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Cavity Beam Position Monitor Development for the ILC Main Linac

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Introduction

ILC Project:
- Next large particle accelerator for high energy physics
- Two ≈ 10 km long superconducting LINACS
- Collide 2×250 GeV electrons and positrons beams at the interaction point (IP)
- Potential Higgs Factory

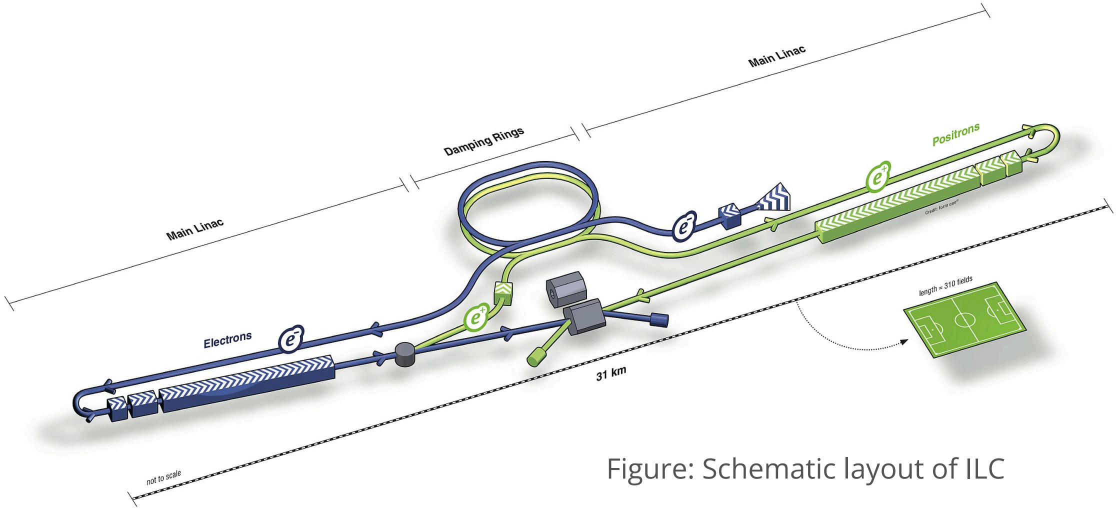


Figure: Schematic layout of ILC

Beam diagnosis:
Measure and evaluate the properties and behavior of the beam (current, position, momentum…)

<u>ILC's demands</u>:
Achieve high luminosity at the IP

To guide and stabilize the beam, we require high-resolution **beam position monitors (BPM)** with spacial resolution < 1 µm

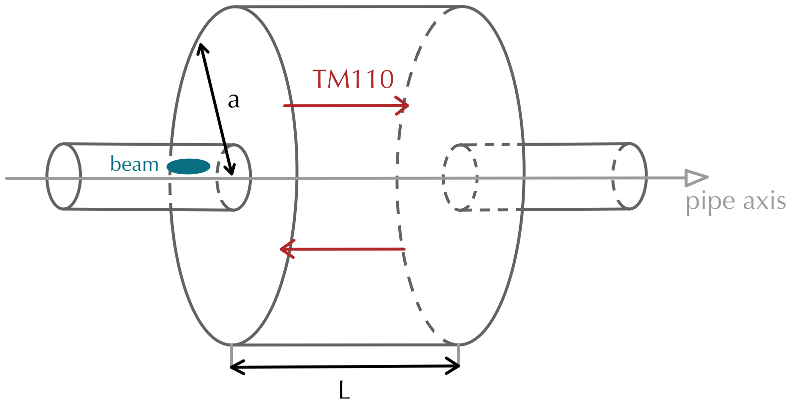


Figure: pill-box cavity BPM scheme

M. Wendt, Cold Cavity BPM R&D for the ILC, FermiLab
M. Wendt, Overview of recent trends and developments for BPM systems, FermiLab
E. Mamad, Particle Physics, Cosmology and Accelerators Lectures FYSC24, Lund University

Introduction

Development of a **re-entrant cBPM for the ILC Main Linac**

Project in collaboration with KEK and CIEMAT: development of the cryostat for a BPM and a super-conducting quadrupole

Mechanical requirements:

- Mechanical fit of the BPM and the SC quadrupole magnet
- Cryogenic and UV conditions have to be met

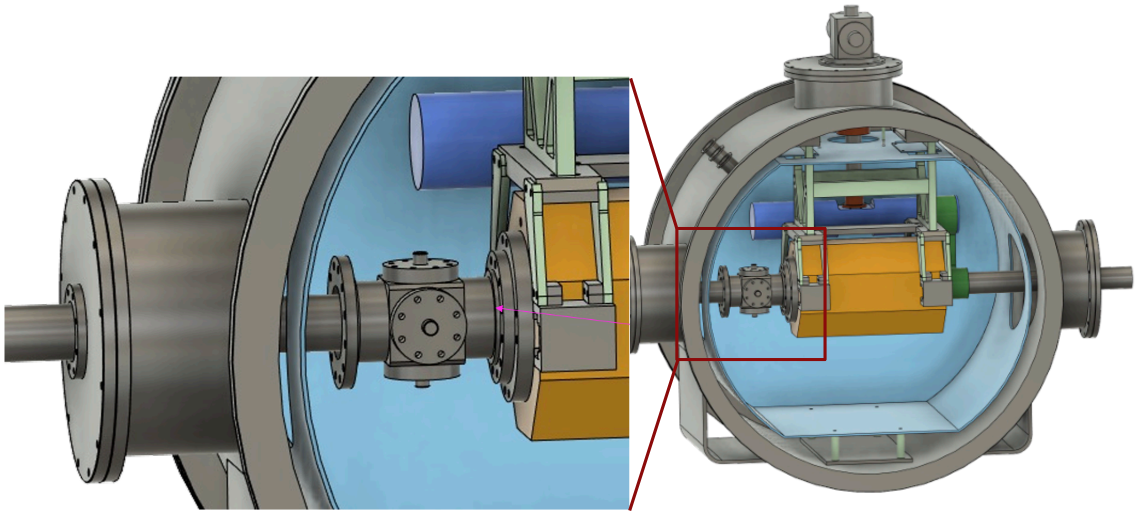


Figure: Cryostat accommodating BPM and SC quadrupole

Measurement requirements:

