RF Cavity Based High Resolution Beam Position Monitors

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Presented at the CAP Steering Committee and ATF Users Meeting

January 31 – February 1, 2001

BINP-Protvino, Russia **ATF-Brookhaven, USA**

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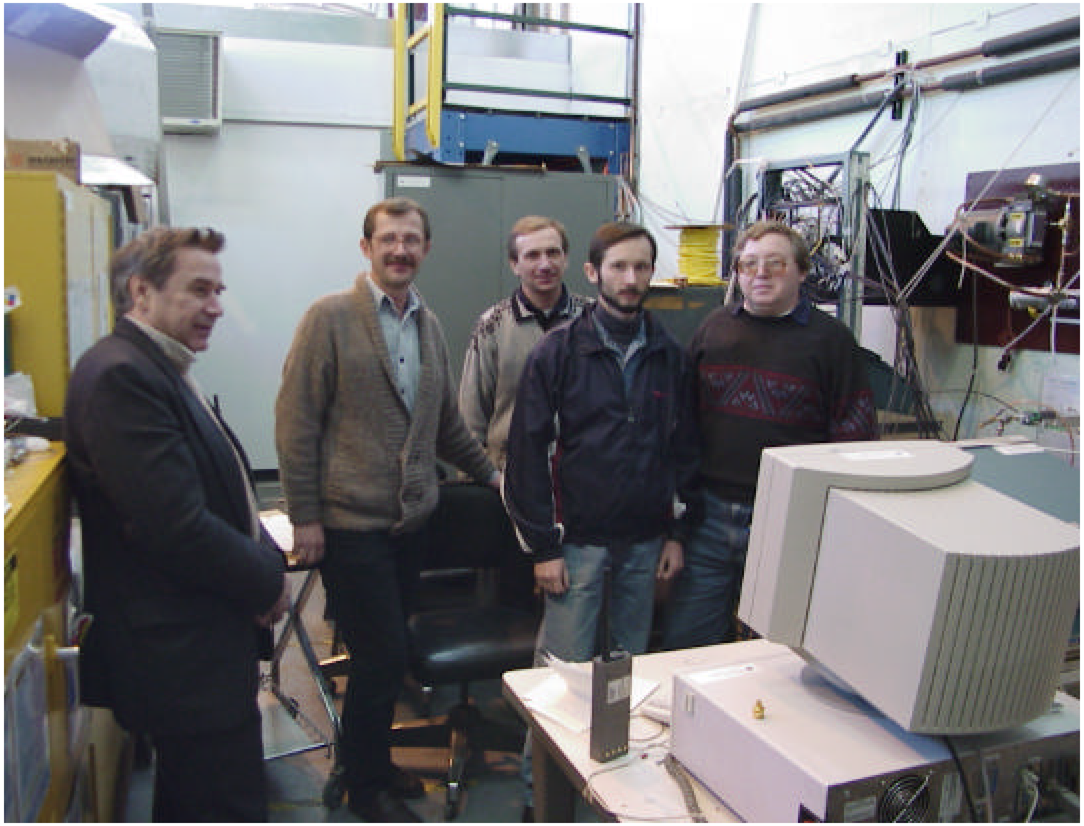
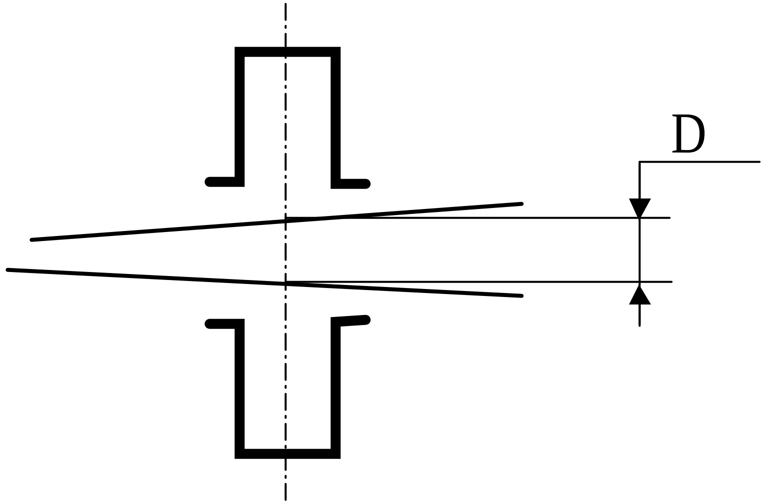


