Introduction to Accelerator Physics
Old Dominion University

Survey of Accelerator Instrumentation

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Tuesday 1 Dec 2011

Class Schedule

- We have only a week of class left!
- Here is a modified version of the syllabus for the remaining weeks including **where we are**

Thursday 1 Dec	**Survey of Accelerator Instrumentation**
Tuesday 6 Dec	Oral Presentation Finals (10 min ea)
Thursday 8 Dec	*No class (time to study for exams!)*
Exam week	*Do well on your other exams!*

- Fill in your class feedback survey!

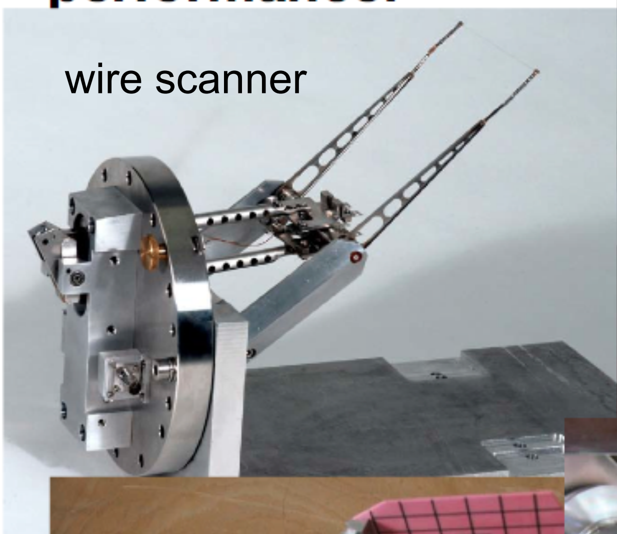
- Email your presentation (pdf, ppt, etc) to Todd by

4 PM Tuesday 6 Dec

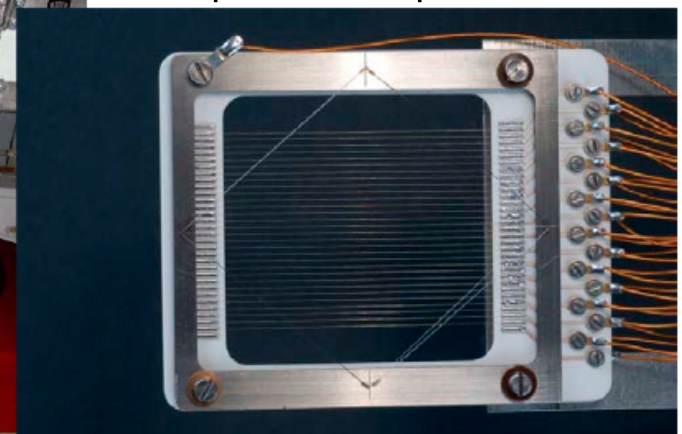
Survey of Accelerator Instrumentation

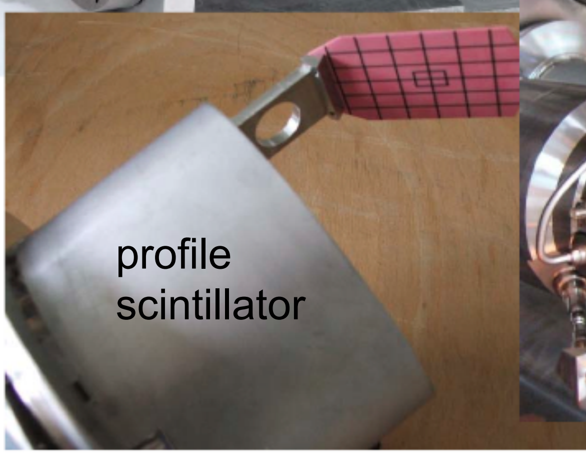
- Various properties of the accelerator beam need to be measured
- Listed roughly in order of difficulty
  - Current/Intensity
  - Transverse position
  - Longitudinal size/distribution
  - Transverse size/distribution
  - (Polarization)
- Challenges include
  - Destructive vs non-destructive (parasitic) measurements
  - Wide dynamic ranges of signals
  - Differing particle beam species

