Detectors & Pulse signals

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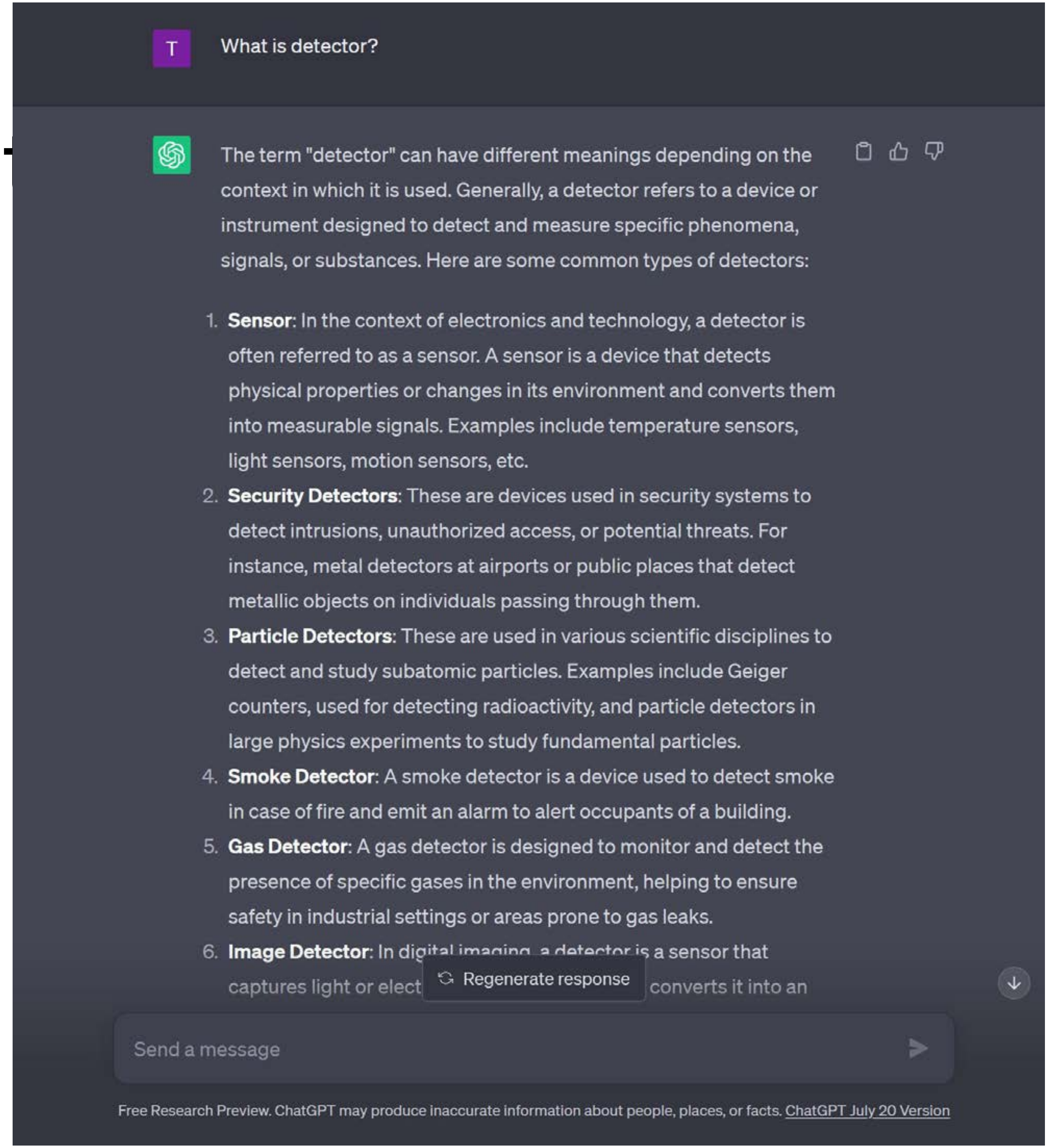
Nishina School 2023

What is de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What is detector?
The term "detector" can have different meanings depending on the context in which it is used. Generally, a detector refers to a device or instrument designed to detect and measure specific phenomena, signals, or substances. Here are some common types of detectors:
1. Sensor: In the context of electronics and technology, a detector is often referred to as a sensor. A sensor is a device that detects physical properties or changes in its environment and converts them into measurable signals. Examples include temperature sensors, light sensors, motion sensors, etc.
2. Security Detectors: These are devices used in security systems to detect intrusions, unauthorized access, or potential threats. For instance, metal detectors at airports or public places that detect metallic objects on individuals passing through them.
3. Particle Detectors: These are used in various scientific disciplines to detect and study subatomic particles. Examples include Geiger counters, used for detecting radioactivity, and particle detectors in large physics experiments to study fundamental particles.
4. Smoke Detector: A smoke detector is a device used to detect smoke in case of fire and emit an alarm to alert occupants of a building.
5. Gas Detector: A gas detector is designed to monitor and detect the presence of specific gases in the environment, helping to ensure safety in industrial settings or areas prone to gas leaks.
6. Image Detector: In digital imaging, a detector is a sensor that
captures light or elect
converts it into an
Regenerate response
Send a message
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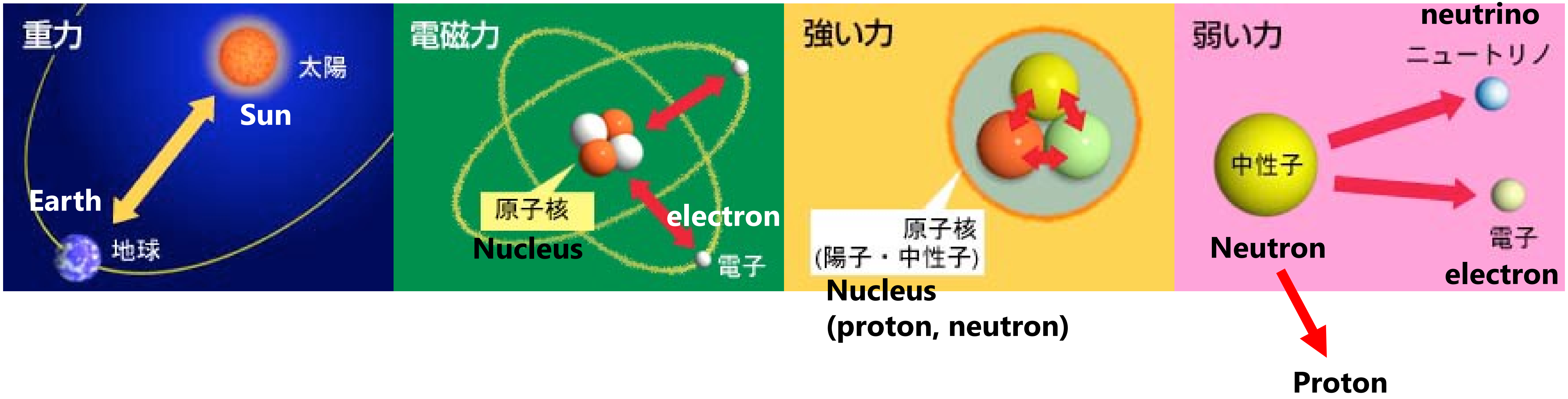
What is detector?

