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BEAM POSITION MEASUREMENT AT THE IP

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1 Introduction

For high precision transverse beam position measurement at the interaction point (IP) a resonant coaxial monitor is proposed using a dipole mode for measurement. Use of resonant amplification is necessary for achieving the required precision. But this means a reduction in time resolution. Some proposals are made to overcome it.

1.1 Requirements

To give a rough survey of what has to be done, the following presuppositions are given:

- beam pipe diameter: $48mm$,
- time-distance of the bunches: $t_B = 350ns$,
- time jitter: $2ps$,
- transverse resolution: $5\mu m$,
- time resolution: $20ns$.

Some general premises are:

- during operation the BPM in the kryostat is not accessible,
- long-time stability (some months) is desired.

2 Design of the Coaxial Cavity Monitor

The monitor looks like the two prototypes in figure 1.1.

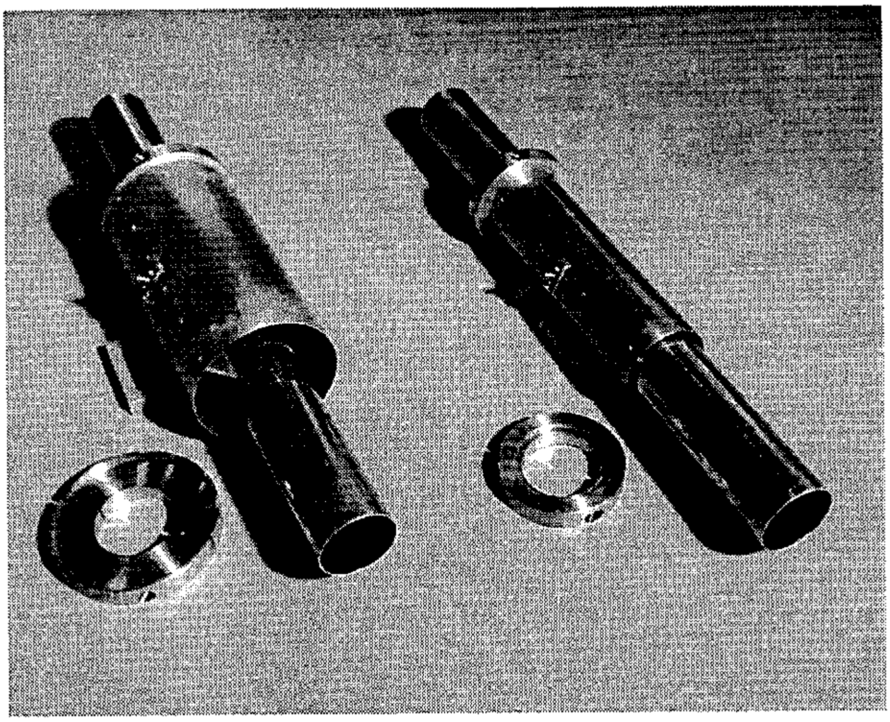

Figure 1.1: Two prototypes A (left) and B (right) of the coaxial beam position monitor.

If the coaxial resonator is unrolled, it looks like a rectangular cavity resonator. This unrolled geometry is shown in figure 1.2.

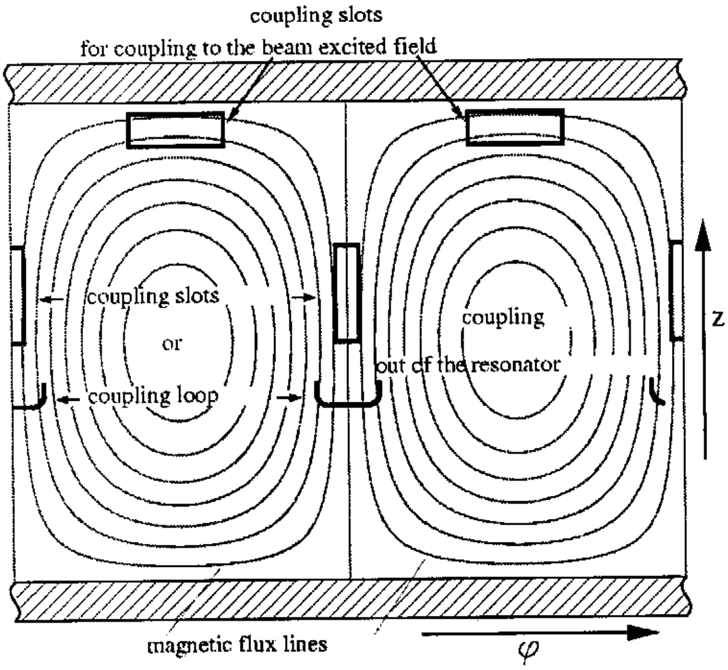

Figure 1.2: Magnetic flux lines of the dipole-mode in the unrolled coaxial cavity.

