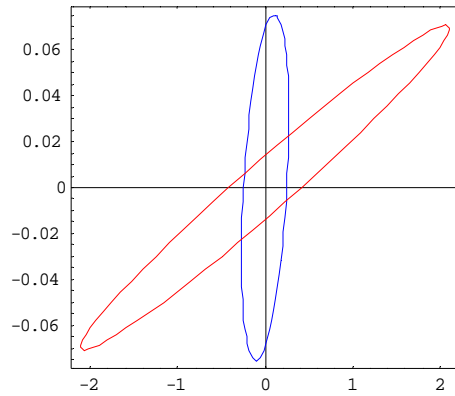
IPM5R01  
Emit. Ratio: 1.67  
CS: 10.412



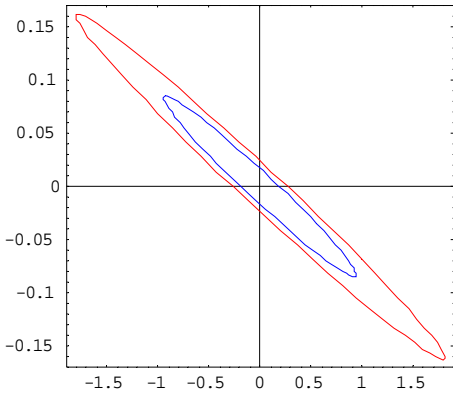
IPM6R01  
Emit. Ratio: 1.58  
CS: 1.54



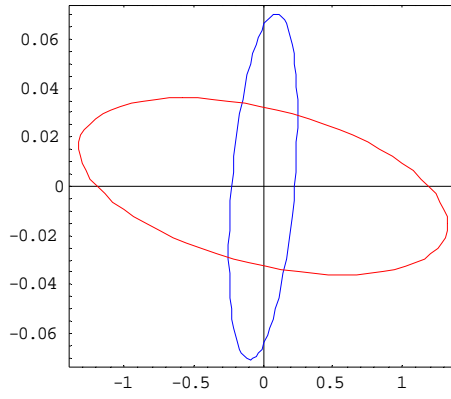
IPM6R01  
Emit. Ratio: 1.58  
CS: 21.203



