Engaging the public in Science with Particle Detectors

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Particles in the wild

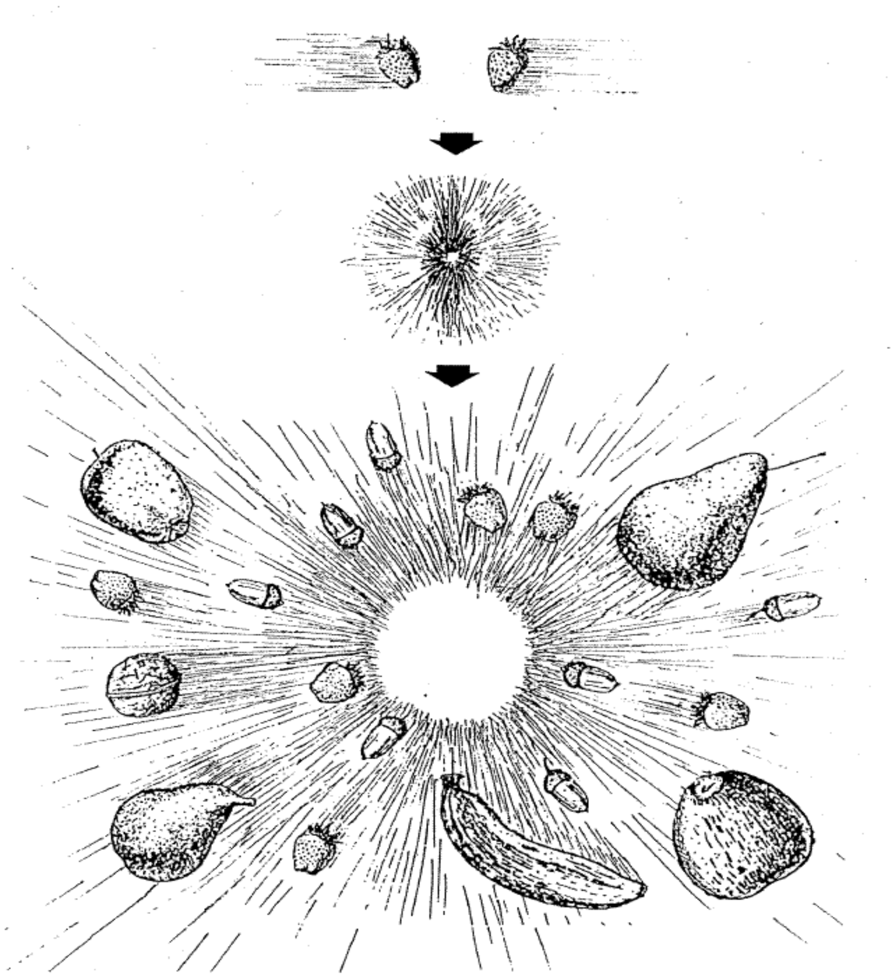
- Accelerators — Particles in captivity
- Radioactivity
- Cosmic rays

