Conceptual Design Of Elliptical Cavity Beam Position Monitors For Heavy Ion Storage Rings

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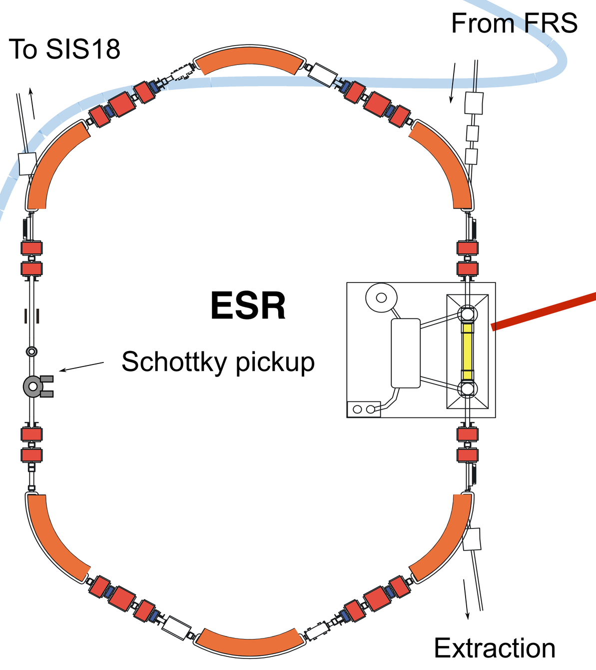
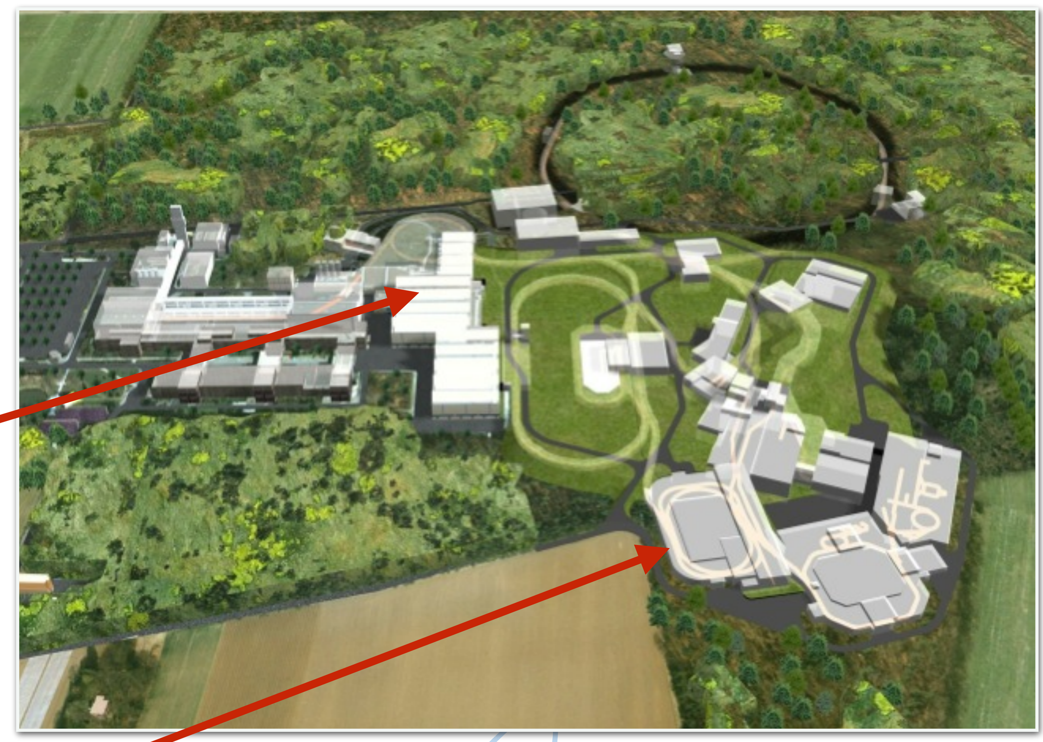
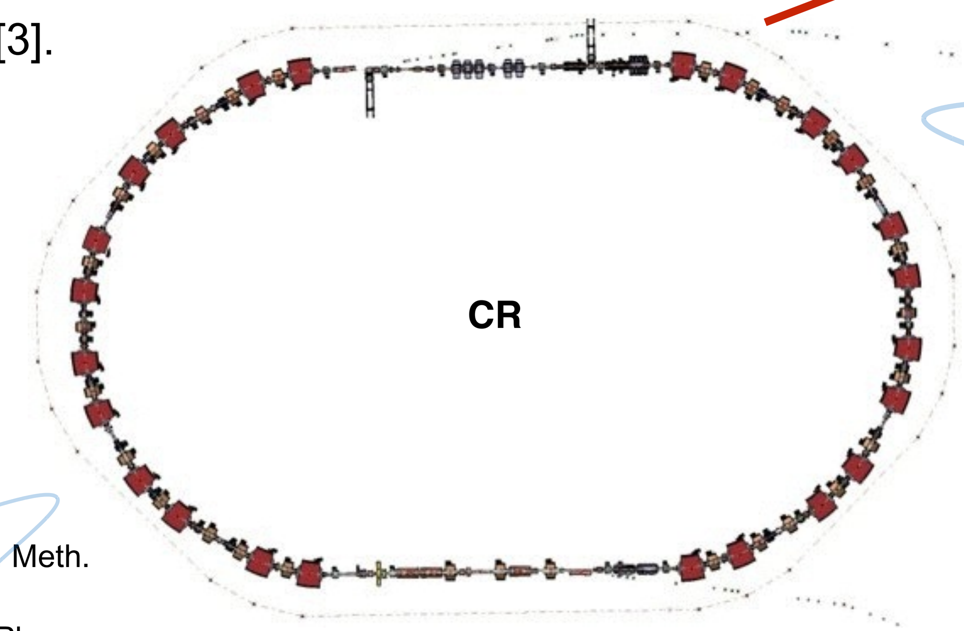