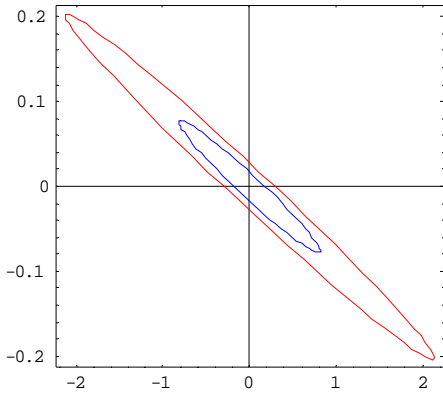
IPM7R01  
Emit. Ratio: 2.7  
CS: 1.105



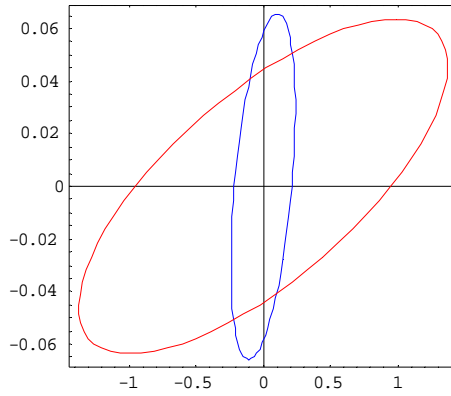
IPM7R01  
Emit. Ratio: 2.7  
CS: 6.599



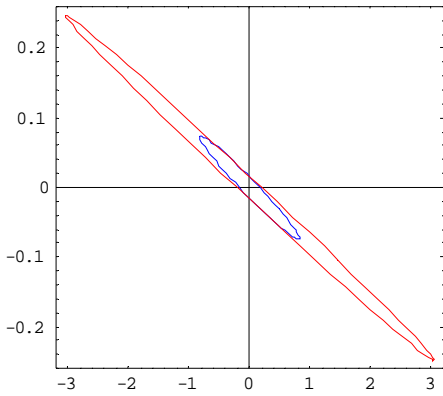
IPM8R01  
Emit. Ratio: 4.32  
CS: 1.11



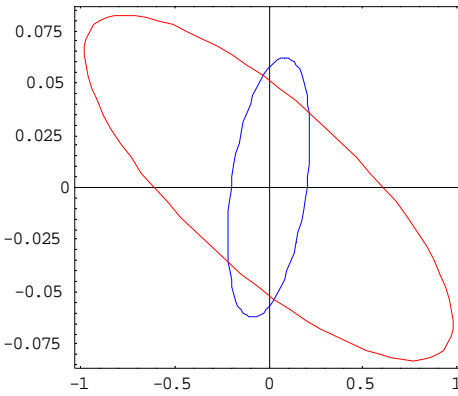
IPM8R01  
Emit. Ratio: 4.32  
CS: 4.408



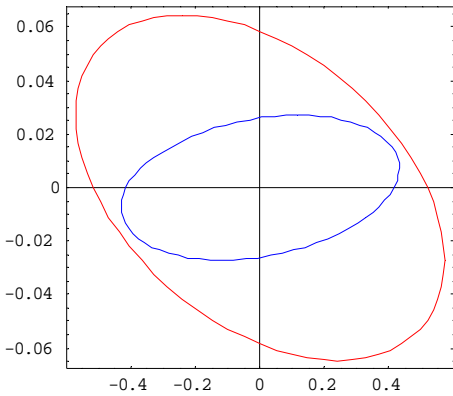
IPM9R01  
Emit. Ratio: 4.04  
CS: 2.046



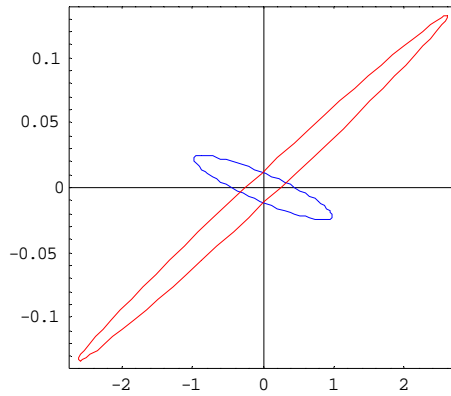
IPM9R01  
Emit. Ratio: 4.04  
CS: 3.749



IPMAT07  
Emit. Ratio: 2.97  
CS: 1.482

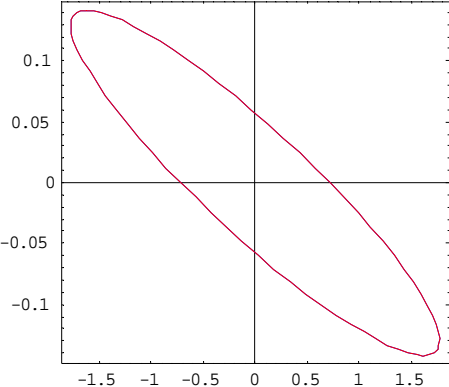


IPMAT07  
Emit. Ratio: 2.97  
CS: 48.083

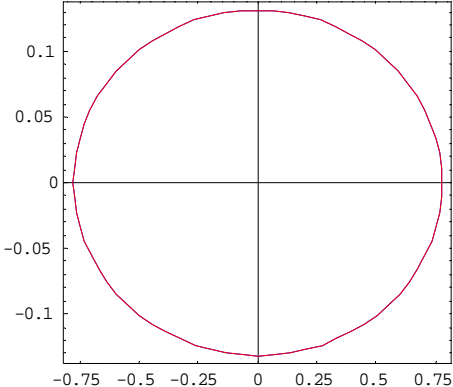


# Propagation of Design Beam at IPM1R01 Using Measured Empirical 4D Matrices

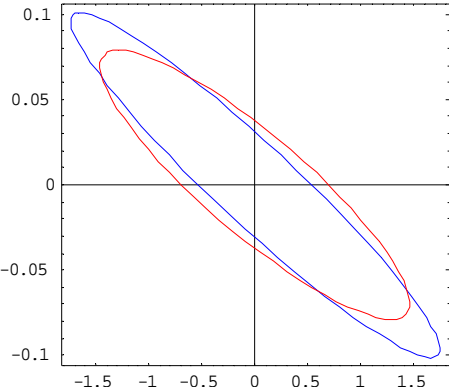
IPM1R01  
Emit. Ratio: 1.  
CS: 1.



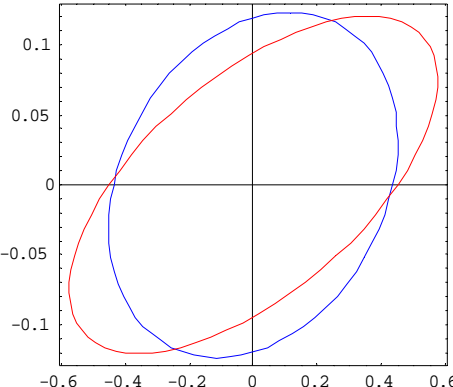
IPM1R01  
Emit. Ratio: 1.  
CS: 1.