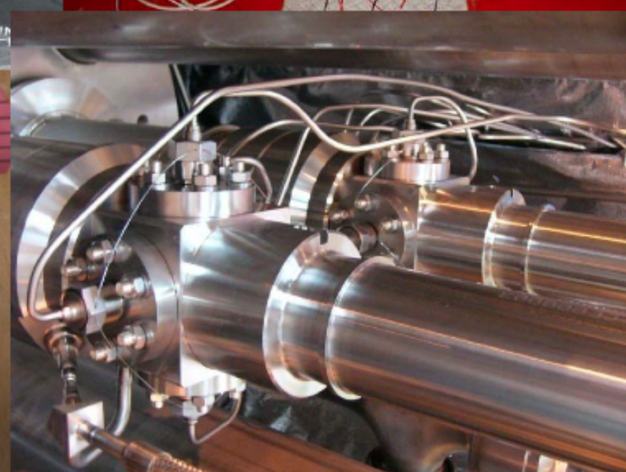
An accelerator can never be better than the instruments measuring its performance!



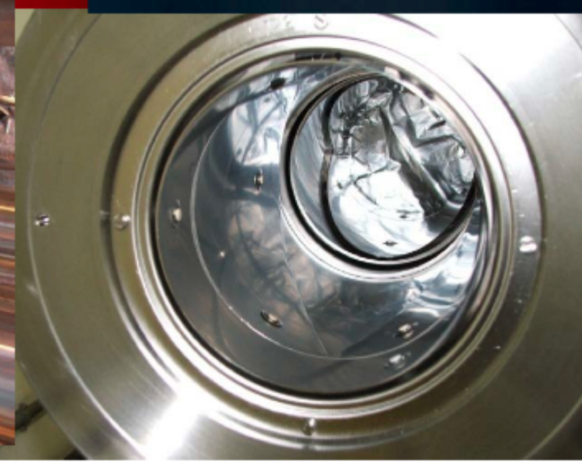
profile "harp"







beam position monitors



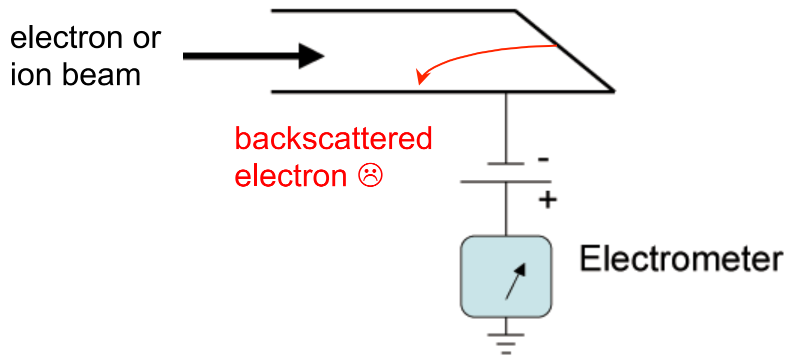
Faraday cup

Uli Raich: CERN Accelerator School

Examples of Accelerator Instrumentation

Instrument	Physical Effect	Measured Quantity	Effect on beam
Faraday Cup	Charge collection	Intensity	Destructive
Current Transformer	Magnetic field	Intensity	Non destructive
Wall current monitor	Image Current	Intensity Longitudinal beam shape	Non destructive
Pick-up	Electric/magnetic field	Position	Non destructive
Secondary emission monitor	Secondary electron emission	Transverse size/shape, emittance	Disturbing, can be destructive at low energies
Wire Scanner	Secondary particle creation	Transverse size/shape	Slightly disturbing ☺
Scintillator screen	Atomic excitation with light emission	Transverse size/shape (position)	Destructive
Residual Gas monitor	Ionization	Transverse size/shape	Non destructive