- Spatial resolution < 1 μm
- Temporal resolution < 369 ns

The designed BPM will initially be tested at ATF (Accelerator Test Facility) and at STF (Superconducting RF Test Facility) at KEK where:

Beam parameters	ATF2	STF	ILC
Beam energy (GeV)	1,3	0,5	250
Bunch charge (nC)	1,6	0,6	3,2
Bunch spacing (ns)	150	6,15	369
Bunch length (mm)	7	3	0,3

M. Wendt, Cold Cavity BPM R&D for the ILC, FermiLab
Tomohiro Yamada, Test cryostat for BPM-SCQ, KEK

I. Resonant cavity Beam Position Monitor

A) Pillbox cavity BPM

➔ **Working principle**

Cavity BPMs are resonant systems crossed by the beam pipe. EM modes are induced on the cavity by the beam and their amplitude depends on the beam position.

Two modes in particular are of interest:

Monopole mode TM_{010} Dipole mode TM_{110}

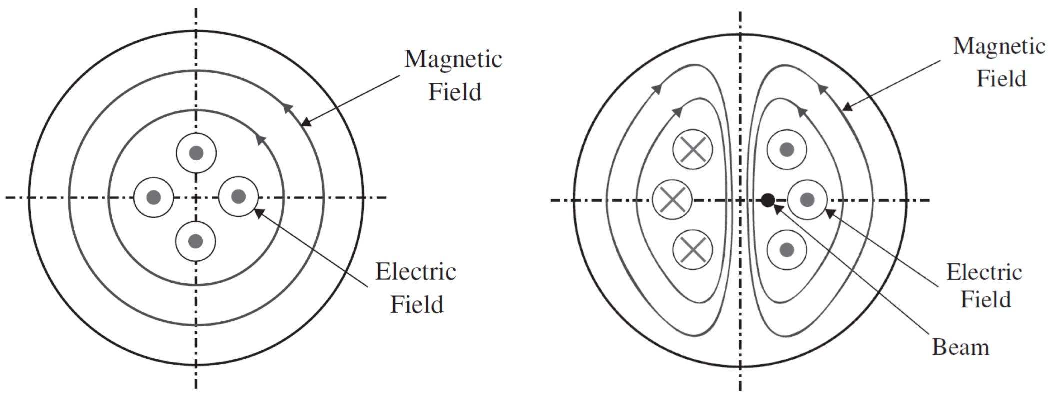


Figure: Cross-sectional view of the TM modes in a pillbox cavity

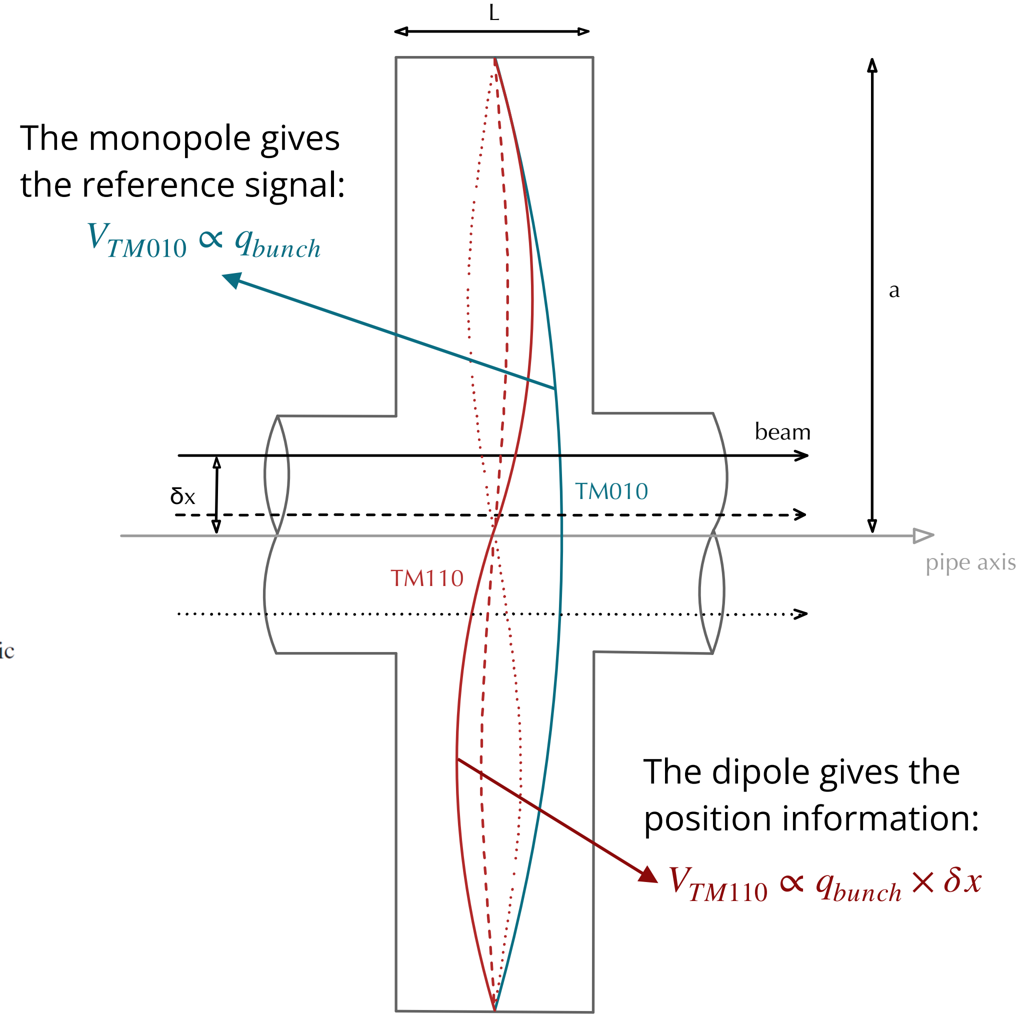
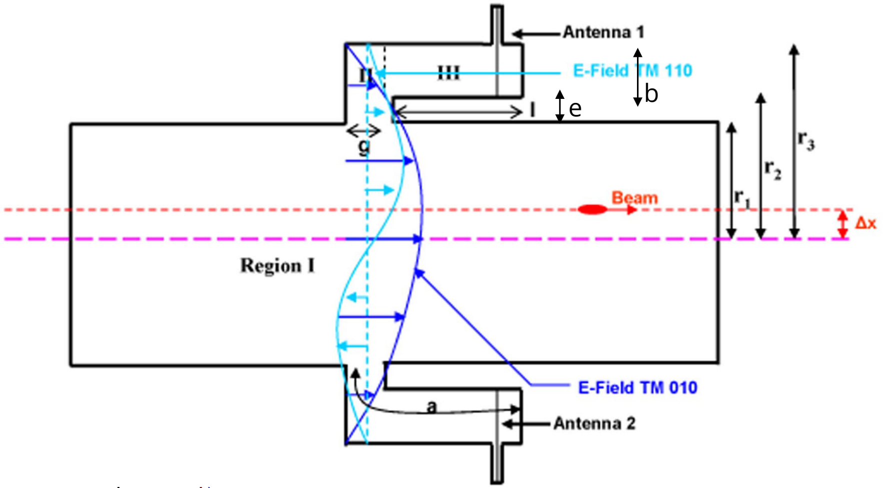