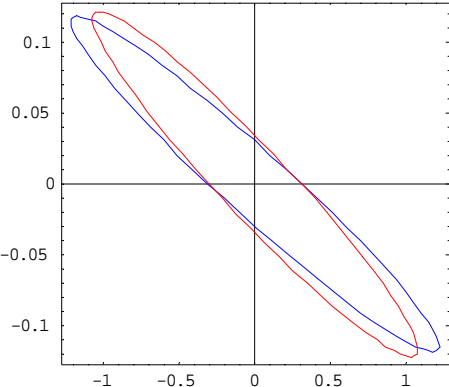
IPM2R01  
Emit. Ratio: 1.01  
CS: 1.134



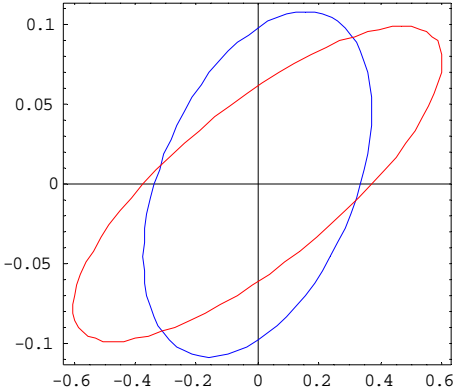
IPM2R01  
Emit. Ratio: 1.01  
CS: 1.161



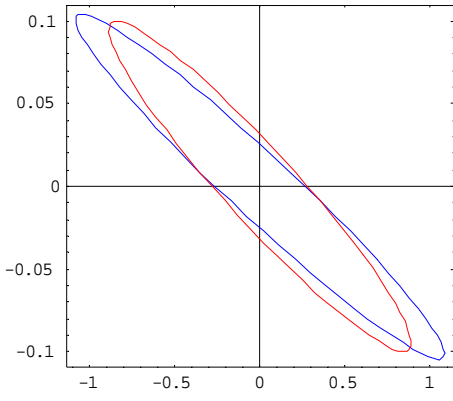
IPM3R01  
Emit. Ratio: 1.01  
CS: 1.169



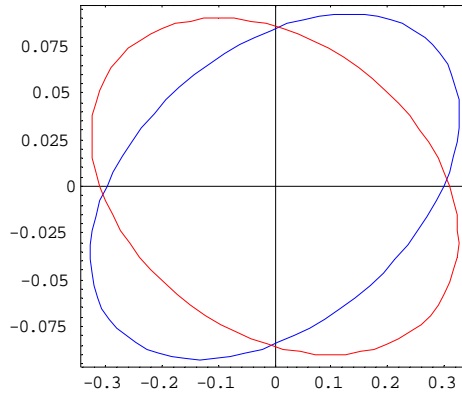
IPM3R01  
Emit. Ratio: 1.01  
CS: 1.487



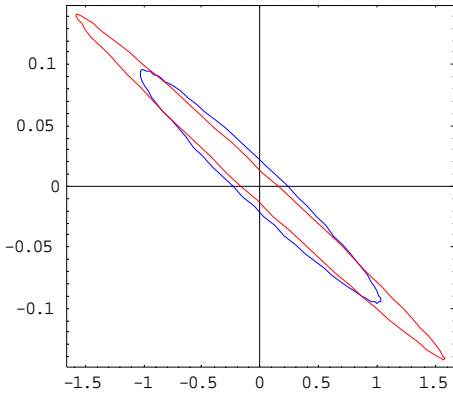
IPM4R01  
Emit. Ratio: 1.01  
CS: 1.188



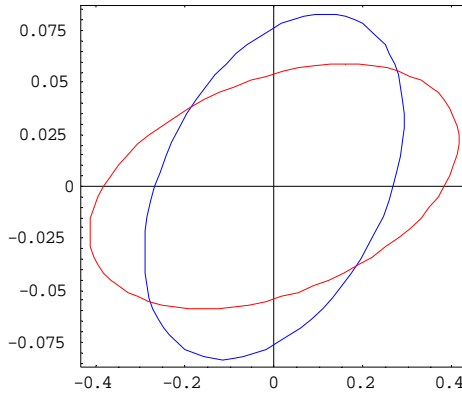
IPM4R01  
Emit. Ratio: 1.01  
CS: 1.292



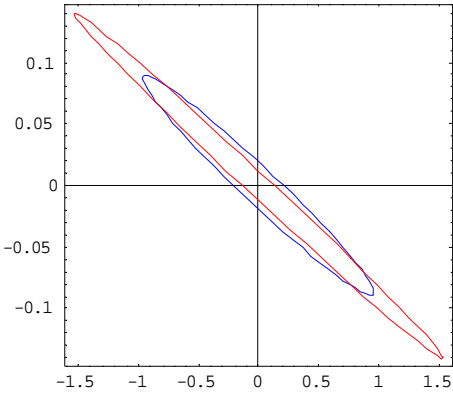
IPM5R01  
Emit. Ratio: 1.01  
CS: 1.379



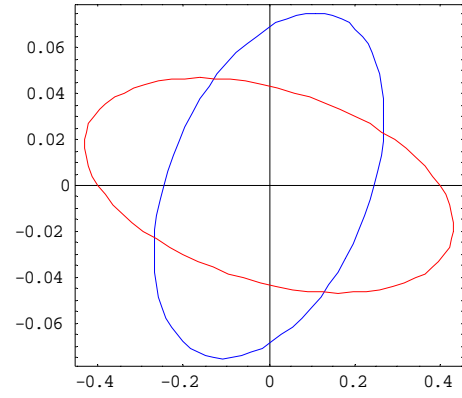
IPM5R01  
Emit. Ratio: 1.01  
CS: 1.3



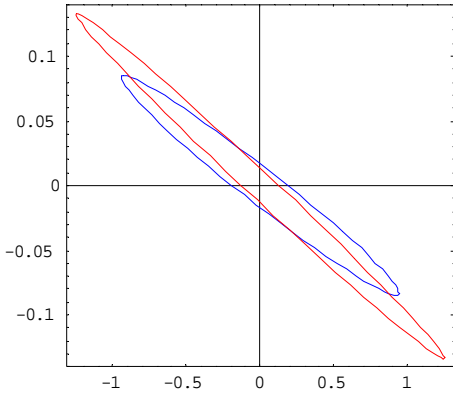
IPM6R01  
Emit. Ratio: 1.01  
CS: 1.467



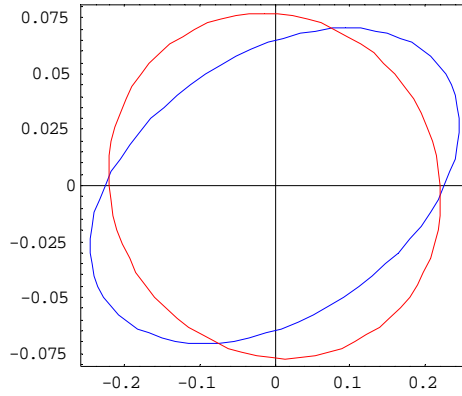
IPM6R01  
Emit. Ratio: 1.01  
CS: 1.925



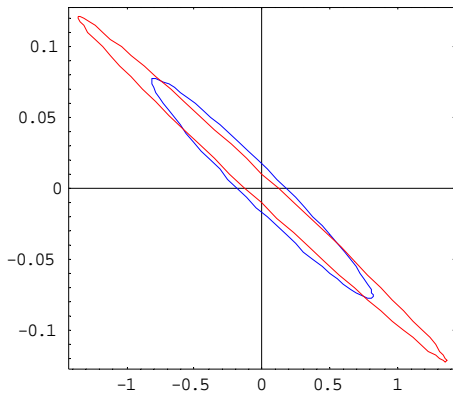
IPM7R01  
Emit. Ratio: 1.07  
CS: 1.965



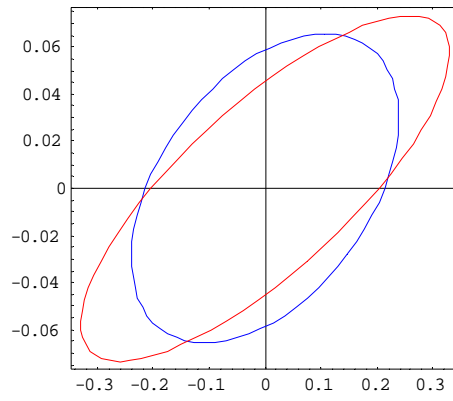
IPM7R01  
Emit. Ratio: 1.07  
CS: 1.137



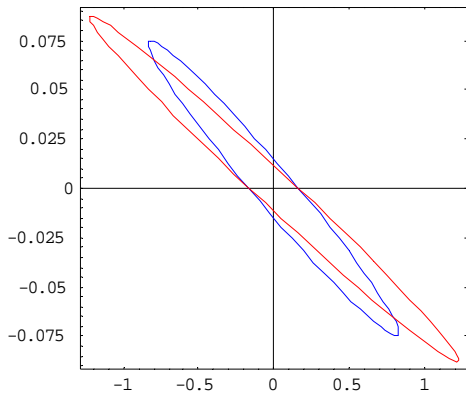
IPM8R01  
Emit. Ratio: 1.06  
CS: 1.532



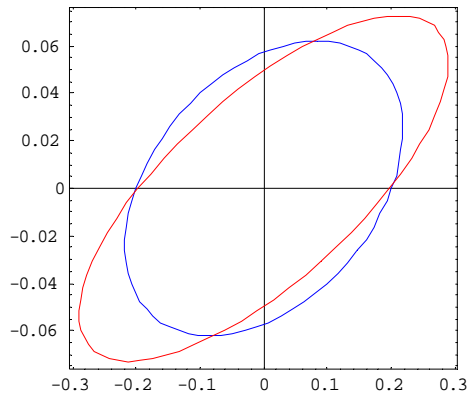
IPM8R01  
Emit. Ratio: 1.06  
CS: 1.214



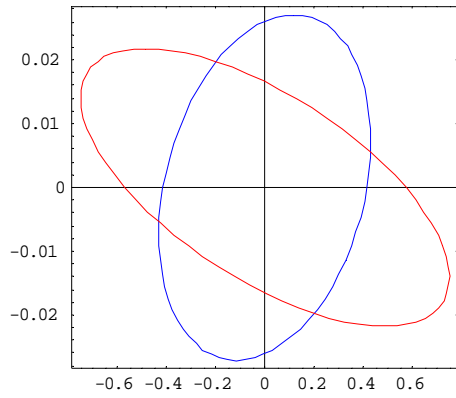
IPM9R01  
Emit. Ratio: 1.15  
CS: 2.066



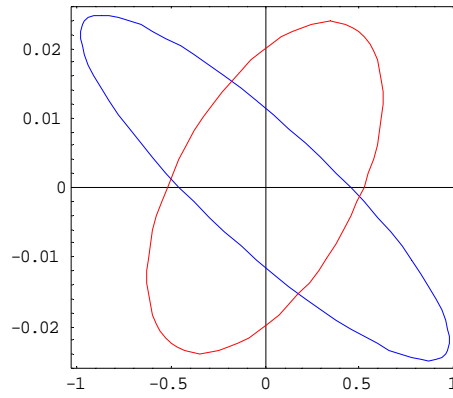
IPM9R01  
Emit. Ratio: 1.15  
CS: 1.151



IPMAT07  
Emit. Ratio: 1.11  
CS: 2.034



IPMAT07  
Emit. Ratio: 1.11  
CS: 4.067





## Addendum. Chicane-to-Nroth-Linac Transport Measured on 10/09/05

On 10/09/05 shortly before OPS launched into Arc-by-Arc Special FOPT to characterize machine transport in detail, prompted by an action item from the 12 GeV beam optics meeting, a series of Special FOPT runs were made with the single aim of characterizing the transport between the Chicane and the North Linac. Although motivated by totally different reasons (to provide input for Injector rematch for Happex), in hindsight these earlier FOPT runs serve to support the outcome of the later measurements and provide further insight into the questions arising from them. The data was not analyzed until now and the result is summarized below in detail. If you are only interested in the punch line, go to the last page.

- The 10/09 data displayed very good coverage of the input 4D phase space due to arrangement of difference orbit launches and the use of considerable number of them. NL orbits were flattened prior to measurement to provide maximum range for FOPT auto-scaling. Plots in the next page show the distribution of orbits in the input phase space at MBL0R04. The following page shows corresponding plots at the end point of the matrix measurement (IPM1L07).
