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ASPECTS ON THE COLD BPM'S IN THE MAIN LINAC

1. **Resolution**
2. **Resolution**
3. **Resolution**
4. **...**

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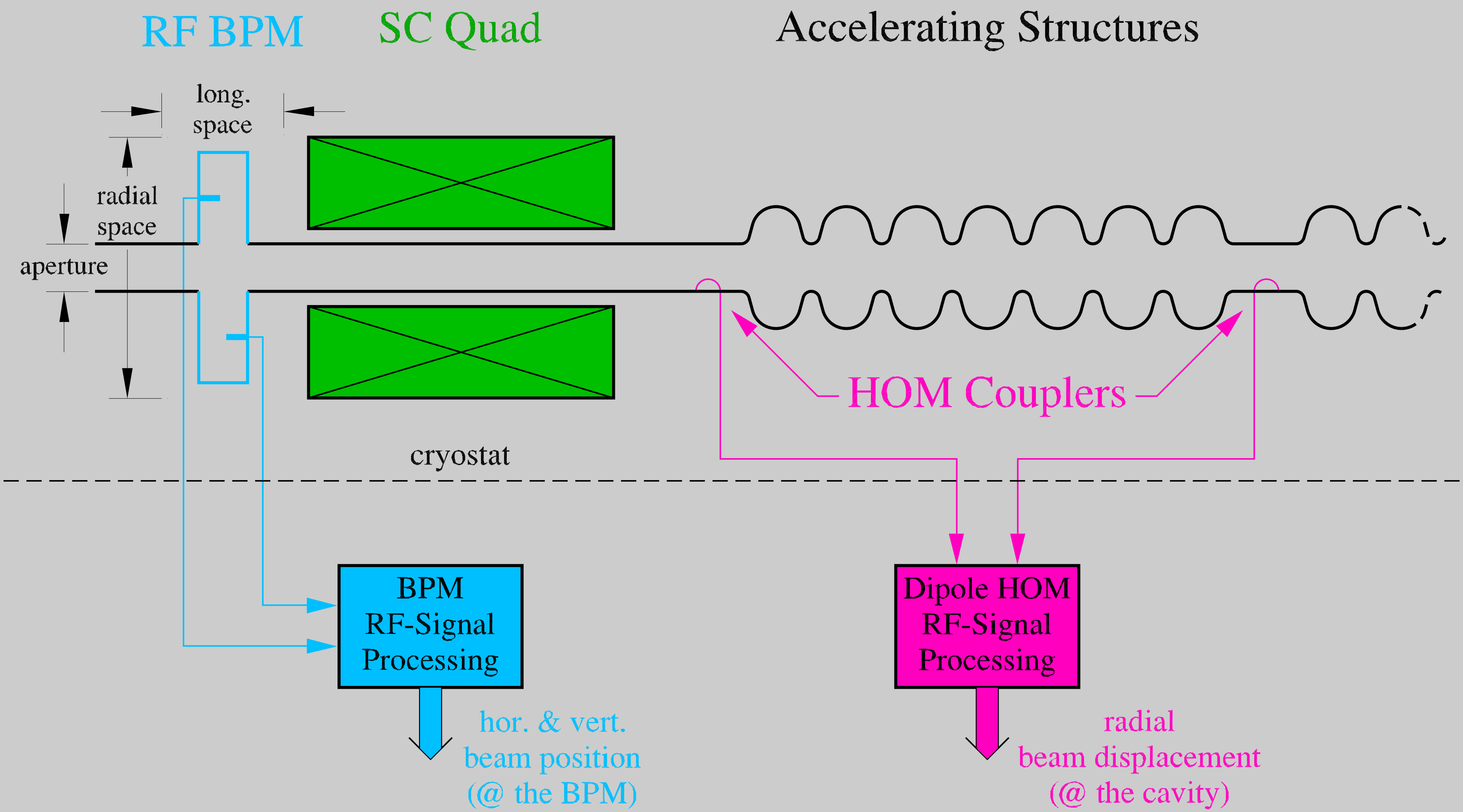
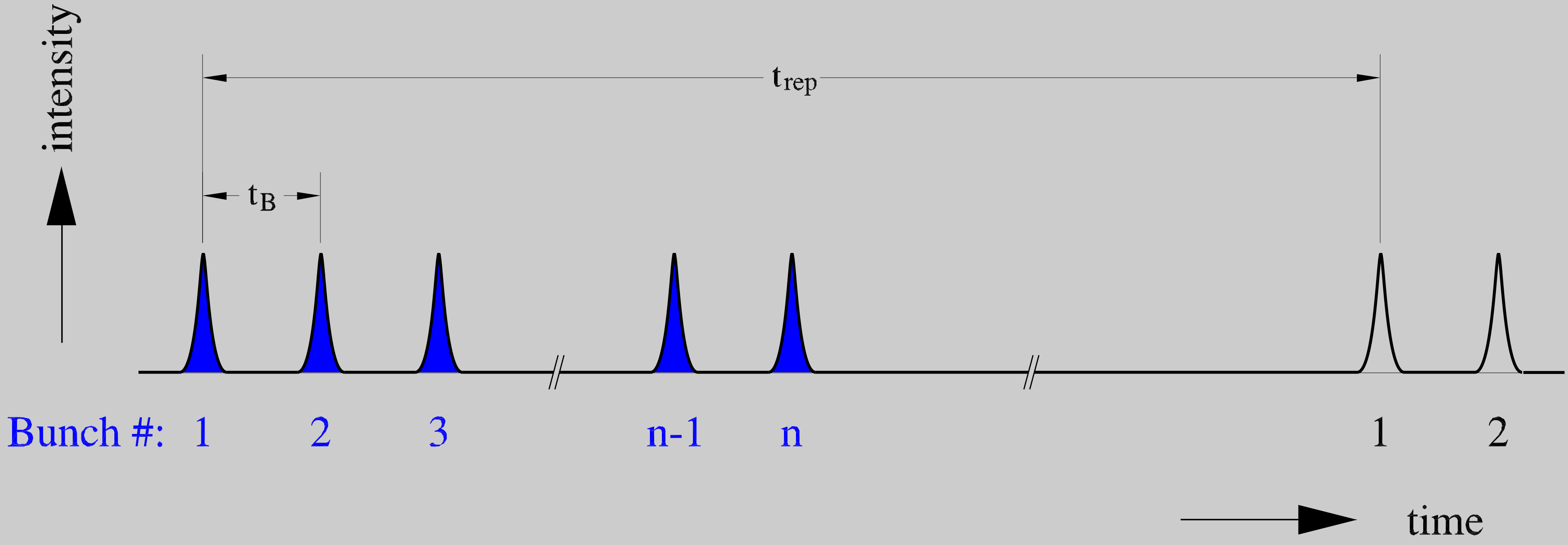
Contents