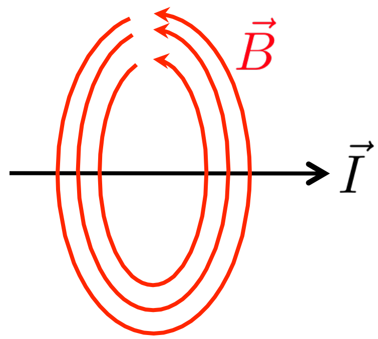
Destructive Intensity Meter: Faraday Cup



- A conductor “cup” absorbs the charge of a low-energy beam
  - Discharge current proportional to total beam charge
  - ~1 nA = 6×10^9 charges/sec in beam current on cup
- Limitations
  - Only low energy beams
    - backscattering charge loss
    - absorb entire incident beam; no beam should penetrate cup
  - Secondary electrons
    - cause additional charge/current that looks like more beam

Parasitic Intensity: Current Transformer

- We can use Ampere's law to measure current passing through a series of transformer loops

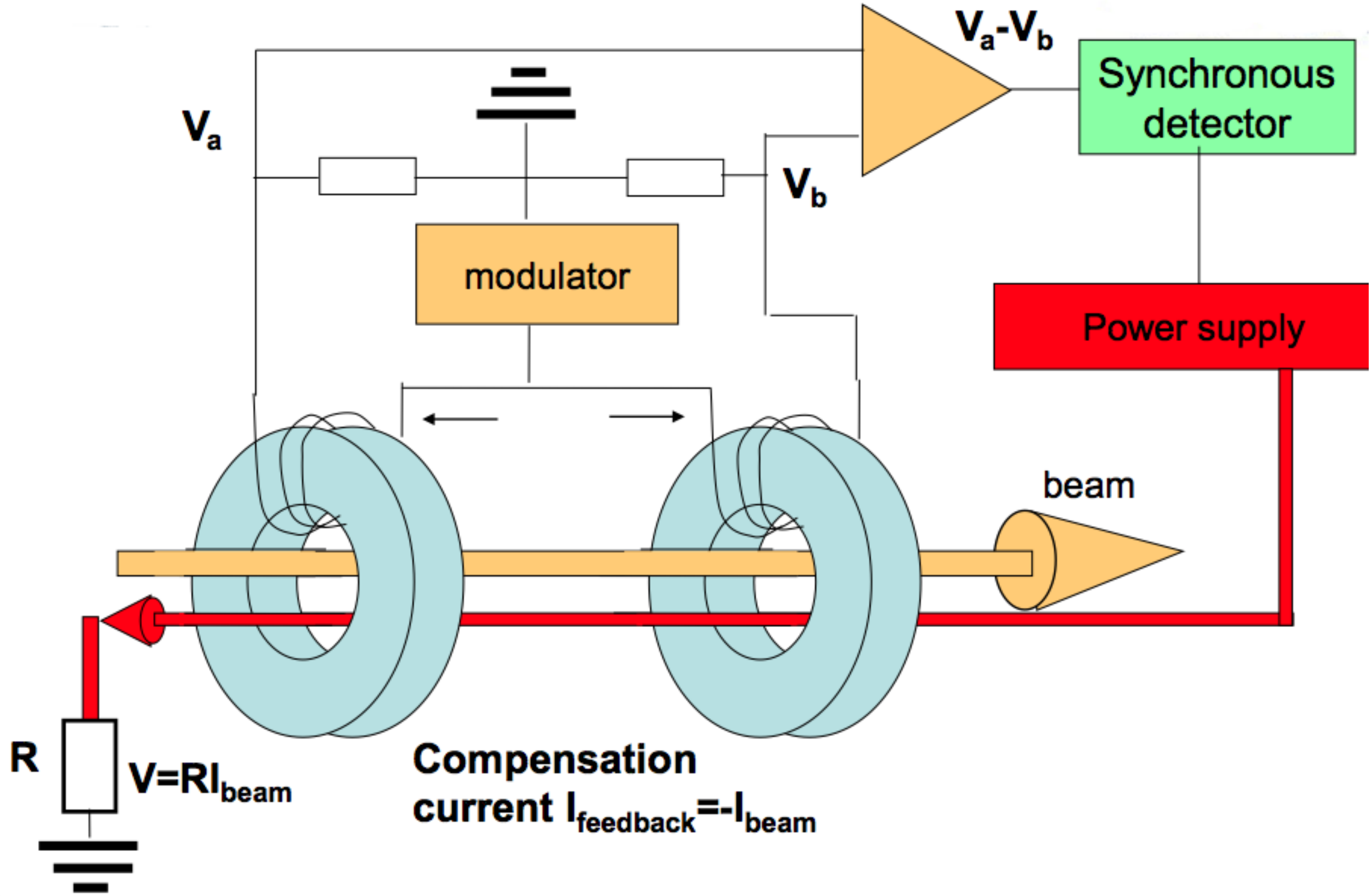


- However, this only creates a magnetic field
  - It's much easier to measure electric fields (voltages, currents)
  - **Faraday's law**: time-varying B field creates E field
  - Alternatively, time-varying magnetic flux creates an EMF (or electric field, or voltage)

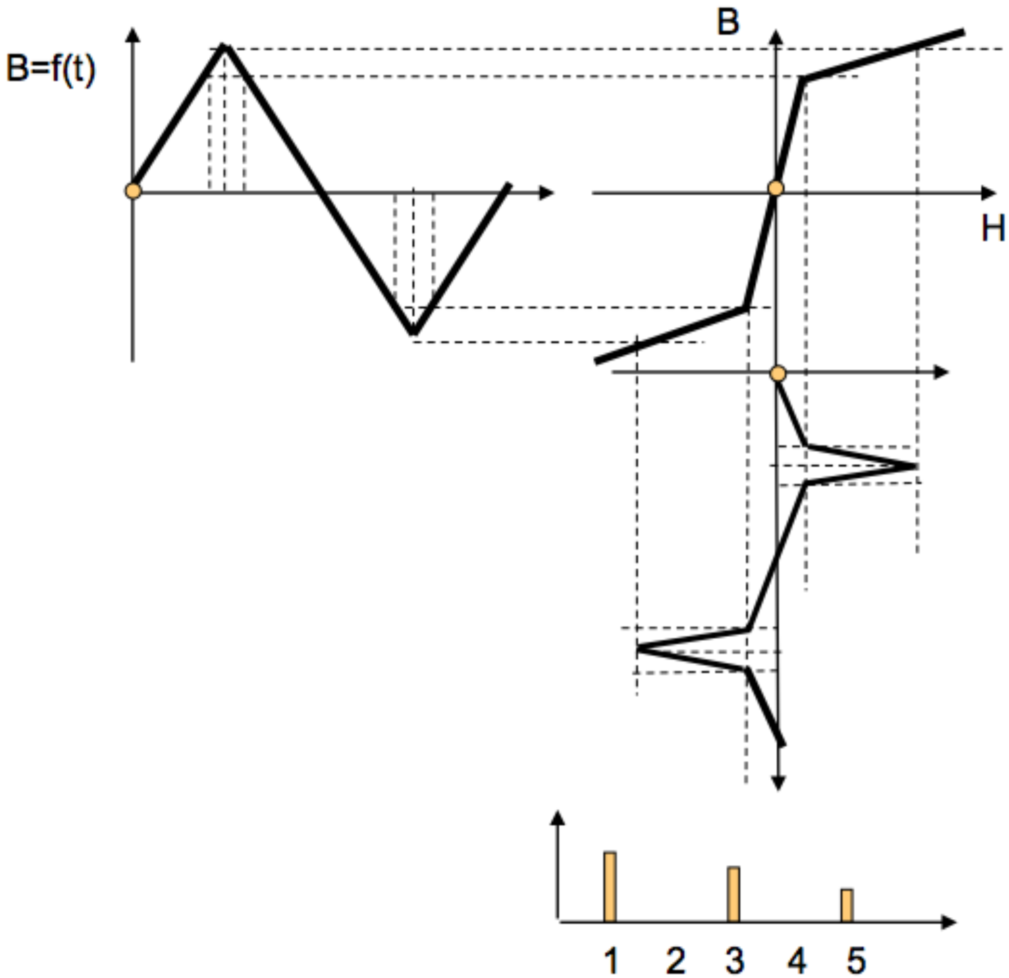
$$|\mathcal{E}| = \left| \frac{d\Phi_B}{dt} \right|$$