- Unfortunately again the North Linac model was not sufficiently good to allow us to push the empirical matrix end point upstream to say, IPM1L02. The fit of difference orbits to the GOLD model (plots in following page) was poor with the first 6 NL BPM's included, especially in X. We have encountered such problems before when the NL gradient calibration was not implemented. This time the fit is not as hopeless, and can be improved significantly by not including these BPM's. The cause to the problem this time is not immediately clear, since there have not been major cavity changes in the NL front end after last gradient CAL. Unfortunately due to this uncertainty any subsequent aberration could not be unequivocally differentiated between that arising from NL gradient and that from Chicane-NL boundary stray field, which require very different countermeasures.
- Nonetheless even limiting ourselves to regions after IPM1L07 goes a long way toward elucidating the picture drawn in the first part of this note. The conclusion<sup>5</sup> from the Arc-to-Arc Special FOPT was that a dominant part of the difficult-to-correct beam spot in the halls likely comes from mismatch between the Chicane and Arc 1, where there is no provision for correction in our standard tune-up procedure. The data discussed here appears to point to the beginning of the North Linac as its major contributor in turn. Again, unfortunately, we could not further differentiate the cause between North Linac gradient error, which represents a dynamic, OPS-correctable problem, and Chicane boundary stray field, which represents a static (?) problem, requiring dedicated configuration examination/correction<sup>6</sup>.
- The empirically measured 4D symplectified matrix from MBL0R04 to IPM1L07 is shown in the next page, in comparison with the DESIGN and GOLD matrices. The quality of this measurement was quite good as can be seen from its ability to explain the  $150 \times 4$  orbit coordinates at the exit point, given the well-distributed input coordinates.
- The empirically measured matrix from MBL0R04 to IPM1L07 is neither particularly XY coupled nor too singular. However, the mere fact that it deviates significantly from the design, which we take as target in performing Injector beam spot matching, is enough to cause problem, as will be seen next.
- In the last page propagation was made on DESIGN beam by DESIGN, GOLD & Measured transfer matrices from IPM0R07 to IPM1L07 and IPM1L28. The discrepancy between DESIGN and reality seems enough to lead to nontrivial consequences. If all analyses presented above are reliable, which I have certain confidence in, then significant beam size growth (not quite emittance yet) should be already present in the North Linac first pass. Later on such amplitude growth can turn into larger-than-nominal projected emittance growth in the presence of otherwise harmless coupling sources, and beam spot going into the halls can be hard to predict. These are points that cannot be confirmed within the scope of available data. Completion of the original test plan with emittance measurements may shed more light on this.