INTRODUCTION



Dedicated BPM's and HOM coupler signals

for beam position measurements in the main linac.



The "bunch-train" is the stimulus signal for the BPM system (not to scale).

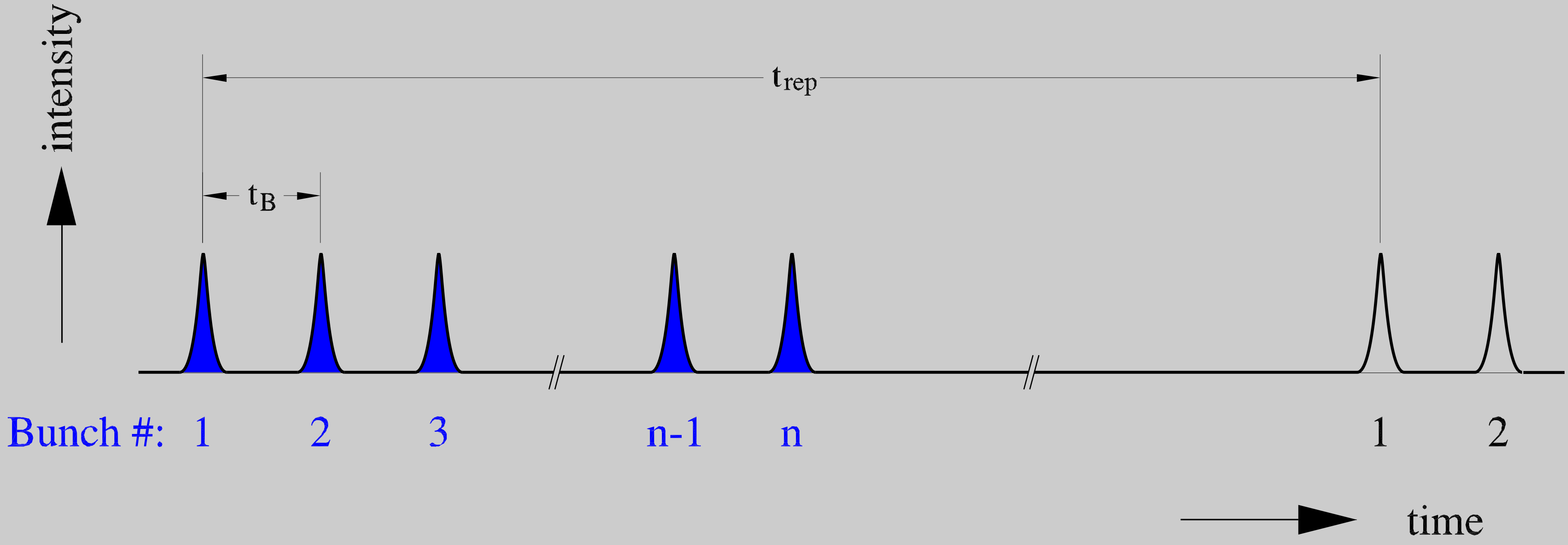
The **time resolution** of the BPM system has to be defined, e. g. should be able to resolve the beam position of any/every single bunch in the bunch-train:

$$\tau_{\mathrm{BPM}} < t_{\mathrm{B}}$$

The **position resolution** improves by averaging the n_{B} single-bunch positions:

$$\mathrm{Resolution}_{\mathrm{multibunch}} \approx \frac{\mathrm{Resolution}_{\mathrm{singlebunch}}}{\sqrt{n_{\mathrm{B}}}}$$

which is equivalent to reducing the bandwidth of the BPM system.



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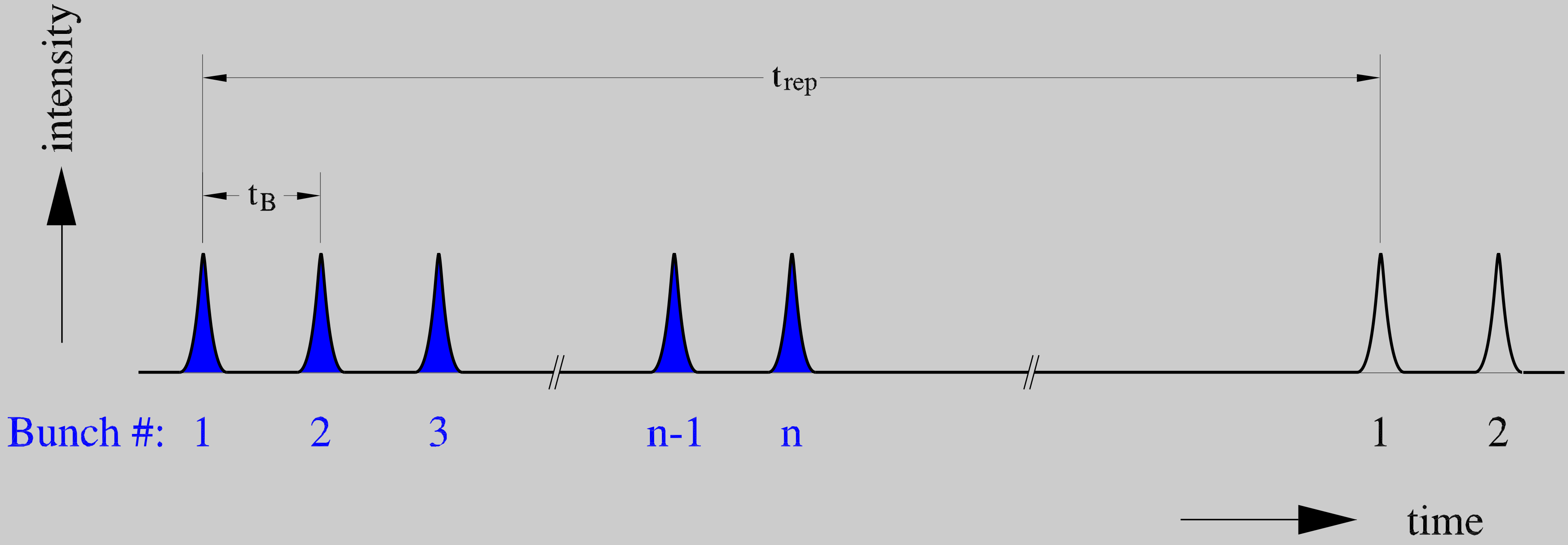

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BPM ASPECTS

Requirements

A clear defined set of **BPM requirements** is mandatory; and it has to be kept up to date(!).