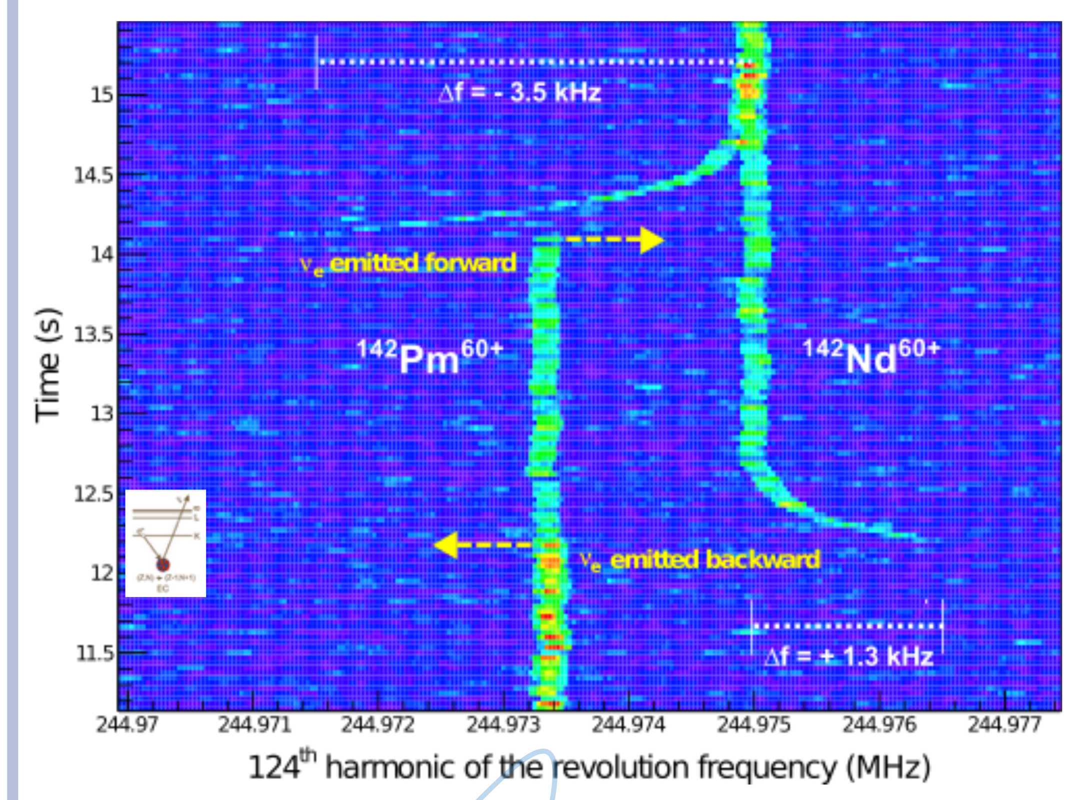


Motivation

Over 50 years in the history of accelerator physics, RF cavities have been used as beam position and intensity monitors. Their structure has been extensively discussed across numerous papers reporting their successful operation.

The application of RF cavities as experimental pickups has recently been extended to include radioactive ion beam (RIB) facilities and heavy ion storage rings. These pickups allow for very sensitive, accurate, and quick characterization of ion beams and turn out to be indispensable tools in nuclear as well as atomic physics experiments. A notable example is the resonant pickup in the ESR at GSI Darmstadt [1] where single ion detection was achieved for lifetime measurements of radioactive nuclides [2]. A similar cavity pickup was installed in CSRe in IMP Lanzhou [3].





Decay of two 142Pm nuclei [2]

References

[1] F. Nolden et. al., Nucl. Inst. Meth. A, 659 (2011) 1 p.69
[2] P. Kienle, F. Bosch et. al., Phys. Lett. B 726 (2013) 4–5, p.638
[3] J. X. Wu et. al., Nucl. Inst. Meth. B 317 (2013) p.623

The Schottky Process

$$i_{\parallel}(t) = Ze\sum_{j=1}^{N}\sum_{m=-\infty}^{\infty}\delta(t - mT_j + \theta_j^0 - \theta_{PU}) = \cdots$$

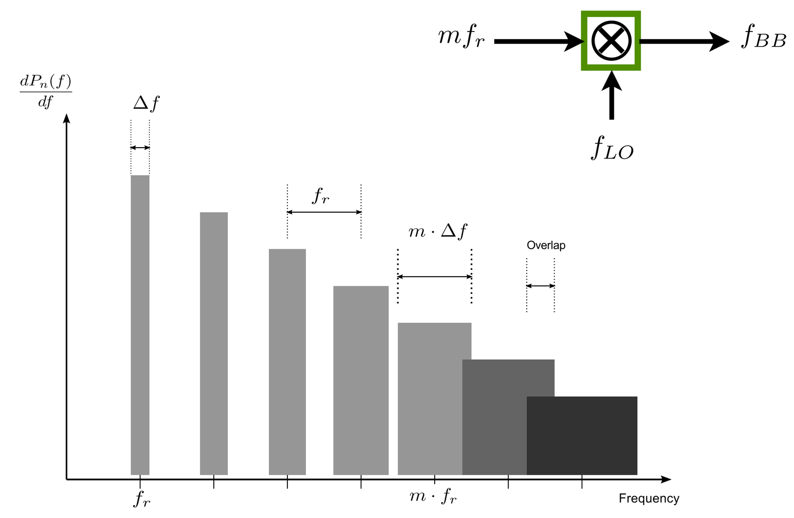
$$= Zef_rN + 2Zef_r\sum_{j=1}^{N}\sum_{m=1}^{\infty}\cos(m\omega_j t + m\Theta_j)$$