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<sup>5</sup> Partial conclusion, since we are not done with the measurements yet.

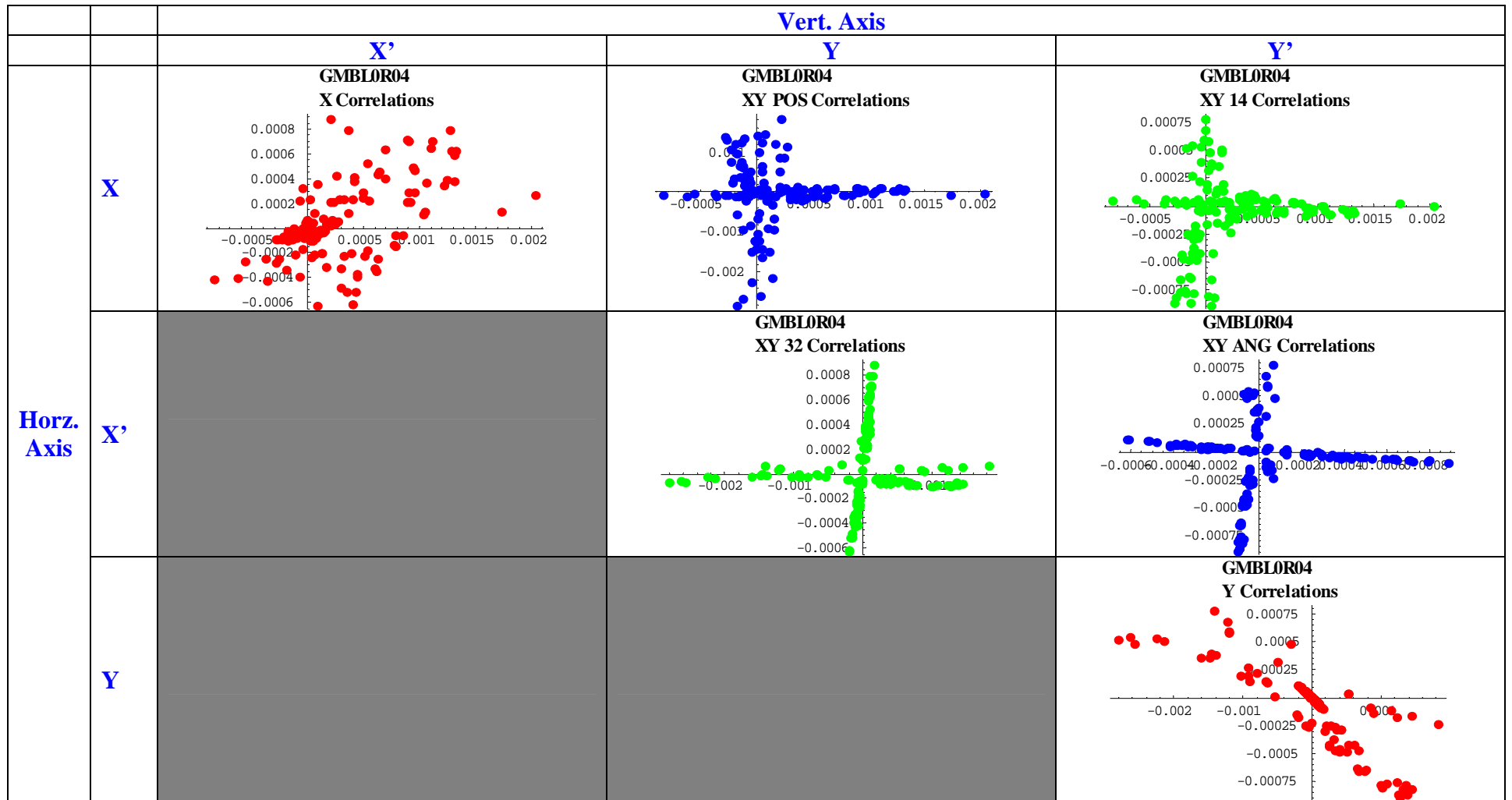
<sup>6</sup> Is it possible to infer from something the correct NL gradient CAL numbers on 10/09?

- All this was done before the 10/14 Injector re-match. Since we have no data, either global Special FOPT or Chicane-NL difference orbit of the same sort taken after 10/14 due to time limitation, it is not clear what the situation was like after Injector re-match.
- Pages 5 & 6 of this document show the matching quad changes (significant) in the Injector, calculated by OTAM, needed to restore the overall match from 0R07 to 1R01. It would be interesting to perform further analysis on the overall transport from 0R to 1R based on current data. The first part of this document may suggest some mitigating role played by 1S matching quads or other 1S components, in view of what is seen here, in containing the gross mismatch already present in North Linac.
- The difference between the DESIGN and GOLD transfer matrices, and the nontrivial implication on beam spot at 1L28 by this difference, suggests that even if there is no optical error, we might want to consider whether always matching to a fixed DESIGN target is a good idea.

