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# Gold Beam Transverse Emittance

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| **(AGS Studies Report No. 358)** |
| **Title: Gold Beam Transverse Emittance** |
| **Study Period:** Various |
| **Participants:** H. Huang, P. Sampson, A. Stillman, S.Y. Zhang |
| **Reported by:** S.Y. Zhang |
| **Machine:** Booster, BTA Transfer Line, AGS |
| **Beam:** Gold Beam |
| **Tools:** Booster IPM, BTA Multiwires, AGS IPM, A20 |
| **Aim:** To evaluate the gold beam emittance at the Booster, the BTA transfer line, and the AGS. To also evaluate the beam emittance variation. |
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**Gold Beam Transverse Emittance**

# 1 Summary


1. In 1996-97 HIP run, at the Booster, the gold beam horizontal normalized emittance, including 95% particles, is $\epsilon^H_{95\%} = 6.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 2.5\ \pi mmmr$.

2. At the BTA transfer line, the observed beam emittance is $\epsilon^H_{95\%} = 9.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 4.5\ \pi mmmr$. However, it is believed that the initial conditions in forming the BTA model carry some error, therefore, the beam emittance calculated using the model is likely to be larger than it should be.

3. The beam emittance at the AGS is $\epsilon^H_{95\%} = 7.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 5\ \pi mmmr$. The emittance growth between the Booster and the AGS is mainly because of the optics mismatch from the BTA to the AGS, which has been observed using the multiwire A20 in the AGS ring.


# 2 Beam Emittance at the Booster

The gold beam is injected from the TTB line to the Booster in about 40 turns. The Booster injection fast bumps are powered to provide horizontal phase space painting, and thus the beam horizontal emittance in the Booster is defined. Meanwhile, the x-y linear coupling is exercised using the skew quadrupoles during the injection period, and the beam vertical emittance is defined.

The Booster beam transverse size is measured using the Booster IPM several times during the run. In Fig.1, the beam size and the normalized emittance are shown. The beam momentum spread is about $dp/p = \pm 0.2\%$, and the beta functions and the dispersion function used in the calculation are $\beta_H = 7.13\ m$, $\beta_V = 5.98\ m$, and $D = 2\ m$. The horizontal normalized emittance at the Booster, therefore, is $\epsilon^H_{95\%} = 6.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 2.5\ \pi mmmr$.

The beam emittance in 1995 HIP run is $\epsilon^H_{95\%} = 6.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 2\ \pi mmmr$.

# 3 Beam Emittance at the BTA Line

In Fig.2, the beam emittance observed at the BTA MW006 is shown. The existing BTA model is usable, however, the initial conditions the beam entering the BTA transfer line is believed to carry some error. There is currently no intention to modify this model, therefore, the problem is looked in other way.

Using the model and the beam positions presented in the Log Book for 1996-97 HIP run, the phase space distribution at the multiwires can be plotted. Also the phase space ellipses of a proper size can be calculated. If the beam and the transfer line model are matched, i.e. the initial conditions in forming the model carry no error, then the two sets of plot should match. The plots for horizontal and vertical data are shown in Fig.3 and Fig.4, respectively. Some mismatch can be observed, where the vertical mismatch is worse than the horizontal one.

We expect, therefore, that both emittances read in the BTA line will be larger than the real emittances, and the vertical one will be overestimated even more. From Fig.2, we have $\epsilon^H_{95\%} = 9.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 4.5\ \pi mmmr$, which are larger than the Booster beam emittances by approximately 46% and 80%, respectively, for horizontal and vertical.

The beam emittance in 1995 HIP run, observed at MW006, is $\epsilon^H_{95\%} = 9.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 4\ \pi mmmr$.

## 4 Beam Emittance at the AGS

In Fig.5, the beam size obtained using the AGS IPM and the normalized emittance are shown. The AGS beam emittances are $\epsilon^H_{95\%} = 7.5\ \pi mmmr$, and vertical $\epsilon^V_{95\%} = 5\ \pi mmmr$. The following parameters are used for the calculation, $dp/p = \pm 0.2\%$, $\beta_H = \beta_V = 22m$, and $D = 2\ m$. In the later part of the cycle, the normalized emittances becomes larger. No real emittance growth is believed happened, however, this cannot be verified. A common feature involved in here and the gold beam emittance measurement of 1995 show that when the *rms* beam size becomes smaller than 3 *mm*, the beam normalized emittance becomes larger. The current understanding of the IPM space charge distortion cannot explain why.

