COSMIC RAYS

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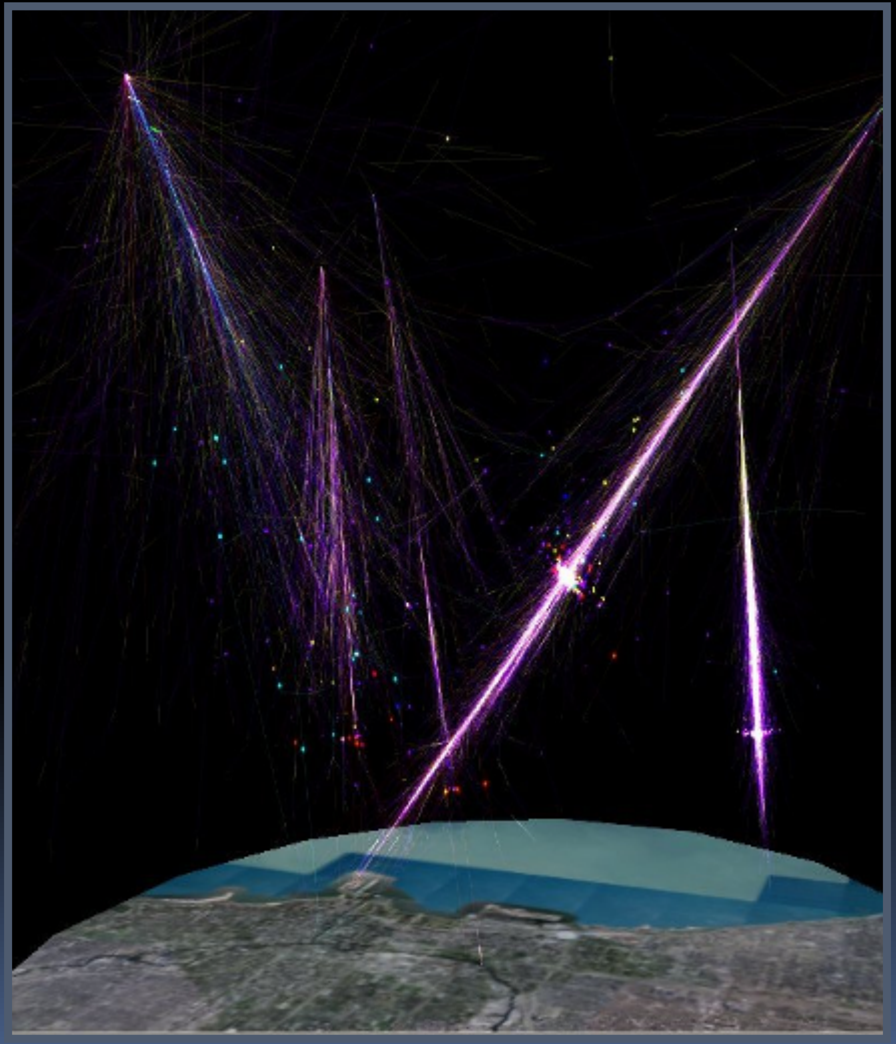
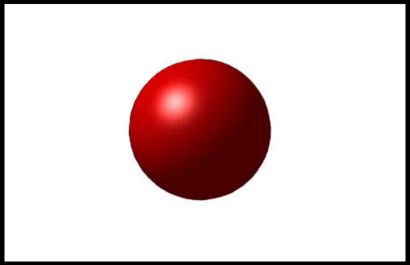
What are cosmic rays?

- Cosmic rays are high energy charged particles
- Protons, nuclei, electrons, positrons
- Traveling at nearly the speed of light
- Striking the Earth from all directions



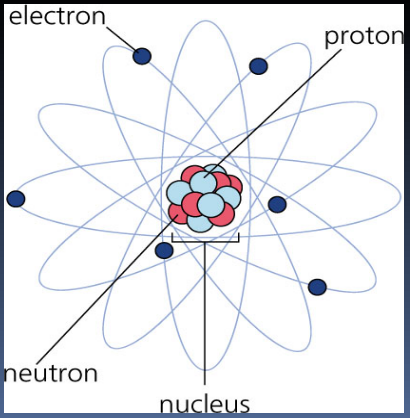
Composition

89% protons (hydrogen nuclei)



