Accelerators Diagnostics

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Diagnostics: What do we want to measure?

- Beam Energy
- Beam Charge/Current
- Beam Position
- Beam Timing
- Transverse Beam Emittance
- Longitudinal Beam Emittance

Introduction

Accelerator performance depends critically on the ability to carefully measure and control the properties of the accelerated particle beams

In fact, it is not uncommon, that beam diagnostics are modified or added after an accelerator has been commissioned

This reflects in part the increasingly difficult demands for high beam currents, smaller beam emittances, and the tighter tolerances place on these parameters (e.g. position stability) in modern accelerators

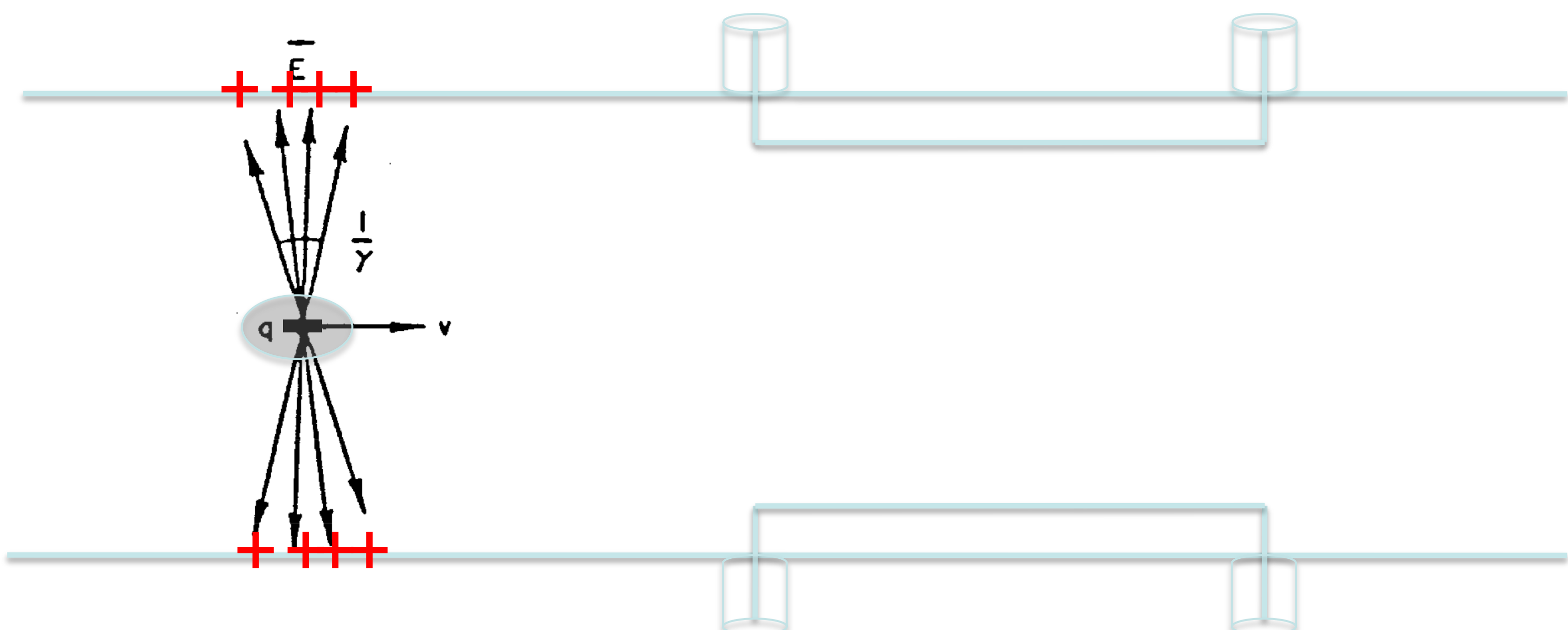
A good understanding of diagnostics (in present and future accelerators) is therefore essential for achieving the required performance

A beam diagnostic consists of

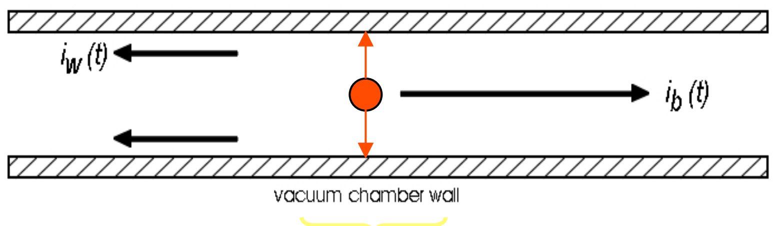
- the measurement device
- associated electronics and processing hardware
- high-level applications

Beam Image Current

- For relativistic beams, the EM fields are flattened to an opening angle of $1/\gamma$, approximating a TEM wave.
- Image current flows on the inner surface of the beam pipe.
- A beam pickup (PU) intercepts some fraction of the image current



General Concept of ElectroMagnetic Detector

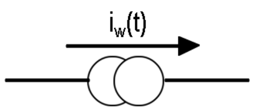


Lorentz-contracted "pancake"

induced wall current $i_w(t)$ has opposite sign of beam current $i_b(t)$: $i_b(t)=-i_w(t)$

Detection of charged particle beams – beam detectors:

i_w is a current source



with infinite output impedance, i_w will flow through any impedance placed in its path

many "classical" beam detectors consist of a modification of the walls through which the currents will flow

Sensitivity of beam detectors:

beam charge:

$$S(\omega) = \frac{V(\omega)}{I_w(\omega)}$$

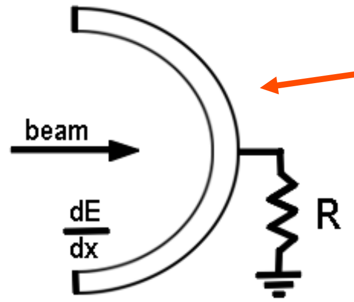
(in Ω)
= ratio of signal size developed $V(\omega)$ to the wall current $I_w(\omega)$

beam position:

$$S(\omega) = \frac{V(\omega)}{D(\omega)}$$

(in Ω/m)
= ratio of signal size developed /dipole mode of the distribution, given by $D(\omega)=I_W(\omega)\,z$, where $z = x$ (horizontal) or $z = y$ (vertical)

Beam Current – the Faraday Cup

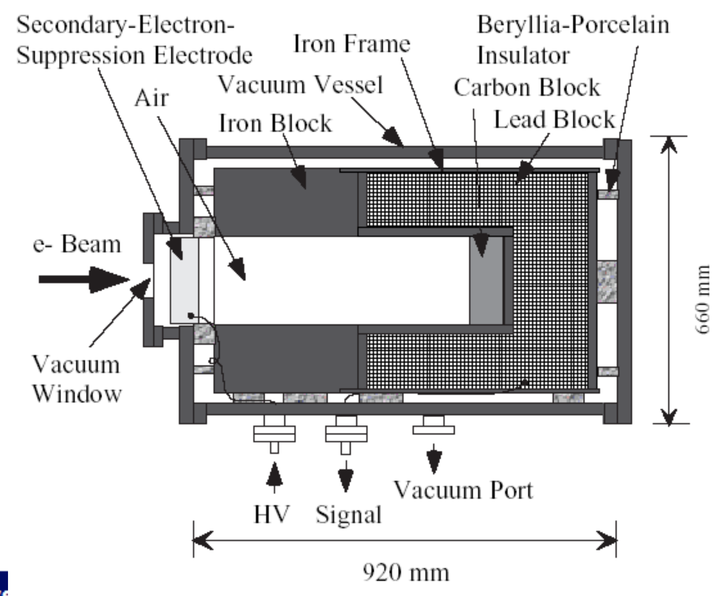


thick (e.g. ~0.4 m copper for 1 GeV electrons) or series of thick (e.g. for cooling) charge collecting recepticles

Principle: beam deposits (usually) all energy into the cup (invasive)
charge converted to a corresponding current
voltage across resistor proportional to instantaneous current absorbed

In practice:
termination usually into 50 Ω; positive bias to cup to retain e- produced by secondary emission; bandwidth-limited (~1 GHz) due to capacitance to ground

cross-sectional view of the FC of the KEKB injector linac (courtesy T. Suwada, 2003)

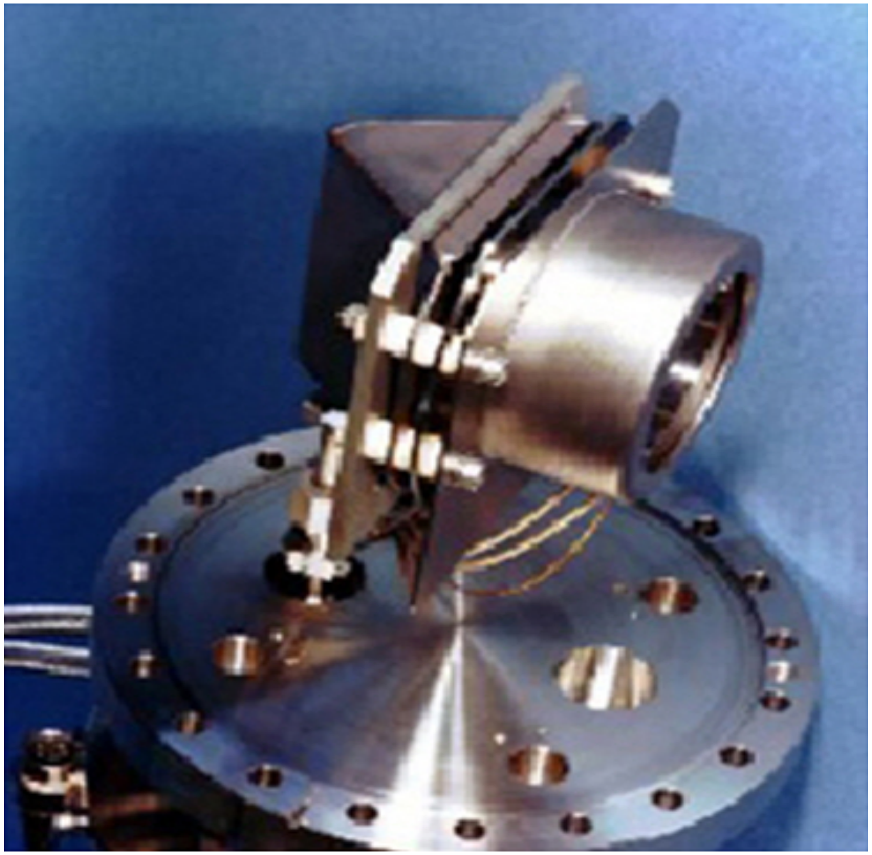


cylindrically symmetric blocks of
- lead (~35 rad lengths)
- carbon and iron
  - (for suppression of em showers generated by the lead)

bias voltage (~many 100 Volts)
- for suppression of secondary electrons

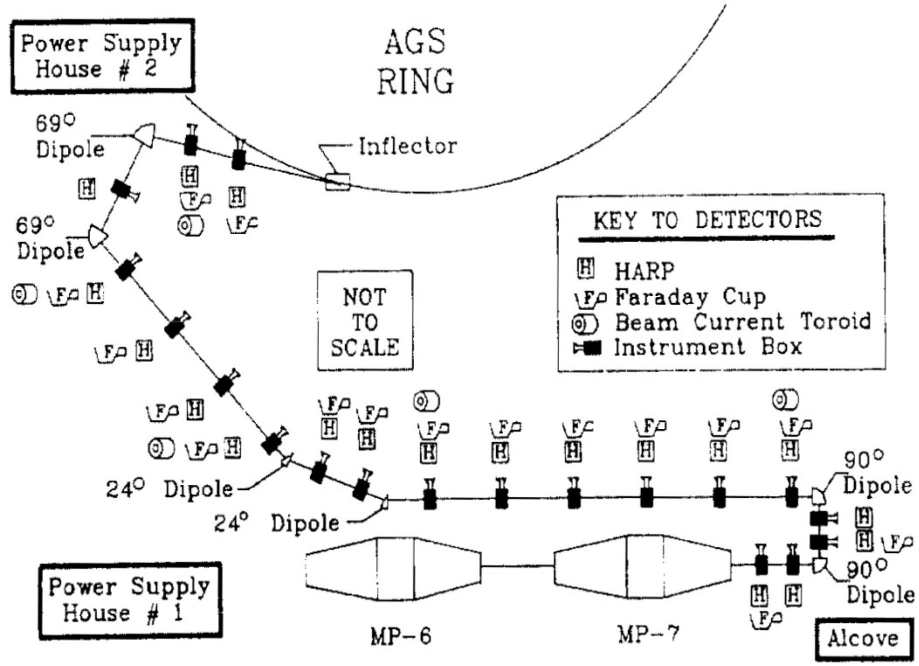
Example: Faraday Cup BNL Transfer Line

photo of FC used in the BNL tandem-to-downstream transfer lines



Cup and shield:	Tantalum
Cup support:	Stainless Steel
Cup insulation:	Ceramics
Cup shape:	Conical
Max. beam power:	600 W (uncooled version) / 6 kW (cooled version)
Connector:	BNC
Max. high voltage:	2500 V
UHV-Feedthrough:	Compressed air actuated Feedthrough

http://www.n-t-g.de/beam_diagnostic_Seite_2.htm



Faraday Cups

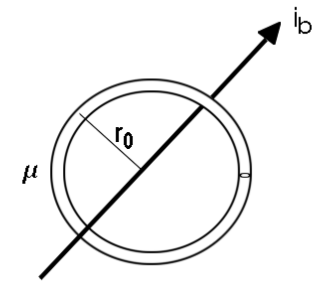
Beam current is monitored at 17 places (Fig. 2) using commercial[3] Faraday cups. Though destructive, they allow pulsed and dc beams to be measured over a wide dynamic range. A bias electrode (-600 V) surpresses secondary emission. The stainless steel frame and alumina insulators allow the assembly to remain in place during bakeout. The conically shaped, uncooled (600 W maximum) tantalum cup has a 1.2 inch aperture. The same type actuator is used as for the HARP, with which it shares a common flange.

The amplifier consists of 2 OP37EZ opamps and a LH0002 driver. Two bits provide 2 mode and 2 gain states. In the dc mode (10/100 nA/V) the bandwidth is reduced to 1 kHz to limit noise. The pulsed mode (10/100 μA/V) bandwidth is 500 kHz. Offset in the high gain/dc mode is the only adjustment.

"Beam instrumentation for the BNL Heavy Ion Transfer Line", R.L. Witkover et al, 1987 PAC

Beam Current – Current Transformers

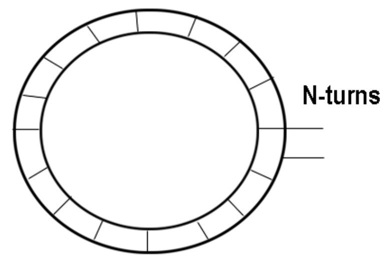
Consider a magnetic ring surrounding the beam, from Ampere's law:



$$\oint \vec{B} \cdot d\vec{l} = \mu I$$

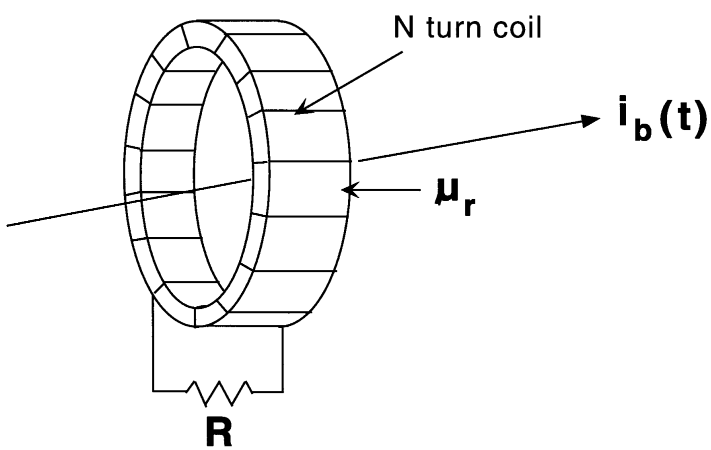
if r_0 (ring radius) >> thickness of the toroid, $B = \frac{\mu i_b}{2\pi r_0}$

Add an N-turn coil – an emf is induced which acts to oppose B:



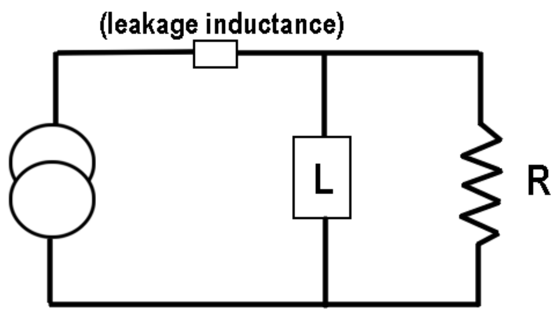
$$\begin{aligned} \epsilon &= \frac{d\phi}{dt} \quad \text{where} \quad \phi = \int \vec{B} \cdot d\vec{a} \\ &= \frac{\mu A}{2\pi r_0} \frac{di_b}{dt} \end{aligned}$$

Load the circuit with an impedance; from Lenz's law, $i_R = i_b/N$:



Principle: the combination of core, coil, and R produce a current transformer such that i_R (the current through the resistor) is a scaled replica of i_b. This can be viewed across R as a voltage.