In 1995, the beam observed at the AGS is 'round', the emittances are $\epsilon^H_{95\%} = \epsilon^V_{95\%} = 6.5\ \pi mmmr$.

## 5 Discussion

1. Exact beam emittance measurement is always difficult, especially in a transfer line. In fact, of importance is to aware the emittance growth, and also the emittance variation in the operation. The results presented in this study report serve for these purposes.

2. In this report, the contribution of the stripping foil in the BTA line, to the emittance growth, is completely disregarded. Note that the MW006 is upstream of the foil.

3. Consider the emittance growth from the Booster to the AGS. The horizontal one grows by 15%, and the vertical one 100%, where the stripping foil effect matters, however, the BTA to AGS optics mismatch is a dominant factor. Using the multiwire A20 in the AGS ring, both horizontal and vertical mismatches have been observed. Note that here the imperfection of the BTA model plays no role.

4. The Booster horizontal and vertical emittances are unlikely to be reduced, since these are crucial in preserving and/or improving the Booster injection efficiency. The BTA to AGS mismatch, however, should be corrected. Other factors relevant to the emittance

are 1) stripping foil effect, 2) transition crossing effect, and 3) the AGS x-y coupling effect.

## 6 Conclusion

| | Booster | BTA | AGS | |
|---|---|---|---|---|
| 1996 H | 6.5 | 9.5 | 7.5 | *pi mmmr* |
| 1996 V | 2.5 | 4.5 | 5 | *pi mmmr* |
| 1995 H | 6.5 | 9.5 | 6.5 | *pi mmmr* |
| 1995 V | 2 | 4 | 6.5 | *pi mmmr* |

**Gold Beam Transverse Normalized Emittance**

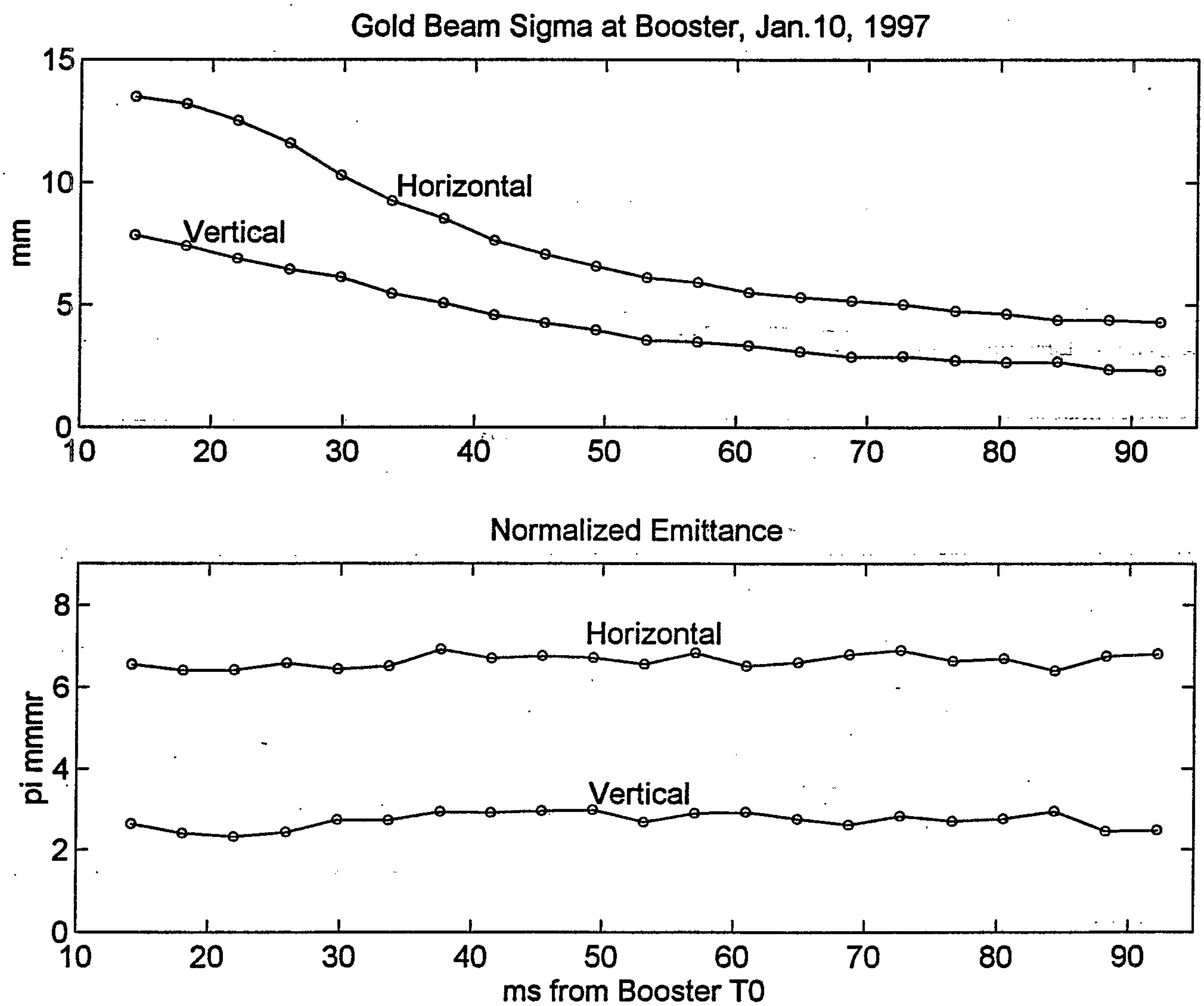
Gold Beam Sigma at Booster, Jan.10, 1997
mm
Horizontal
Vertical
15
10
5
0
10
20
30
40
50
60
70
80
90
Normalized Emittance
pi mmmr
Horizontal
Vertical
8
6
4
2
0
10
20
30
40
50
60
70
80
90
ms from Booster T0