- Generally, a detector refers to a device or instrument designed to detect and measure specific (physical) phenomena, signals, or substances.

- Without detector we cannot know what is happened, what is passing through.
- With detector, we can see signal from particles through the interaction between detector and particle.
    - e.g. cosmic rays

The four interactions

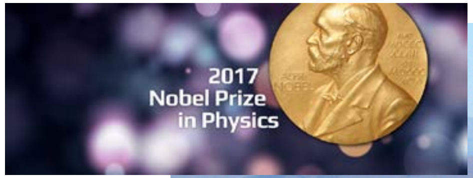
Gravity　　Electromagnetic force　　Strong force　　Weak force

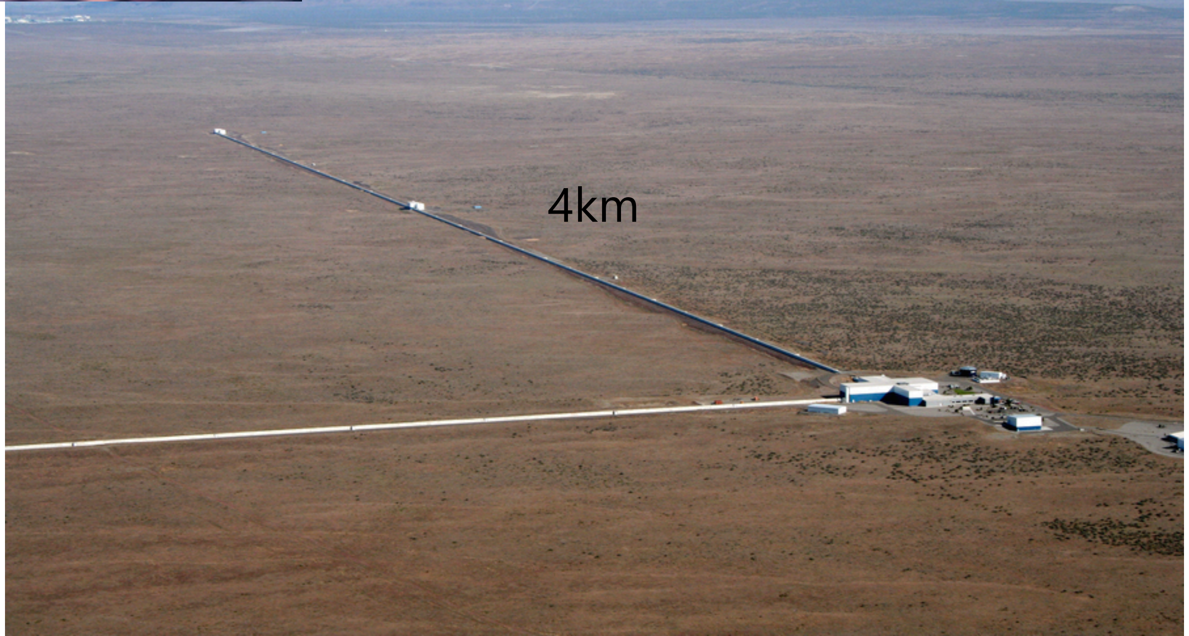


- We utilize interactions between detectors and particles.