  - Use two transformer loops in a "humbucker" configuration

DCCT Implementation



DCCT Signals: No Beam

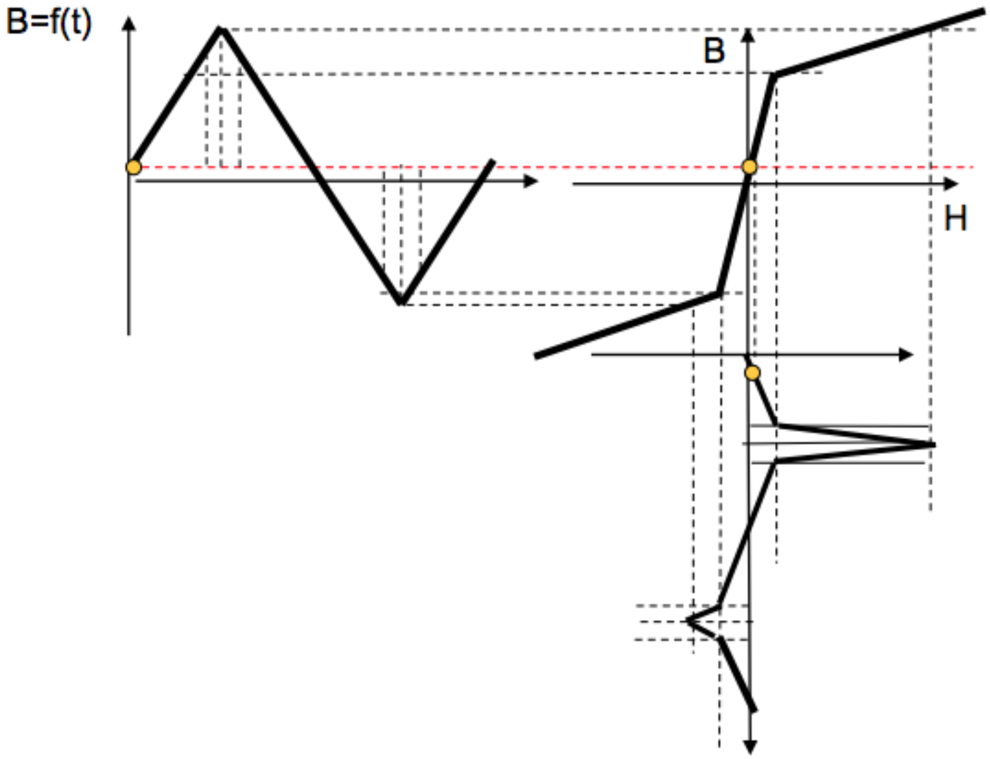


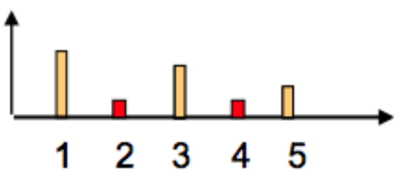
$$U = NA\frac{dB}{dt}$$

$$B = \frac{\int U dt}{NA} + B_0$$

Modulation current has only odd harmonic frequencies since the signal is symmetric

DCCT Signals: With Beam





Sum signal becomes non-zero
Even harmonics appear

- Feedback feeds back a counter-current through the toroids to zero out the even harmonics
  - Feedback counter-current is equal to the beam current

Parasitic Intensity: Current Transformer

- DCCTs are used for "nearly DC" and DC beams
  - synchrotrons (many circulating bunches)
  - linacs (e.g. CEBAF, with continuous beams)