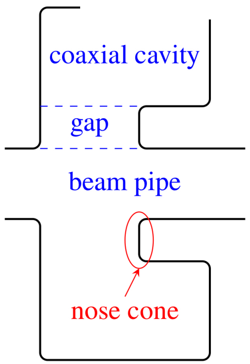
Figure: Representation of the E-fields induced in the cavity

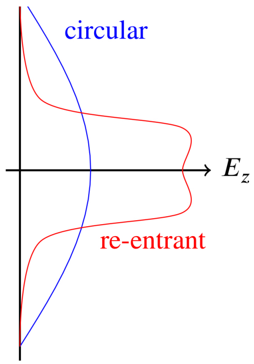
I. Resonant cavity Beam Position Monitor

B) Re-entrant cavity BPM: a model from C. Simone - Saclay

- **Geometry and modes:**

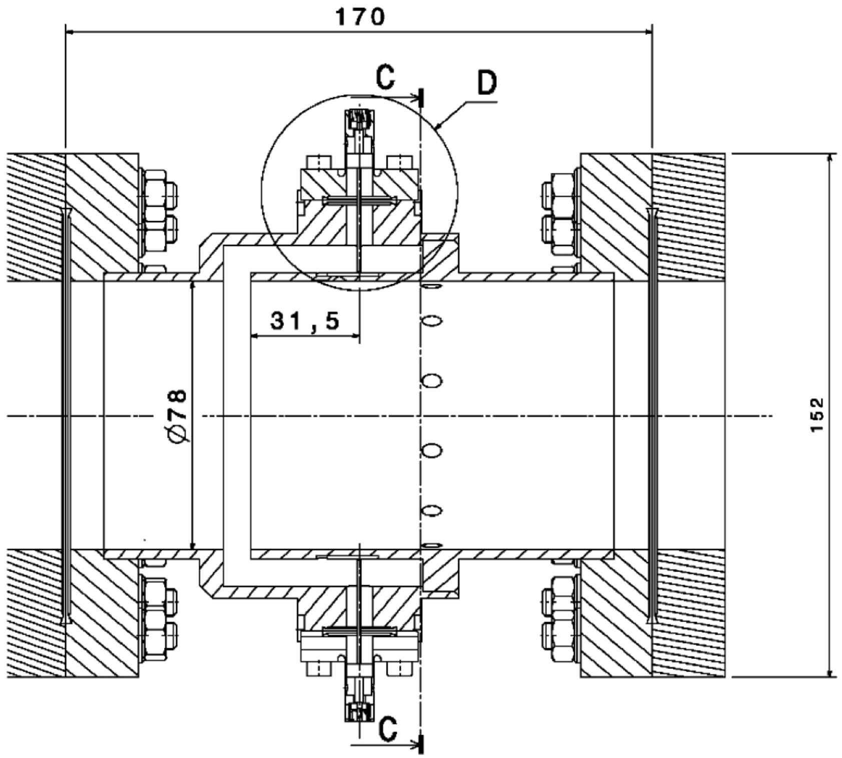






E field is concentrated on the *nose cone*
This structure increases the sensitivity

Saclay: Simone - Re-entrant cavity BPM for X-FEL



Resonance frequencies: $f_{010} = 1.25$ GHz and $f_{110} = 1.72$ GHz

Spacial resolution: 5 µm and temporal resolution τ = 10 ns

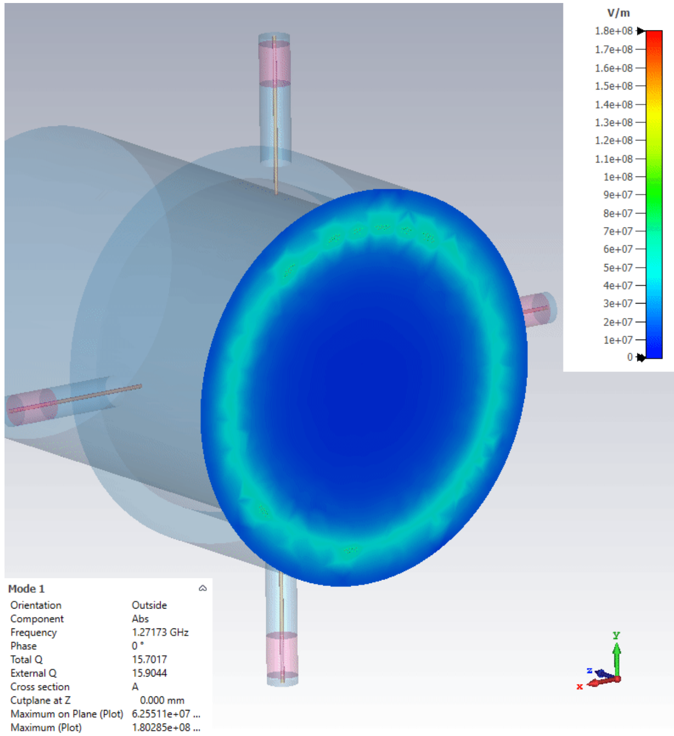
R. Lorenz, Cavity Beam Position Monitors, DESY
M. Viti, Resonant Cavities as Beam Position Monitor, DESY

