Quadrated Dielectric-Filled Cavity Resonator as Beam Position Monitor

PAUL SCHERRER INSTITUT

S.Srinivasan, Paul Scherrer Institut
5232 PSI Villigen, Switzerland

Dipole Mode for Position Information, TM110

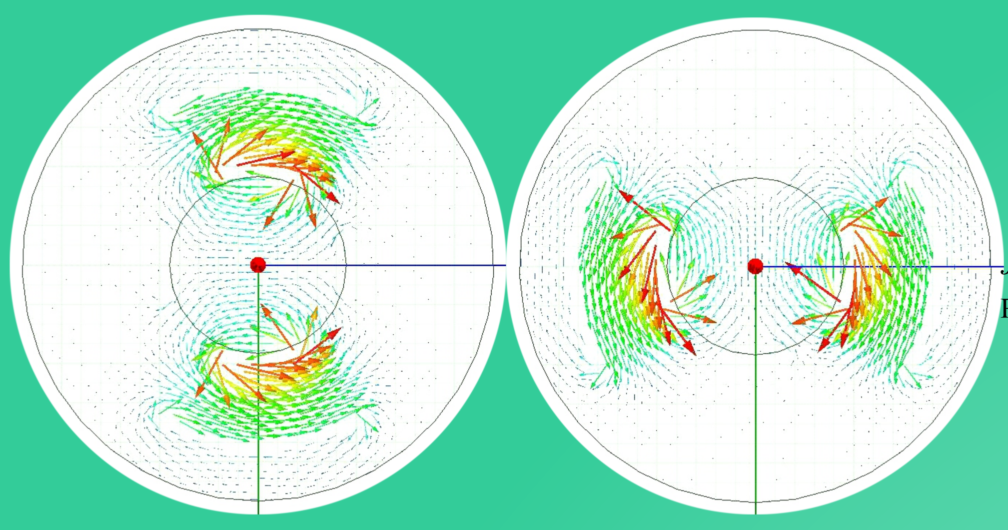


Fig. 1: H field vector corresponding to the Y and X Dipole field configuration

The resonance frequency and z component of the mnoth TM mode Electric field for a given displacement is given as

$$E_{mn0} = C_{mn0} J_m (a_{mn} \Delta x / R_{res}).\cos(m\phi).e^{-j\omega z}$$

$$f_{mn0} = c_o a_{mn} / 2\pi R_{res}$$

J_m is the mth order Bessel, a_{mn} is the nth root of it, C_{mno} is the amplitude, R_{res} is the radius of the capacitive gap

The R/Q of the TM110 mode at the position of maximum Electric field is

$$\left(\frac{R}{Q}\right)_{110} = \frac{2.Z_0.l.(J_1^{\max})^2.T_{tr}^2}{\pi.R_{res}.J_o^2(a_{11}).a_{11}} \approx 130.73.\frac{l}{R_{res}}.T_{tr}^2$$

Z_o is the free-space impedance of 377Ω,
l is the length of the gap, T_{tr} is the transit-time factor.

The induced voltage is then given by

$$V_{110}^{in}(\Delta x) = \omega.q.\left(\frac{R}{Q}\right)_{110} \left\langle \frac{a_{11}.\Delta x}{2.J_1^{\max}.R_{res}} \right\rangle = \frac{\Delta x.q.l.T_{tr}^2.2474}{R_{res}^3}\left[\frac{Vm}{pC}\right]$$

q is the bunch charge, ω is the angular resonance frequency

the pickup voltage terminated with 50 Ohms is then given by

$$V_{110}^{out}(\Delta x) = \left(\frac{R}{Q}\right)_{110} .\omega.q.\sqrt{\frac{50\Omega}{Q_L}} B_c \frac{\beta}{1+\beta}$$

B_c is the beam coupling coefficient in angle bracket
β is the pickup coupling coefficient as Q_o / Q_L

Dipole mode amplitude linearly proportional to beam position and zero for centered beam. The information is direct and no need of subtraction as in capacitive probes. For detection of single bunches, induced voltage should be high. Optimize shunt impedance by reentrant design.
Fields and signals of TM110 mode(1,2):