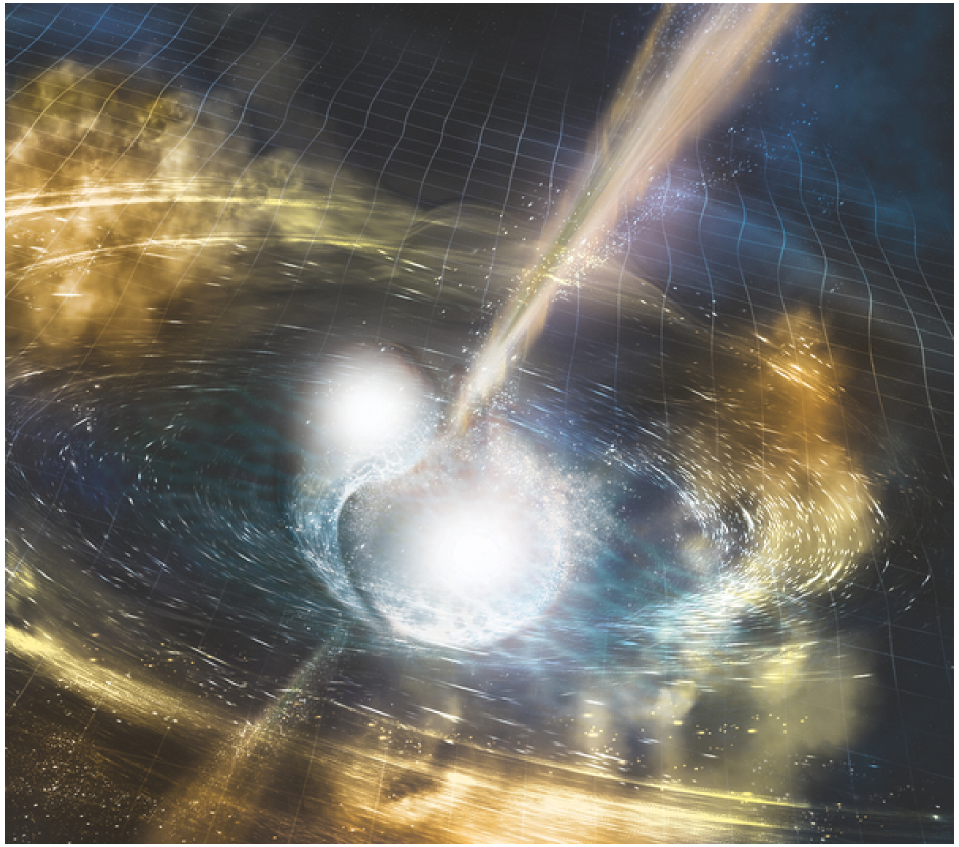
Utilization of gravity

- The LIGO detector
- Sense the space-time vibration with a laser interferometer





Gravitational wave from neutron star merger



Utilization of weak interaction

- Detector for neutrino
- Neutrino has only weak interaction

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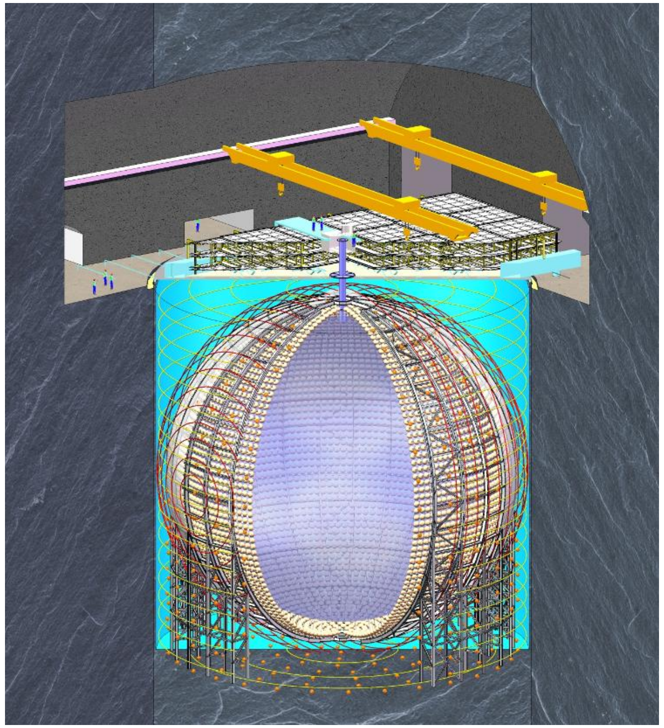
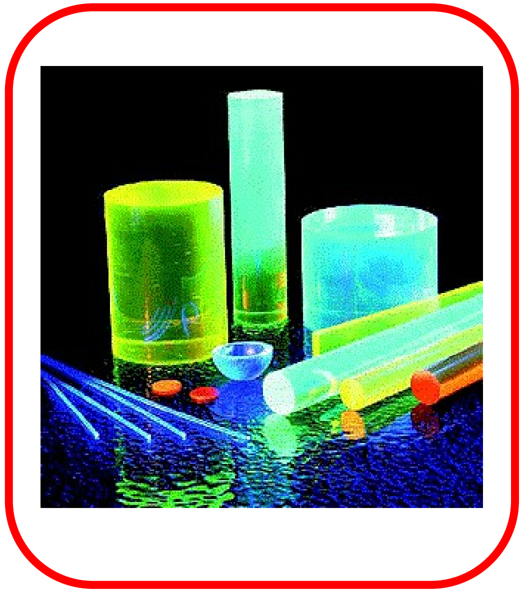


Most of detectors utilize electromagnetic interaction

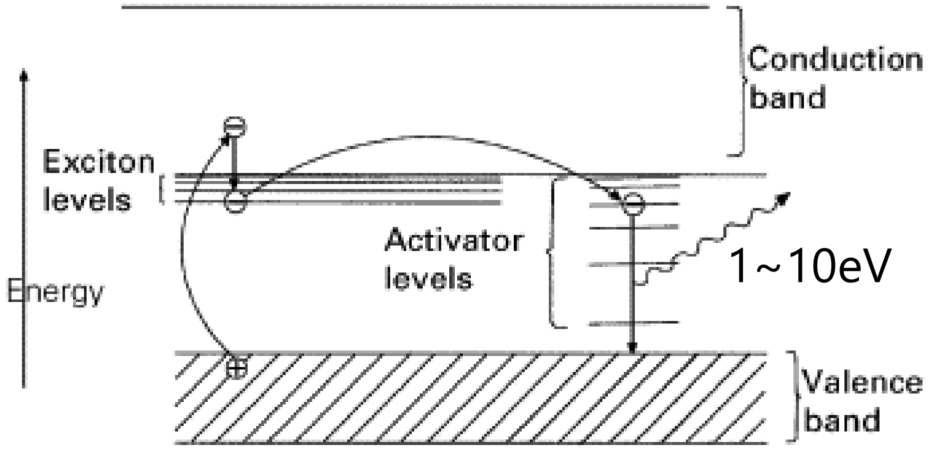
- Because of long range, stronger interaction.
- Photon and all of charged particles interact electromagnetically.
  - Photon, electron, proton, ions and so on.



Scintillator

Scintillation is

- A flash of light produced in a phosphor by absorption of an ionizing particle or photon
(The American Heritage Dictionary).
- Excited atoms (or molecules) in the medium release the energy due to de-excitation by photons.