I. Resonant Cavity BPM

B) Re-entrant cavity BPM: a model from C. Simone - Saclay

Monopole mode TM_{010}

$f_{010} = 1.25$ GHz

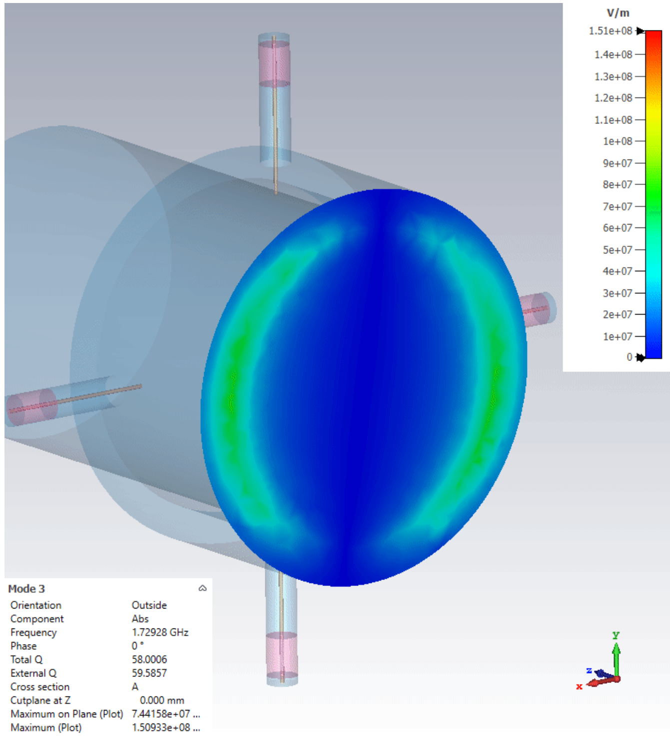


Yields reference signal

Dipole mode TM_{110}

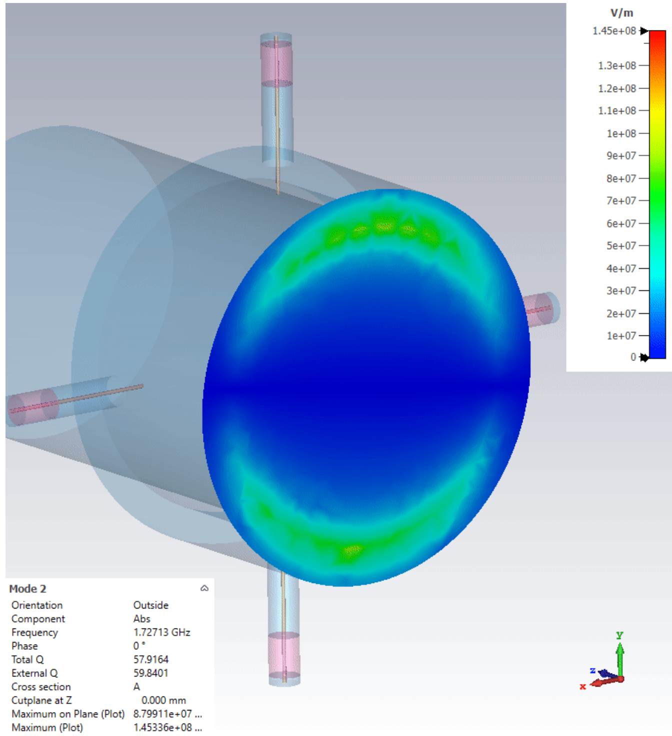
$f_{010} = 1.72$ GHz

degeneration on x



Yields position signal on x

degeneration on y

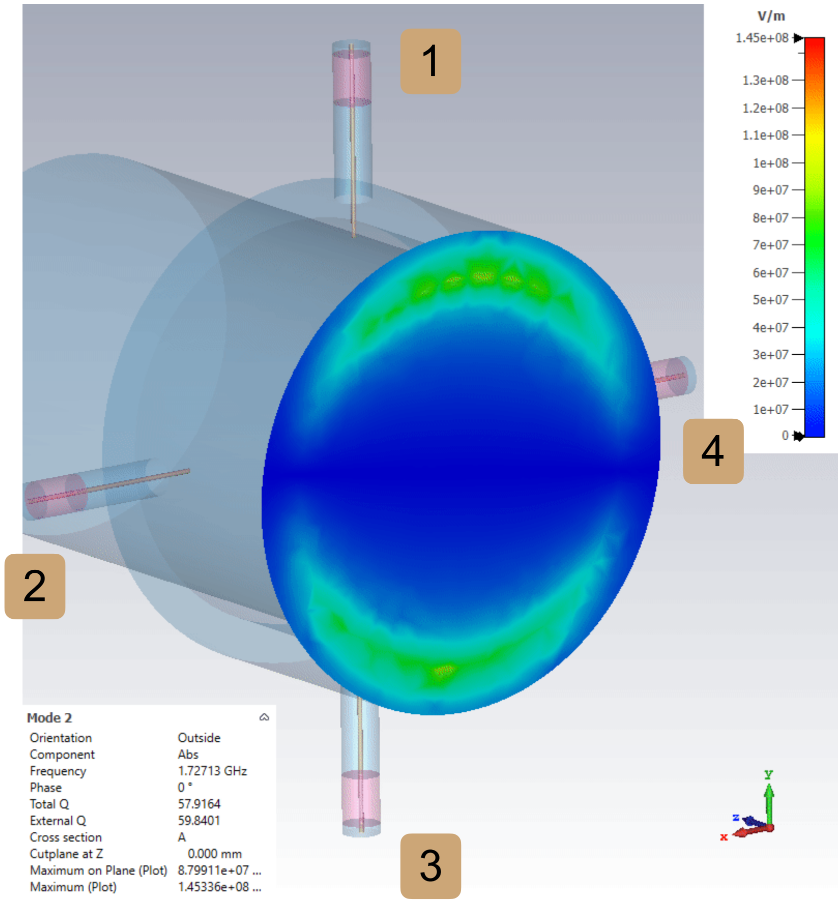


Yields position signal on y

R. Lorenz, Cavity Beam Position Monitors, DESY
M. Viti, Resonant Cavities as Beam Position Monitor, DESY

I. Resonant cavity Beam Position Monitor

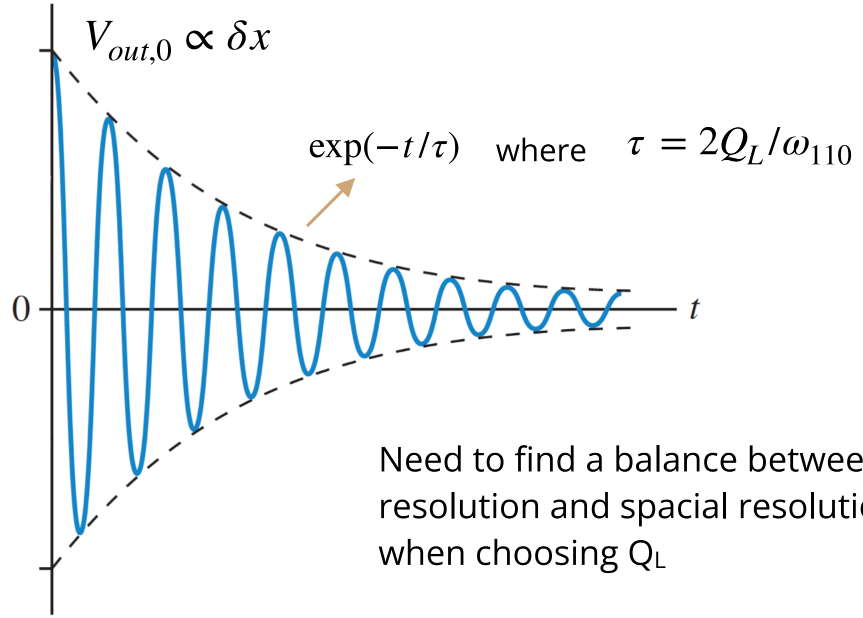
C) Signal extraction



➔ **Output signal on the time domain:**

The position signal oscillates at the dipole mode resonance frequency and decays exponentially with decay constant τ:

$$V_{position}(t) = V_{out,0} \sin(\omega_{110}t + \varphi) \exp(-t/\tau)$$



Need to find a balance between time resolution and spacial resolution when choosing Q_L

II. Project definition and objectives

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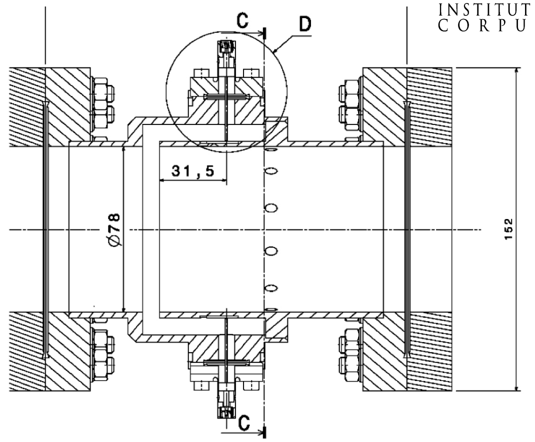
➡ **Modify an existing cBPM design to fit ILC demands and improve spacial resolution**



Challenges to overcome:

❖ Improve spacial resolution of the re-entrant cBPM (under 1 µm)

❖ Mechanical attachment and alignment with SC quadrupole

❖ cBPM and read-out system has to be suitable to perform measurements at ATF and STF

- bunch repetition of STF provokes overlapping and cancelling of signals (lowers-down the spacial resolution)
- Could by addressed by:
  - shifting the resonance frequency of the cBPM
  - reconstruction of signals with signal processing

➡ **Buy a cBPM from Claire Simone (Saclay)**

❖ Test cBPM and electronics at ATF linac by the end of 2024 or beginning of 2025

Beam parameters	ATF2	STF	ILC
Beam energy (GeV)	1,3	0,5	250
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III. Design studies of the cBPM

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A) Geometry studies of the cBPM

- **Eigenmode solver in CST**

Evaluate the E and M fields distributions, coupling to antennas and the influence of geometrical parameters on the resonant frequency and quality factor Q_L