The signal couples from the beam tube through rectangular coupling slots. With the area of these slots the coupling factor and consequently the magnitude of the signal can be tuned. For the measurement of the beam position the field mode TE_{021} is used, as shown in figure 1.2

with his magnetic flux lines. The resonance frequencies of three modes in both prototypes are listed in table 1.1.

	monitor A		monitor B	
mode	calculat.	measurem.	calculat.	measurem.
	[GHz]	[GHz]	[GHz]	[GHz]
TE_{011}	0.944	1.000	1.171	1.147
TE_{021}	1.372	1.520	1.949	1.936
TE_{012}	1.605	1.677	1.748	1.729

table 1.1: Resonant modes in the two prototypes.

To get a better impression of the resonators geometry a 3D view is depicted in figure 1.3.

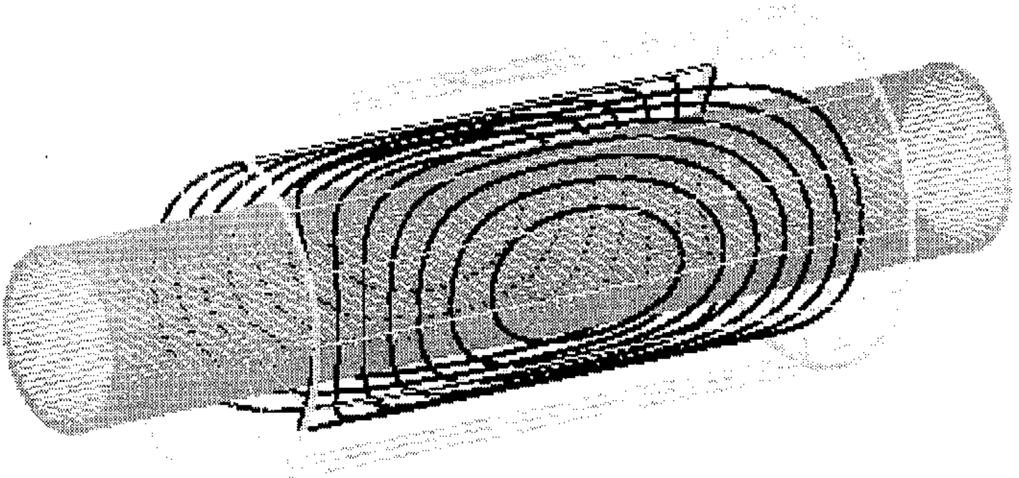

Figure 1.3: 3D view of the coaxial monitor cavity around the beam tube with the magnetic flux lines of the dipole mode.

The resonance frequency of the modes, especially the dipole mode, can be tuned with the length of the resonator. Figure 1.4 shows it for the approximation of a rectangular cavity. A change in diameter changes the resonance frequency of the dipole mode less, since it elongates slightly the circumference. So the diameter can be changed

- to adapt for the available space,
- to adjust the Q-value.