} Particles in the wild

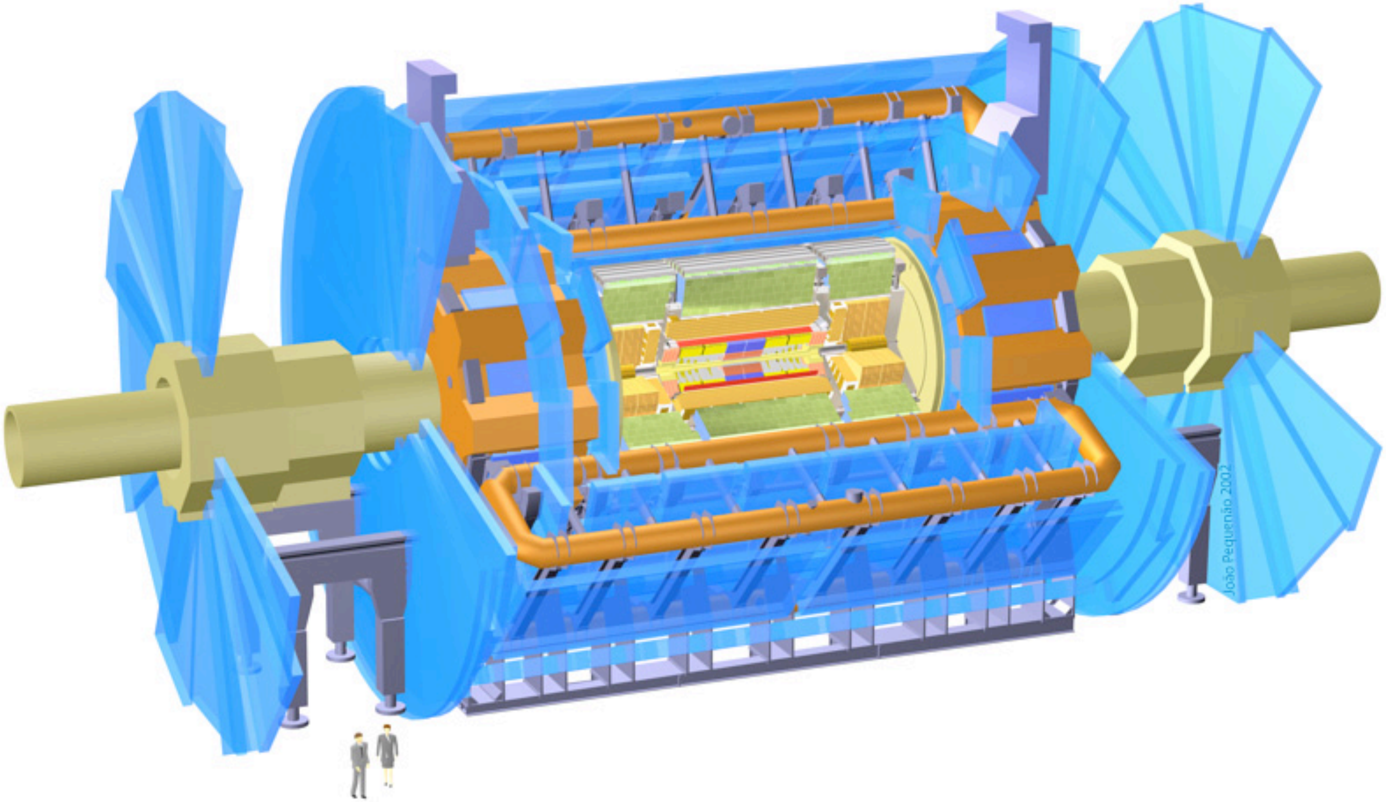
$E=mc^2$ Energy ⟷ Matter

New particles are produced

New particles are produced!