Current Transformer Bandwidth



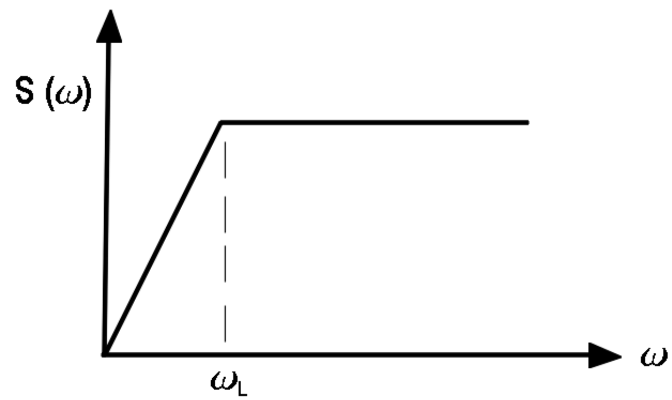
$$L = \frac{N^2}{R_h}$$

with R_h = reluctance of magnetic path

$$R_h = \frac{l}{\mu A}\ [\mathrm{H}^{-1}] \longrightarrow L = \frac{N^2 \mu_r \mu_0 A}{l}$$

sensitivity:

$$S = \frac{R}{\sqrt{1 + (\frac{\omega_l}{\omega'})^2}} \qquad \omega_l = \frac{R}{L}$$



cutoff frequency, ω_L, is small if $L \sim N^2$ is large

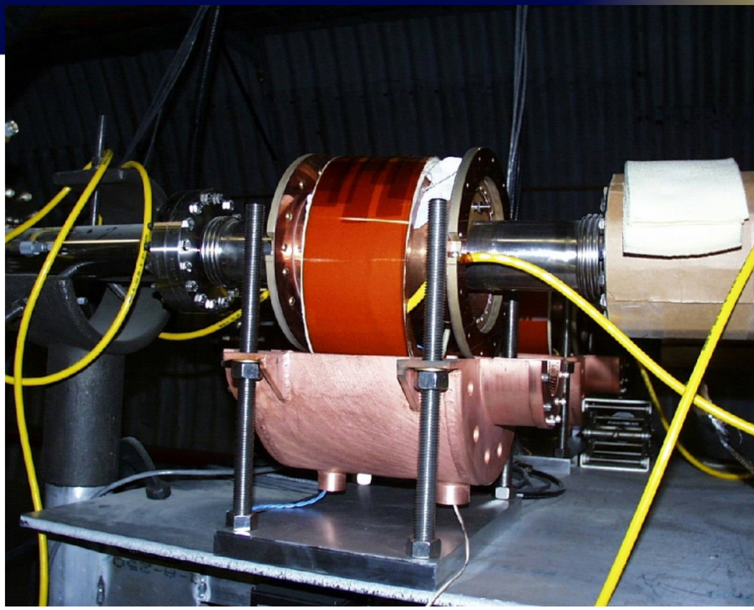
detected voltage:

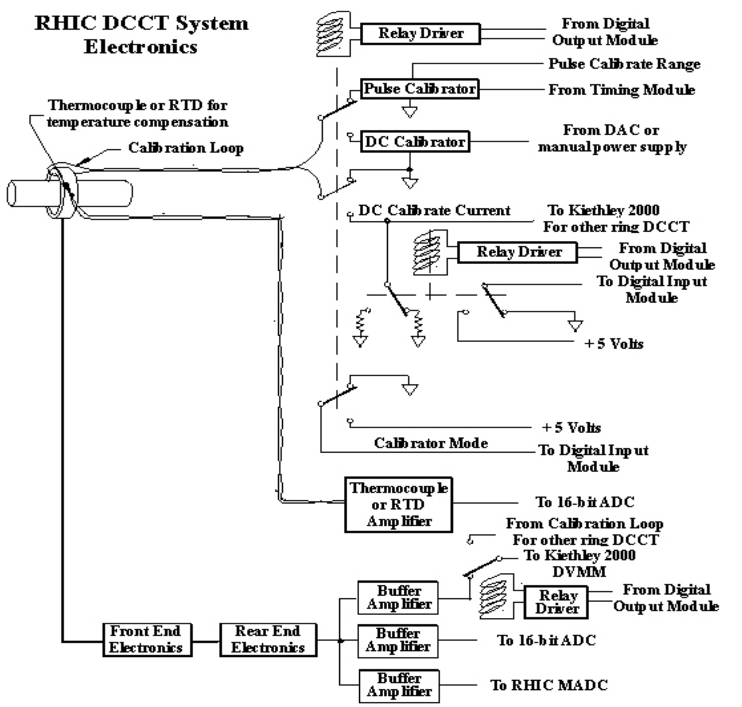
$$V(t) = \frac{i_b R}{N} e^{-(\frac{R}{L})t}$$

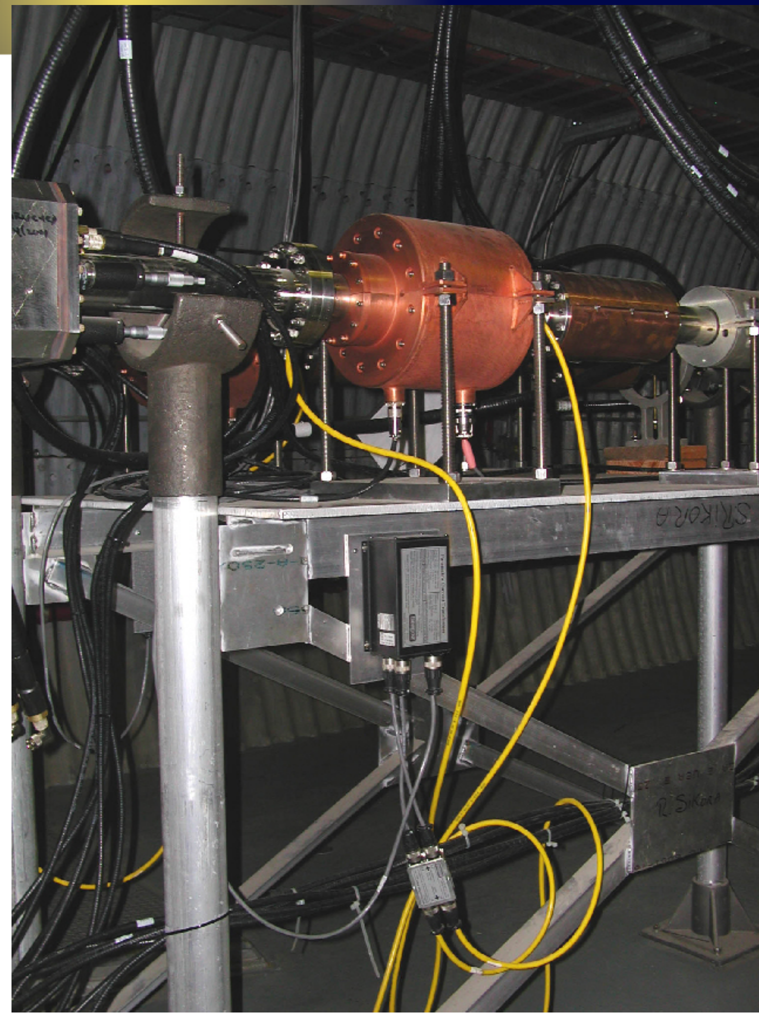
if N is large, the voltage detected is small

trade-off between bandwidth and signal amplitude

Example: RHIC Current Transformer





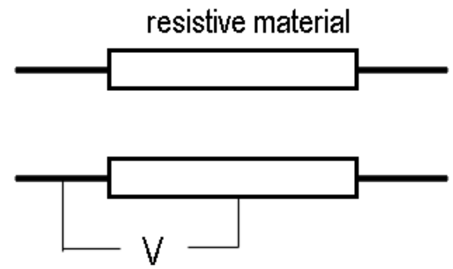


http://www.agsrhichome.bnl.gov/RHIC/Instrumentation/Systems/DCCT

“Overview of RHIC Beam Instrumentation and First Experience from Operations”, P. Cameron et al, DIPAC 2001

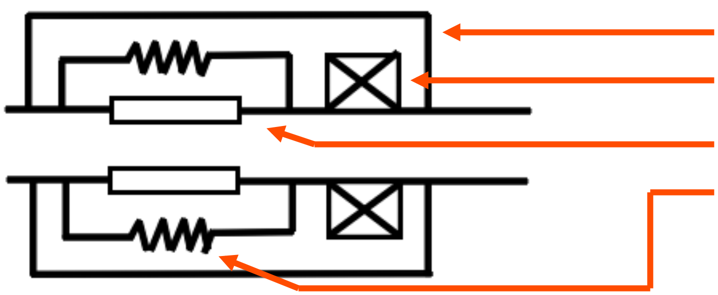
Beam Current – Wall Gap / Current Monitor

principle:
remove a portion of the vacuum chamber and replace it with some resistive material of impedance Z



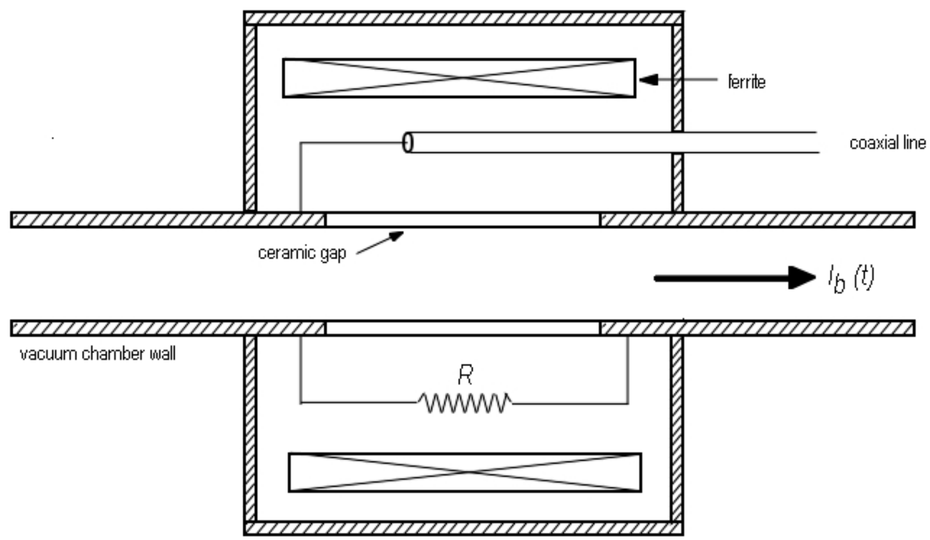
detection of voltage across the impedance gives a direct measurement of beam current since $V = i_w(t)\, Z = -i_b(t)\, Z$

(susceptible to em pickup and to ground loops)



- add high-inductance metal shield
- add ferrite to increase L
- add ceramic breaks
- add resistors (across which V is to be measured)

alternate topology - one of the resistors has been replaced by the inner conductor of a coaxial line

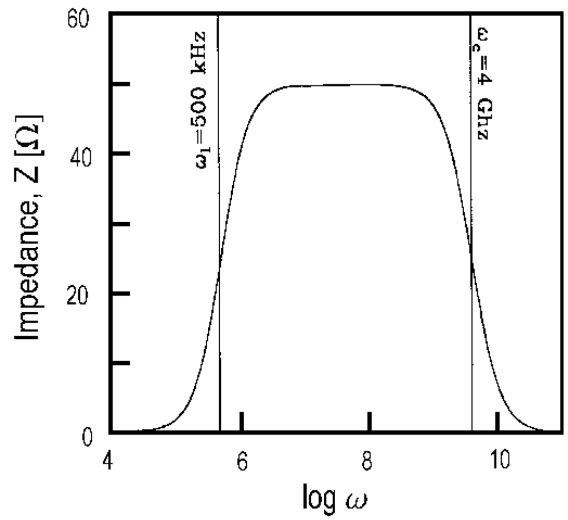


Wall Current Monitor Bandwidth

sensitivity:

circuit model using parallel RLC circuit:

$$\frac{1}{Z} = \frac{1}{R} + \frac{1}{j\omega L} + j\omega C$$



high frequency response is determined by C:

$$|Z(\omega \to \infty)| = \frac{R}{\sqrt{1 + (\frac{\omega}{\omega_C})^2}} \qquad (\omega_C = 1/RC)$$

low frequency response determined by L:

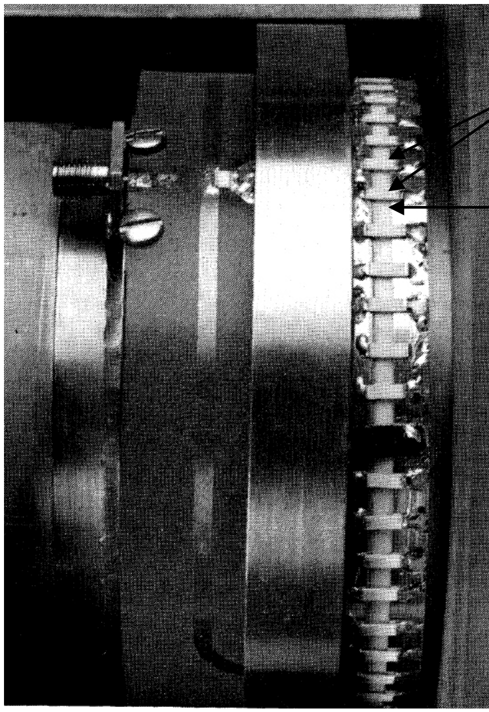
$$|Z(\omega \to 0)| = \frac{R}{\sqrt{1 + (\frac{\omega_L}{\omega})^2}} \qquad (\omega_L = R/L)$$

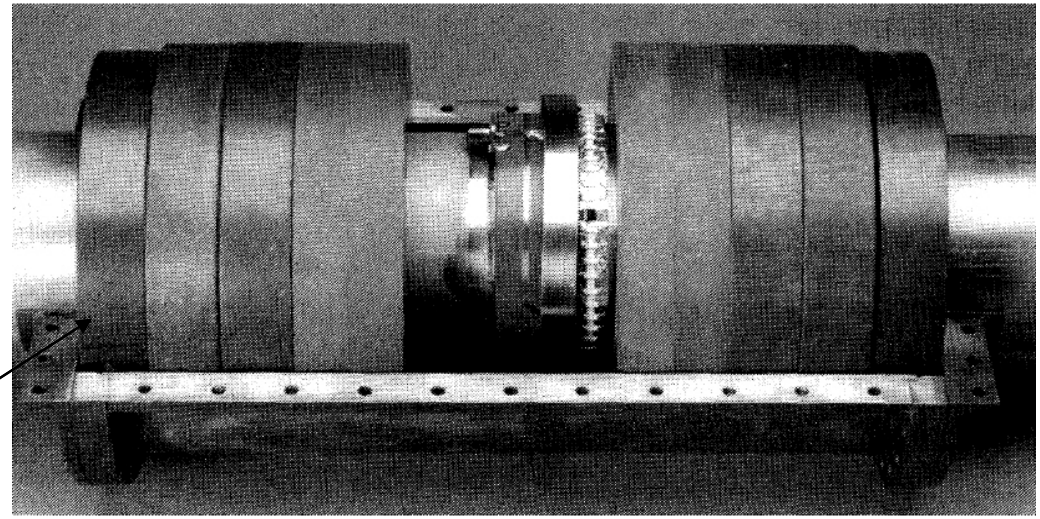
intermediate regime: $R/L < \omega < 1/RC$ – for high bandwidth, L should be large and C should be small

remark: this simplified model does not take into account the fact that the shield may act as a resonant cavity

Example WCMs

RHIC design based on prototype WCM shown below by R.C. Webber.
"The RHIC [WCM] system", P. Cameron, et al, PAC (1999)





"An Improved Resistive Wall Monitor", B. Fellenz And Jim Crisp, BIW (1998) for the FNAL main injector

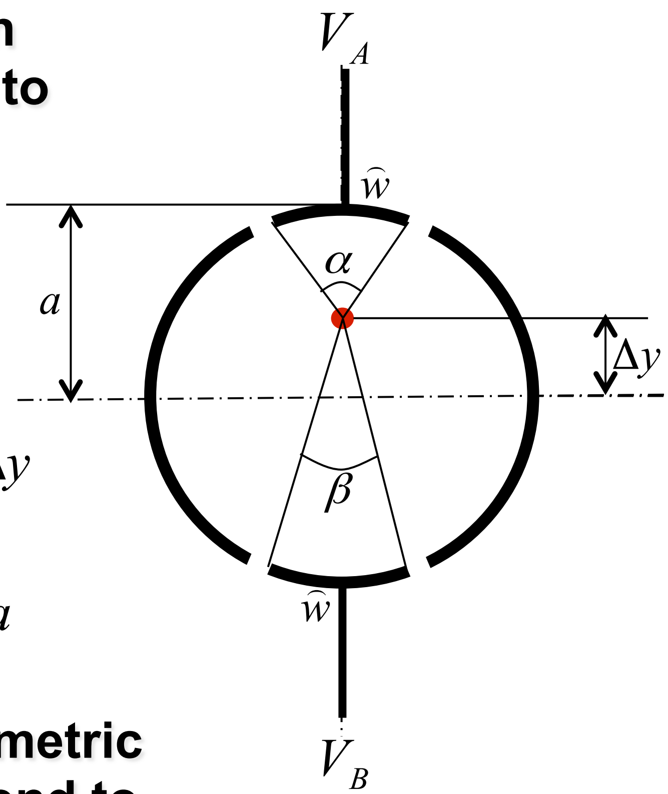
"Longitudinal Emittance: An Introduction to the Concept and Survey of Measurement Techniques Including Design of a Wall Current Monitor", R.C. Webber (FNAL, 1990) available at:
http://www.agsrhichome.bnl.gov/RHIC/Instrumentation/Systems/WCM
/WCM%20Shafer%20BIW%201989%2085_1.pdf

Electromagnetic Beam Position Monitors

In electromagnetic BPMs, the image charge in an electrode is proportional to the beam current and to the angle included between the beam and the electrode extremes:

$$V_A = G\,I\,\alpha$$
$$V_B = G\,I\,\beta$$

$$But \quad \widehat{w} = \alpha(a-\Delta y) = \beta(a+\Delta y)$$



$$V_A = G\,I\,\frac{\widehat{w}}{a-\Delta y} \qquad V_B = G\,I\,\frac{\widehat{w}}{a+\Delta y}$$

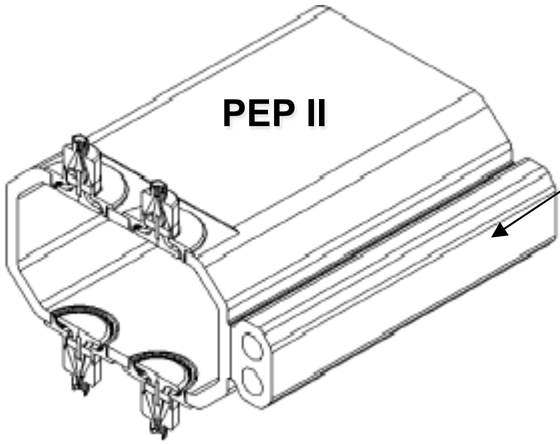
$$V_A - V_B = \frac{2G\widehat{w}}{a^2-\Delta y^2}\,I\,\Delta y \qquad V_A + V_B = \frac{2G\widehat{w}}{a^2-\Delta y^2}\,I\,a$$

$$\frac{V_A - V_B}{V_A + V_B} = \frac{\Delta y}{a}$$

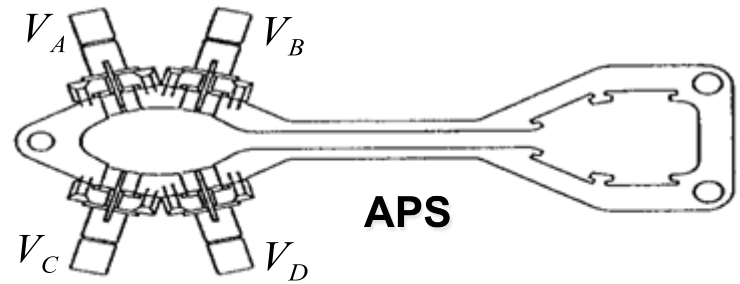
In addition to this geometric effect, the field lines tend to cluster closely in the region of the nearest electrode (the *E* field must be perpendicular to the walls). For this geometry, this gives an additional factor two:

$$\boxed{\Delta y \cong \frac{a}{2}\,\frac{V_A - V_B}{V_A + V_B}}$$

"Button" Type BPMs

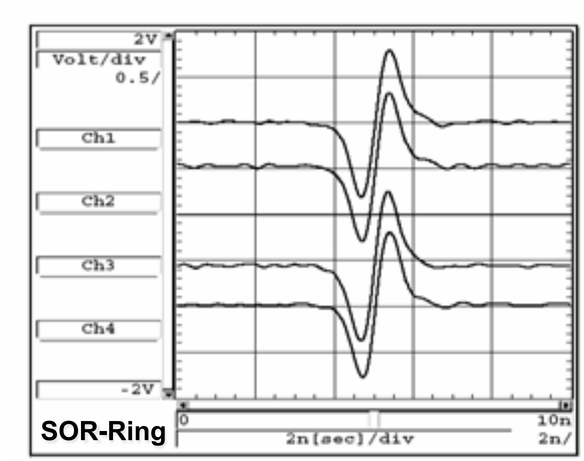


• Typical geometry used in the presence of synchrotron radiation.