Requirements of Linear Colliders to BPM resolution

- For the modern projects of linear colliders the beam stability should be better than 0.1 micron in the main linac and a few nanometers in final focus system (FFS); otherwise the luminosity will decrease.
- Thus it seems convenient to use a Beam Position Monitor (BPM) with the resolution better than 0.1 micron in the single bunch regime for monitoring of the beam position along the linac and a BPM with the resolution about 1 nm - for FFS.

Definition of BPM resolution

We define BPM resolution D as a minimal beam shift, which can be observed by the BPM.



Microwave cavity as BPM

- It is well known idea to use for beam position monitoring a TM110 mode exited by the off-center beam in circular cavity.
- There are two main problems which limit the resolution of such BPM:
  - large amplitudes of the beam-exited common-modes;
  - thermal noise of detection electronics.

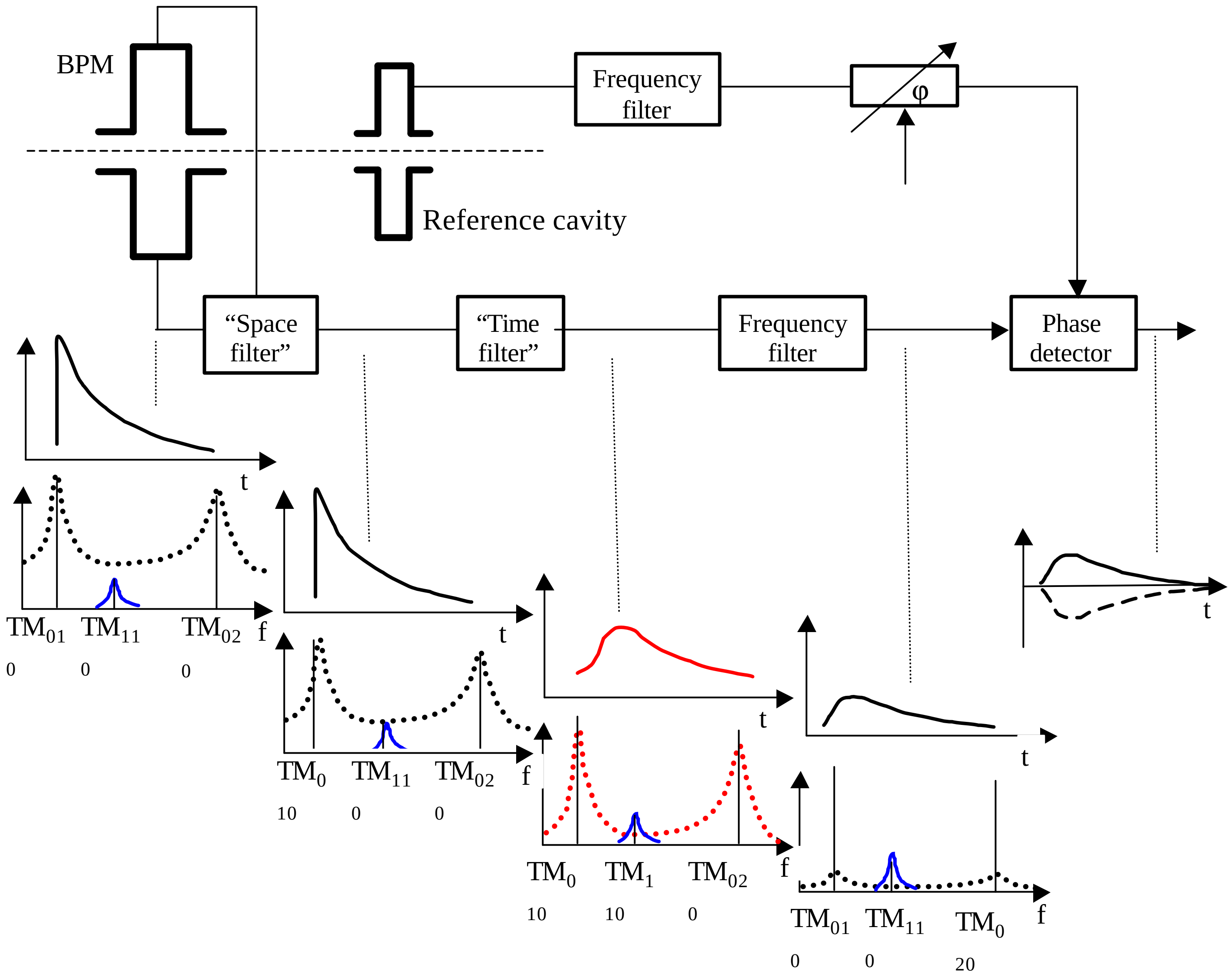
Four stages of common-mode rejection

For Δ=0.1 μm $\frac{P_{010}}{P_{110}} \approx 4 \bullet 10^9$ or 96 dB

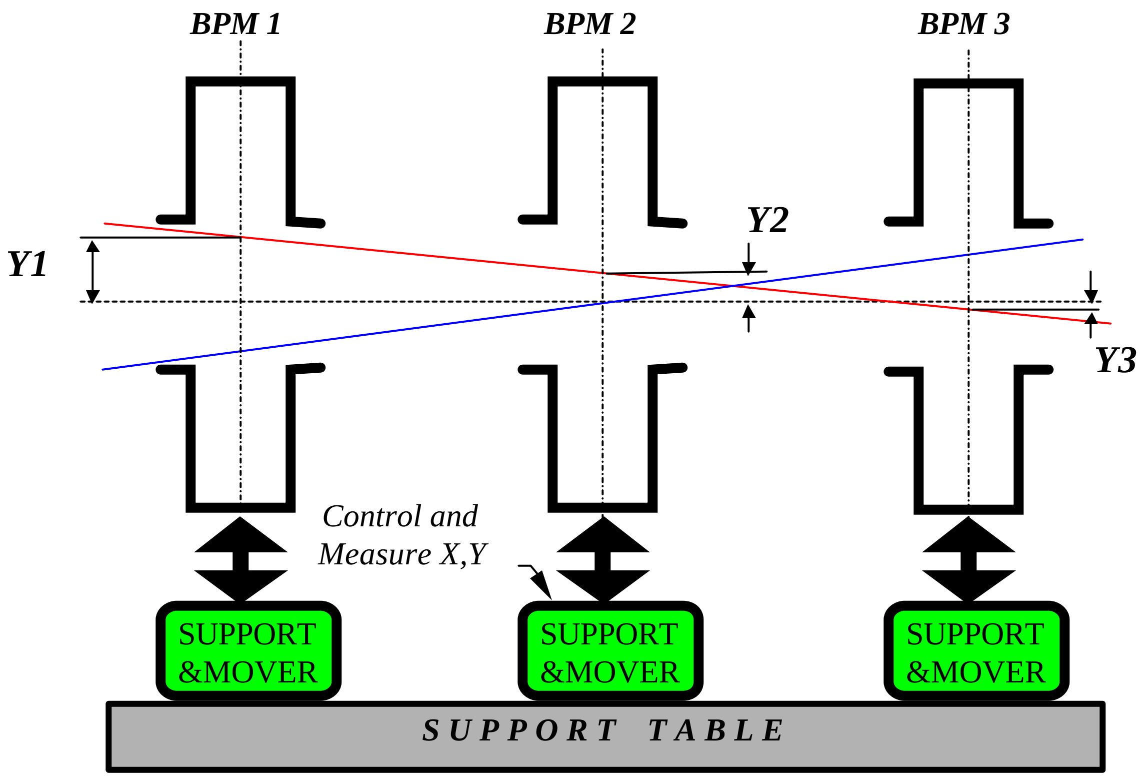
For Δ=1 nm $\frac{P_{010}}{P_{110}} \approx 4 \bullet 10^{13}$ or 136 dB

- **“Space filter”**
- **“Time filter”,**
- **Frequency filter**
- **Phase detection**