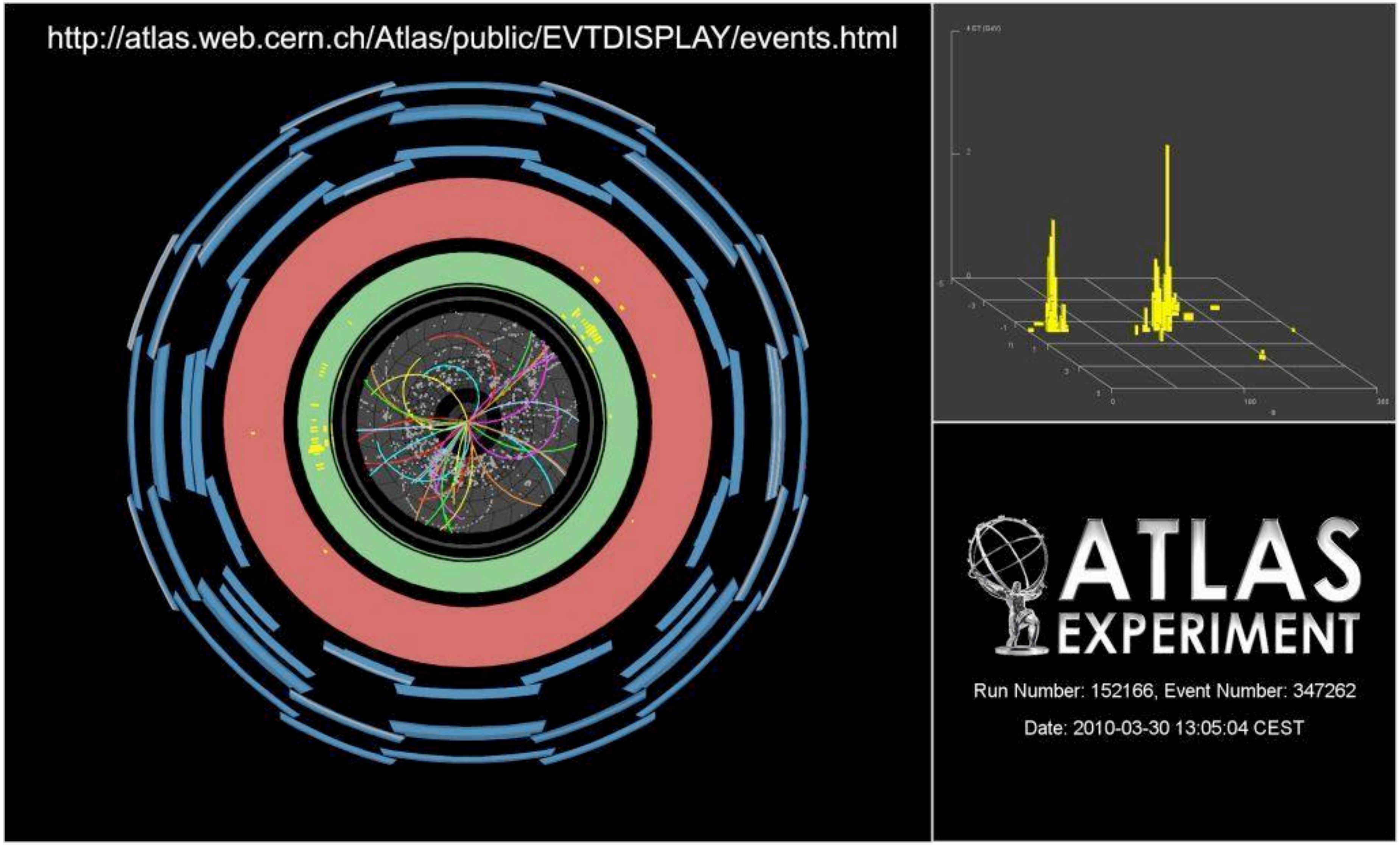
ATLAS experiment at the LHC



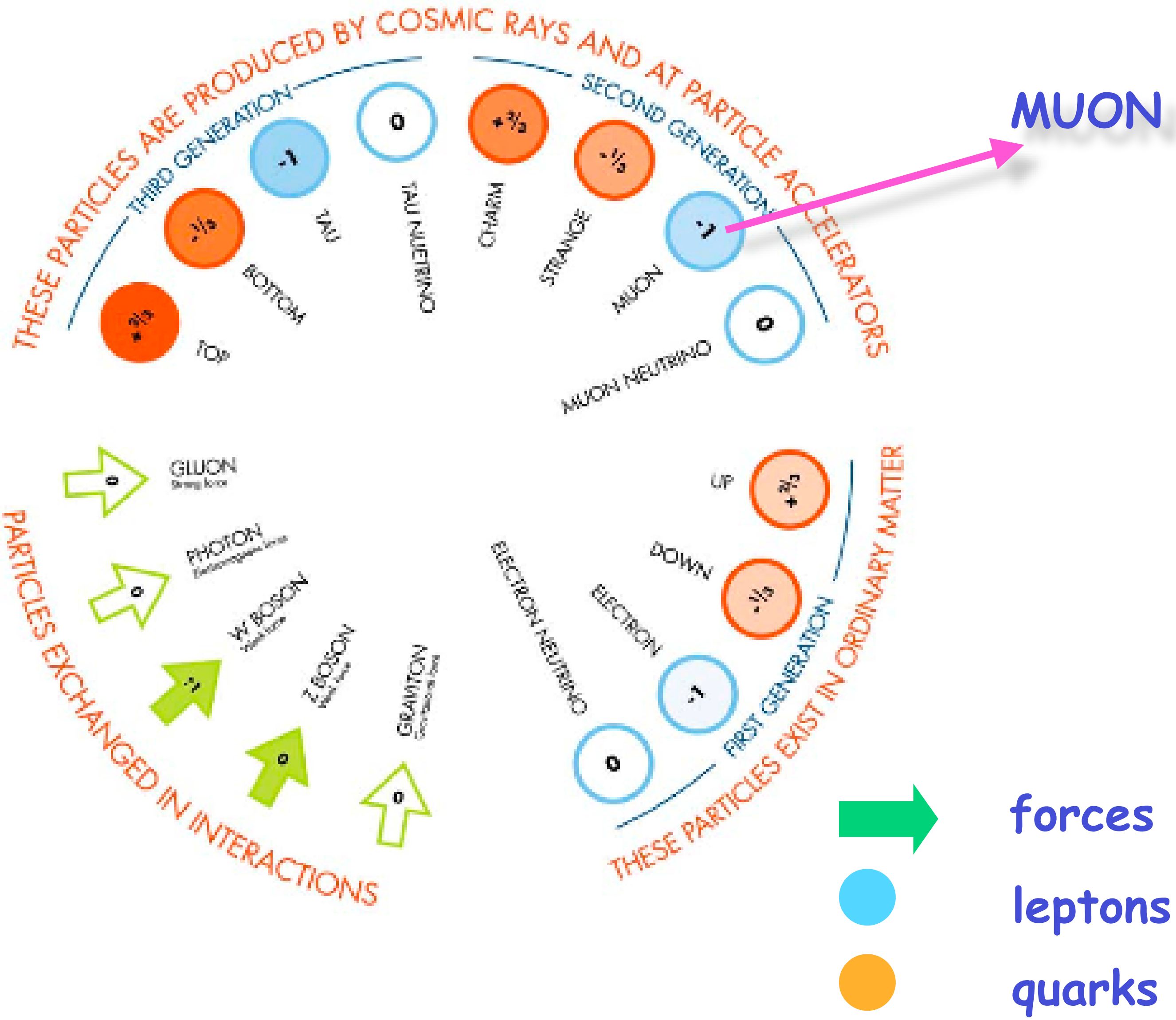
- Proton + proton collisions
- 14×10^{12} eV – world's highest energy facility

A charged particle (q Coulombs) dropping through a potential, V Volts, acquires energy E=qV (1 Volt gives energy of 1eV).