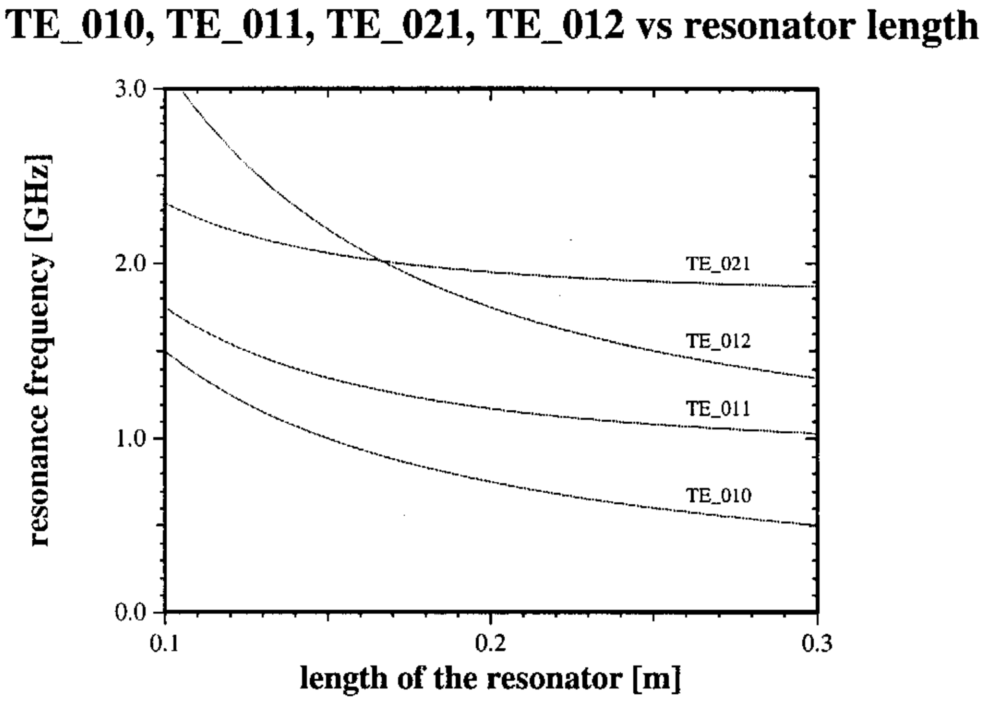

Figure 1.4: Resonance frequency of 4 Modes in a rectangular cavity with variable length.

3 Measurements

3.1 Measurement technique

The beam is simulated by a tightened 0.4mm silver wire. The position of the beam tube with the monitor in relation to the wire is adjusted with a x-y-table.

3.2 Measurement of the amplitude

Figure 2.1 shows the amplitude measurement of prototype a. The transmission measurement gives the signal in relative units versus the transverse position of the wire in the beam tube.

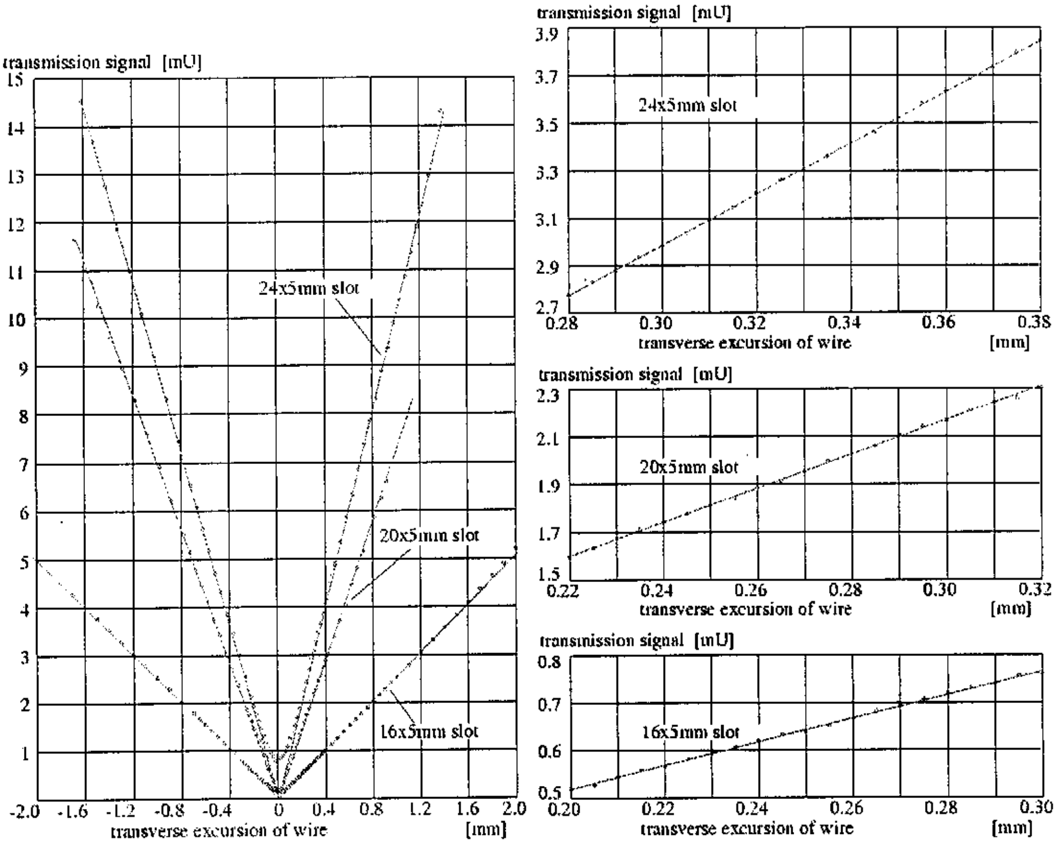

Figure 2.1: Amplitude measurements with prototype A for a wide transverse range (left) and a sector (right) for three different coupling slot length.