-

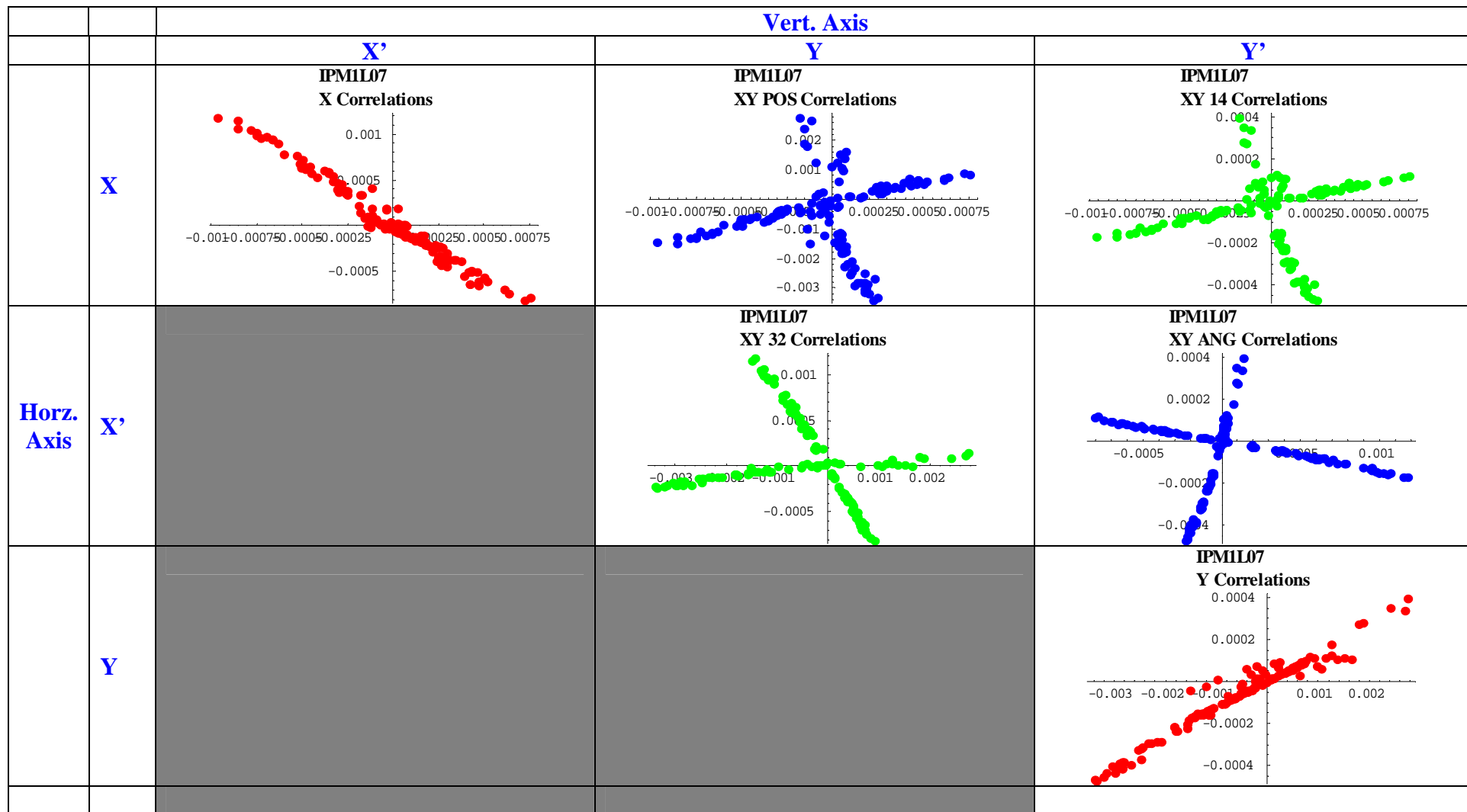
# Phase Space Coverage at Entrance (MBL0R04)

## Phase space distributions of difference orbits in various 2D subspaces



# Phase Space Coverage at Exit (IPM1L07)

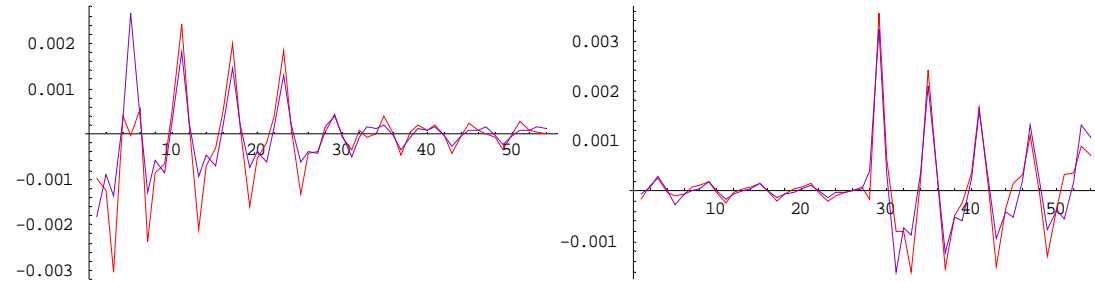
## Phase space distributions of difference orbits in various 2D subspaces



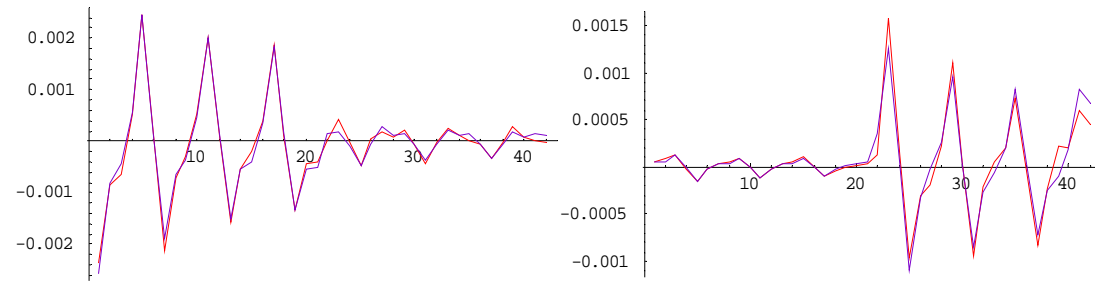
# Defective North Linac Model Possibly due to Uncertainty in Gradient Calibration