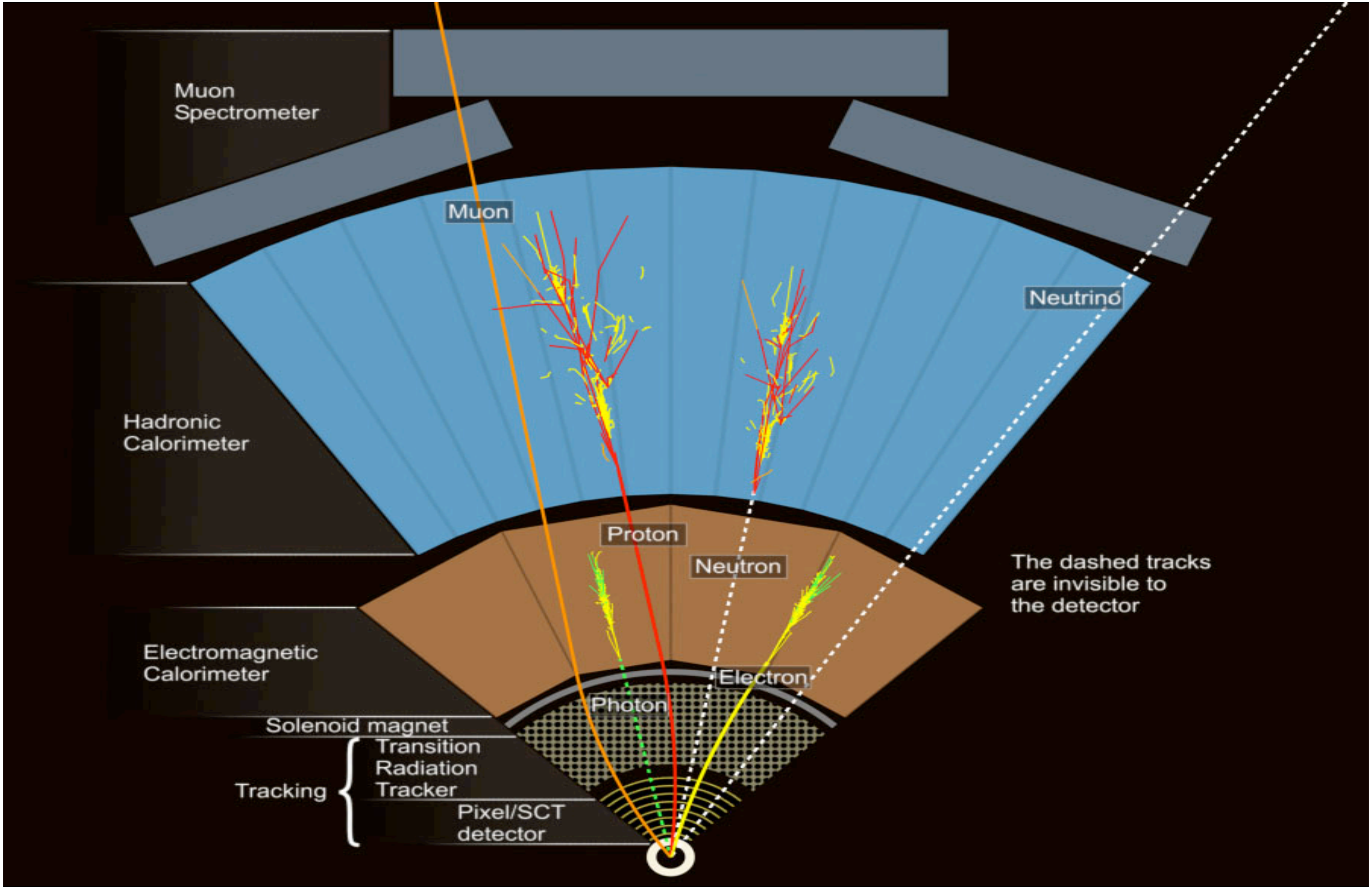
A big digital camera…



Particle wheel



Particle detection

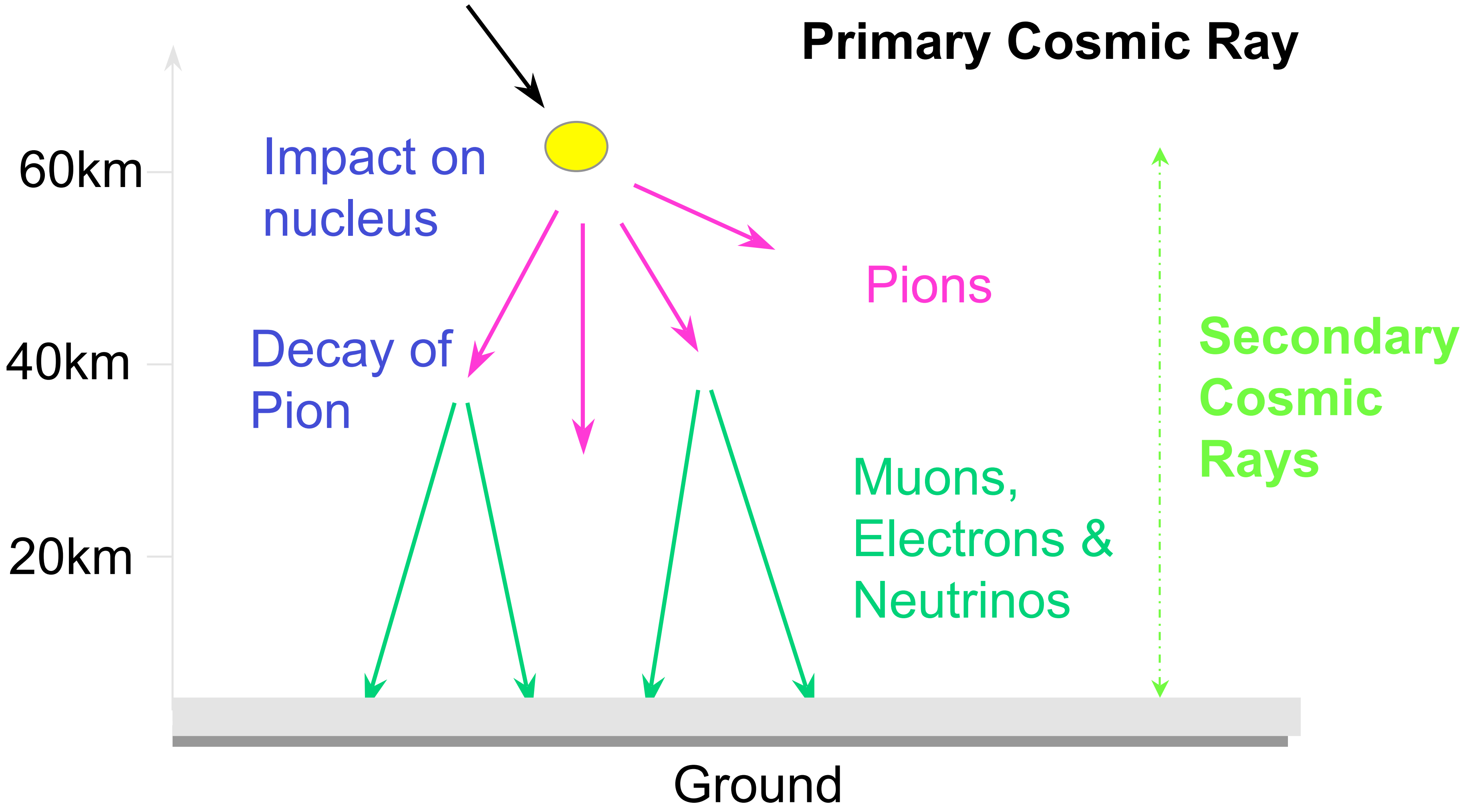


Particles in the wild

- Primary high energy cosmic ray in upper atmosphere (mainly protons from supernovae).
- Collision with nucleus
- Initiates "cascade"
  - Secondary cosmic rays
  - Higher energy primary
    - ⇒ larger secondary shower