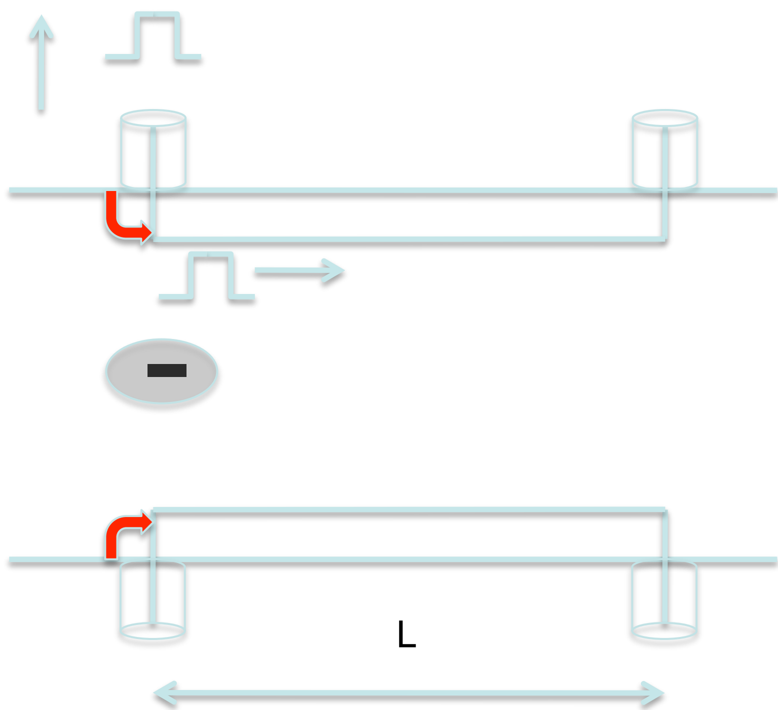
$$\Delta x = K \frac{(V_A + V_C) - (V_B + V_D)}{V_A + V_B + V_C + V_D}, \qquad \Delta y = K \frac{(V_A + V_B) - (V_C + V_D)}{V_A + V_B + V_C + V_D}$$

• Capacitive type (derivative response), low coupling impedance, relatively low sensitivity, best for storage rings.



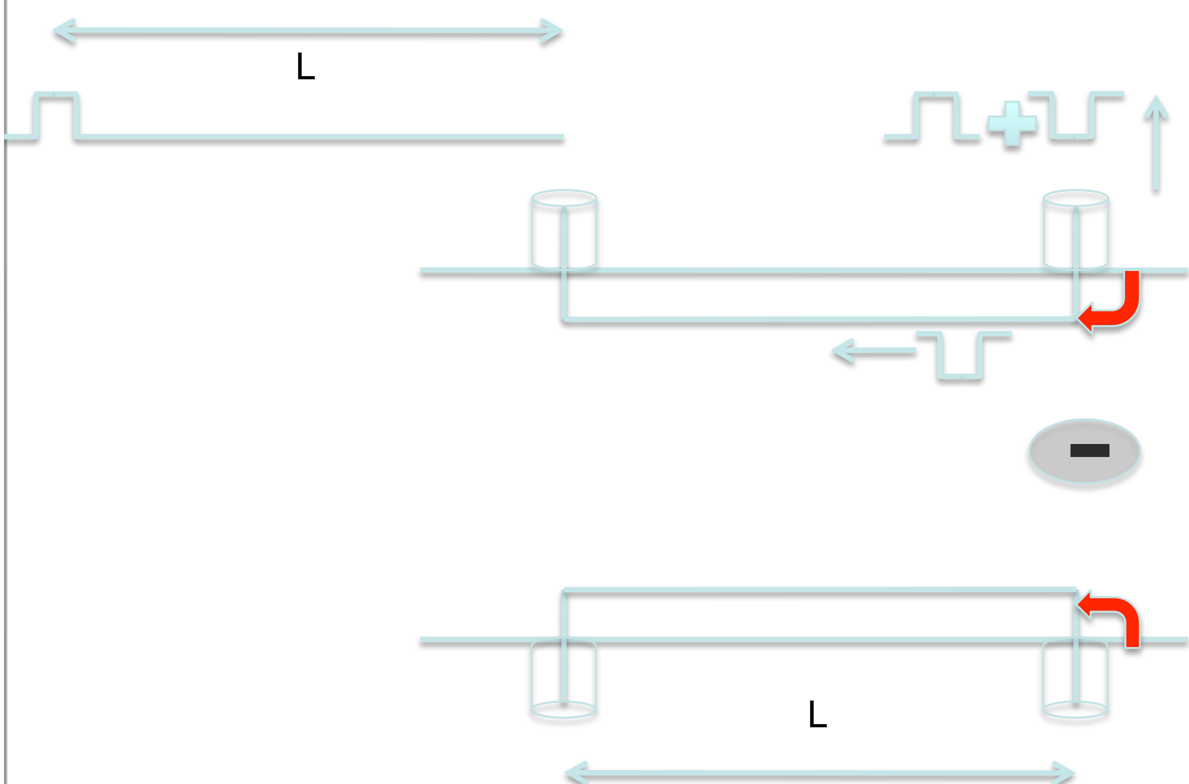
Stripline as a Pickup

- Beam passes upstream port of PU
  - Induced voltage at gap
  - If stripline impedance is matched to upstream output port, half of pulse exits port, the other half travels downstream. For vacuum, pulses moves at c.



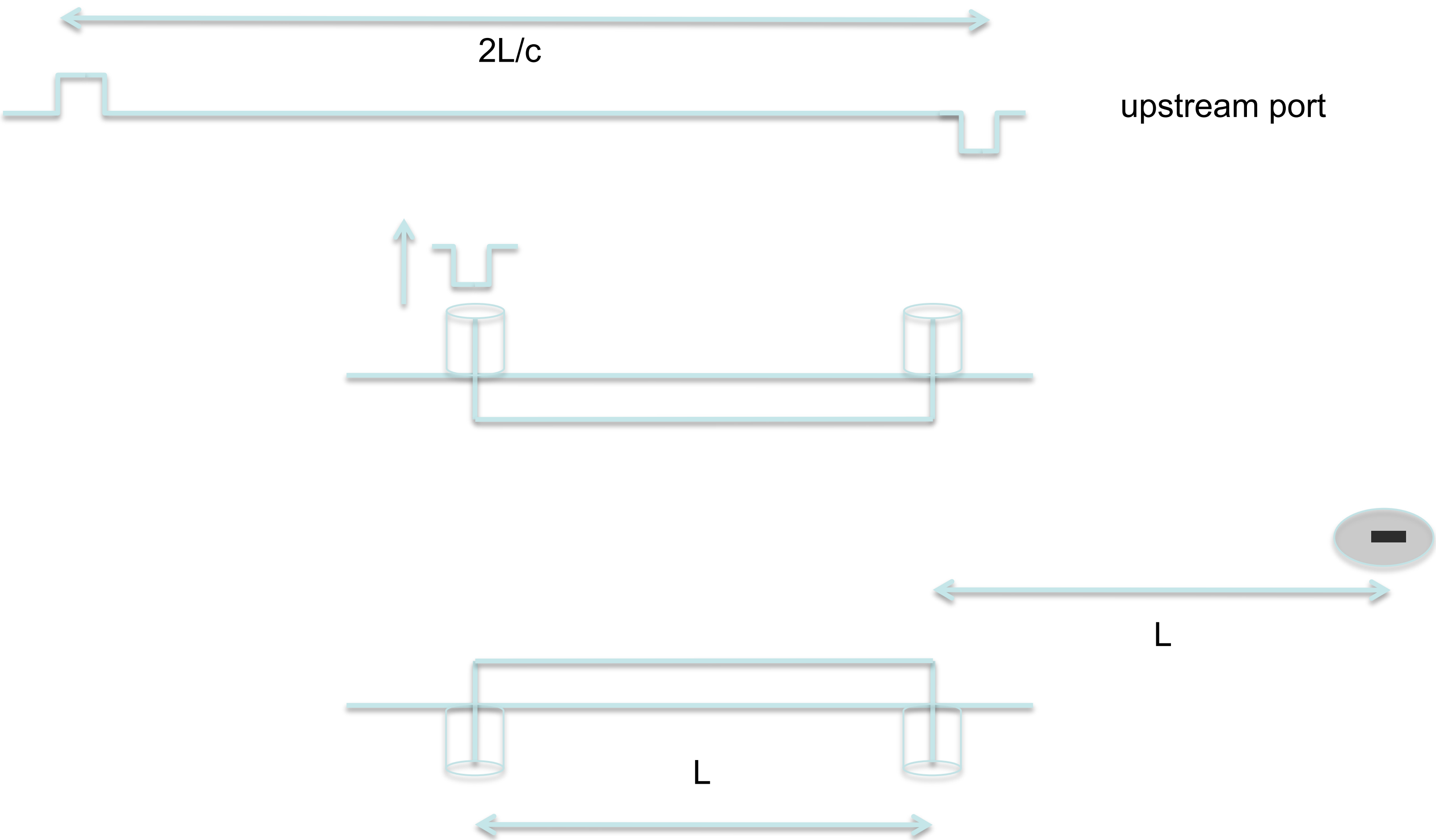
Stripline as a Pickup

- Beam passes downstream port of PU
  - Induced voltage at gap (opposite polarity to upstream port)
  - If stripline impedance is matched to downstream output port, half of pulse cancels pulse from upstream port, the other half travels upstream and is observed at upstream port at a time 2L/c.



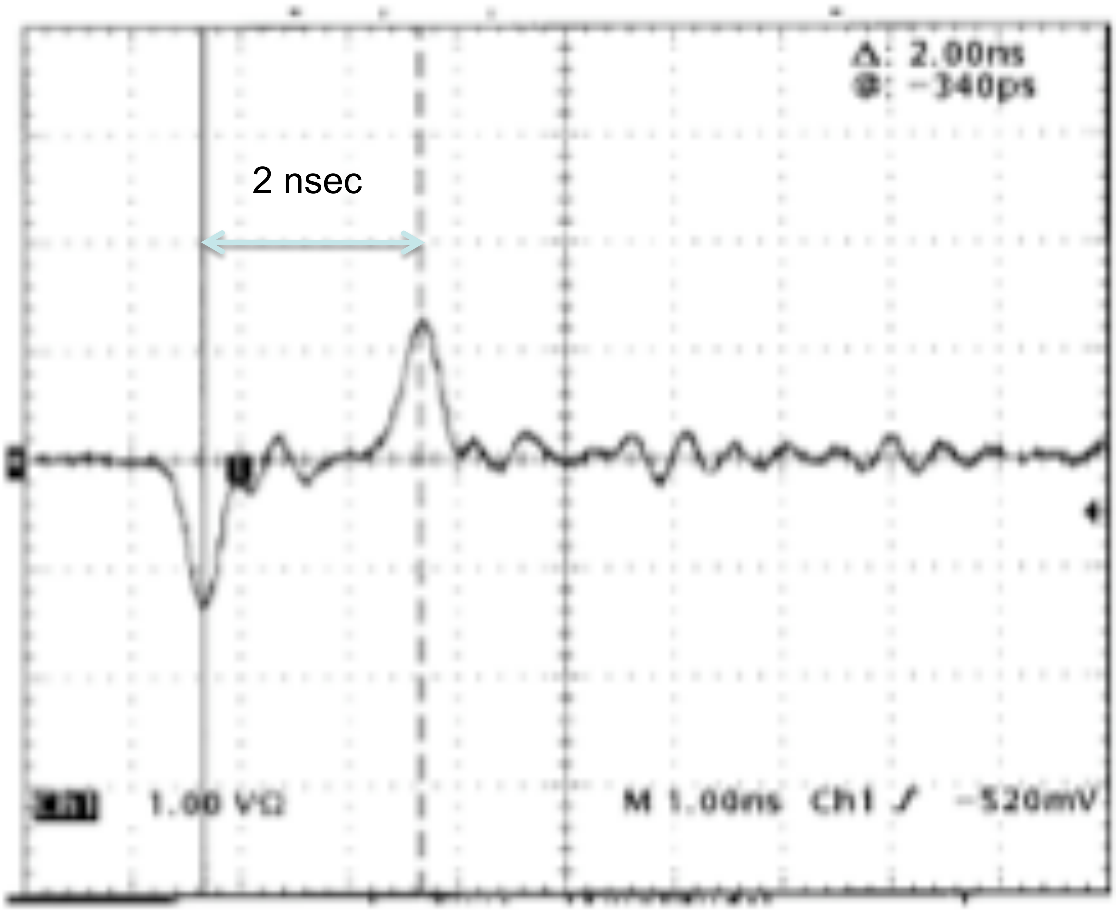
Stripline as Pickup

- The downstream pulse exits through the upstream port at a time 2L/c. No signal from downstream port (ideal case)



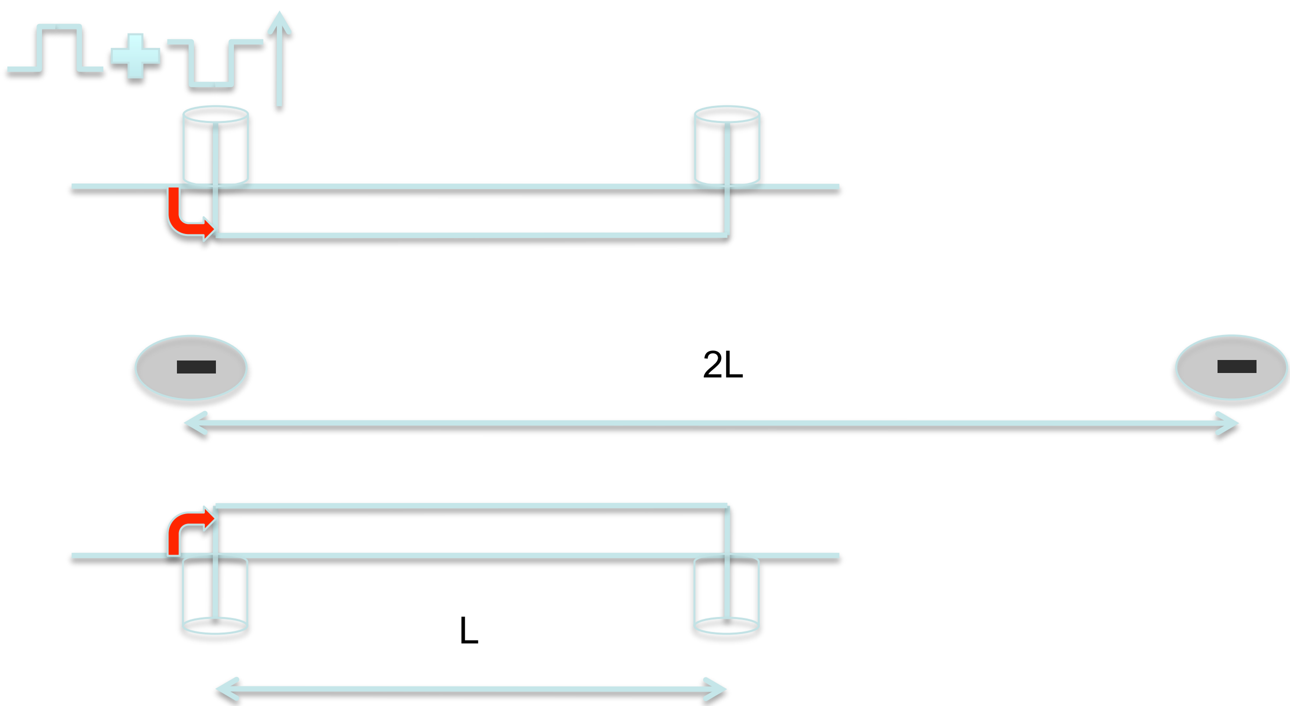
Example Stripline Signal

- Advanced Light Source stripline. Signal at the upstream port. Kicker length is 1 nsec (30 cm)