Concept of BPM signal processing

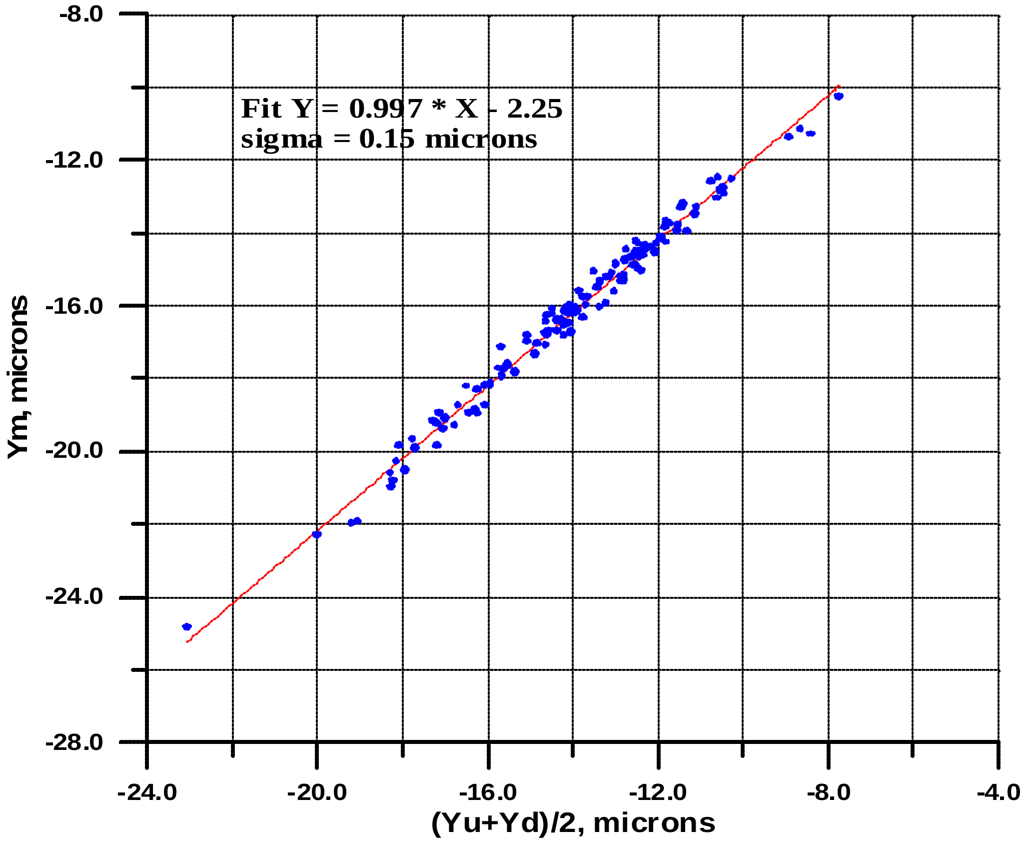


Experimental setup for excluding jitter of the beam trajectories



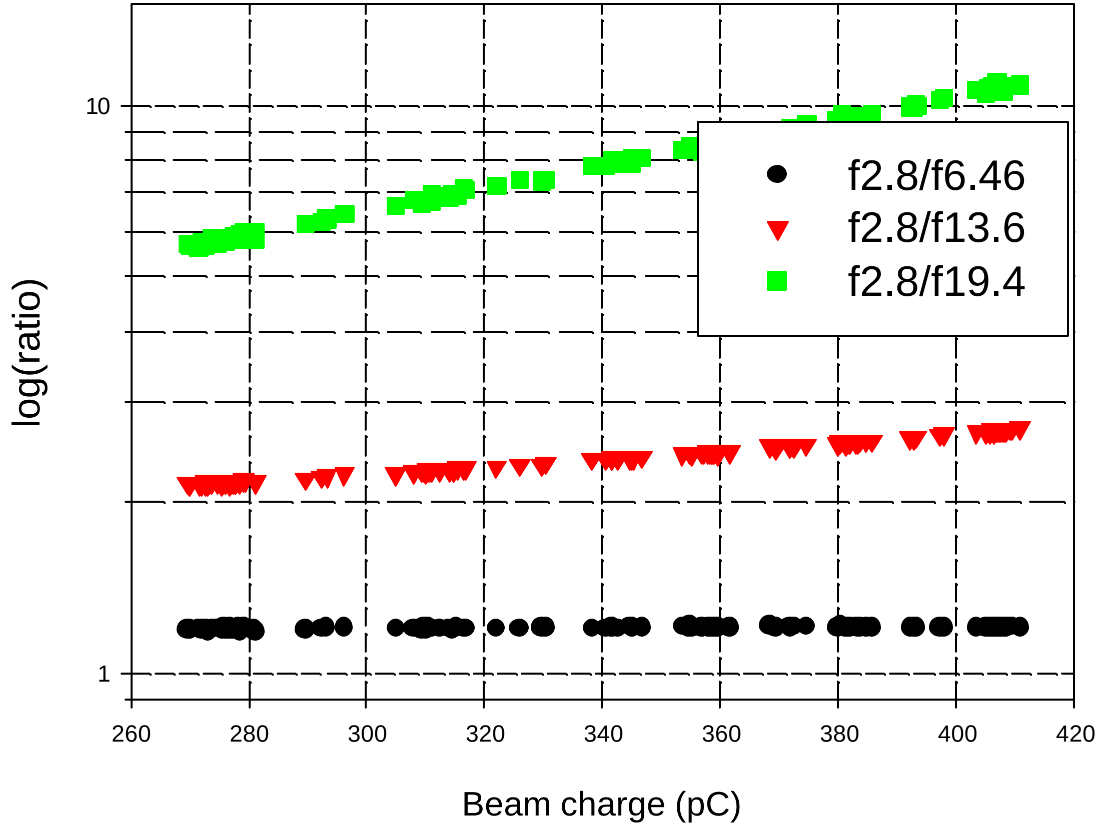
$$Y2 = (Y1 + Y3)/2$$

BPM resolution, achieved during the experiment at ATF BNL is 150nm



Determination of the BPM resolution.