Simulation Results and Comparison with Monopole Cavity systems

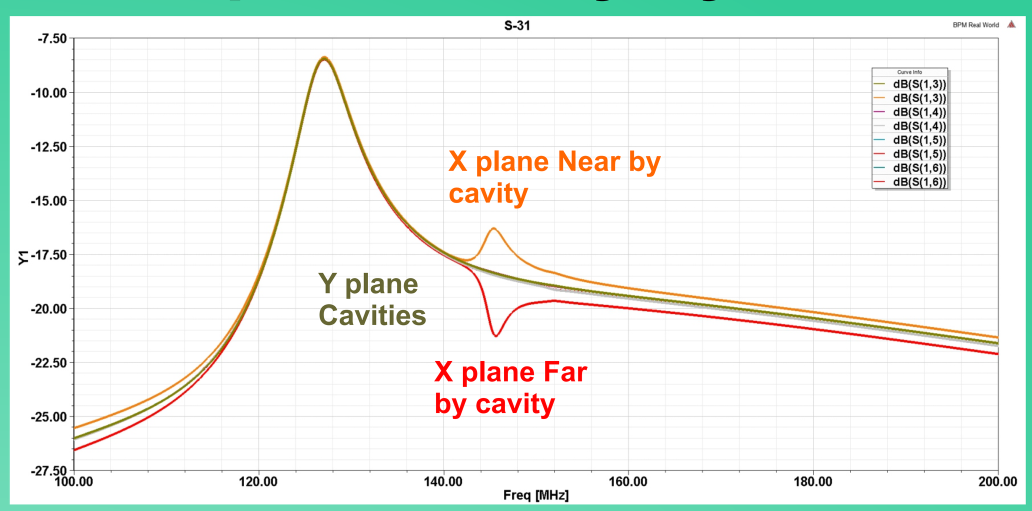


Fig. 2: Simulation S-parameter between beam entrance port and pickup port for 2mm offset

Position Offset (mm)	Nearby Pickup (nV)	Far by Pickup (nV)	Delta Signal (nV)
0	38.75	38.75	0
2	39.67	38.43	1.24
5	40.19	37.67	2.52
10	41.61	36.36	5.25

Tab. 1: Monopole Cavity

Position Offset (mm)	Near Field Cavity Signal (nV)
1	17.64
2.5	21.28
5	28.09
10	38.77

Tab. 2: Dipole Cavity

Dipole mode should be farther away from the Monopole mode to prevent mode contamination. Mode contamination can be prevented by waveguide coupling. Not suitable for us though as the design will be enourmous.