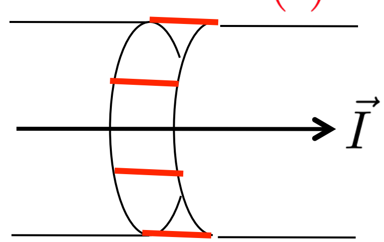
  - High sensitivity and resolution due to feedback mechanism
  - Parasitic, so can be used with physics-quality beams

- Drawbacks
  - Sensitive to magnetic background (needs good shielding)
  - Requires careful calibration between pickup toroids
  - Cannot readily determine time structure of bunch
    - Feedback loop gives "average" beam current

Bunch Structure: Wall Current Monitors

- The charged beam travels around the accelerator
  - Usually in a conductive vacuum chamber
  - An equal and opposite “image charge” moves with the beam on the vacuum chamber wall
    - The conductive vacuum pipe acts as a Faraday cage
- We can interrupt the vacuum pipe to measure this image charge
  - In the simplest case, we could cut the vacuum pipe and bridge the gap with resistors
  - Measuring V(t) across a known R gives I(t) and thus beam current

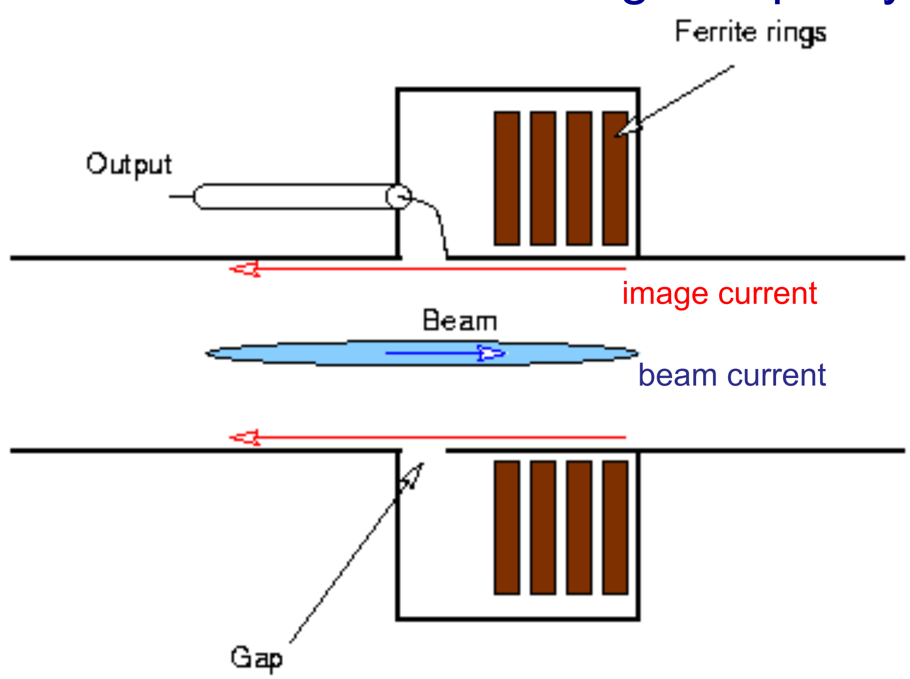
$$V(t) = RI(t)$$

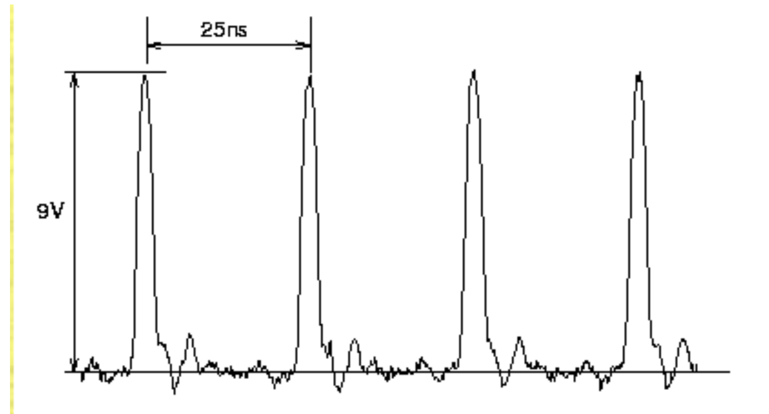


  - But this is not good enough for large frequency ranges (GHz!)

