Beam Position Monitors

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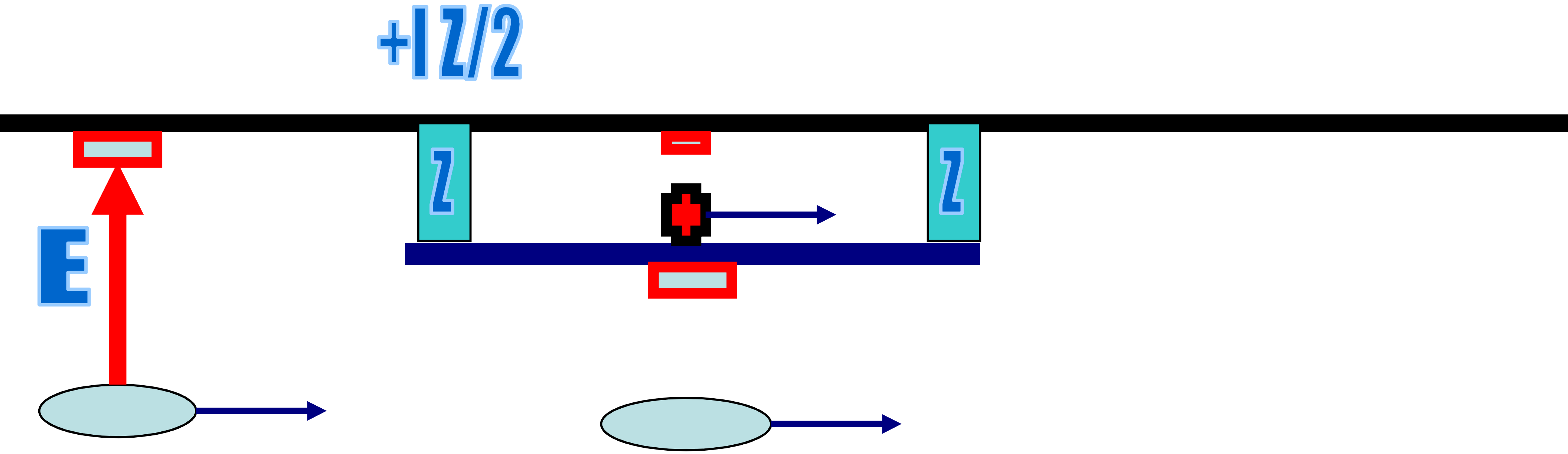
BPM Resolution Requirements

- Resolution requirements for averaged beam vertical position CW vs. CCW:
- $\pm 10\mu m$ (10^6 Hz) per BPM.
- $\pm 10nm$ (1Hz) per BPM.
- $\pm 10pm$ (10^{-6} Hz) per BPM.
- With 64 BPMs for 10^7s, $\pm 1pm$.
- The above is for magnetic focusing.
- For electric focusing, we need $10\times$ better.