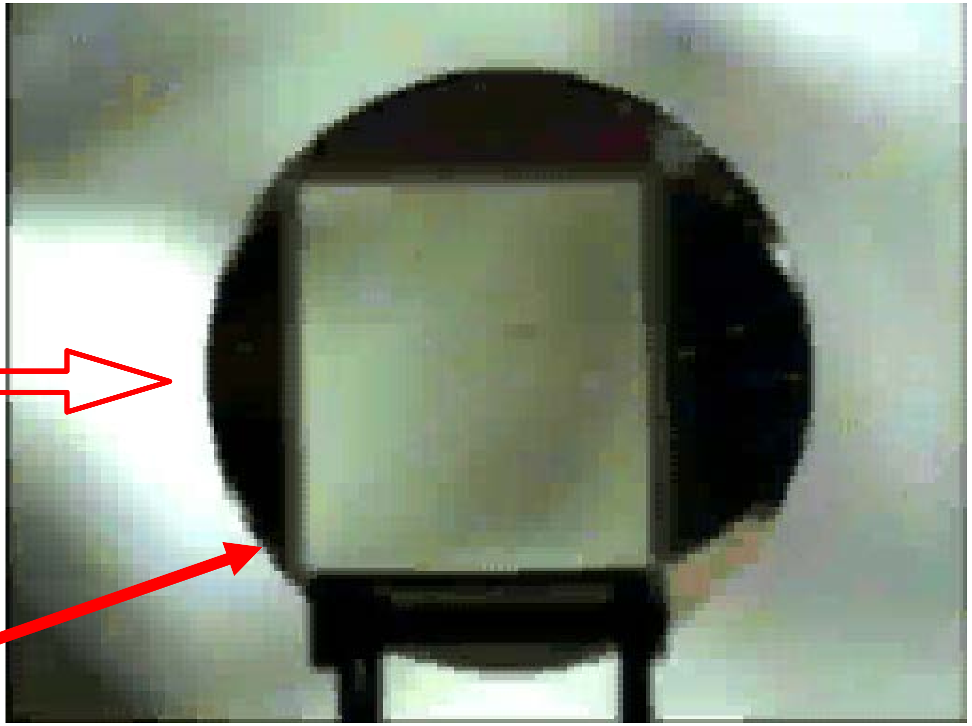


1~10eV : 1240~124nm

Visible light : 380~700nm

Scintillation light from charged particles passing through matter

^{20}Ne beam injection

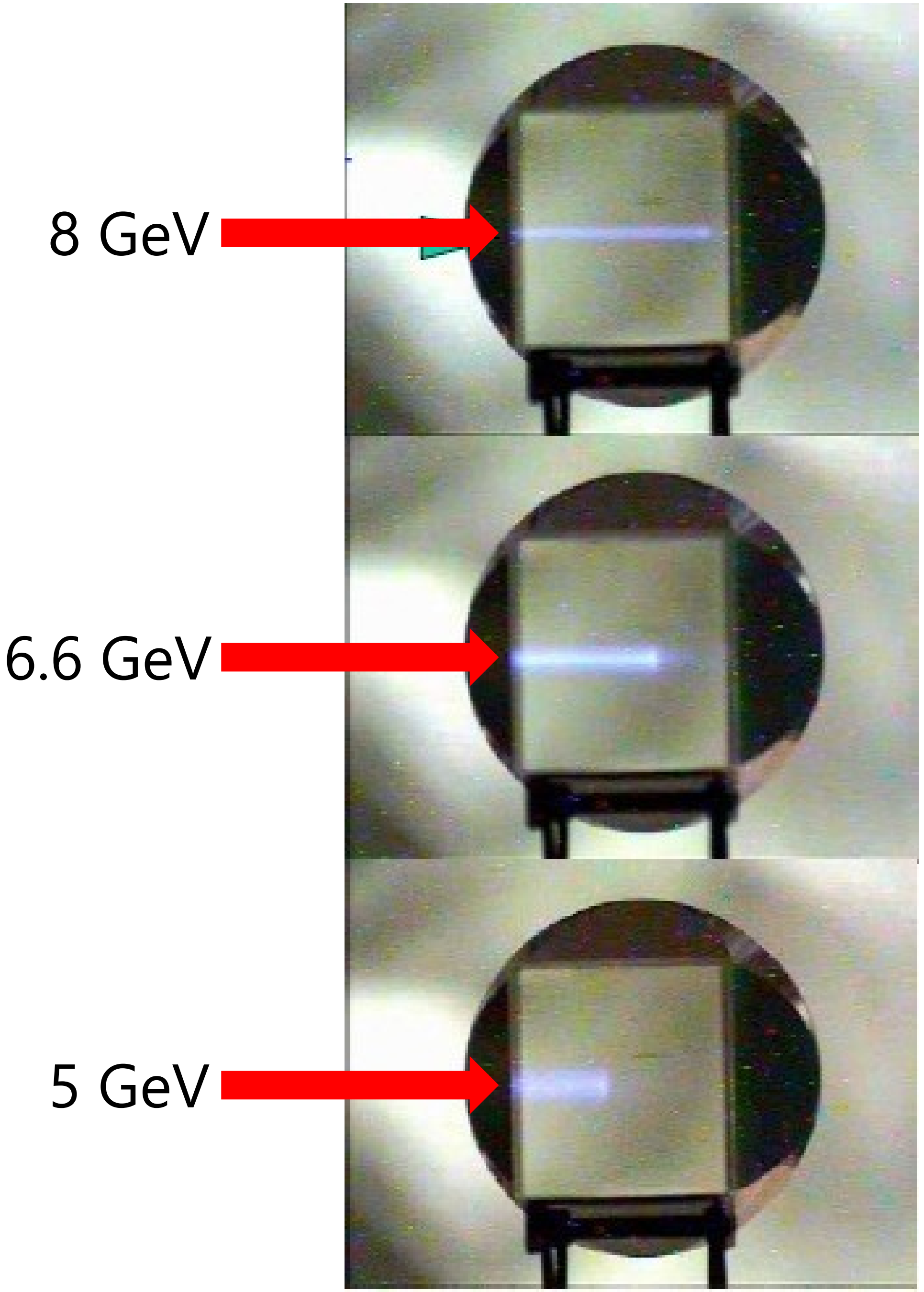


^{20}Ne beam from accelerator

GSO scintillator
= Gd_2SiO_3

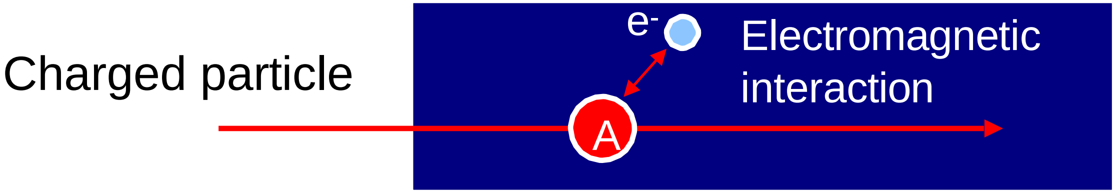
Path Length vs Energy

- The beam is slowing down inside the scintillator.
- A whole kinetic energy of beam is deposited inside the scintillator.
- Kinetic energy is converted into the scintillation light.
- Lower Energy ⇄ Shorter Path Length.



Energy loss of charged particles in matter

What is happening in the matter?



Ionization of atoms
Excitation of atoms / molecules

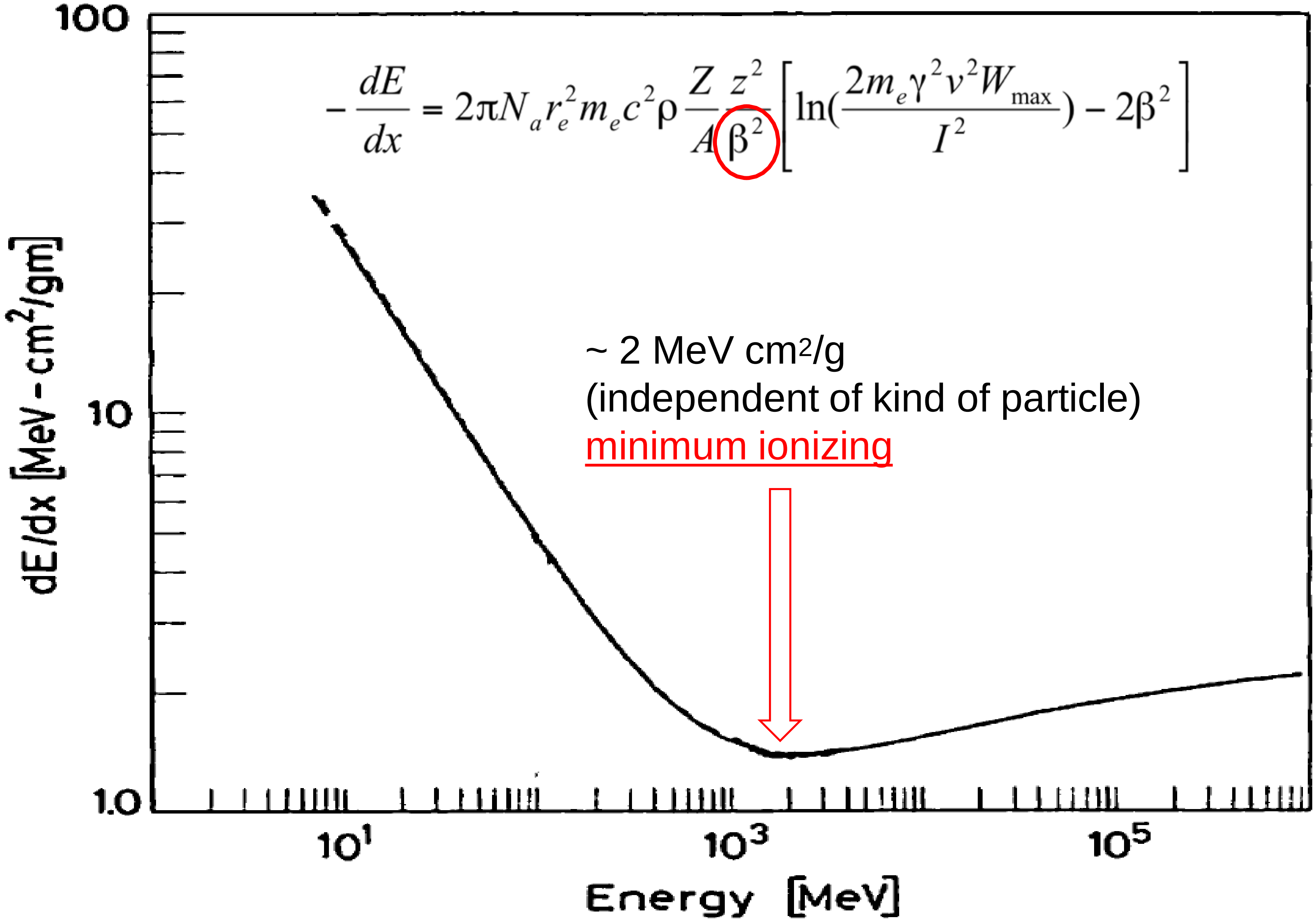
◆The Bethe-Bloch formula (energy-loss formula)

$$-\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\left(\frac{2 m_e \gamma^2 v^2 W_{max}}{I^2}\right) - 2\beta^2\right]$$