- Charged particles at Earth's surface are mainly <u>muons</u>.

A Cosmic Shower

Understood in 1911-1912 as "radiation of very high penetrating power entering our atmosphere from above"



Cosmic rays

Muons:Minimum ionising particles
Hence long, straight tracks
200 times more massive than electron

Sea level: 150 muons/sec
per 1 square metre

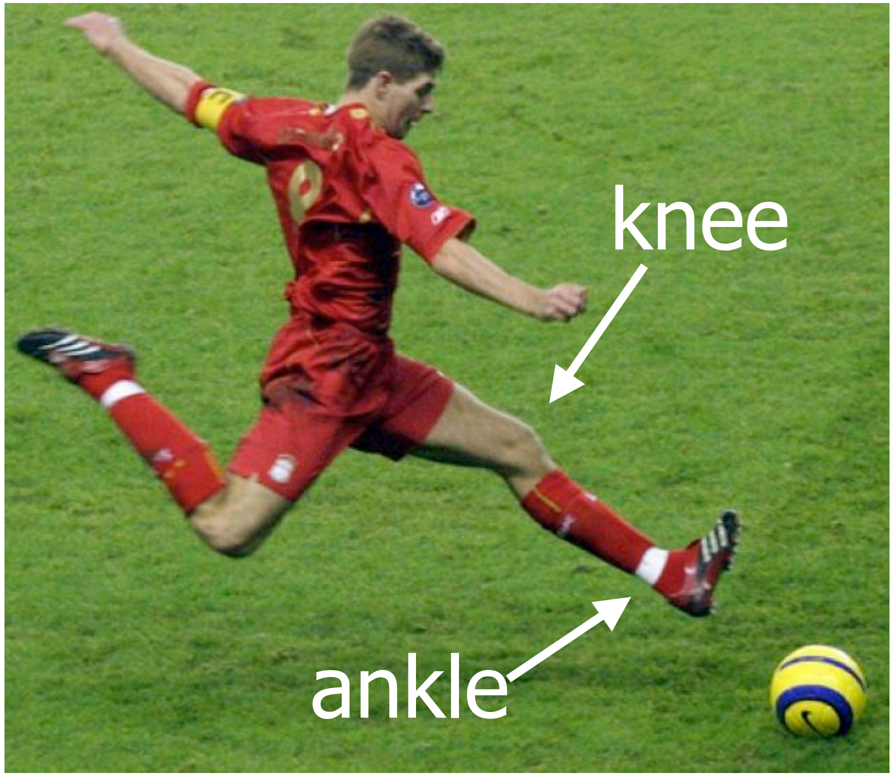
The field of Particle Physics originated in
cosmic ray research