10% Helium nuclei

1 % Electrons, heavier elements



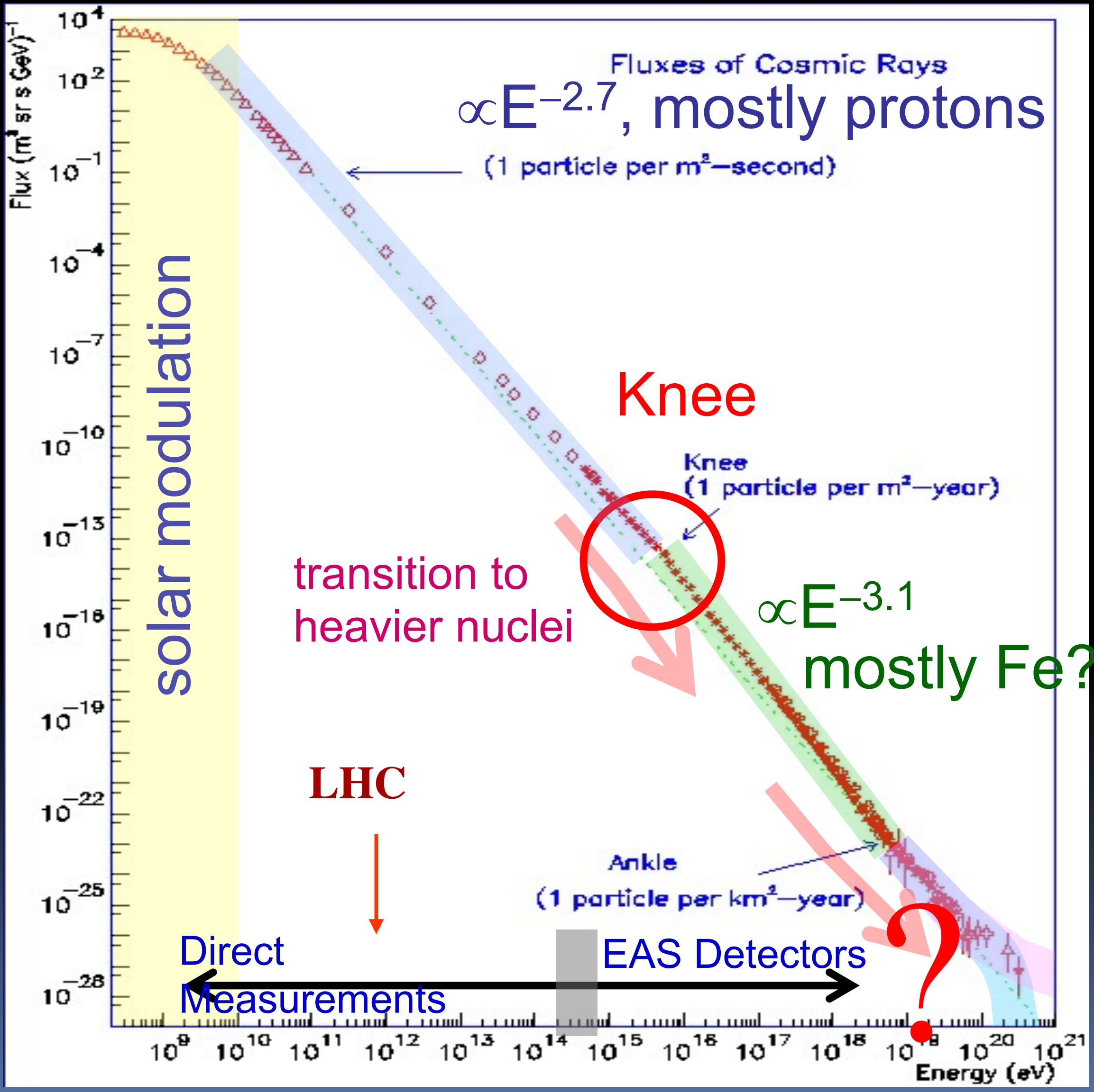
Origin

- Extra-galactic cosmic rays originate and are accelerated by supernovae explosions.
- The Sun also emits cosmic rays as solar flares

