Beam Diagnostics

Lecture 2

Uli Raich

CERN AB - BI

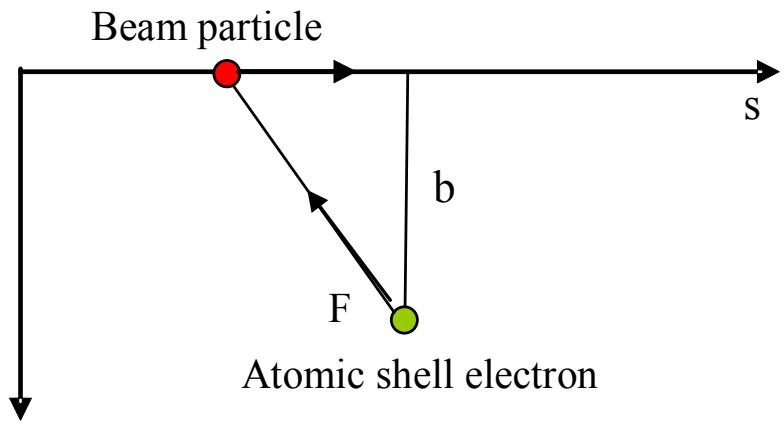
(Beam Instrumentation)

Contents of lecture 2

- Interaction of charged particles with matter
- Scintillating screens
- In/Out mechanisms
- Secondary Emission Grids
- Wire Scanners
- Position measurements
- Position sensitive wall current monitor
- A few words on Schottky pick-ups

Interaction of particles with matter

- Coulomb interaction
- Average force in s-direction=0
- Average force in transverse direction <> 0
- Mostly large impact parameter => low energy of ejected electron
- Electron mostly ejected transversely to the particle motion



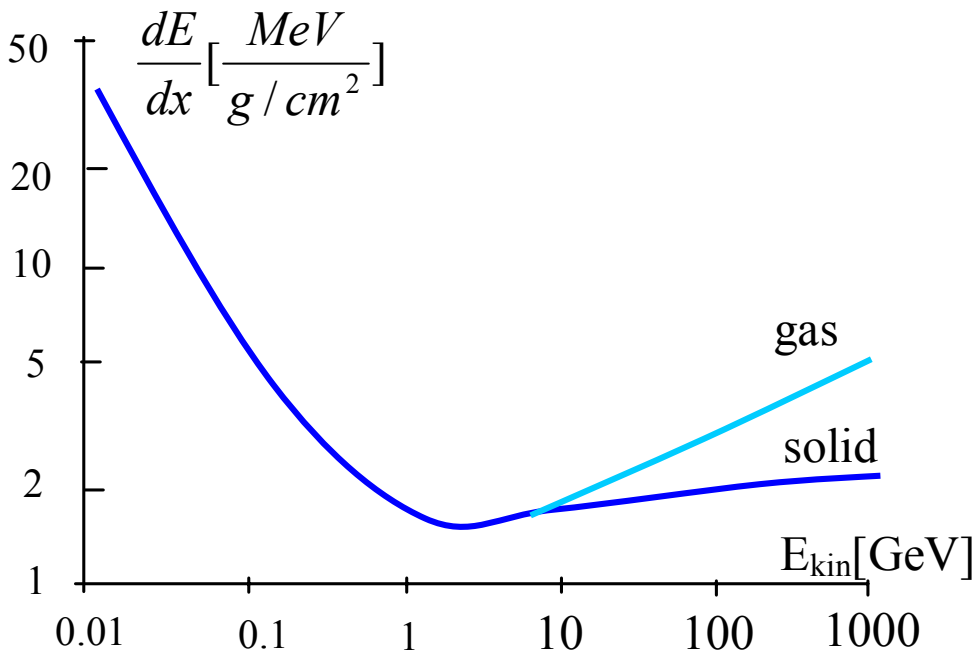
Bethe Bloch formula

$$-\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 \frac{Z_T}{A_T} \rho \frac{Z_p^2}{\beta^2} [\ln \frac{2m_e c^2 \gamma^2 \beta^2}{I} - \beta^2]$$

- with the following constants:
  - N_A: Avogadro's number
  - m_e and r_e: electron rest mass and classical electron radius
  - c: speed of light
- the following target material properties:
  - ρ: material density
  - A_T and Z_T: the atomic mass and nuclear charge
- and the particle properties:
  - Z_p: particle charge
  - β: the particles velocity and $\gamma = \frac{1}{\sqrt{1-\beta^2}}$

Dependance on Z_p^2

High energy loss a low energies



Heavy ions at low energy are stopped within a few micro-meters
All energy is deposited in a very small volume

Scintillating Screens

Method already applied in cosmic ray experiments

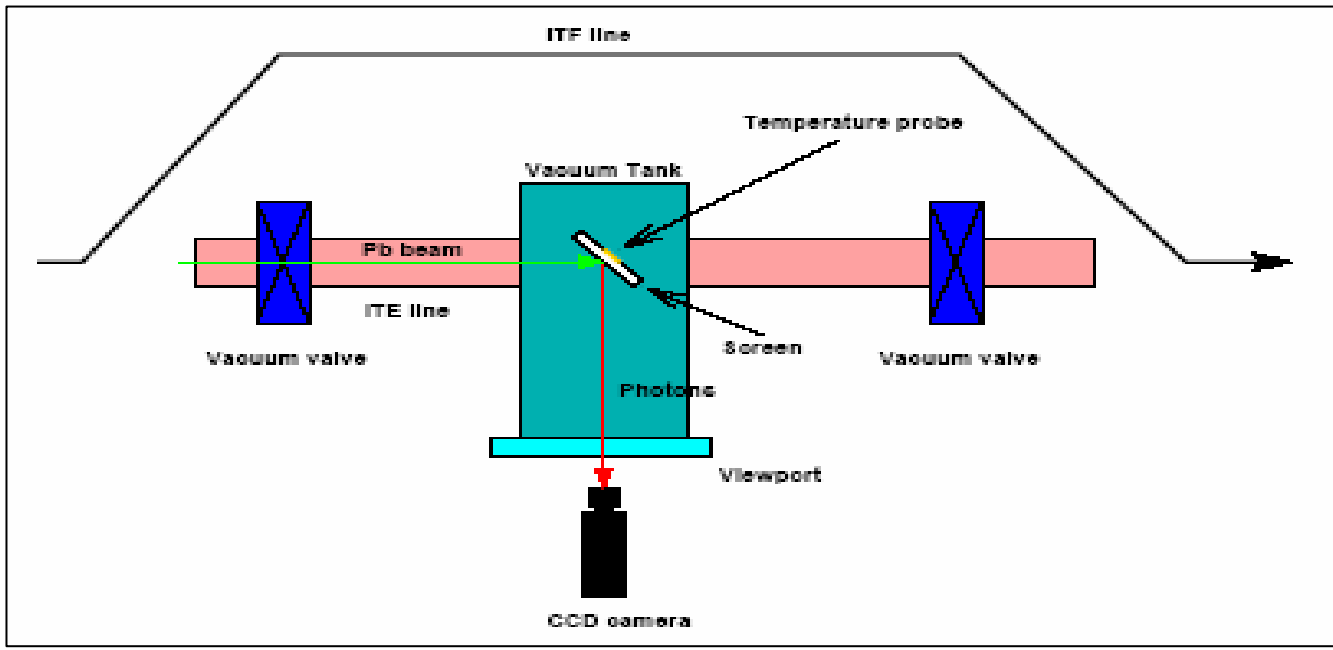
- Very simple
- Very convincing

Needed:

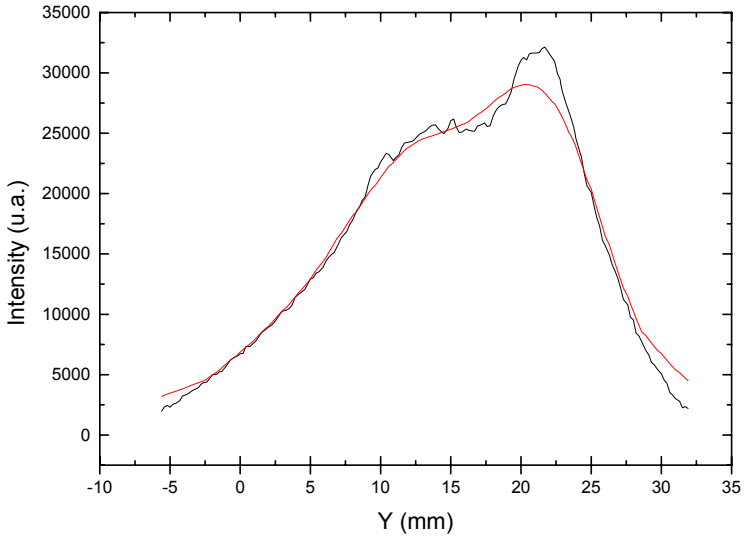
- Scintillating Material
- TV camera
- In/out mechanism

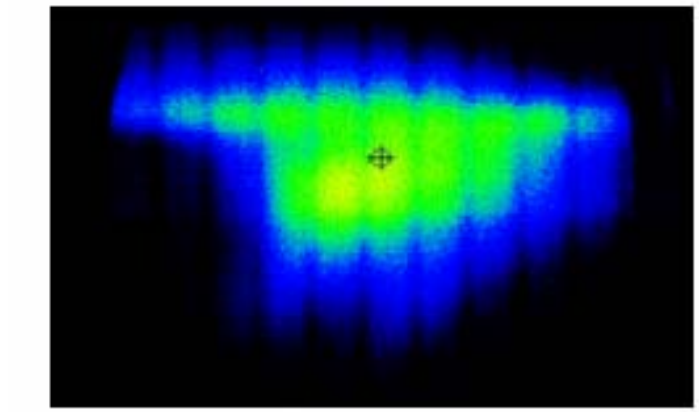
Problems:

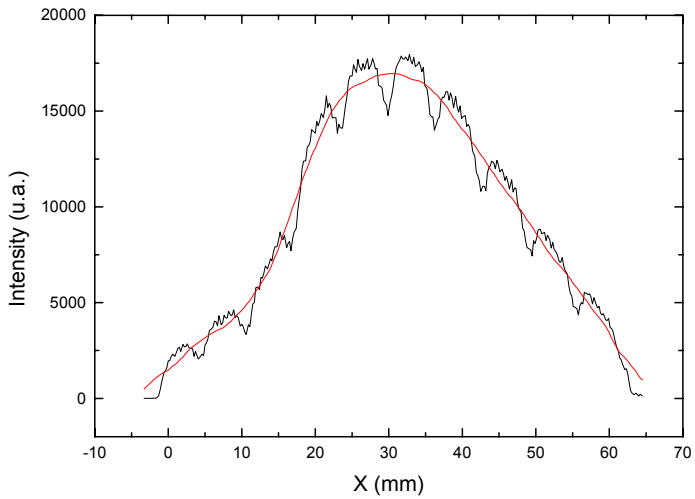
- Radiation resistance
- Heating of screen (absorption of beam energy)
- Evacuation of electric charges



Frame grabber







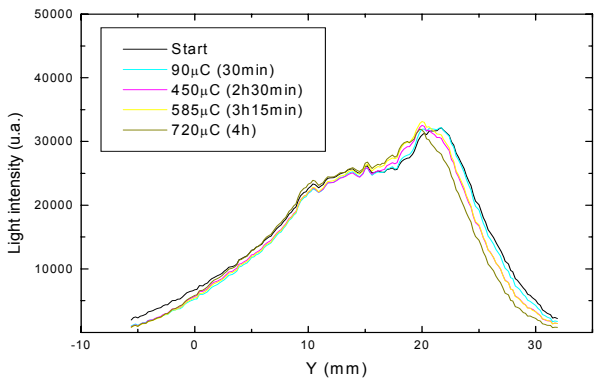
- For further evaluation the video signal is digitized, read-out and treated by program