Fig.1

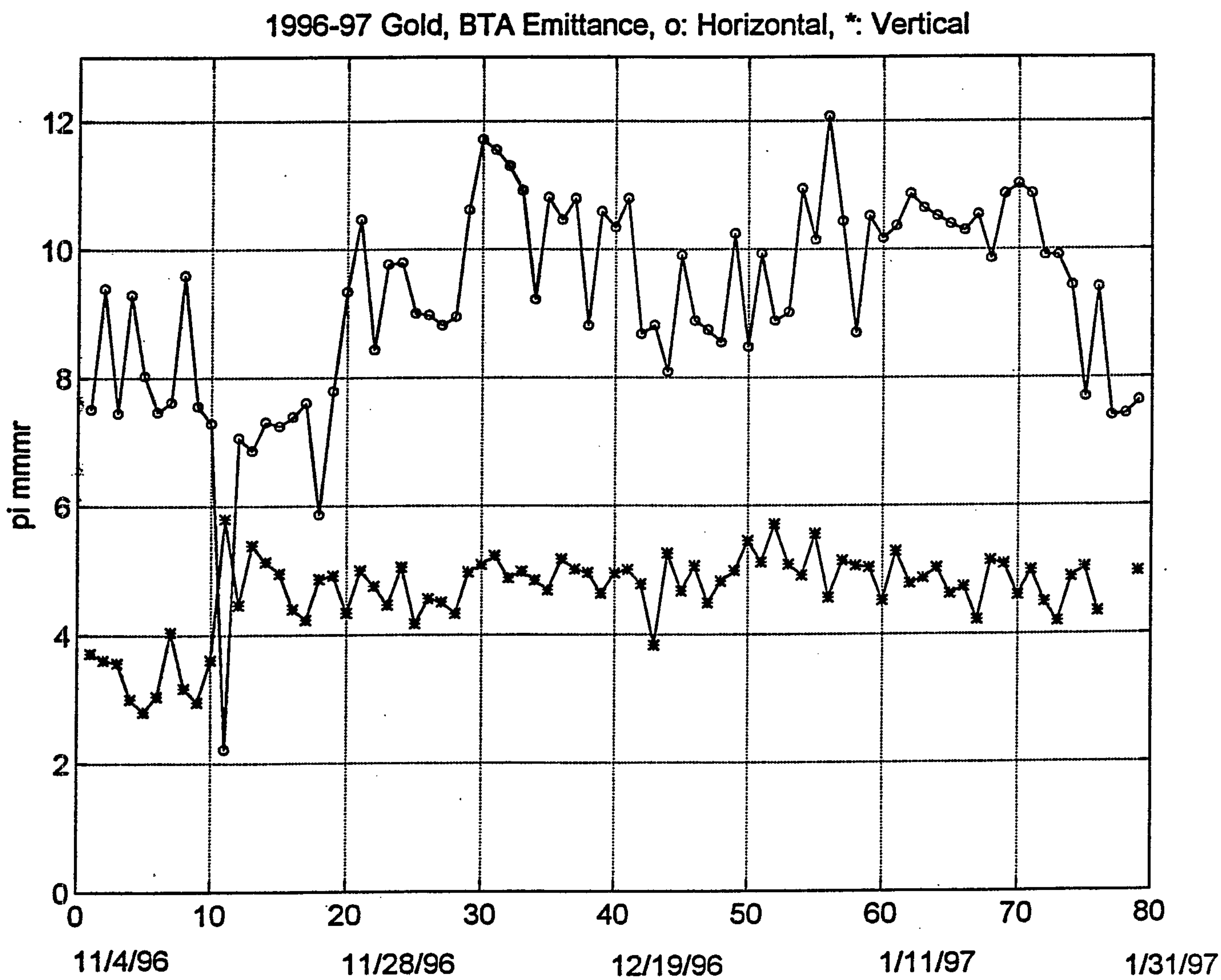
1996-97 Gold, BTA Emittance, o: Horizontal, *: Vertical
pi mmmr
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
11/4/96
11/28/96
12/19/96
1/11/97
1/31/97

