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Emittance Dilution due to Misalignment of Quads and Cavities of ILC Main Linac

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- For beam energy 250 GeV, two optics for 35 MV/m; (a) ‘weak focus’ and (b) ‘strong focus’, were made as shown in Fig. 1. In the optics (a), there is one quad for every two cryo-modules up to beam energy of 125 GeV and one quad every three cryo-modules from 125 GeV to 250 GeV. In the optics (b), one quad for every cryo-module up to beam energy of 125 GeV and one quad every two cryo-modules from 125 GeV to 250 GeV. These are FODOs and the phase advance per cell is 60 degree in all cases. One cryo-module has 10 cavities.
- Tracking simulation was done using SLEPT. Beam parameters were; single bunch, 2E10 particles/bunch, bunch length 0.3 mm (rms), initial energy 5 GeV, initial uncorrelated energy spread 2.8%(rms), initial normalized emittance 2E-8 m. Misalignment of quads and cavities, and quad-BPM offset were set as gaussian random. Only single bunch effects were considered and short range wakefunctions in TESLA-TDR were used. Average of vertical emittance at the end of the linac over 100 different random seeds is presented for each condition.
- Sensitivities of the two optics to cavity misalignment are shown in Fig. 2; emittance as function of cavity misalignment without any corrections. Emittance dilution in the weak focus optics is larger by factor about 1.5 compare with the strong focus optics. It means the alignment tolerance of the cavities is tighter by factor sqrt(1.5). If 4% emittance dilution due to cavity misalignment is acceptable, the tolerance is about 0.4 mm for the weak focus optics and 0.5 mm for the strong focus optics.
- Three kinds of orbit corrections, as described in page 5, were tested. Every quad was assumed to have a BPM and a steering. Correction (A) the orbit goes through the center of every quad with error of quad-BPM offset. Correction (B) tries to make kicks at quads (kicks by quad field and steering) minimum. Correction (C) is between (A) and (B). The weight ratio was chosen as 1E-3 empirically, where the results are not sensitive to slight change of the number.
- Fig. 3 shows examples of the results of correction (B) and correction (C) for the strong focus optics. The lines indicate the beam orbits and the plots are positions of quads. Misalignment of quads and cavities were set as 0.3 mm and quad-BPM offset 20 microns. Displacement of orbits after correction (B) tends to be much larger than quad misalignment. It may cause problems in BPM dynamic range besides wakefield in the cavities. Displacement of orbits after correction (C) are in the range of quad misalignment.

- Fig. 4 shows emittance as function of quads and cavities misalignment (the same rms for quads and cavities) for three corrections. Quad-BPM offset was set as 20 micron. Emittance with the correction (A), one-to-one, is very sensitive to the misalignment (Note the different vertical scale from the other corrections). Correction (C) is better than (B). Emittance dilution for the strong focus optics is larger than that for weak focus optics, but the dependence on the misalignment for two optics are similar. Emittance dilution due to quad and cavity misalignment of 0.4 mm (difference from dilution without misalignment) is about 4% of initial emittance.
- Fig 5. shows emittance as function of quad-BPM offset error. Misalignment of quads and cavities were set as 0.3 mm. Emittance with the correction (B) and (C) are very sensitive to the quad-BPM offset. Correction (C) gives better results than (B). Emittance dilution for the strong focus optics is larger than that for weak focus optics by factor about 4, meaning the tolerance of quad-BPM offset error is tighter by factor 2. If 20% emittance dilution due to quad-BPM offset is allowed, the tolerance is about 30 micron for the weak focus optics and 15 micron for the strong focus optics.
- Finally, Fig. 6 shows emittance as function of cavity misalignment for the correction (C), quad misalignment was set as 0.3 mm and quad-BPM offset 20 micron. Compared with Fig. 4, it is shown that alignment of quads should be more accurate than alignment of cavities.
- Assuming quad and Cavity misalignment 0.4 mm, Quad-BPM offset 20 micron, expected emittance dilution using the correction (C) is:

    35 MV/m strong focus optics: 52% (normalized emittance 0.05 E-8 m)

    35 MV/m weak focus optics: 16% (normalized emittance 0.46 E-8 m)
- Very rough numbers for the tolerances will be:

    Quad and cavity alignment: 0.4 mm

    Quad-BPM offset error: 20 micron
- Tilts of cavities (beam will be transversely kicked) have not been considered here. The effects can be significant and will be studied next. [Suggested by C.Adolphsen and P.Tenenbaum.]