- The RMS **position resolution** of the BPM pickup or complete system (i. e. with read-out electronics) in a specified integration (measurement) time; e. g. 10 μm SB, 1 μm BT (?).
- The transverse **measurement range** to be covered; e. g. $\pm$ 15 mm @ 10 μm SB res. (?). Specify extended ranges with reduced resolution; e. g. $>$ 15 mm @ 20 μm SB res. (?).
- Nominal **beam/bunch intensities**, e. g. 0.5...2 nC/bunch (?). Defines the dynamic range of the read-out electronics. The BPM system will have a reduced resolution at lower intense beams(!).
- **Linearity** and **orthogonality**, i. e. cross-talk between horizontal and vertical axis; e. g. $<$ 2 % @ $\pm$ 15 mm (?). Systematic nonlinearities of the BPM pickup can be linearized by 2D field mapping procedures.
- Absolute **precision** and **reproducibility**, after a temperature cycle of the cryostat, etc.; e. g. $<$ 200 μm (?).

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Mechanical and Environmental Aspects

Beside the usual mechanical and vacuum aspects, the operation of the BPM pickup detector in a cryogenic, cleanroom approved environment requires additional care:

- **Beam pipe aperture**, i. e. circular cross-section of ?? mm diameter (TESLA: 78 mm). Keep in mind: The position resolution scales with the beam pipe aperture!
- **Longitudinal** and **radial space** for the BPM pickup.
- Flange types and location, bellows, mounting issues.
- **RF-signal cables** in the cryostat (low signal losses, high temperature isolation).
- **Cryogenic RF vacuum feedthroughs** for the pickup signals (low VSWR at operation frequencies, UHV stable ceramics after many temperature cycles).
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Other Aspects

- Beam coupling impedance, i. e. **wake potential** of the BPM pickup due to the perturbation of the beam's EM-field (adds to the heat load in the cryostat and may cause beam break-up forces in long bunch trains).
- Assembly and series production issues.
- Radiation related aspects (cables, connectors, electronics, etc.) and reliability (MTBF).
- Costs, number of required BPM's (TESLA: 2×368).
- Special requirements for linac commissioning, e. g. beam intensity measurement, low-intense "pilot" bunch orbit observation (dynamic range!).
- Data-acquisition and transfer aspects, interface to the control system (fiber or copper links, data communication industry standards, etc.).
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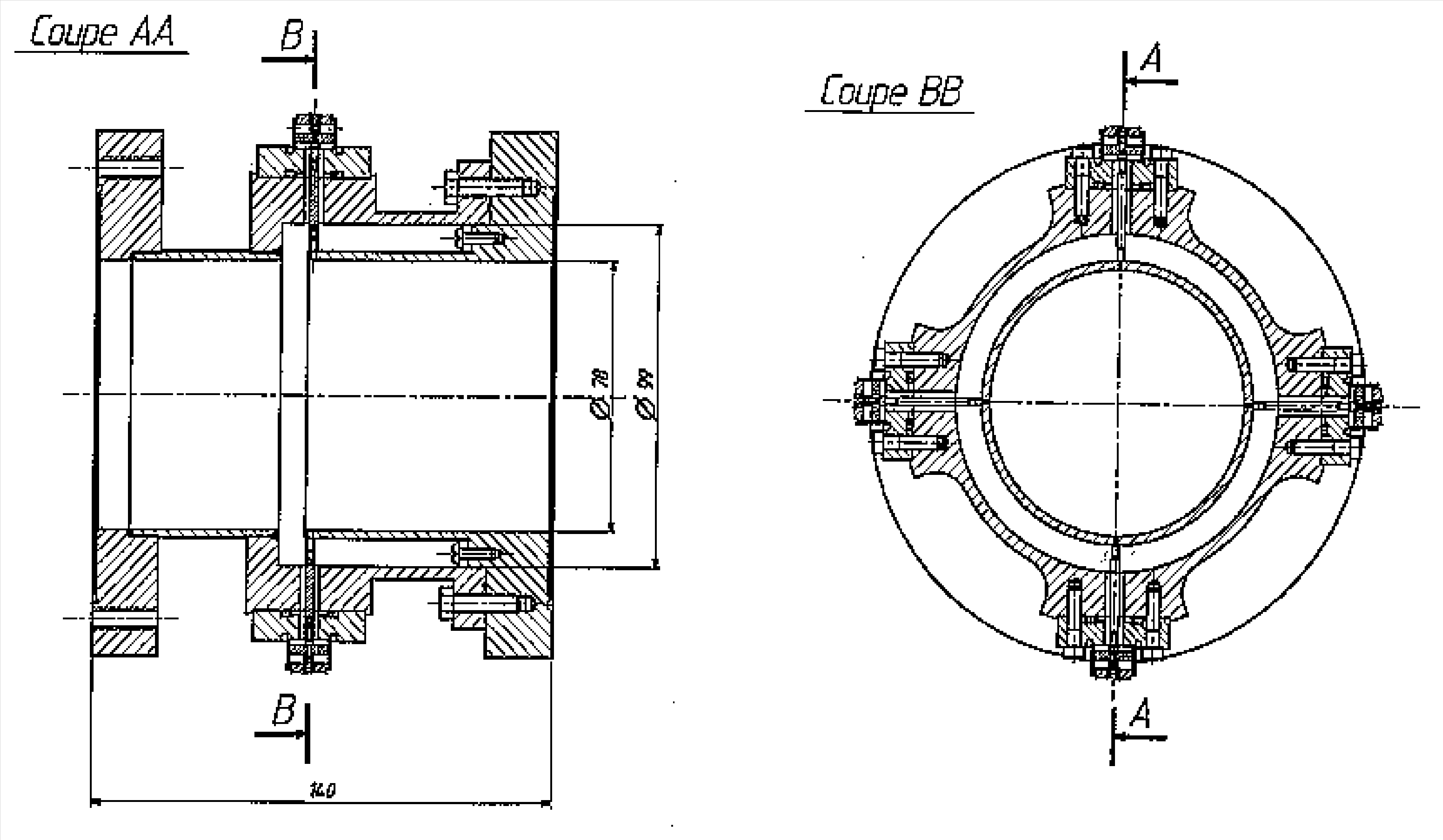
CANDIDATES FOR COLD BPM PICKUP'S

