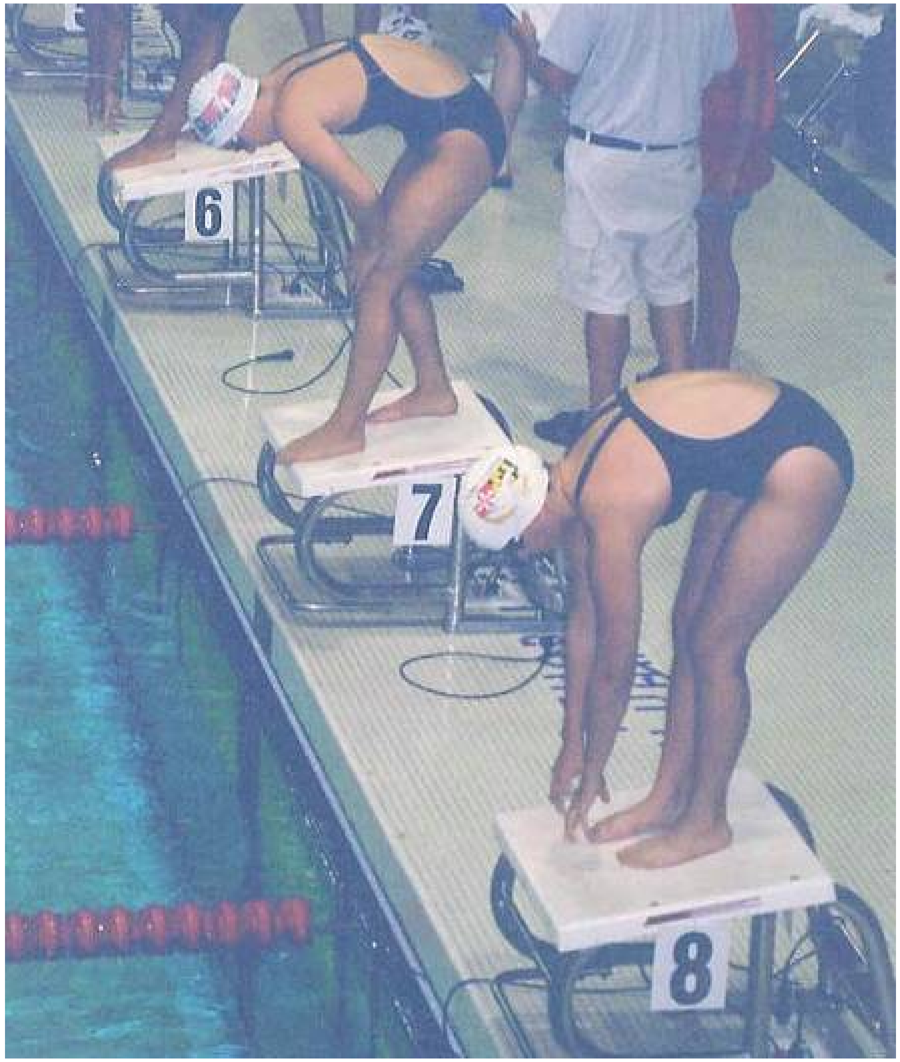
Modern Particle Accelerators and Detectors

A Household Survey

Carl A. Gagliardi

Alyson Clarke

- High school All Star swimmer
- My niece



To do well in her sport, she really needs to know how to **ACCELERATE**

Deena Greer

- Physician
- My wife

To **ACCELERATE** healing, she needs to **DETECT** problems that are impossible to see

How Do We Accelerate?

Let's ask Alyson

We drop things!

How Do We “Drop” Particles?

We can only build so many accelerators next to cliffs

Deena has a better idea! **VOLTS**

The Van de Graaff Accelerator

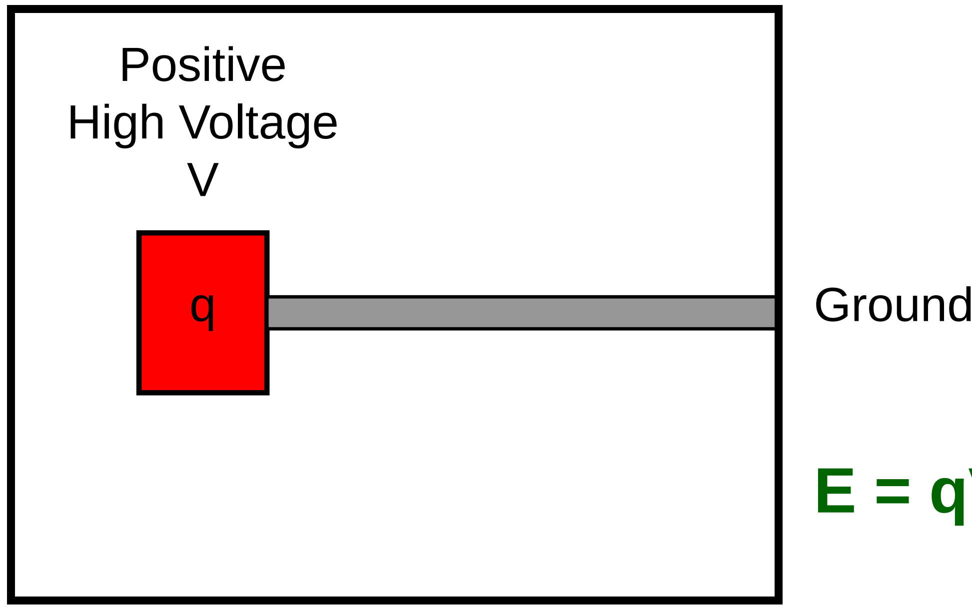
- Start with positively charged particles at high voltage
- Let them “fall” to ground potential
- They accelerate during the process

A Problem:

-- Difficult to make q>2

-- Difficult to make V larger than a few million volts

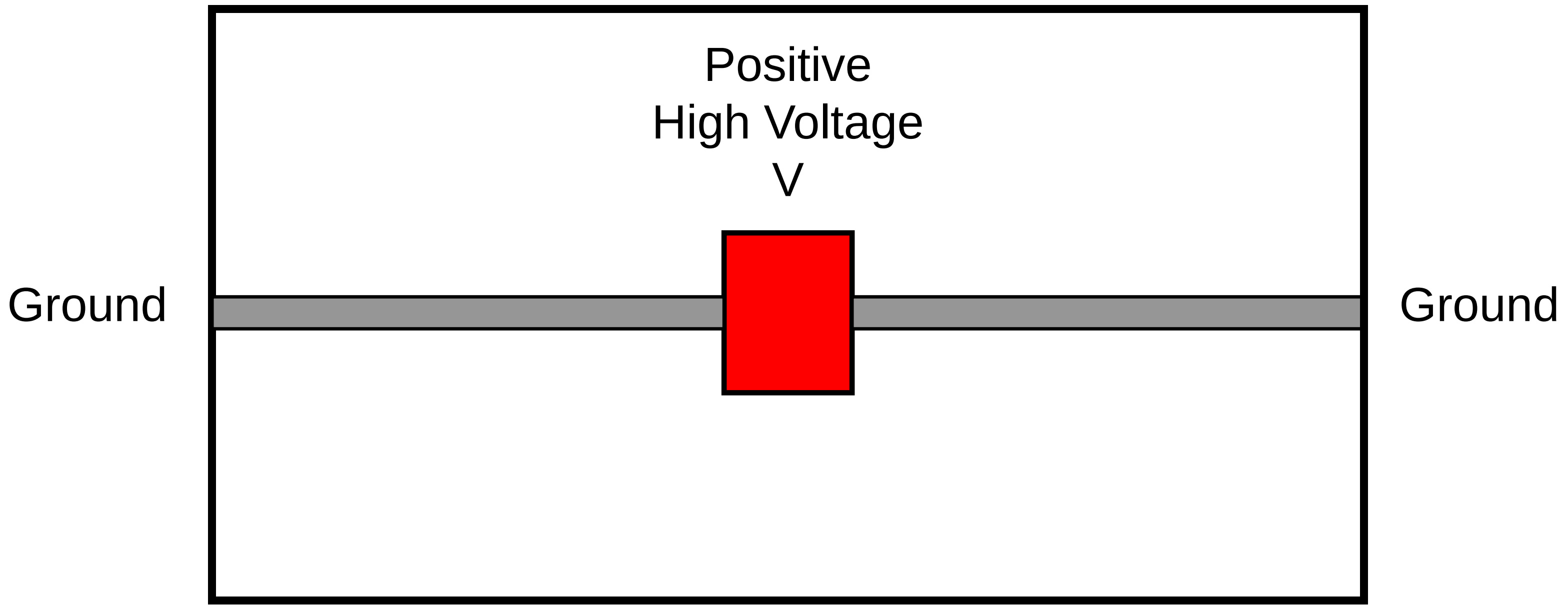
➔ **Difficult to make E large!**



$E = qV$

The Tandem Van de Graaff Accelerator

- Start with negative ions at ground
- Let them “fall” to positive high voltage
- Strip many electrons off the ion to produce a large positive charge
- Let the positive charge “fall” back to ground
- The particles accelerate during **both** steps



Can achieve energies of 10’s of millions of electron volts (MeV), or velocities up to 20% of the speed of light

Can Investigate Many Nuclear Reactions

- Very useful to study reactions with a broad range of light to intermediate mass nuclei
- Alpha particles (the nuclei of helium atoms) can be accelerated to ~30 MeV, representing 7.5 MeV/nucleon or ~13% of the speed of light.
- Can penetrate to the nucleus of essentially any atom up to lead

Alpha particle
Charge = +2

Lead nucleus
Charge = +82

Maybe Even I Can Do This!

Well, maybe not

Not Useful for Reactions with Heavy Nuclei

- Can accelerate gold nuclei to ~200 MeV, but this is only ~1 MeV/nucleon or 5% of the speed of light
- Not energetic enough to penetrate to the nucleus of a second heavy atom!

Gold nucleus
Charge = +79

Lead nucleus
Charge = +82

We need **another** trick!

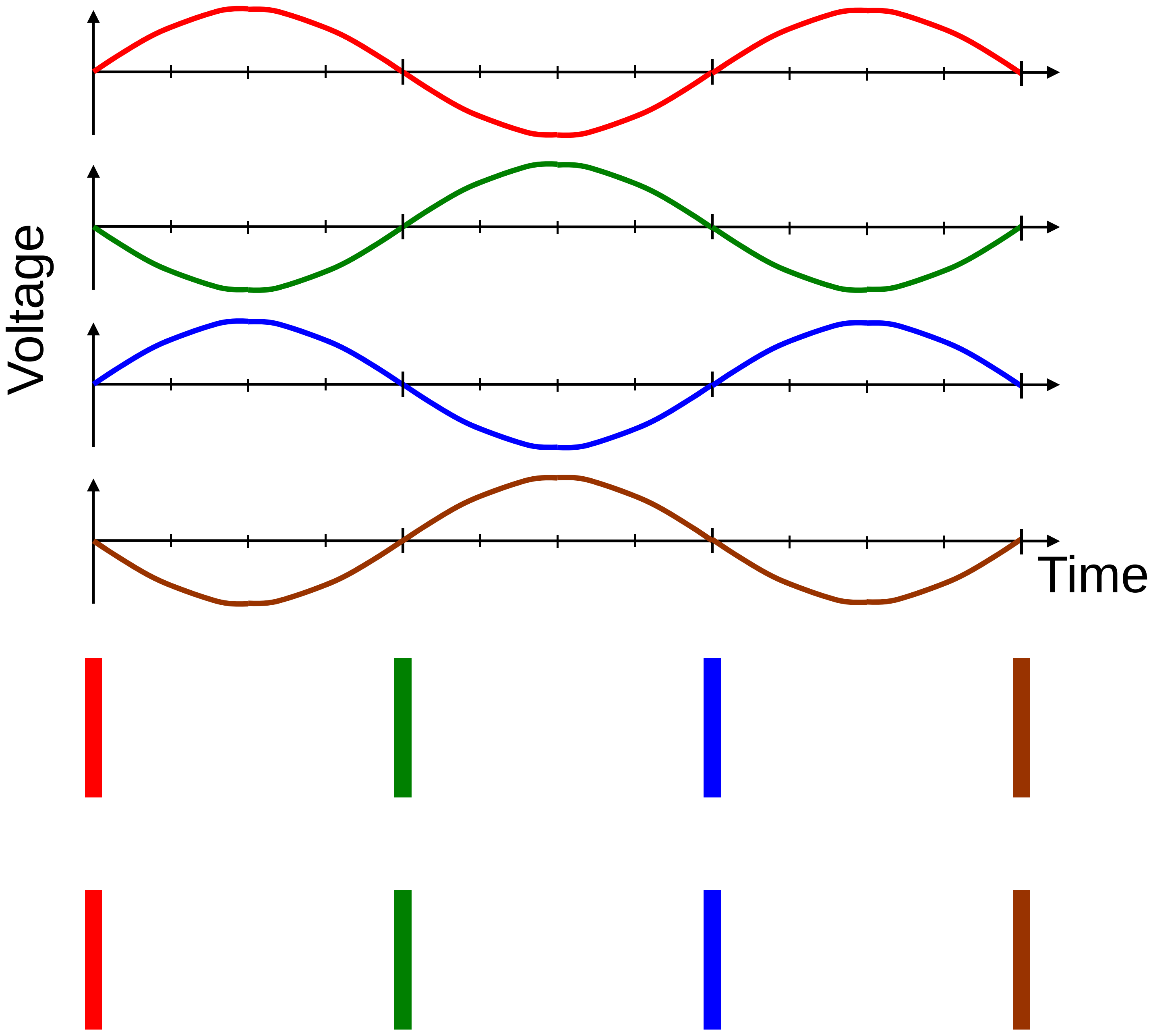
Another Trick

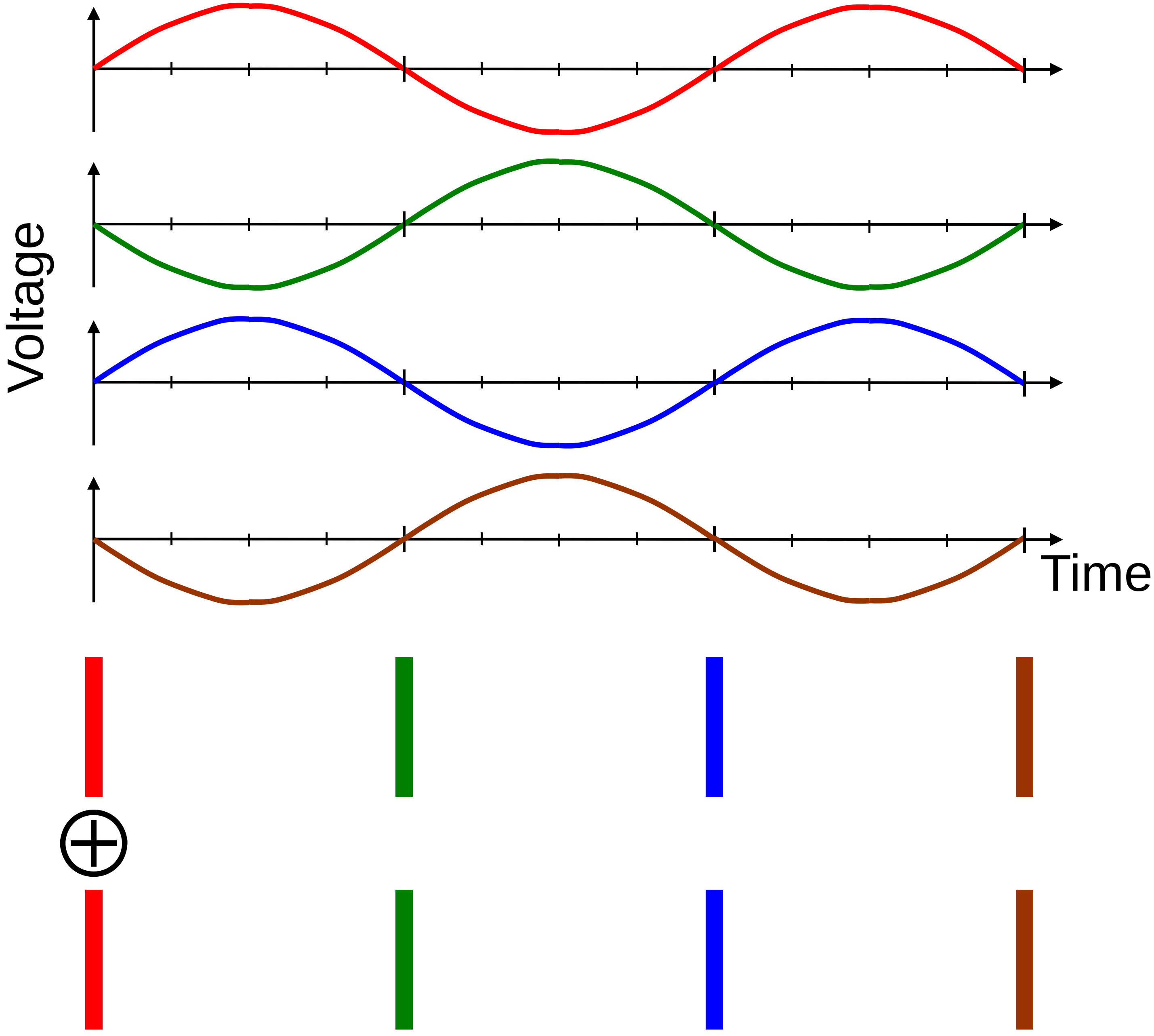
To go high, pump **many** times!

Swing Sets → Particle Accelerators ??

Uncle Carl, do I need to explain **everything** to you?

