Signals

- Signal

  generalised name for input into instrument system

- Might seem logical to consider signals before sensors but can now see

  wide range of signal types are possible

  depend on sensor

  depend on any further transformation - eg light to electrical

- Most common types of signal

  short, random pulses, usually current, amplitude carries information

  typical of radiation sensors

  trains of pulses, often current, usually binary

  typical of communication systems

  continuous, usually slowly varying, quantity - eg. current or voltage

  slow - typical of monitoring instruments

  fast - eg cable TV, radio

- terms like "slow", "fast" are very relative!

Typical signals

- Some examples

Signal source	Duration
Inorganic scintillator	$e^{-t/\tau}$ τ ~ few µs
Organic scintillator	$e^{-t/\tau}$ τ ~ few ns
Cerenkov	~ns
Gaseous	few ns - µs
Semiconductor	~10ns
Thermistors	continuous
Thermocouple	continuous
Laser	pulse train ~ps rise time or short pulses ~fs

- However, we will find later that speed of signal is not always sufficient to build fast responding systems

Signal formation

- Issues in practical applications

duration

radiation: depends on transit time through sensor and details of charge induction process in external circuit

linearity

most radiation sensors characterised, or chosen for linearity

for commercial components can expect non-linearity, offset and possible saturation

reproducibility

eg. many signals are temperature dependent in magnitude - mobility of charges

other effects easily possible

ageing

sensor signals can change with time for many reasons

natural degradation of sensor, variation in operating conditions, radiation damage,...

- all these effects mean one should always be checking or calibrating measurements intended for accuracy as best one can