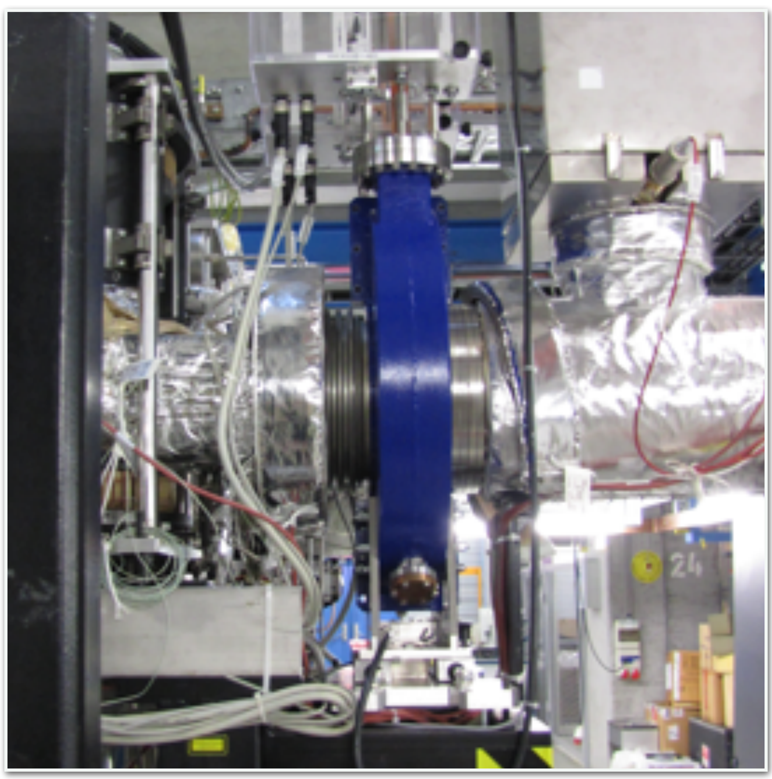
$$= I_B + \delta i_{\parallel}(t)$$

$$r_{ii}(t+\tau, t) = \cdots$$

$$= (Ze)^2 f_r^2 N^2 + 2(Ze)^2 f_r^2 \sum_{j=1}^{N}\sum_{m=1}^{\infty}\cos(m\omega_j\tau)$$