The voltage **ALTERNATES**


Voltage
Time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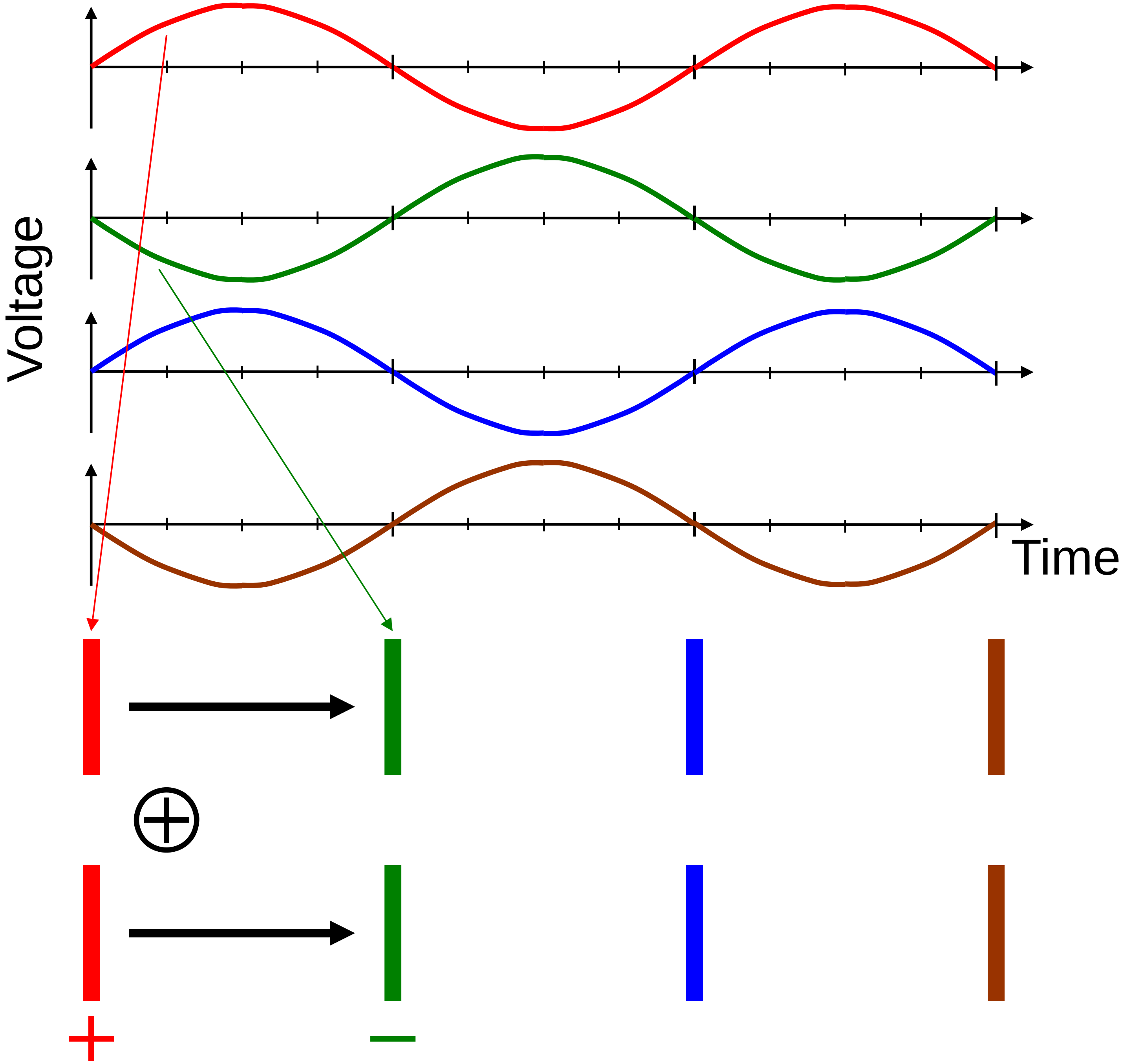

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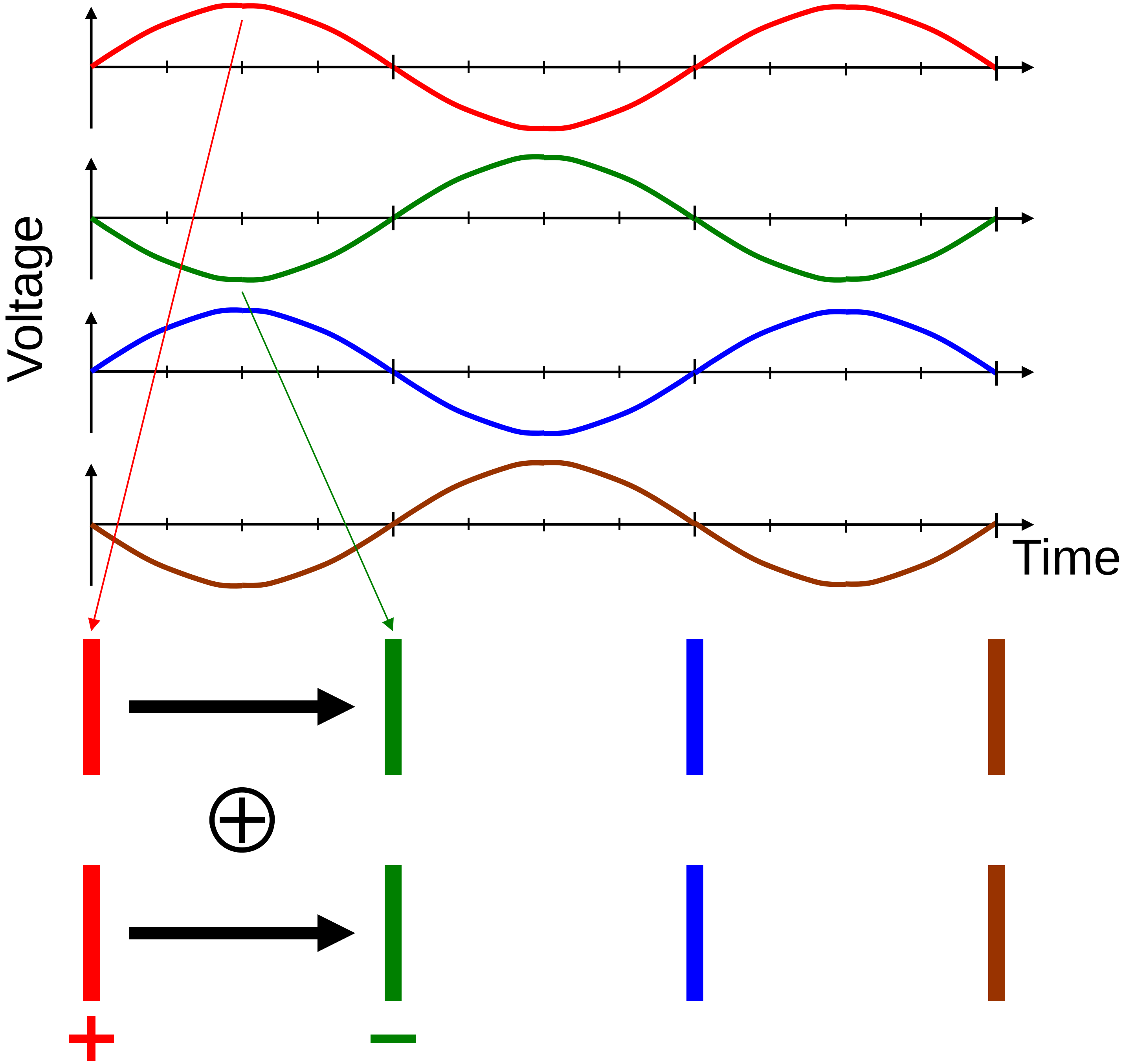
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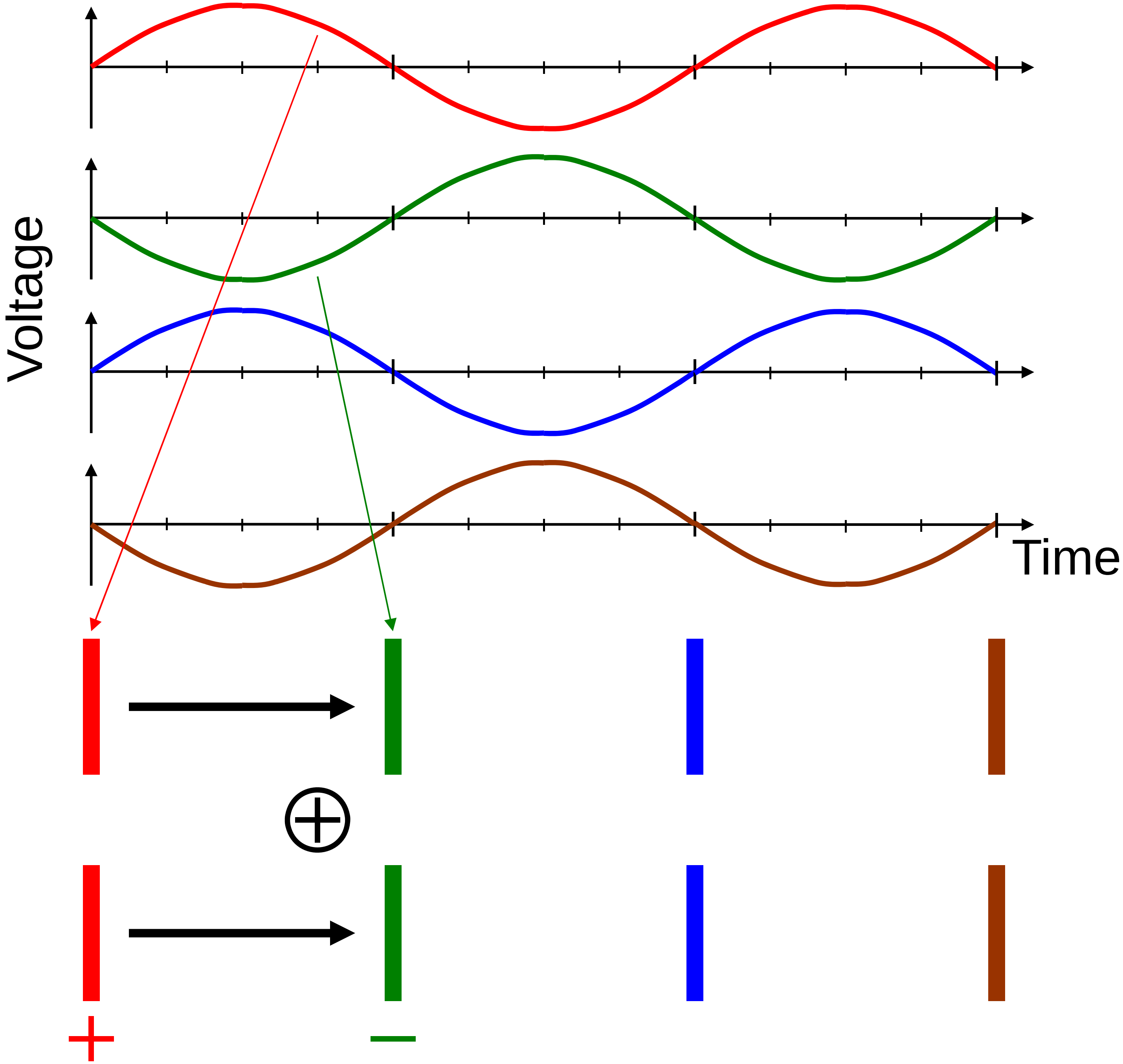

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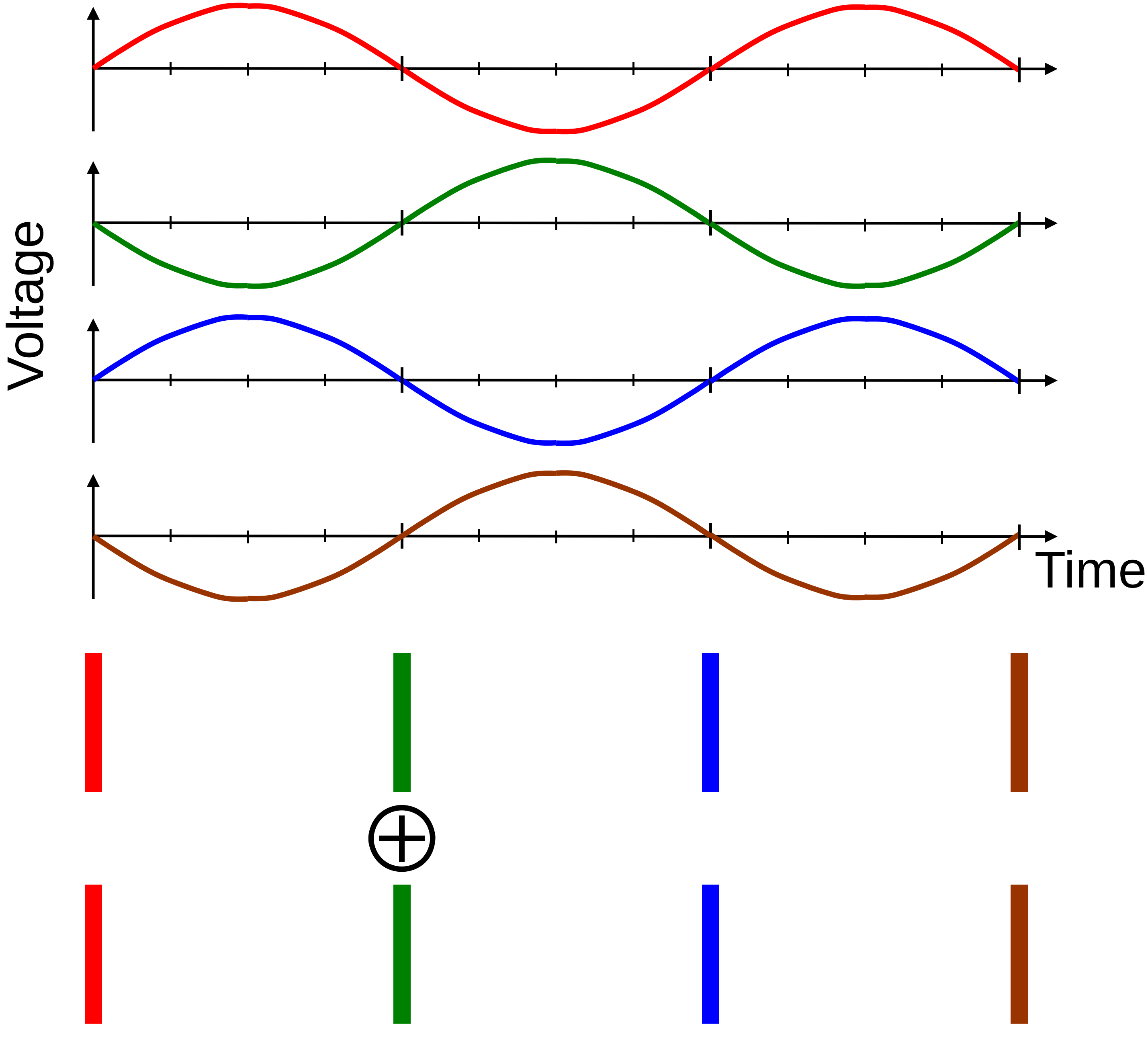
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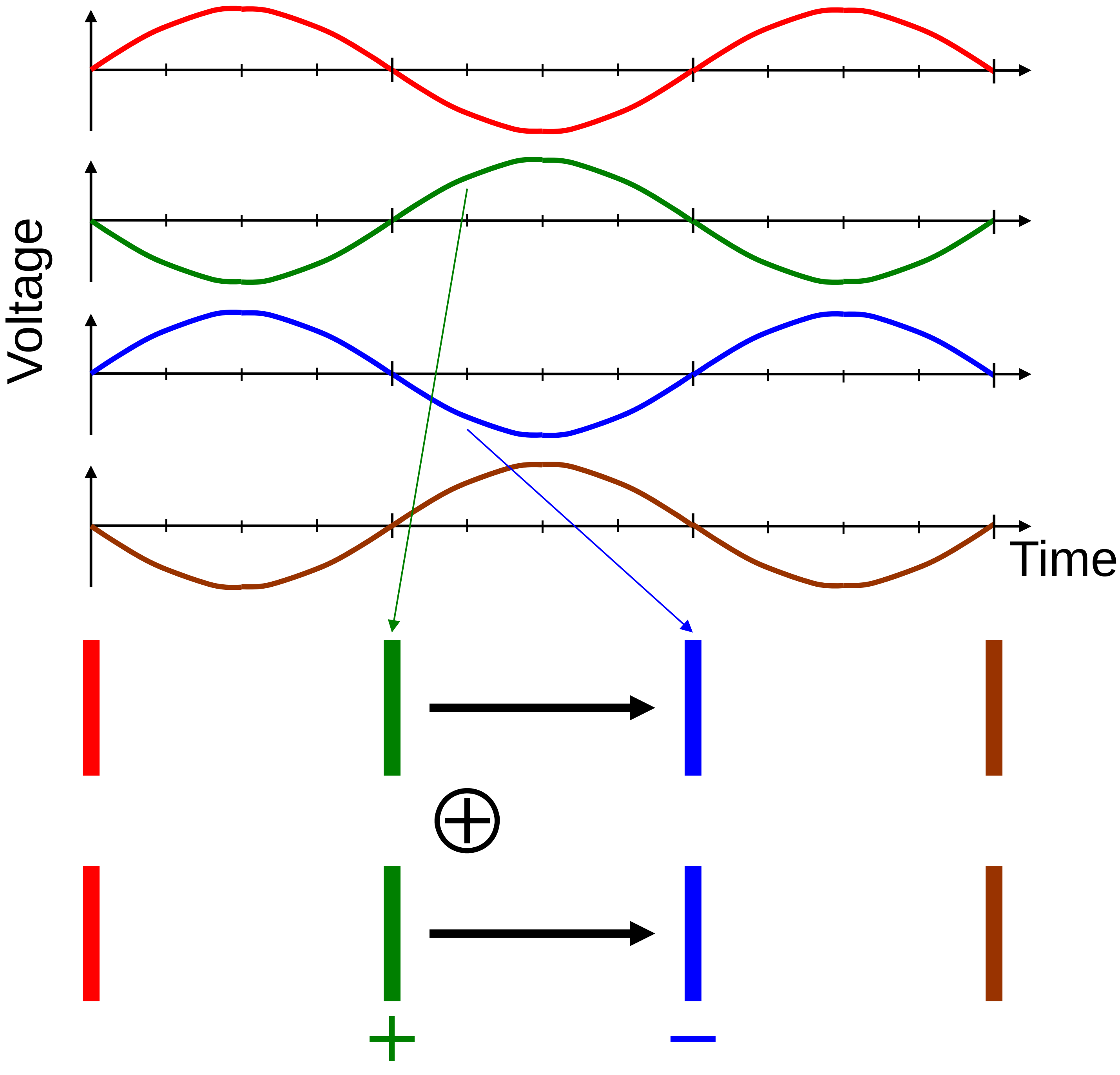
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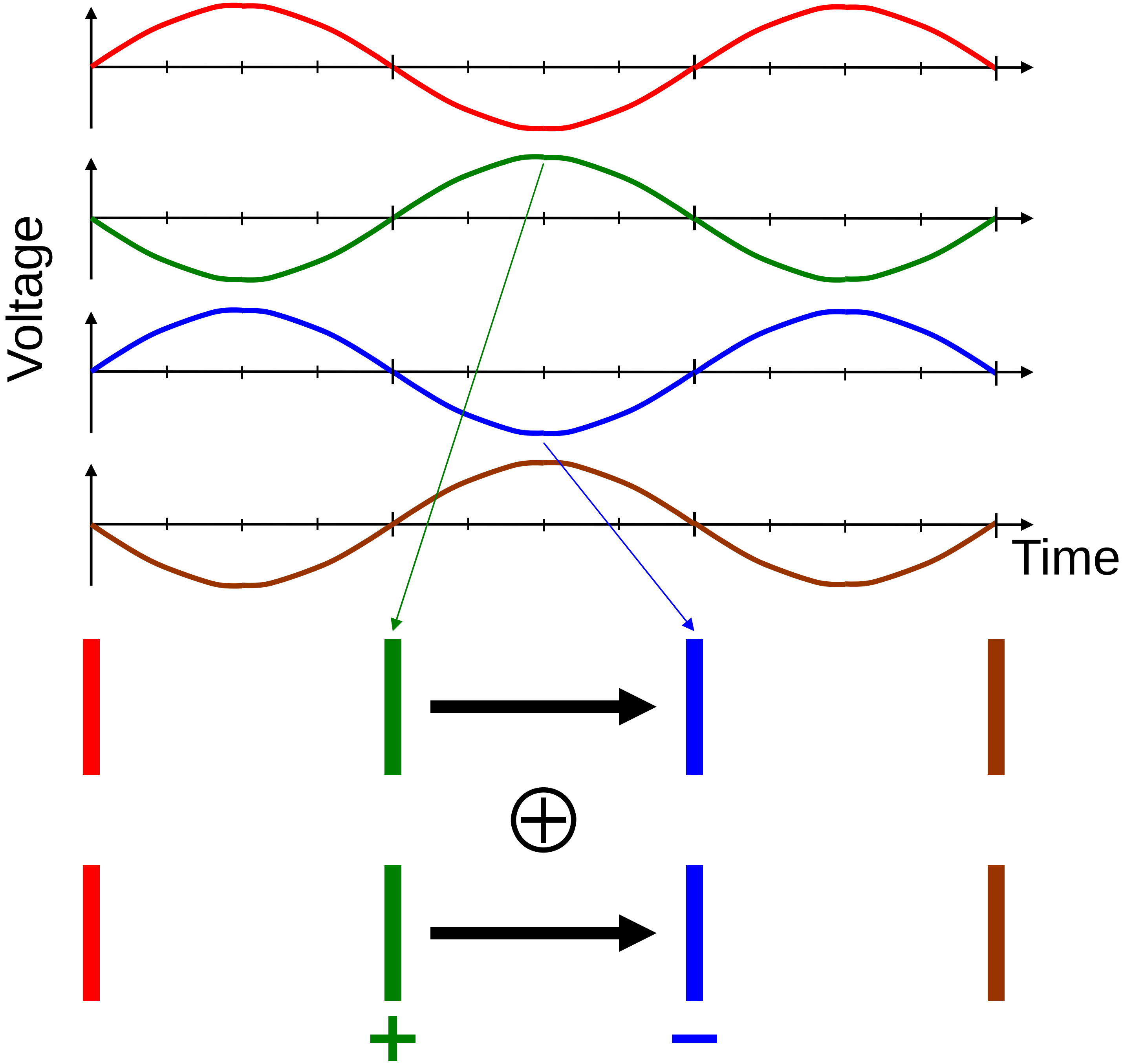
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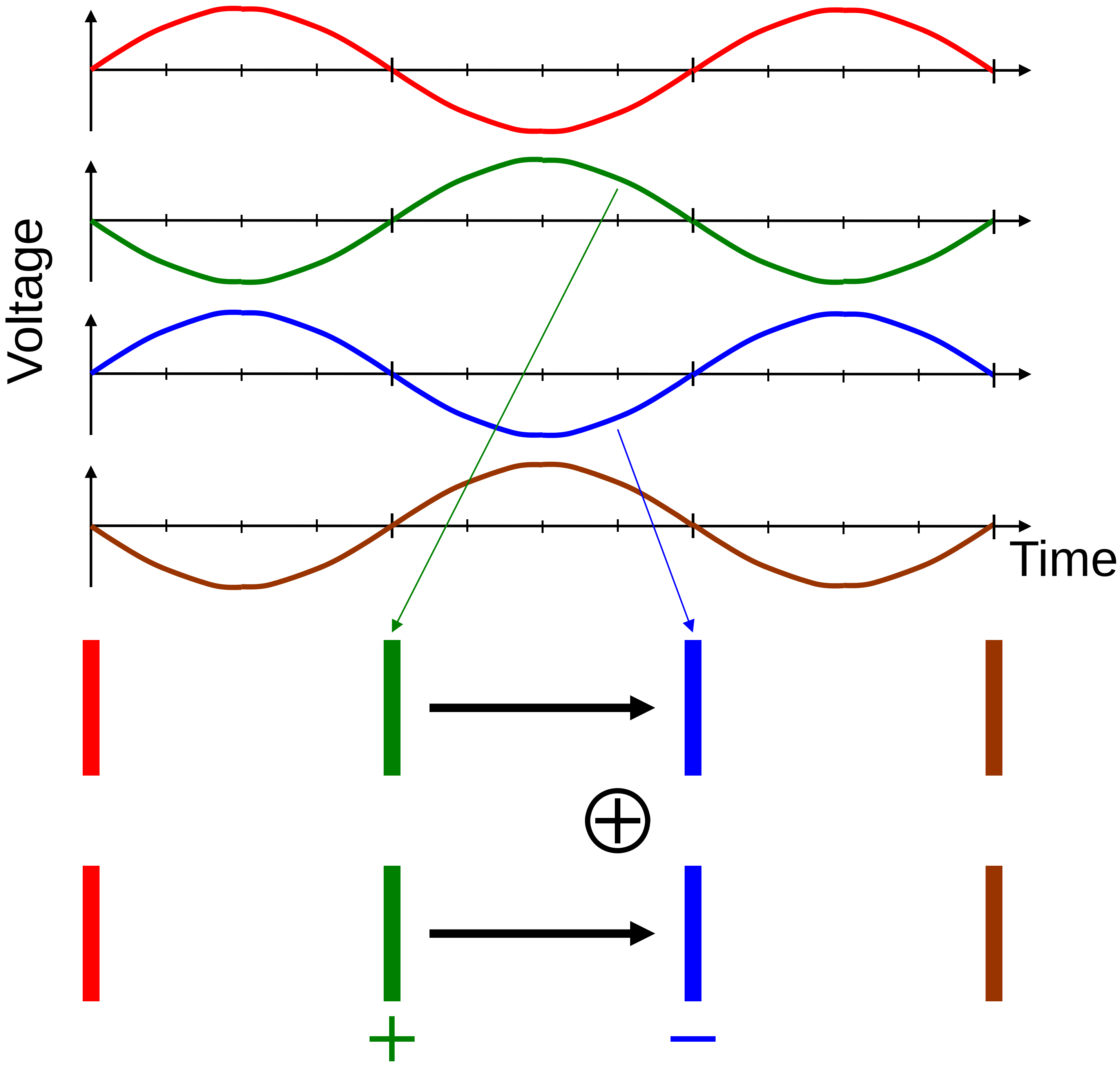