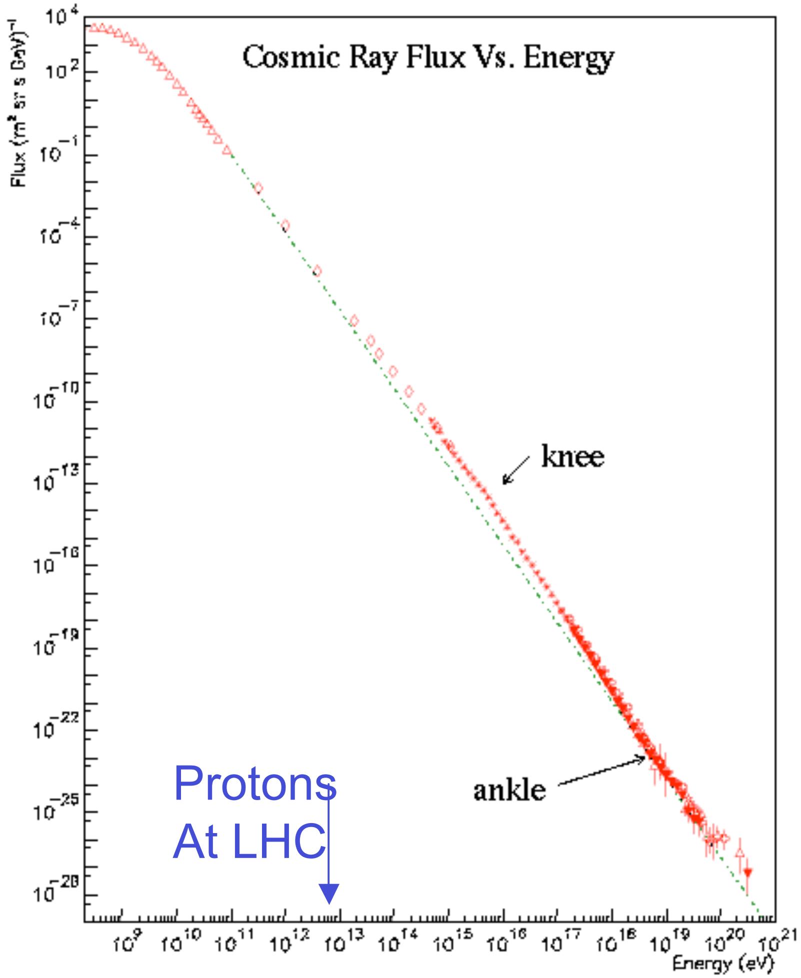
Muon, pion, positron, kaon, Lambda
all discovered in cosmic rays

- Cosmic rays: Proof of special relativity !

Experiments: cosmic rays

Above 10^{20}, 1 per km^2 per millennium
Below knee: within Milky Way Galaxy.
Above knee: must be extra galactic





Spark jumps between two charged objects

Ionization !