Broadband BPM's (-)

- Electrostatic **"Button" BPM** or electromagnetic **"Stripline" BPM**.
- Broadband transfer characteristic (BW > 1 octave).
- Pickup electrodes couple to a part of the EM-field of the beam (image current), $Z_{\text{elec}}(x, y) > 0$, which sets the position sensitivity in the order of $V_A/V_B \approx 1$ dB/mm (assuming 70 mm beam pipe diameter).
- The BPM resolution is defined mainly by the S/N-ratio of the read-out electronics and it's integration time. Button pickup based BPM systems have a rather low or moderate single-bunch postion resolution ($\approx 50\ \mu$m). High resolution ($1\ \mu$m) is only possible by increasing the integration time (narrow bandwidth, as done in BPM systems of synchrotron light sources) or using long stripline pickups in a small beam pipe aperture (SLAC FFTB).
- Low-cost, simple mechanics (Button BPM's), and low wake potential.

Semi-Resonant BPM's (+)

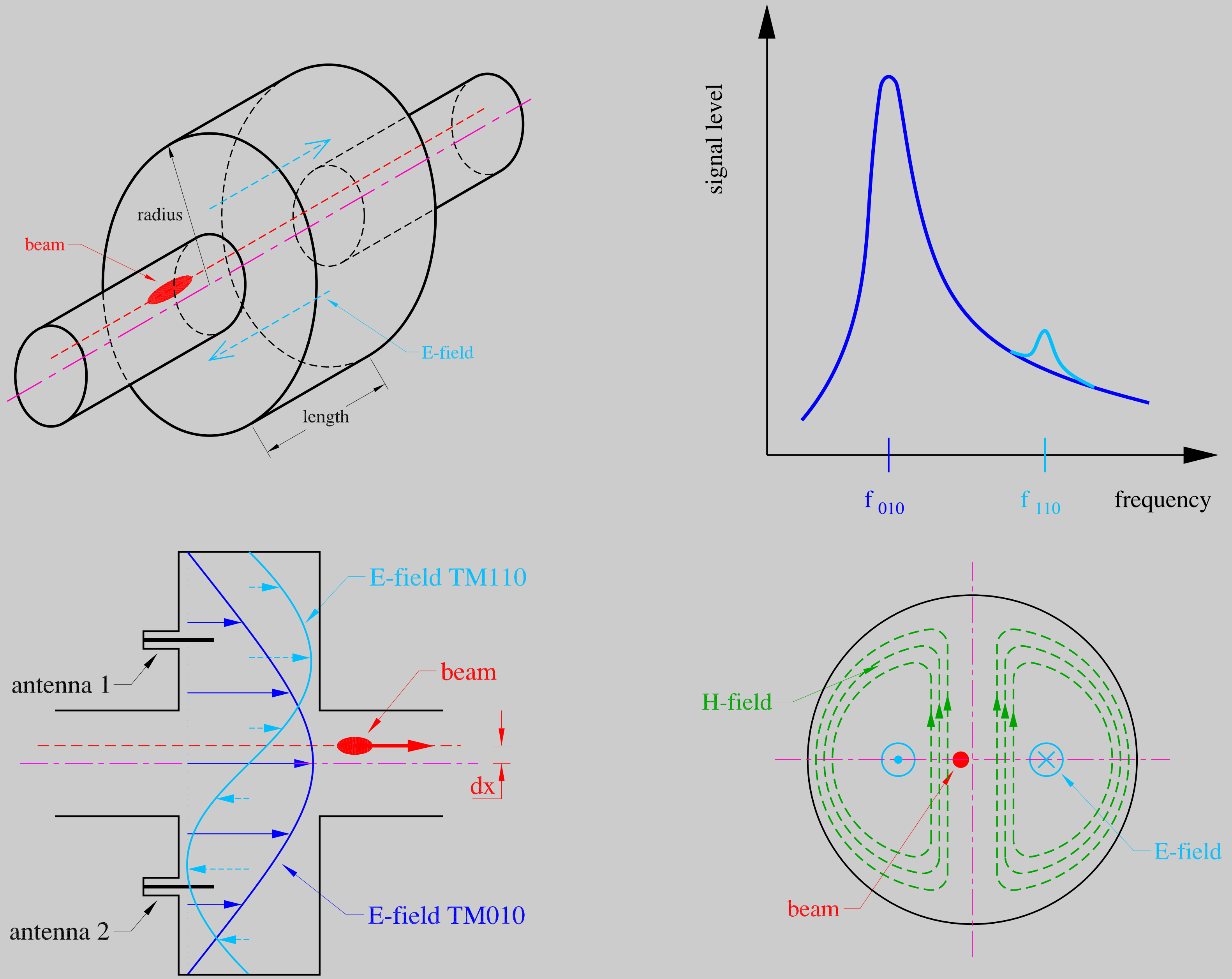
- **Re-entrant coaxial-cavity BPM**.
- Broadband transfer characteristic (BW $>$ 100 MHz).
- 50 Ω loaded transmission-line, operated on the beam-excited evanescent fields of the fundamental TE_{11} waveguide dipole mode (i. e. below cut-off frequency).
- Expect moderate to good single-bunch resolution ($\approx$ 10 μm) depending on integration time and performance of the read-out electronics.
- Good linearity ($<$ 1 %), moderate operation frequency.
- Rather compact dimensions and simple machinable mechanics.
- Low wake potential.
- Operational experience under cryogenic & cleanroom conditions at a test installation in TTF2(!).