N_a: Avogadro's number
r_e: classical electron radius
m_e: electron mass
c: speed of light
ρ: density of absorbing material
Z: atomic number of absorbing material
A: atomic weight of absorbing material

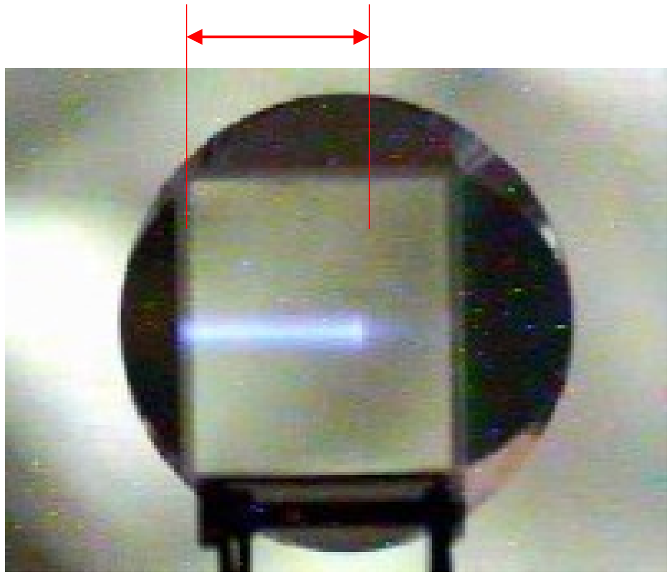
β: velocity of **incident** particle (v/c)
γ: Lorentz factor of **incident** particle [$1/\text{sqrt}(1-\beta^2)$]
z: charge of **incident** particle
W_{max}: maximum energy transfer in a single collision
I: mean excitation potential

Energy loss of charged particles in matter



Energy loss of charged particles in matter

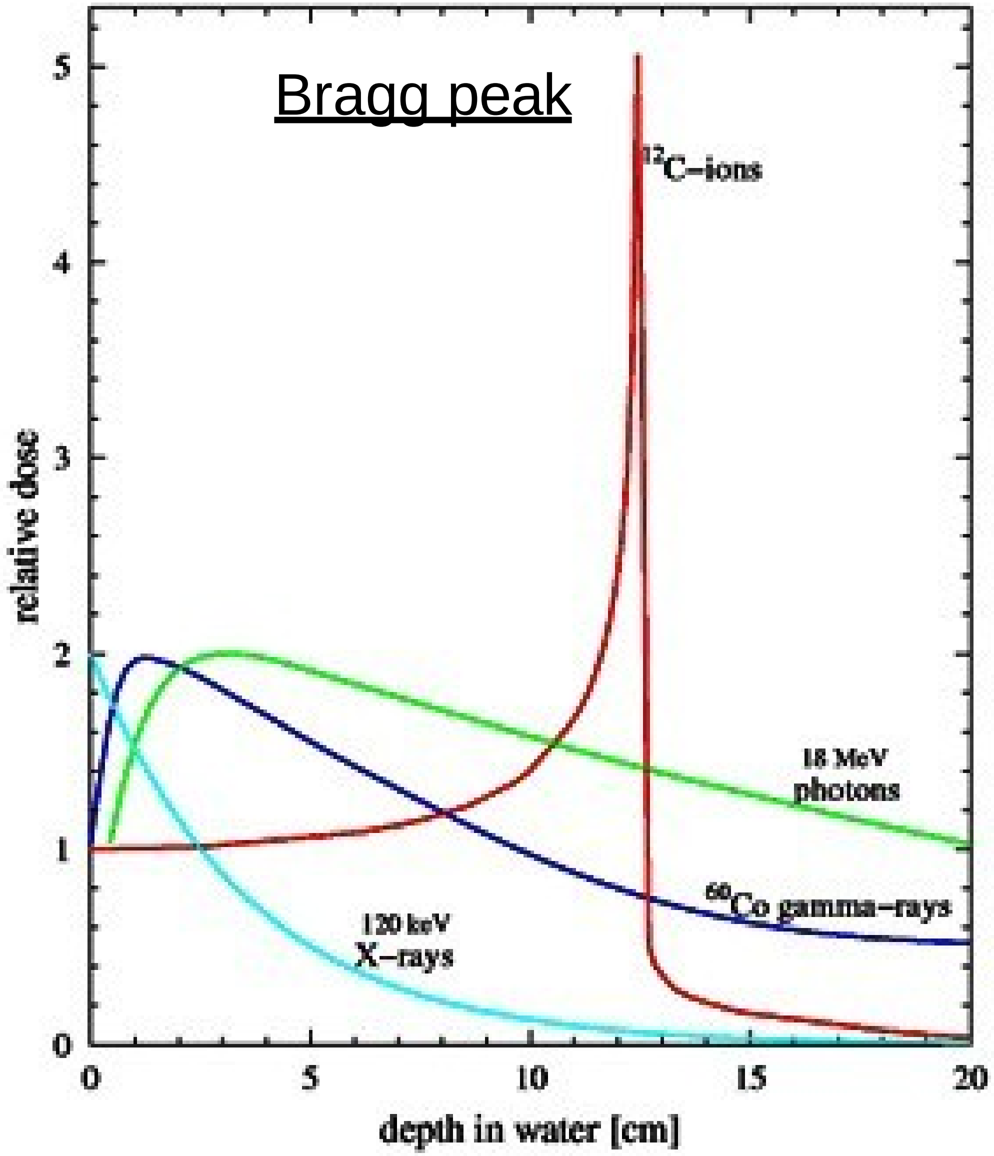
range



How much energy deposits per unit length?

Bragg peaks are used for (heavy) ion radiotherapy to burn the tumors of cancers.