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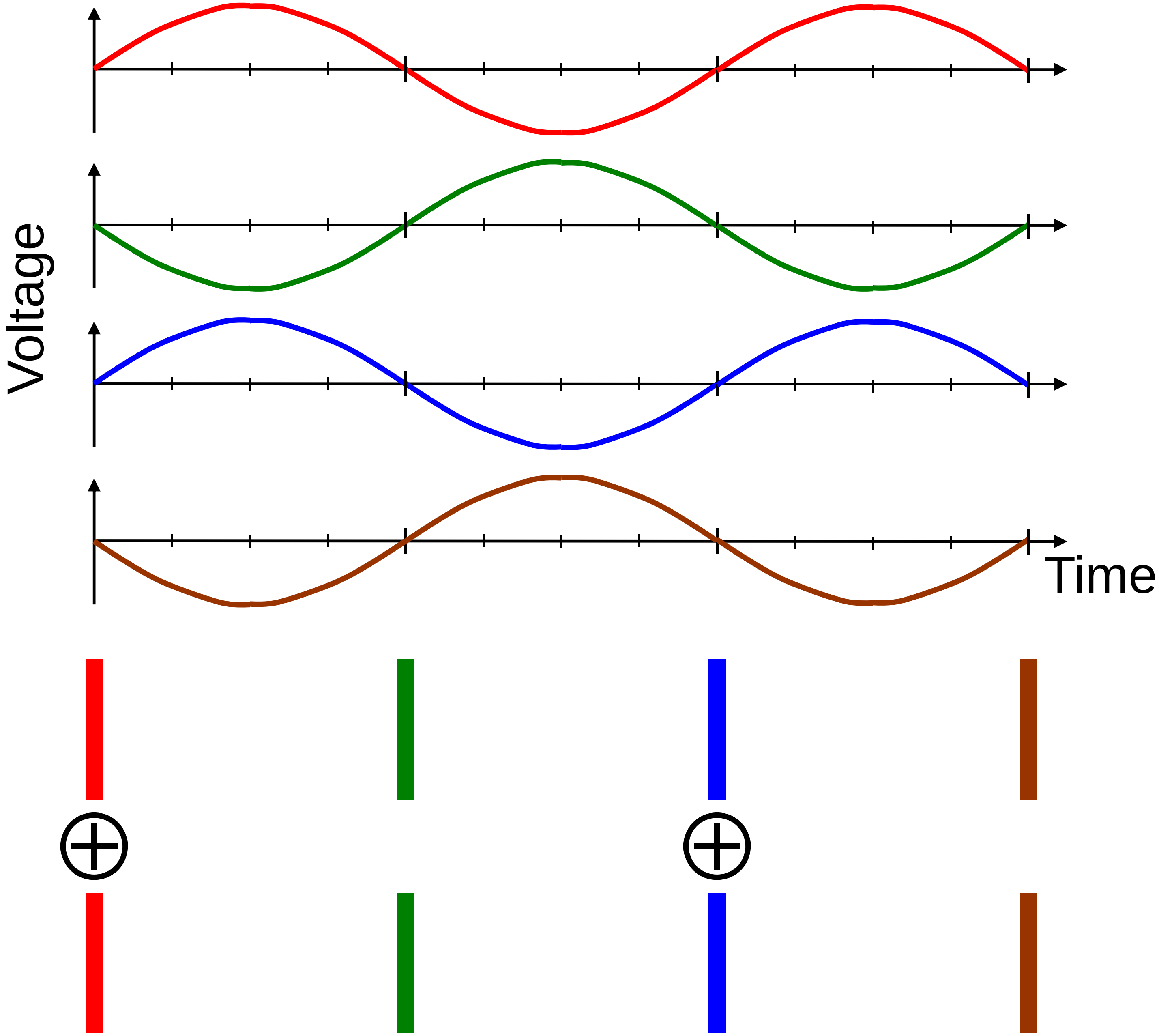
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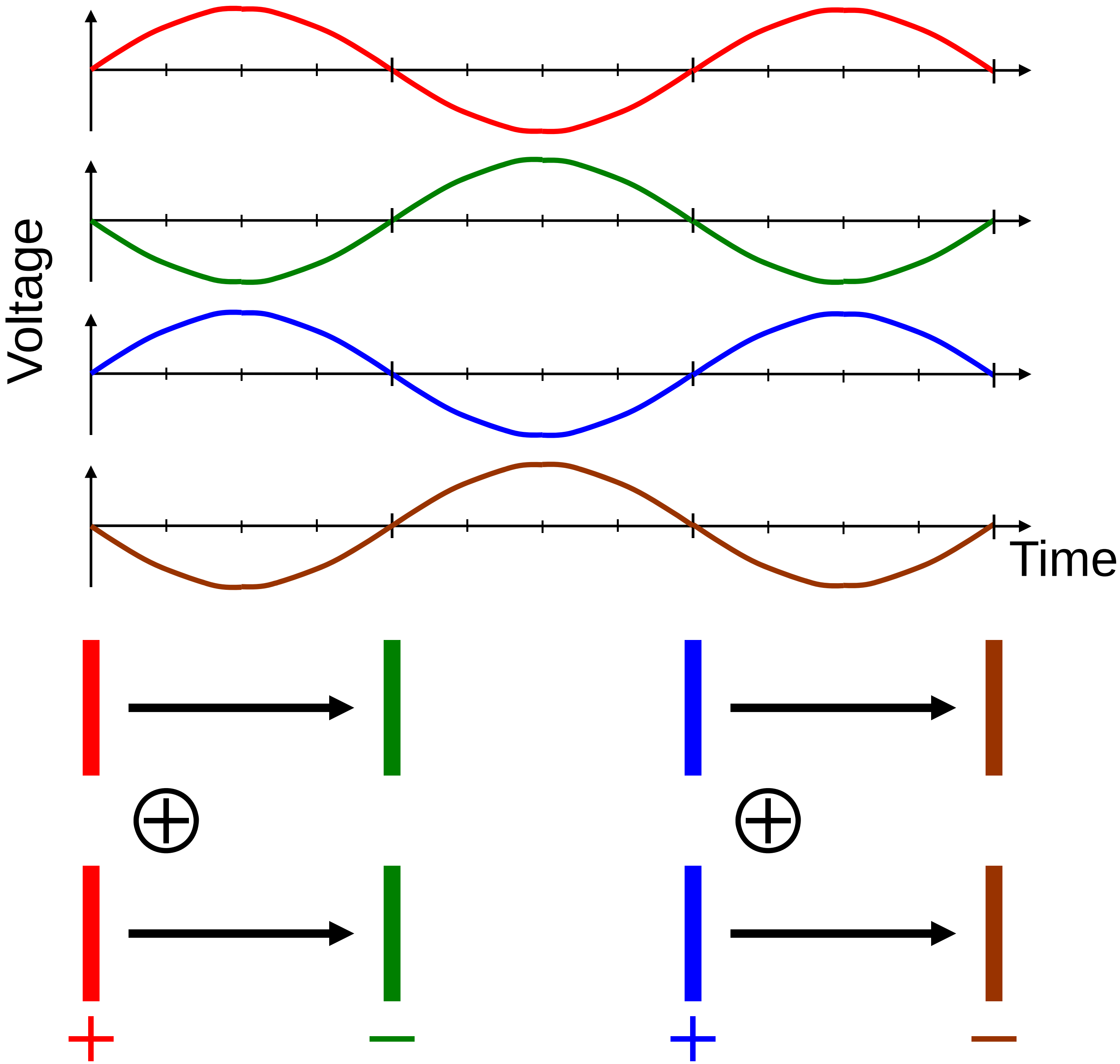

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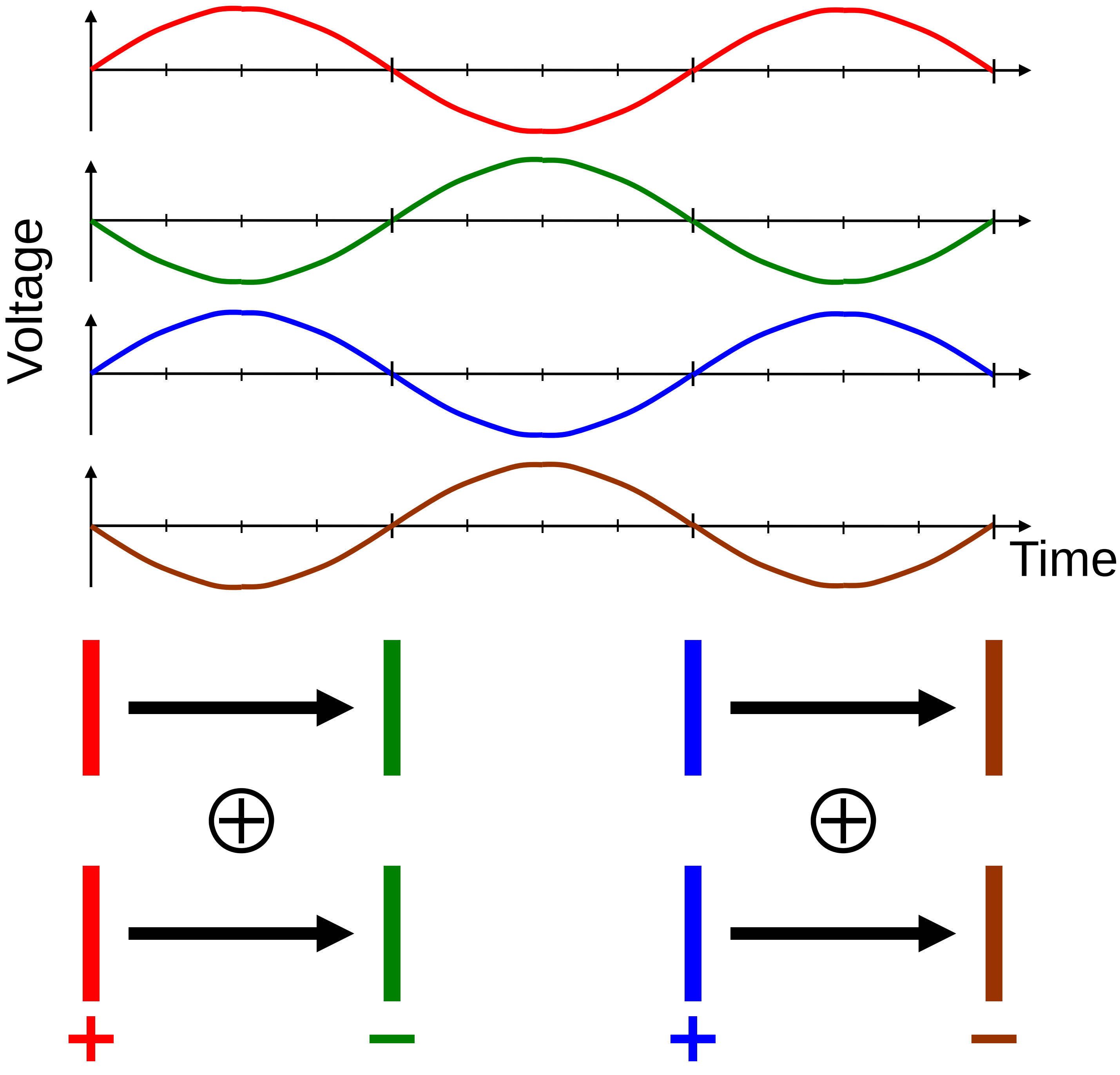