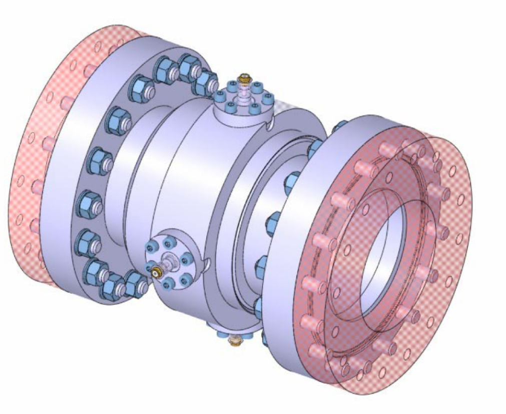


Fig. 8: Design of the new cavity BPM

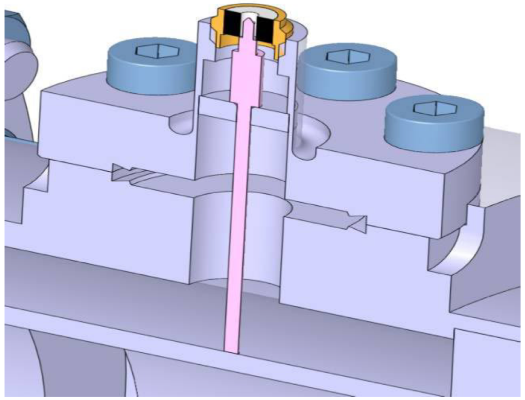
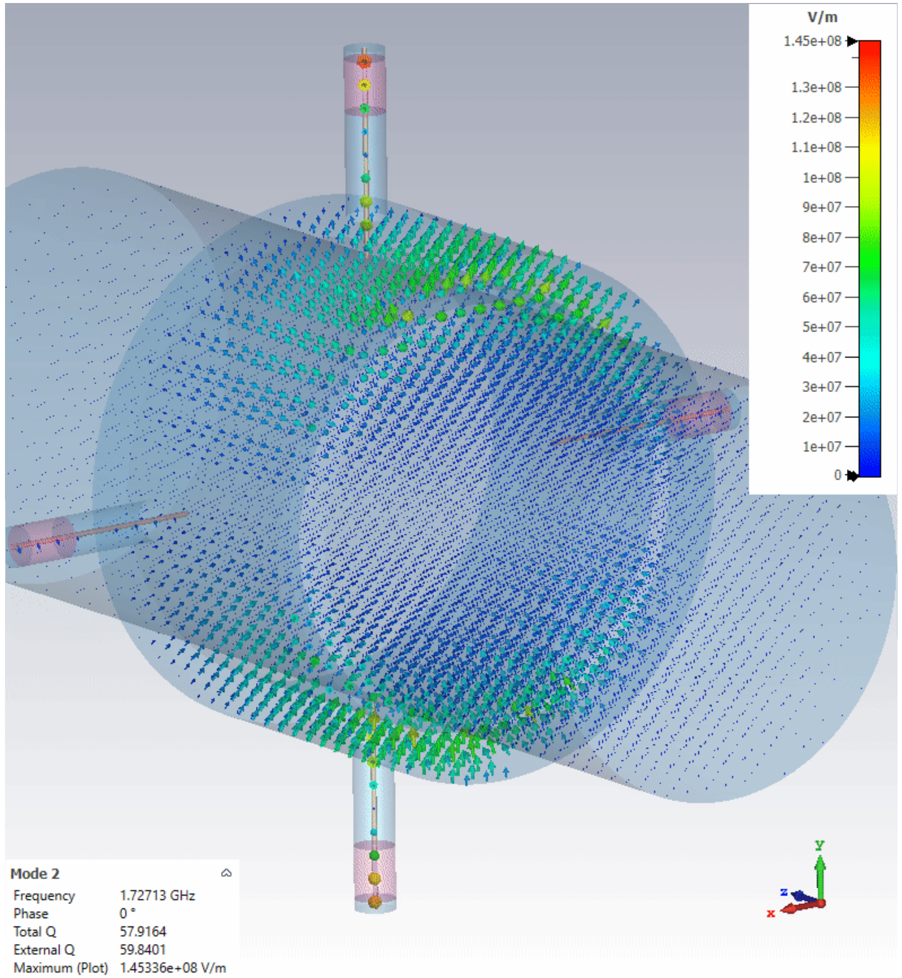