## Trajectory fit of 2 difference orbits in NL (red: data; blue: fit to model)

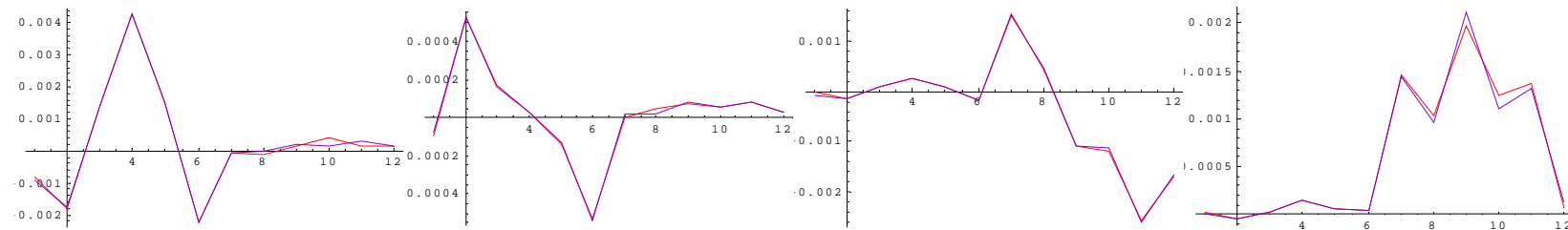
### Including IPM1L02-IPM1L07



### Excluding IPM1L02-IPM1L07



## Typical trajectory fit of difference orbits in Chicane (red: data; blue: fit to model)



**DESIGN Matrix from MBL0R04 to IPM1L07 (This is what we assume when using BPAM)**

**Momentum Ratio: 0.3102**

$$\begin{pmatrix} 0.452001 & -4.08546 & 0 & 0 \\ -0.0972682 & 1.56552 & 0 & 0 \\ 0 & 0 & 1.20801 & -0.949914 \\ 0 & 0 & 0.161314 & 0.129962 \end{pmatrix}$$

X-Sub Matrix SVD Condition Number 62.3751

Y-Sub Matrix SVD Condition Number 7.61956

4 X 4 Matrix SVD Condition Number 62.3751

**GOLD Matrix from MBL0R04 to IPM1L07 (This is our best guess on how to modify matching target)**

**Momentum Ratio: 0.3549**

$$\begin{pmatrix} 0.487814 & -4.46286 & 0 & 0 \\ -0.097317 & 1.61786 & 0 & 0 \\ 0 & 0 & 1.12205 & -1.73025 \\ 0 & 0 & 0.156829 & 0.0744603 \end{pmatrix}$$

X-Sub Matrix SVD Condition Number 64.1769

Y-Sub Matrix SVD Condition Number 11.9844

4 X 4 Matrix SVD Condition Number 64.1769

**MEASURED Matrix (Symplectified) from MBL0R04 to IPM1L07<sup>7</sup> (This is what really happened)**

**Momentum Ratio: 0.3549**

$$\begin{pmatrix} 0.171516 & -1.43509 & 0.0509297 & -0.0333616 \\ 0.0532087 & 1.61515 & -0.0167348 & 0.0407596 \\ -0.164316 & -1.18448 & 1.95092 & 7.3411 \\ -0.0187321 & -0.144268 & 0.188446 & 0.890241 \end{pmatrix}$$

On-Diag.Normalized Determinant 0.995724

Off-Diag.Normalized Determinant 0.00427604

4D Determinant Ratio 0.99786

X-Sub Matrix SVD Condition Number 13.2256

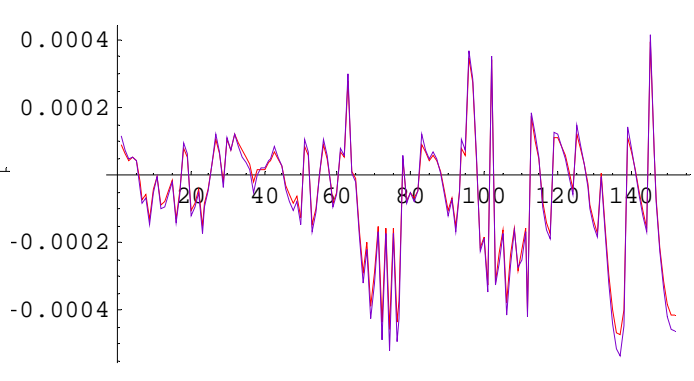
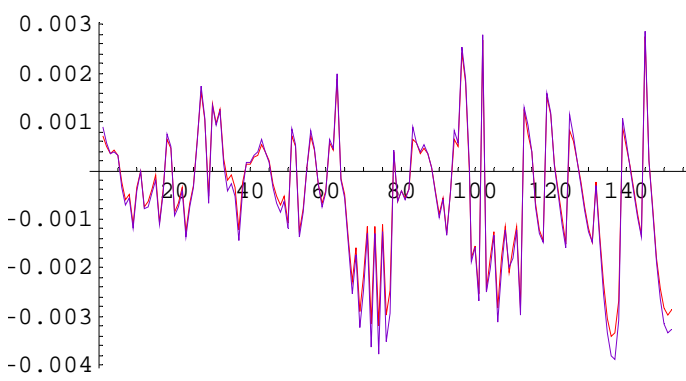
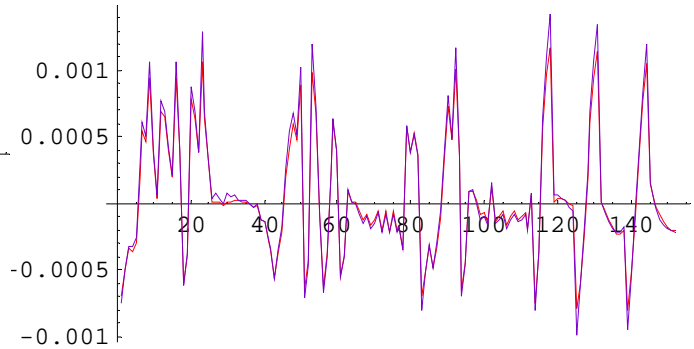
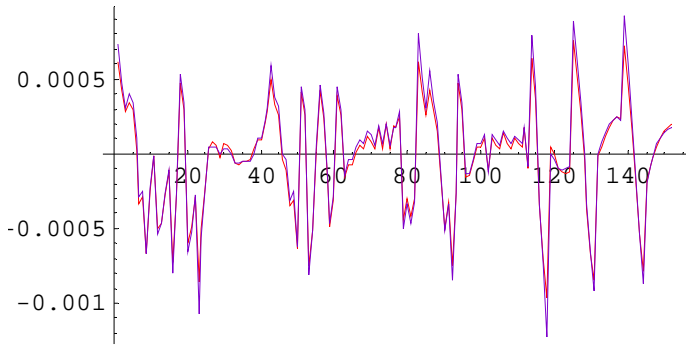
Y-Sub Matrix SVD Condition Number 165.609