Strip-line BPM Cartoon for Relativistic Bunch for Non-experts



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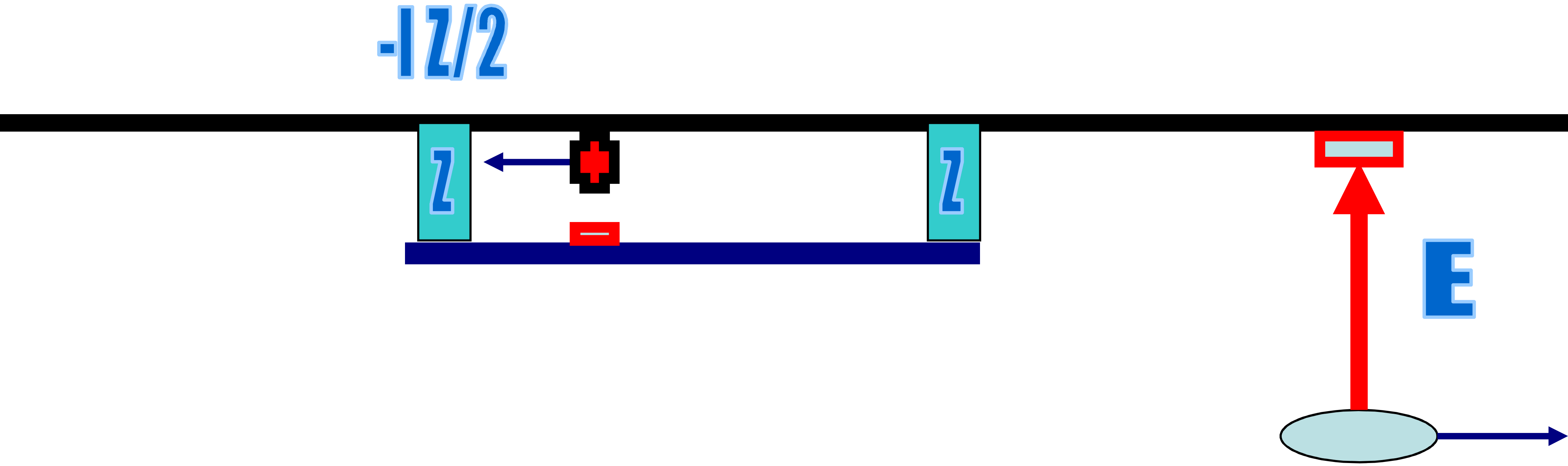


Strip-line BPM resolution from Peter Cameron's June C-AD Review Talk

- The average power available in the signals from each of the four lines is about -25dBm at the feedthrus. Conservatively estimating losses of 28dB, the signal power available after digitization will be approximately -53dBm.
- The resulting signal-to-noise ratio, given the thermal noise floor of -173dBm/Hz, will be ~120dB in a 1 Hz bandwidth. With the 10mm half aperture, the resolution in the 1 Hz bandwidth will be 10nm.
- BPM electronics that will provide this measurement resolution are commercially available.

Issues

- Strip-line BPMs have the resolution, but
- Beam impedance $Re(Z_L) \approx 25\Omega$.
- $64 \times 25\Omega = 2.4K\Omega$.
- This is a lot compared to other stuff, like the E plates, etc., and is a spin systematic.
- Requirement for the whole ring is $<10K\Omega$.
- Also, strip-line systematic errors are challenging at the 1pm level: $x = V_R - V_L$