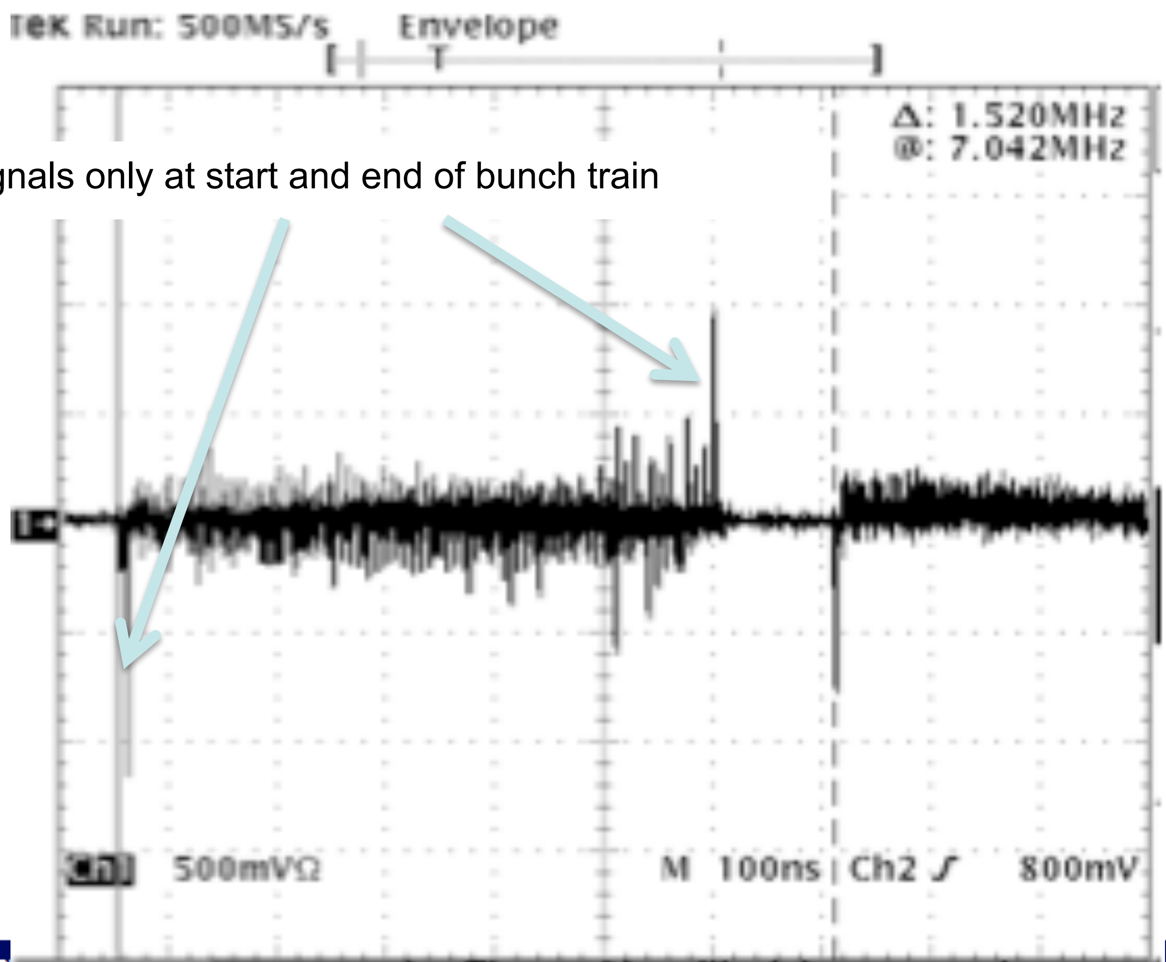
Multibunch signals

- Multibunch beam with bunches separated by 2L/c. The next bunch signal cancels the downstream signal from the previous bunch. Therefore, NO SIGNAL for this bunch spacing! Maximum signal power for a bunch spacing of L/c.



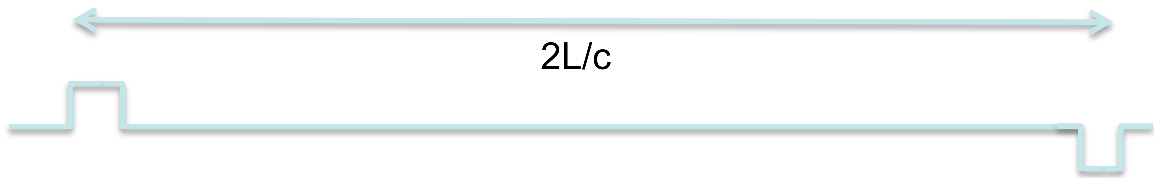
Example Multibunch Signal

- ALS stripline kicker (used as a PU, upstream port)
- L=30 cm (1 nsec), Bunch spacing 60 cm (2 nsec)



Frequency Response

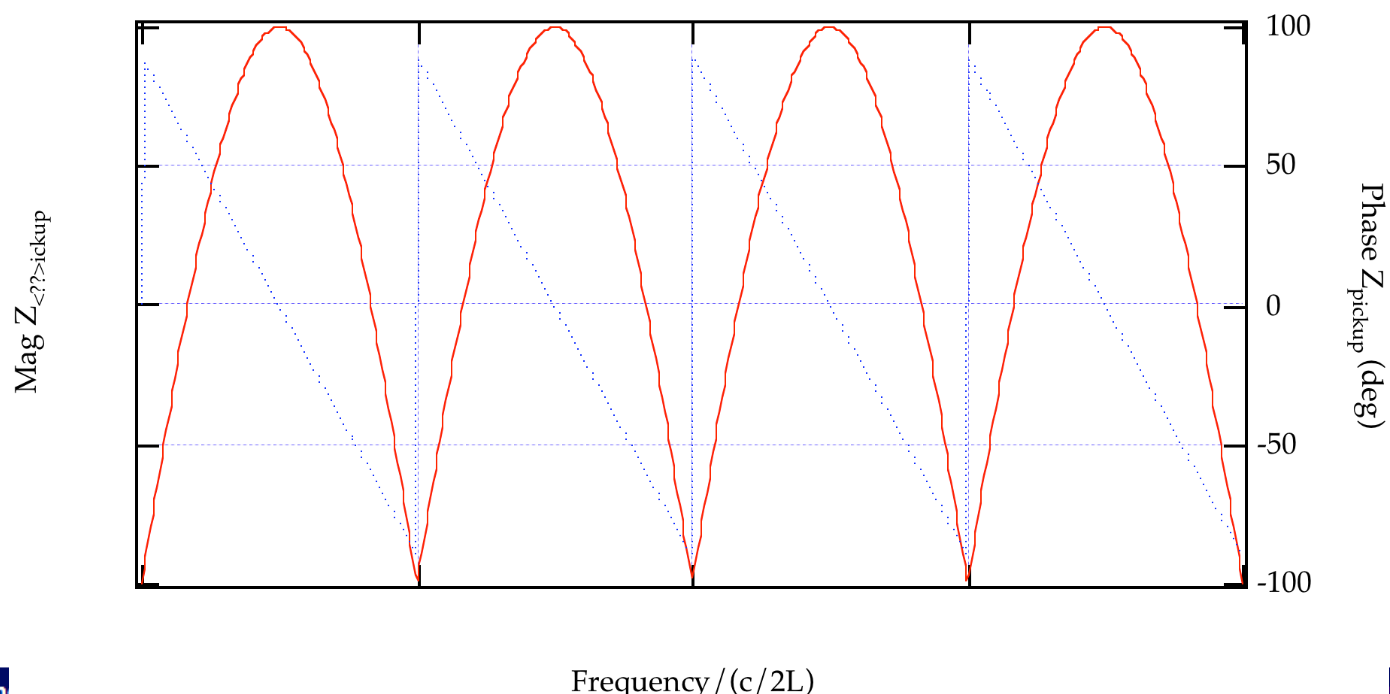
- The signal from the upstream port is a bipolar pulse separated by 2L/c



- This signal in the frequency domain is given by (assume the pulses are delta functions)

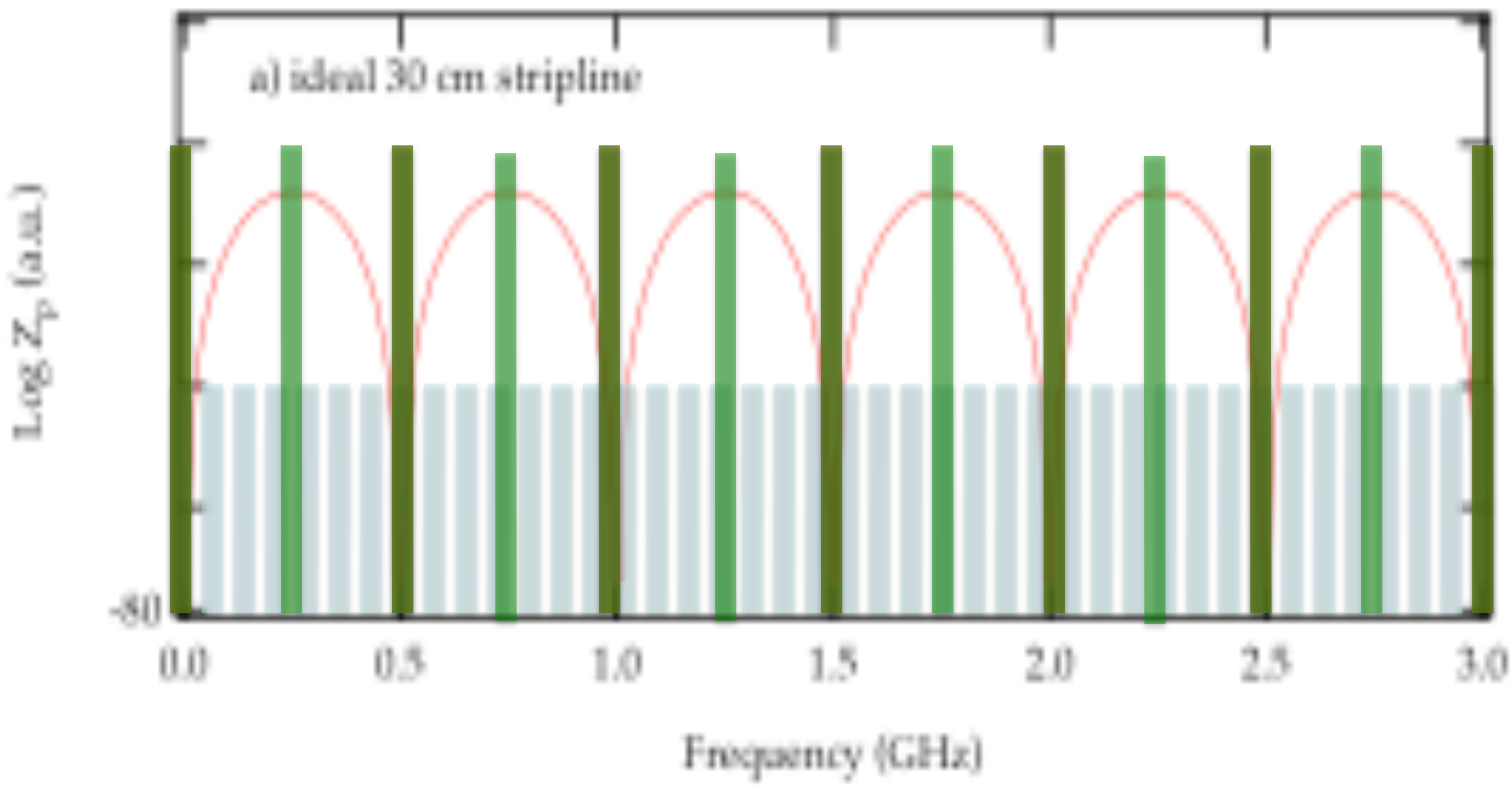
$$V_1(\omega) = \frac{1}{2} g R_0 I_b \left(1 - e^{-2jkL}\right)$$

g=fraction of image current intercepted by stripline
R_0=stripline characteristic impedance



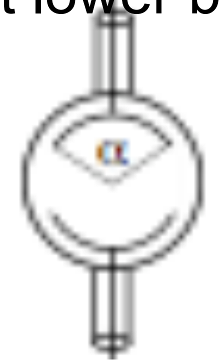
Beam Signal in Frequency Domain

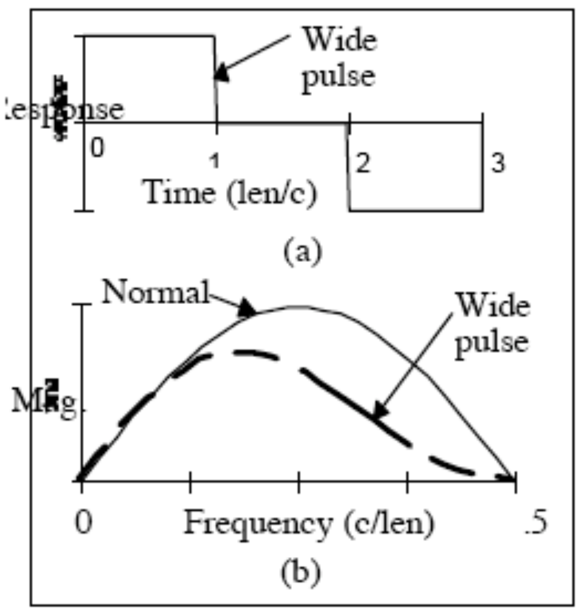
- Frequency domain signal is the product of the beam spectrum with the pickup impedance
  - Signal bunch
  - Multibunch
    - Separation by 2L/c
    - Separaction by 4L/c

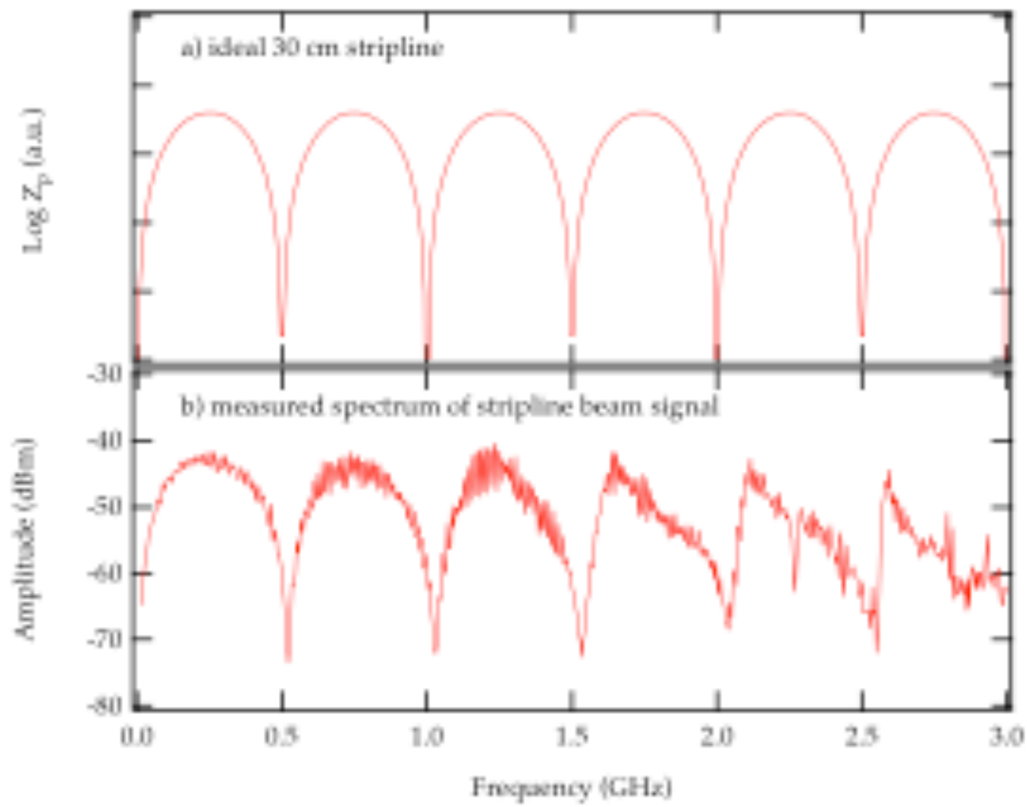


Bandwidth Limitations

- At higher frequencies, the stripline deviates from the ideal response.
- One issue is width of the pickups broadening the delta function response at the pickup. Wider pickups have larger signal but lower bandwidth