Discovery

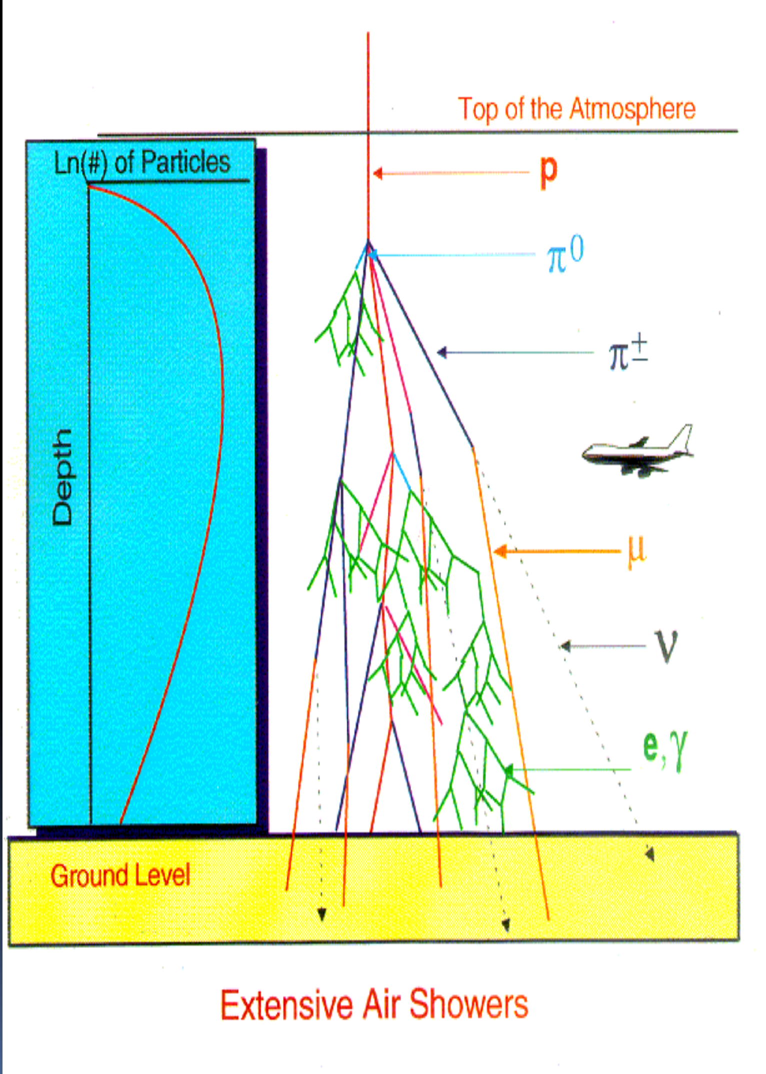
- Cosmic rays were first observed by Victor Hess in 1912.
- He detected radiation in the upper atmosphere using an electroscope in a balloon.
- He repeated the experiment during solar eclipse to determine this radiation was not coming entirely from the sun.
- Hess was awarded the Nobel Prize in 1936 for this discovery.

