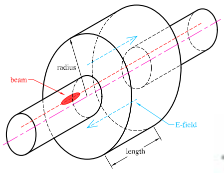
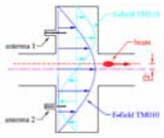
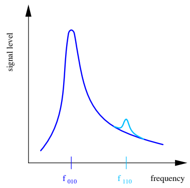
Cavity BPM (1)

- The beam passing through the cavity excites some RF modes
- Signal voltage of the monopole mode is proportional to beam intensity and does not depend on the beam position.
- Dipole mode voltage is proportional to the distance of the beam from the centre axis of the monitor.







by Claire Simon, -CEA-

Cavity BPM (2)

- Arranged around the beam tube, the cavity is composed of a mechanical structure with four orthogonal feedthroughs (or antennas).
- Cavity RF -> cf RF cavity design CAS 2007
  - Main RF characteristics for a cavity:
    - Frequencies
    - Coupling Q
    - R/Q

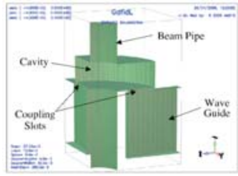
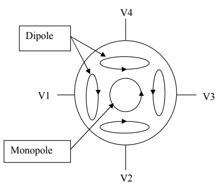


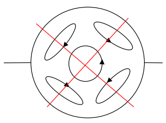
Figure 1: A quarter view of the inside surface of a BPM installed at ATF.

Cavity BPM (3)



V1 = V(monopole) - V(dipole)
V2 = V(monopole) + V(dipole)
V3 = V(monopole) + V(dipole)
V4 = V(monopole) – V(dipole)

- **Due to tolerances in machining, welding and mounting, some small distortions of the cavity symmetry are generated. A beam displacement in the 'x' direction gives not only a reading in that direction but also a non zero reading in the orthogonal direction 'y'.**
- **This asymmetry is called cross talk.**



Example: Pill box cavity

S-Band Cavity BPM Prototype

Frequency (GHz)	2.856
External Q	553
Beam pipe radius (mm)	17.81
Cell radius (mm)	60.0
Cavity gap	10.0
Waveguide radial dimensions (mm)	70.0
Waveguide axial dimension (mm)	75.0
Waveguide height	10.0

ILC S-band-BPM   Snowmass 8/16/05   Z. Li

Resolution

Resolution : RMS value related to the minimum position difference that can be statistically resolved.

- **Position signal**

$$V_{dipole} = qx\sqrt{Z_0 \frac{k_{loss,TM11}}{2}\frac{\omega_0}{Q_L}\frac{\beta}{1+\beta}}$$

(1/2 is due to the power splitted to two pickups)

- **Noise** determined by the thermal noise and the noise from signal processing channel

Thermal noise : $P_{th} = k_b * T * BW$

kb = Boltzmann's constant (1.38*10-23J/K), BW (Hz) = bandwidth of the signal processing channel, and T (K) = room temperature.

Noise from the signal processing: $P_n = NF * G * P_{th}$.

NF= total noise figure of the signal processing channel, G = gain of the signal processing and Pth = thermal noise.

Cavity BPM

- **Cavity BPM features:**
  - **Good resolution** (<< sub-micron cf Waltson, KEK-ATF program).
  - **Robust at cryogenic temperature**
  - **Symmetrical and easy machining**
  - **Possibility of bunch to bunch measurement**
  - **Dynamic range**
  - **Accuracy**
    Centering established by reasonable machining tolerances.

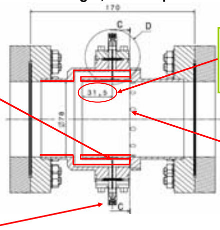
Re-entrant BPM (1)

Re-entrant cavity BPM installed in a warm section on the FLASH linac

Re-entrant Cavity (2)

- It is arranged around the beam tube and forms a coaxial line which is short circuited at one end.
- The cavity is fabricated with stainless steel as compact as possible:

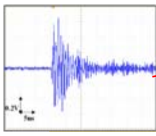
170 mm length, 78 mm aperture.



Cu-Be RF contacts welded in the inner cylinder of the cavity to ensure electrical conduction.

Feedthroughs are positioned in the re-entrant part to reduce the magnetic loop coupling and separate the main RF modes (monopole and dipole)

Twelve holes of 5 mm diameter drilled at the end of the re-entrant part for a more effective cleaning.