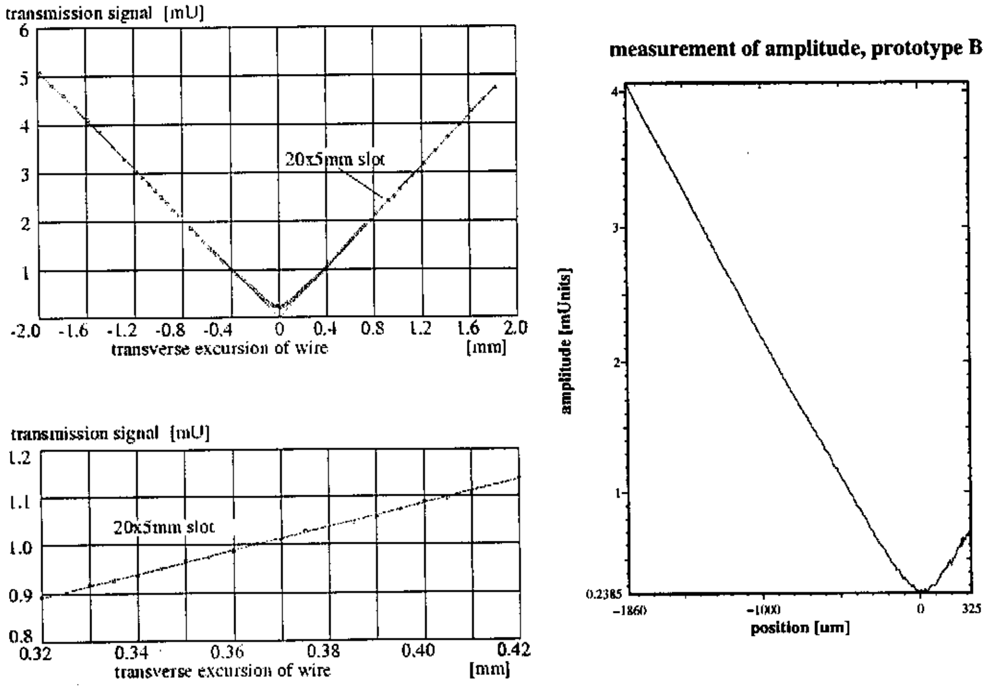

Figure 2.2: Amplitude measurements with prototype B for a wide transverse range (left,upper) and a sector (left,lower) and a repeated measurement (right).

One can see that the straight line did not reach the origin. That means there exists some kind of noise which superposes the low signal measurement. In the accelerator enviroment, where the structure is closed against irradiation, it may be reduced markedly.

3.3 Measurement of the Phase

For testing the sensibility despite the noise a phase measurement is done as can be seen in figure 2.3.

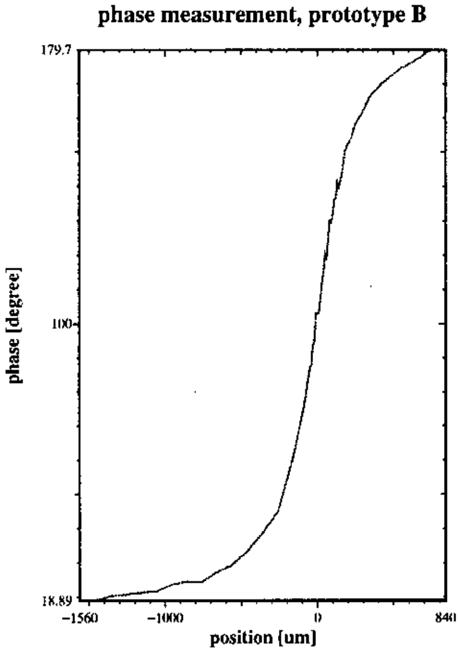

Figure 2.2: Phase measurements with prototype B for a wide transverse range.

This phase measurement gives a high resolution in the zero area. One problem is that phase measurement requires a phase benchmark. The fundamental mode, which is not noticeable dependent on the beam position, is applicative for this task. The jags are due to inadequacy in the setup (for example flexible cable). But in the machine everything can be fixed, which guarantees even a tricky phase measurement

4 Some Considerations concerning the Time Resolution

4.1 Time Jitter

From the bunch compressor a time jitter of $20ps$ is given. In figure 3.1 the randomized influence on the amplitude of the signal of several time jitters are depicted.