$$\langle \delta i_{\parallel}^2\rangle = 2(Ze)^2 f_r^2 N = 2Zef_rI_{beam}$$





The ESR resonant pickup

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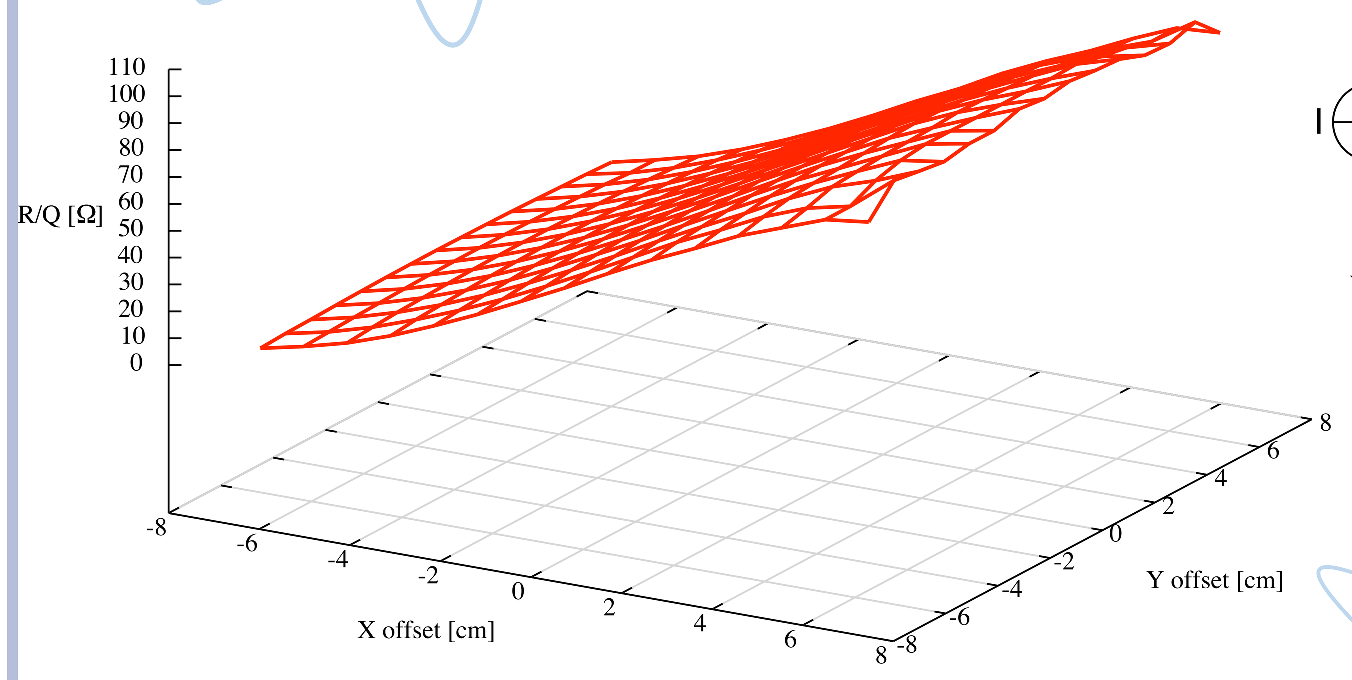
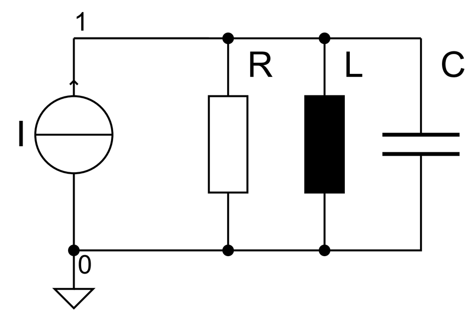
M.S.S. acknowledges partial support by the Alliance Program of the Helmholtz Association (HA216/EMMI). X.C. acknowledges support of the European Union under contract number PITN-GA-2011-289485. The authors thank I. Schurig and S. A. Litvinov for their help on the CR storage ring.



Simulated R/Q map



RLC circuit model

Modal analysis

$$P_{diss,\nu} = \frac{U_\nu^2}{R_{sh,\nu}} = \frac{1}{2}\frac{U_\nu^2}{R_\nu}$$ Lost power each mode

$$Q_\nu = \frac{\omega_{0\nu}W_\nu}{P_{diss,\nu}} \qquad \delta\omega_{0\nu} = \left(\frac{\omega}{\omega_{0\nu}} - \frac{\omega_{0\nu}}{\omega}\right)$$

$$Z(\omega) = \sum_\nu \frac{R_\nu}{1 + iQ_\nu(\delta\omega_{0\nu})}$$ Impedance

$$U = \hat{U}\Lambda(\beta)$$ Induced voltage

$$\hat{U} = \int_{-d/2}^{d/2} E_z\, dz$$ for d → 0 and β → 1

$$\Lambda(\beta) = \frac{\int_{-d/2}^{d/2} E_z \cos\left(\frac{2\pi f}{\beta c}z\right) dz}{\int_{-d/2}^{d/2} E_z\, dz}$$ Transit time factor

$$\langle P_{out}\rangle|_{mf_r} = \langle P_{diss}\rangle|_{mf_r} = (Ze)^2 f_r^2\, \widehat{R_{sh,\nu}}\, \Lambda(\beta)^2$$

Single particle power at critical coupling

$$\left(\frac{R_{sh}}{Q}\right)_\nu = \left(\frac{\widehat{R_{sh}}}{Q}\right)_\nu \Lambda_\nu(\beta)^2$$ The characteristic impedance

Mode of operation

Particle identification:
- Schottky noise analysis.