Resonant Cavity BPMs

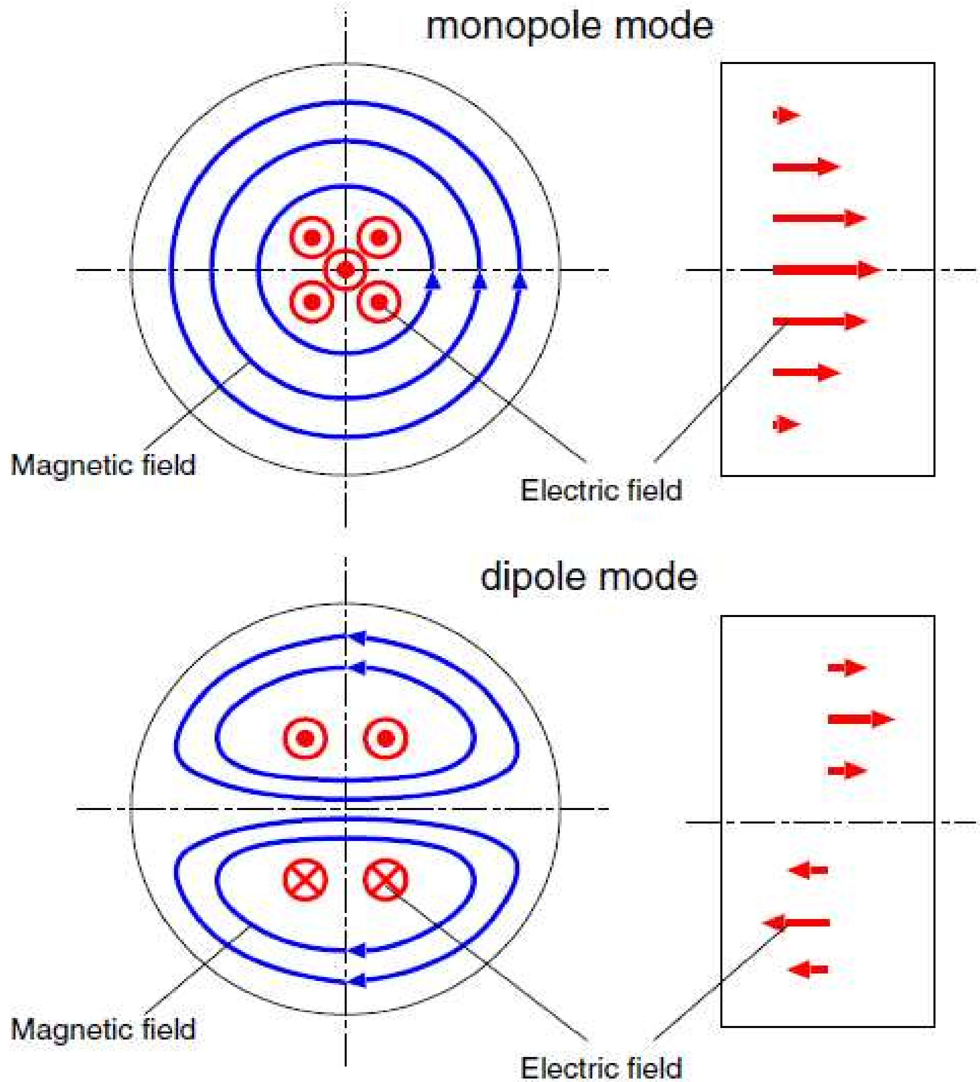


FIG. 1. (Color) First two eigenmodes, TM_{010} (monopole mode) and TM_{110} (dipole mode), of a cylindrical cavity.

Dipole TM_{110} Mode

- First order: $(Iy)_{CW}$ - $(Iy)_{CCW}$
- Monopole mode TM_{010} measures $(I_{CW} - I_{CCW})$. Need several of these.
- If $y_{CW} = y_{CCW} = y$, then
- Second order: $(I_{CW} - I_{CCW})\, y$.
- With only one beam measure y, and zero with feedback, i.e. center beam in cavity.
- S/N is better than stripline BPM because cavity has Q $\approx 5\times10^3$, i.e. signal is at one f with narrow δf.

Cavity Beam Impedance

- Re (Z_L) is zero to first order in monopole mode,
- i.e., zero if (I_{CW} -I_{CCW}) = 0.
- Zero to second order in dipole mode,
- i.e., zero if (I_{CW} - I_{CCW}) y = 0.
- Re(Z_L) <<10KΩ.

Dipole Mode Cavity Design

- Working with Mike Blaskiewicz et al.
- Preliminary:
- 2.5GHz TM_{110} mode.
- $R/Q = 18\Omega$ for 1cm offset.
- $Q \approx 5000$.
- 12cm(V)×12.8cm(H)×5cm(L).
- RF is 0.1GHz with 2.5GHz modulation.

