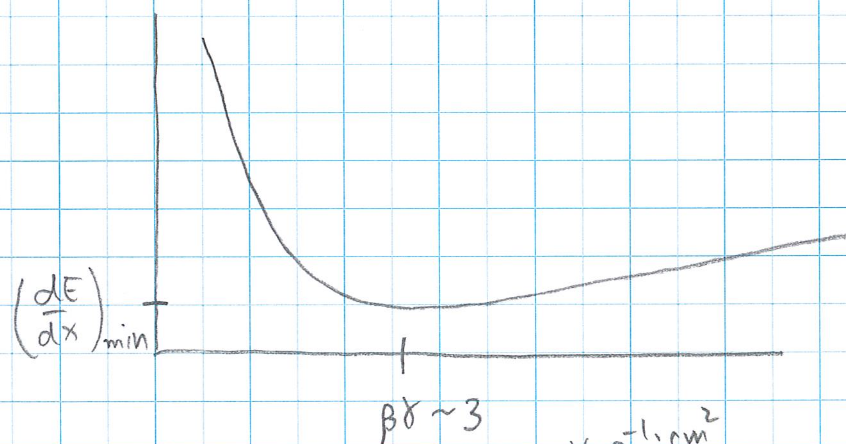
Lecture #6

Particle detectors

Ultimately, what we detect is ionizing charged particles.

Energy loss:

$$\left\langle -\frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \log\left(\frac{2 m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} \right) - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

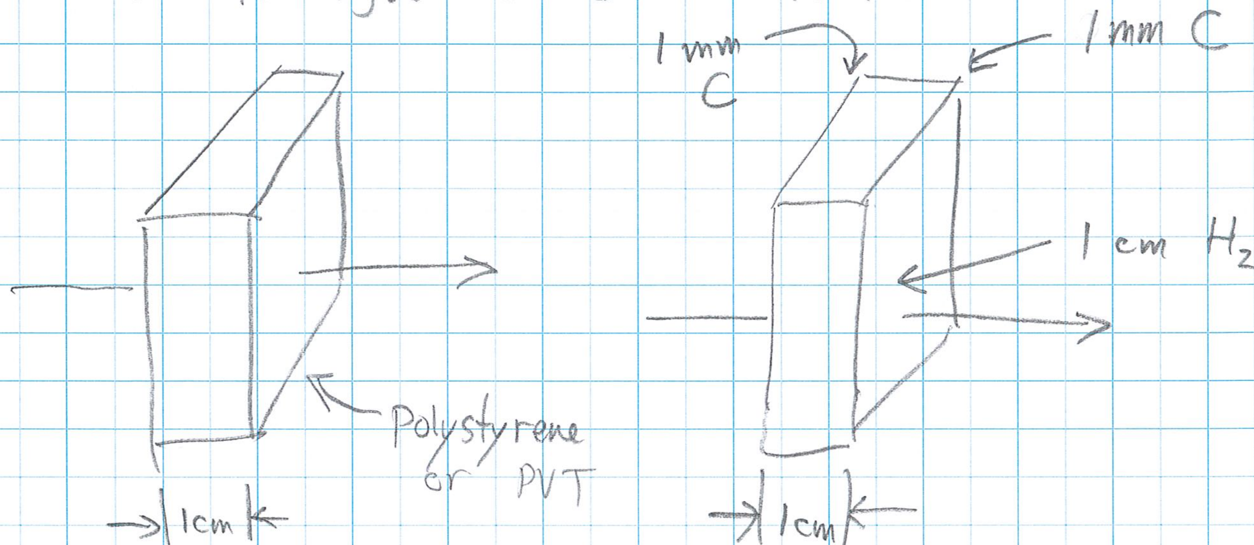


$MeV \cdot g^{-1} \cdot cm^2$

Material	$(dE/dx)_{min}$	ρ	dE/dx (MeV/cm)
H_2 (gas)	4.103	0.084 g/ℓ	0.000345
Ar (gas)	1.519	1.662 g/ℓ	0.00252
Xe (gas)	1.255	5.483 g/ℓ	0.00688
Be	1.595	1.848 g/cm^3	2.948
C	1.725	2.210 g/cm^3	3.812
Al	1.615	2.699	4.359
Fe	1.451	7.874	11.425
Cu	1.403	8.960	12.571
Pb	1.122	11.350	12.735
U	1.081	18.950	20.485
Polystyrene	1.936	1.06	2.052
PVT	1.956	1.03	2.015

For simplicity, we will assume that particles are minimum ionizing unless we specify otherwise.