Fig.1, Optics

Square root of beta-function of three models;
(a) 35 MV/m weak focussing
from 5 GeV to 125 GeV: 2 modules/quad
from 125GeV to 250 GeV: 3 modules/quad
(b) 35 MV/m strong focussing
from 5 GeV to 125 GeV: 1 modules/quad
from 125GeV to 250 GeV: 2 modules/quad

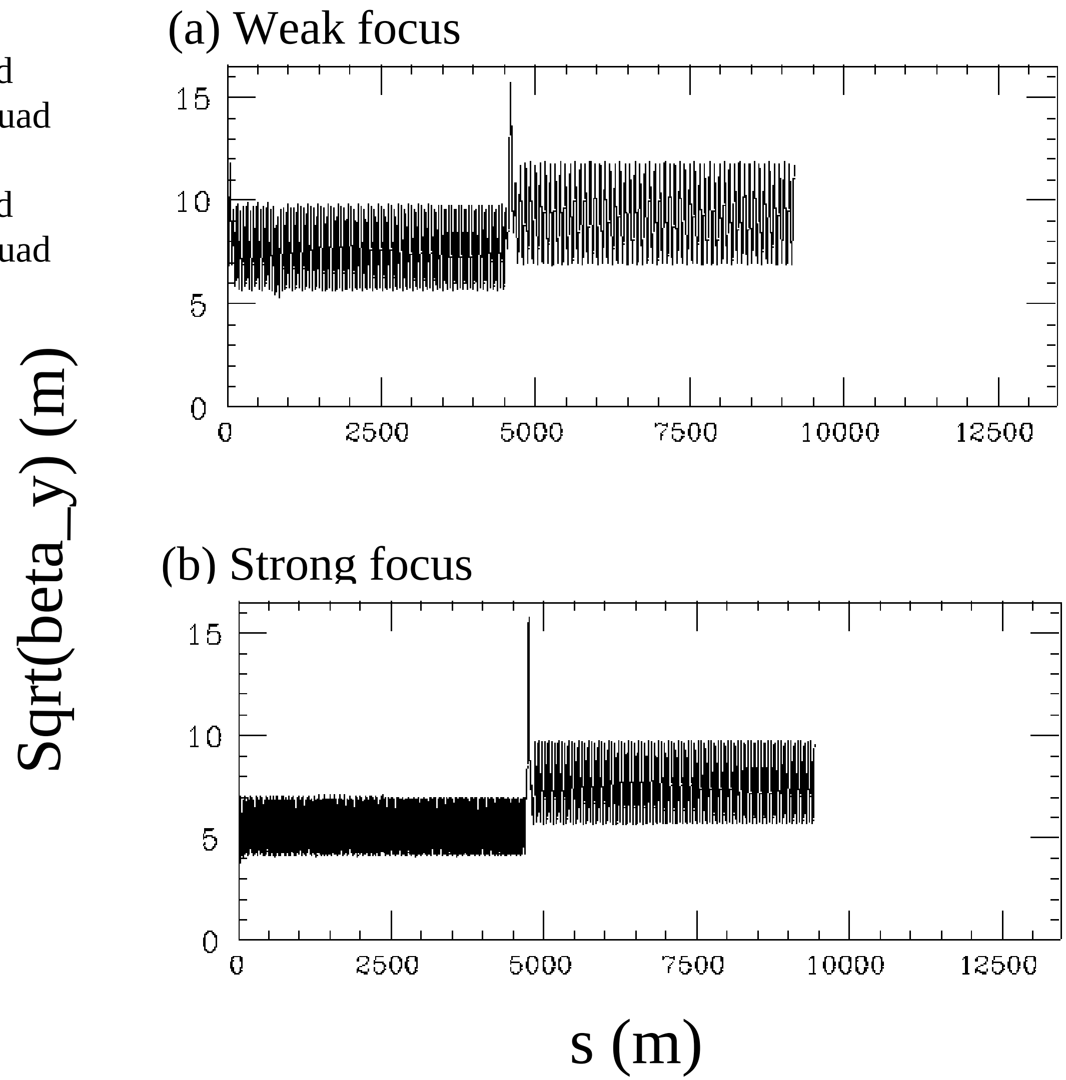