Optical transmitters

- Semiconductor lasers most widely used

  Now dominate telecomms industry

  >> *Gb/s operation*

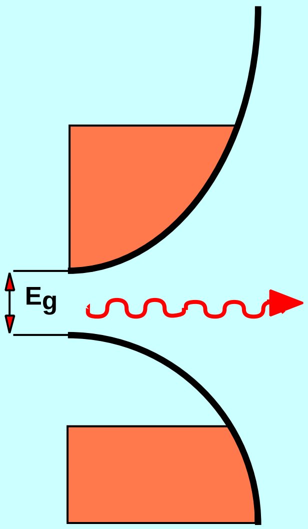
- Principle

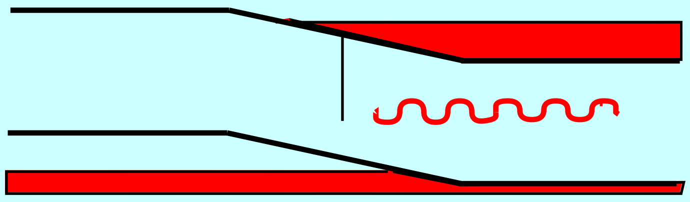
  Forward biased p-n diode

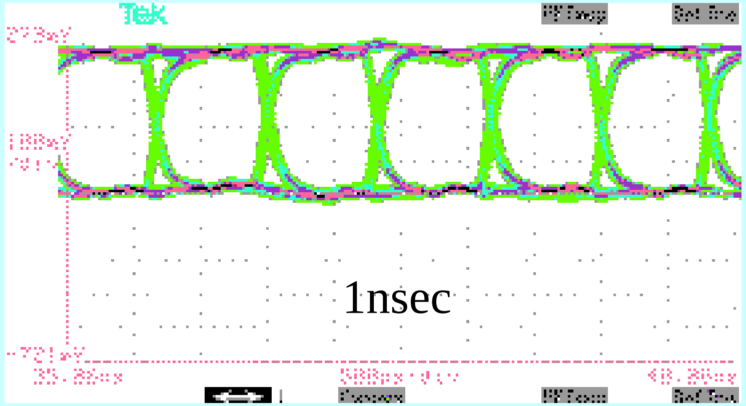
  => *population inversion*

  direct band gap material

GaAs	*~850nm*
GaAlAs	*~ 600-900nm*
In, Ga, As, P	*~0.55-4µm*







- + polished optical facets

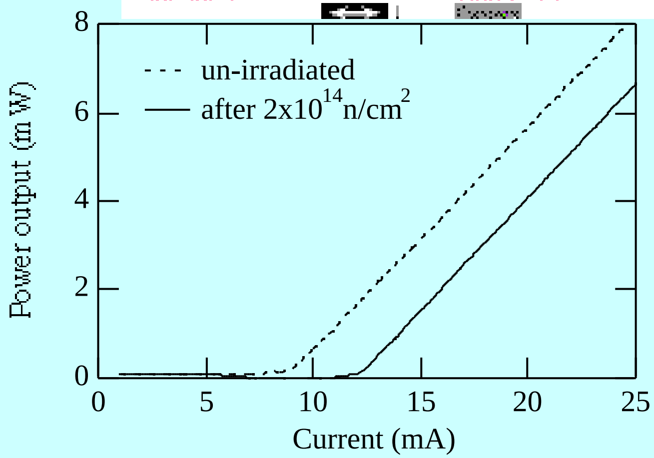
  => Fabry-Perot cavity

  optical oscillator

  lase at $I > I_{threshold}$

  photon losses from cavity or absorption

  often very linear



Modern semiconductor lasers

•Quantum well structures

confine charge carriers to active layer

refractive index difference

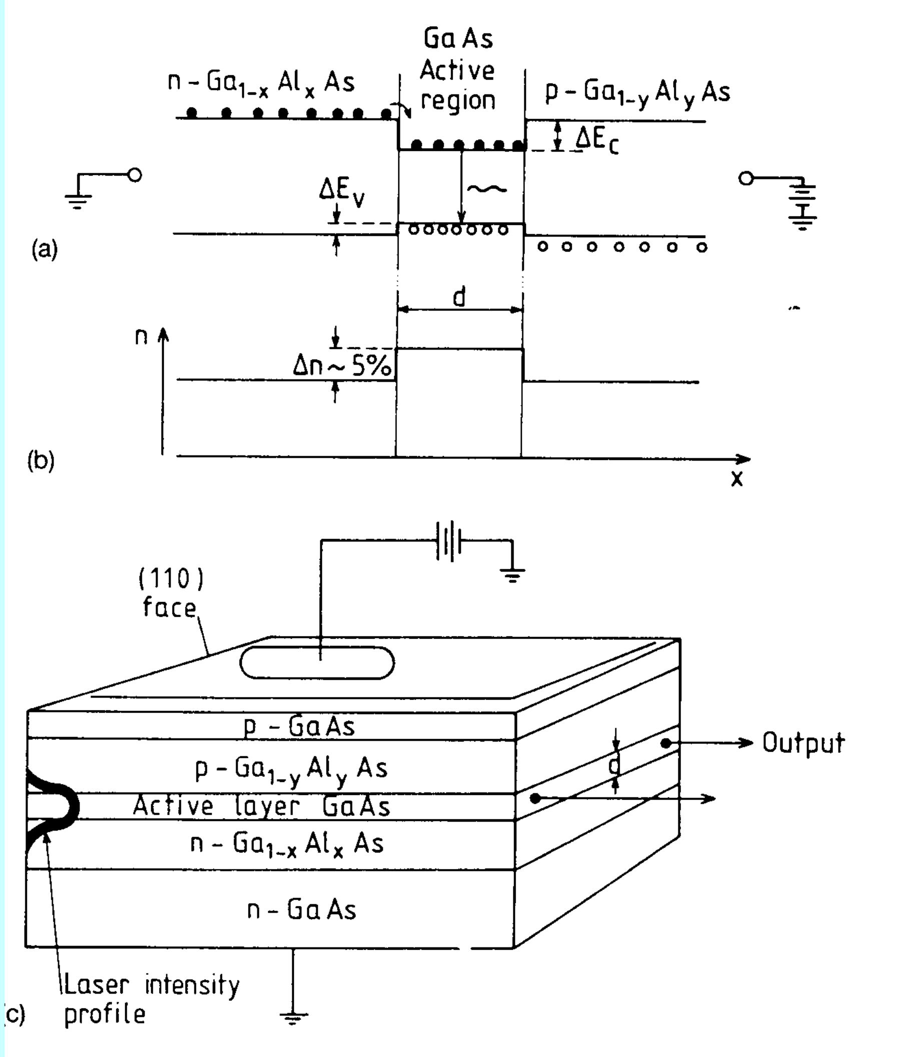
=> *waveguide confines light*

minimise lateral dimensions for efficiency

& low $I_{threshold}$

=>*low power (~mW), miniature devices*

well matched for optical fibre transmission



•VCSELs Vertical Cavity Surface Emitting Laser

emit orthogonal to surface

ultra-low power

cheap to make (test on wafer)

can be made in arrays

non-linear L-I characteristic

but very suitable for digital applications

Passage of radiation through matter

- Need to know a few elementary aspects of signal formation whether interested in light or other radiation

  How far does radiation penetrate?