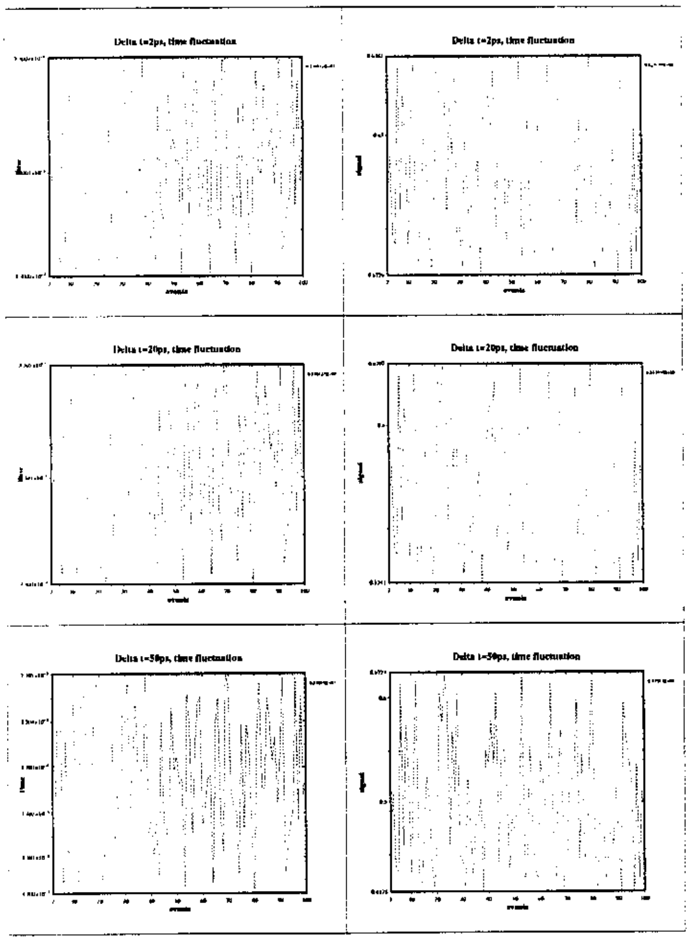

Figure 3.1: Variation of the signal amplitude for a time jitter of $\Delta t = 2ps$ (upper), $\Delta t = 20ps$ (center) and $\Delta t = 50ps$ (lower).

The small fluctuation of the signal makes it feasible to neglect this influence.

4.2 Signal Progression at the Monitor

In figure 3.2 the position of the quadrupoles and the three BPM's for one side of the IP is given.

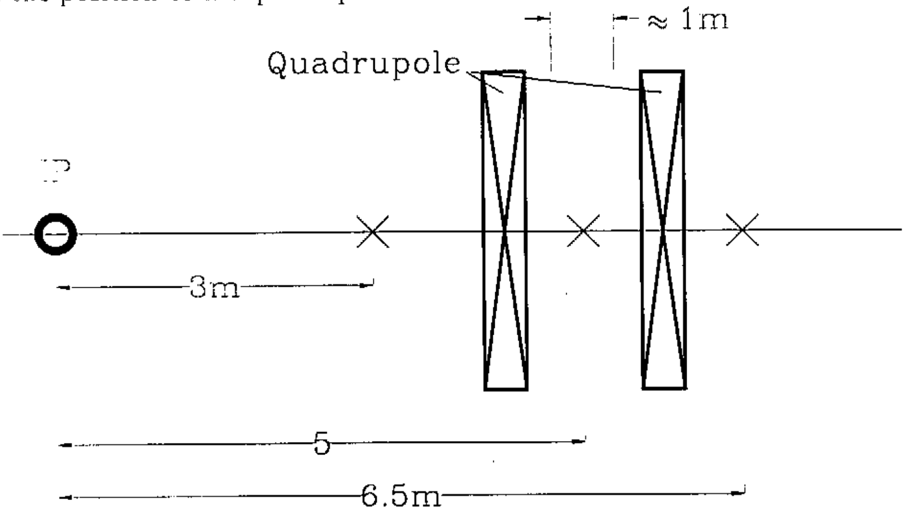

Figure 3.2: proposed arrangement of the 3 planned BPM's.

Figure 3.3 shows the signal structure at each monitor with a working frequency of $1.95GHz$ and a cyvity quality number of 850.