Consider the energy lost as a particle moves through some material:



Energy loss

$$\Delta E = \left(\frac{dE}{dX}\right)_{min} \cdot \rho \cdot \Delta X$$

$$= (2.052 \text{ MeV/cm})(1\text{cm})$$

$$= 2.052 \text{ MeV}$$

$$\Delta E = (0.000345 \text{ MeV/cm})(1\text{cm})$$

$$+ 2(3.812 \text{ MeV/cm})(0.1\text{cm})$$

$$= 0.763 \text{ MeV}$$

What happens to the ions created in the material when the charged particle passes through?

Plastic scintillator

Clear, can be cut, cast, polished, thermoformed.

Doped with * * magic chemicals * so that electrons emit light when they are reabsorbed.

Desirable properties:

Light should propagate without being re-absorbed.

Light should be emitted fast (not in a slow glow).

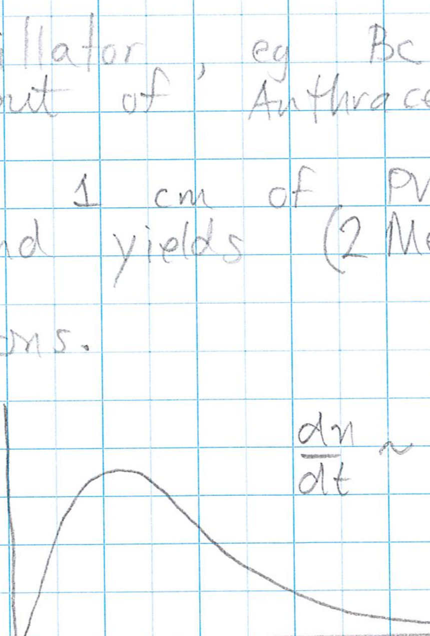
Anthracene: 17,400 photons / MeV
peak wavelength is typically ~ 450 nm (blue).

Commercial scintillator, eg BC-408
64% light output of Anthracene, 11,136 photons/MeV

A MIP through 1 cm of PVT deposits about 2 MeV and yields (2 MeV)(11136 /MeV)

= 22,300 photons.

Time structure



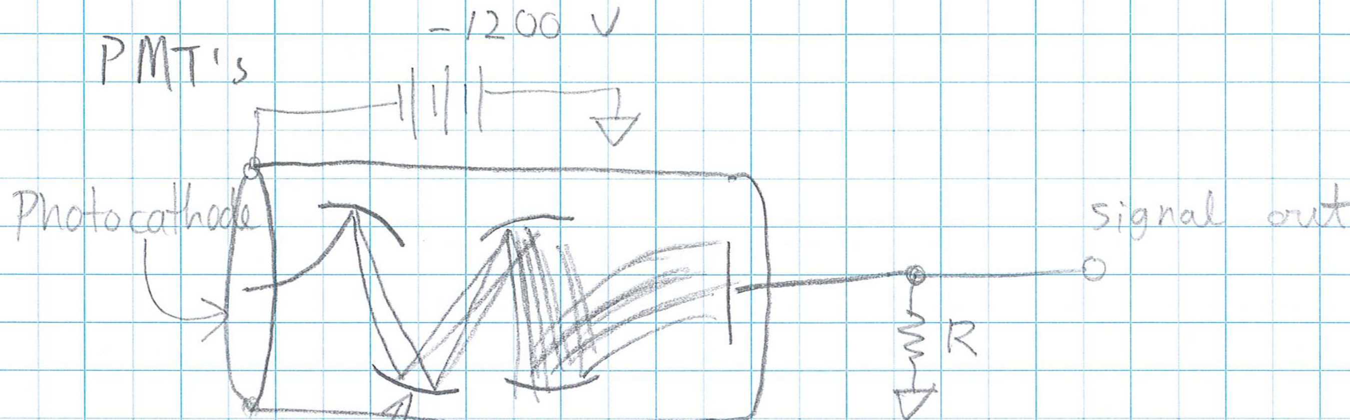
$$\frac{dn}{dt} \sim \left(1-e^{-t/\tau_r}\right) e^{-t/\tau_f}$$

$\tau_r \sim 0.9$ ns
$\tau_f \sim 2.1$ ns

Detecting scintillation light.