Fig. 9: Design of the new feedthrough

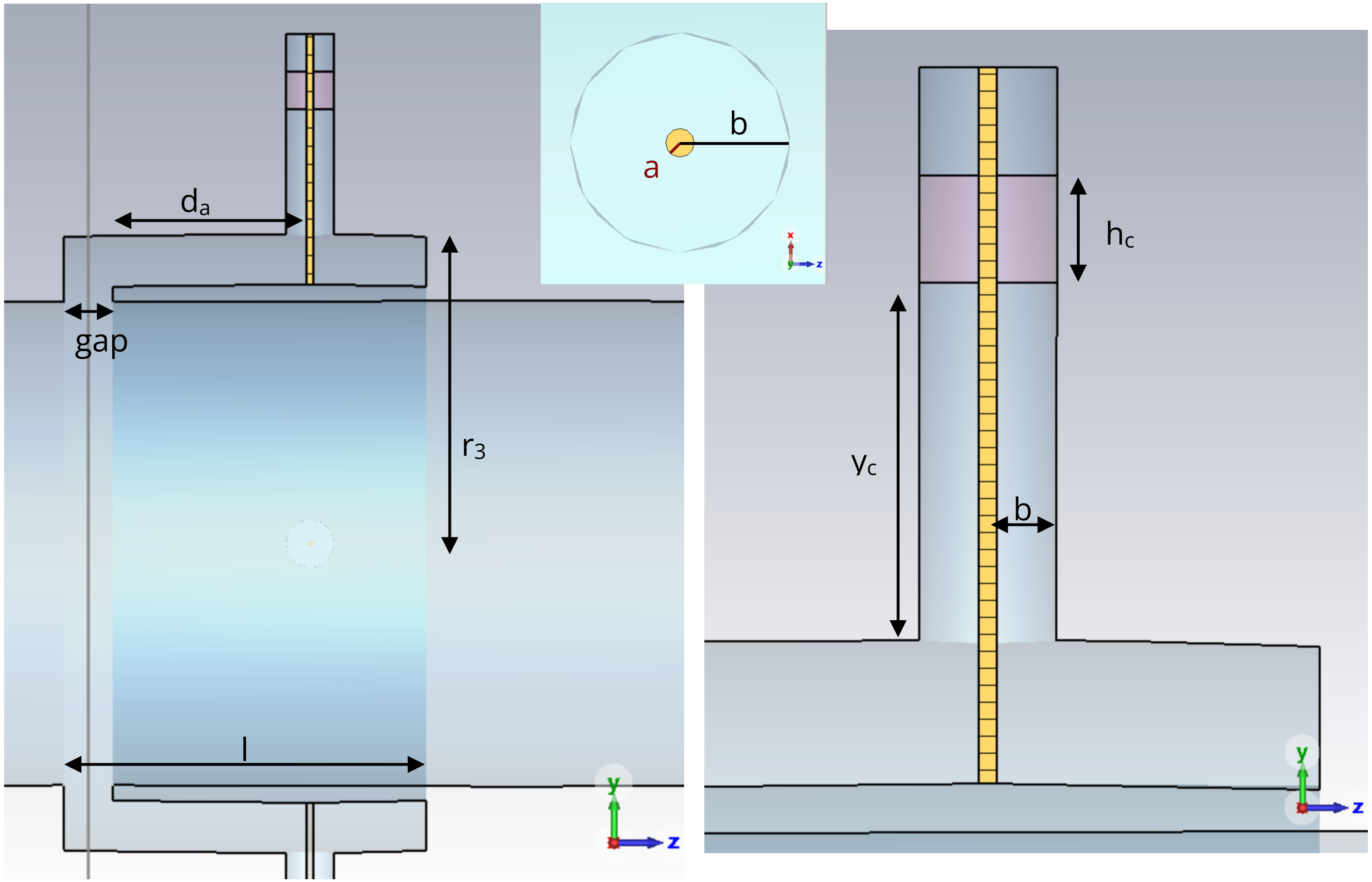


CST Studio Suite, Charged Particle Simulation - Workflow & Solver Overview, 3DExperience
C. Simon, WP11 (Beam diagnosis) The re-entrant BPM, CEA, Saclay, France

III. Design studies of the cBPM

A) Geometry studies of the cBPM

- **Parametric study**



Preliminary conclusions:

Higher influence on **Q_L (dipole)** (and **τ**):

- ↘ when l ↗ (cavity length)
- ↗ when d_a ↗ (antenna distance)
- ↗ when h_c ↗ (thickness of seal)
- ↘ when a ↗ (radius of inner conductor) (but limited)

Higher influence on **R/Q (dipole)** (sensitivity):

- ↗ when r_3 ↗ (cavity aperture)
- ↘ when l ↗ (cavity length)

➡ Parameters usually affect al variables at the same time. Need of careful selection.

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III. Design studies of the cBPM

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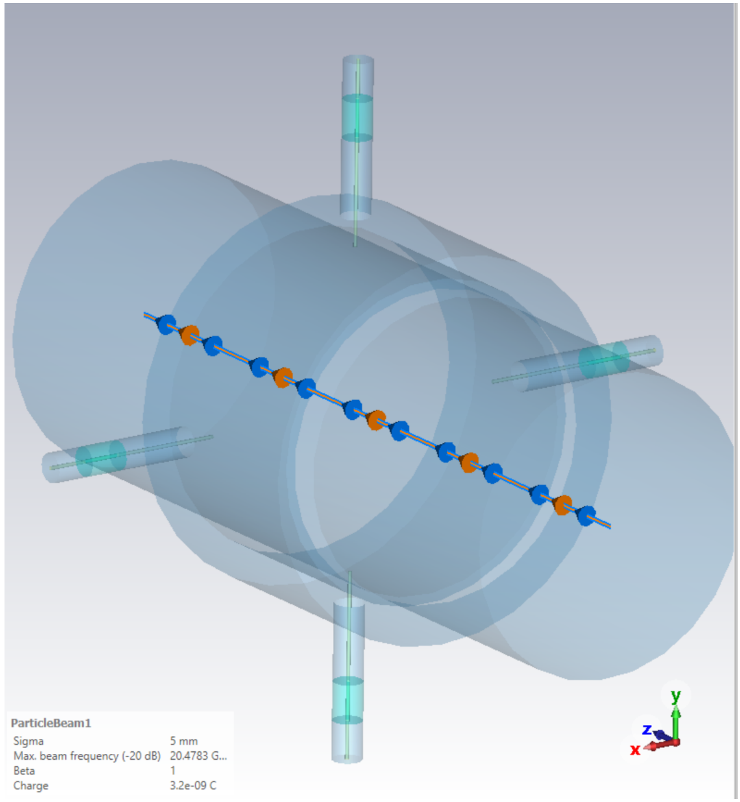
B) Inclusion of a perturbation in the cBPM

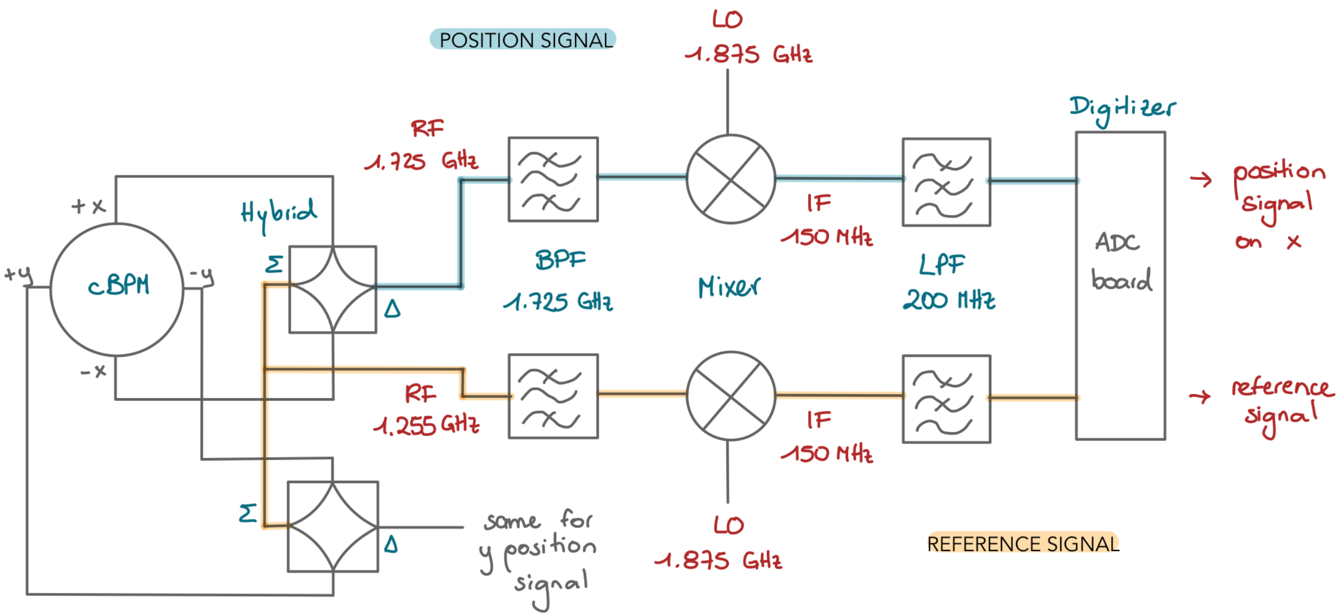
- **Wakefield solver in CST**



Evaluate the E and M fields under the presence of a beam and their response to different offsets