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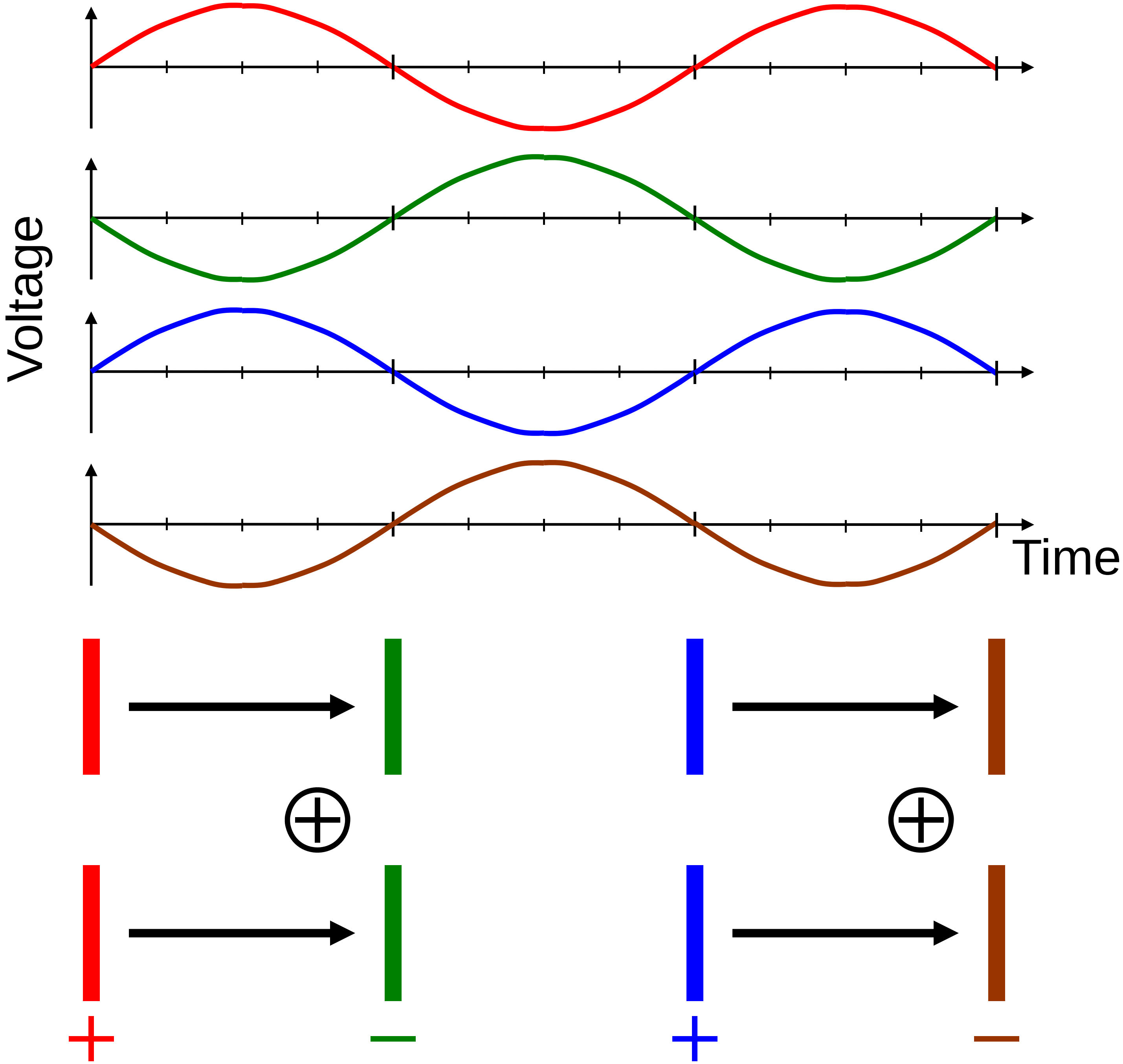
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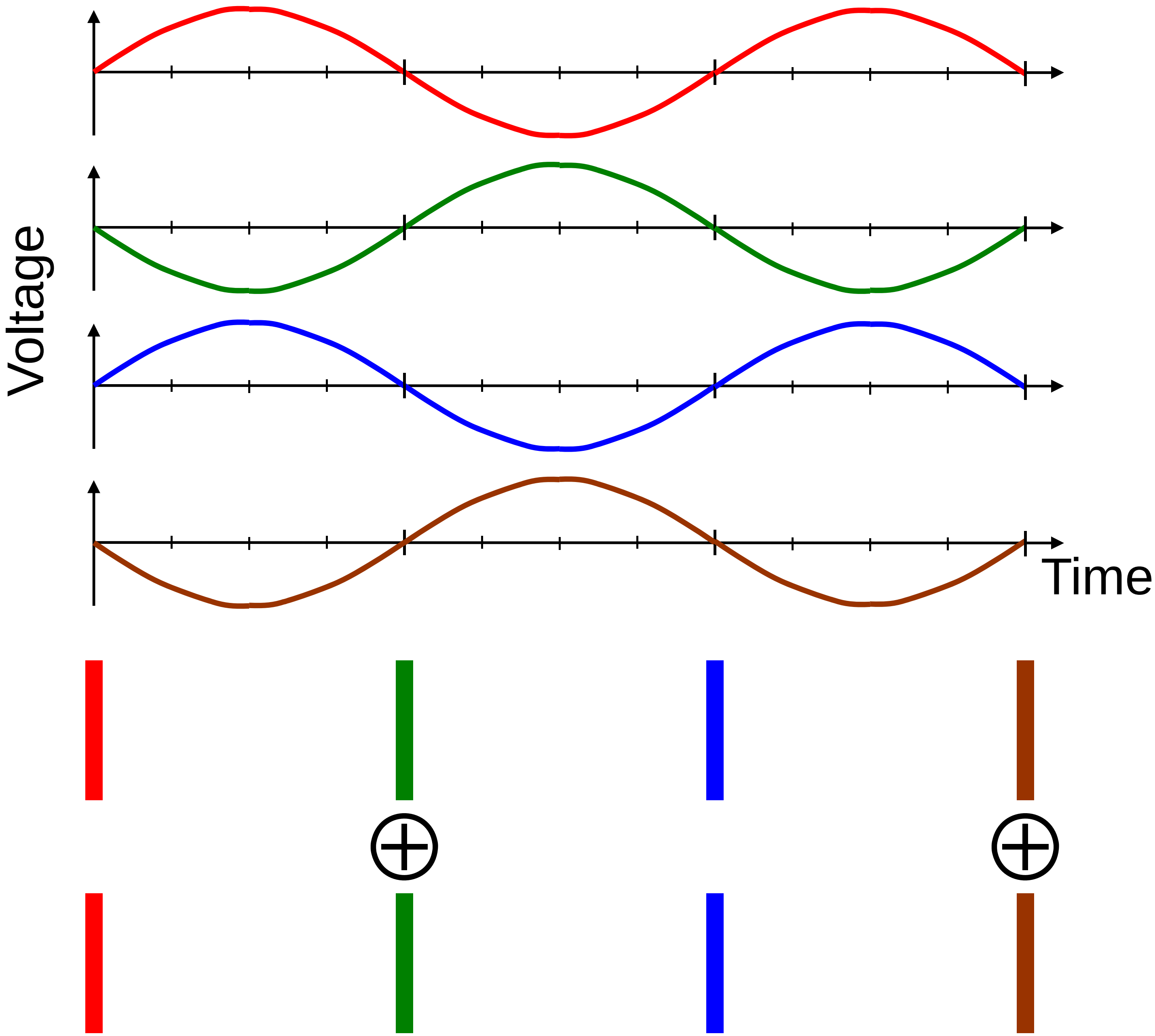
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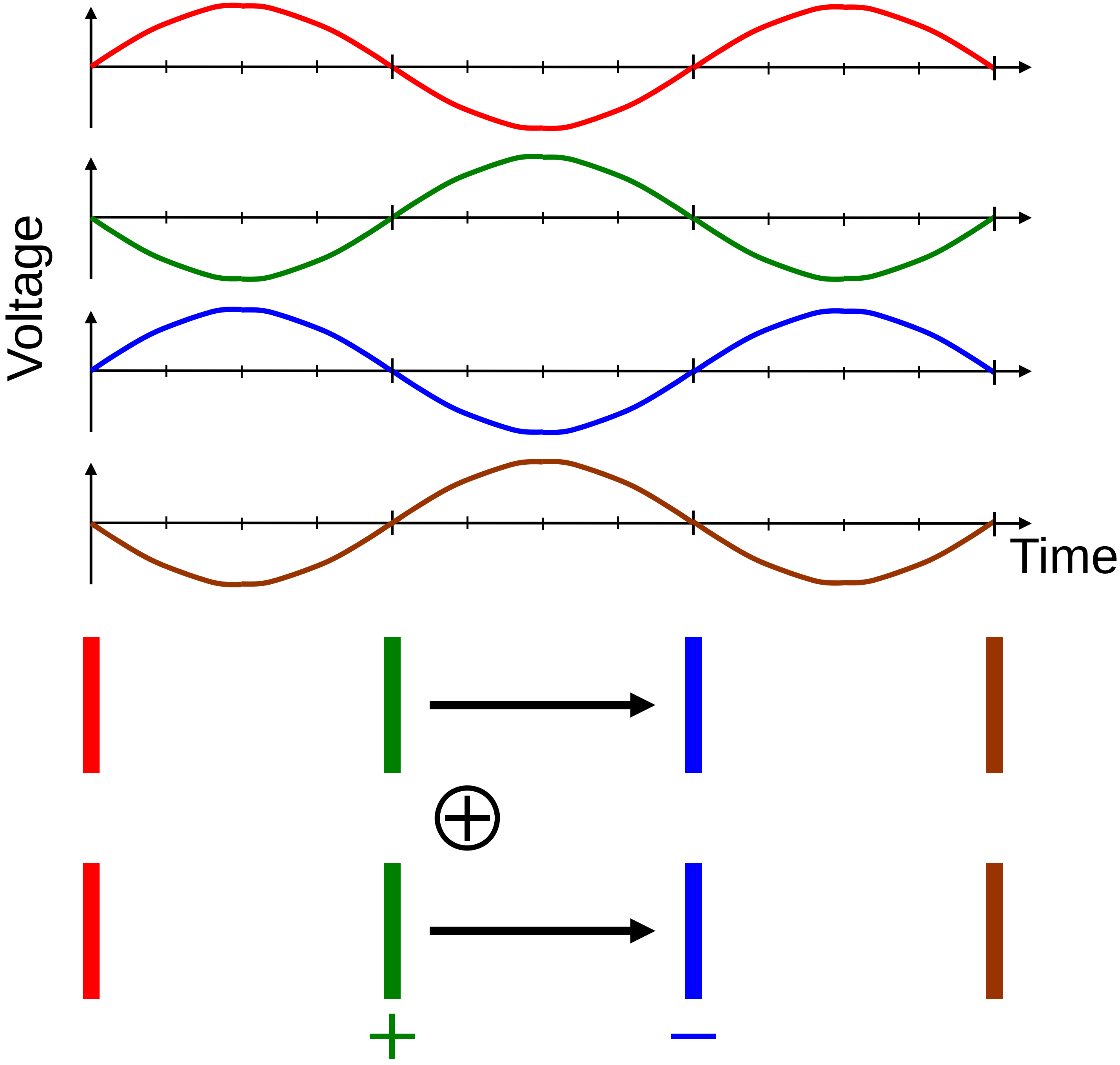
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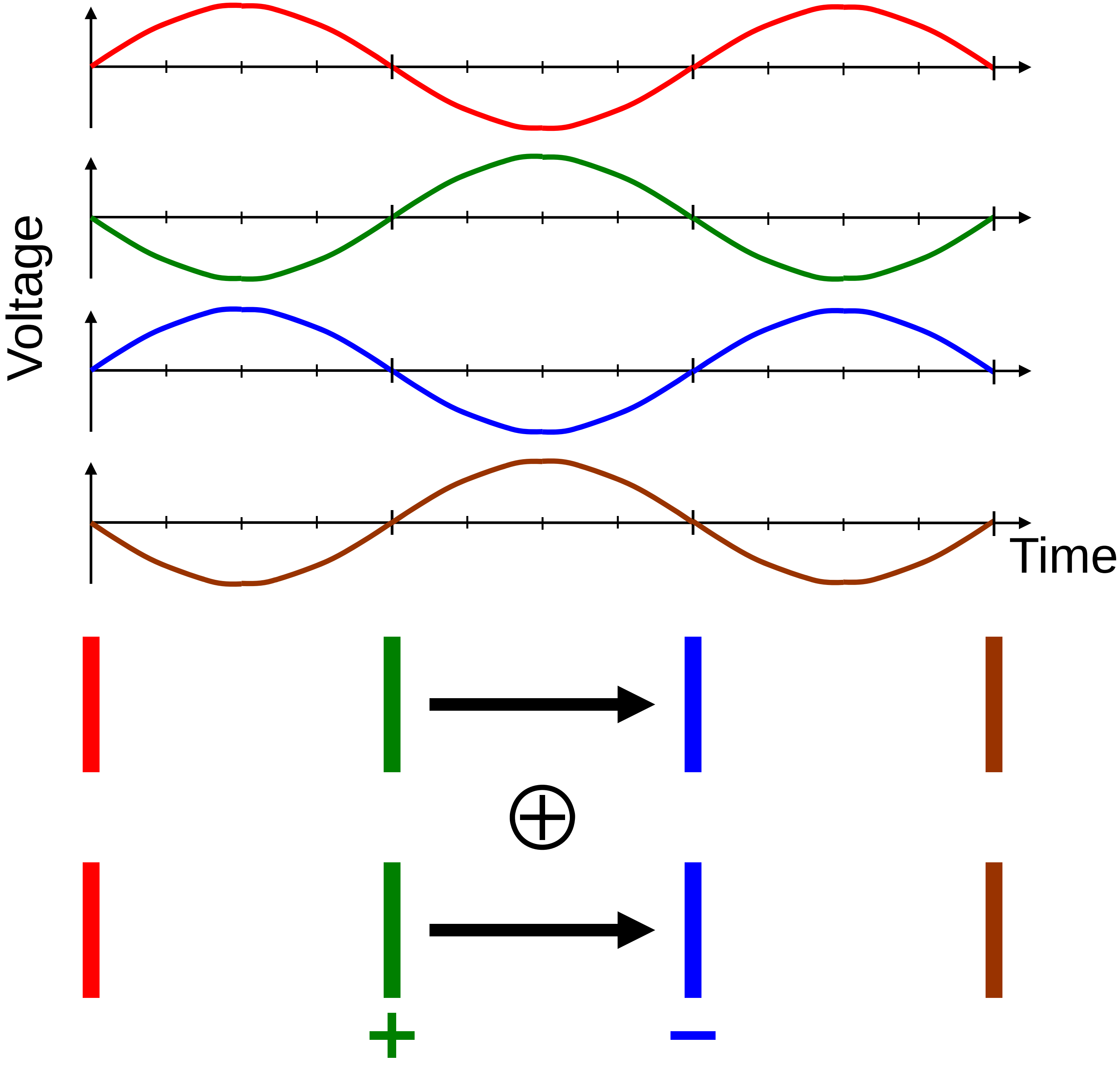
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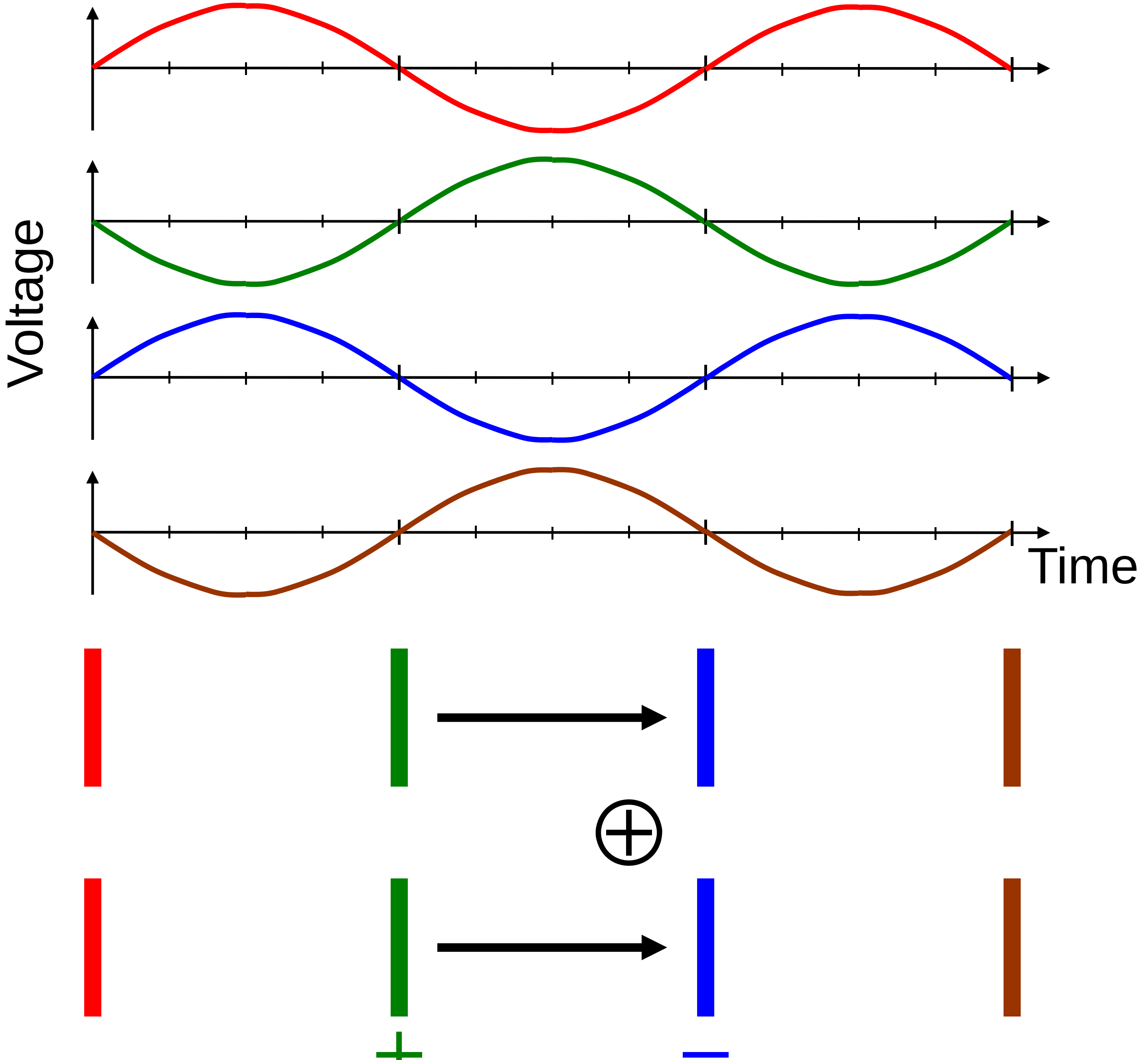
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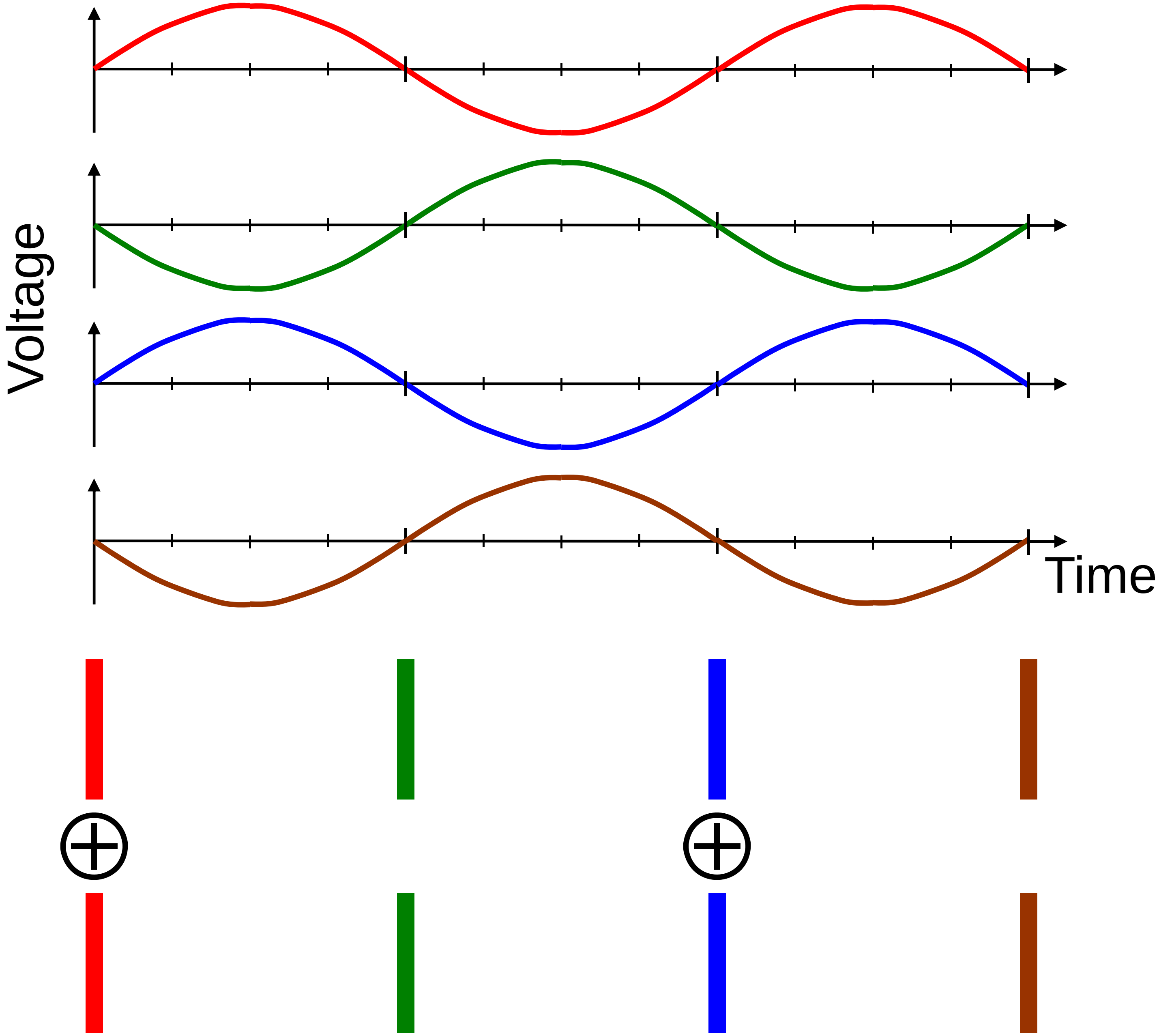
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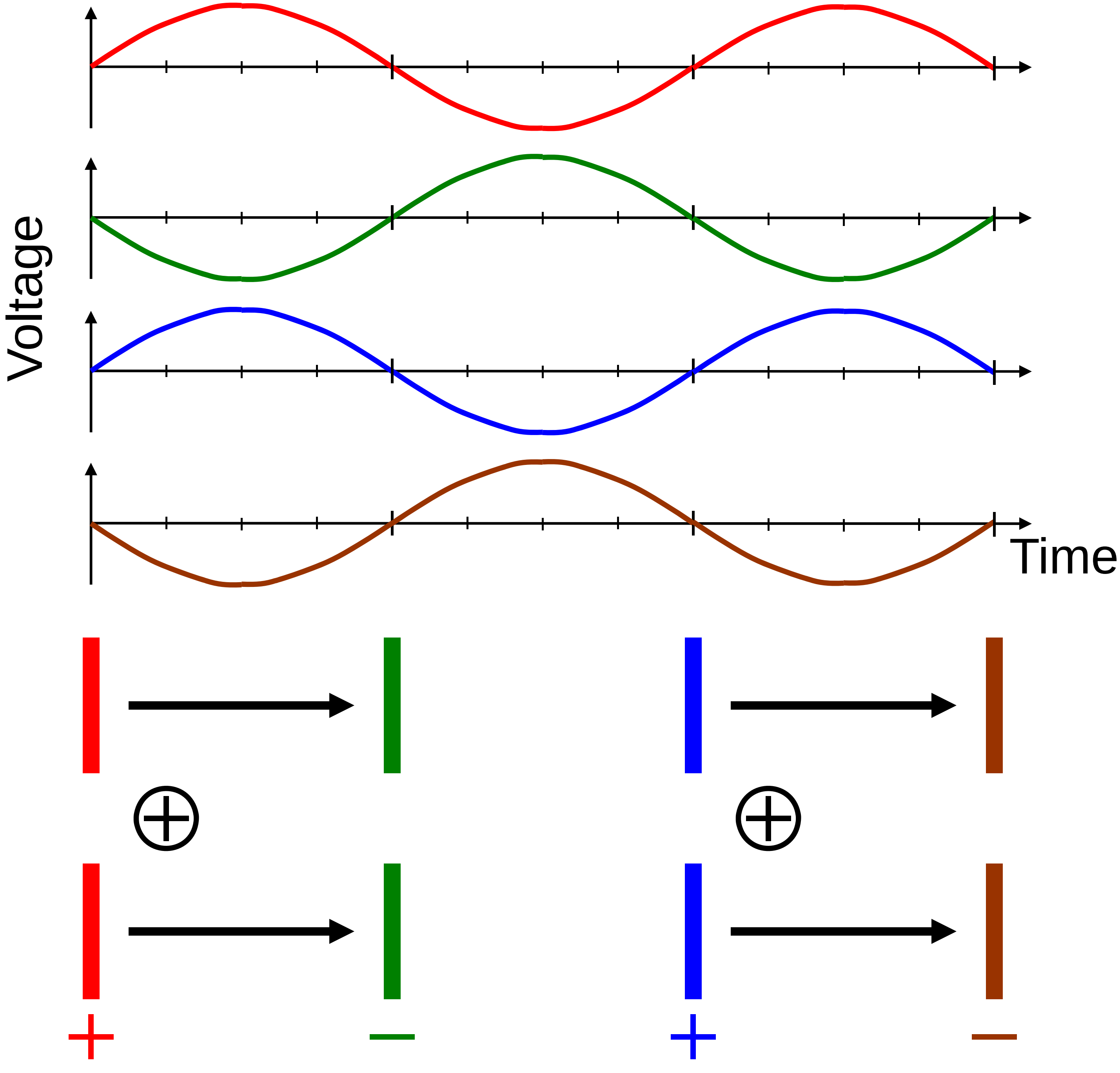