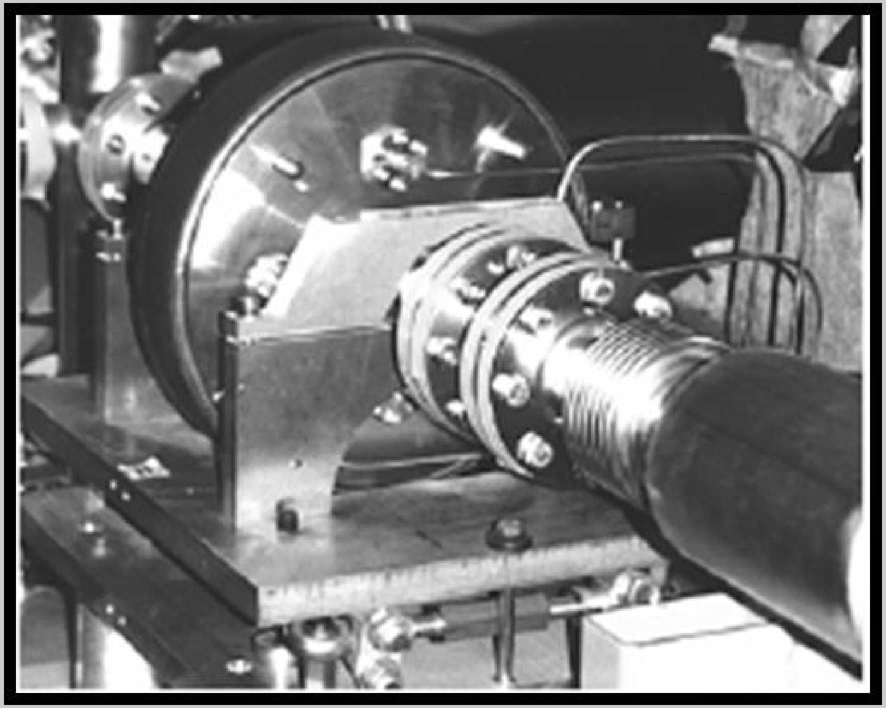
Re-entrant coaxial-cavity BPM for TTF2.