Sensitivity to pulse shape



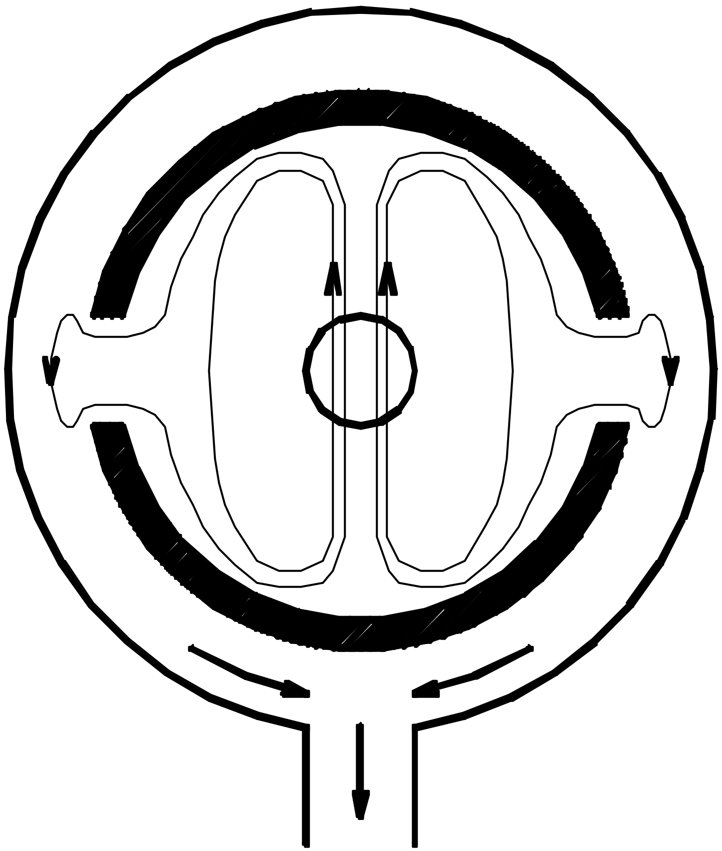
Output voltage from RF cavity VS. beam charge. Signals at 6.4GHz, 13.6 GHz and 19.4 GHz were normalized with 2.856 GHz reference cavity. One could see clear deference for different frequencies on charge/pulse shape dependence of output signal.