Power Spectral density:
- Schottky "bands"
- Mixed down signal

At higher harmonics:
- Given Δf, shorter Δt
- Given Δt, higher Δf resolution

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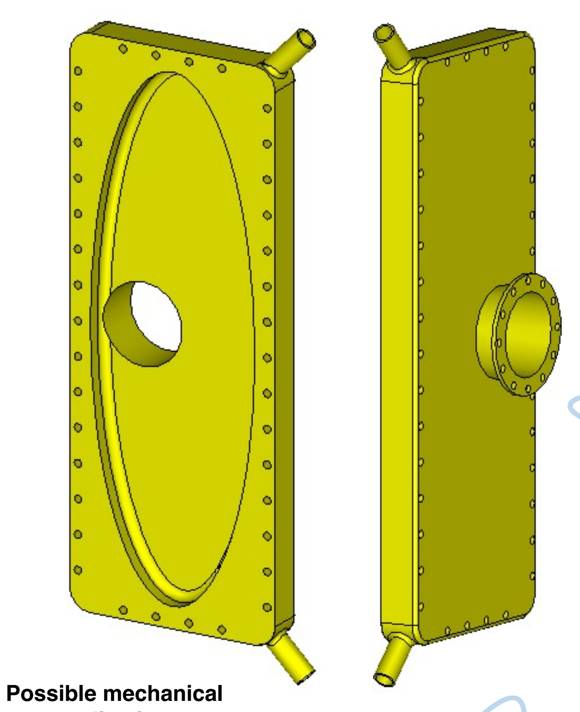
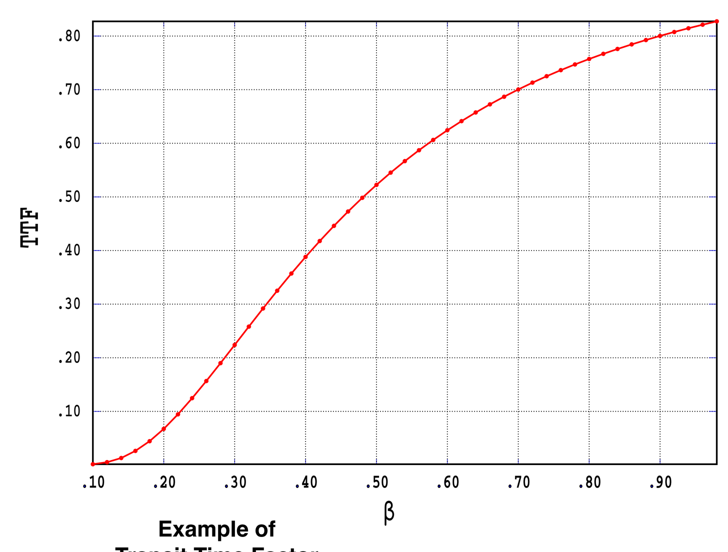