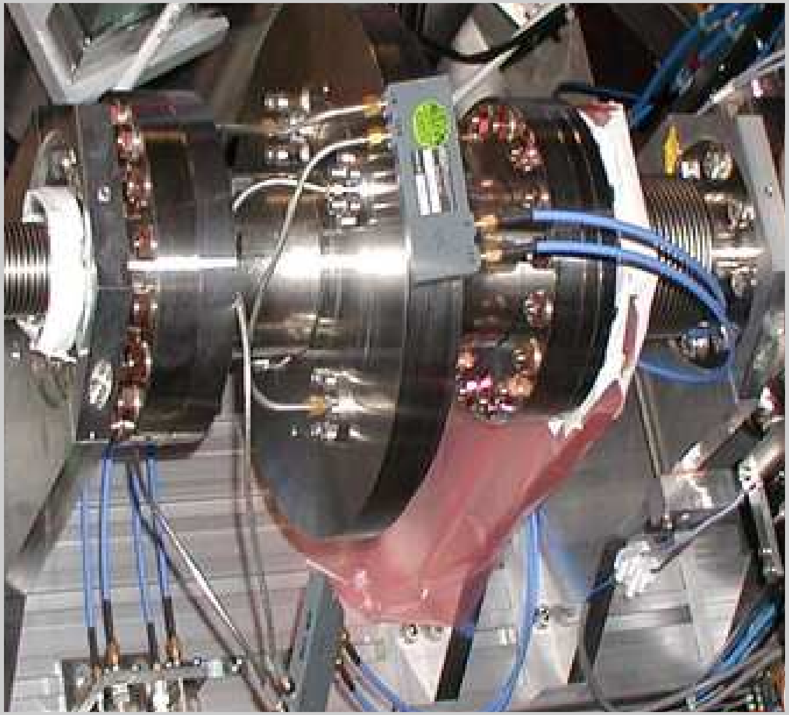
Resonant BPM's (+)

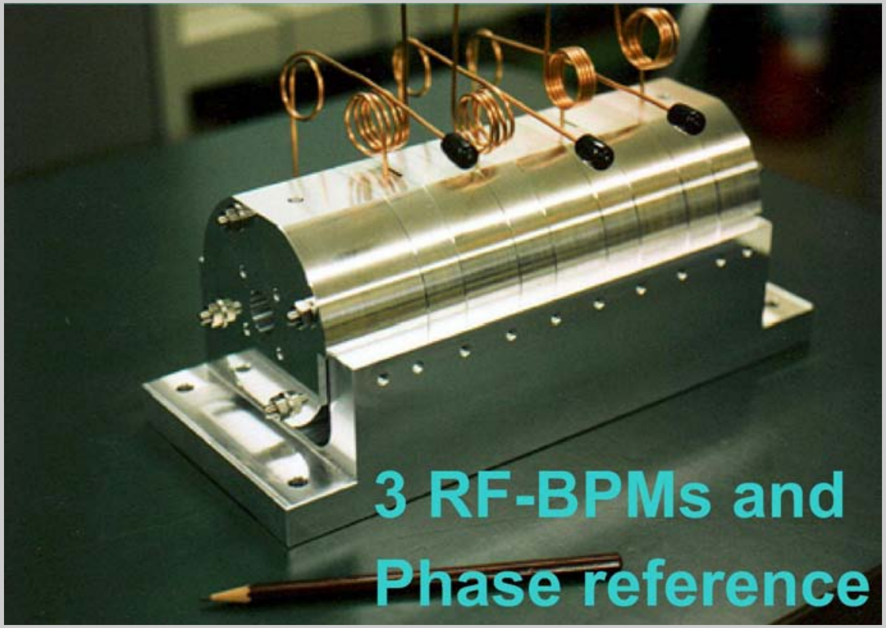
- Dipole-mode (TM_{110}) "pill-box" **cavity BPM**, with of without modifications (shape modifications to fix the polarization axes, waveguide ports to suppress the fundamental monopole TM_{010} mode, etc).
- Narrowband, resonant transfer characteristic ($Q \approx 500 \ldots 5000$).
- The beam excited dipole eigenmode of the cavity BPM has a linear beam displacement dependence, giving a zero output signal with the beam in the center.
- Cavity BPM's have the potential to achieve very high resolutions (nm-range), depending on the TM_{110} mode operating frequency, it's Q-value, and some other factors (precision of the mechanics, common mode suppression, read-out electronics, etc.).
- Cavity BPM's have several issues, which can be addressed by modifying the basic pill-box design: xy-axes cross-talk (polarization), common mode suppression, single-bunch time resolution, wake potential.
- Long term operational experience(!) under cryogenic & cleanroom conditions with several 1.5 GHz dipole-mode cavity BPM's at TTF.



Principle of a cavity BPM.