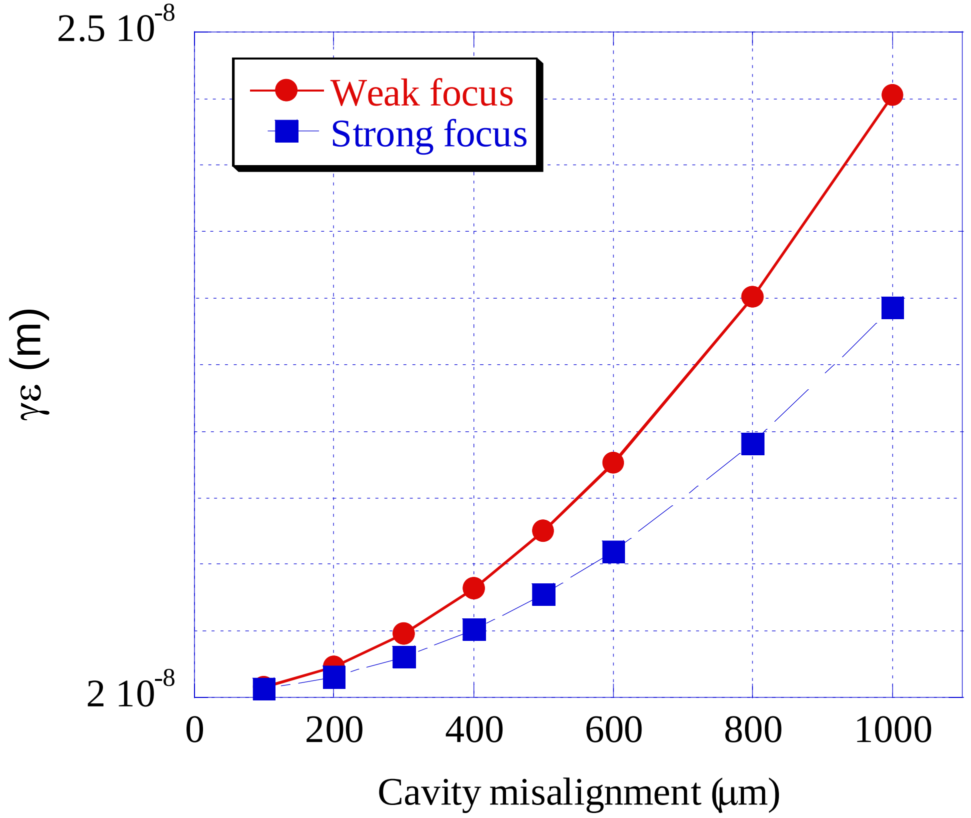


Fig.2

Emittance vs. Cavity misalignment (rms).
No misalignment of quads. No corrections.



Three kinds of orbit corrections

Use steering, or correction coils of quads.
Every quad has a BPM and a correction coils.

Correction (A): One - to - one

Minimize BPM readings.