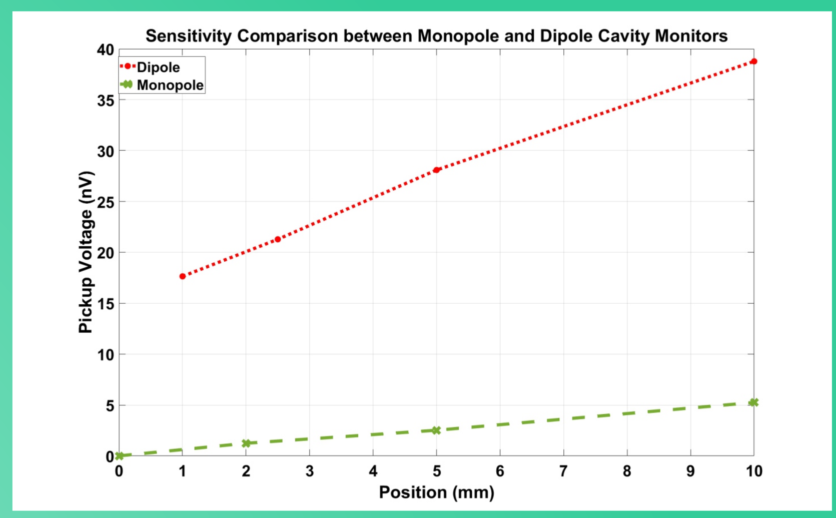


Fig. 3: Monopole cavity Vs Dipole cavity sensitivity

3D View of the Prototype

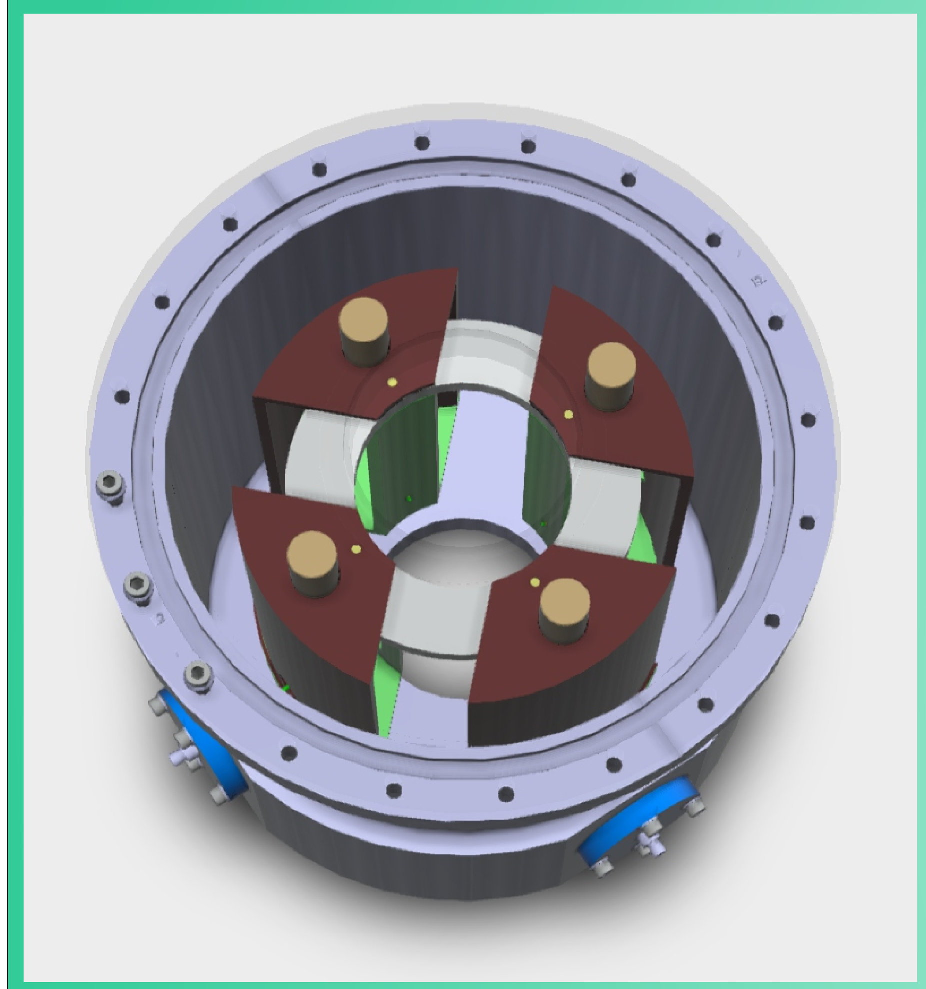
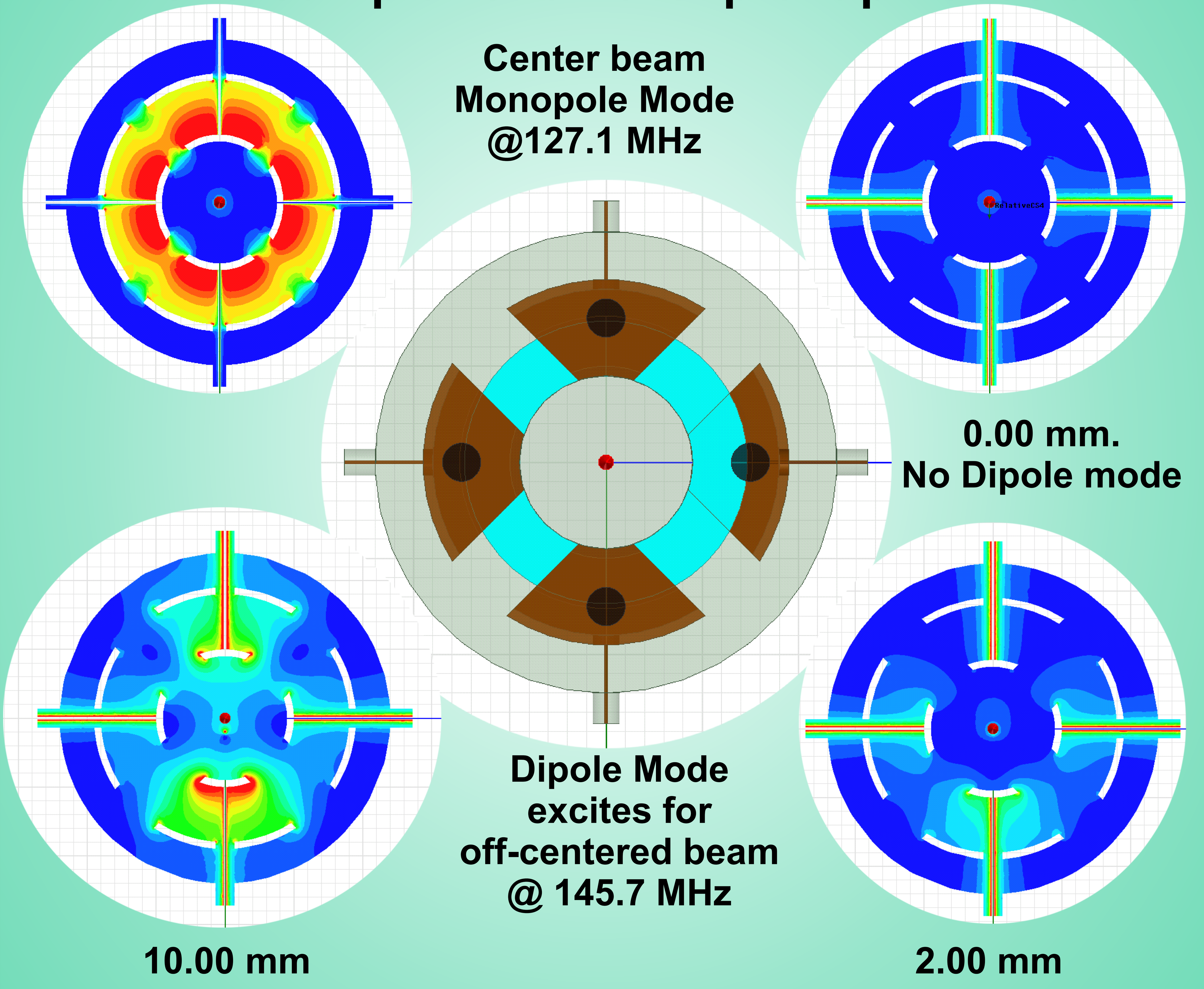