Ref: GSI web



Calculation for Range → SRIM code (free soft)

http://www.srim.org/

======= Target Composition ========

Atom Name	Atom Numb	Atomic Percent	Mass Percent
C	6	100.00	100.00

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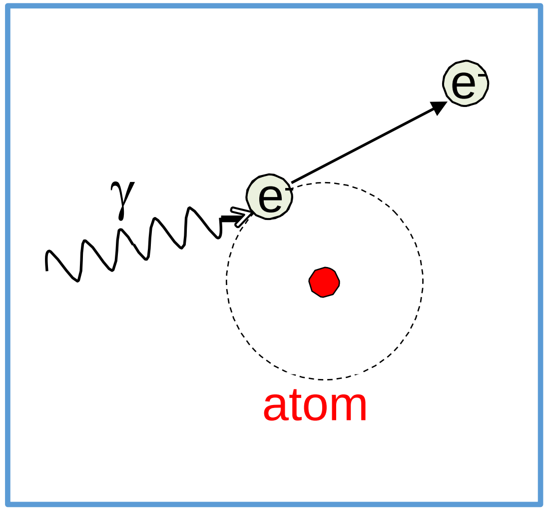
Proton beam in Carbon

Bragg Correction = 0.00%
Stopping Units = MeV / (mg/cm2)
See bottom of Table for other Stopping units

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
500.00 keV	3.534E-01	2.738E-04	4.40 um	1837 A	1974 A
550.00 keV	3.334E-01	2.524E-04	5.04 um	2092 A	2182 A
600.00 keV	3.160E-01	2.342E-04	5.72 um	2347 A	2402 A
650.00 keV	3.007E-01	2.186E-04	6.44 um	2601 A	2632 A
700.00 keV	2.872E-01	2.051E-04	7.19 um	2856 A	2873 A
800.00 keV	2.640E-01	1.828E-04	8.80 um	3732 A	3385 A
900.00 keV	2.450E-01	1.651E-04	10.54 um	4553 A	3934 A
1.00 MeV	2.291E-01	1.507E-04	12.41 um	5350 A	4520 A
1.10 MeV	2.163E-01	1.387E-04	14.40 um	6134 A	5138 A
1.20 MeV	2.035E-01	1.286E-04	16.51 um	6915 A	5788 A
1.30 MeV	1.923E-01	1.199E-04	18.74 um	7703 A	6473 A
1.40 MeV	1.825E-01	1.124E-04	21.11 um	8501 A	7191 A
1.50 MeV	1.737E-01	1.058E-04	23.59 um	9309 A	7943 A
1.60 MeV	1.659E-01	9.998E-05	26.20 um	1.01 um	8727 A
1.70 MeV	1.588E-01	9.481E-05	28.93 um	1.10 um	9543 A
1.80 MeV	1.524E-01	9.017E-05	31.77 um	1.18 um	1.04 um
2.00 MeV	1.412E-01	8.219E-05	37.81 um	1.48 um	1.22 um

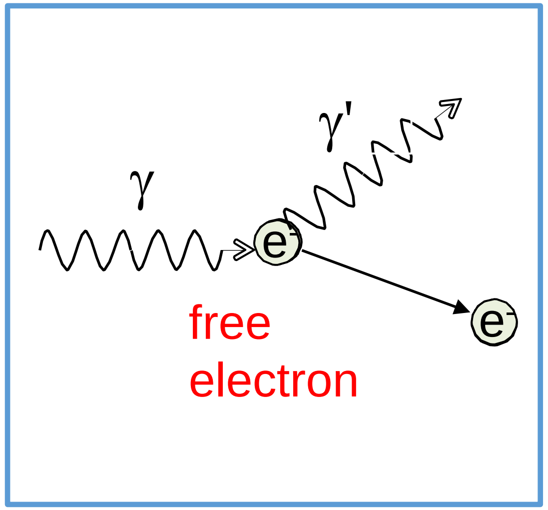
Interaction of photons in matter: 3 types of interactions

(1) Photoelectric effect



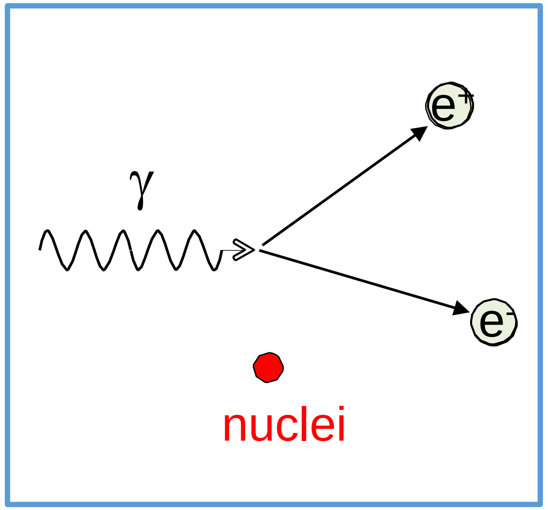
- γ-ray knocks-on the electron bounded in an atom and is absorbed.
- All the Energy is deposited.
- High-Z material better.
  - $\sigma \propto Z^{4-5} \cdot E^{-3.5}$

(2) Compton scattering



- γ-ray knocks-on a free electron and is scattered.
- γ' may escape.
- Klein-Nishina formula
- $\sigma \propto Z$: # of electrons

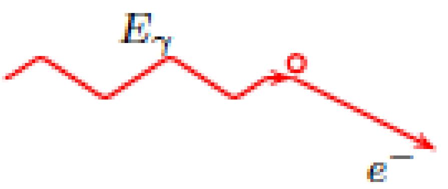
(3) Pair production



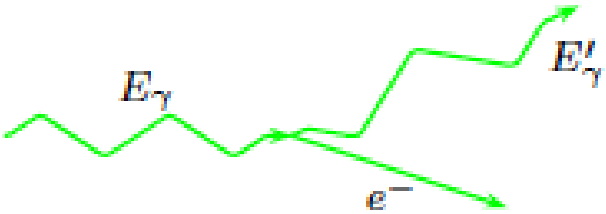
- Only occurs in strong E field near nuclei.
- 1 or 2 γ's (>511 keV) may escape.
- $E_\gamma > 2m_e = 1.02$ MeV/c^2
- Important for MeV γ-ray.