➡ Retrieve signal from the output ports and reconstruct beam dependence on the amplitude of the dipole mode

- **Signal processing in MATLAB**



III. Design studies of the cBPM

B) Inclusion of a perturbation in the cBPM

Example for beam with 500 µm of offset in the x direction

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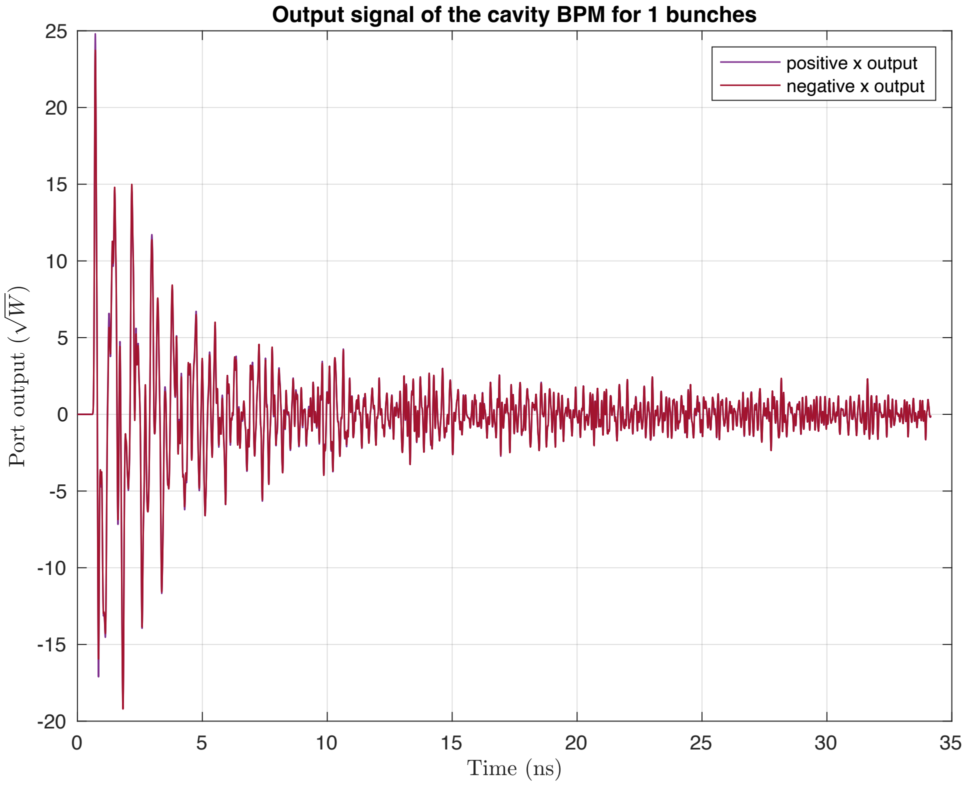
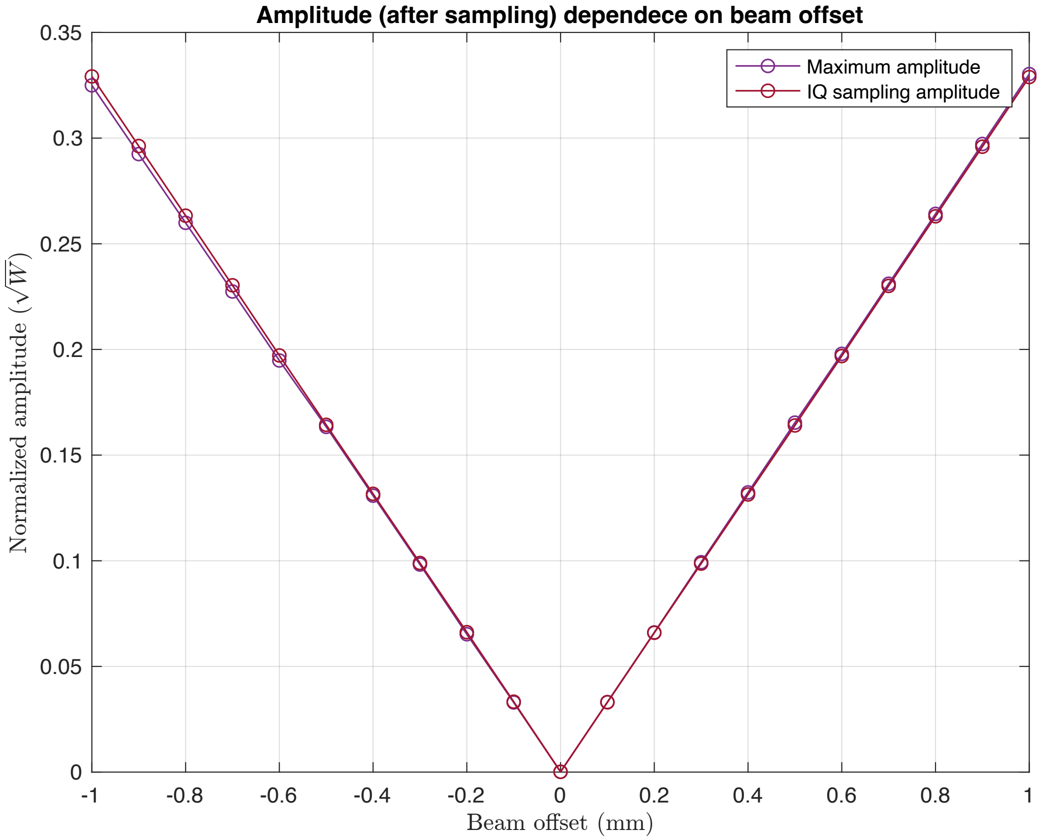
- **Signal processing in MATLAB**



$\Rightarrow$

Repeating process for a range of offsets:



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Thank you for your attention

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