Plans

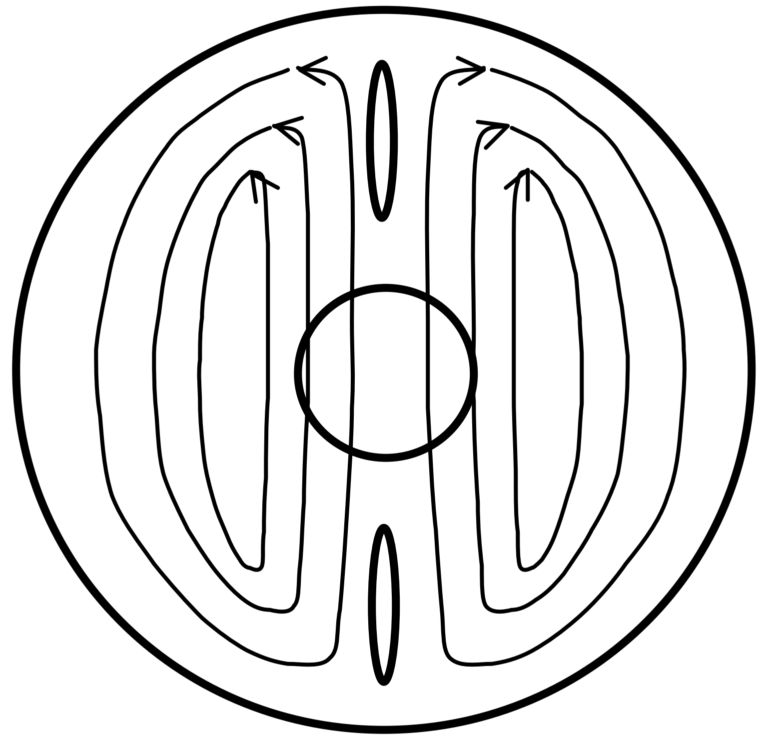
1. Installation of new cavities with working frequency 6426 MHz instead of 13566 MHz will give next advantages:
   - all fabrication inaccuracies will take smaller effects on electrical characteristics of cavities because of lower frequency;
   - new design of “space filter” will allow to obtain the better common-modes rejection and to increase the isolation between signals from X and Y directions;
   - RF-electronics on frequency 6426 MHz can be made with wider dynamic range and better linearity.
2. Reference signal from reference cavity with limiting amplifier on the intermediate frequency will be used. It will fix phase of reference signal relative to beam phase.
3. Shortening of the distance between BPMs will reduce an influence of magnetic fields on BPM resolution determination. (This influence occurs due to transformation of beam energy jitter to addition position jitter, which can not be excluded by using three BPMs).
4. From reference cavity signals of two common-modes (TM010 and TM020) will be measured to estimate bunch length and energy jitter.

“Space filter”