Energy Spectrum



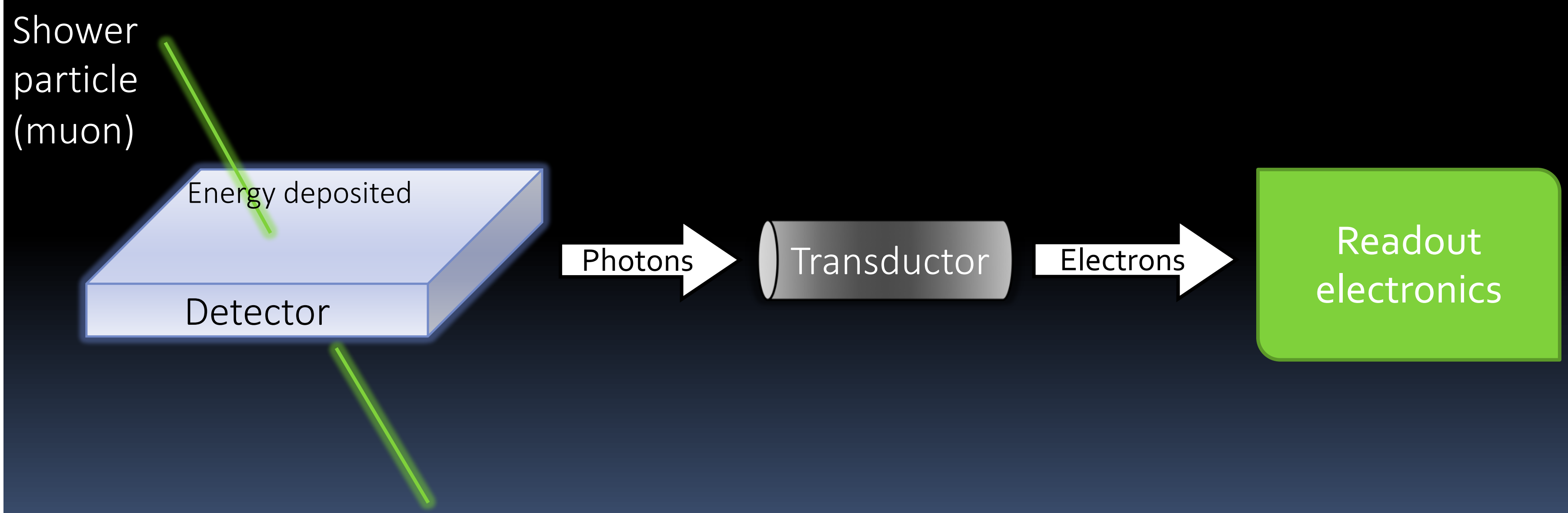
A Cosmic Ray Shower

- Cosmic ray particles entering the Earth's atmosphere collide (mainly) with oxygen and nitrogen nuclei
- This high energy collisions produce a cascade of lighter particles, a so-called *air shower*.

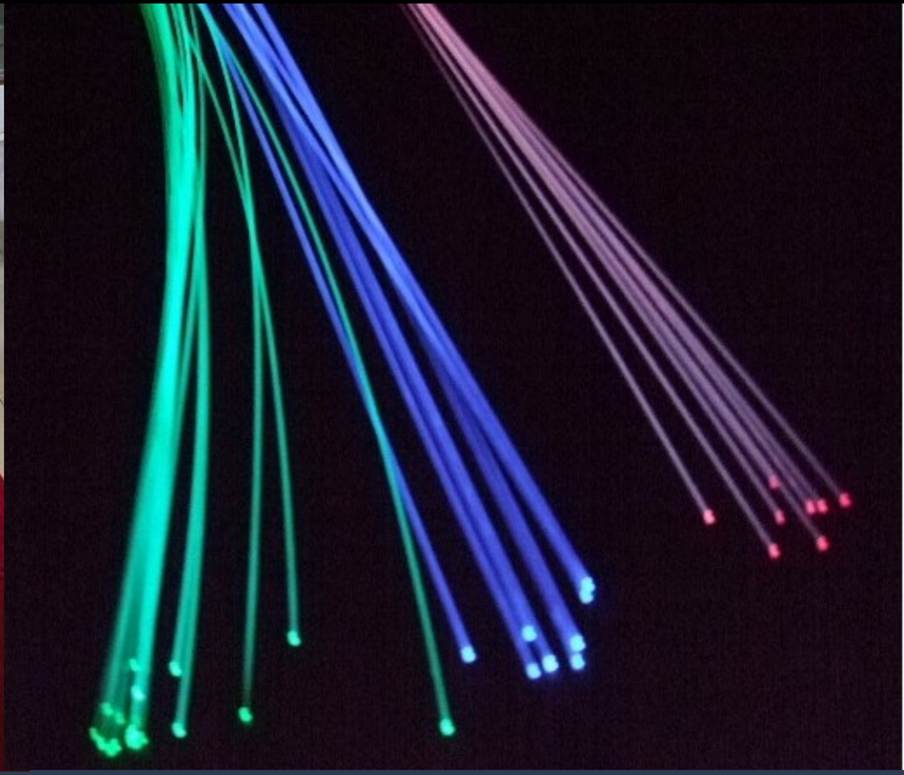


How do we measure the cosmic rays?