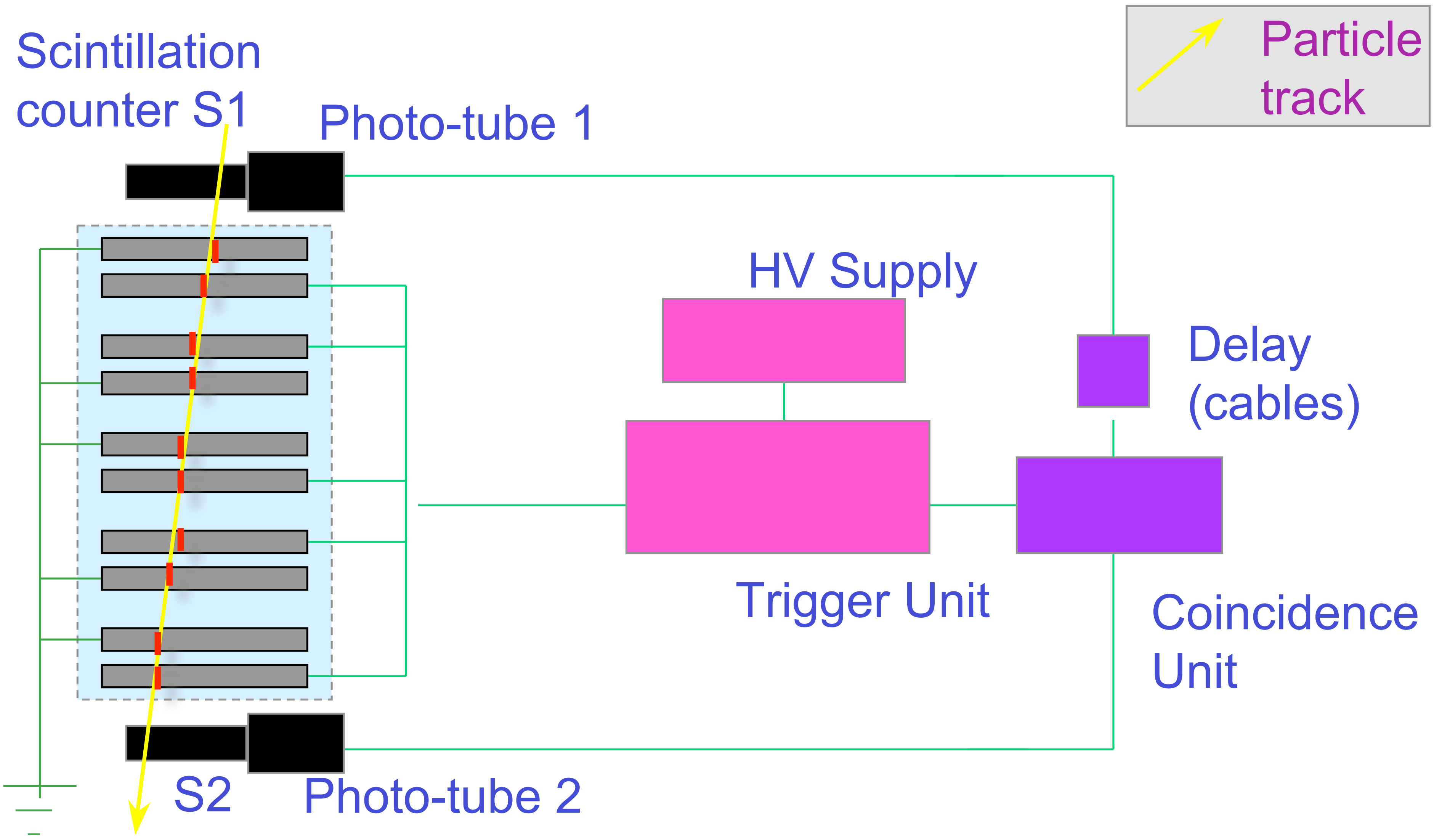
Ionization

When a high-energy charged particle crosses a material, it may transfer energy to the electrons in the material's atoms

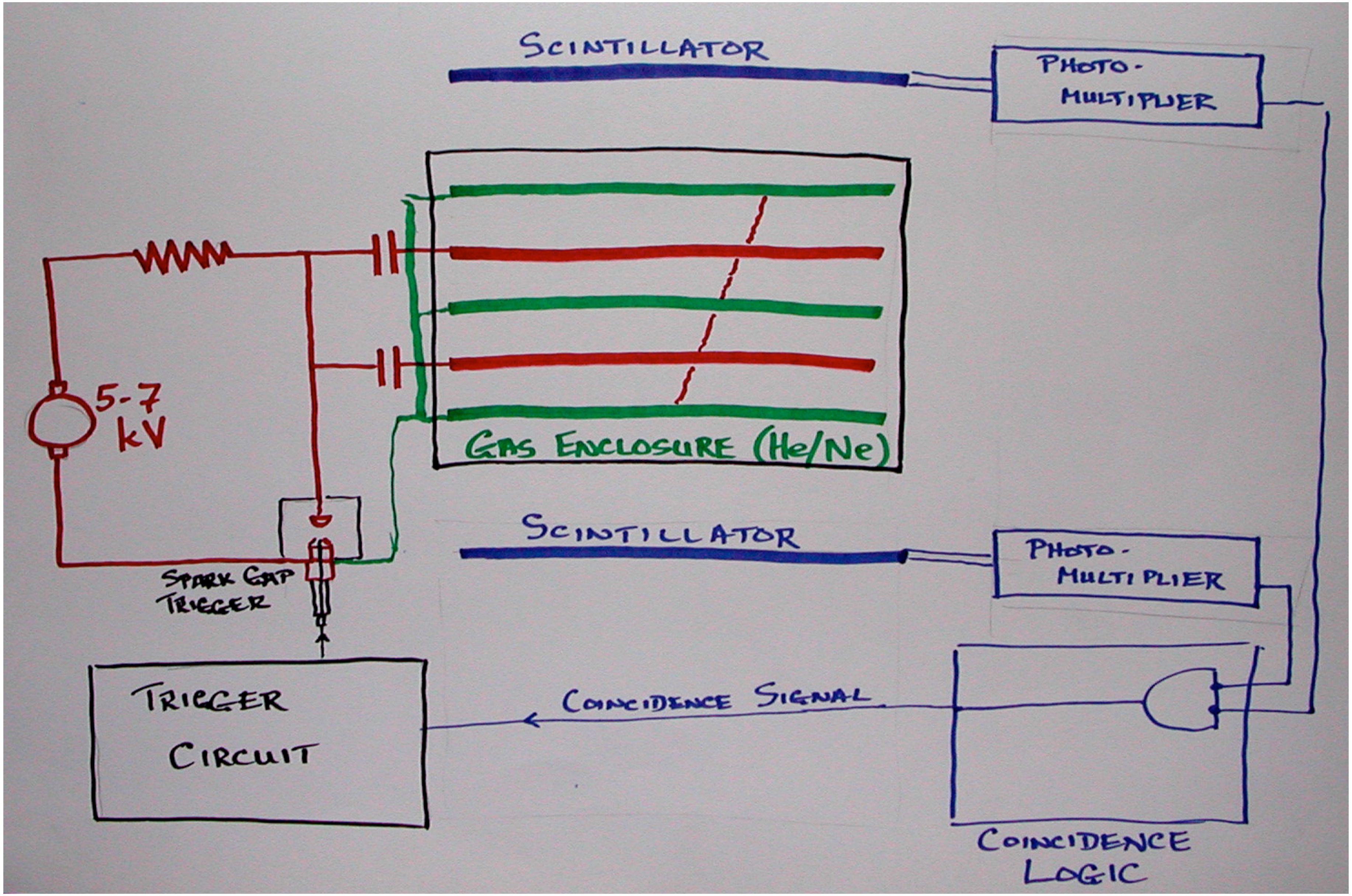
This results in ionization if an electron gains enough energy to escape from its orbit, leaving behind a positively charged ion