  How much of incident energy is absorbed?

- Signal current - duration and magnitude

  consequence of charge carriers generated

  electrons + holes (semiconductor) or ions (gases, liquids)

  current duration depends on

  distance over which charge deposited

  rapid absorption or thin sensor give fast signals

  electric field

  only charges in motion generate currents

  current in external circuit is **induced**

Light

- $I \sim I_0 \exp(-L/L_{abs})$

  $1/L_{abs} = N_{atom}\sigma$ $N_{atom} = \rho N_{Avogadro}/A$ = no. atoms per unit volume

- Photoabsorption

  E ~ eV- 100keV atom ionised in single process, all photon energy transferred

  at low energies depends on atomic properties of material

  at higher energies $\sigma_{pa} \sim Z^{4-5}/E_\gamma^3$ above K-shell edge

- Compton scattering

  ~MeV quantum collision of photon with charged particle, usually e^-

  transfer of part of photon energy, often small

- Pair production

  >> MeV

  all energy transferred to e+e- pair

  to conserve momentum and energy, needs recoil

  must take place in field of nucleus or electron

Light absorption -

- Low energies

see consequence of atomic behaviour

eg silicon bandgap

NB strong dependence on wavelength in near-visible regions

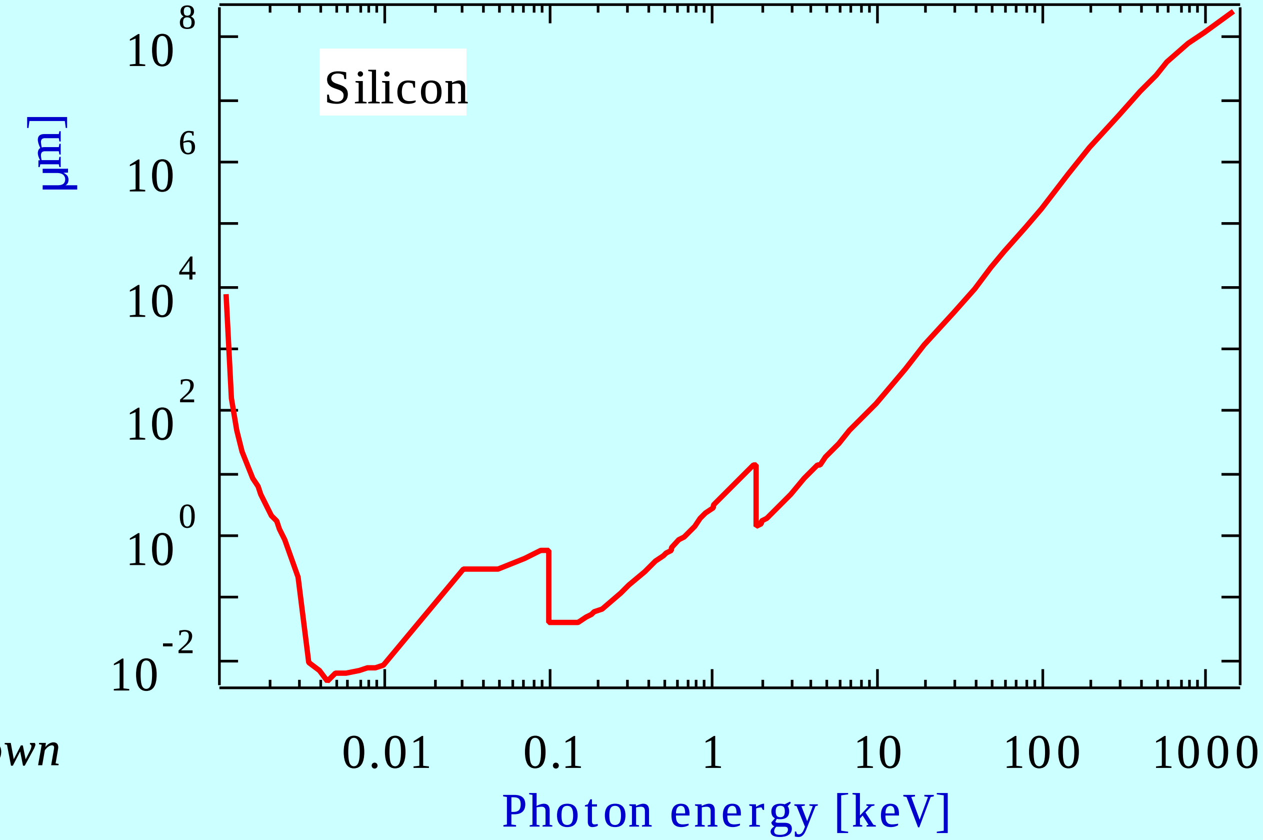
- High energies

atomic shell structure visible

then electrons appear as quasi-free

Compton scattering starts to dominate

at ~60keV - not shown



Light absorption

•Far UV to x-ray energies

atomic shell structure

photo-absorption

coherent = Rayleigh scattering

atom neither ionised nor nor excited

incoherent = Compton

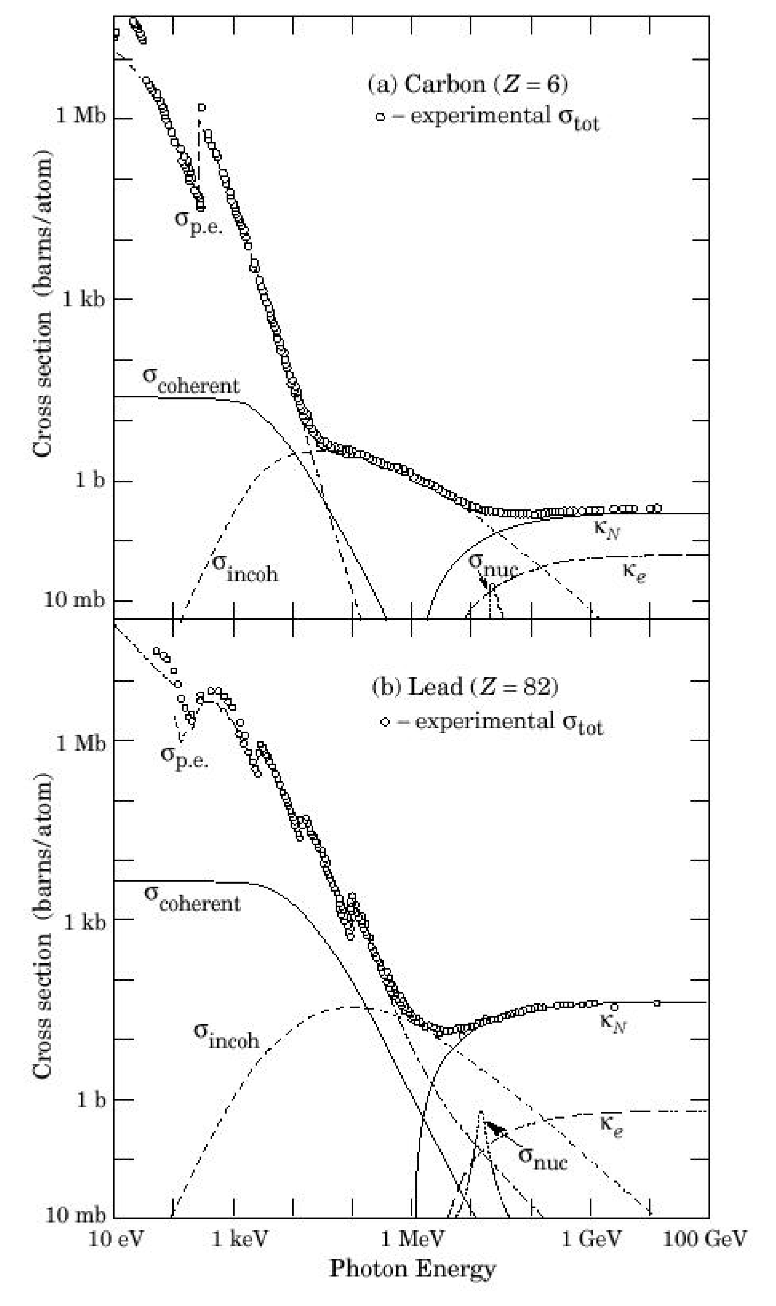
$\sigma = Zf(E_\gamma)$

pair production $E_\gamma > 2m_e$

contributions from nucleus (~Z^2)

and atomic electrons (~Z)