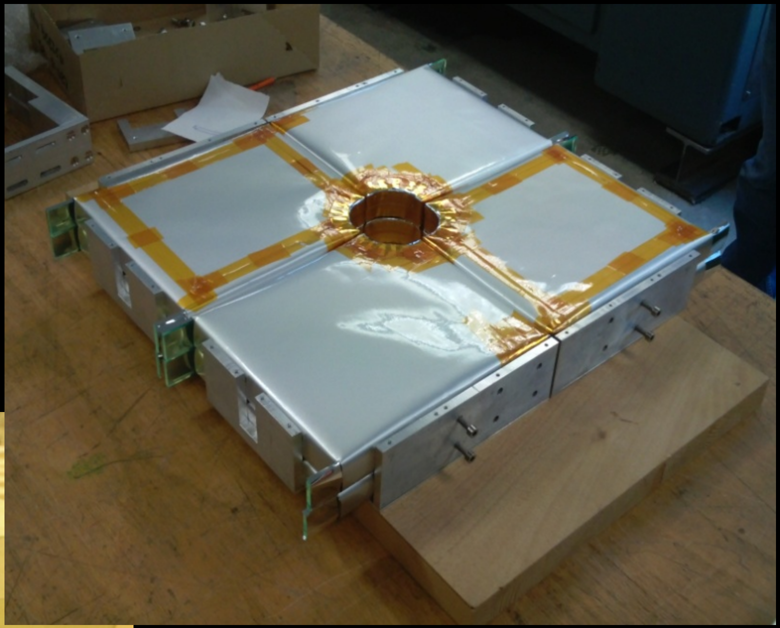
- We detect the shower products that make it through the atmosphere down to the Earth’s surface.



Plastic Scintillators



Detectores



Scintillation Detectors

As a charged particle traverses certain materials exciting the atoms (or molecules) a small fraction of the energy is released as photons when they de-excite. These materials are called scintillators.

Scintillation light can be used to:

- Signal the presence of a charged particle
- Measure the time it takes for a charged particle to travel a known distance: *time of flight technique*
- Measure energy since the amount of light is proportional to energy deposition

There are different types of materials that scintillate:

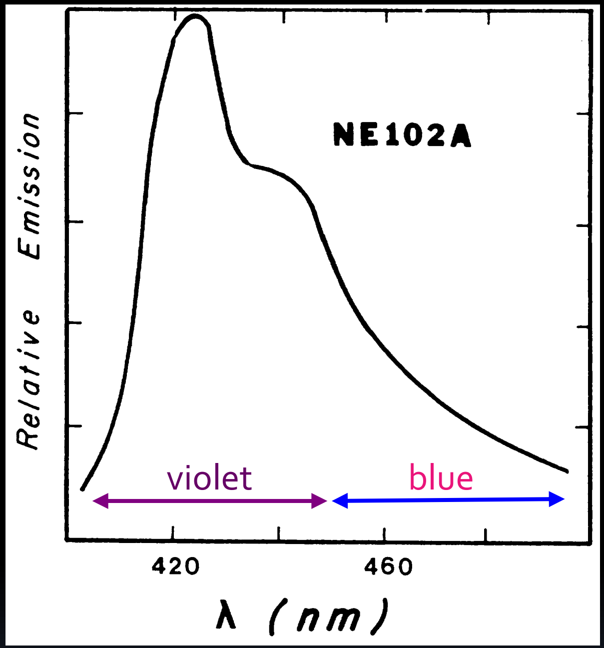
Inorganic crystals (NaI, CsI, BGO)
Organic molecules (Anthracene)
Organic plastics (see table on next page)
Organic liquids (toluene, xylene)
Our atmosphere (nitrogen)