Bunch Structure: Wall Current Monitors II

- Connect a nicely-matched 50Ω coaxial cable instead
- Maintain vacuum with a box around the coaxial cable
- Control frequency response of box with ferrite rings
  - Ferrites look like low-pass filters for electromagnetic waves
  - High frequency beam structure will couple to the coax and be measurable with good quality





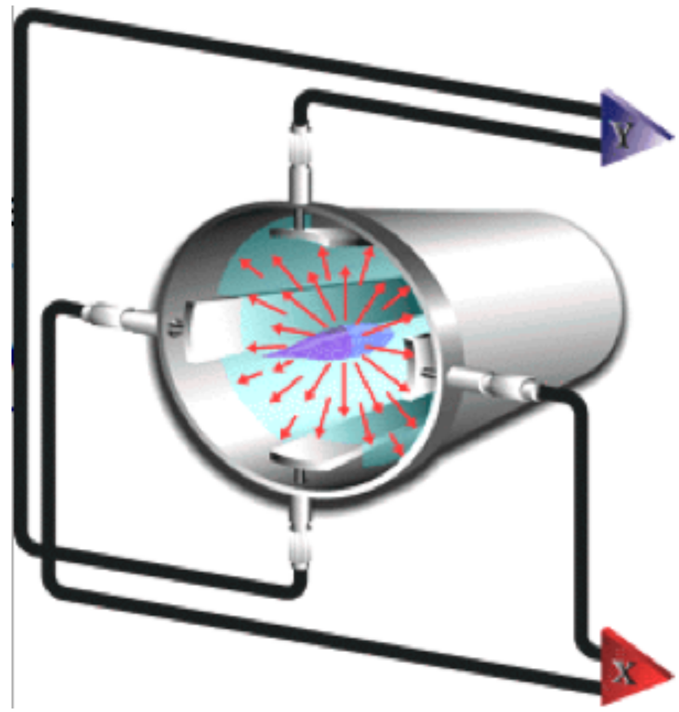
LHC-style beam, 24e9 p/bunch
25 ns spacings, 2.4 ns full width half max
9V peak signal!

Beam Position

- Current moving past a pickup gives an electromagnetic signal
  - This signal is often proportional to the proximity of the beam
  - We can use small antennas (buttons or striplines) to pick up the signal of the passing beam at X and Y locations

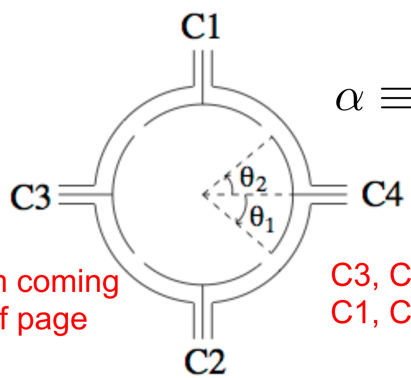
  - Depends strongly on the bunch structure of the beam

  - Need two pickups (one on either side for each plane) to compensate for changes in signal due to beam intensity



Beam Position II

- Stripline pickups are like antennas that detect the image current



beam coming out of page

C3, C4: horizontal striplines
C1, C2: vertical striplines

$$\alpha \equiv \theta_2 - \theta_1 \qquad \frac{V_4 - V_3}{V_4 + V_3} = 4\frac{\sin(\alpha/2)}{\alpha}\left(\frac{x}{b}\right) + O\left(\frac{x^3}{b^3}\right) + O\left(\frac{xy^2}{b^3}\right)$$

$$\text{In limit } \alpha \to 0, \quad x \approx \frac{b}{2}\left(\frac{V_4 - V_3}{V_4 + V_3}\right)$$

- Voltage is proportional to dq/dz, derivative of beam current