Old design

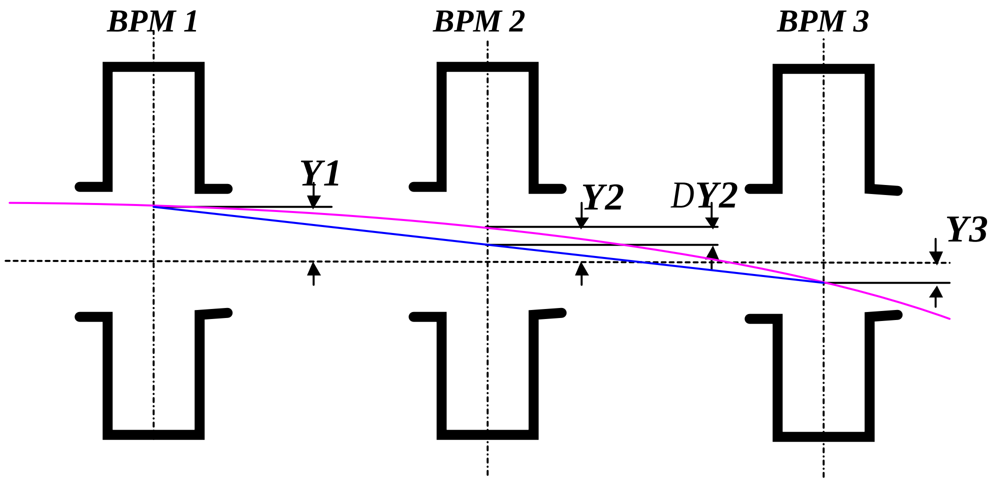


New design



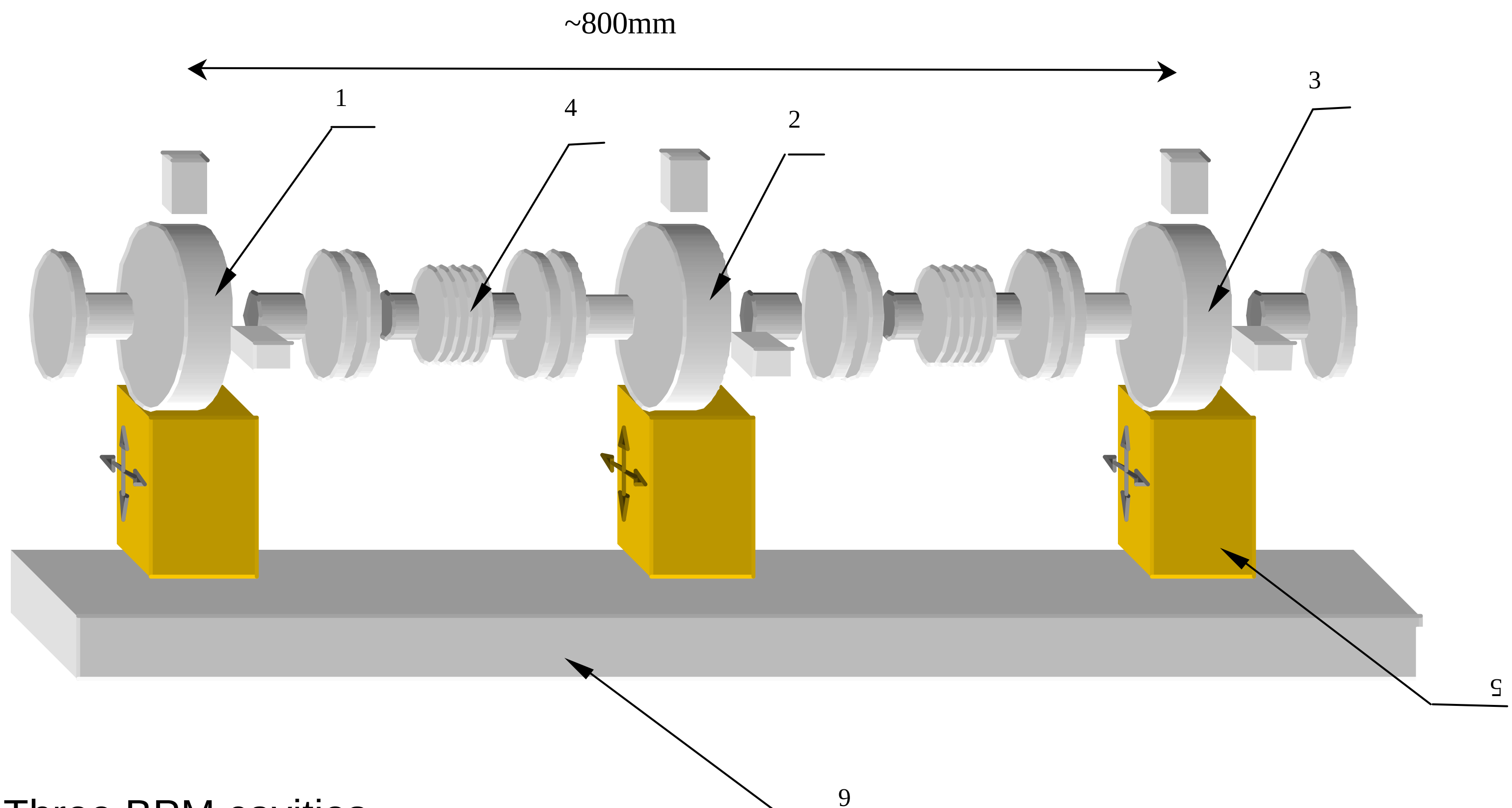
Magnetic fields effect

- The beam trajectory along the BPMs is not absolutely rectilinear of the effect of the magnetic field has influence on moving charged particles. And even in a permanent magnetic field (e.g. the magnetic field of the Earth, magnetic fields from movers and other equipment) trajectory deflection from the line is not abiding. It is determined by the beam energy. Therefore, in resolution determination the energy jitter in an accelerator yields erroneous reading when three BPMs are used.