Interaction of photons in matter: 3 types of interactions

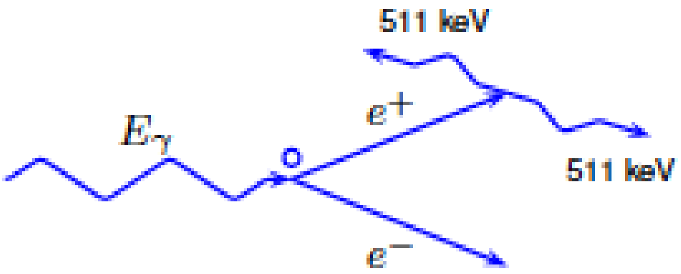
Photoelectric Absorption

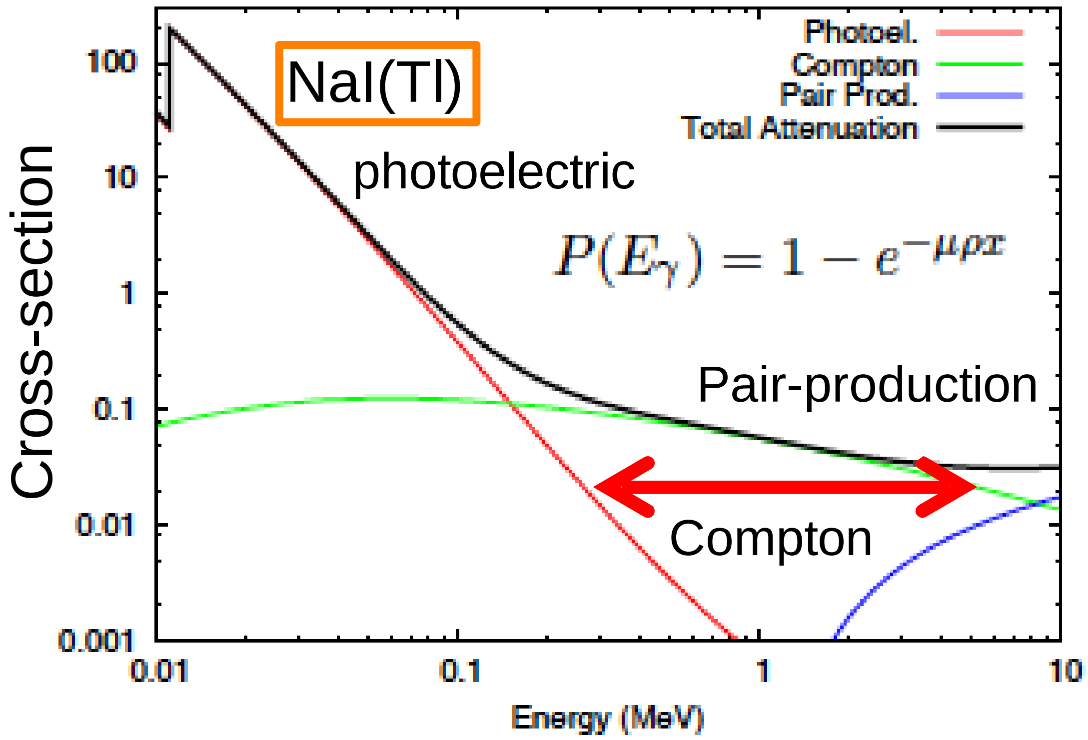


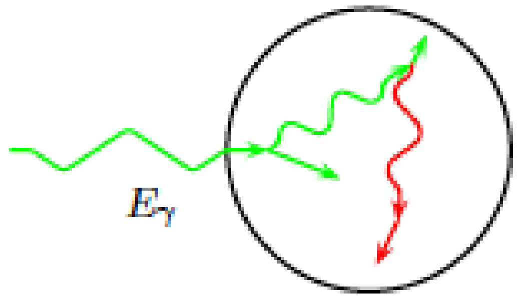
Incoherent Scattering
(Compton)



Pair Production ($E_\gamma > 1022$ keV)

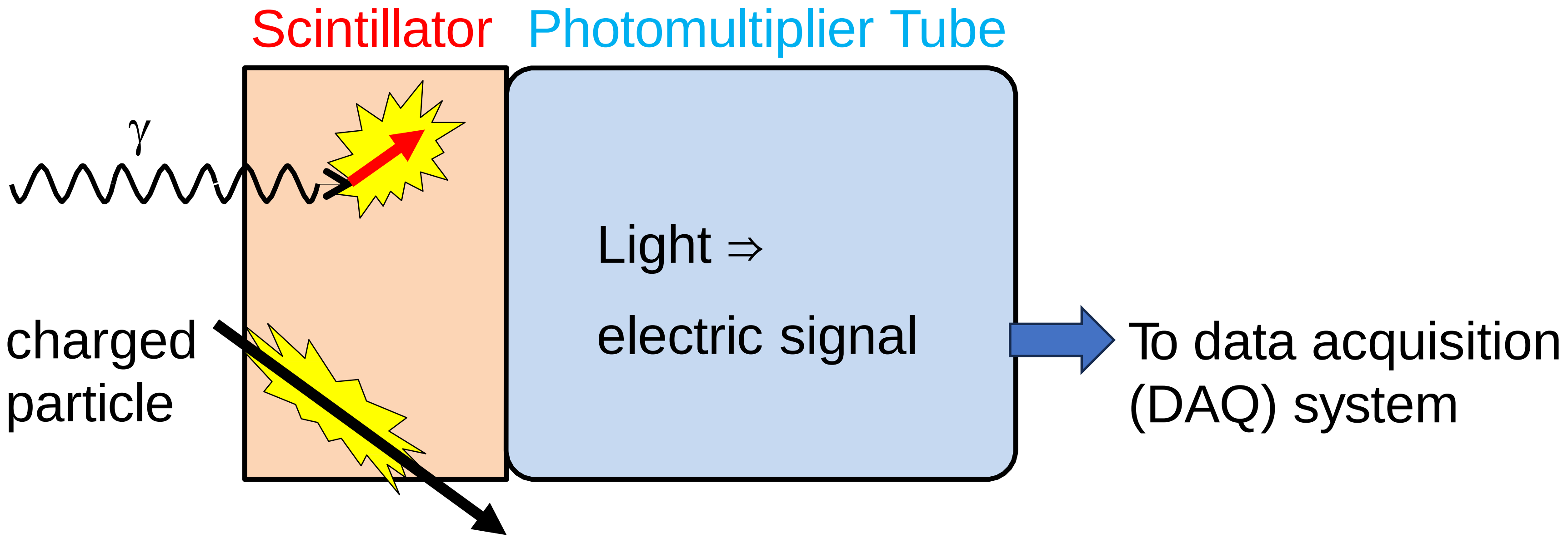






many interactions required to deposit **full energy** inside detector volume

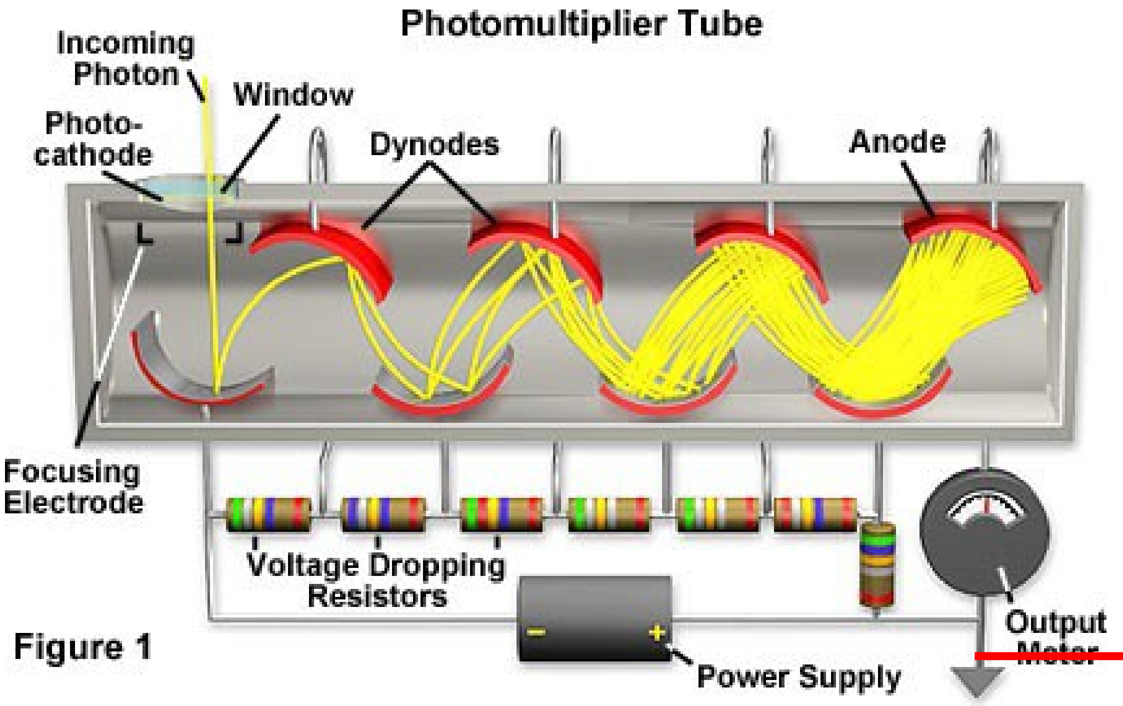
Scintillation counter



- Passage of charged particles excite molecule or crystal
- Scintillation light is emitted
- The light is collected and converted into a signal with PMT
- The electric signal is recorded with a data acquisition system

How to convert scintillation light to signal

- Noble light detector! ⇨ PMT (Photomultiplier Tube)
- One optical photon can be detectable.
- Efficiency ~ 25% (photocathode)
- Gain ~ $10^{5\text{-}6}$ (electric amplification factor)



Photocathode: convert a photon into a photoelectron via photoelectric effect.