Stripline kickers: a simplified model

- We apply an alternating voltage between the plates:

$$V = V_0 e^{i\omega t}$$

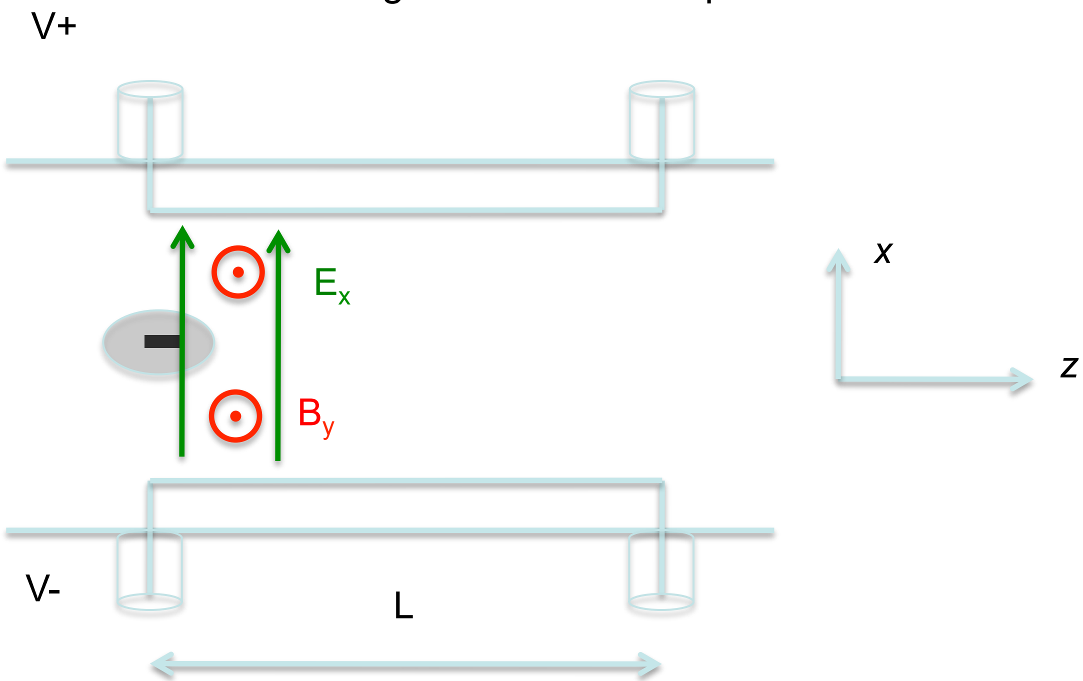
- From Maxwell's equations, there are electric and magnetic fields between the plates:

$$E_x = E_0 e^{i(kz-\omega t)} \qquad B_y = \frac{E_0}{c} e^{i(kz-\omega t)}$$

A particle traveling in the $+z$ direction with speed c will experience a force:

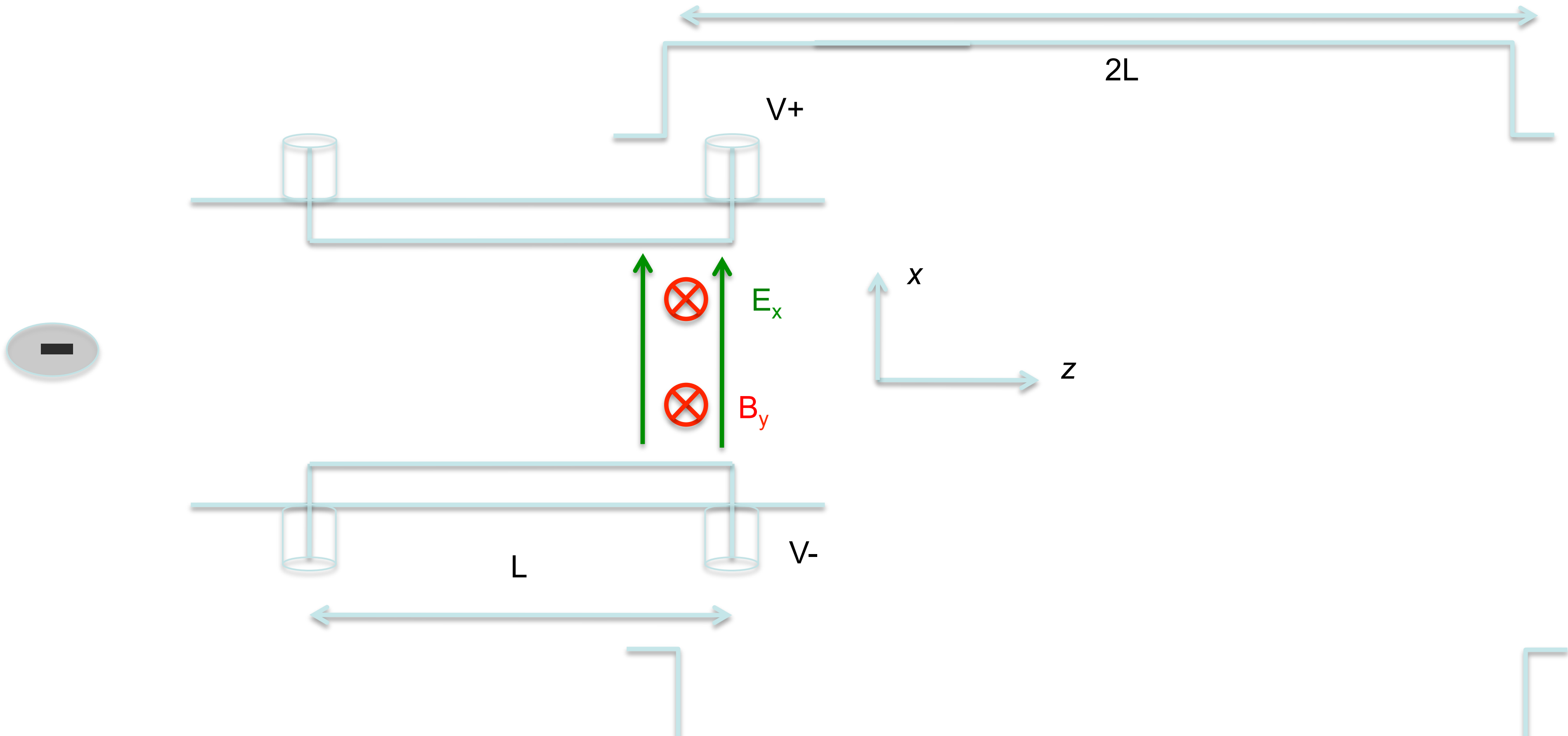
$$F_x = q\left(E_x - v_z B_y\right) = q(1-\beta)E_0 e^{-i(1-\beta)\omega t}$$

- For an ultra-relativistic particle, and the electric and magnetic forces almost exactly cancel: the resultant force is small. But for a particle traveling in the opposite direction to the electromagnetic wave, and the resultant force is twice as large as would be expected from the electric force alone.



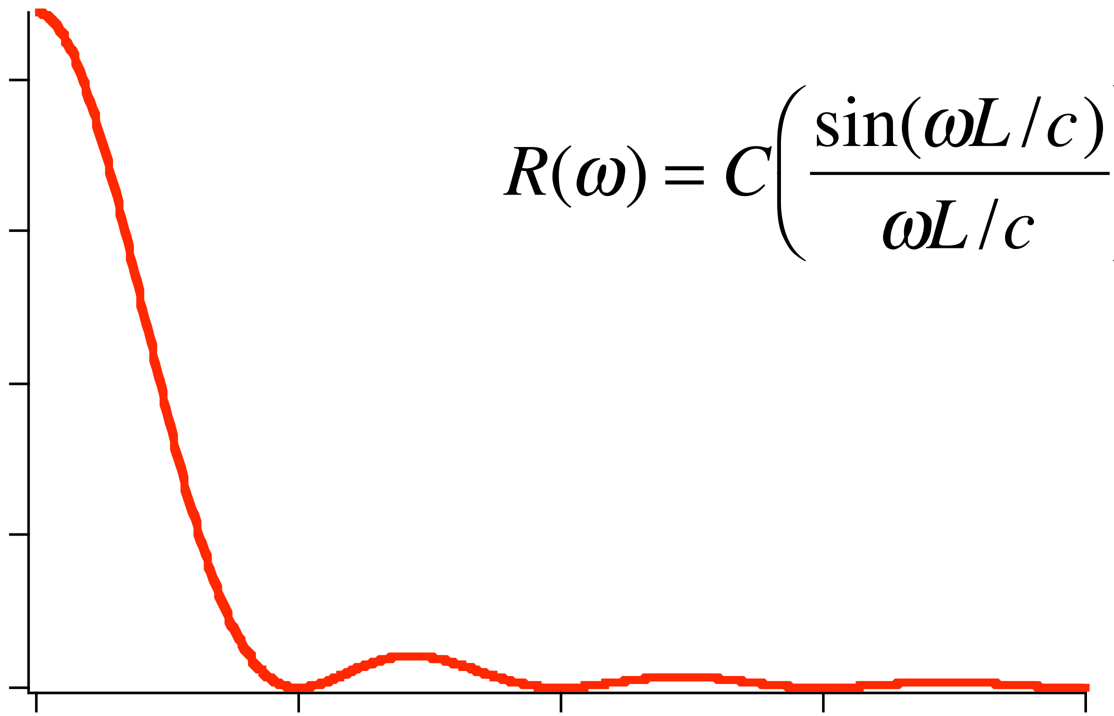
Stripline Kickers

- Consider a differential voltage pulse into the downstream port
  - Forces from E and B fields are equal and in the same direction
  - Pulse must be twice as long as kicker length for greatest efficiency
  - To give individual bunches separate kicks, kicker must be less than twice the bunch spacing.



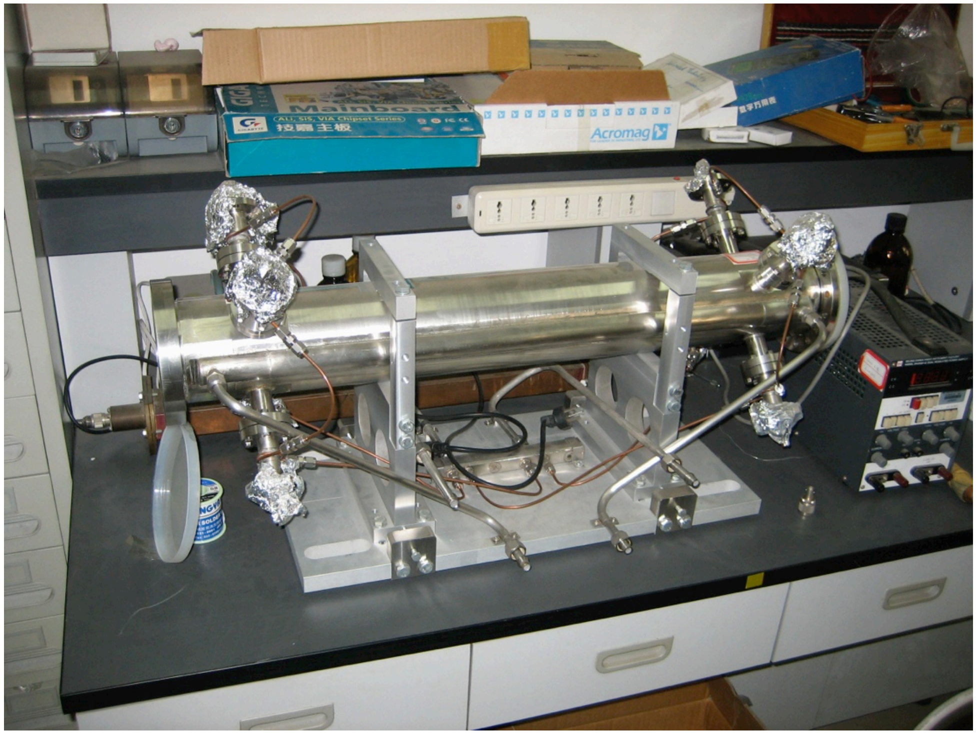
Transverse kicker frequency response

- Transverse kicker frequency response can be found from transform of square pulse
  - Nonzero DC response (i.e. works as constant deflector)
  - First zero in response at f=c/2L
  - Best response at baseband. Reduced response in upper bands.

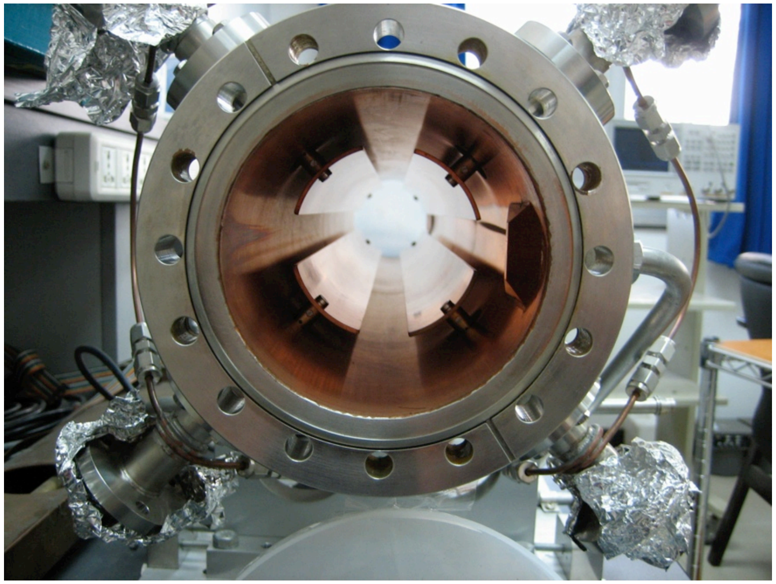


$$R(\omega) = C\left(\frac{\sin(\omega L/c)}{\omega L/c}\right)^2$$

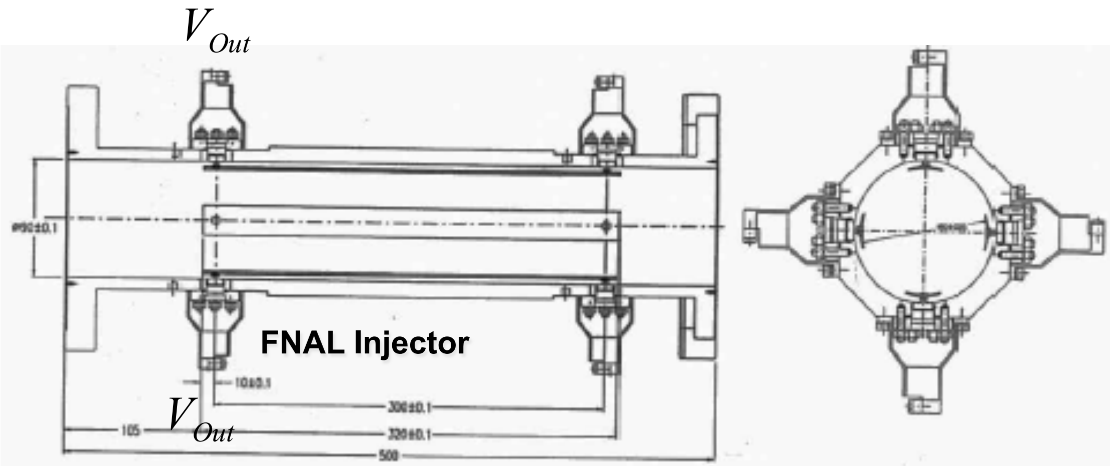
Example: BEPC-II Stripline Kicker

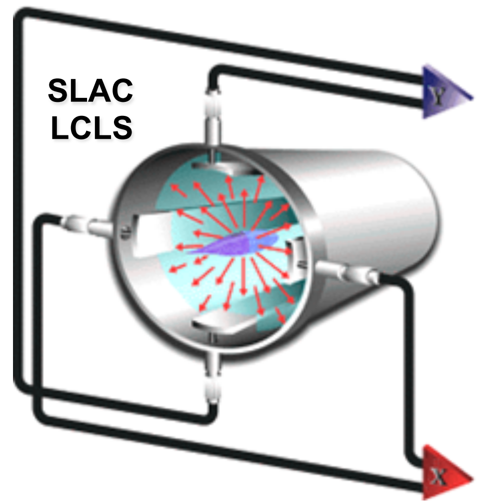


Often, horizontal and vertical electrodes are combined in the same tank.

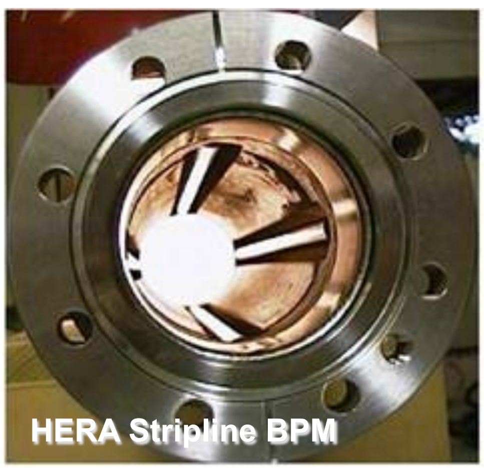


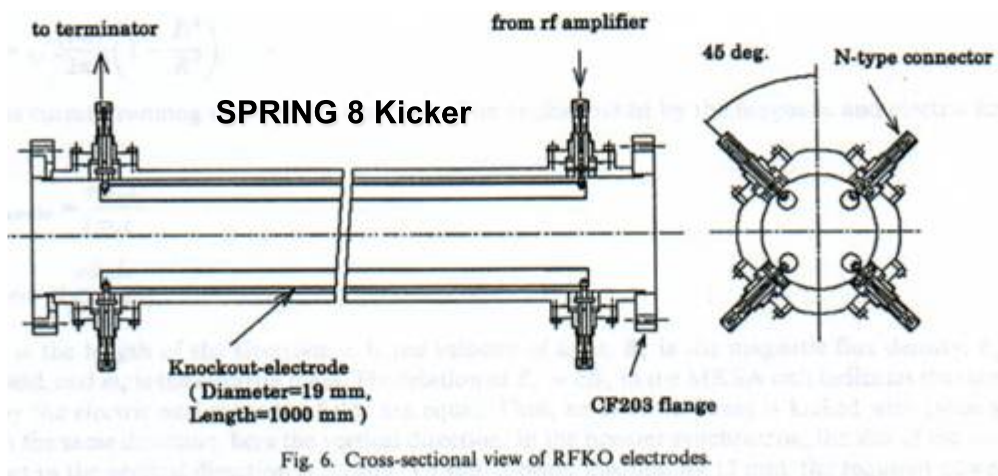
Stripline BPM





- **Stripline structures are also widely used as the "kicker" in transverse and longitudinal feedback systems.**