small contribution from nuclear interactions

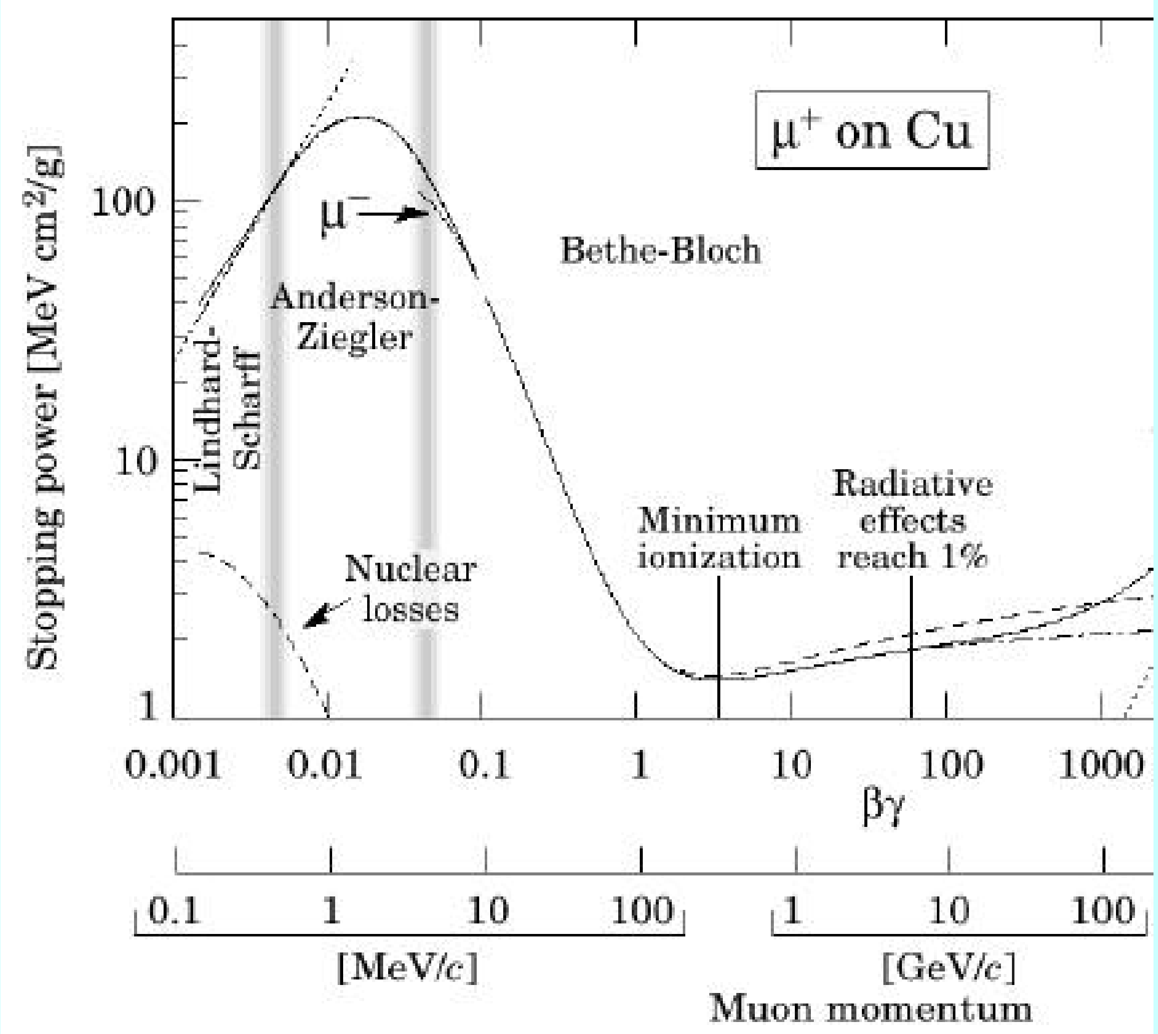


Charged particles

•Ionisation dominates   Units: x = density x thickness = [g.cm^{-2}]

Stopping power = dE/dx   scales in similar way for all particles with p/m = βγ

dominated by interactions with atomic electrons



•low energies

slow particles lose energy rapidly

dE/dx increases with β

to maximum

Bragg peak

•relativistic energies

decline ~ 1/β^2

to minimum value

further slow rise ~ log(p/m)