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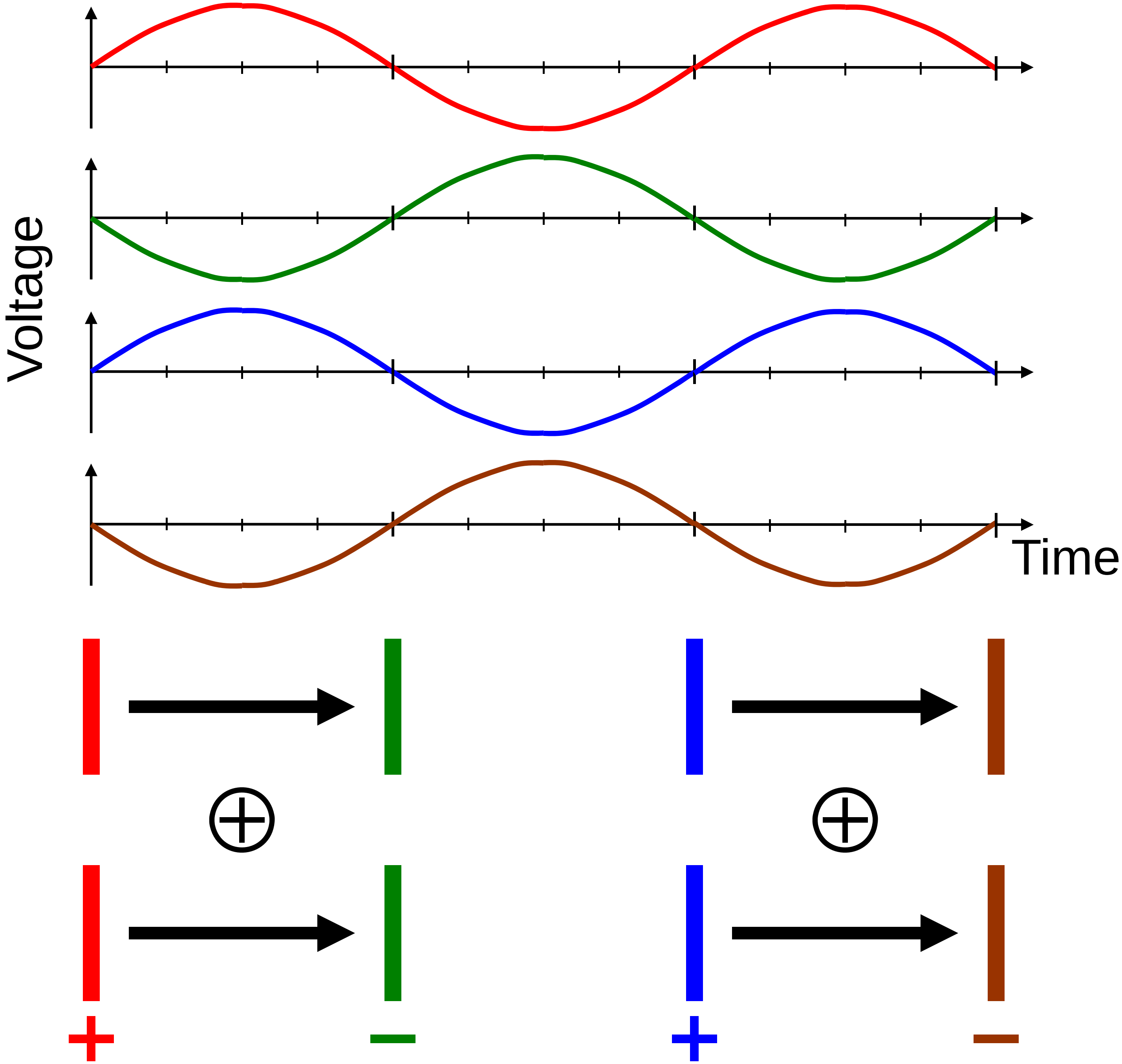
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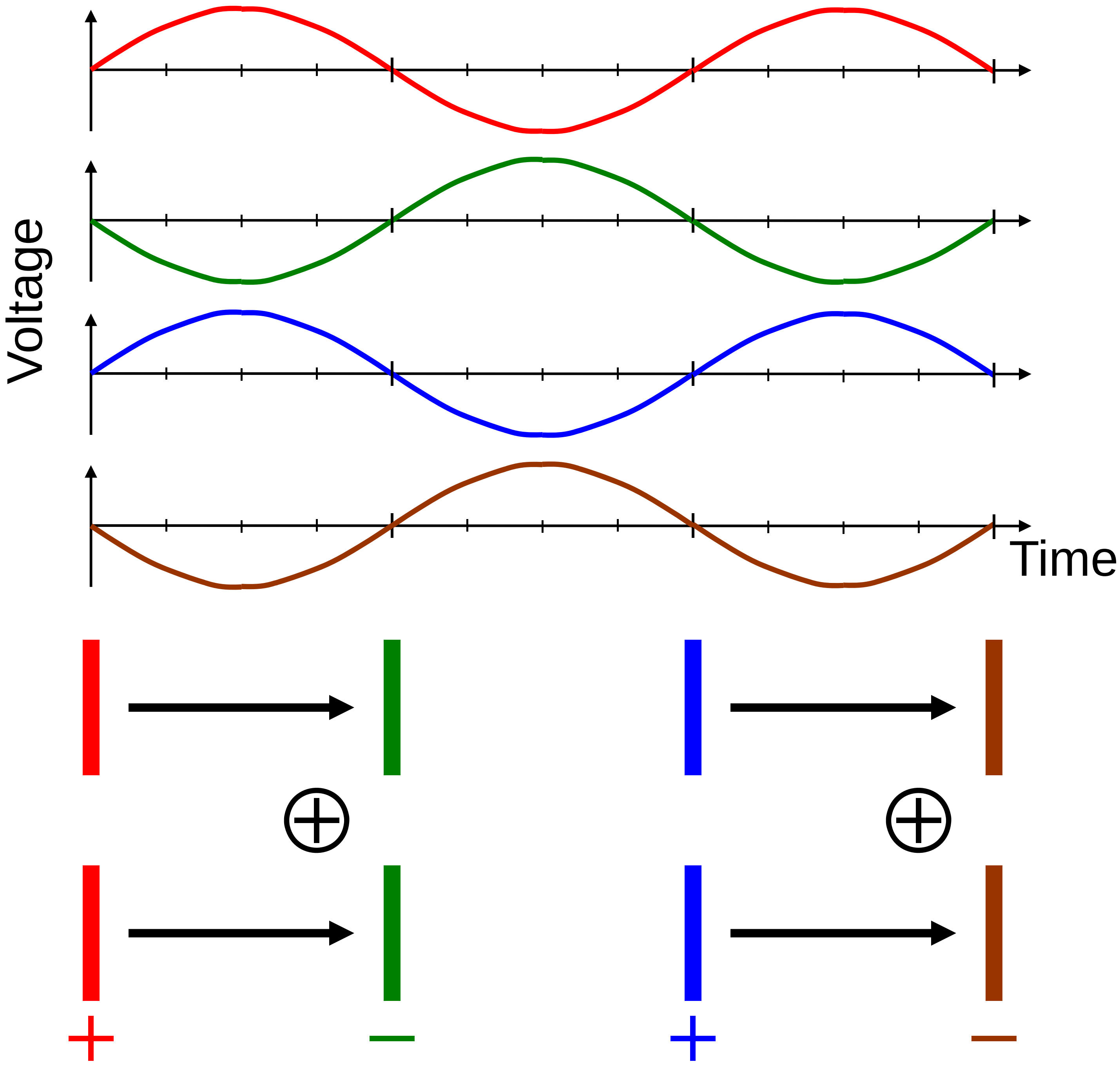
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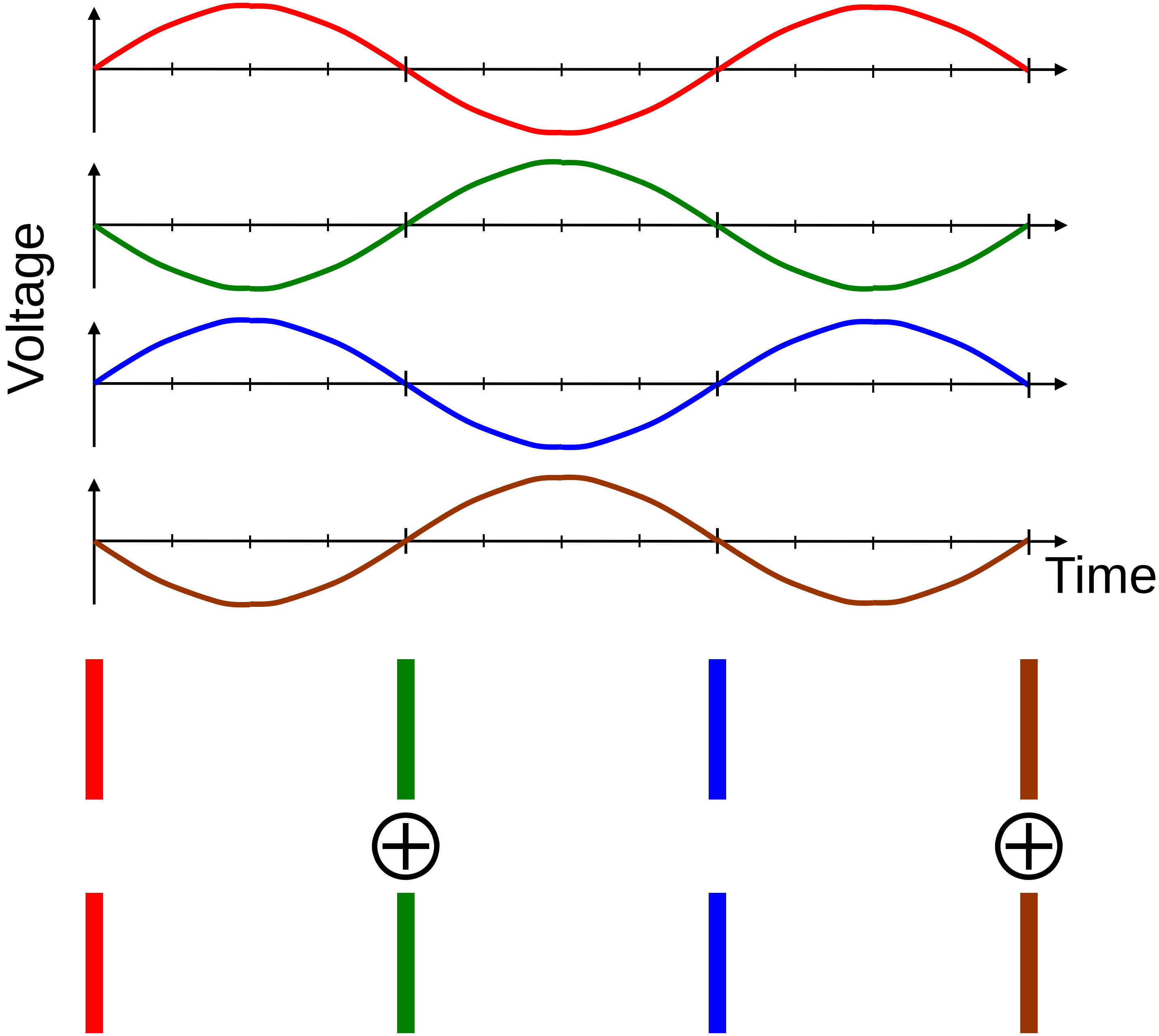
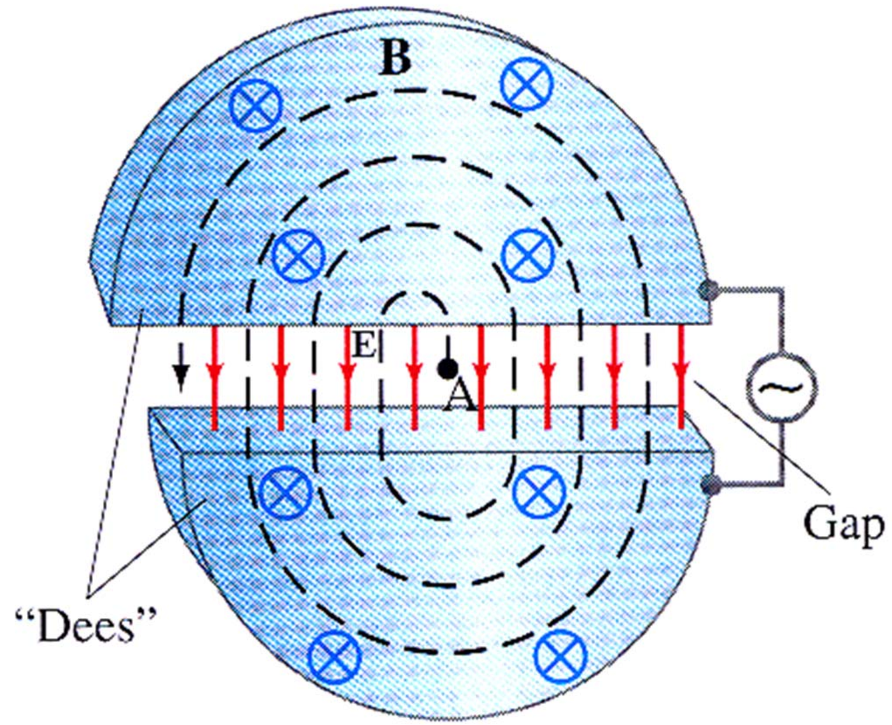

Voltage
Time

The Cyclotron

- The first accelerator to use alternating voltages was the cyclotron
- Invented by Ernest Lawrence in the late 1920's
- Combines alternating voltages with magnetic fields



A Modern Example

The Texas A&M K500 Superconducting Cyclotron -- can accelerate alpha particles to 280 MeV and uranium over 2000 MeV (40% and 14% of the speed of light, respectively)

Another Application: the Linear Accelerator

The 2-mile long Stanford Linear Accelerator speeds electrons up to 45-50 GeV (billions of electron volts) or ~99.999999995% of the speed of light.

A Multi-Accelerator Complex
The **R**elativistic **H**eavy **I**on **C**ollider -- **RHIC**

RHIC at Brookhaven National Laboratory

- Accelerates gold nuclei to 19,700 GeV or 99.996% of the speed of light
- **Two separate beams collide with each other.**
- Au+Au with **each at 19,700 GeV** is equivalent to a **single Au nucleus of 4,200,000 GeV** hitting a second Au nucleus at rest