Signal from one pickup

RF Characteristics of the BPM

- **Resonant modes**

Eigen modes	F (MHz)			Q_l			$(R/Q)_l$ (Ω) at 5 mm	$(R/Q)_l$ (Ω) at 10 mm
	Calculated with HFSS in eigen mode	Measured in lab.	Measured in the tunnel	Calculated with HFSS in eigen mode	Measured in lab.	Measured in the tunnel	Calculated	Calculated
Monopole mode	1250	1254	1255	22.95	22.74	23.8	12.9	12.9
Dipole mode	1719	1725	1724	50.96	48.13	59	0.27	1.15

- Q determined by HFSS with matched feedthroughs.
- With Matlab and the HFSS calculator, we computed R/Q ratio.
R: the Shunt impedance and Q: the quality factor

$$\frac{R}{Q} = \frac{V^2}{2*\pi*f*W} \qquad V = \left|\int E(z)*e^{jkz}dz\right| \quad \text{and} \quad k=w/c$$

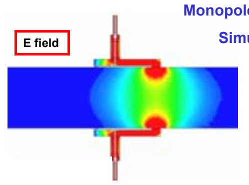
- Difference on Q factors can be explained by the boundary conditions which are not the same during the measurements in laboratory and in the tunnel.

RF Cavity and Fields (1)

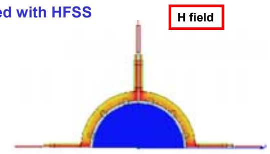
Monopole mode (f = 1255 MHz)

Simulated with HFSS

E field



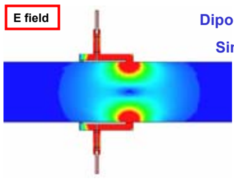
H field



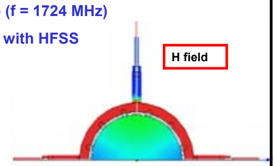
Dipole Mode (f = 1724 MHz)

Simulated with HFSS

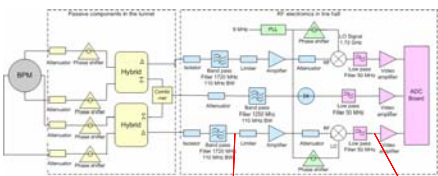
E field



H field

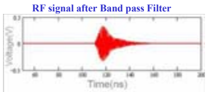


Signal Processing (2)

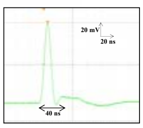


Signal processing electronics installed in the hall

RF signal after Band pass Filter



IF signal after Lowpass Filter on channel Δ

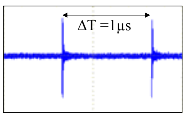


Time Resolution

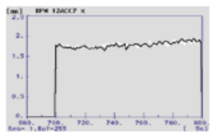
- Damping time is given by using the following formula : $\tau = \frac{1}{\pi * BW}$

With $BW = \frac{f_d}{Q_{ld}}$ fd: dipole mode frequency
Q_ld: loaded quality factor for the dipole mode

	Damping Time cavity only
BPM	9.4 ns



RF signal measured at one pickup



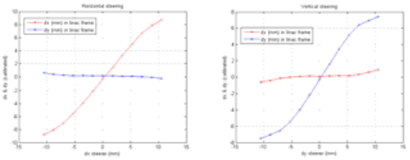
Position of 100 bunches in a macro-pulse read by the re-entrant BPM

Possibility bunch to bunch measurements

Beam tests on the BPM

➢ Calculate for each steerer setting, the relative beam position in using a transfer matrix between steerer and BPM.

➢ The beam tests were carried out at room temperature and are encouraging.



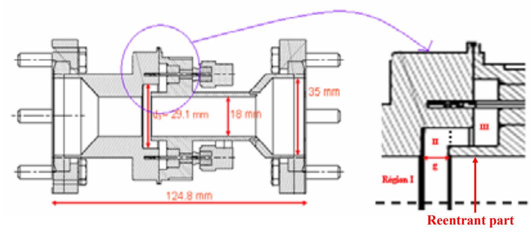
Calibration results in LINAC frame from horizontal (left) and vertical (right) steering

➢ **Good linearity in a range +/- 5 mm**

➢ **Resolution measurement: correlation of the reading of one BPM in one plane against the readings of all other BPMs in the same plane (using linear regression).**

➢ **RMS resolution around 4 µm on the Y channel and 8 µm on the X channel.**

Reentrant cavity designed for the probe beam of CTF3



- **Beam pipe (I),**
- **Gap (II)**
- **Coaxial cylinder (III)**