Organic scintillators properties

Type	Light[a] output	λ_{max}[b] (nm)	Attenuation[c] length (cm)	Risetime (ns)	Decay[d] time (ns)	Pulse FWHM (ns)
NE 102A	58–70	423	250	0.9	2.2–2.5	2.7–3.2
NE 104	68	406	120	0.6–0.7	1.7–2.0	2.2–2.5
NE 104B	59	406	120	1	3.0	3
NE 110	60	434	400	1.0	2.9–3.3	4.2
NE 111	40–55	375	8	0.13–0.4	1.3–1.7	1.2–1.6
NE 114	42–50	434	350–400	~1.0	4.0	5.3
Pilot B	60–68	408	125	0.7	1.6–1.9	2.4–2.7
Pilot F	64	425	300	0.9	2.1	3.0–3.3
Pilot U	58–67	391	100–140	0.5	1.4–1.5	1.2–1.9
BC 404	68	408	—	0.7	1.8	2.2
BC 408	64	425	—	0.9	2.1	~2.5
BC 420	64	391	—	0.5	1.5	1.3
ND 100	60	434	400	—	3.3	3.3
ND 120	65	423	250	—	2.4	2.7
ND 160	68	408	125	—	1.8	2.7

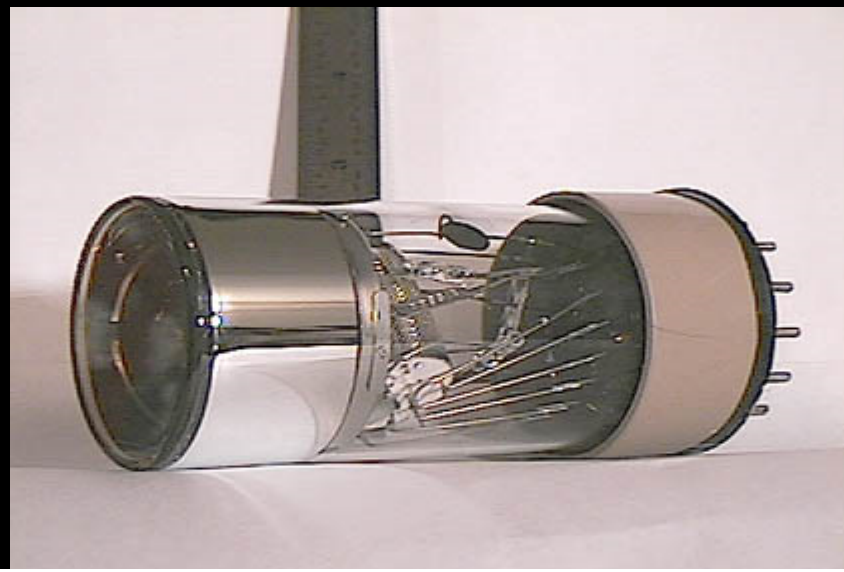
[a] Percentage of anthracene.
[b] Wavelength of maximum emission.
[c] $1/e$ length.
[d] Main component.