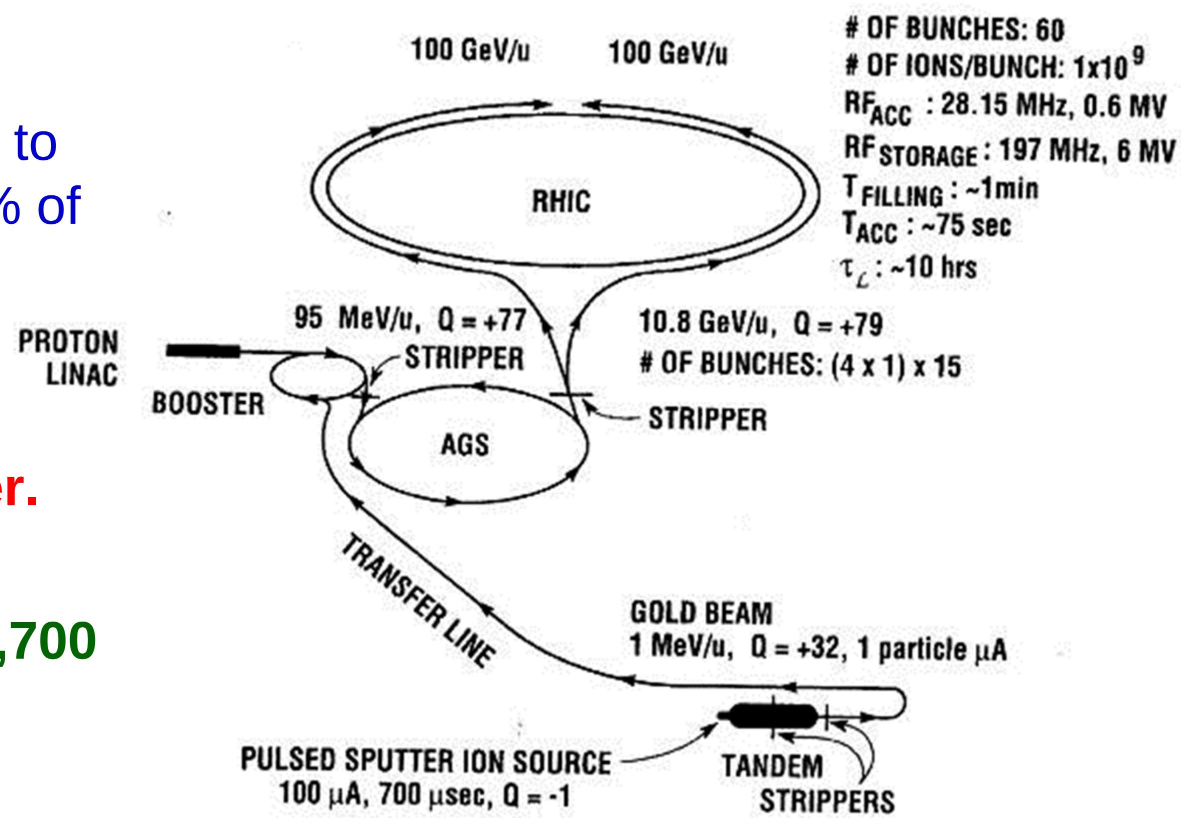
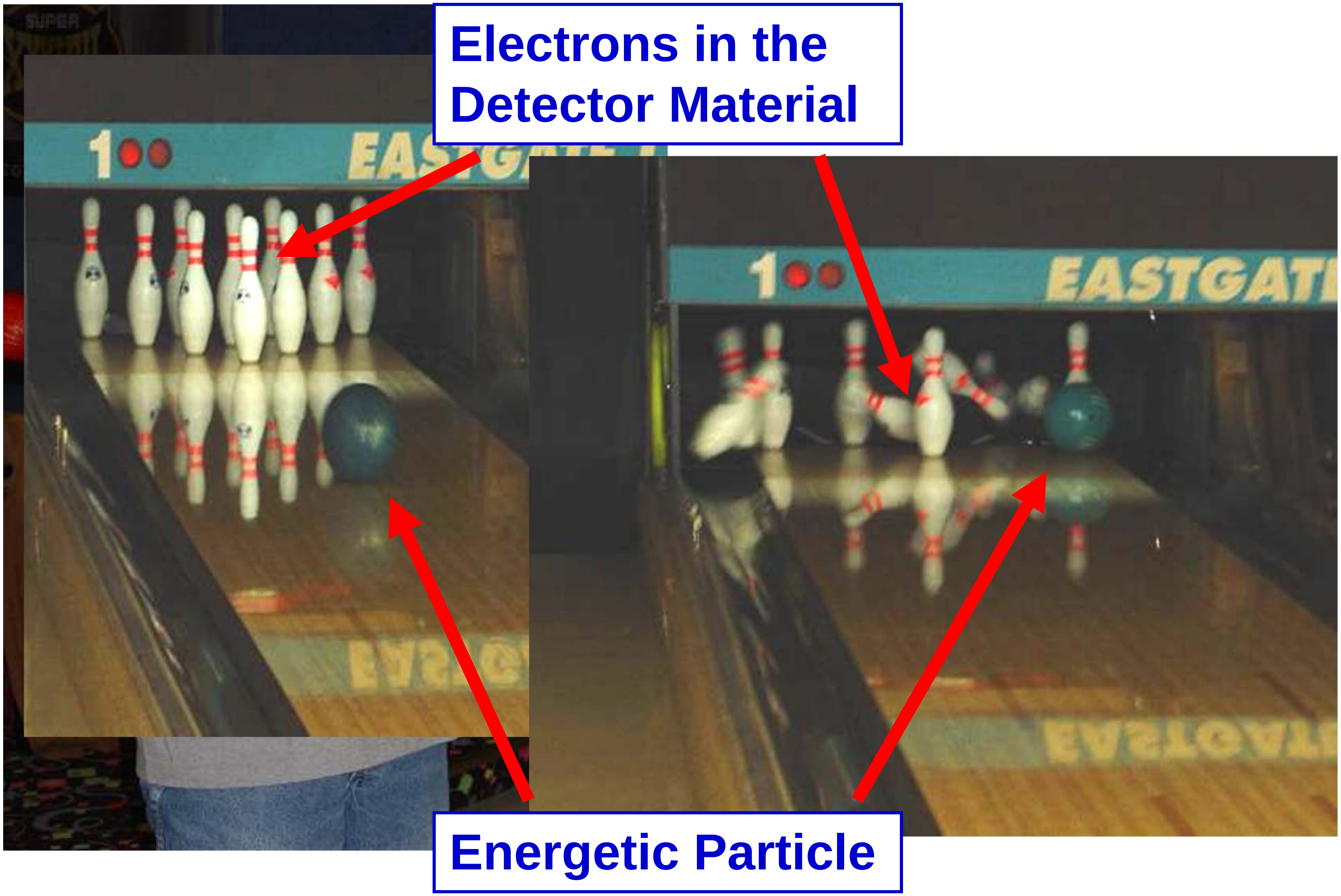


Fig. 2. RHIC acceleration scenario for Au beams.

RHIC: the Relativistic Heavy Ion Collider

The Principle Behind All Particle Detectors



Some Historical Background – the First Tracking Detector

Clouds

The Cloud Chamber

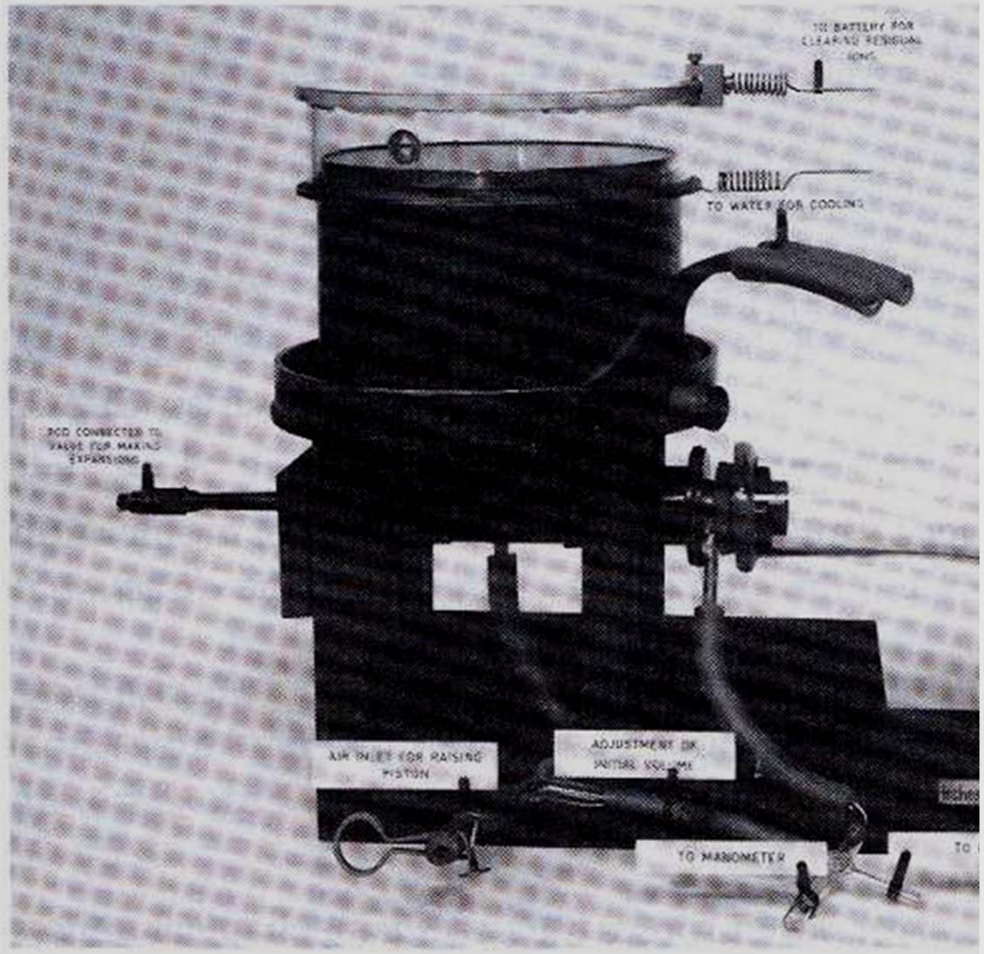
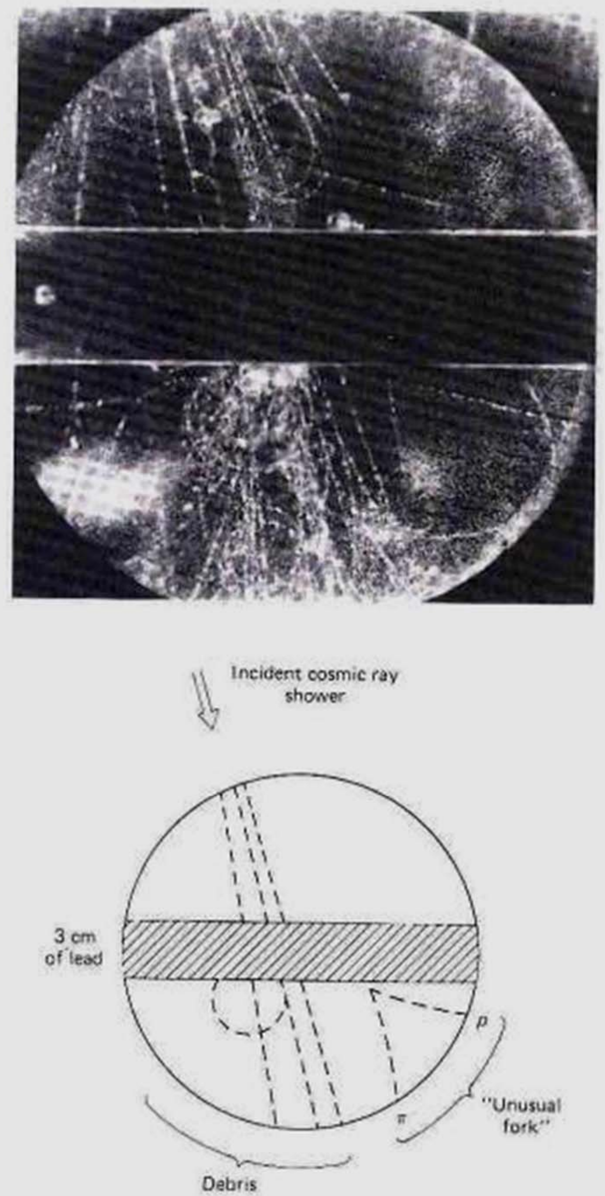


Figure I.3 An early particle detector: Wilson's cloud cha
Science Museum, London.)



Another Important Historical Detector

Bubbles

The Bubble Chamber

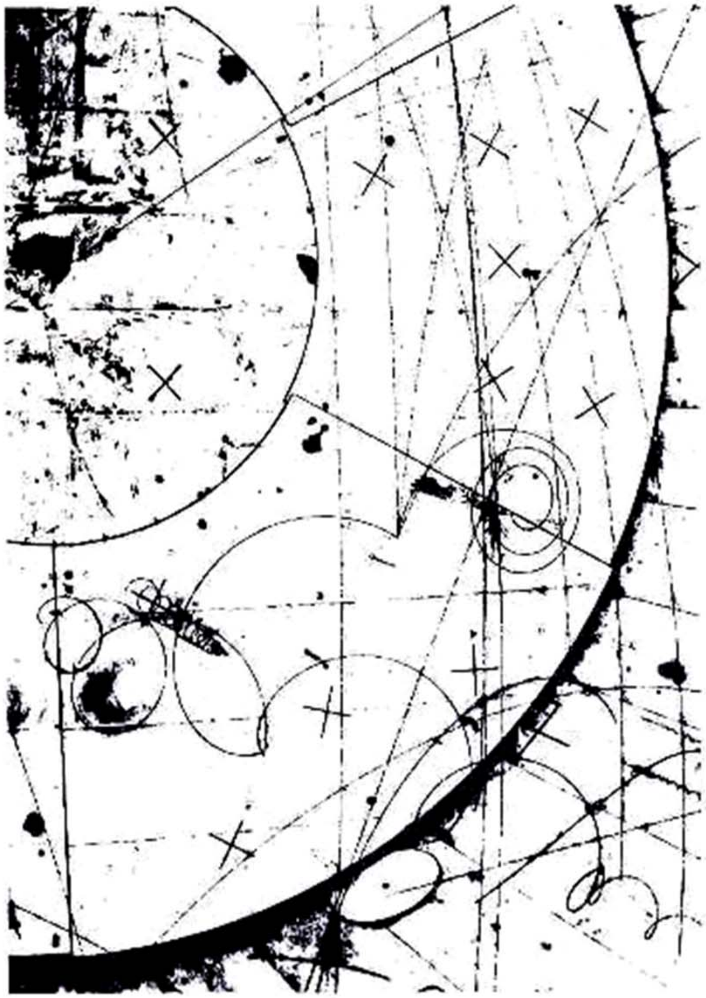
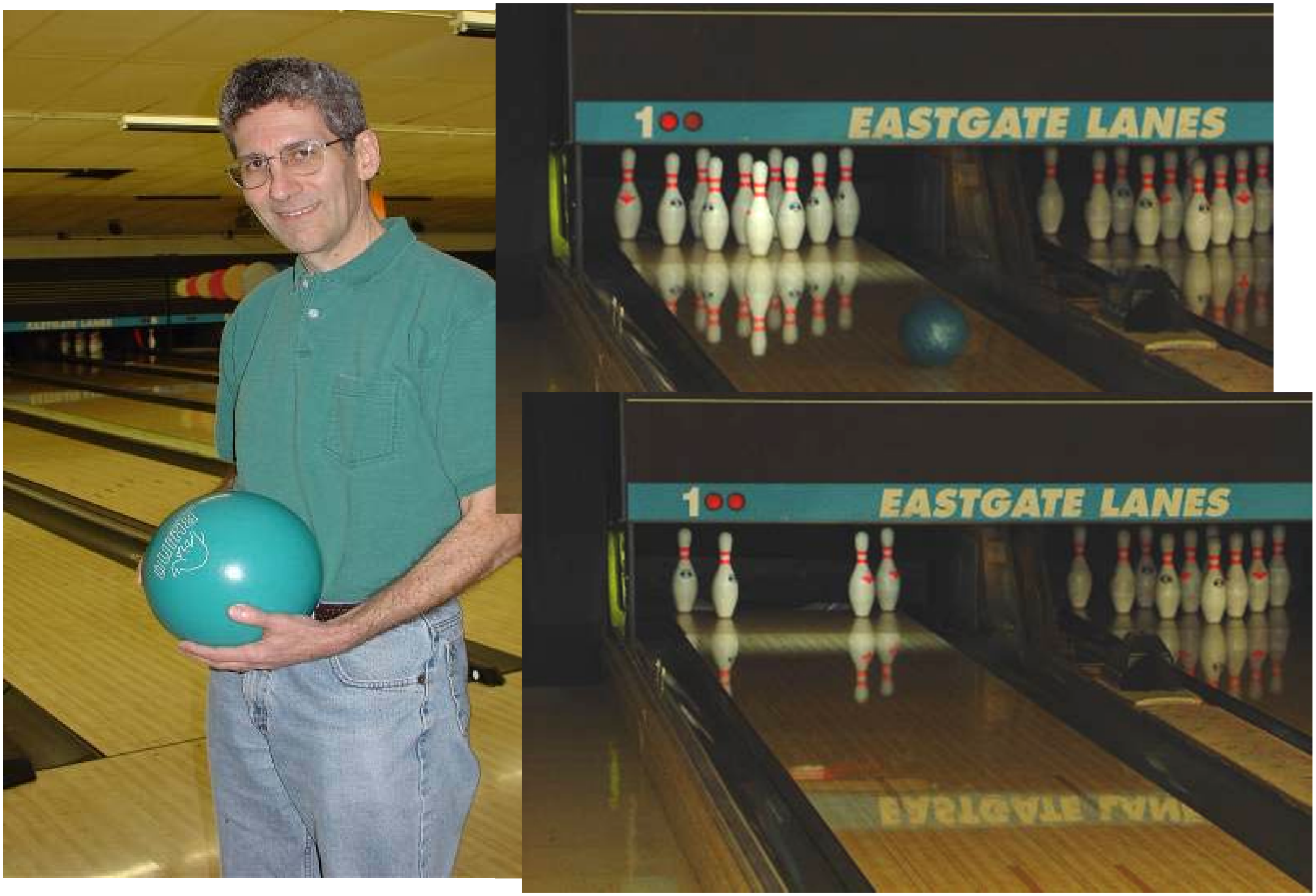


Figure 2.15 Example of charmed-particle production and decay in the hydrogen bubble chamber BEBC exposed to a neutrino beam at the CERN SPS. (Courtesy CERN.)

Maybe I Can Build a Detector, Too?

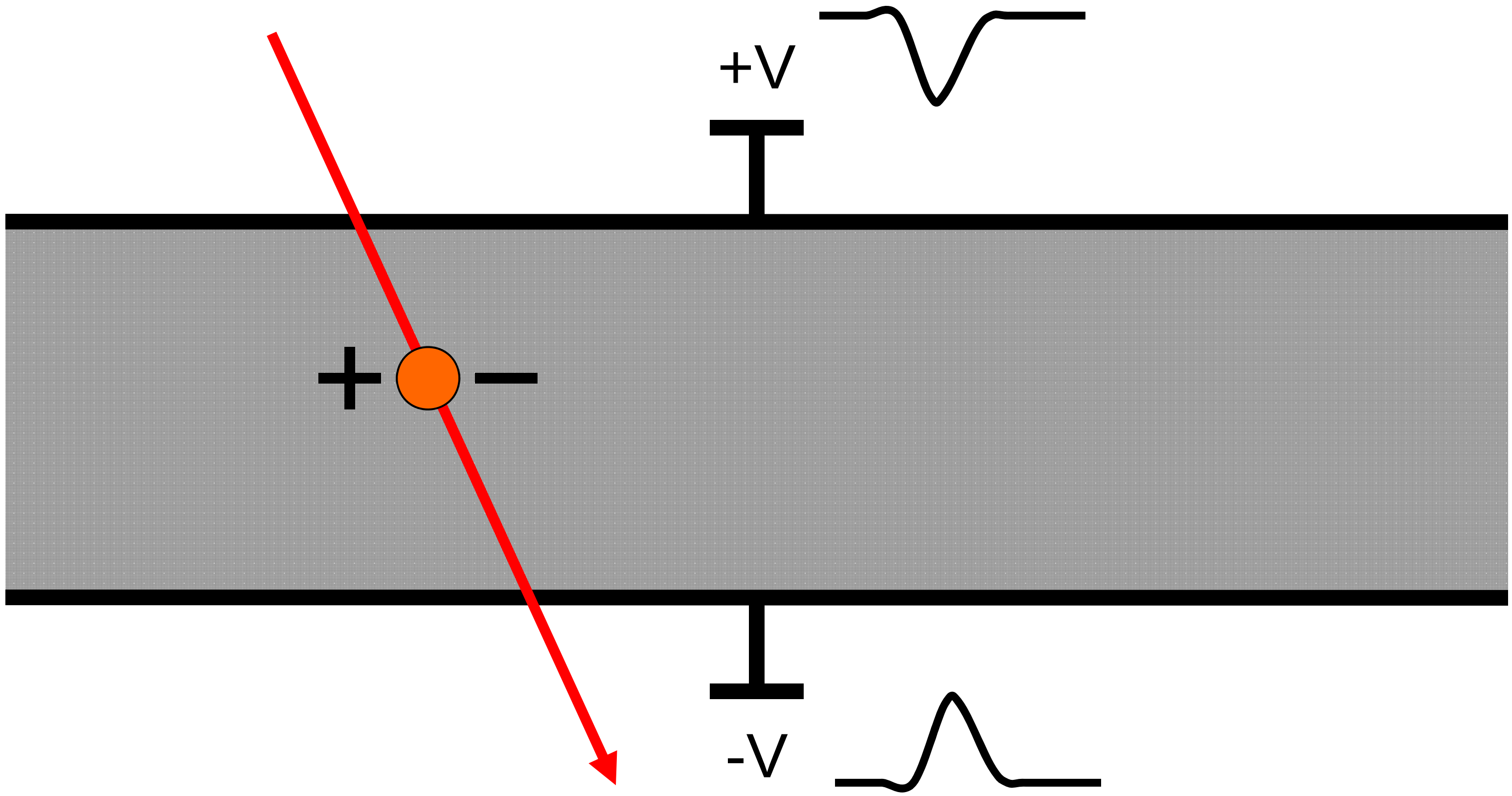


Detector Misfire!!!