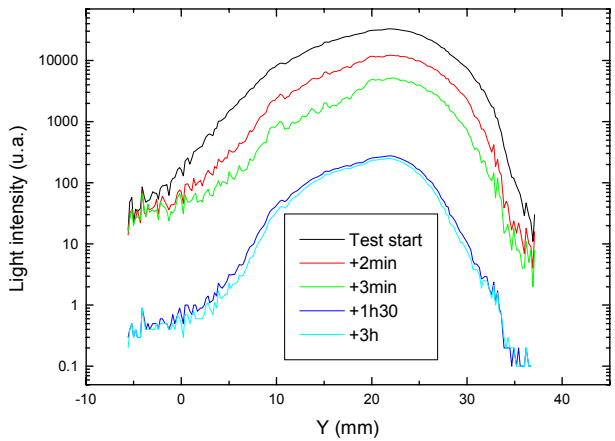
Test for resistance against heat-shock

Material	ρ g/cm^3	c_p at 20°C J/gK	k at 100°C W/mK	T_{max} °C	R at 400 °C $\Omega.cm$
Al_2O_3	3.9	0.9	30	1600	10^{12}
ZrO_2	6	0.4	2	1200	10^{3}
BN	2	1.6	35	2400	10^{14}

Better for electrical conductivity (>400°C)

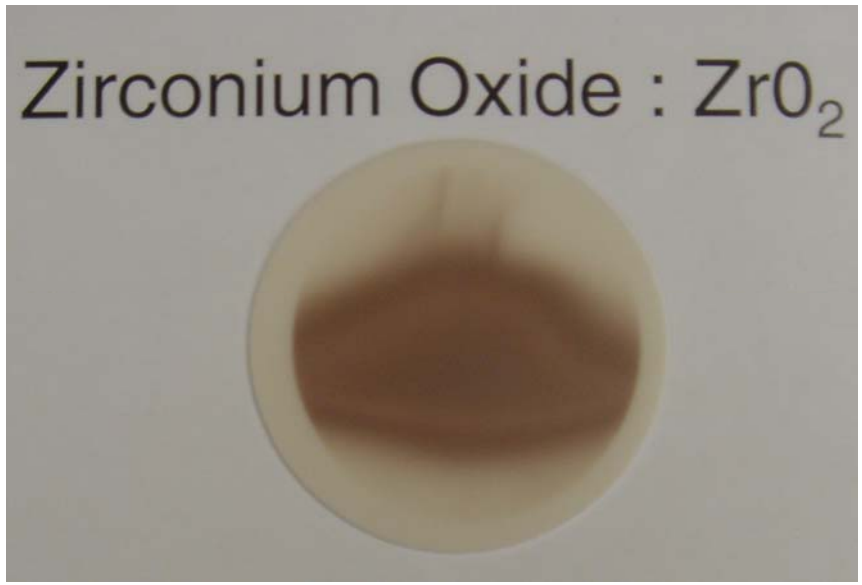
Better for thermal properties
(higher conductivity, higher heat capacity)





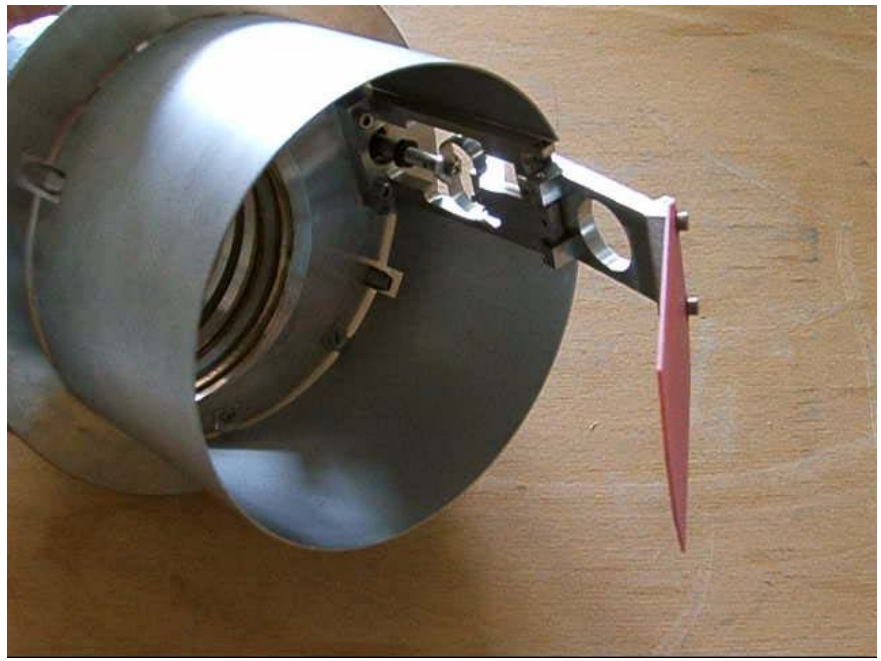
Degradation of screen

Degradation clearly visible
However sensitivity stays essentially the same



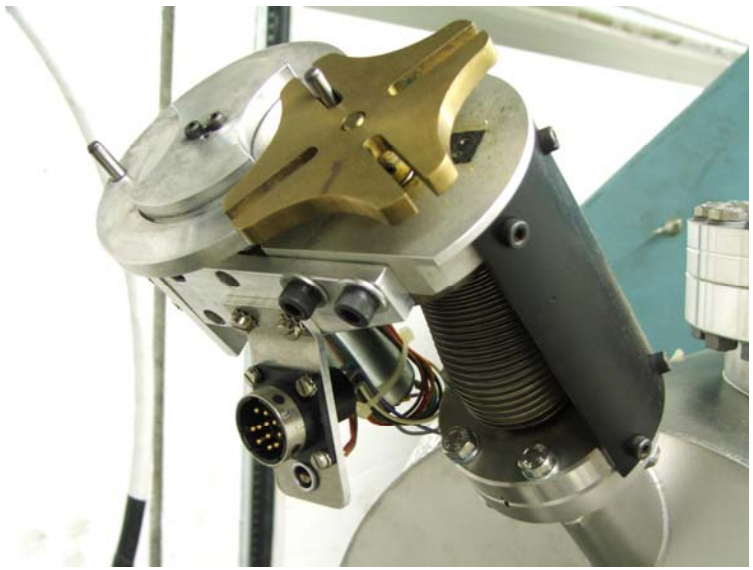
Screen mechanism

- Screen with graticule

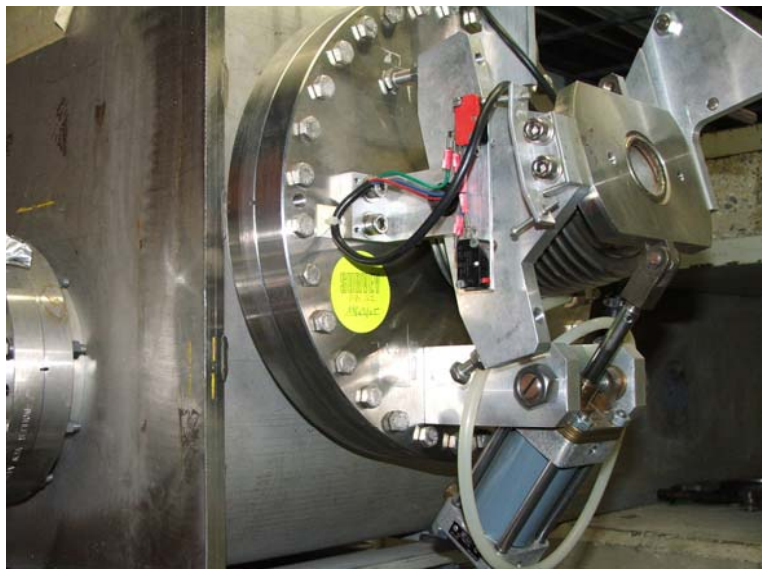


In/out mechanisms

Rotary mechanism driven by electric motor



Mechanism driven pneumatically



Profile measurements

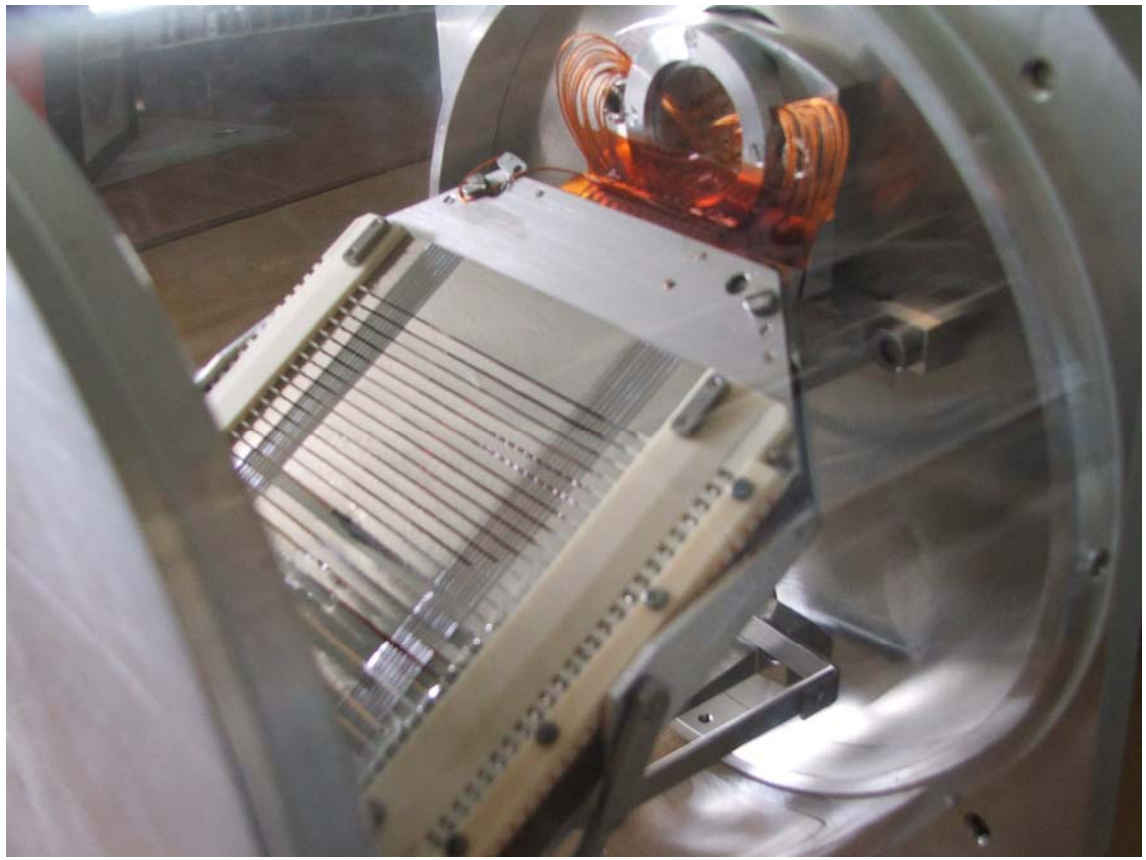
- Secondary emission grids (SEMgrids)

When the beam passes secondary electrons are ejected from the ribbons

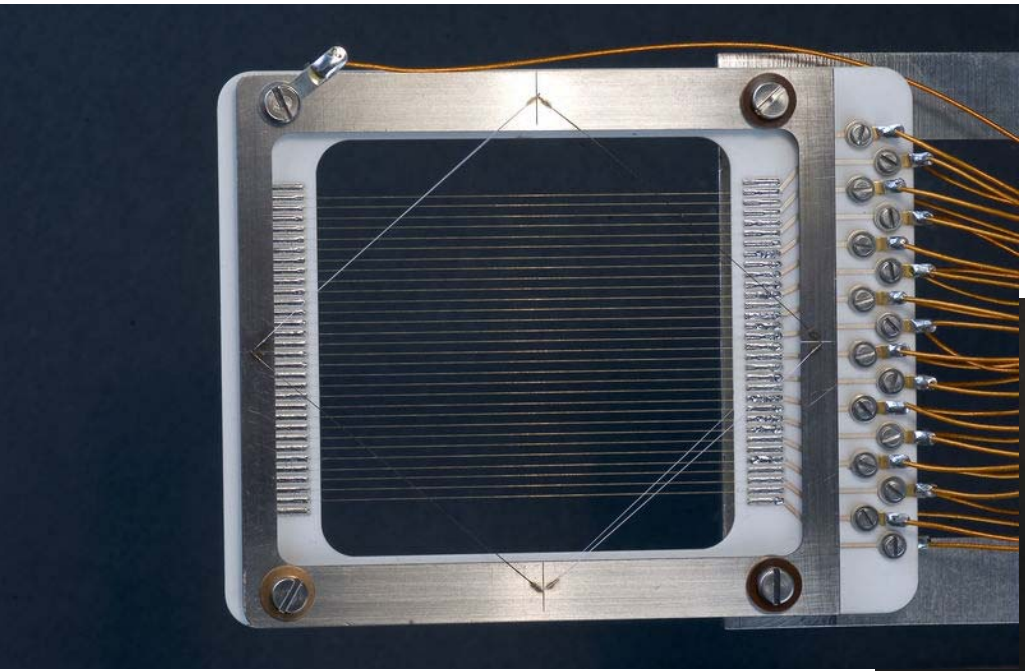
The current flowing back onto the ribbons is Measured