Correction (B): Kick minimization

$$\text{Minimize } \sum_i \left(\theta_i - k_i y_i\right)^2,$$

θ_i : kick angle of steering at i-th quad

y_i : BPM reading at i-th quad

k_i : K-value of the i-th quad

Correction (C): Combined (A) and (B)

$$\text{Minimize } \sum_i r^2 y_i^2 + \sum_i \left(\theta_i - k_i y_i\right)^2,$$

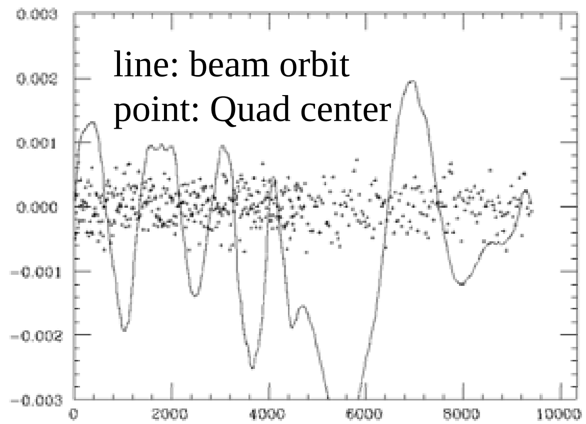
r : Weight ratio. $= 10^{-3}$

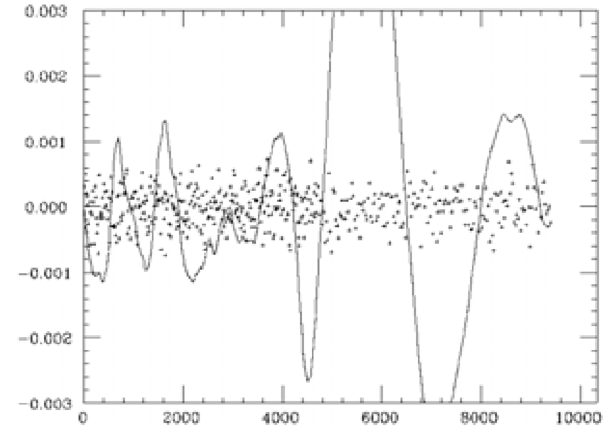
Examples of orbit after correction (B) and (C).

Quad misalignment 0.3 mm, Quad-BPM offset 20 μm

Fig.3

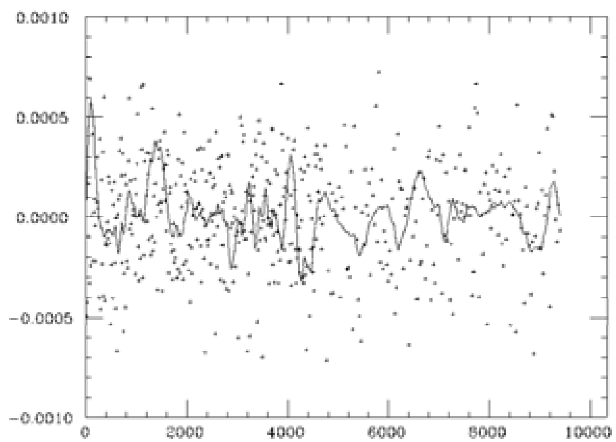
Orbit correction (B)

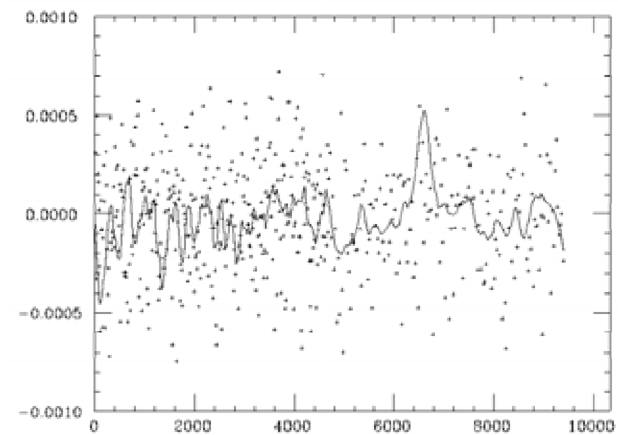




s (m)