A Modern Workhorse Nuclear and Particle Physics Detector

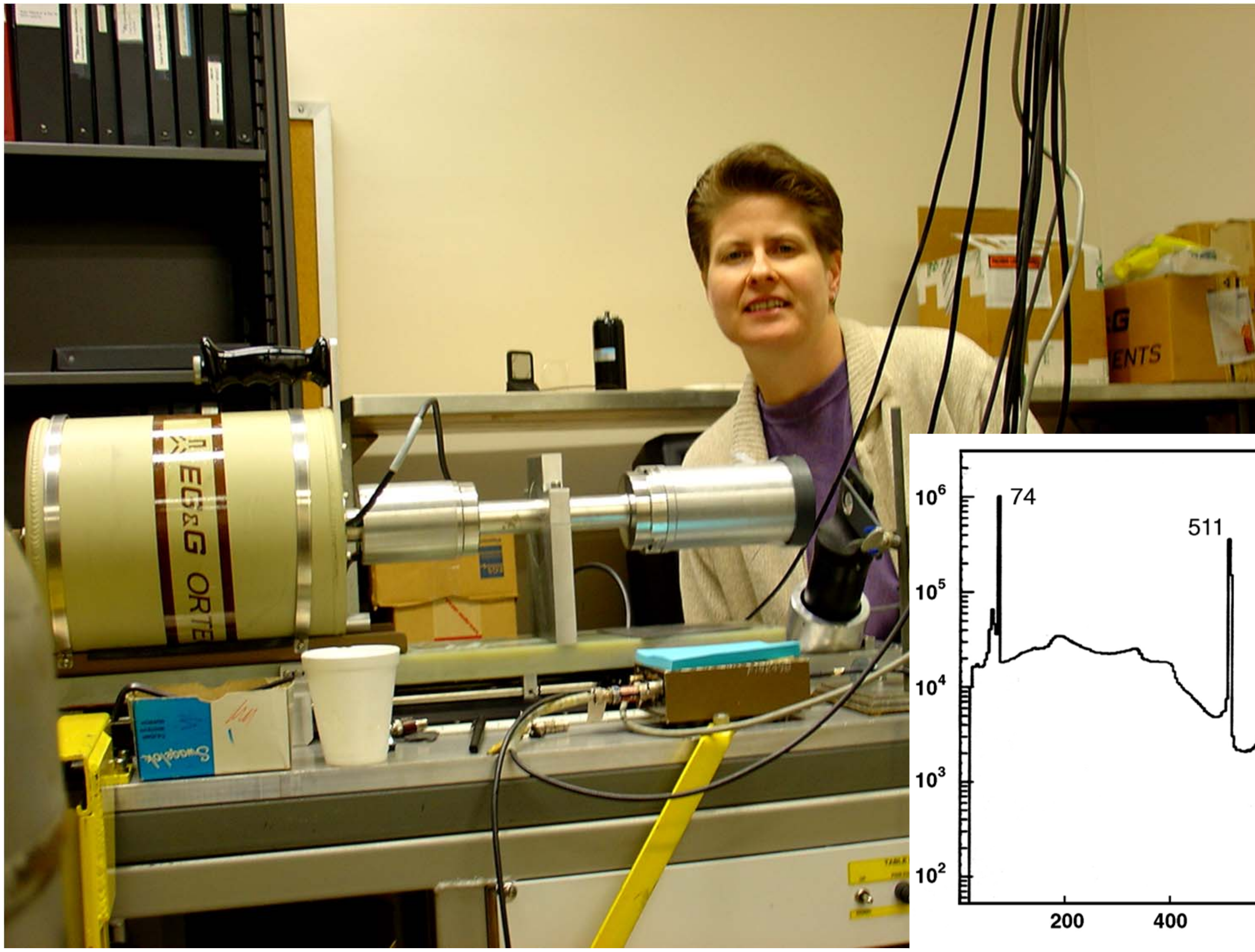
Semiconductor diodes – “Ge” and “Si” detectors

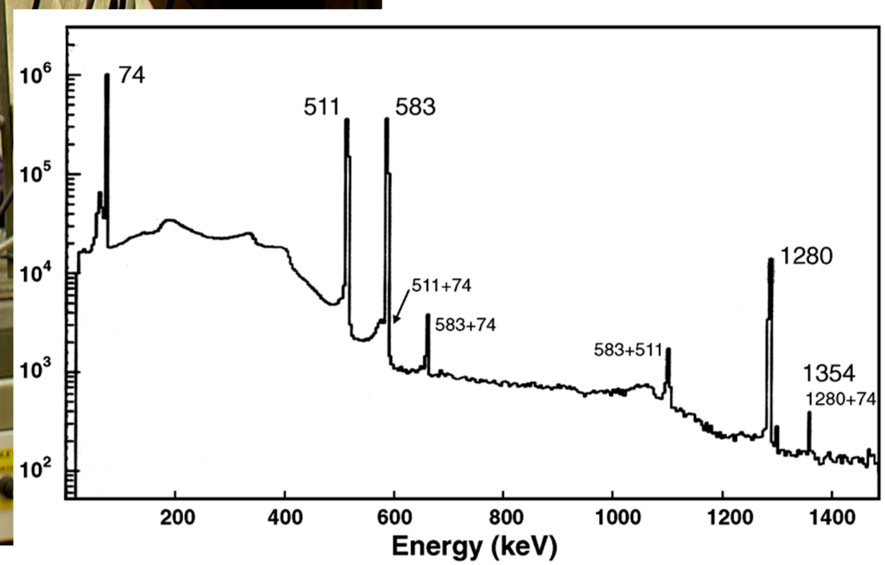
Ge and Si Detectors



Can be used to measure energies precisely,
or positions precisely, or both.

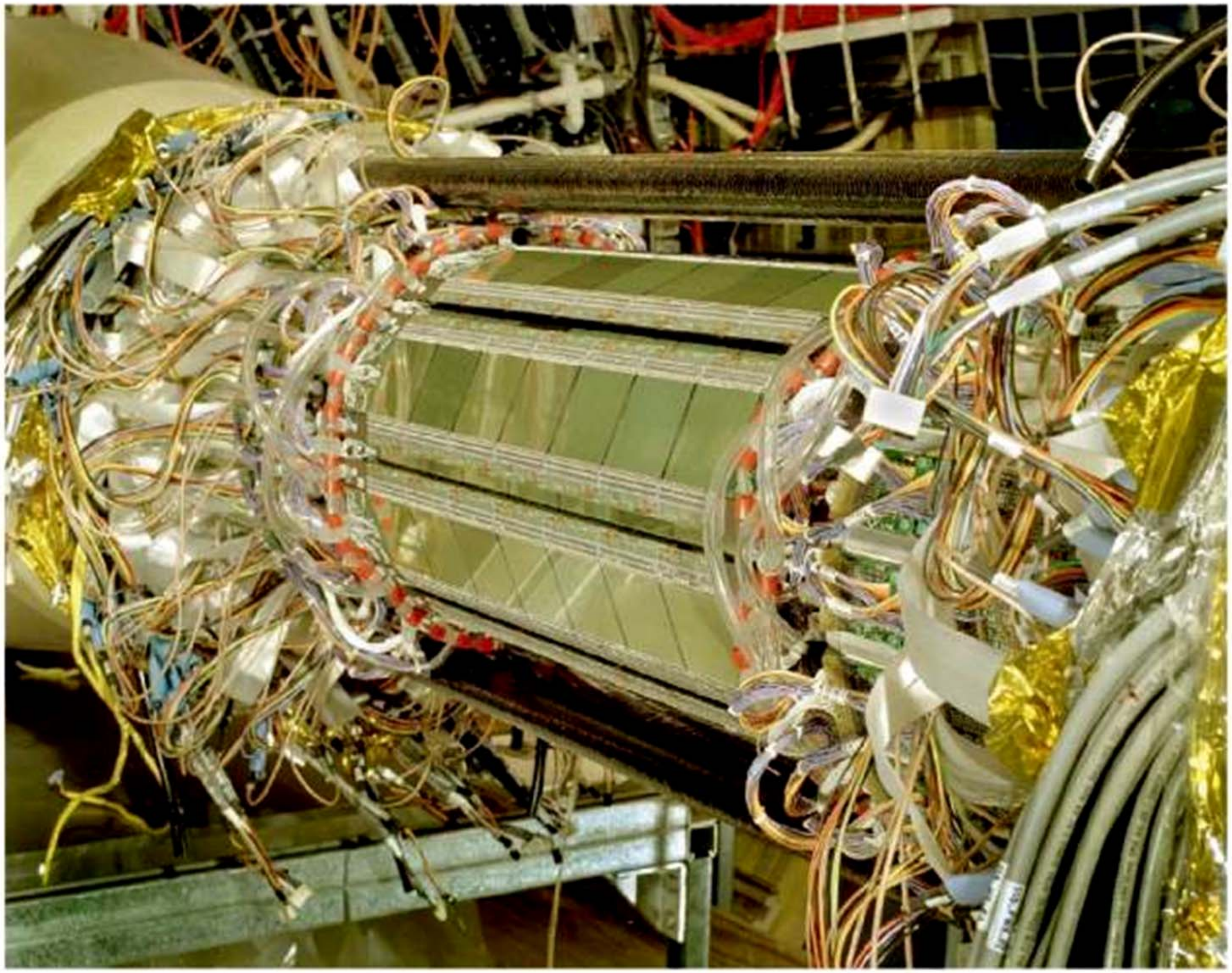
A Single Ge Detector





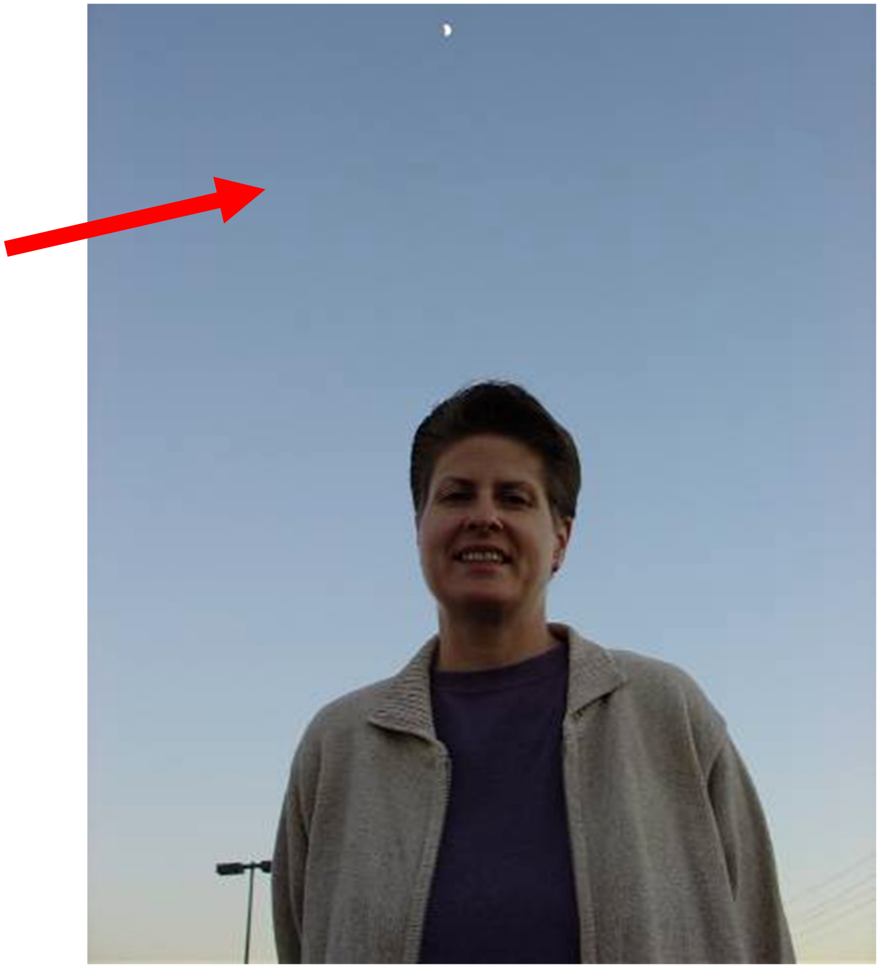
The most precisely calibrated Ge detector in the world is at Texas A&M.

The STAR Silicon Vertex Tracker



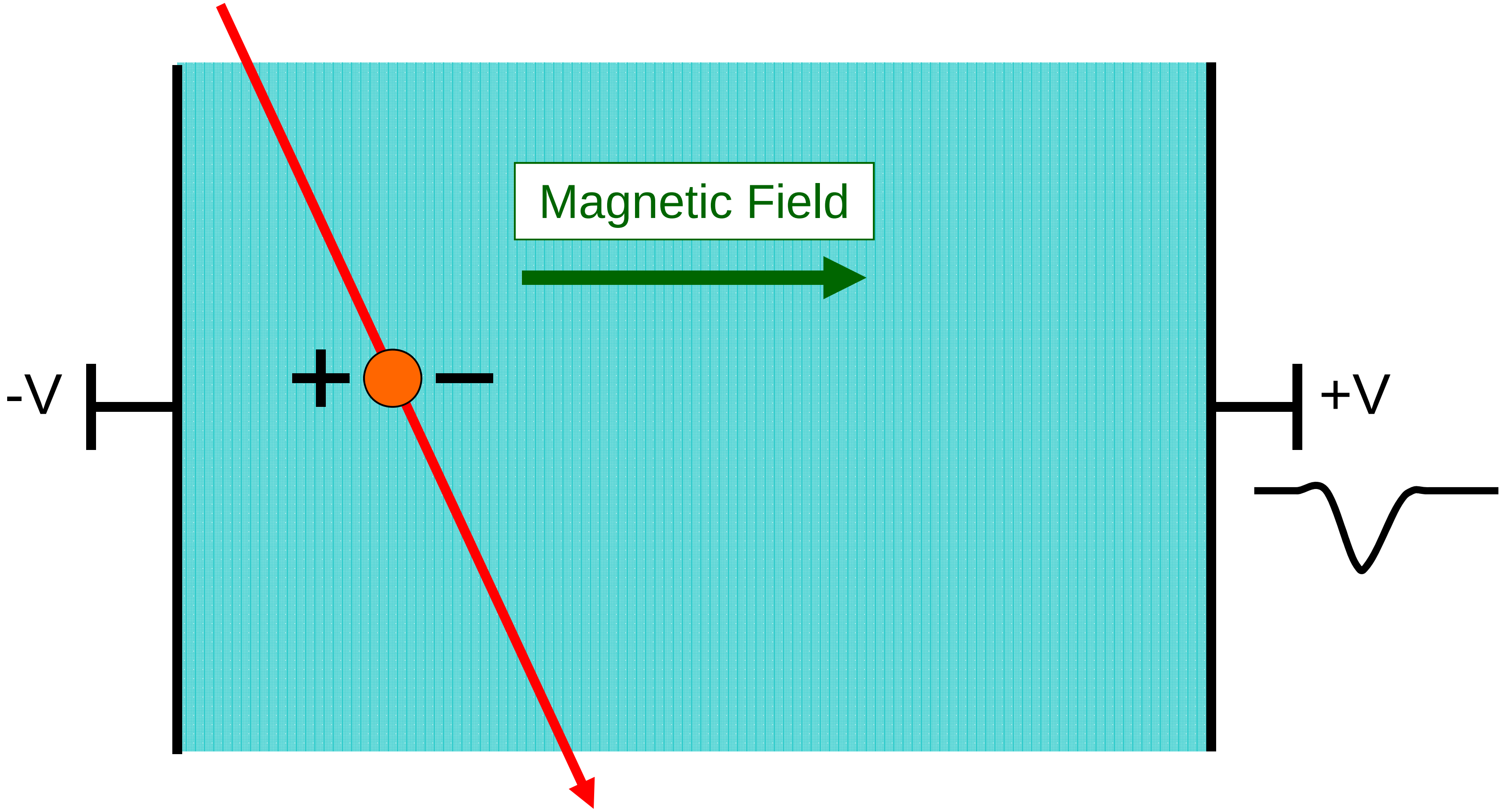
Used to measure charged-particle positions to a few thousandths of an inch.

Another Modern Workhorse Nuclear and Particle Physics Detector



Gaseous detectors

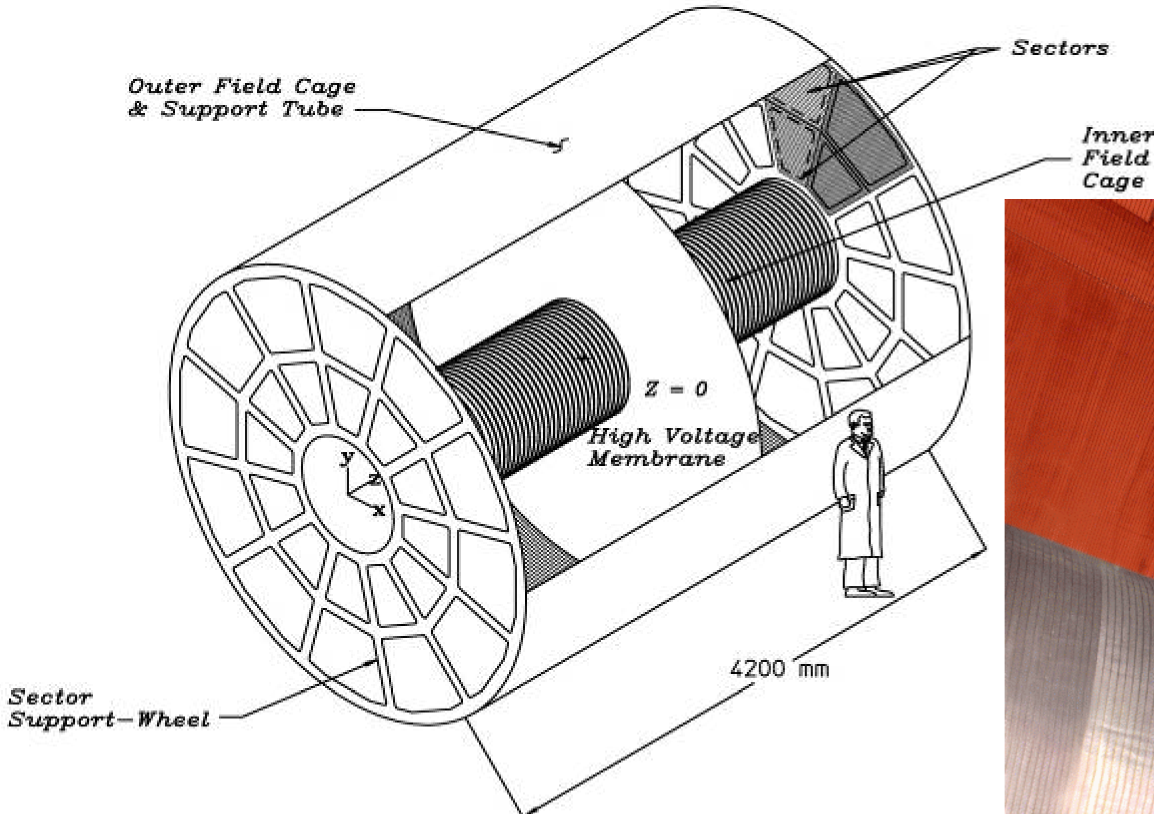
One Example: the **T**ime **P**rojection **C**hamber



The time to reach the end of the TPC determines the distance drifted in the gas.

A **3-D camera** to measure particle positions.