4 X 4 Matrix SVD Condition Number 169.252

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<sup>7</sup> Relative scaling of 1.105 between STP & SEE BPM's was used in obtaining this result.

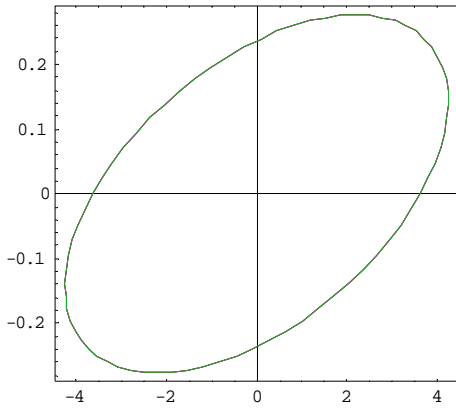
**Agreement with difference orbit measurement (red: measured X, X', Y, Y' responses at IPM1L07 to various 60 MeV excitations; blue: prediction by empirical 4x4 matrix on orbits at MBL0R07)**



# Propagating DESIGN Beam at IPM0R07 by DESIGN, GOLD and Measured Matrices.

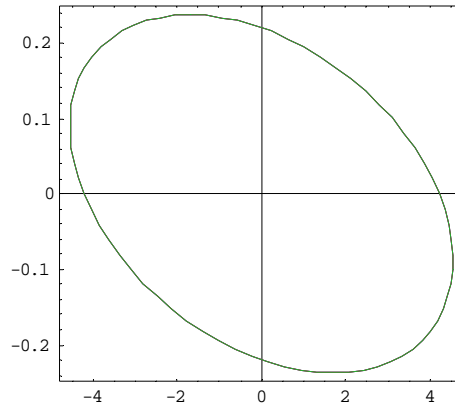
IPM0R07

Emit. Ratio: 1. 1.  
CS: 1. 1.



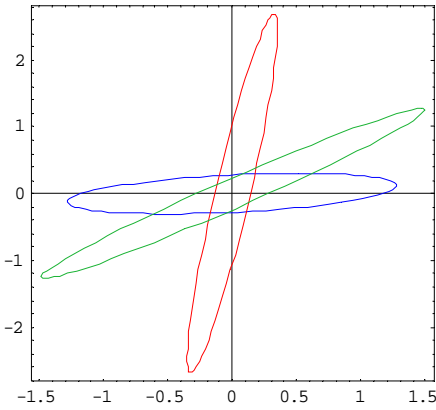
IPM0R07

Emit. Ratio: 1. 1.  
CS: 1. 1.



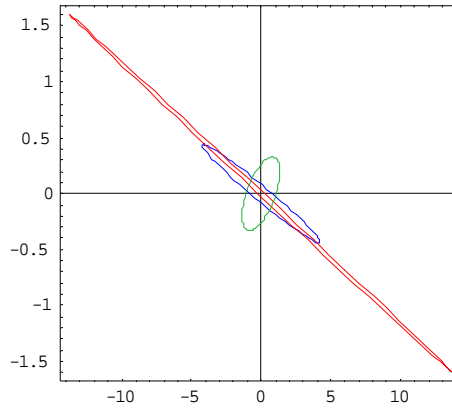
IPM1L07

Emit. Ratio: 1.04 1.04  
CS: 44.161 49.369



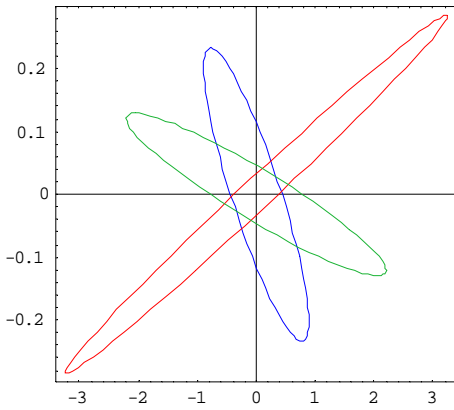
IPM1L07

Emit. Ratio: 1.04 1.04  
CS: 7.997 140.356



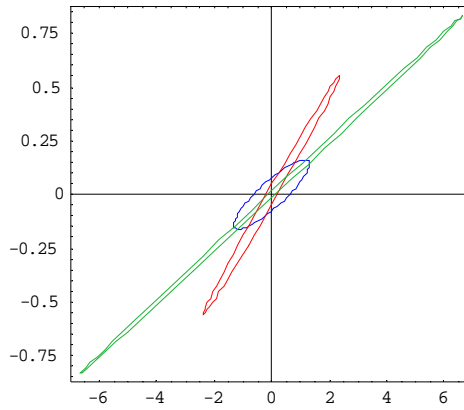
IPM1L28

Emit. Ratio: 1.04 1.04  
CS: 45.107 49.369



IPM1L28

Emit. Ratio: 1.04 1.04  
CS: 8.826 140.356



**First emittance ratio & CS are between Measured & DESIGN  
Second emittance ratio & CS are between Measured & GOLD**