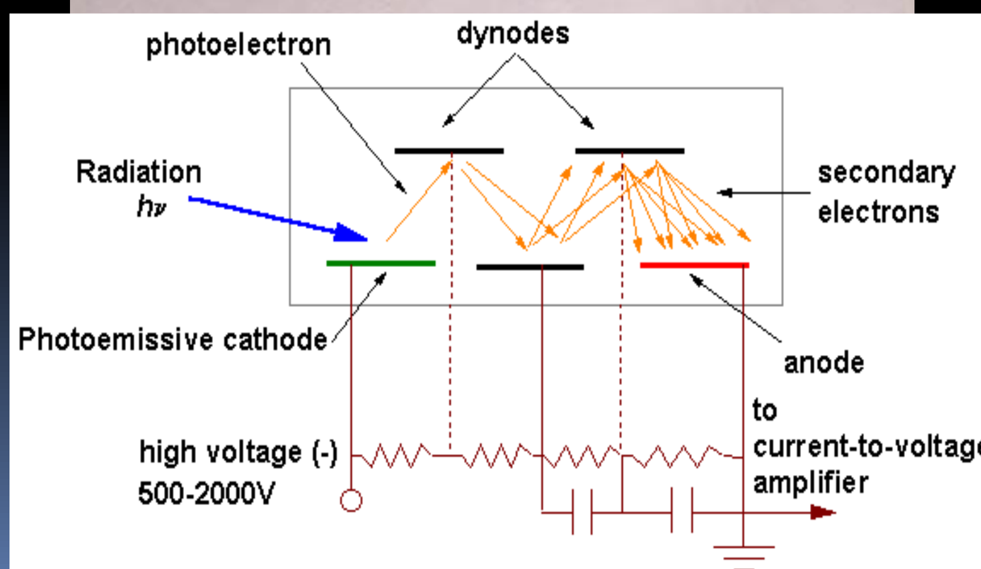
Typical cost 1$/in²



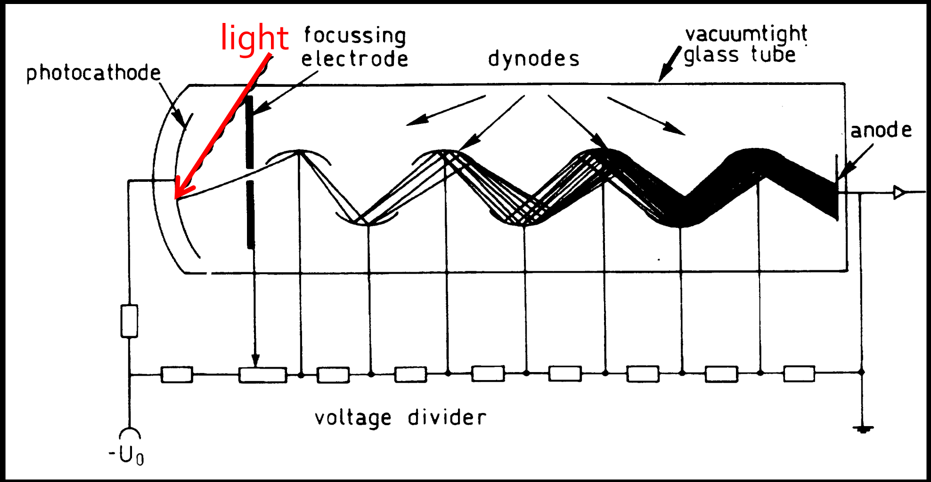
NE102A emission spectrum

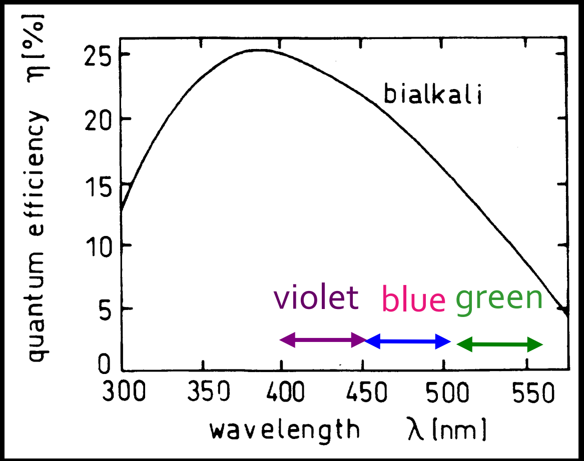
Photomultiplier Tubes (PMT's)