•most cosmic rays and high energy particles approximately MIPs

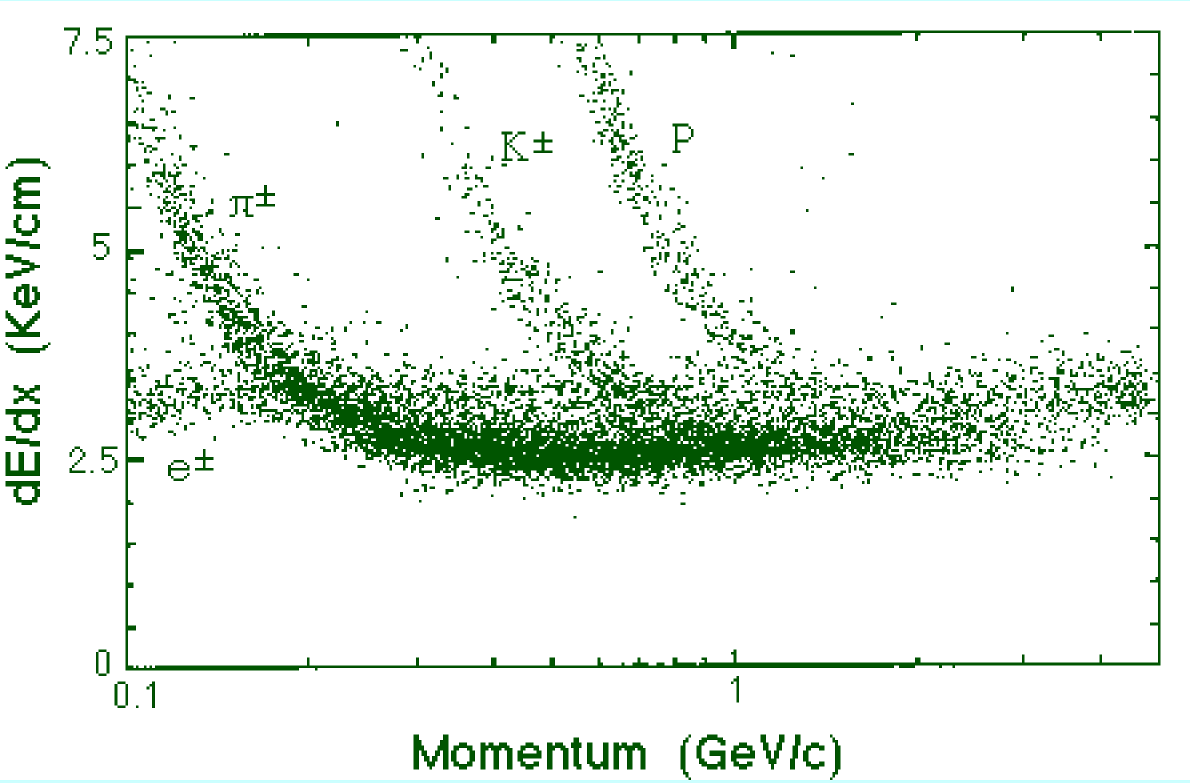
dE/dx

•Measured energy loss can provide another way of identifying particles

gas detectors with multiple samples of ΔE from same particle

momentum measurement is needed - from bending in B field

accompanied by good calibration of p and dE/dx



Electrons

- are special because of their low mass

  classically accelerated charge radiates

- brehmstrahlung radiation in matter

  acceleration in nuclear field

- synchrotron radiation in accelerators

  generates beams of low energy x-rays

  typical E ~ 1-10keV

  widely used for studying atomic properties, eg protein crystallography

Other neutral particles

- neutrons

  do not generate ionisation directly so hard to measure

- at low energies

  mostly elastic collisions with atoms in material

  simple kinematics determines energy transfer

$$\Delta T_{max} = 4AT_{inc}/(1+A)^2$$

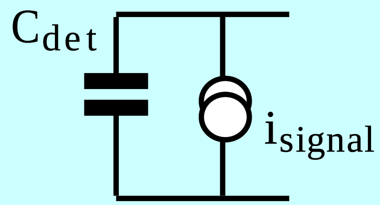
  low Z materials favoured to absorb neutron energy

  C, D_2O moderators in nuclear reactors

  hydrogenous or boron compounds used as detectors

Sensor equivalent circuits

•Many of the sensors considered so far can be modelled as



current source + associated capacitance

typical values ~ few pF

but can range from

~100fF semiconductor pixel

~10-20pF gas or Si microstrip, PM anode

~100pF large area diode

~µF wire chamber

usually there is some resistance associated with the sensor, eg leads or metallisation but this has little effect on signal formation or amplification

•Notable exception: microstrips - gas or silicon

the capacitance is distributed, along with the strip resistance

forms a dissipative transmission line