Fig. 4: 3D view of the position cavity

- Alumina Ceramic
- Floating Aluminum Cavities
- PEEK Ceramic as support
- Magnetic coupling through loop

two measurement ports per plane:
- for symmetry
- for common-mode rejection

H Field plots of the BPM prototype taken at the transversal plane of the pickup locations



Test bench Results

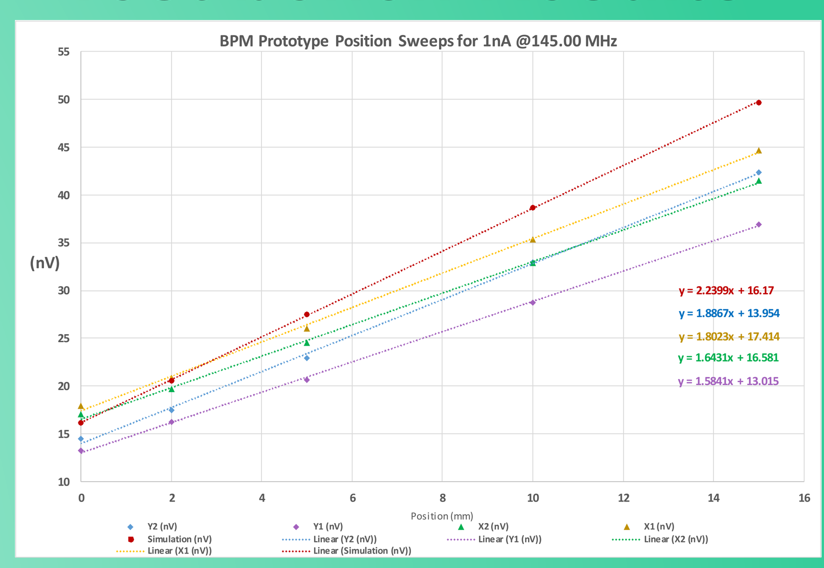


Fig. 5: Comparison between Simulation and Individual pickups for position offsets in +ve direction.