Fig.2

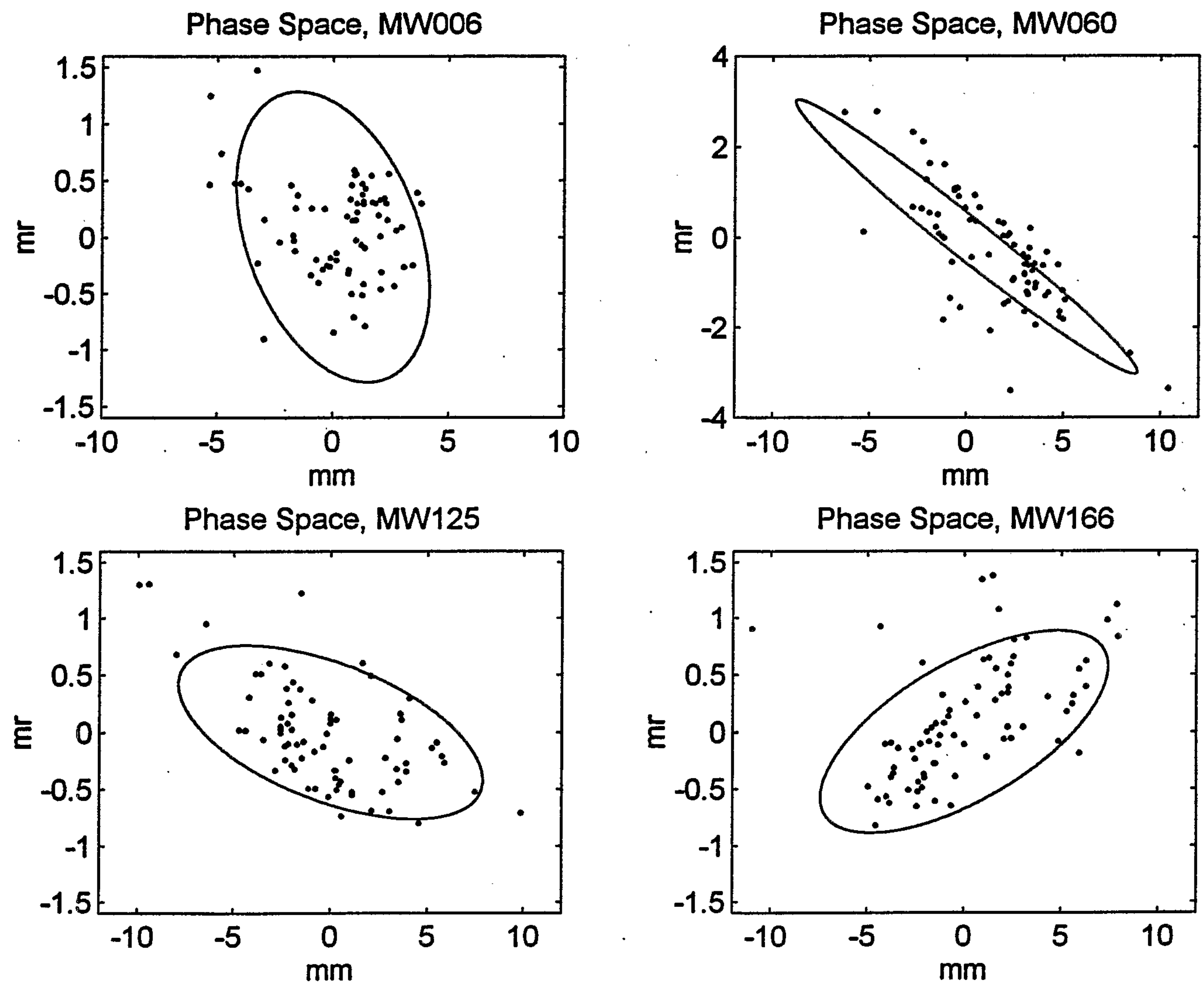


Fig.3 Horizontal

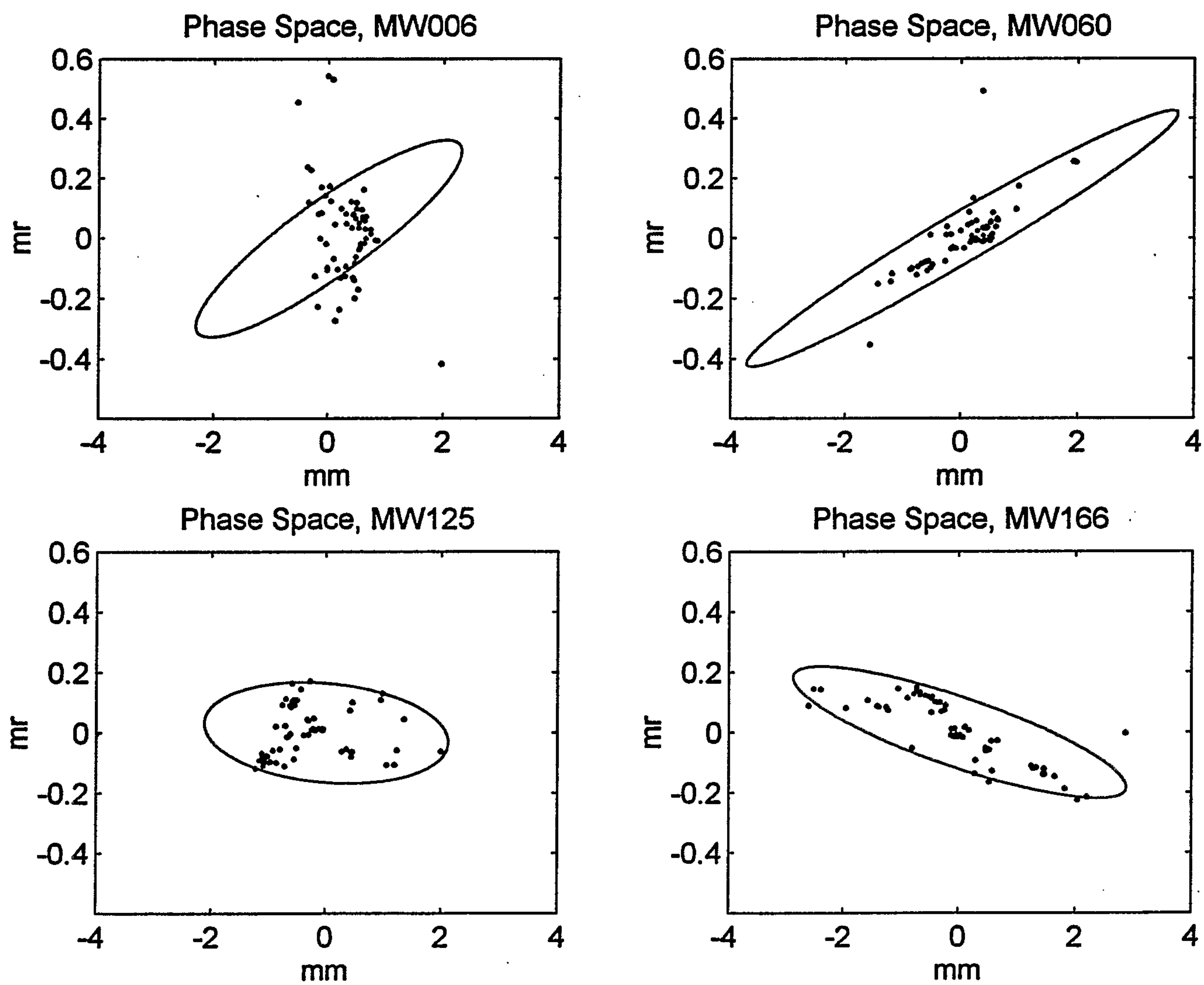


Fig.4 Vertical