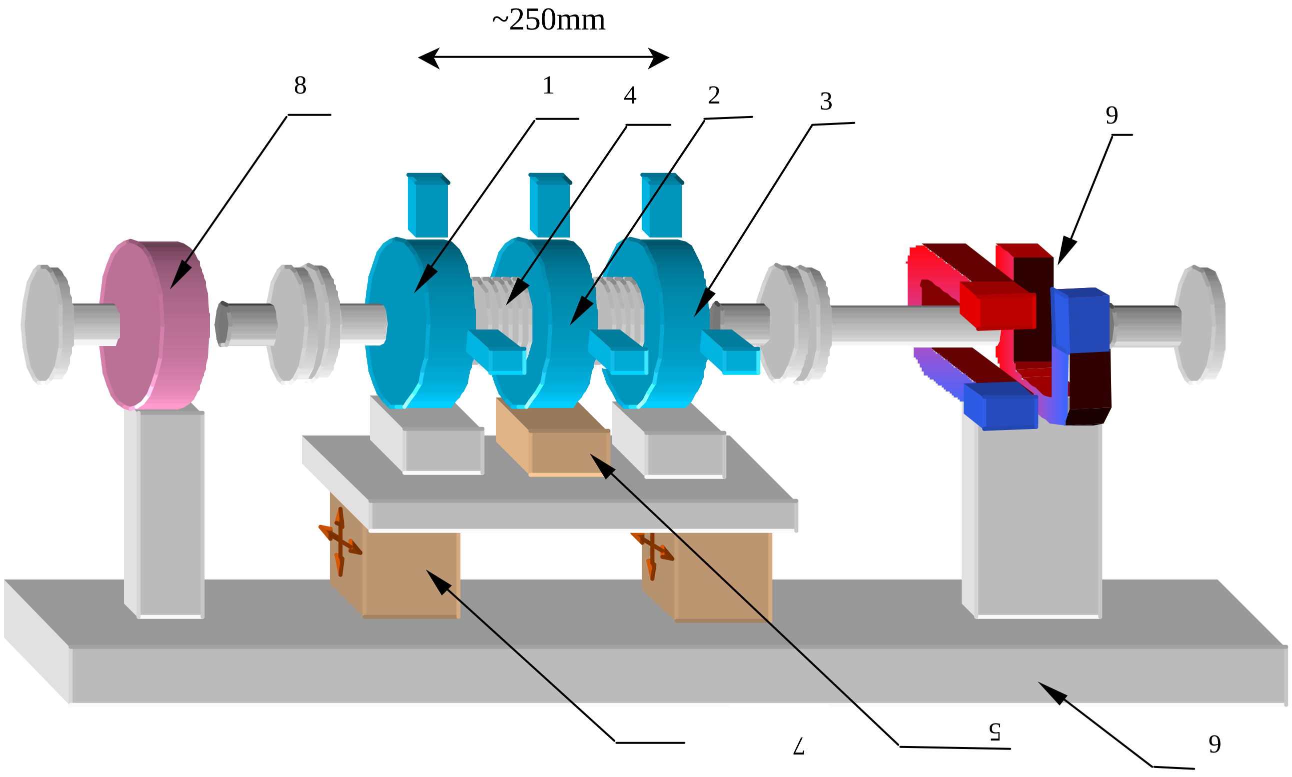
- ΔY2=Y2-(Y1+Y3)/2 depends from distance between BPMs.
- It is proposed to minimize distance between cavities in new experimental setup.

Old setup



- (1,2,3) Three BPM cavities
- (4) Bellow
- (5) High precision bi-directional electromagnetic mover (0-2mm)
- (6) Support table

New setup



- (1,2,3) Three new BPM cavities
- 4 Bellow, 5 High precision bi-directional mover (0-200nm)
- 6 Support table
- 7 High precision bi-directional step mover (+/- 1mm)
- 8 Reference Cavity, 9 Beam Corrector