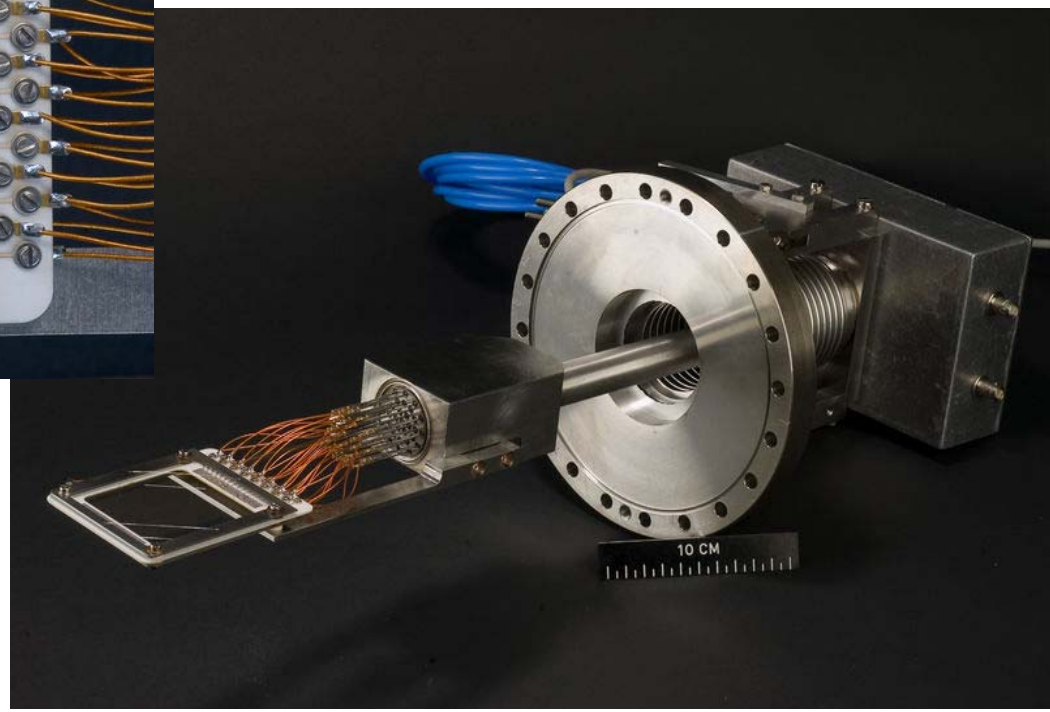
Electrons are taken away by polarisation voltage

One amplifier/ADC chain channel per ribbon

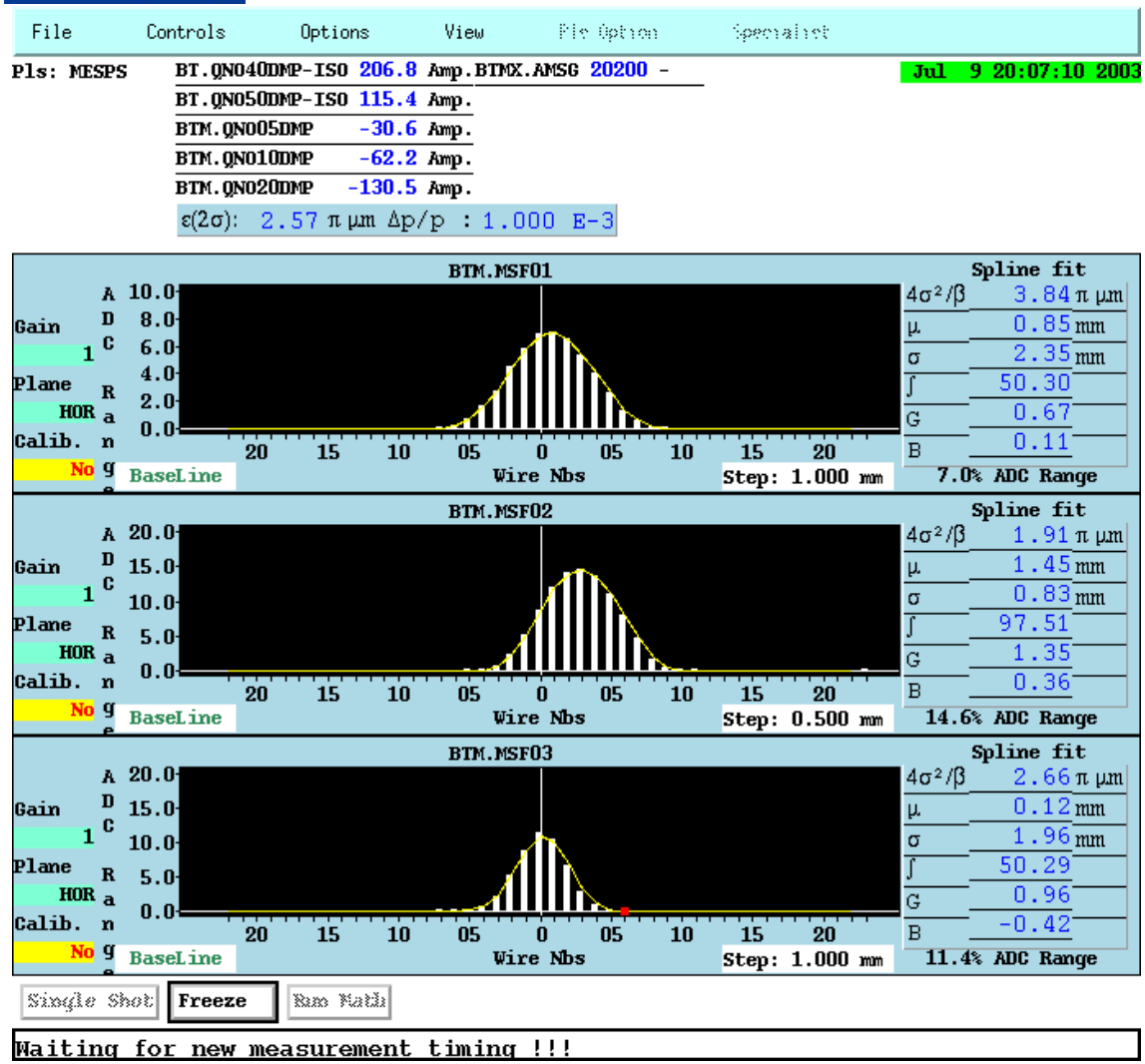


SEMgrids with wires





Profiles from SEMgrids



Projection of charge density projected to x or y axis is Measured

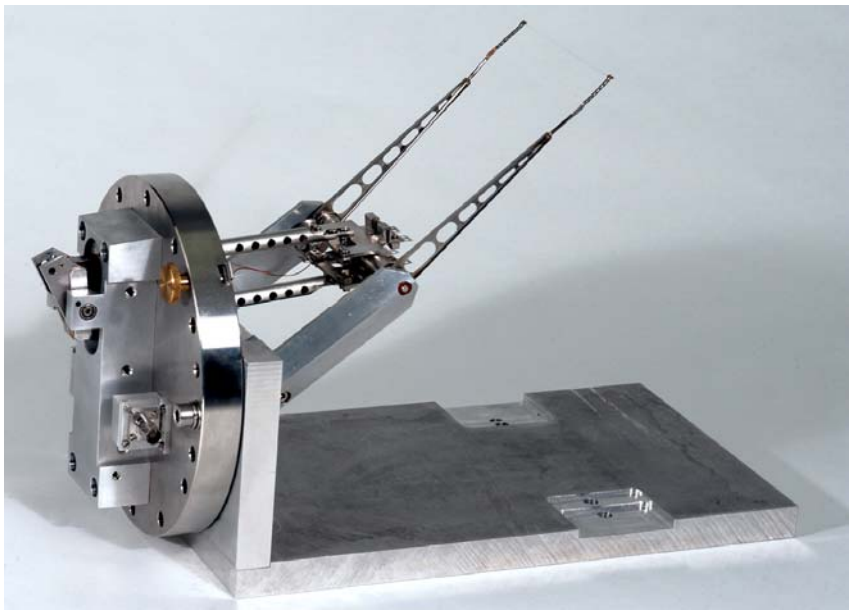
One amplifier/ADC per wire
Large dynamic range

Resolution is given by wire distance

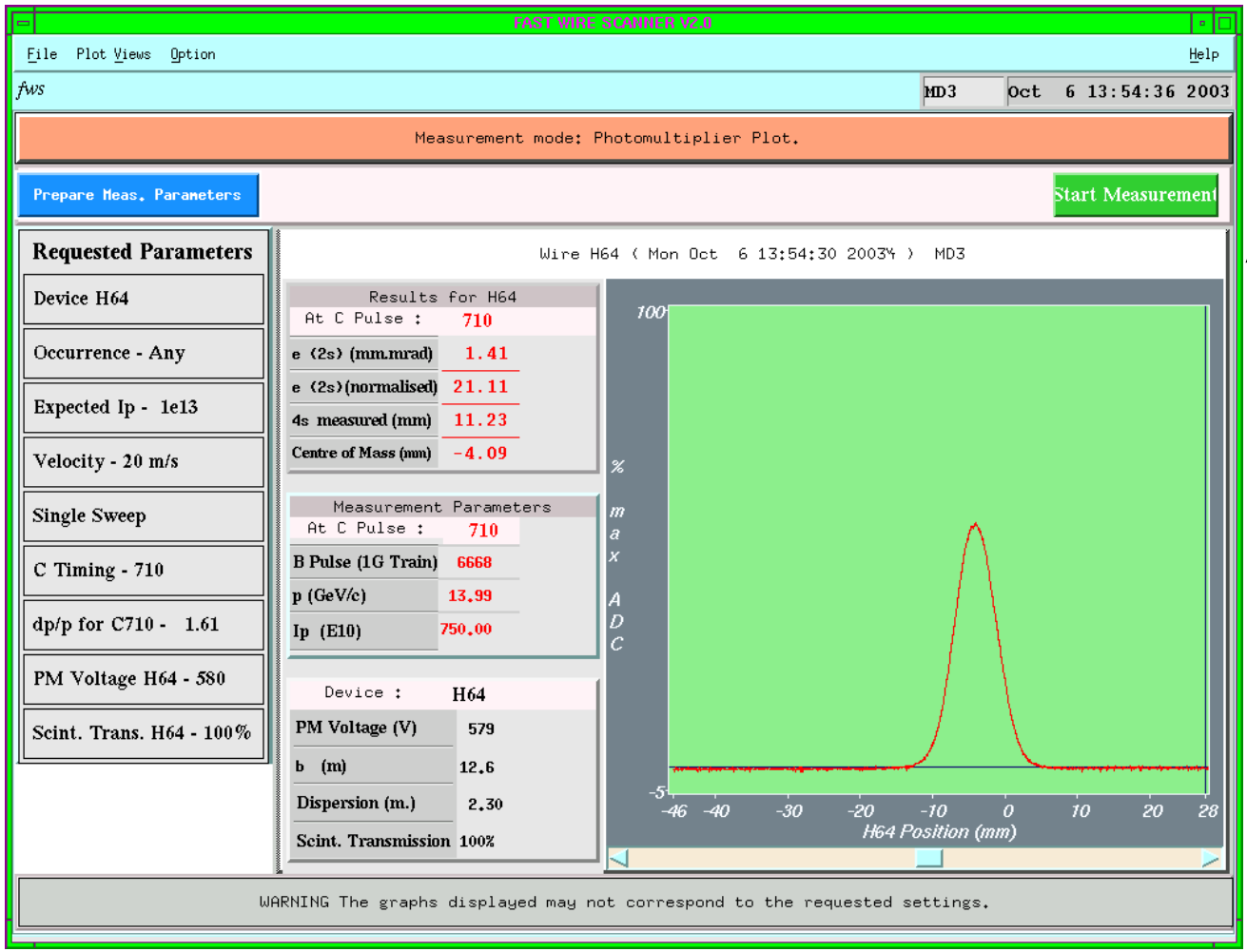
Used only in transfer lines

Wire Scanners

A thin wire is quickly moved across the beam
Secondary particle shower is detected outside the vacuum chamber on a scintillator/photo-multiplier assembly
Position and photo-multiplier signal are recorded simultaneously



Wire scanner profile



High speed needed because of heating.