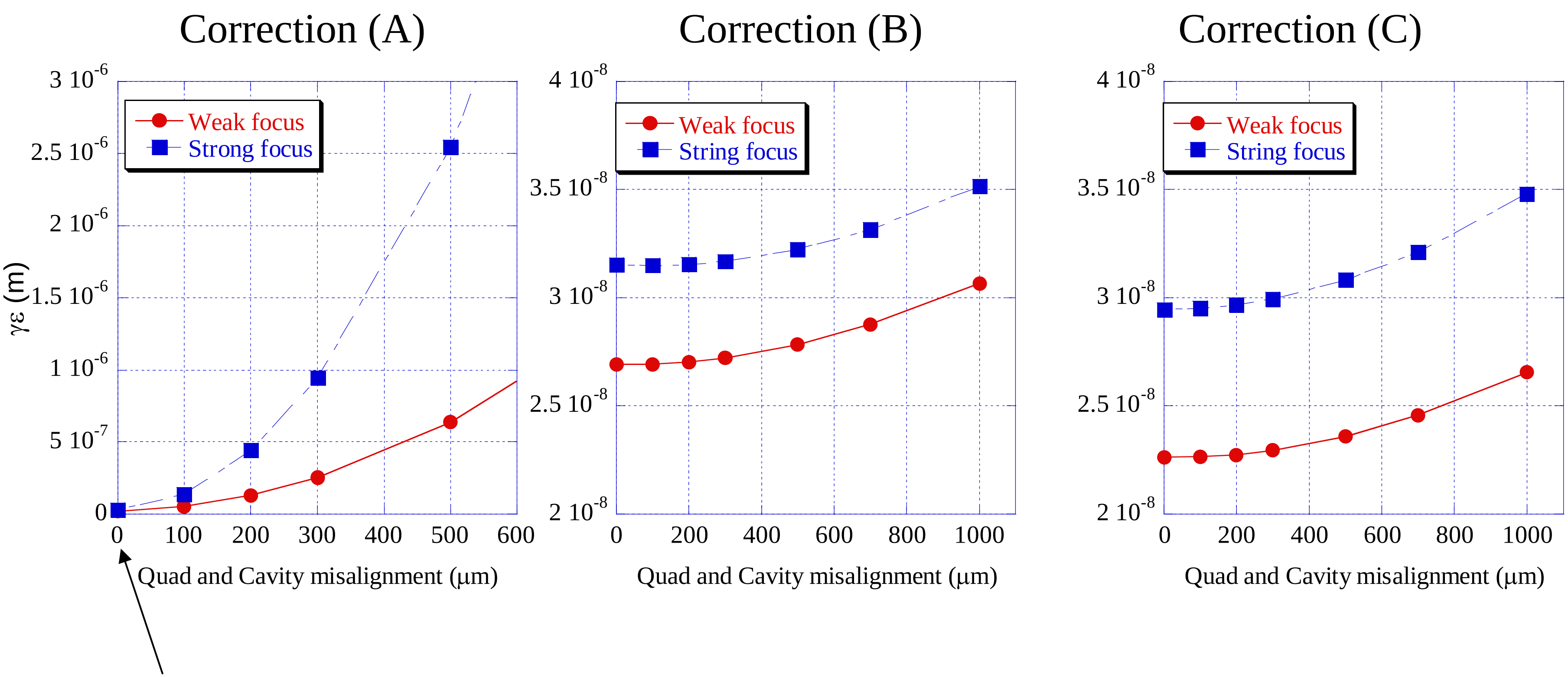
Orbit correction (C)





Emittance vs. Quad and Cavity misalignment (the same rms for quads and cavities). Quad-BPM offset 20 μm.