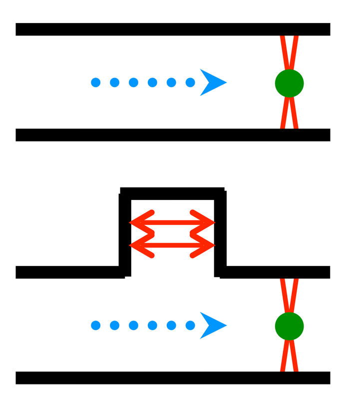
Possible mechanical realisation

The R/Q map

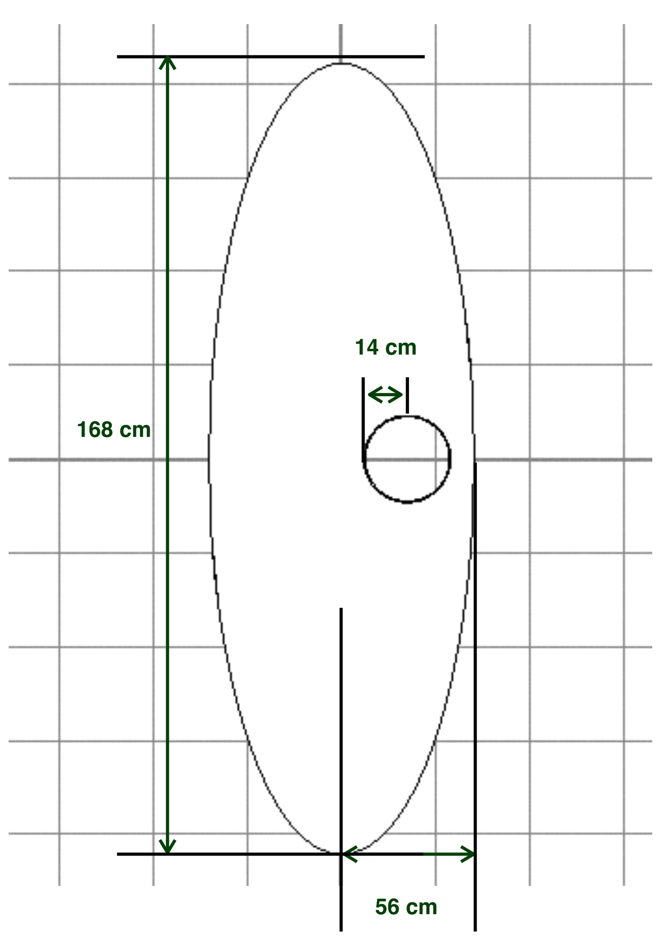
Characteristic impedance:
- Integrated quantity along the z axis
- Depends on TTF and transversal position
- 3D plot shows the R/Q map
- Flat for longitudinal detector
- Tilted plane style for transversal sensitivity



Example of Transit Time Factor



Particles lose energy to trapped modes

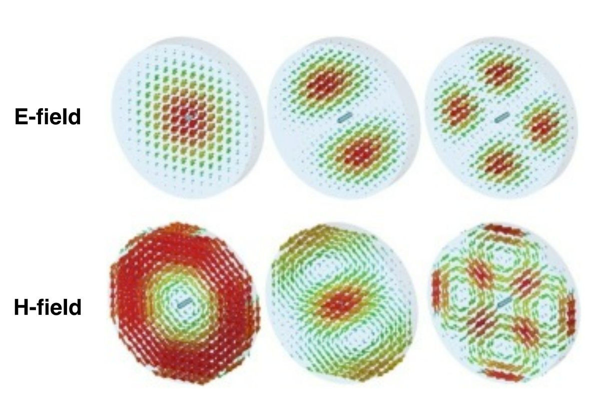


Simulation model

GSI and FAIR

GSI Darmstadt:
- Full name "GSI Helmholtzzentrum für Schwerionenforschung GmbH"
- Large scale accelerator facility since 1972
- Accelerates "everything" !
- UNILAC, SIS18 and ESR

FAIR:
- Future extension to GSI
- Many experiments and international collaborations
- APPA, CBM, NUSTAR and PANDA



First significant modes of a shallow pillbox

Generalization to elliptical geometry

Cavity with elliptical cross section:
- position sensitive R/Q map
- beam pipe off center along the short axis
- good for large beam pipe apertures

Toy model:
- Bench top circular model has been produced
- Fully automated bead pull measurement system