Beam Position – Cavity BPMs

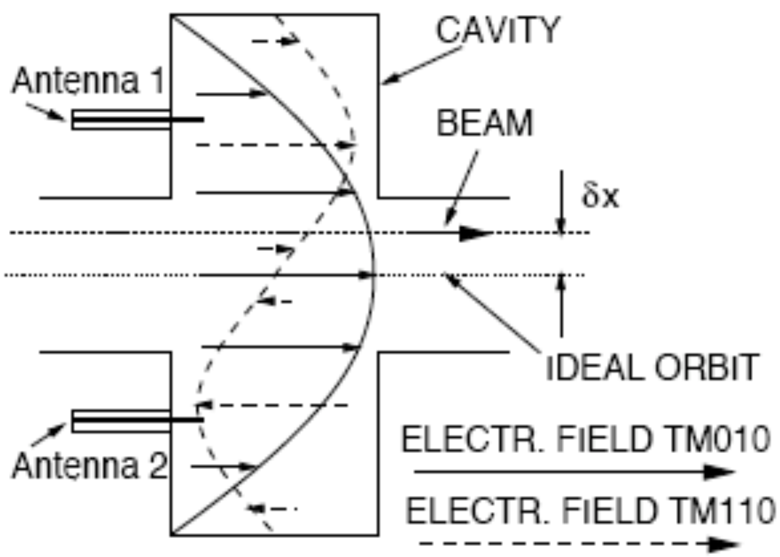
principle: excitation of discrete modes (depending on bunch charge, position, and spectrum) in a resonant structure; detection of dipole mode signal proportional to bunch charge, q×transverse displacement, δx

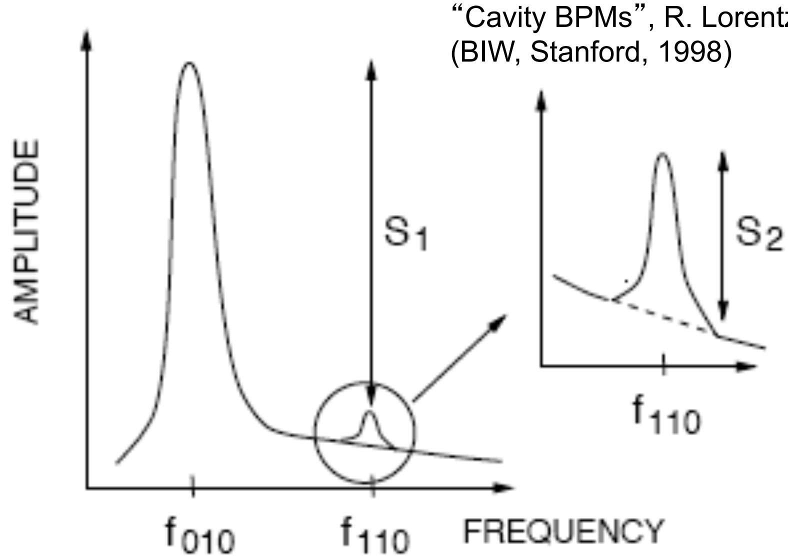
theoretical treatment: based on solving Maxwell's equations for a cylindrical waveguide with perpendicular plates on two ends

motivation: high sensitivity (signal amplitude / μm displacement)
accuracy of absolute position, LCLS design report

dipole mode cavity BPM consists of (usually) a cylindrically symmetric cavity, which is excited by an off-axis beam:

reference:
"Cavity BPMs", R. Lorentz
(BIW, Stanford, 1998)





TM_{010}, "common mode" ($\propto$ I)
TM_{110}, dipole mode of interest

} amplitude detected at position of antenna contains contributions from both modes → signal processing

- One example of a typical Cavity BPM signal path
  - Dipole cavity gives offset signal. Magic-T used to subtract monopole mode
  - Separate monopole cavity used to produce reference signal

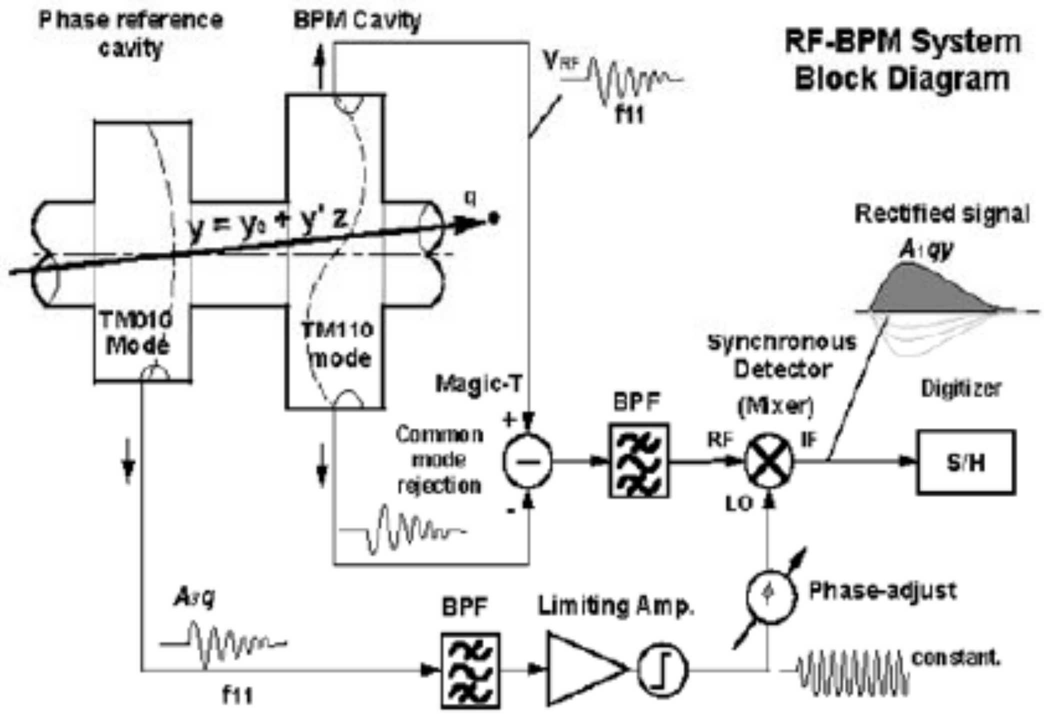
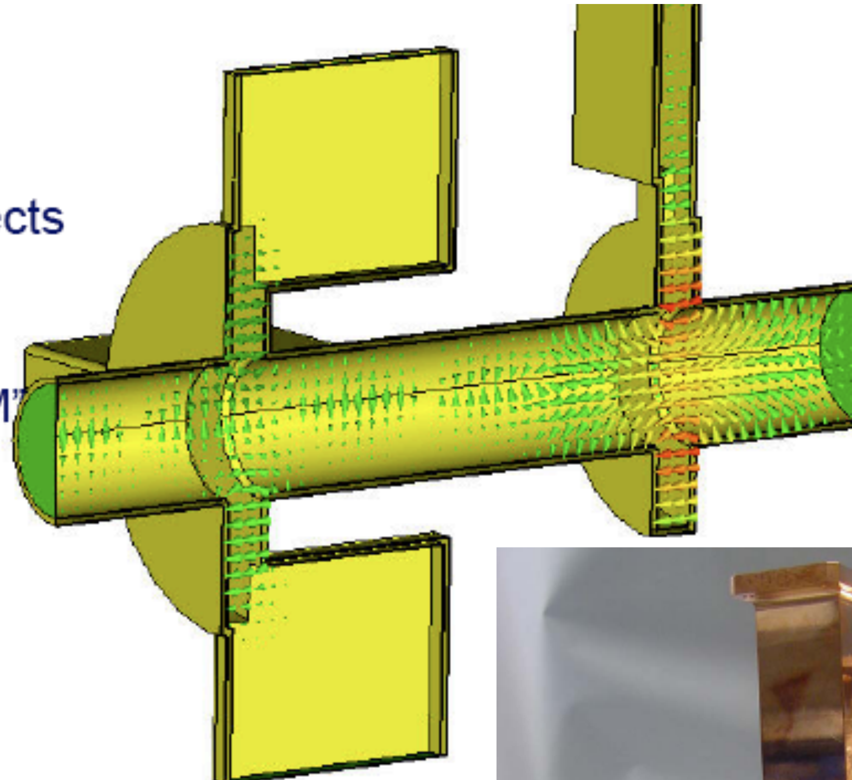


Fig. 2. Simplified RF-BPM Diagram.

Example: LCLS Cavity BPM

Concepts

- Avoid the monopole mode
- Cavity-waveguide coupler rejects monopole mode by symmetry
  - Zenghai Li (PAC 2003)
  - T. Shintake, "Comm-free BPM"
  - V. Balakin (PAC 1999)
- Predecessor at KEK's ATF
  - 16 nm resolution in test beam Walston, (NIM 2007)



Choices

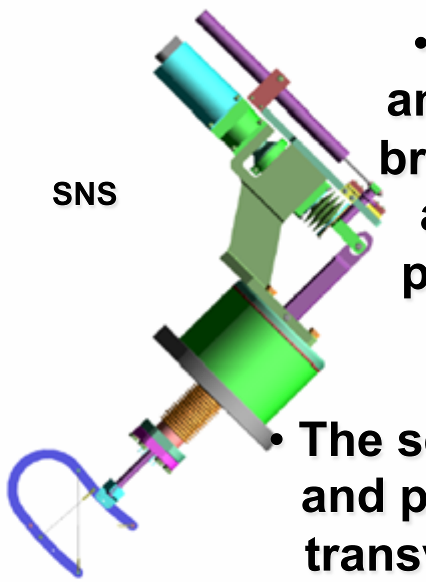
- Single, degenerate X&Y cavity
- Reference cavity per BPM

Steve Smith, SLAC

Beam Profile Monitors: Wire Scanners

• A moveable wire scans the beam transversally.

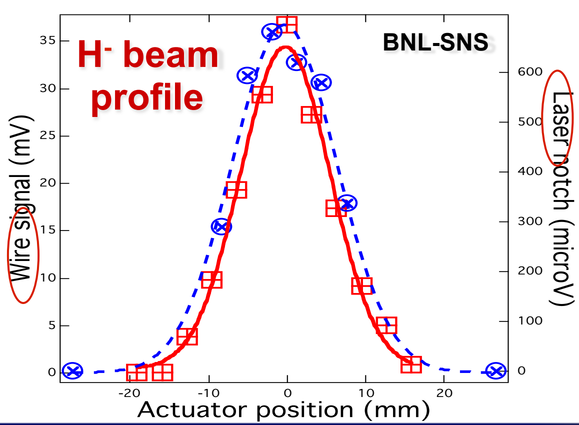
SNS

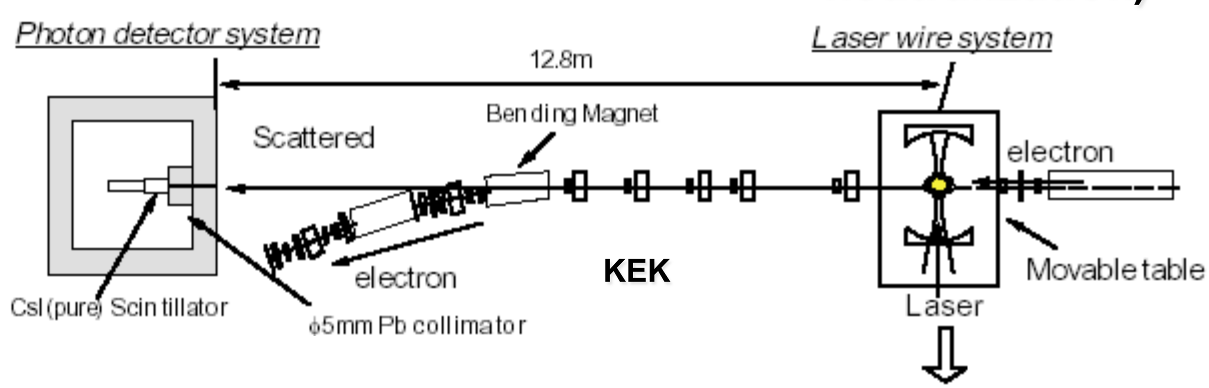


• The interaction between the beam and the wire generates (by ionization, bremsstrahlung, atomic excitation, …) a “shower” of secondary emission particles proportional to the number of beam particles hitting the wire.

• The secondary particles (mainly electrons and photons) are detected and the beam transverse profile can be reconstructed.

•The wire material can be a metal, carbon, or … a laser beam (Compton scattering, neutralization)





Transverse Beam Emittance – Laser Wire Scanners

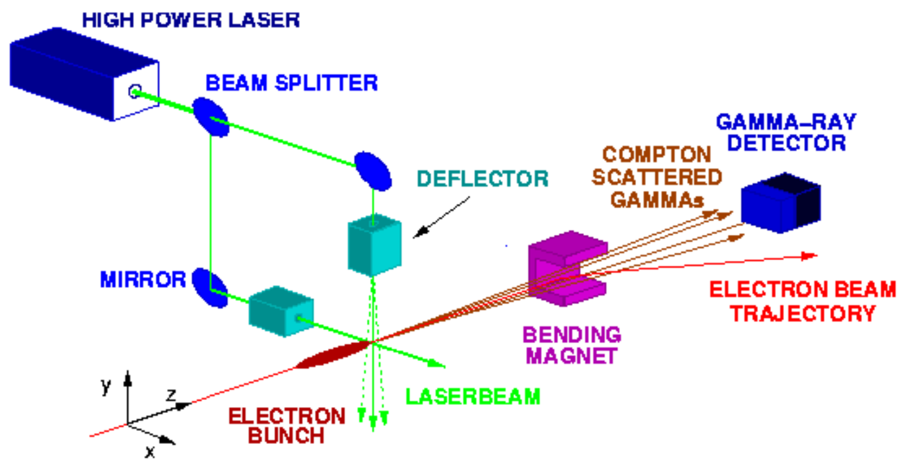
principle: laser wire provides a non-invasive and non-destructable target
wire scanned across beam (or beam across wire)

constituents: laser, optical transport line, interaction region and optics, detectors

beam size measurements: forward scattered Compton γs or
lower-energy electrons after deflection by a magnetic field

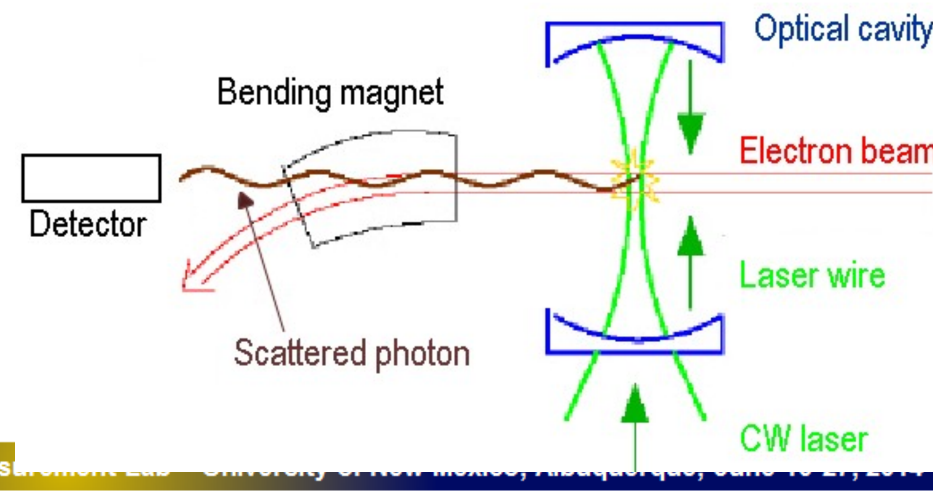
schematic of the laser wire system planned for use at PETRA and for the third generation synchrotron light source PETRA 3 (courtesy S. Schreiber, 2003)

high power pulsed laser



overview of the laser wire system at the ATF (courtesy H. Sakai, 2003)

optical cavity pumped by CW laser (mirror reflectivity ~99+%)

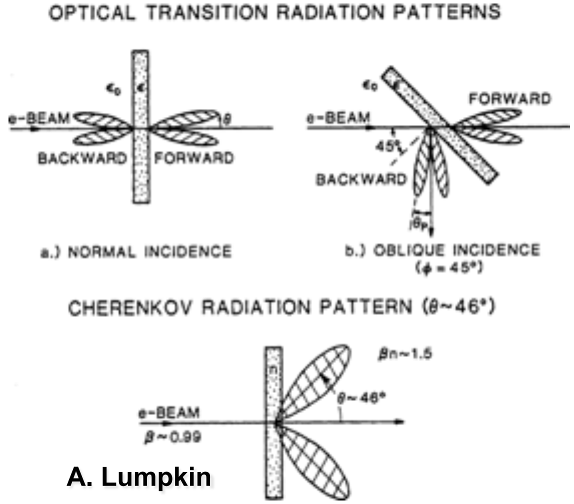


Photon-based Beam Profile Monitors

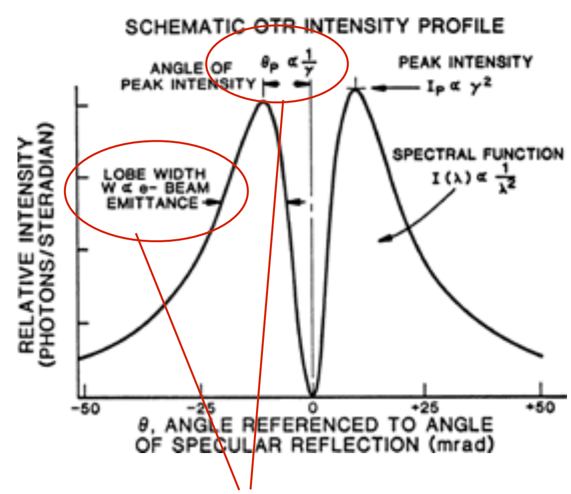
• Photon diagnostics exploiting the described emission mechanisms are widely used for measuring the transverse and longitudinal profiles of relativistic beams.

• In fact, the spatial distribution of the photons reproduces the particle distribution of the beam and can be conveniently used for the characterization of the beam.

• Monitors exploiting transition and Cerenkov radiation are relatively invasive and are mainly used in single pass or few-turns accelerators.