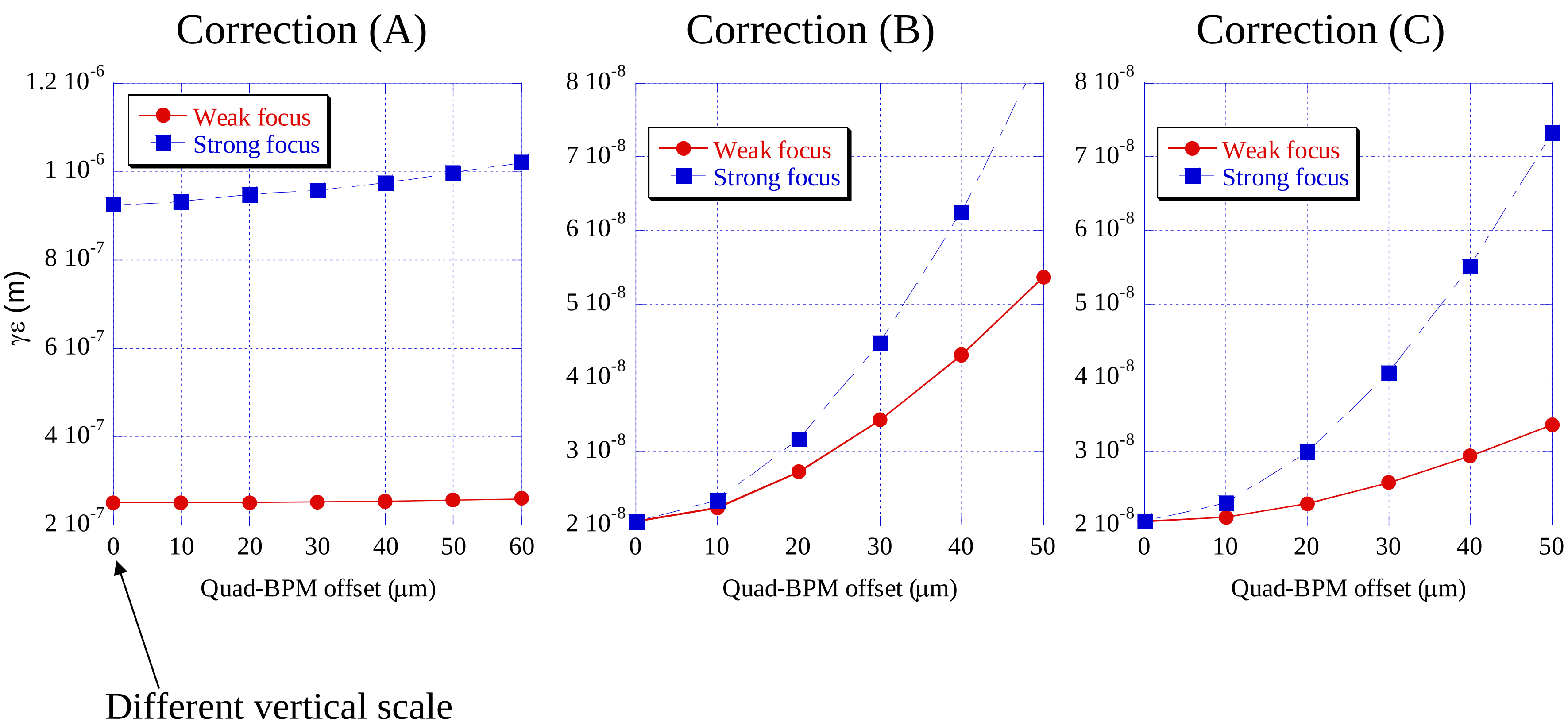
Fig.4



Different vertical scale

Emittance vs. Quad-BPM offset.
Quad and Cavity misalignment 0.3 mm (the same rms for quads and cavities).

Fig.5



Emittance vs. Cavity misalignment.
Quad misalignment 0.3 mm and Quad-BPM offset 20 μm.

Fig.6