Two Cells using dipole mode

f = 2.5 GHz

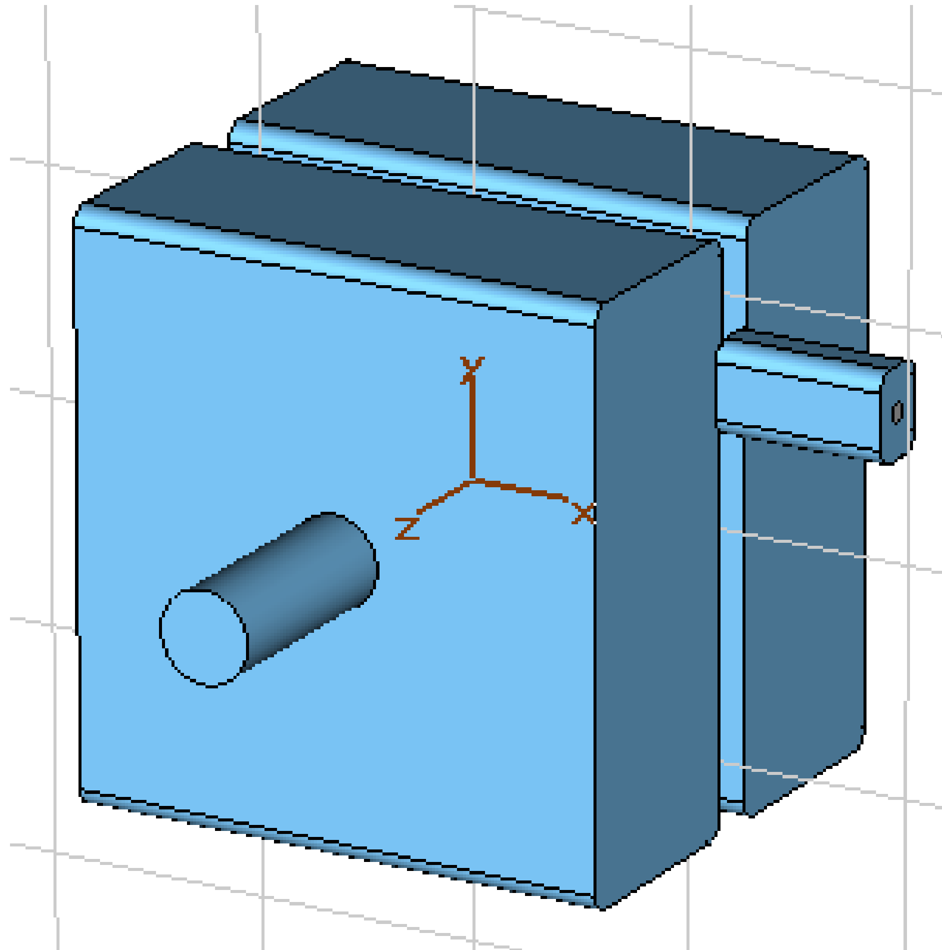
R/Q = 18Ω for y=1cm

Q = 15,000 for Cu

Take Q=5000

$$D(t) = I_{cw}(t)y_{cw}(t) - I_{ccw}(t)y_{ccw}(t)$$

Drive at exact multiple of freq



Are We the Only People Trying for Nanometer Precision?

- Y. Inoue et al., Phys. Rev. ST – Acc. and Beams 11, 062801 (2008).
- ILC R&D at KEK ATF.
- Achieved ±9nm precision over a dynamic range of 5μm with 6GHZ Dipole Resonant Cavity for each 7×10^9 electron bunch. This is best resolution achieved yet. Their goal is 1nm.
- Our requirement: ±10nm for δy for 10^6 turns of 2×10^{10} $\beta=0.6$ protons.
- Light Source 2 also needs nm precision.
- We benefit from their efforts, even though we can't just use their designs.

Sensitivity/Systematics

- Add $B_R\sin(\omega_{BR}t)$ and $E_v\sin(\omega_{EV}t)$
- $\approx$1Hz frequency.
- This moves the CW/CCW beams in the same or opposite directions.
- Set to $\approx$10nm during setup, for example.
- Set to $\approx$10pm during physics running, for example.
- See effect in both the BPM and spin signals.

Peter’s Level of Effort Estimate

- 0.5FTE during detailed design,
- 1 FTE during construction and commissioning.
- Total $0.45M.
- Peter didn’t give us plan, milestones, etc., before he had heart attack last month.
- Low technical risk for magnetic focusing,
- Higher technical risk for electric focusing.