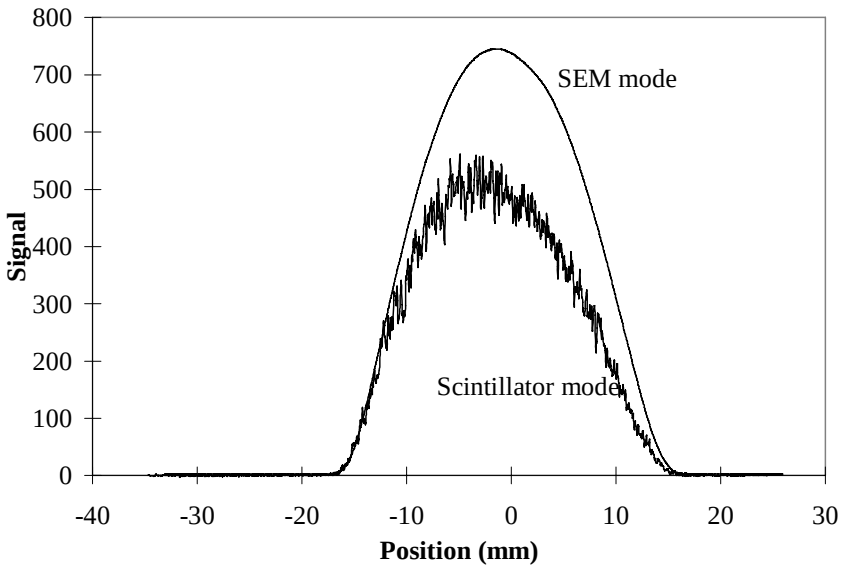
Adiabatic damping

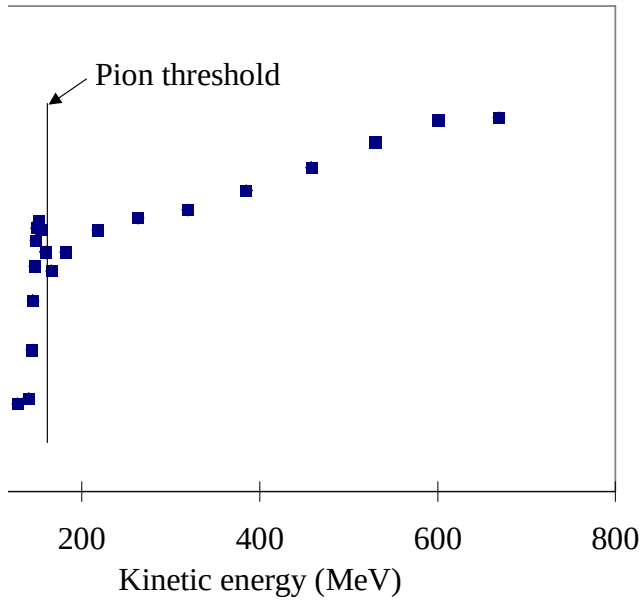
Current increase due to Speed increase

Speeds of up to 20m/s => 200g acceleration

Problems at low energy

- Secondary particle shower intensity in dependence of primary
.



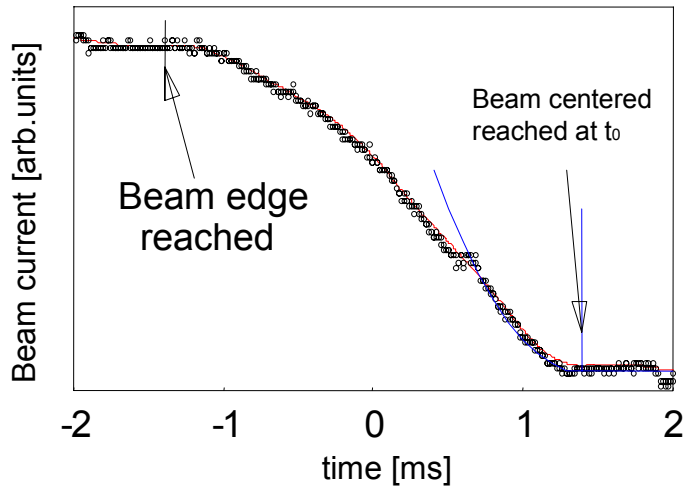


Wire scanners and partially stripped ions

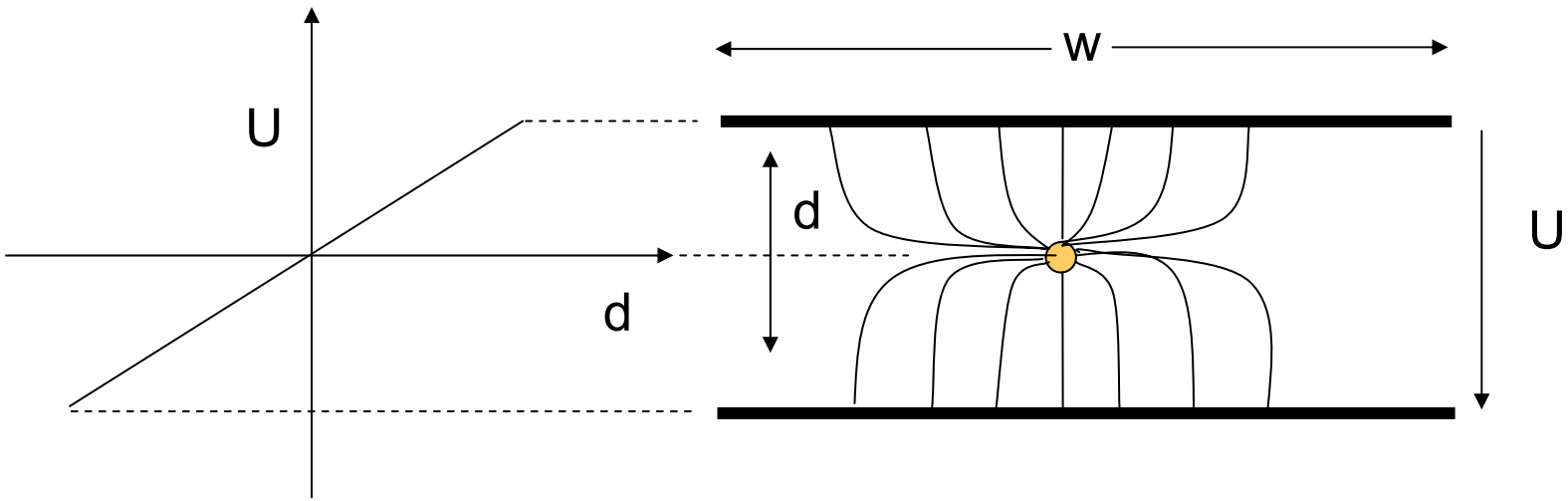
Partially stripped ions loose electrons when interacting with the wire

The beam is lost

Can measure amplitude distribution however

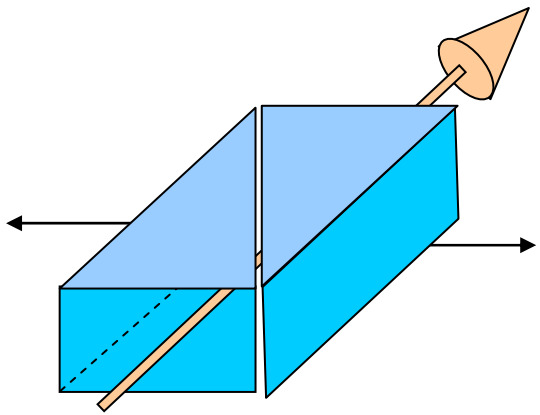


Position measurements

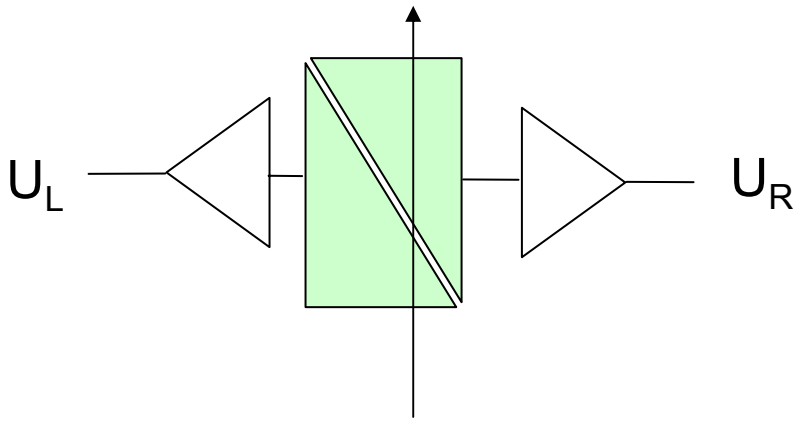


If the beam is much smaller than w, all field lines are captured and
U is a linear function with replacement
else: Linear cut (projection to measurement plane must be linear)