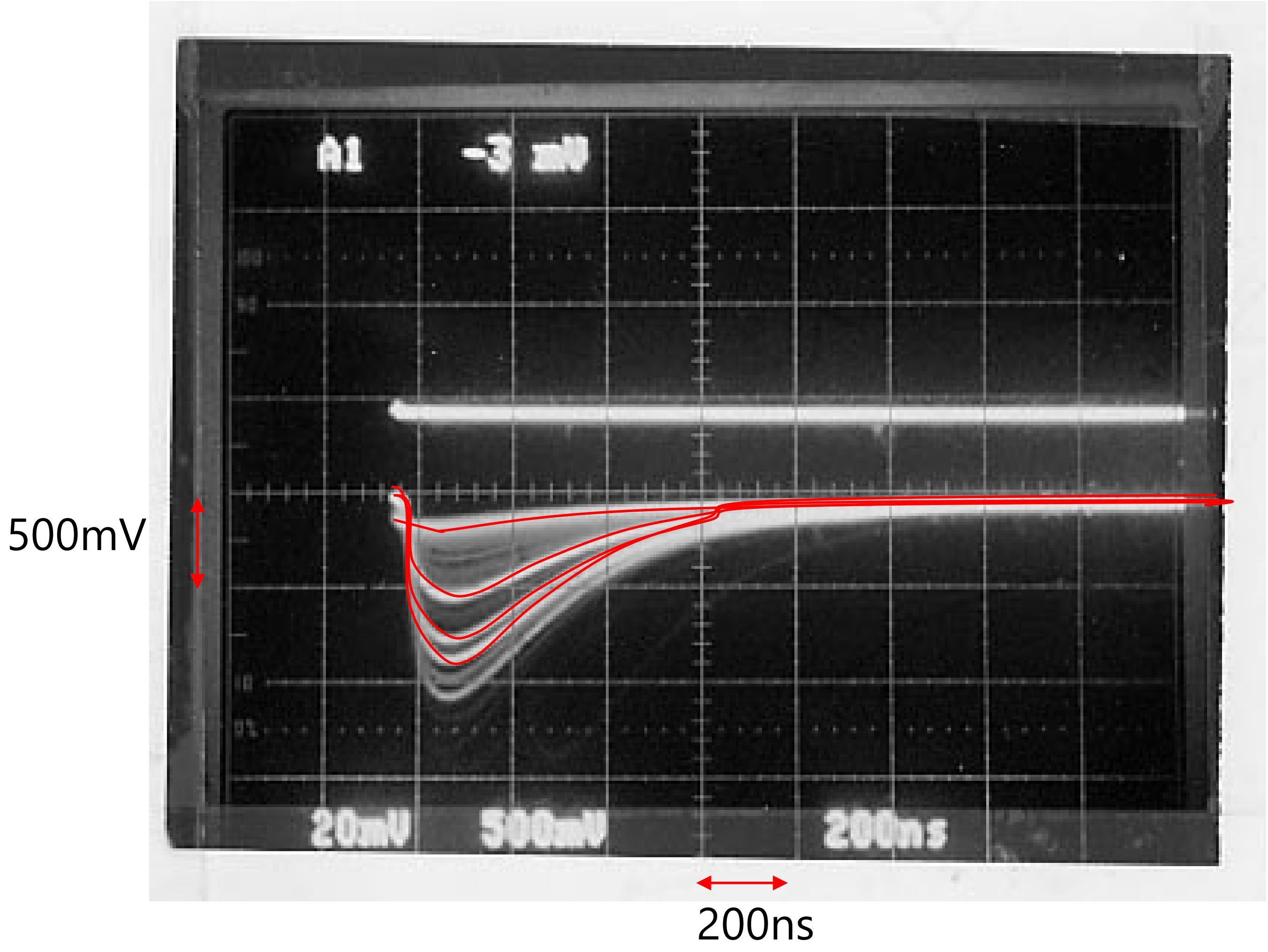
Dynode: coated by alkali metal. Multiply electrons.

Anode: the last stage of the multiplication process.

→ Electric signal!

Heavy ion signals: $^{7,8}Li$, $^{11,12}Be$, $^{14,15}B$ and $^{17,18}C$ using RIPS

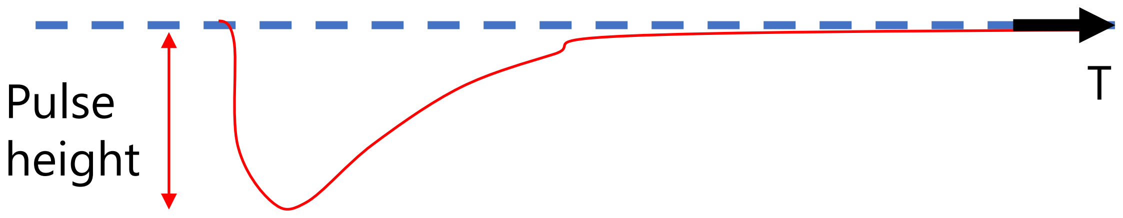
Pulse signal from PMT
displayed with oscilloscope

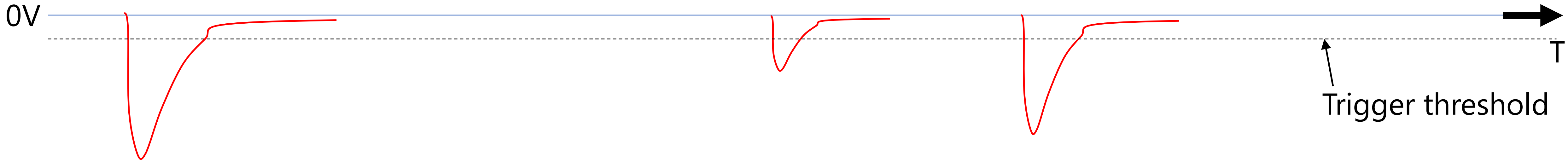


Heavy ion signals: ^{7,8}Li,^{11,12}Be,^{14,15}B and ^{17,18}C using RIPS

Pulse signal from PMT
displayed with oscilloscope

Pulse height corresponds to
number of photo-electrons





- By the way, why do we need scintillator+PMT to see photon? Can't we see photon only with photomultiplier tube?