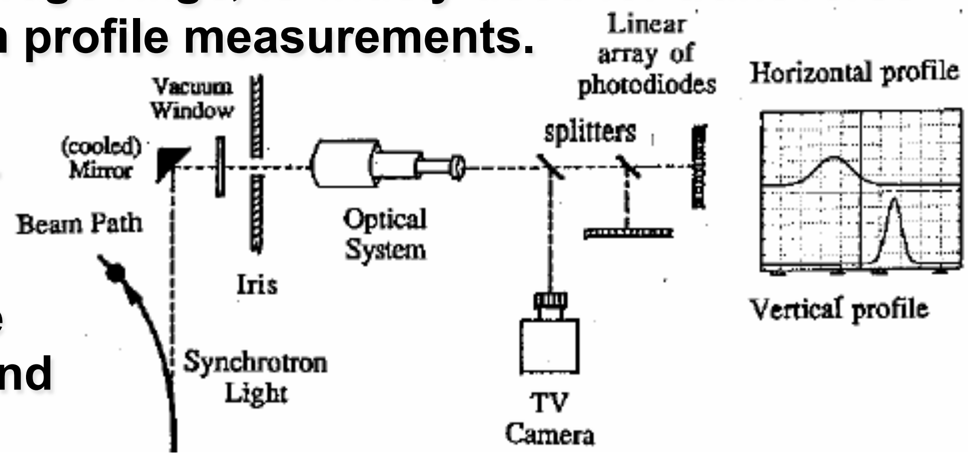
A. Lumpkin



• The angular distribution of the photons depends on several beam parameters. This fact can be exploited for the measurements of quantities other than the beam distribution as well.

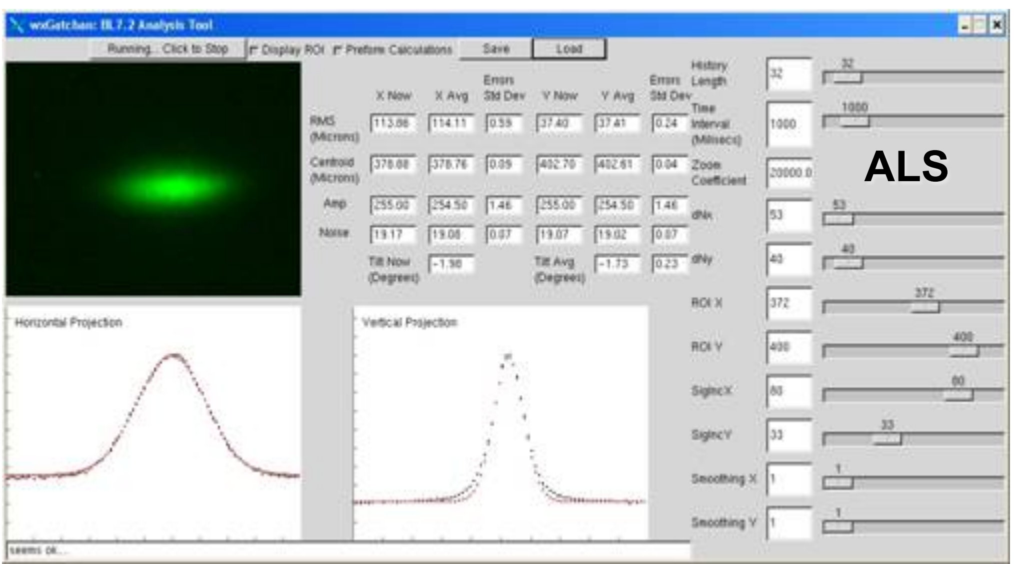
Synchrotron Radiation Monitors

• Synchrotron radiation, very abundant in electron and positron accelerators and present in very high energy proton storage rings, is widely used for transverse and longitudinal beam profile measurements.



• One of the appealing features of such diagnostic systems is that they are non-invasive.

• The resolution of these monitors are limited by the geometry of the system and by the radiation diffraction.



• The geometric limitation requires small aperture systems while the diffraction term requires large apertures and shorter photon wavelengths. Tradeoff solutions must be adopted.

• The typical resolution in electron storage rings using hard x-ray photons ranges between few and tens of microns.

Photon-based Longitudinal Profile Monitors

- In photon-based longitudinal beam profile monitors, “fast” detectors such as *streak cameras*, *fast photodiodes and photomultipliers* are used.
  In last generation streak cameras systems, time resolutions of several hundreds of fs have been achieved.

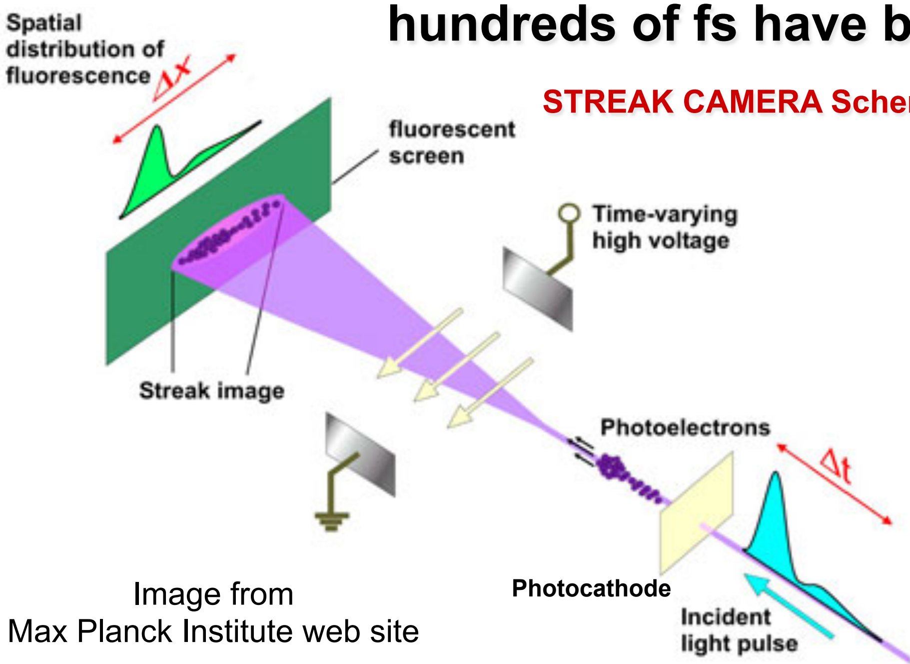
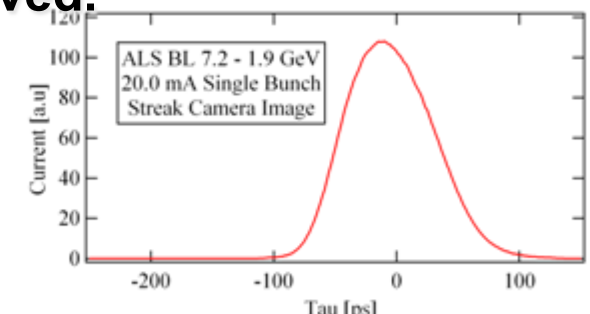
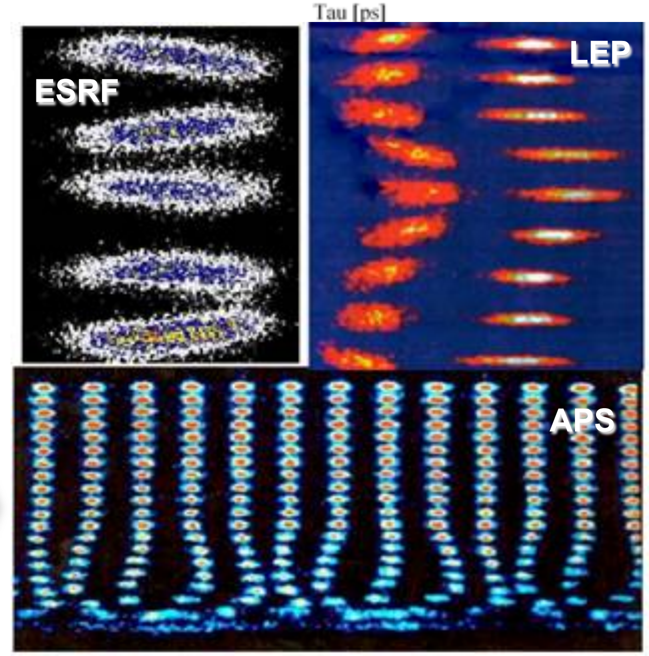


Image from
Max Planck Institute web site

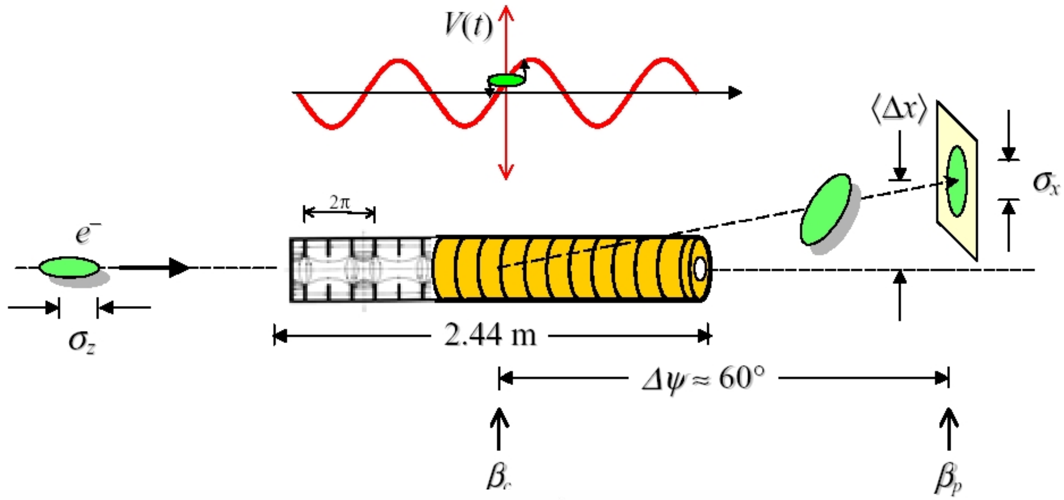


- Streak cameras with an additional pair of sweeping electrodes (orthogonal to the other one) have single bunch-single turn capabilities and can be used for the characterization of single and multibunch intabililities.



Bunch Length – Transverse Mode Cavities

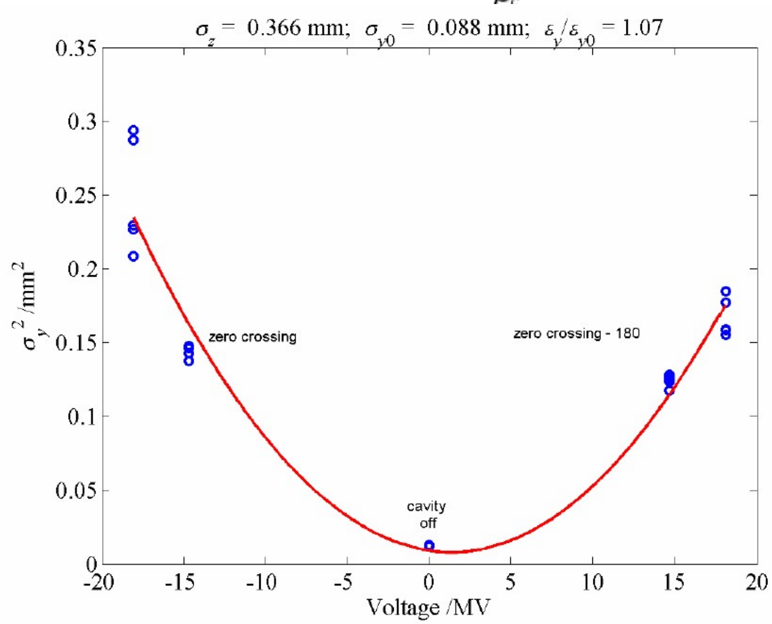
Principle: use transverse mode deflecting cavity to "sweep"/kick the beam, which is then detected using standard profile monitors



Principle of the TM_{11} transverse mode deflecting cavity

introduce x-z correlation

oriented to displace beam vertically while a horizontal bending magnet deflects the beam onto the screen



$$\sigma_y^2 = A(V_{rf}-V_{rf,min})^2 = \sigma_{y0}^2$$

$$\sigma_z = A^{1/2}E_0\lambda_{rf}/2\pi R_{34}$$

σ_z expressed in terms of fit parameter, A

(figures courtesy R. Akre, 2003)

Other Beam Profile Monitors

• The simplest beam profile monitor is probably the one using fluorescent screens intercepting the beam.

• The beam particles hitting the screen material excite the atoms that subsequently radiate a photon in the visible range when decaying back to the ground state.

• The resulting image of the beam on the screen can be visualized by a ccd camera and eventually digitized by a frame grabber for further analysis.

• Such monitors are destructive and are typically used only in beam transferlines.

•Another category of beam profile monitors are the ionization chambers.

• In this monitor, a gas in a dedicated portion of the vacuum chamber is ionized by the passage of the beam.
Depending on the scheme used, either the electrons or the ionized atoms can be detected for the beam profile reconstruction. Time of flight analysis of the ionized particles is usually necessary.

• Because of their perturbative nature, these monitors are mainly used in single pass accelerators.

Schottky Noise Monitors

A beam is composed by a finite number of particles. The beam signal collected by a detector at a fixed position in a storage ring shows statistical fluctuations of the intensity due to the random arrival time of the particles at the detector position. Such intensity fluctuations are referred as Schottky noise (SN).

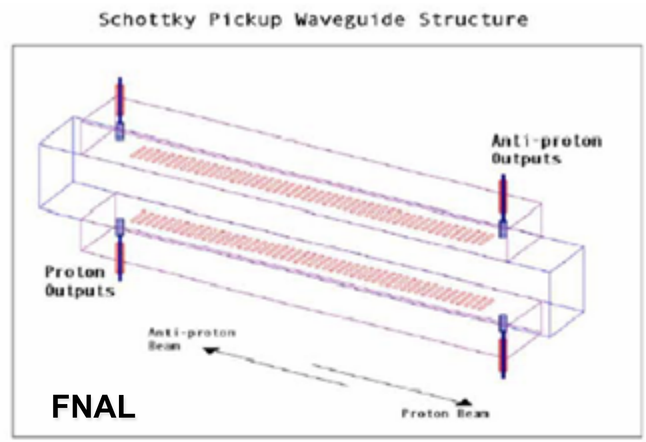
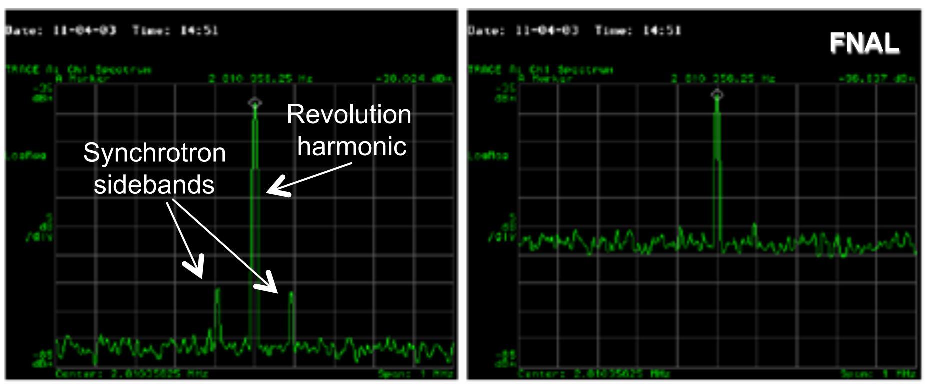


Fig. 2. Waveguide structure

SN spectra contain a lot of information concerning a number of beam quantities, including longitudinal and transverse tunes, momentum spread and beam current. Schottky noise monitors are actually the main non-invasive diagnostic tool used in heavy particle storage rings.



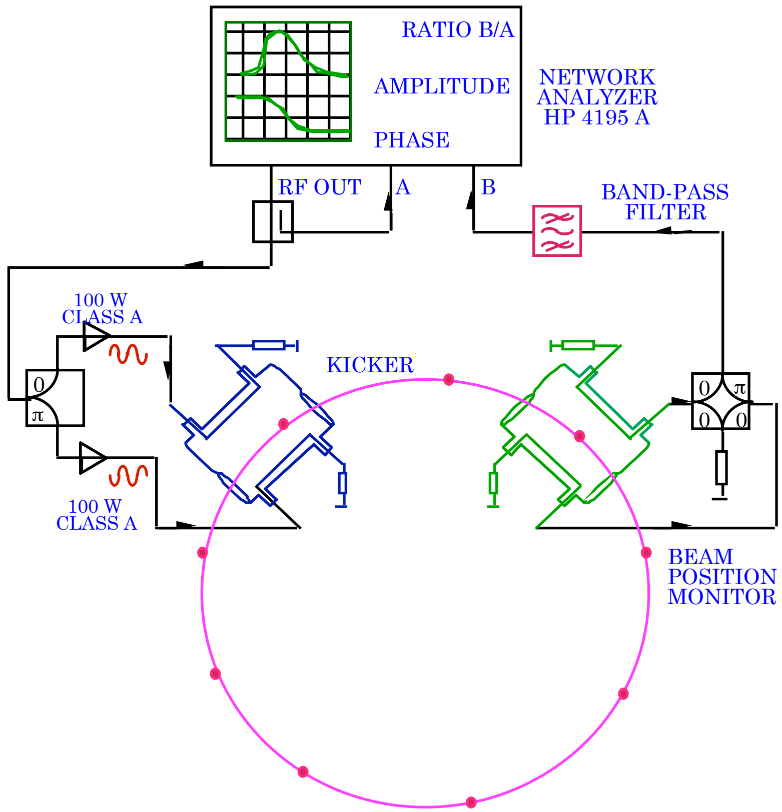
Horizontal Anti-proton Sum

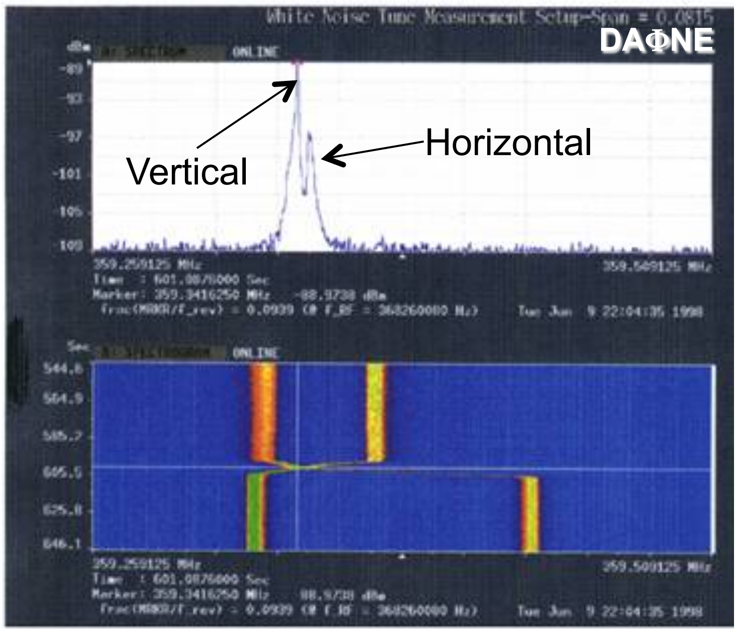
Horizontal Anti-proton Delta

Schottky noise cannot be used in electron and positron machines because in those accelerators, the noise due to synchrotron radiation quantum fluctuations is strong and covers the Schottky noise.