Shoebox pick-up



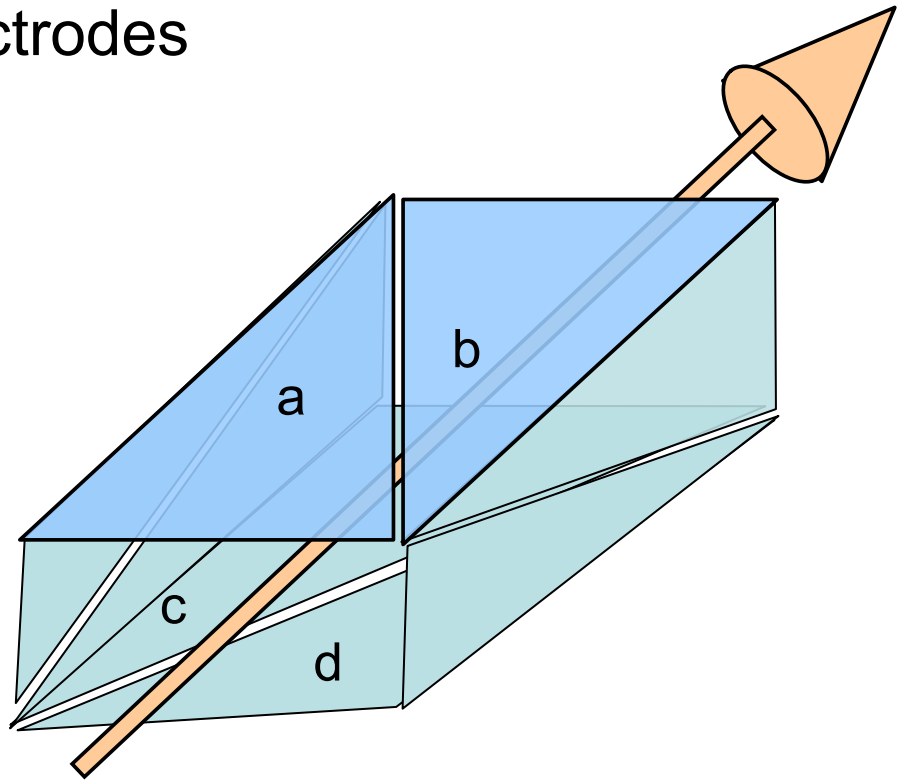
Linear cut through a shoebox



$$x \propto \frac{U_L - U_R}{U_L + U_R} = \frac{\Delta}{\Sigma}$$

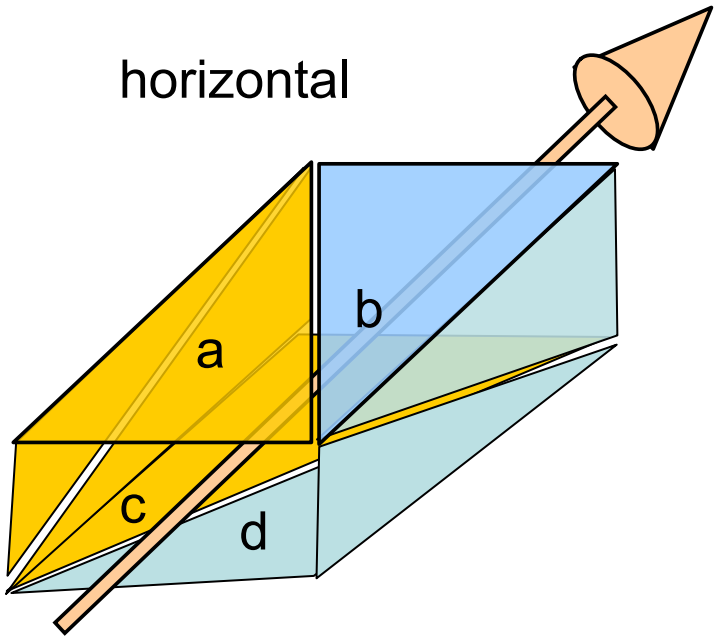
Doubly cut shoebox

- Can measure horizontal and vertical position at once
- Has 4 electrodes

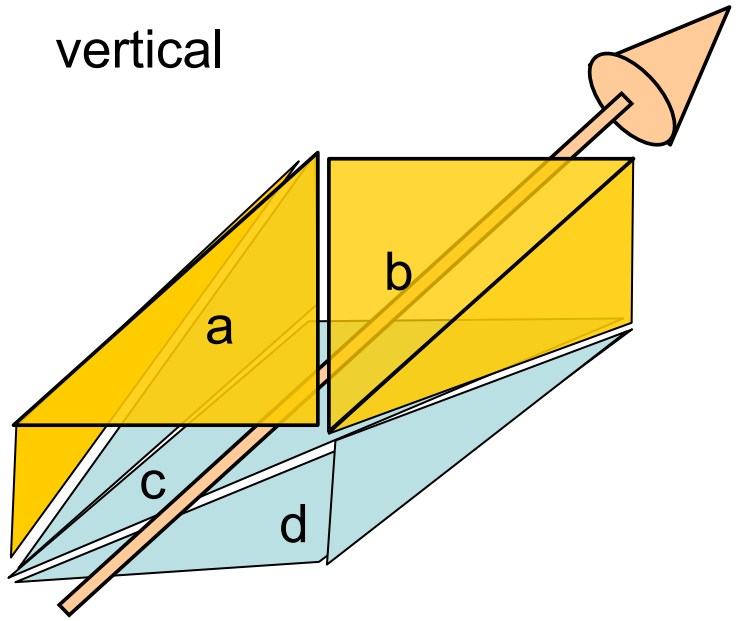


Simulatenous horizontal and vertical measurement

horizontal



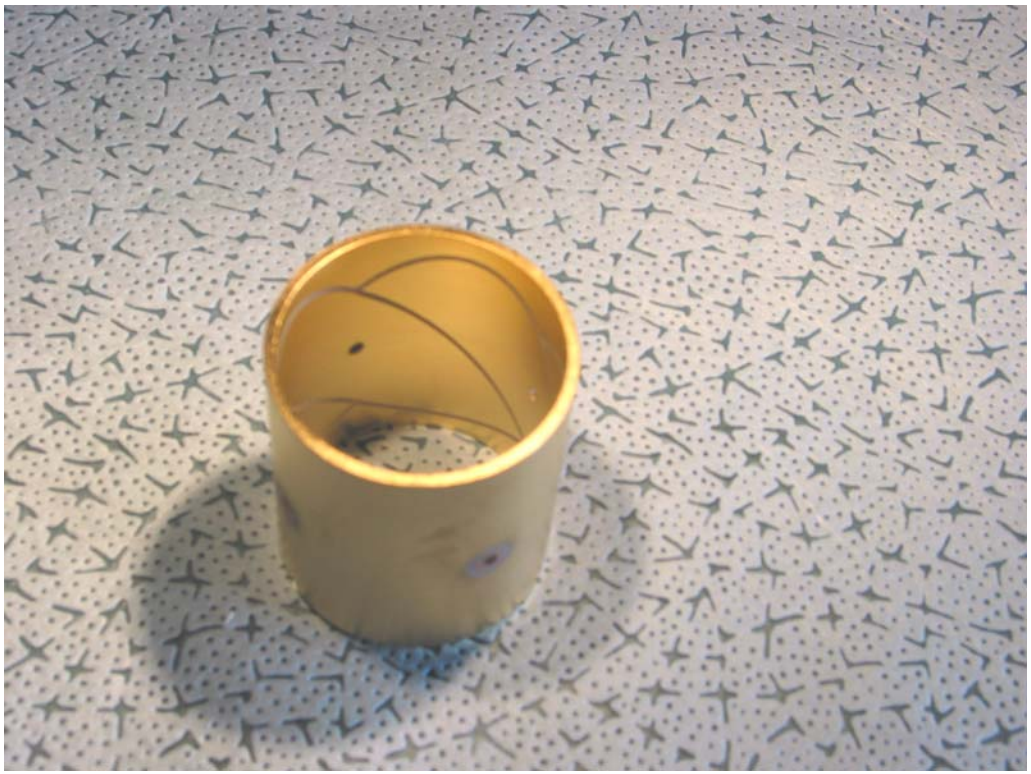
vertical



$$X = \frac{(U_a + U_c) - (U_b + U_d)}{\Sigma U}$$

$$Y = \frac{(U_a + U_b) - (U_c + U_d)}{\Sigma U}$$

Photo of a cylindrical pick-up



A cylindrical pick-up with its connections

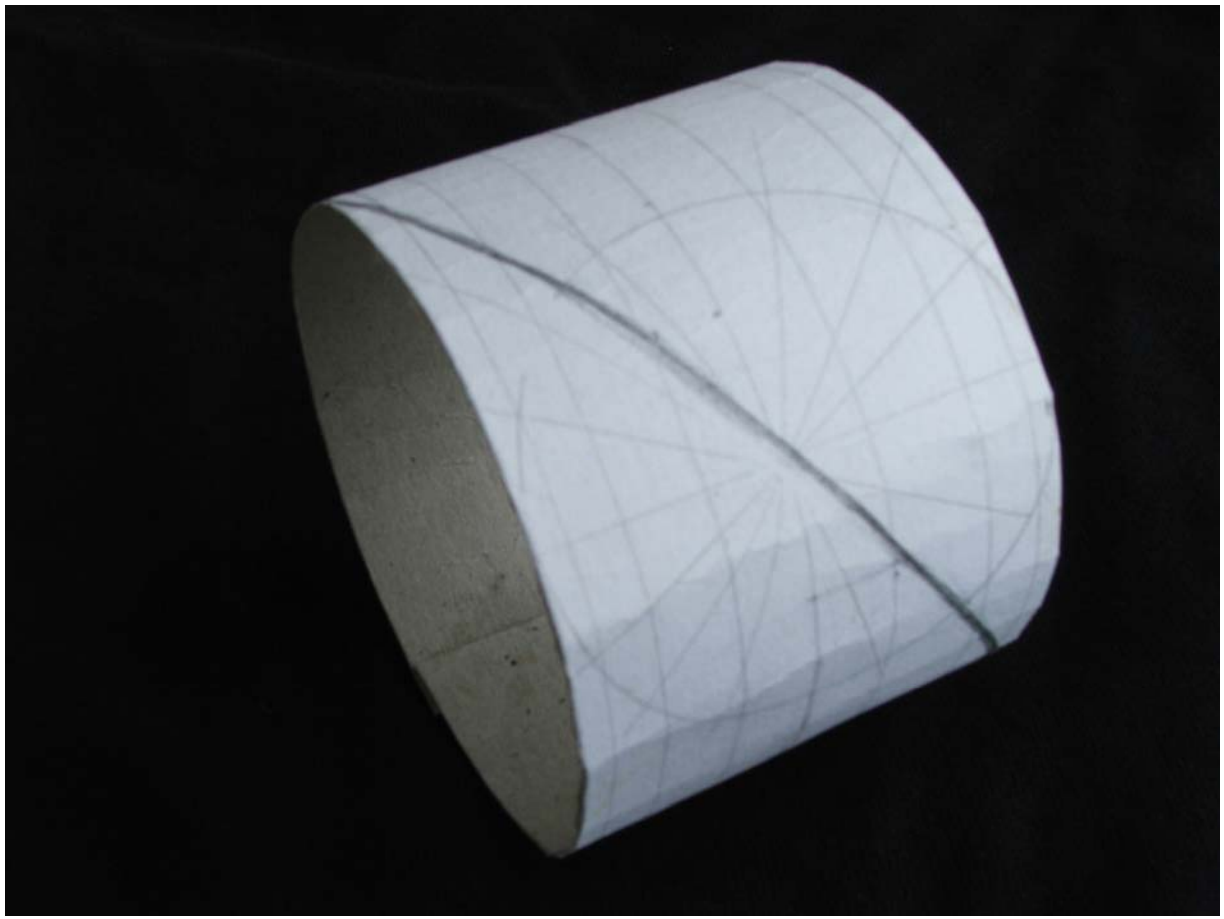
The cuts can be made by photo chemical means of mechanically

Here done with a sand-blasting device

Photo by L. Søby

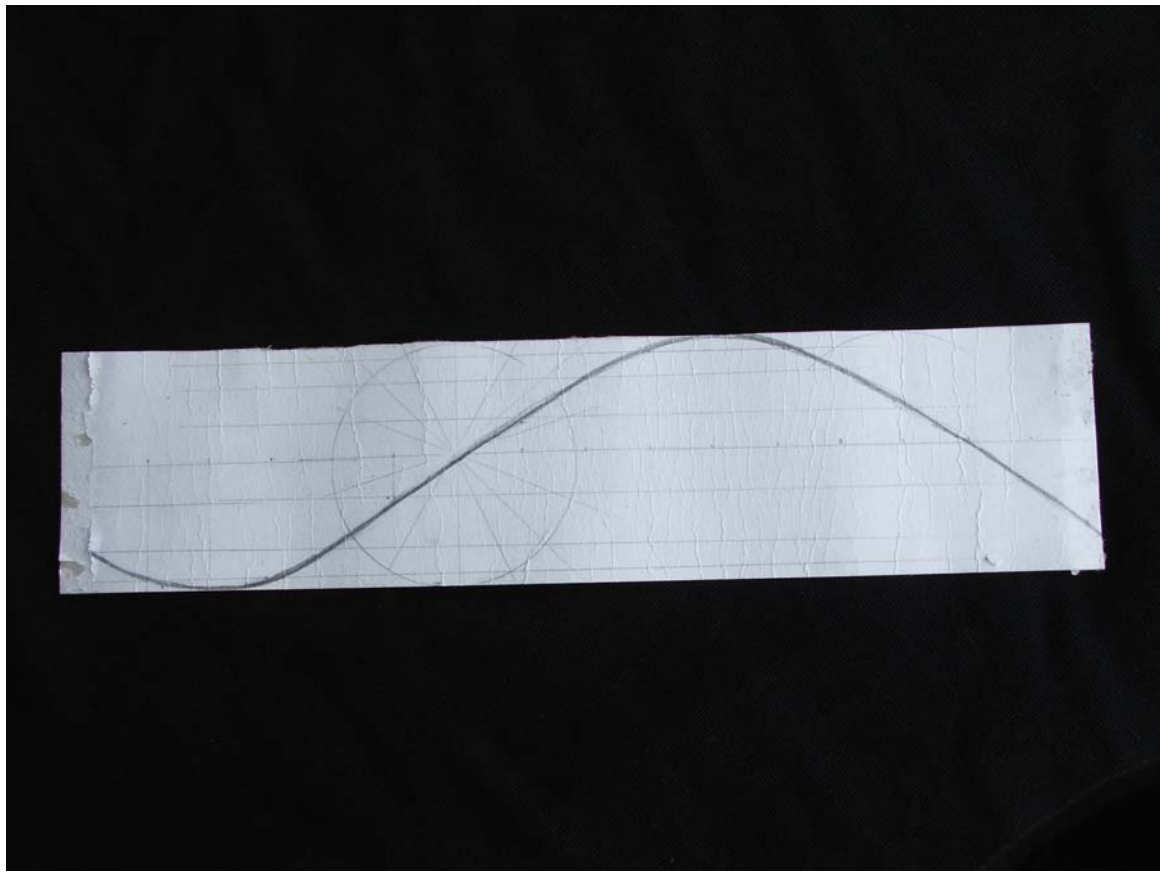
Building a cylindrical paper pick-up

- A linear cut in a cylinder:



Unfolding the cylinder

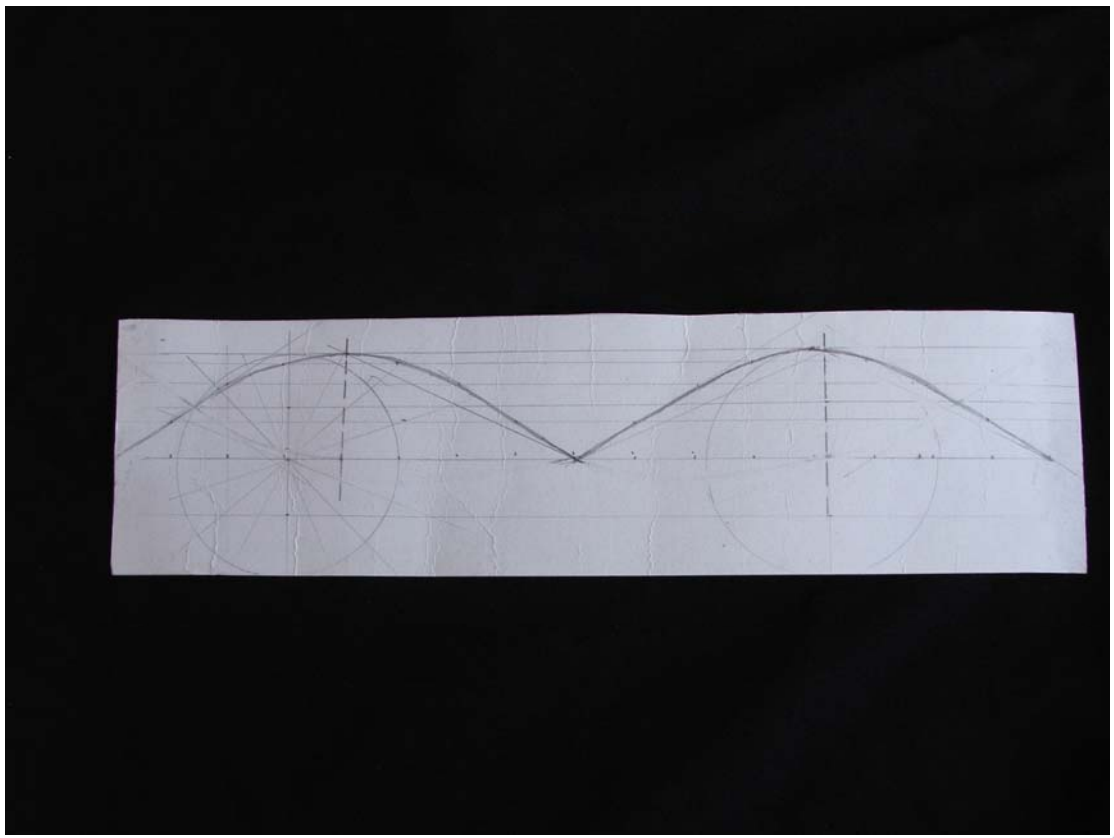
- When unfolded the cut becomes a sine curve



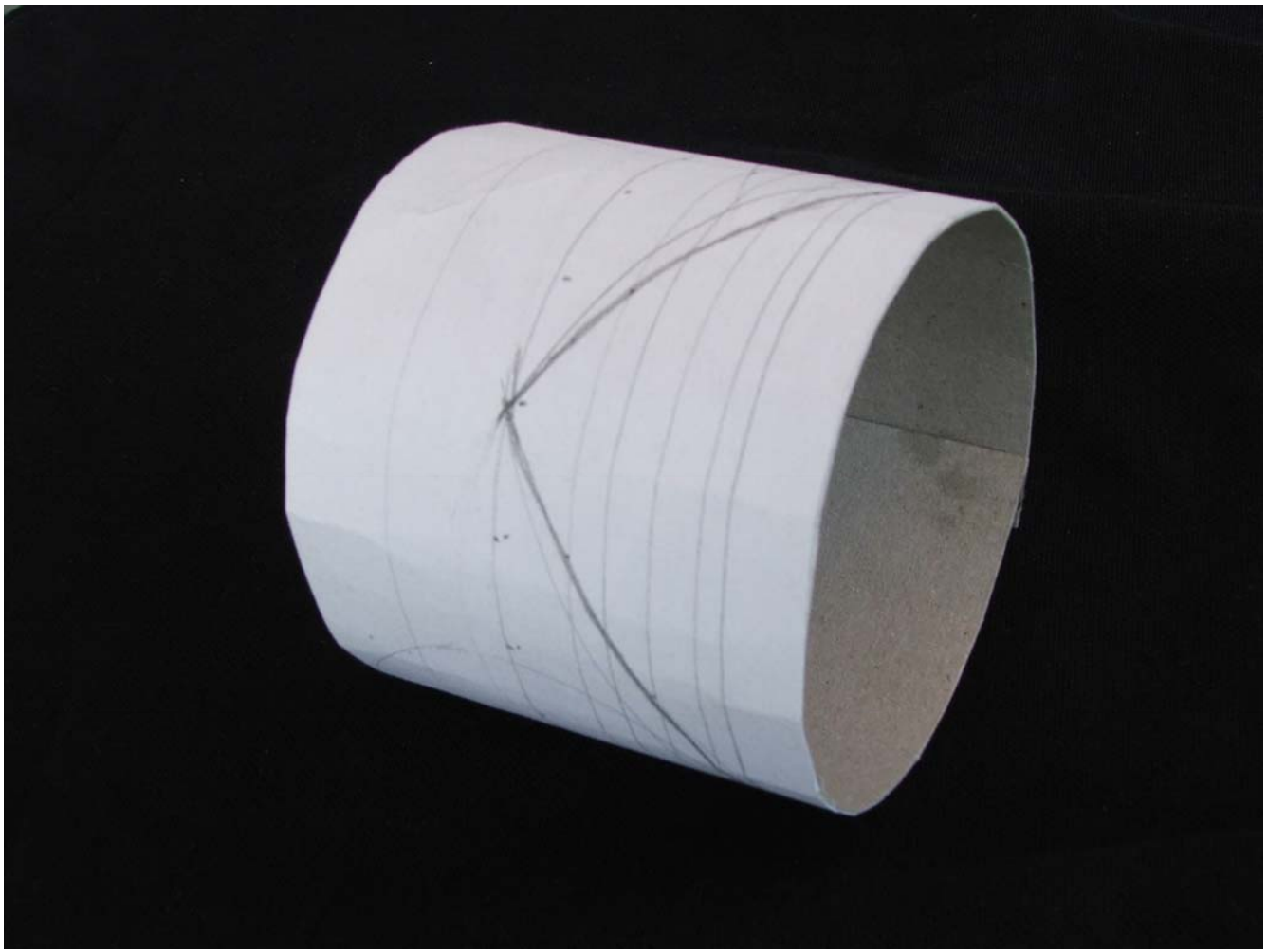
Flipping the sine curve

What happens if we flip use abs (sin(x)) instead?

Mirror the negative sine part?

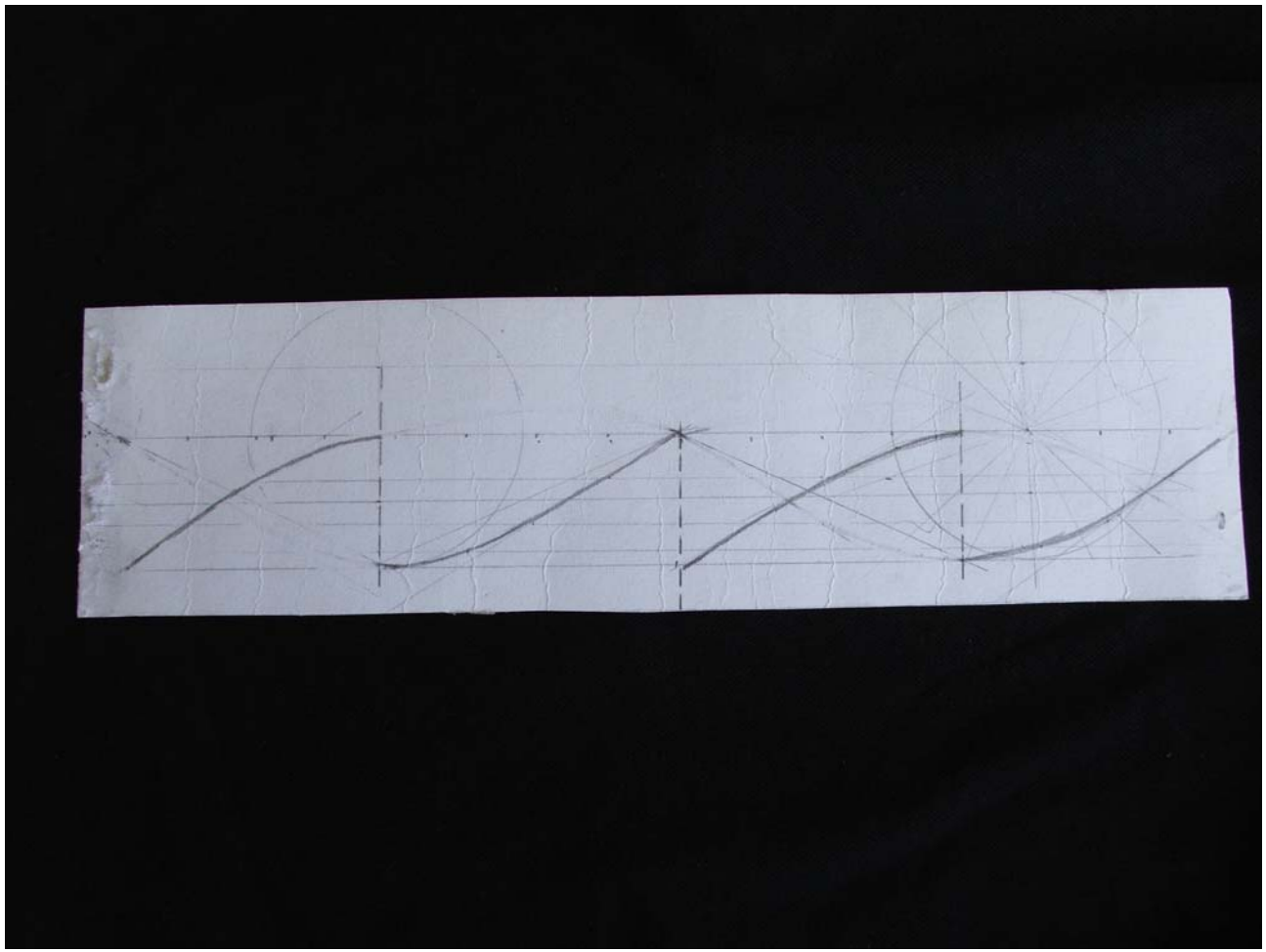


The cylinder is cut twice!