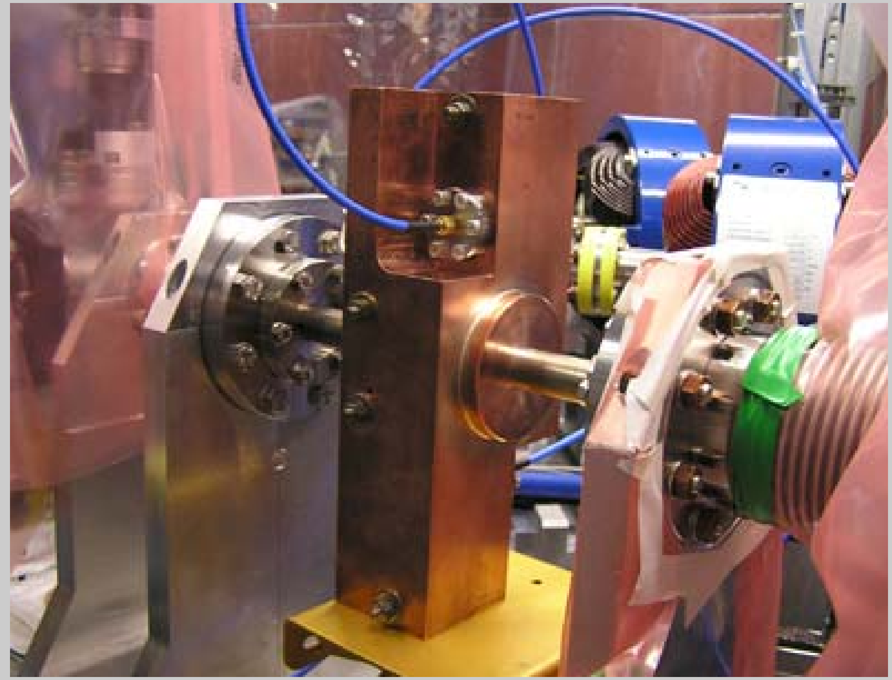


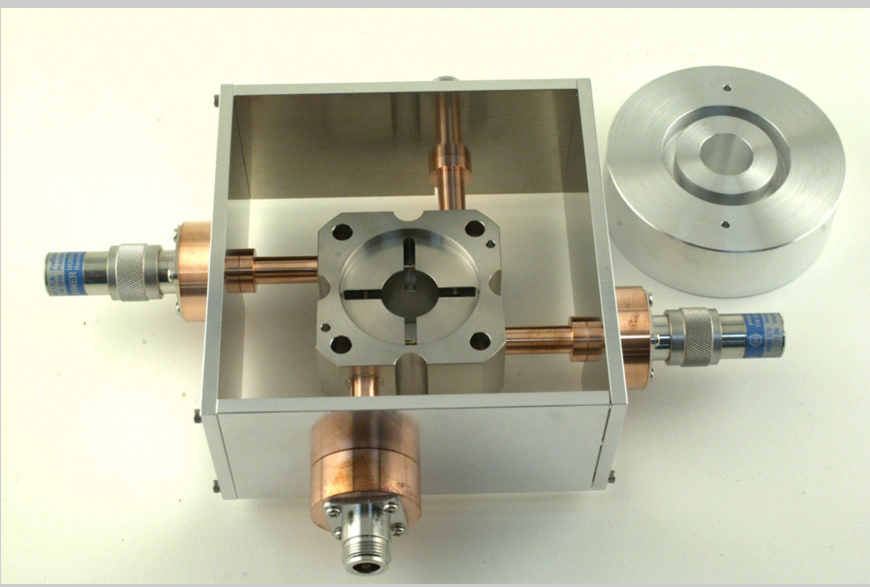




Examples of cavity BPM's:

- 1.5GHz cavity BPM of the TTF at DESY, now operating in the cryostat (up, left).
- Modified 1.5 GHz cavity BPM tested at the ELBE linac (up, right).
- C-Band cavity BPM tested at the SLAC FFTB, showing **25 nm resolution!** (down, left).





Examples of "COM free" cavity BPM's:

- 1.5 GHz cavity BPM prototype, TU-Berlin & DESY (up, left).
- 5.5 GHz cavity BPM tested at the ELBE photoinjector (up, right).
- C-Band (4.8 GHz) cavity BPM prototype, Spring-8 (down, left).

CONCLUSIONS

- Dedicated BPM's and HOM-based beam measurements will be used for beam position measurements along the main linacs.
- **Position resolution** is an important BPM parameter, but many other aspects have to be considered.
- The BPM requirements, in connection to the main linac beam parameters, have to be worked out and continuously updated.
- (Semi)-Resonant BPM's, e. g. cavity BPM, are a good choice as main linac BPM.