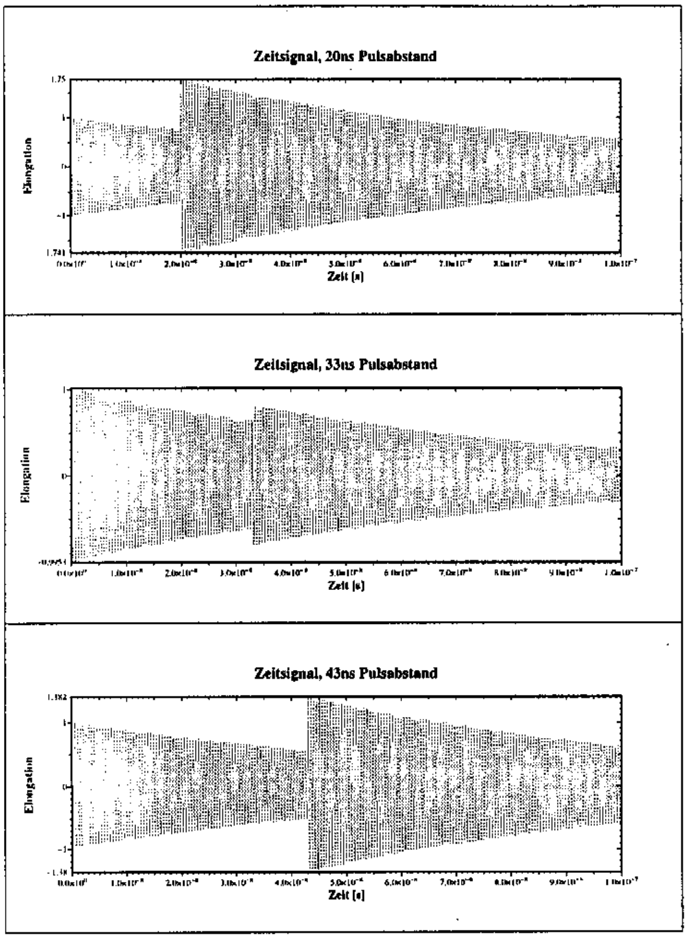

Figure 3.3: Signal structure at the three BPM's, $\nu = 1.95GHz$, $Q = 850$.

It can be recognized that the signals from the incoming and the outgoing bunch are overlapping. One chance to eliminate that could be to reduce the Q-value as far as the signals are separated. But according to the short times required here this would mean a tremendous loss of amplification. The claimed resolution could not achieved. So another option is presented.

4.3 Time Resolution using the 3 Monitors

Three monitors are planned to install at each side of the IP. This delivers some redundant information, which can be used for getting the amplitude of the signal without complete declining of the former one. Knowing the position and therefore the distances the phase relations can be taken into account.
Looking on the three monitors a, b and c at the times t_1, t_2, t_3, t_4, t_5 and t_6 one gets the following system of equations:

$$t_1 \; : \; A_{a1} = T_{11} \tag{1}$$

$$t_2 \; : \; A_{a2} = T_{21} \tag{2}$$

$$t_3 \; : \; A_{a3} = T_{31} \tag{3}$$

$$t_4 \; : \; A_{c2} = T_{32} + \cos(\varphi_3 - \Delta\varphi)\exp(-[\varphi_3 - \Delta\varphi])T_{31} \tag{4}$$

$$t_5 \quad : \quad A_{b2} = T_{22} + \cos(\varphi_2 - \Delta\varphi)\exp(-[\varphi_2 - \Delta\varphi])T_{21} \tag{5}$$

$$t_6 \quad : \quad A_{a2} = T_{12} + \cos(\varphi_1 - \Delta\varphi)\exp(-[\varphi_1 - \Delta\varphi])T_{11} \tag{6}$$

One vertical elongation can be calculated from the two others:

$$\begin{aligned} T_{21} &= T_{31} + \frac{T_{11} - T_{31}}{x_I + x_{II}} x_I \\ &= \frac{T_{31}x_{II} + T_{11}x_I}{x_I + x_{II}} \end{aligned} \tag{7}$$

This means with (1) to (6) one has 6 equations available to calculate 5 unknowns, since the phase differences φ_1, φ_2, φ_3 are known from the lengths. If furthermore the unpredictable phase differences $\Delta\varphi$ are neglected, the whole matter becomes much more easy.

5 Conclusion

This kind of BPM presented here is well suited for high precision beam position measurement combined with restrictions in the available transverse space. The simplicity of the setup is appropriate to the inaccessibility in the kryostat. The structure being made of metal totally avoids problems with hazardous materials. With the redundancy of three BPM' the needed high time resolution can be overcome.