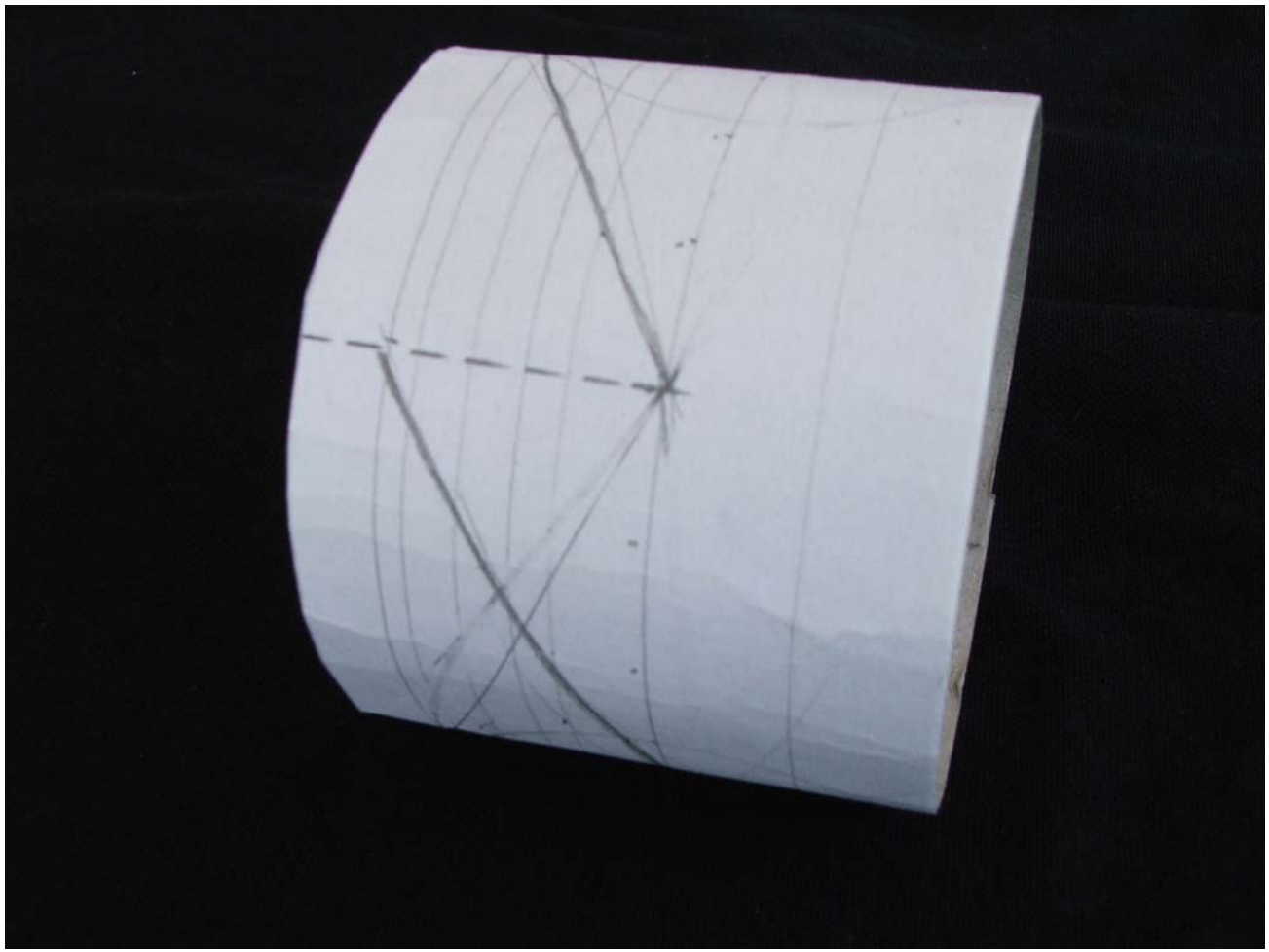


- Horizontal and vertical cut

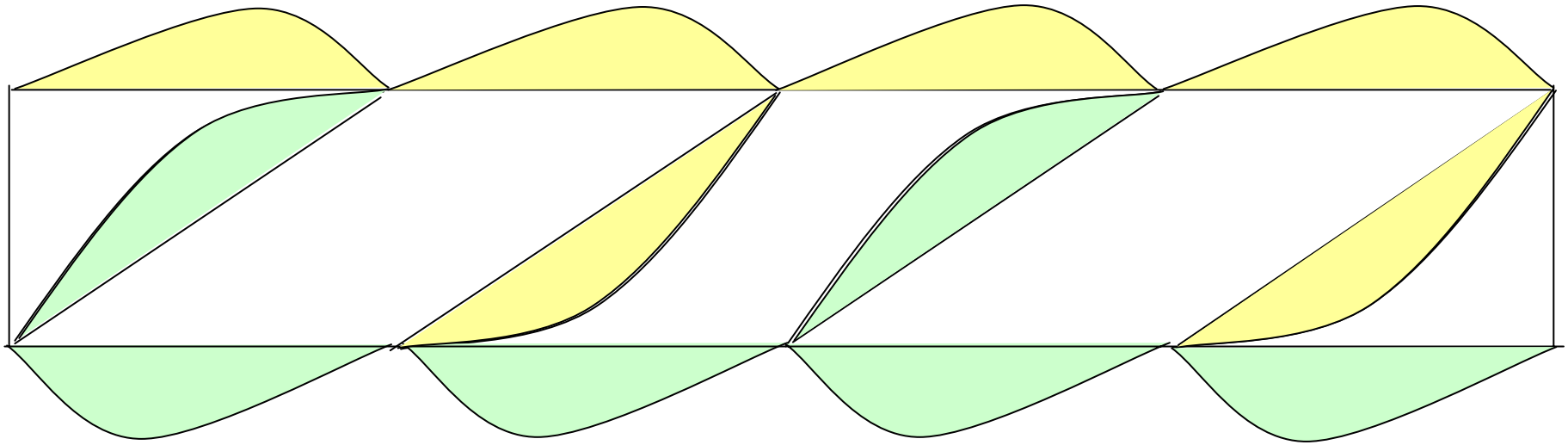
Flipping half the sin curve upside down



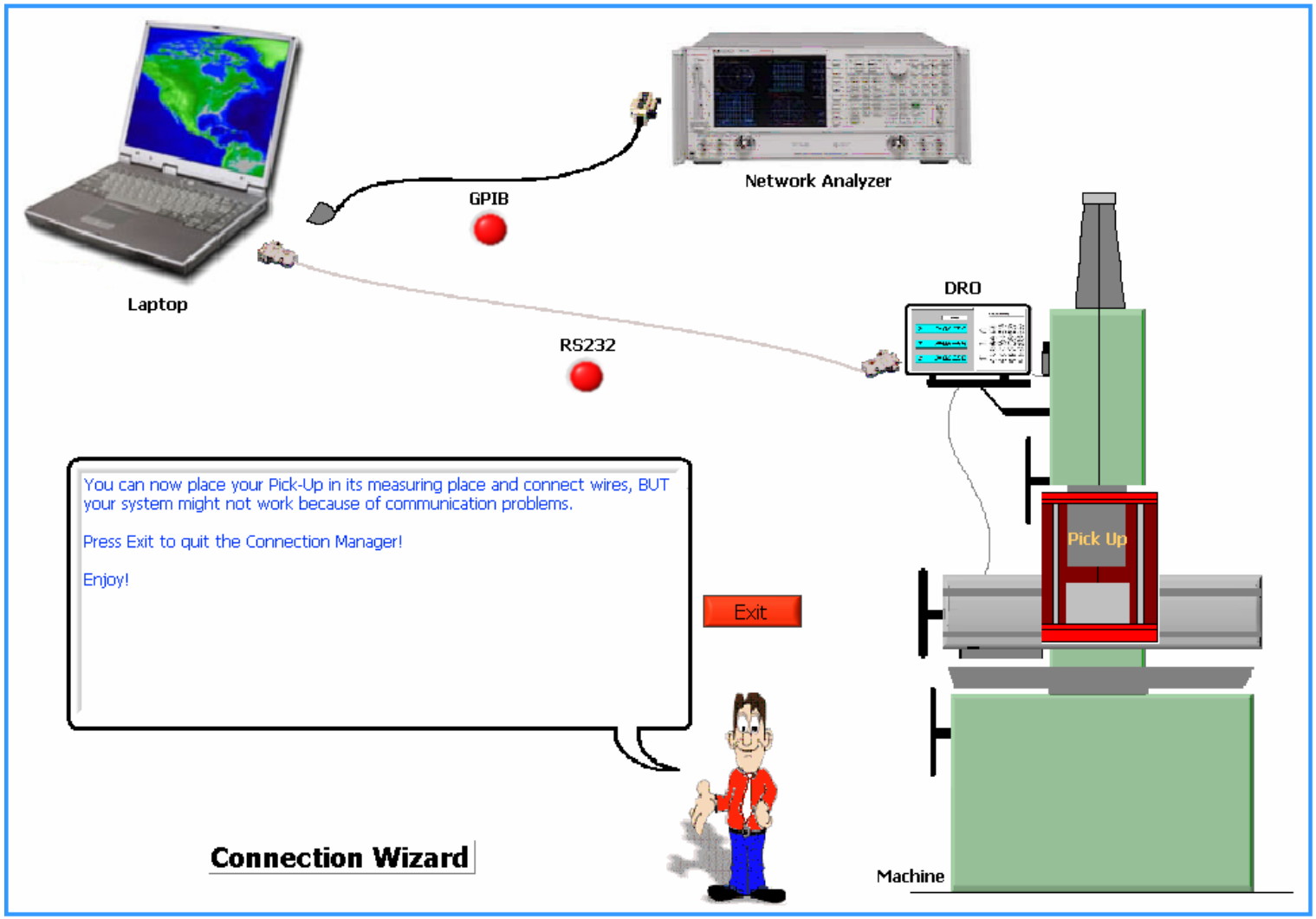
Cut in the same direction



Using all the electrode surface

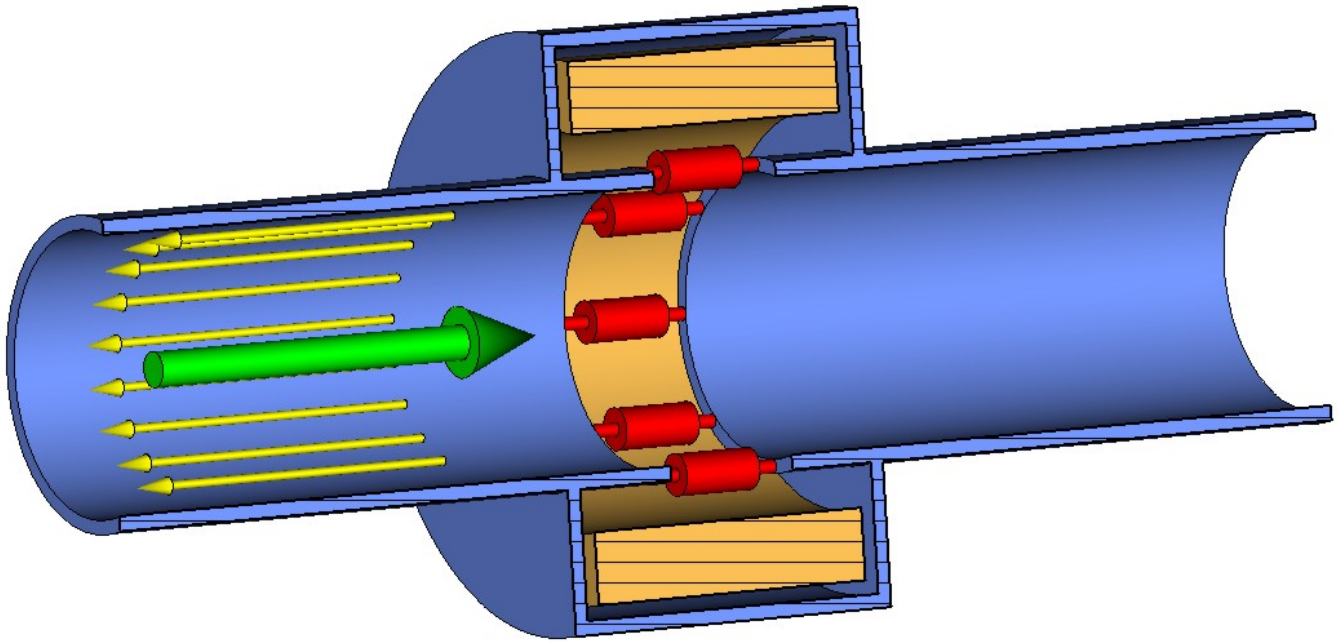


Pick-up Calibration



Calibration of the pick-up

Wall Current Monitor (WCM) principle



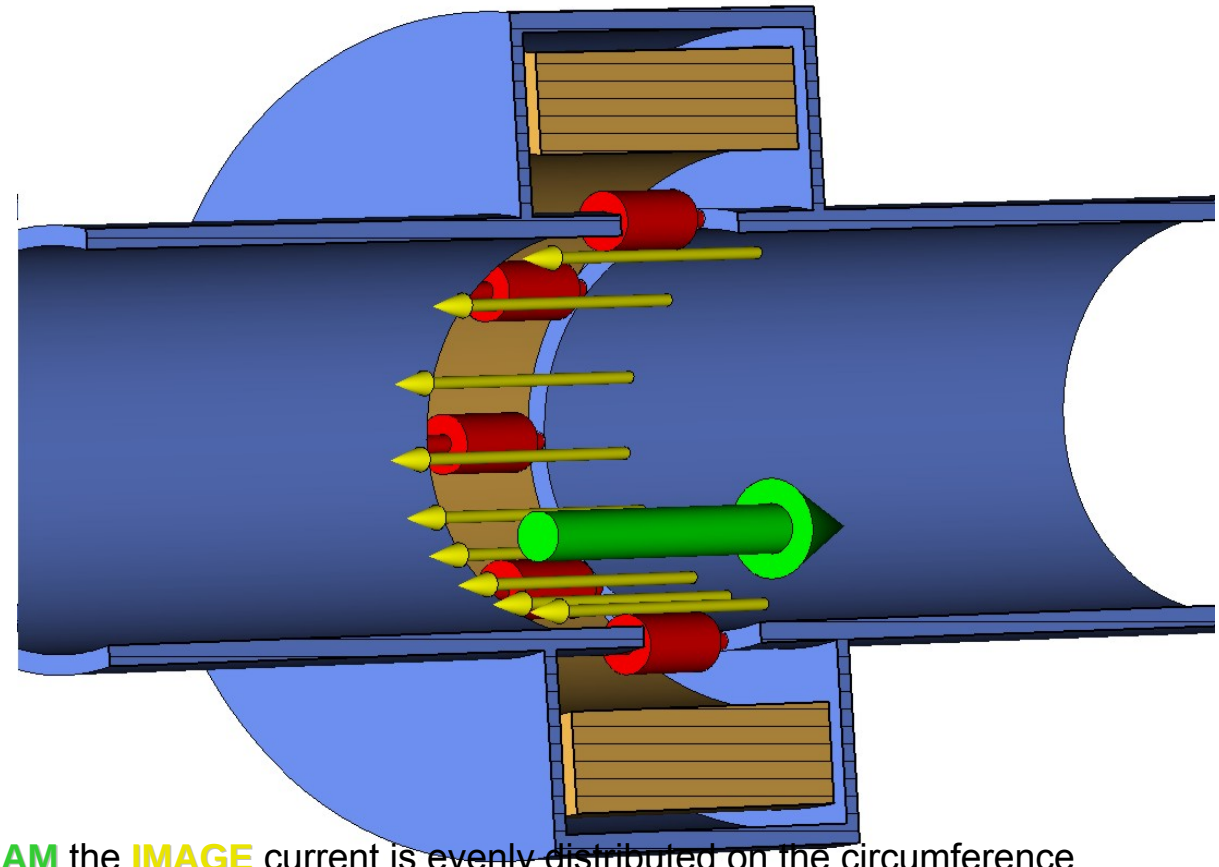
- The **BEAM** current is accompanied by its **IMAGE**
- A voltage proportional to the beam current develops on the **RESISTORS** in the beam pipe gap
- The gap must be closed by a box to avoid floating sections of the beam pipe
- The box is filled with the **FERRITE** to force the image current to go over the resistors
- The ferrite works up to a given frequency and lower frequency components flow over the box wall

Slide by M. Gasior

WCM as a Beam Position Monitor

$$f_{L\Sigma} = \frac{R}{2\pi L_{\Sigma}}$$

$$f_{L\Delta} = \frac{R}{2\pi L_{\Delta}}$$

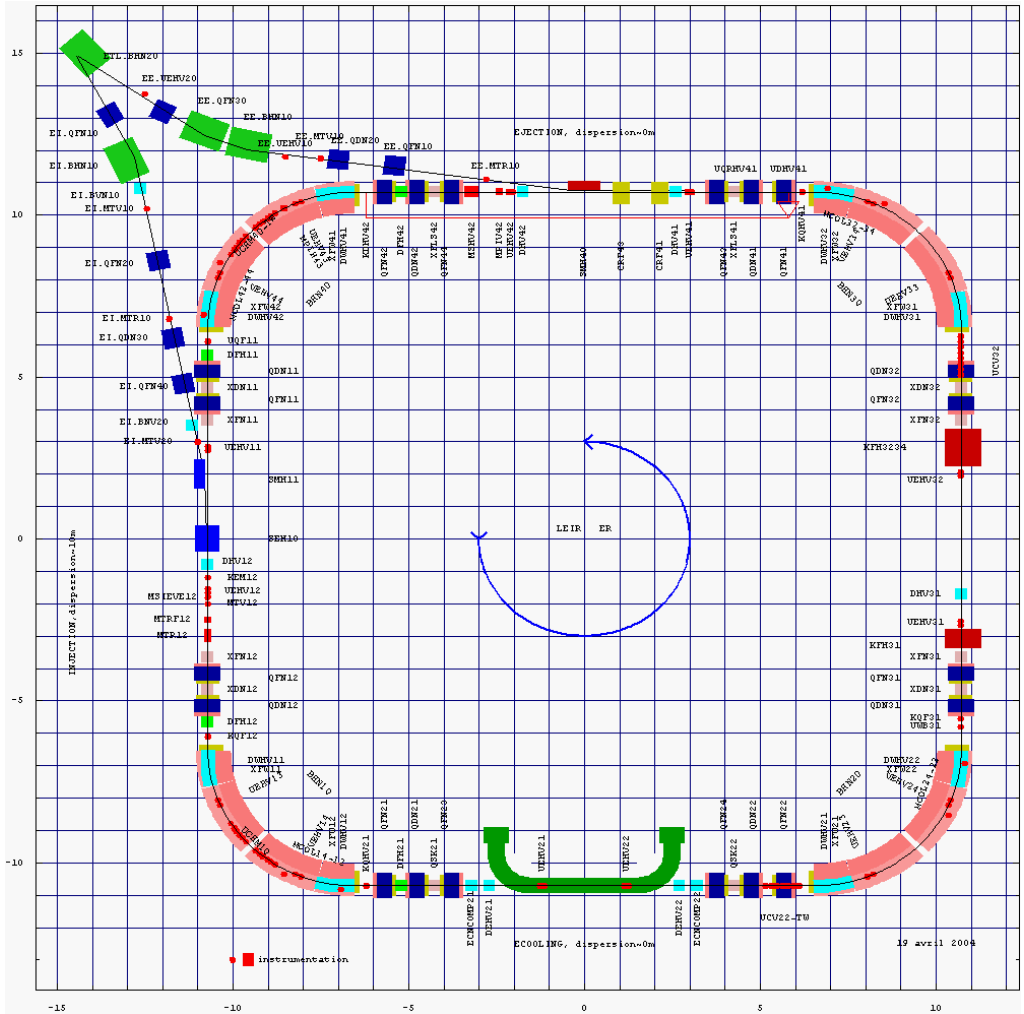