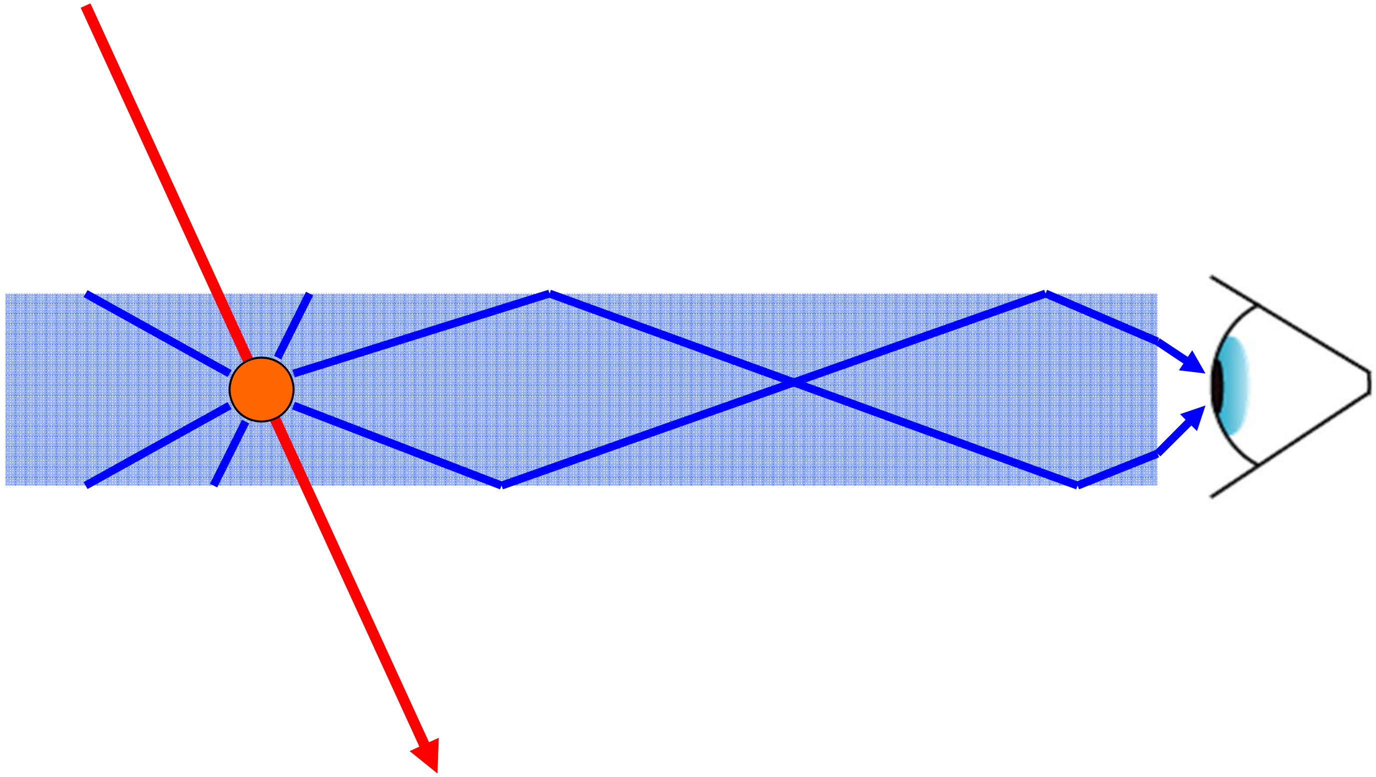
The STAR Time Projection Chamber



Yet a Third Modern Workhorse Nuclear and Particle Physics Detector

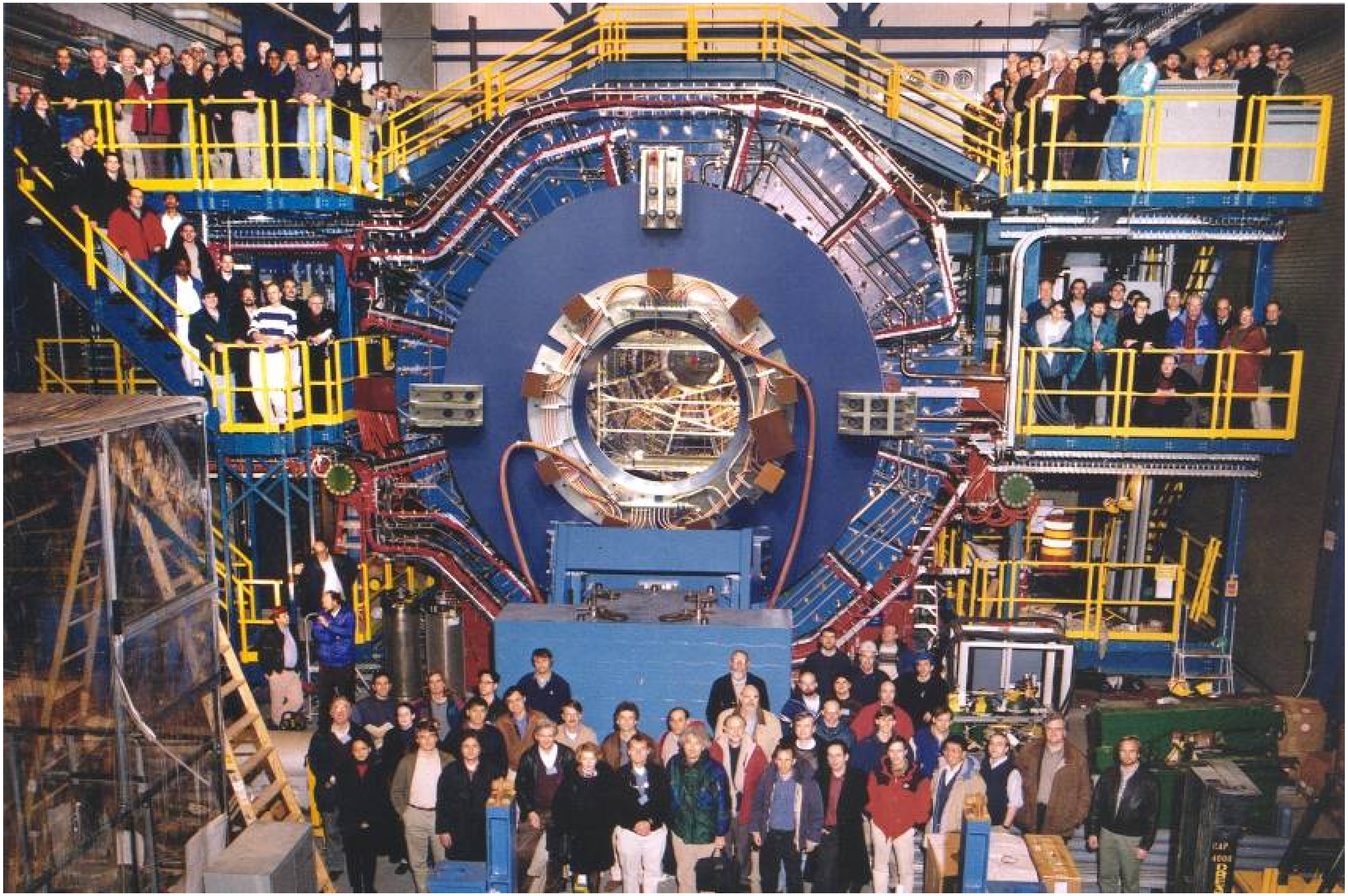
"Scintillation" and Cherenkov detectors. Emit a flash of light when an energetic charged particle passes through.

Scintillator and Cherenkov Detectors

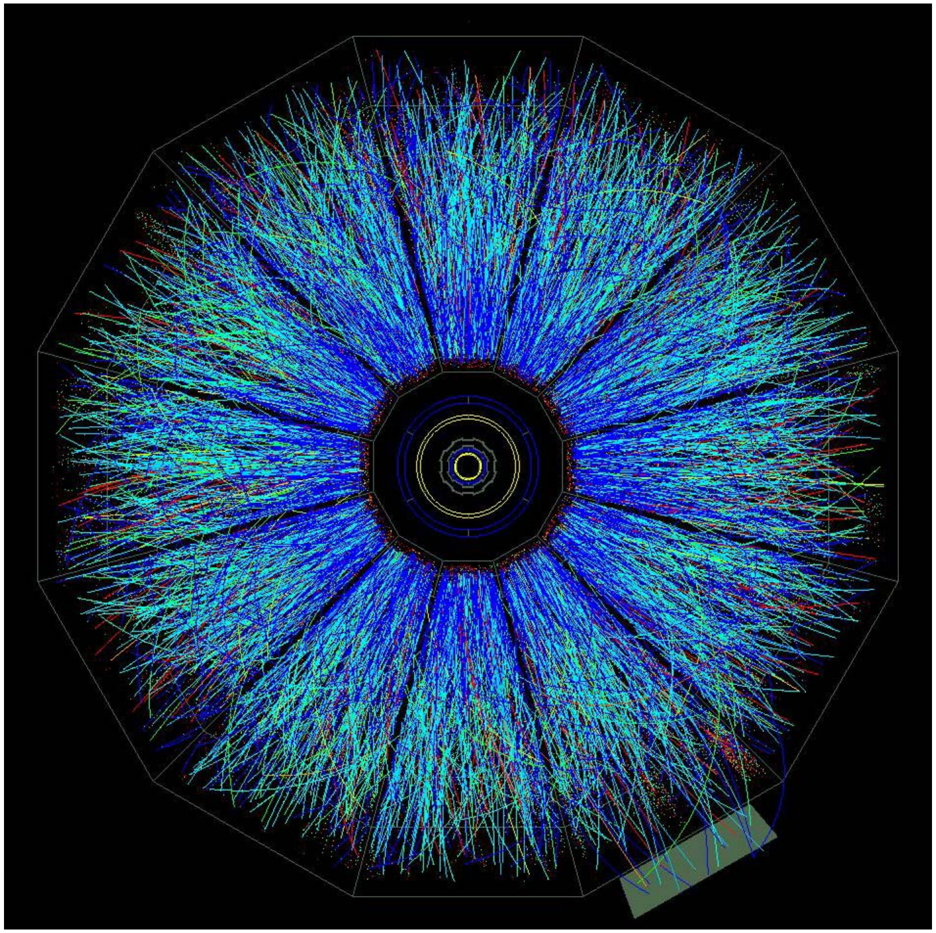


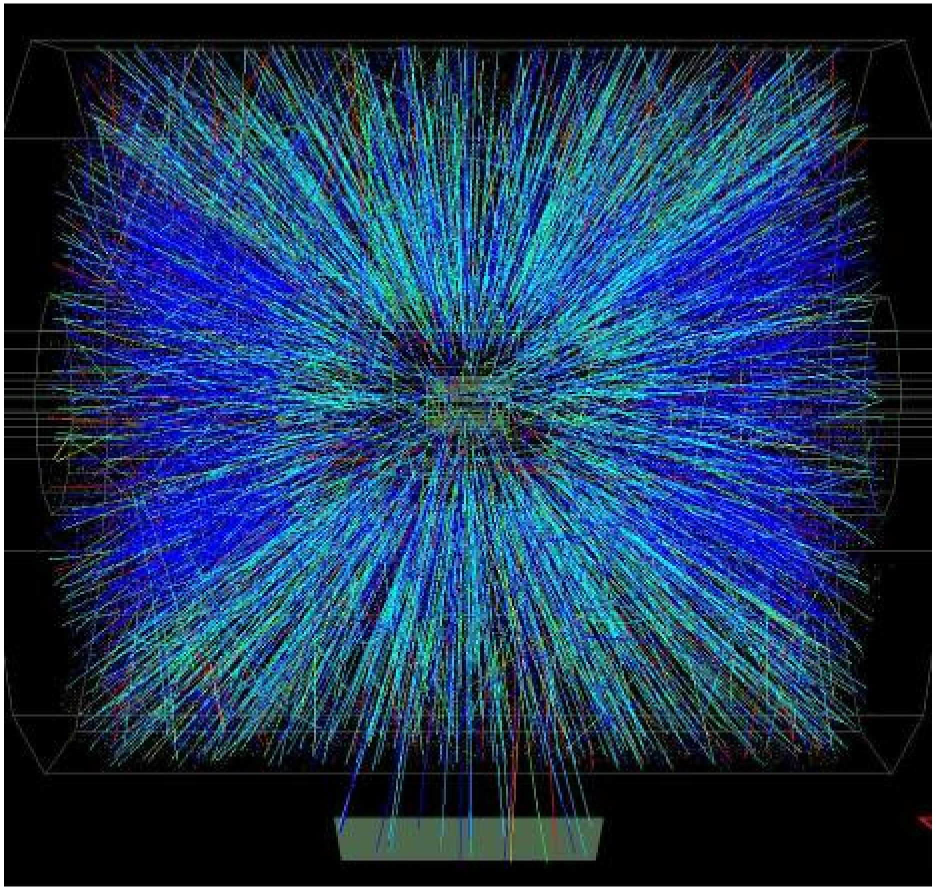
Can have very fast response (few x 10^{-9} sec).
Therefore, often used for “triggering”.

STAR: the **S**olenoidal **T**racker **A**t **R**HIC



STAR Event from a Au+Au Collision

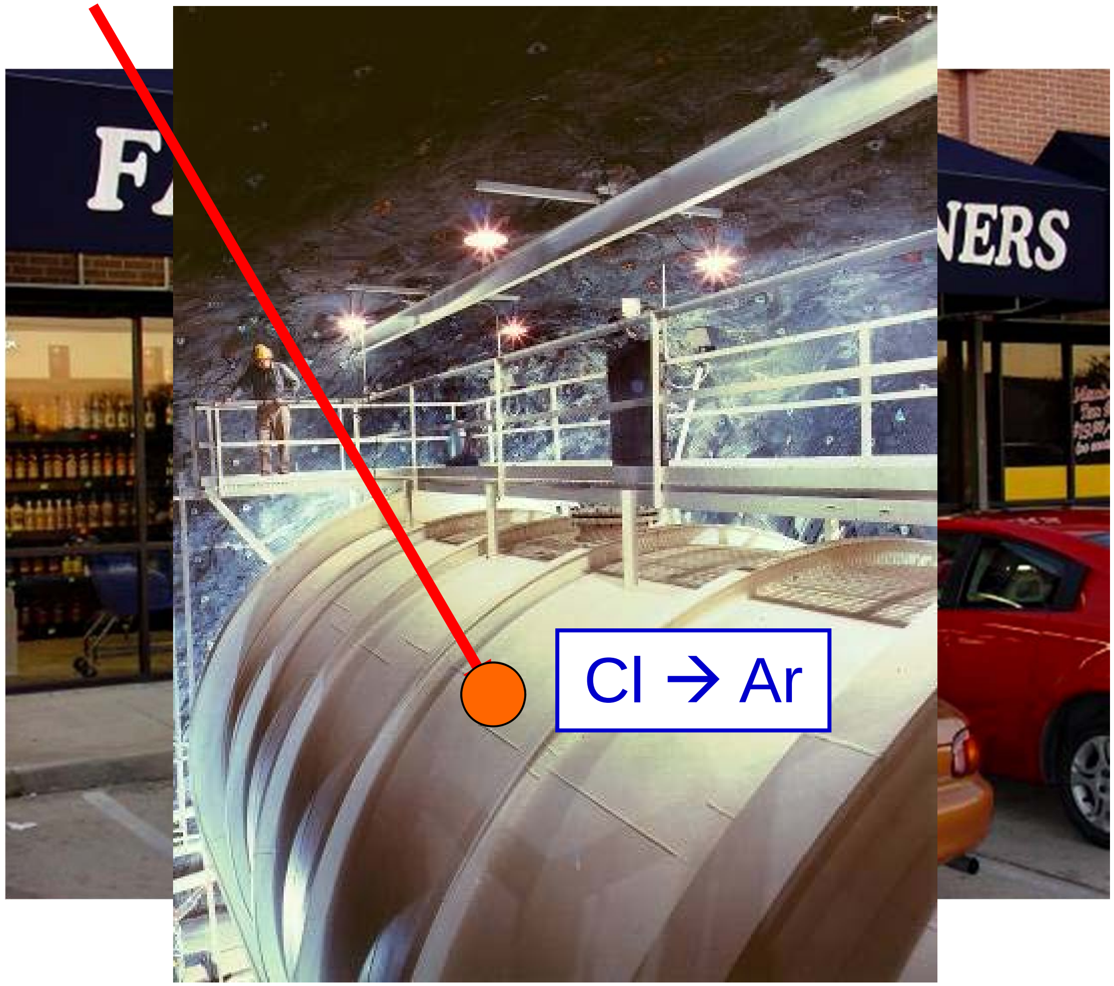




Solar Neutrino Detectors

- Not all modern nuclear and particle physics detectors are based at accelerators.
- 2002 Nobel Prize in Physics was awarded for pioneering measurements of the neutrinos that are emitted from the sun.
- Neutrinos are **really hard** to detect!
- **Very large** detectors → use “common” materials

Homestake Mine Solar Neutrino Experiment

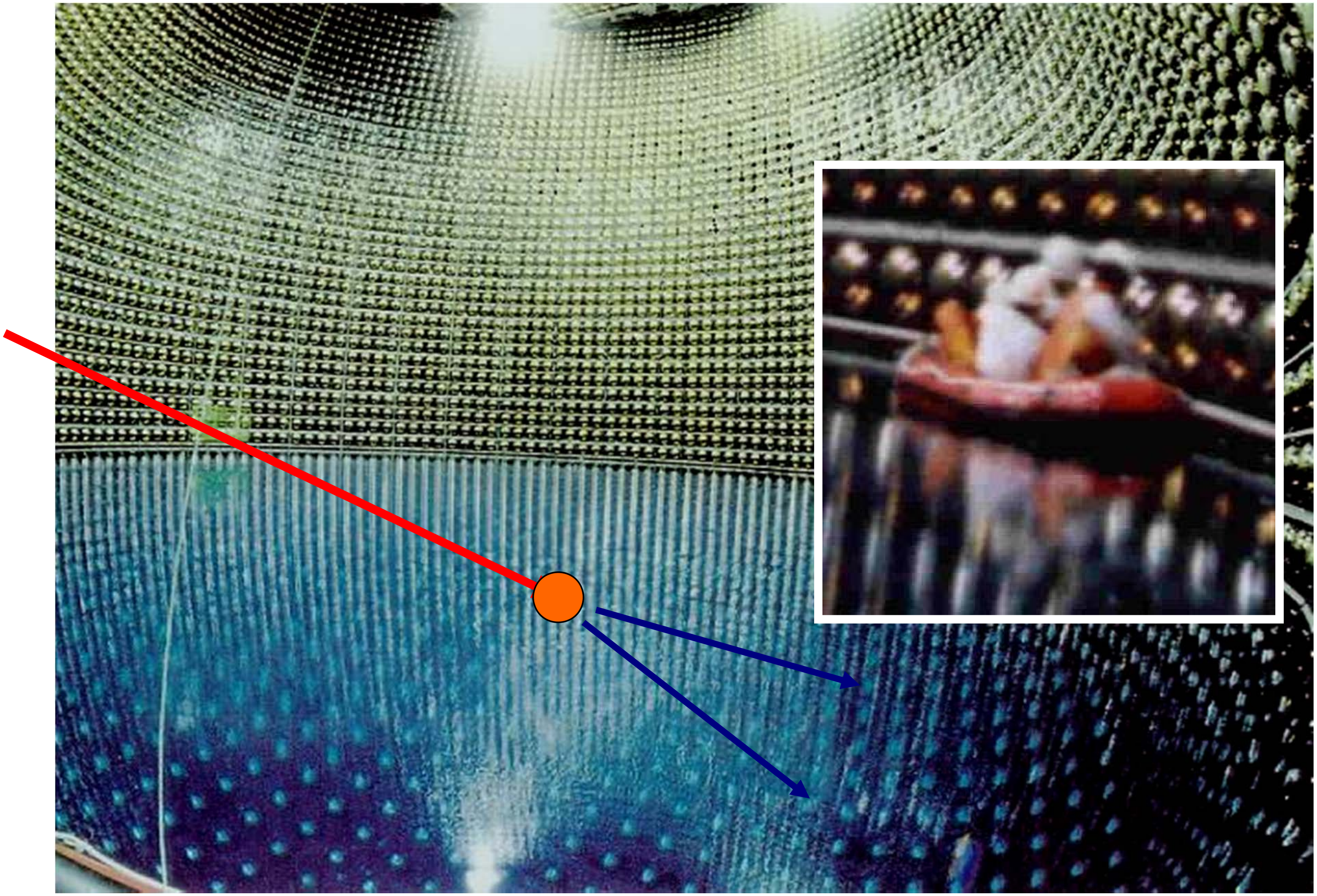


-- 100,000 gallons of dry cleaning solution, a mile underground
-- Detect less than 10 (!!!) individual Ar atoms per month

Kamioka, Super-K, and SNO Experiments

Large water tanks, deep underground, used as Cherenkov detectors

Super-K Neutrino Detector



In spite of our modern technologies, there are some things we will **never** detect!

What did I do wrong this time ?????

But We Are Doing Pretty Well!