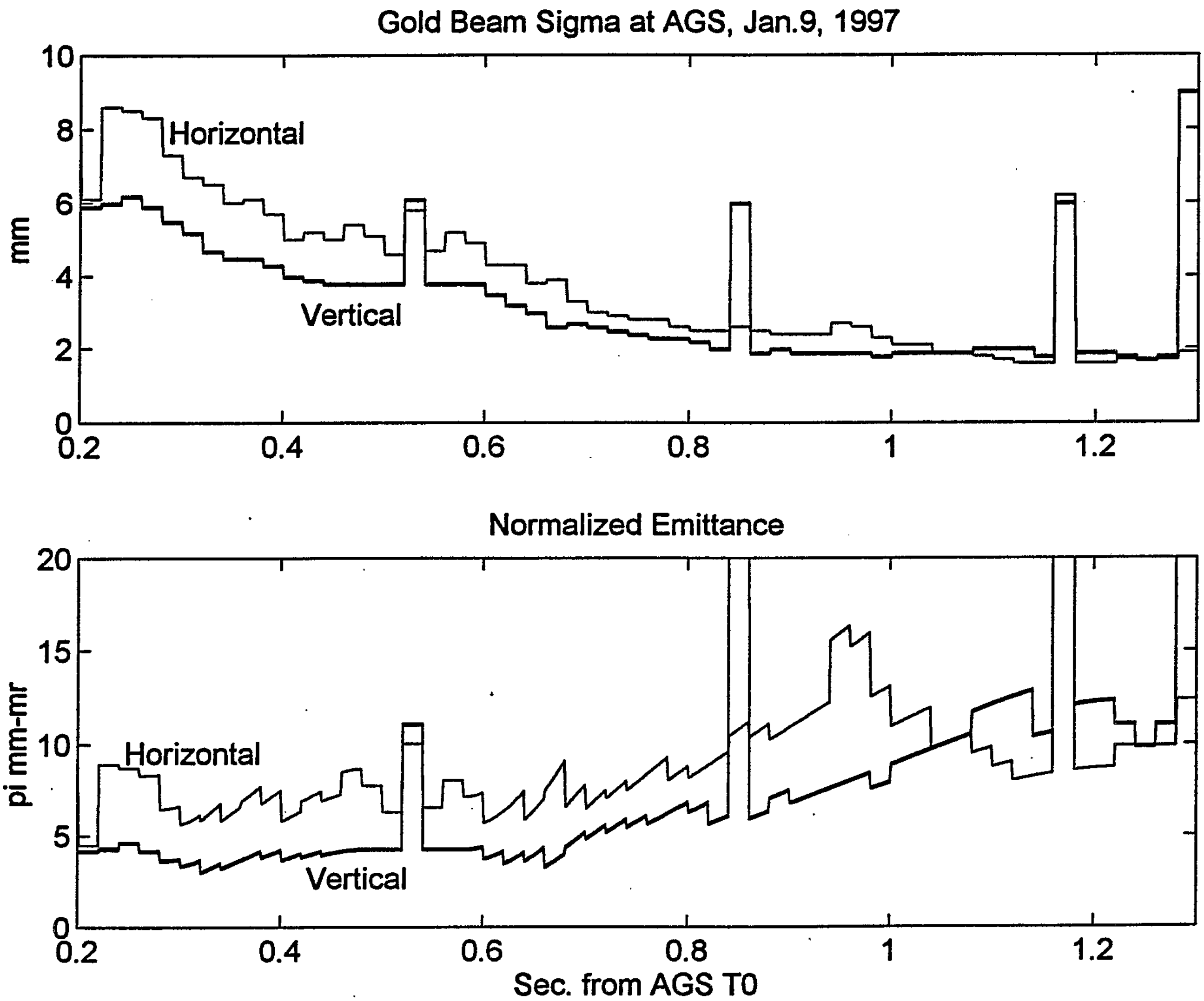
Gold Beam Sigma at AGS, Jan.9, 1997
mm
Horizontal
Vertical
0
2
4
6
8
10
0.2
0.4
0.6
0.8
1
1.2
Normalized Emittance
pi mm-mr
Horizontal
Vertical
0
5
10
15
20
0.2
0.4
0.6
0.8
1
1.2
Sec. from AGS T0

Fig.5