Difference between individual cavities due to precision and assembly errors.

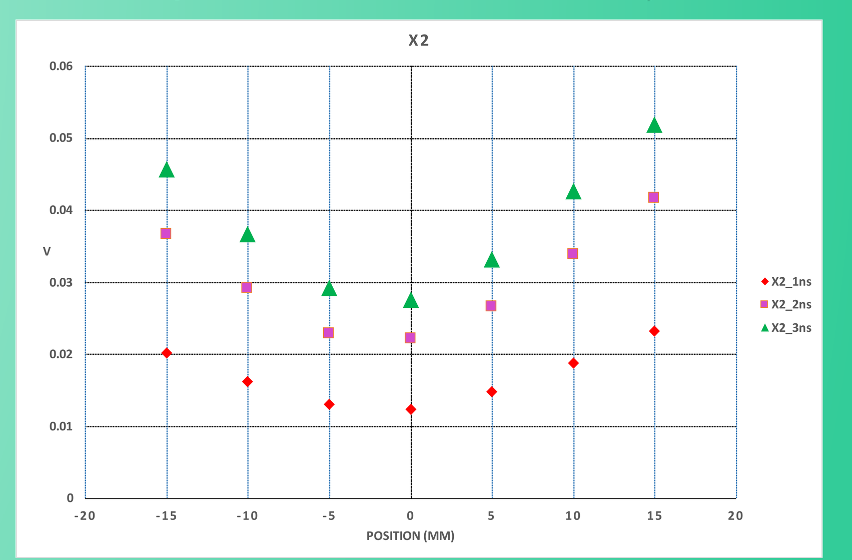
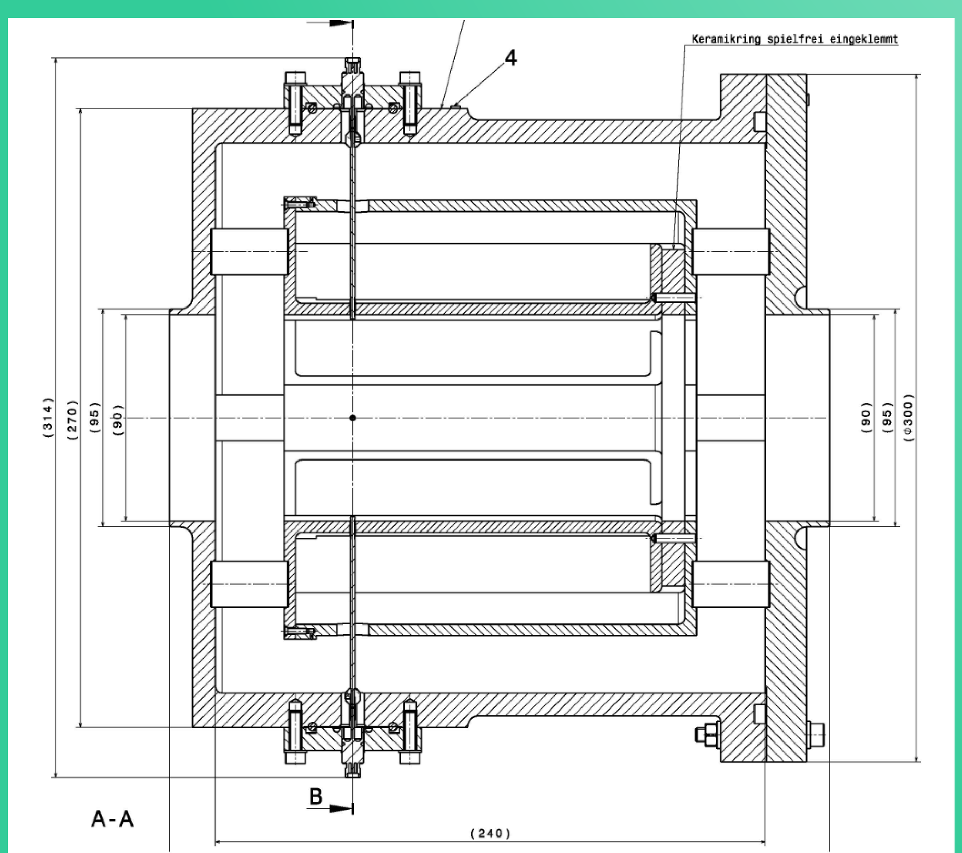
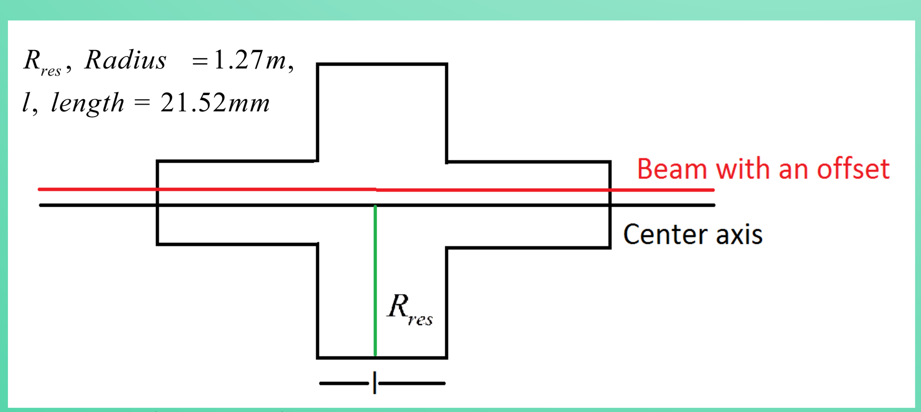