PMT Properties



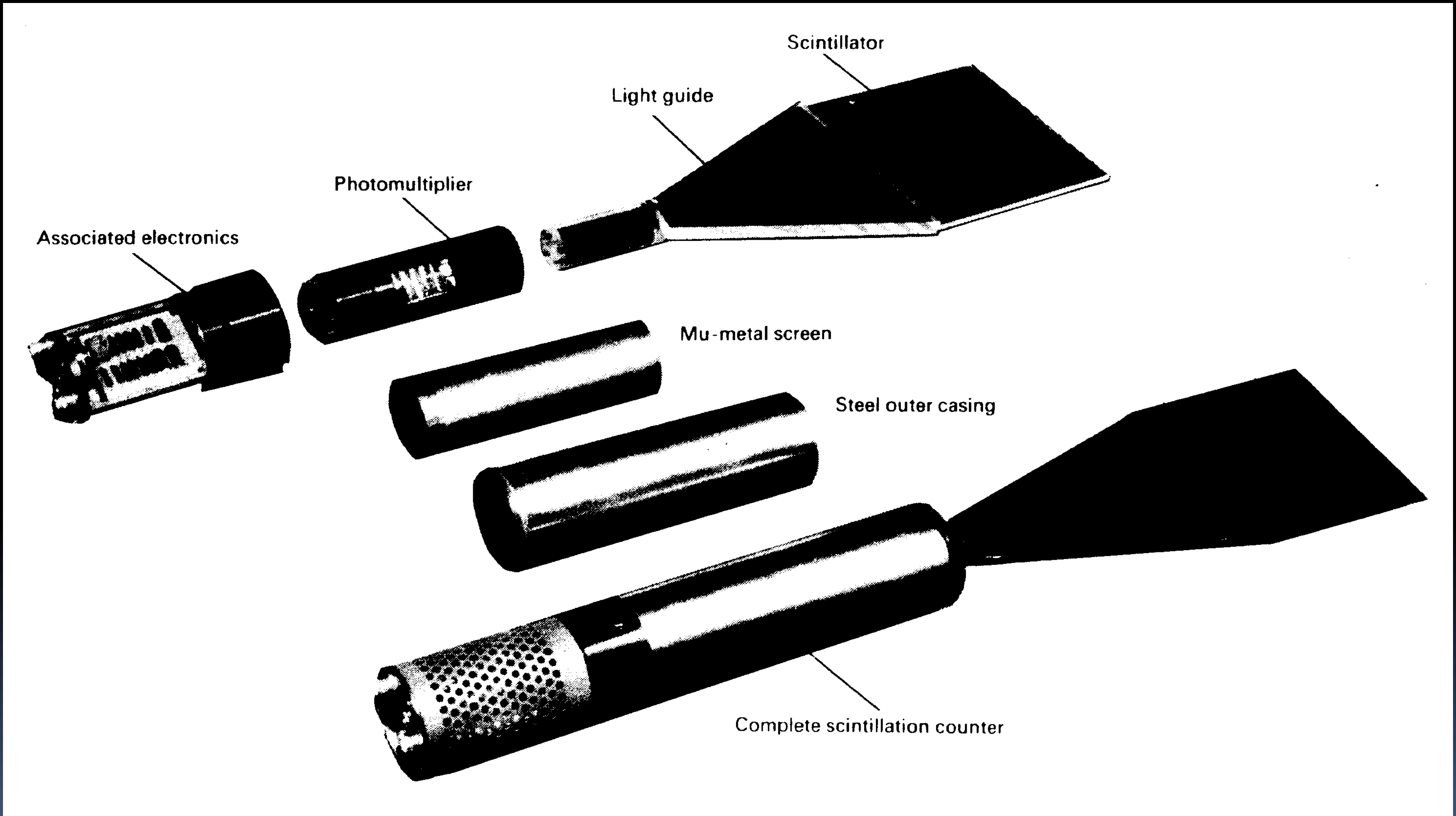


In situations where a lot of light is produced (>10³ photons) a photodiode can be used in place of a PMT

Properties of phototubes:

- Very high gain; $10^6 - 10^8$
- Single photon counting
- Off the shelf item with a wide variety of features (size, gain, sensitivity)
- Sensitive to magnetic fields (shield against earth's): use "mu-metal"

A Typical Detection System



Scintillator Counter Example

Some typical parameters for a scintillation counting system

Average energy loss in scintillator	2 Mev/cm
Scintillation efficiency	1 photon/100 eV
Collection efficiency	0.1
Quatntum efficiency of PMT photocathode	0.25
PMT gain	10^6
PMT transit time	50 ns
Input impedance of counting circuit	50 Ω

What is the amplitude of the electrical pulse from a 1-cm thick plastic scintillator?

Suppose a charged particle passes perpendicularly through this counter:

1. It deposits ~ 2 MeV, that produces ~ $2\text{x}10^4$ photons
2. Approximately $2\text{x}10^3$ of them reach the PMT
3. They produce ~ 500 photo-electrons
4. That multiply to $5\text{x}10^8$ electrons at the PMT output. They represent a charge of $8\text{x}10^{-11}$C
5. Since this charge is collected in $5\text{x}10^{-8}$ s the current pulse is

   $I = (8 \times 10^{-11}\ C) / (5\text{x}10^{-8}\ s) = 1.6 \times 10^{-3}\ A$
6. Or by Ohm's law

   $V = I R = (1.6\text{x}10^{-3}A)\ (50\ \Omega\ ) = 80\ mV,$

   large enough to see with a scope.