Photomultiplier tubes
Wavelength shifting fibers
Avalanche photodiodes
Silicon photomultipliers

PMT's



Bialkali
CsK

BeCuO emits more electrons

High voltage (eg few 100 volts) between each dynode accelerates electrons from rest.

$N_e = \delta^N N_\gamma$ δ typically ~ 2.5

N can be quite a few. eg, 16.

$G = (2.5)^{16} \sim 2 \times 10^6$.

Light collection efficiency $\sim 10\%$?

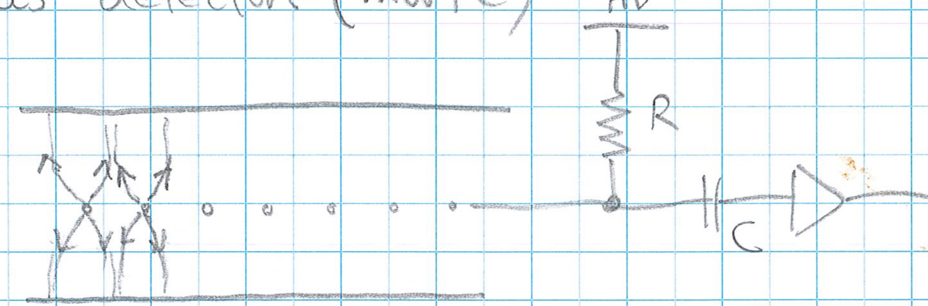
$N_e = N_\gamma \varepsilon G = (22{,}300)(0.1)(10^6) \sim 2 \times 10^9$

$= 360 \text{ pC}$

$I = \dfrac{\Delta Q}{\Delta t} \sim \dfrac{360 \text{ pC}}{10 \text{ ns}} \sim 36 \text{ mA}$, $R = 50\Omega$

$V = IR$, $V = 1.8 V$.

Gas detectors (MWPC)



Wires are held at a large positive voltage. Ions drift towards the planes, electrons drift towards the wires.

Drift speed is approximately constant,

$$v = \mu E \qquad \mu \sim 1.5\ cm^2/V\cdot s$$

Near the anode wire the electric field is very large. Avalanche breakdown increases the number of electrons/ions at the wire, proportional to the drift charge.

The electric field does work on the ions as they are repelled from the wire.

$$V = W/Q$$

A pulse is induced that is amplified by a preamplifier.

How many ions per cm?

Table 34.5: Properties of noble and molecular gases at normal temperature and pressure (NTP: 20° C, one atm). E_X, E_I: first excitation, ionization energy; W_I: average energy per ion pair; $dE/dx|_{\min}$, N_P, N_T: differential energy loss, primary and total number of electron-ion pairs per cm, for unit charge minimum ionizing particles.

Gas	Density, $\mathrm{mg\,cm^{-3}}$	E_x eV	E_I eV	W_I eV	$dE/dx\|_{\min}$ $\mathrm{keV\,cm^{-1}}$	N_P $\mathrm{cm^{-1}}$	N_T $\mathrm{cm^{-1}}$
He	0.179	19.8	24.6	41.3	0.32	3.5	8
Ne	0.839	16.7	21.6	37	1.45	13	40
Ar	1.66	11.6	15.7	26	2.53	25	97
Xe	5.495	8.4	12.1	22	6.87	41	312
CH_4	0.667	8.8	12.6	30	1.61	28	54
C_2H_6	1.26	8.2	11.5	26	2.91	48	112
iC_4H_{10}	2.49	6.5	10.6	26	5.67	90	220
CO_2	1.84	7.0	13.8	34	3.35	35	100
CF_4	3.78	10.0	16.0	54	6.38	63	120

If $\Delta E = 0.763$ MeV and $W_I \sim 40$ eV
then there are about 20,000 ions created.

Multiplication factor (gas gain) 10^3 ?

20×10^6 ions at the wire.

Good timing resolution. Drift time determines location of primary ionization.