- For a centered **BEAM** the **IMAGE** current is evenly distributed on the circumference
- The image current distribution on the circumference changes with the beam position
- Intensity signal (Σ) = resistor voltages summed
- Position dependent signal (Δ) = voltages from opposite resistors subtracted
- The Δ signal is also proportional to the intensity, so the position is calculated according to Δ/Σ
- Low cut-offs depend on the gap resistance and box wall (for Σ) and the pipe wall (for Δ) inductances

Slide by M. Gasior

Measuring Beam Parameters on unbunched Beams

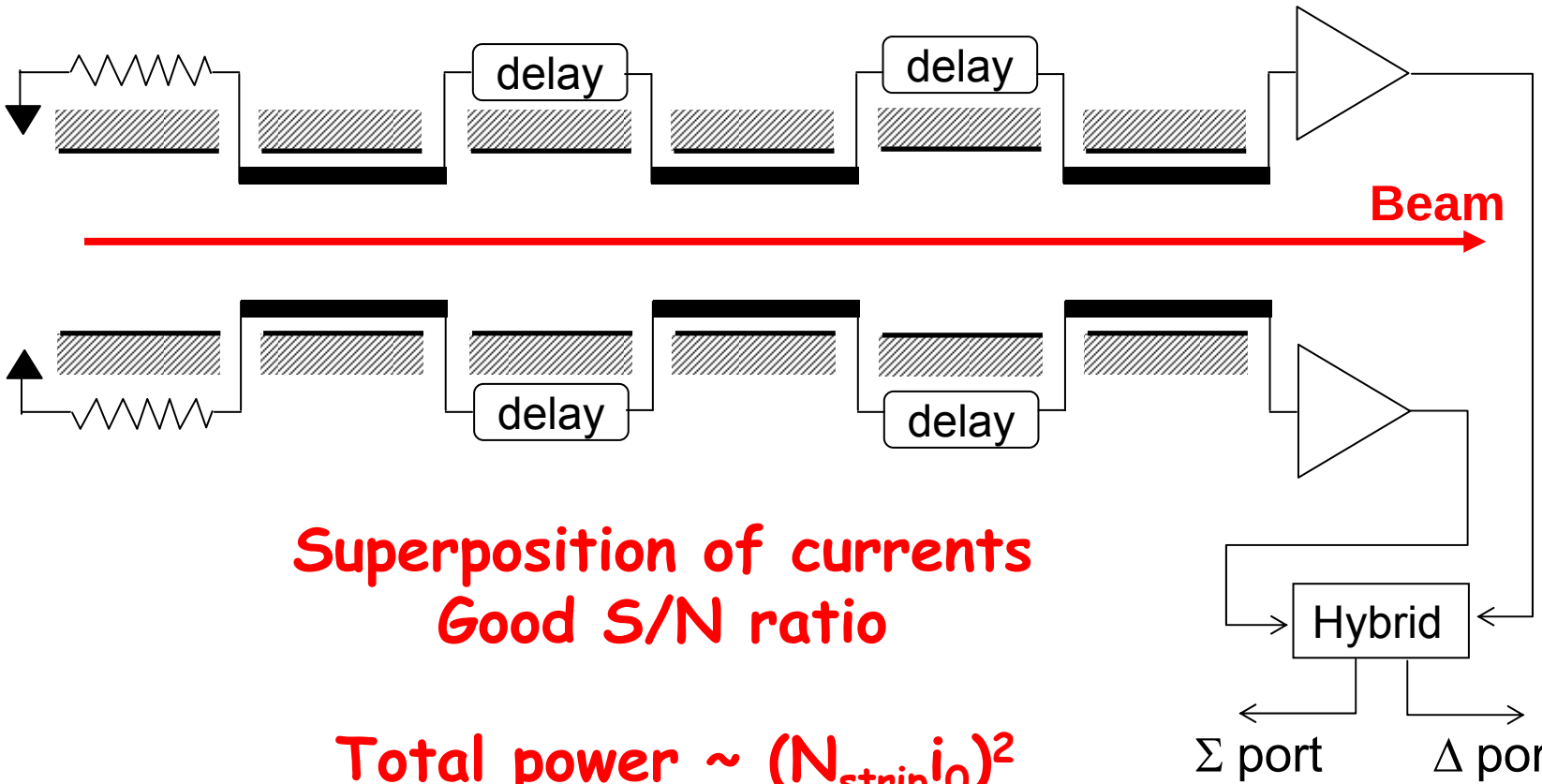
- LEIR used for ion accumulation
- Multiturn injection of unbunched beams
- Electron cooling
- Bunching and acceleration



Travelling Wave Pick-up

Principle of travelling wave stripline

- Travelling-Wave Striplines for ***low energy particles***



Superposition of currents
Good S/N ratio

Total power ~ $(N_{strip} i_0)^2$

Schottky Measurements

The noise generated by single particles is collected

From statistical properties the Δp/p can be extracted