Fig. 6: Pickup response for pulse @72.85 MHz of different pulse widths. All plots for the same pulse height.

- Dipole cavity BPMs provide the amount of displacement as it is proportional to charge and offset.
- Monopole cavity at same resonance frequency necessary to subtract the charge dependency(3).
- Also, can be used to determine the sign of displacement by placing it in the beam-line certain distance ahead(3).
- Blessing in disguise is the Monopole mode contamination that results in different signal levels for the same offset.
- Positional map can be used to determine sign and displacement

Comparison with Pillbox Equivalent for 2 mm offset





$$V_{110}^{in}(\Delta x) = \omega.q.\left(\frac{R}{Q}\right)_{110} \left\langle \frac{a_{11}.\Delta x}{2.J_1^{\max}.R_{res}} \right\rangle = \frac{\Delta x.q.l.T_{tr}^2.2474}{R_{res}^3}\left[\frac{Vm}{pC}\right] = 92.30nV \text{ for Dielectric filled}$$

$$V_{110}^{in}(\Delta x) = \omega.q.\left(\frac{R}{Q}\right)_{110} \left\langle \frac{a_{11}.\Delta x}{2.J_1^{\max}.R_{res}} \right\rangle = \frac{\Delta x.q.l.T_{tr}^2.2474}{R_{res}^3}\left[\frac{Vm}{pC}\right] = 0.071nV \text{ for Pillbox Equivalent}$$

$$V_{110}^{out}(\Delta x) = \left(\frac{R}{Q}\right)_{110} .\omega.q.\sqrt{\frac{50\Omega}{Q_L}} B_c \frac{\beta}{1+\beta} = 25nV(approx.) \text{ for Dielectric filled}$$

$$V_{110}^{out}(\Delta x) = \left(\frac{R}{Q}\right)_{110} .\omega.q.\sqrt{\frac{50\Omega}{Q_L}} B_c \frac{\beta}{1+\beta} = 0.047nV(approx.) \text{ for Pillbox Equivalent}$$

can we optimize??

- minimize cross-talk by designing two individual cavities. (1 for x and 1 for y)
- prevent mode contamination by design optimization.
- compromise between strong or weak coupling

Acknowledgement

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References

1. Ronald Lorenz, Cavity Beam Position Monitors
2. F. J. Cullinan et al, Long bunch trains measured using a prototype cavity BPM for the Compact Linear Collider
3. Jian Chen et al, Study of the crosstalk evaluation for Cavity BPM

Conclusion

- Minimum signal we expect to measure is 10 nA.
- For lower intensities, we need longer signal integration time.
- Effect of beam angle on resolution needs to be studied.
- Cavity symmetry is an important condition as every asymmetry can influence the cross-talk and is thus seen on individual pickup ports in Fig. 6

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Contact: sudharsan.srinivasan@psi.ch