Tune Measurement

• In electron and positron machines, in order to measure the betatron tunes in the absence of instabilities, coherent beam oscillations need to be excited.

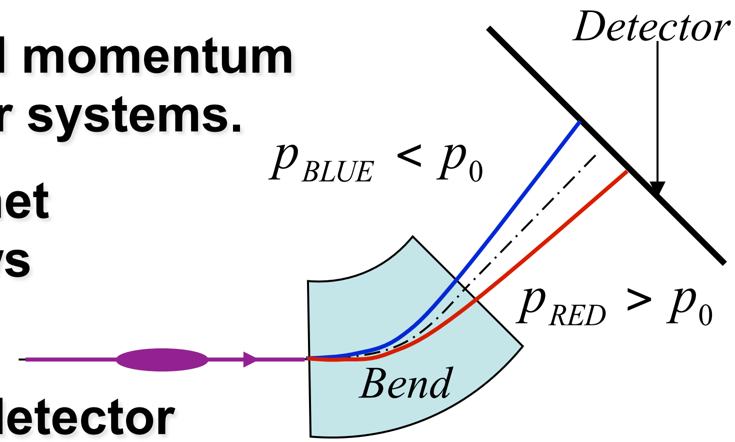




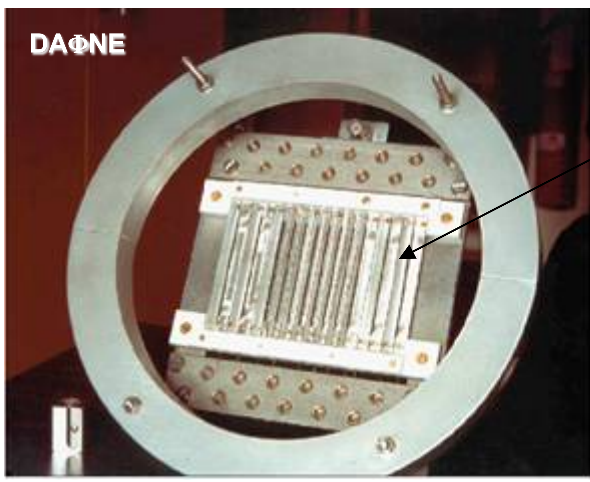
• Synchrotron tune can be measured by modulating the RF phase or amplitude and by measuring the induced sidebands using the sum signal from a pick-up.The same detection part of the betatron tune measurement system can be used.

Momentum and Momentum Spread Measurement

- In linacs and transferlines the momentum and momentum spread are mainly measured by spectrometer systems.

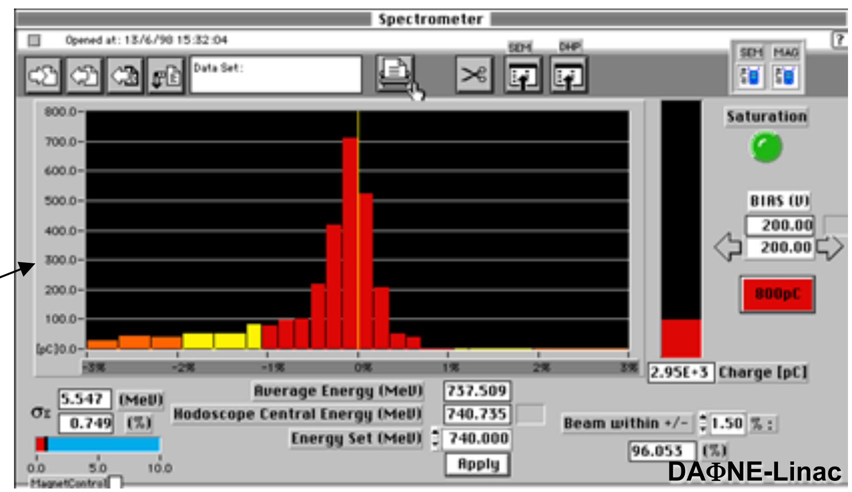


- The beam enters in the field of a dipole magnet where particles with different momenta follows different trajectories.
- The particle position is then measured on a detector downstream the magnet.



Secondary emission hodoscope

Spectrometer control window



- The spectrometer resolution is limited by the intrinsic beam size at the detector plane and by field non-linearities.

Momentum Spread & Emittance Measurement in Rings

- In electron and positron storage rings the equilibrium beam emittance and the momentum spread can be measured by the combined measurement of at least two transverse beam profiles at two different ring locations.

- The beam size at a particular azhimutal position is given by:

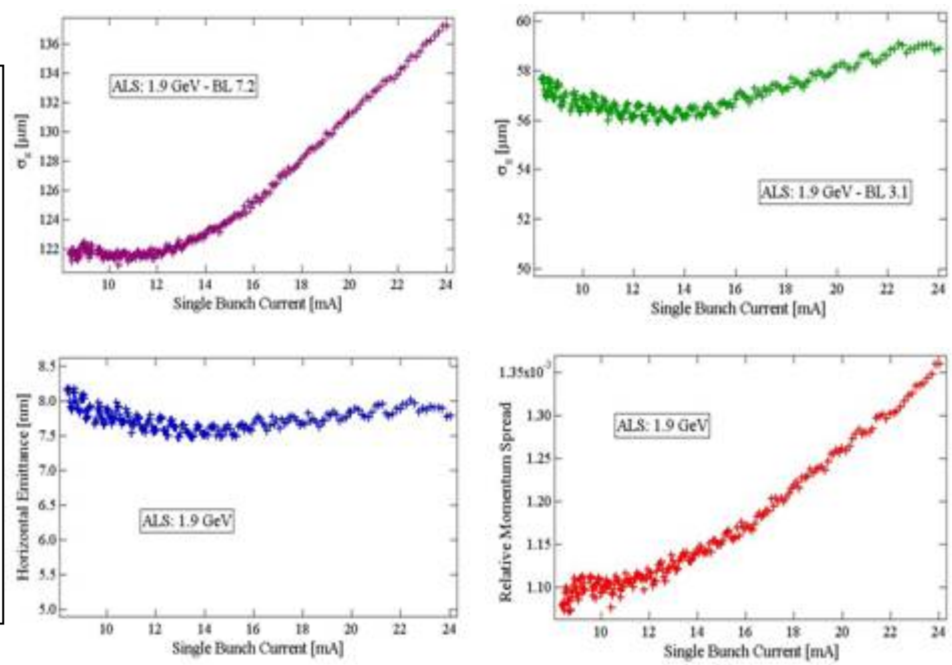
$$x_{rms\,i} = \left(\beta_{xi}\varepsilon \frac{1}{1+\kappa} + \left(\eta_{xi} \frac{\sigma_p}{p} \right)^2 \right)^{1/2} \qquad i \equiv system\ index = 1,\, 2$$

- If the beam size is measured in two different points of the ring and the optical functions at such points are known, then:

$$\boxed{\varepsilon_x = \frac{\varepsilon}{1+\kappa} = \frac{x_{rms1}^2 \eta_{x2}^2 - x_{rms2}^2 \eta_{x1}^2}{\beta_{x1}\eta_{x2}^2 - \beta_{x2}\eta_{x1}^2}}$$

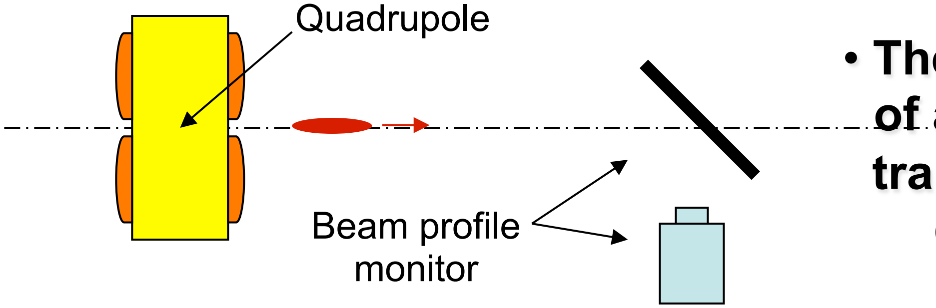
$$\boxed{\left(\frac{\sigma_p}{p} \right)^2 = \frac{x_{rms2}^2 \beta_{x1} - x_{rms1}^2 \beta_{x2}}{\beta_{x1}\eta_{x2}^2 - \beta_{x2}\eta_{x1}^2}}$$

ε:	emittance
p:	momentum
β:	beta function
η:	dispersion
κ:	emittance ratio
x_{rms}:	rms beam size



Emittance Measurement In Linacs and Tranferlines

- A "popular" technique for measuring the emittance in linacs or transferlines uses the so-called "**three gradient method**".



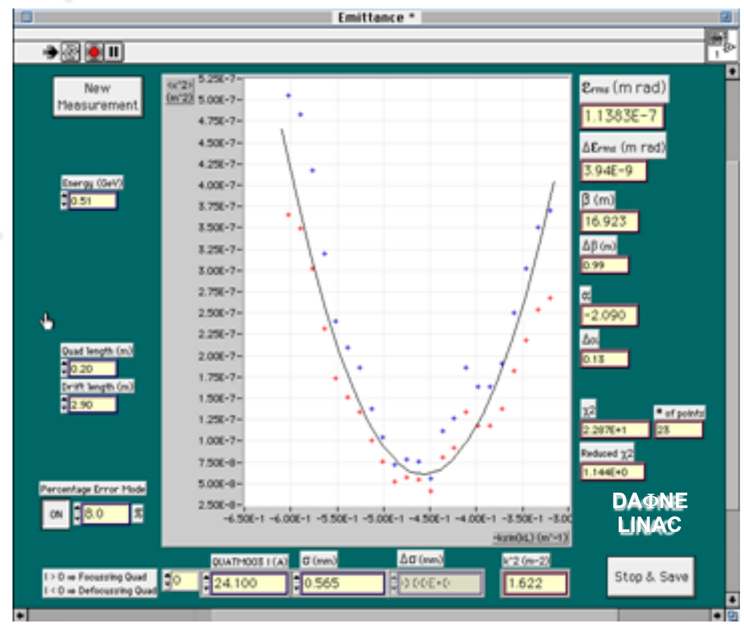
- The gradient (focusing-defocusing strength) of a quadrupole is changed and the related transverse beam profiles are recorded by a detector downstream the quadrupole.

- The measurement requires a minimum of 3 different quadrupole gradients but the accuracy can be improved if more points are taken.

- The beam size at the detector is defined by the beam emittance and by the local beta function. The emittance is an invariant while the beta changes with the changing quadrupole gradient.

- An analytical expression linking the transverse profiles with the beam emittance can be derived and used for fitting the experimental data.

- From the fit, the values for the emittance and for the optical functions at the quadrupole position can be finally extracted.



References

R. Littauer, “Beam Instrumentation”, Proc. Physics of High Energy Particle Accelerators (Stanford, CA, 1982); AIP Conf. Porc. 105 (1982) 869.

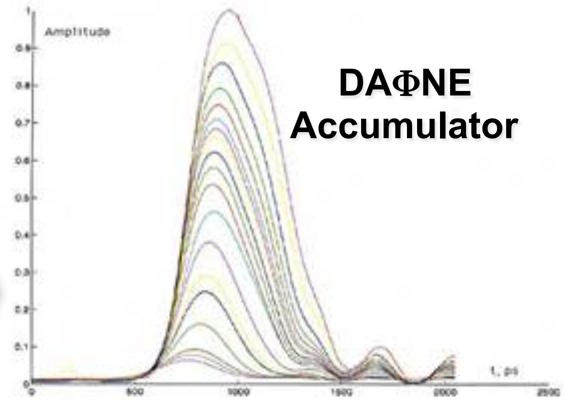
M. Serio, “Diagnostica e misure”, Seminars on DAΦNE, February 2000.

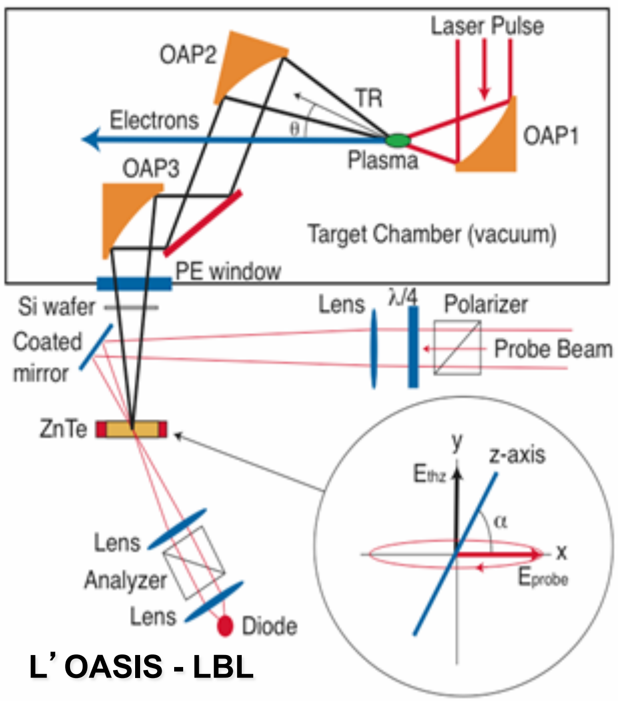
M. Zolotorev, “Radiation and Acceleration”, tutorial, LBL 2005.

M. Minty, “Diagnostics”, CAS Synchrotron Radiation and Free-Electron Lasers, Brunnen, Switzerland, July 2003.

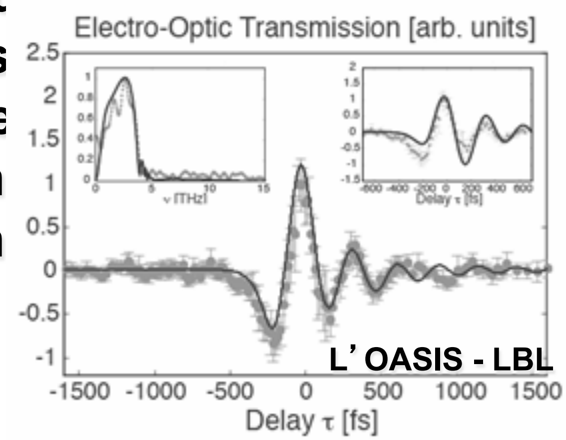
More on Longitudinal Profile Monitors

- For relatively long bunches ~ 100 ps or longer electromagnetic pickups can be efficiently used.
- In this example, the beam inside the DAΦNE Accumulator (~ 150 ps rms) is measured by using the signal from a stripline.



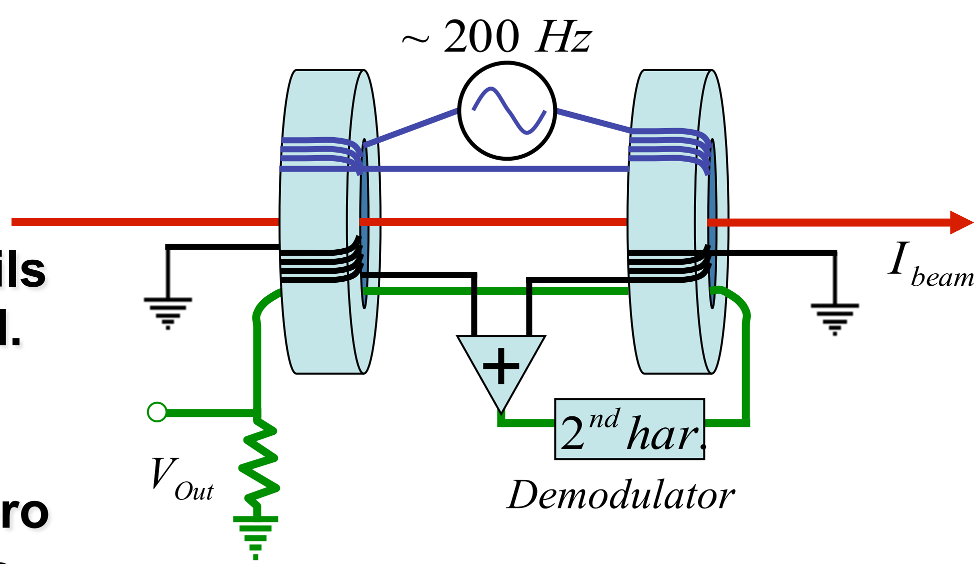


- Femtoseconds resolution (or even smaller) can be achieved by interferometric techniques involving coherent light in the Far-IR (coherent synchrotron radiation, coherent transition radiation, …) or by electro-optic techniques using non-linear crystals and laser probing.



Beam Current Monitors:
The DC Current Transformer

- For measuring the average beam current (DC component), the **parametric current transformer** or **DC current transformer** (DCCT) is used:



- The DCCT uses two high permeability cores driven to saturation by a low frequency current modulation.
- The signals from two secondary coils of the cores are mutually subtracted.
- Because of the non-linear magnetization curve of the core material, this difference signal is zero only when the beam current is zero.
- In the presence of beam current this difference signal is non-zero and in particular shows a second harmonic component.
- A current proportional to the amplitude of this component is fed back into a third coil in order to compensate for the beam current and to make the difference signal zero.
- At equilibrium, the current flowing in this third coil is equal in amplitude to the beam current but opposite in sign.