In presence of a large electric field, a current flow is created along the path of lowest electrical resistance. These current flows are seen as sparks.

The Spark Chamber



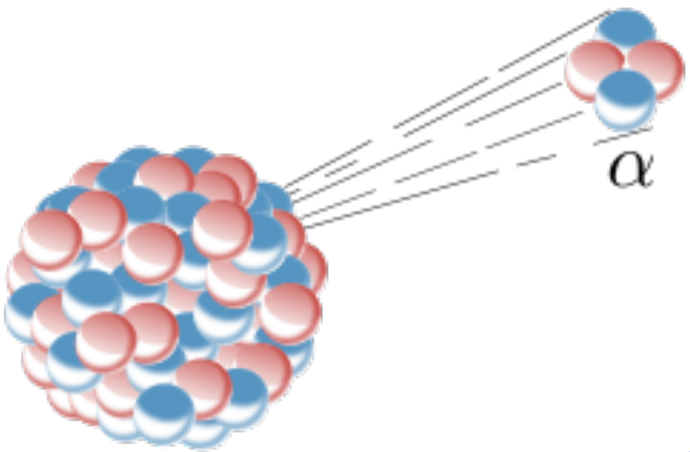
A typical detector



A small example

Alpha decay

A type of radioactive decay in which atomic nucleus emits
alpha particle: 2 protons + 2 neutrons
And transforms into an atom with mass number 4 less
and atomic number 2 less



$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

For example:

$$^{232}_{90}Th \rightarrow {}^{228}_{88}Ra + {}^{4}_{2}He$$

Alpha particles

Alpha particle typical kinetic energy of 5 MeV (speed of 0.05 c)
Relatively large mass, charge +2 and low velocity

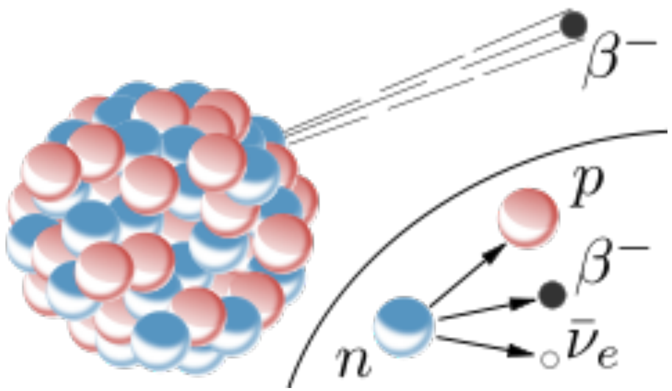
Very likely to interact with other atoms and loose energy:
stopped within a few cm of air (range)

Low penetrating power,
High ionization ability

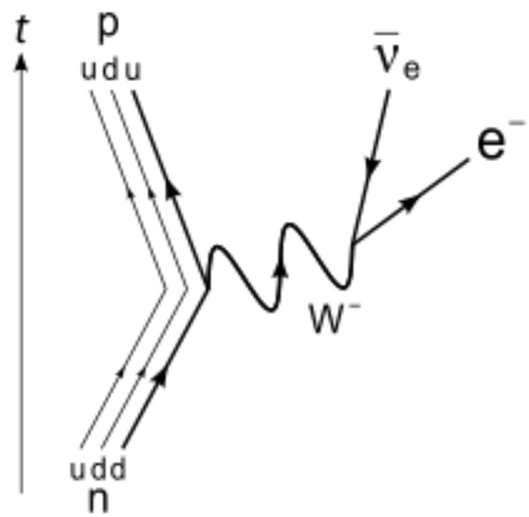
Expect short and intense track

Beta decays

A nucleus is converted into its next-higher neighbour on the periodic table
While emitting electron and anti-neutrino



$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^- + \bar{\nu}_e$$



For example:

$$^{40}_{19}K \rightarrow {}^{40}_{20}Ca + e^- + \bar{\nu}_e$$

Beta particles

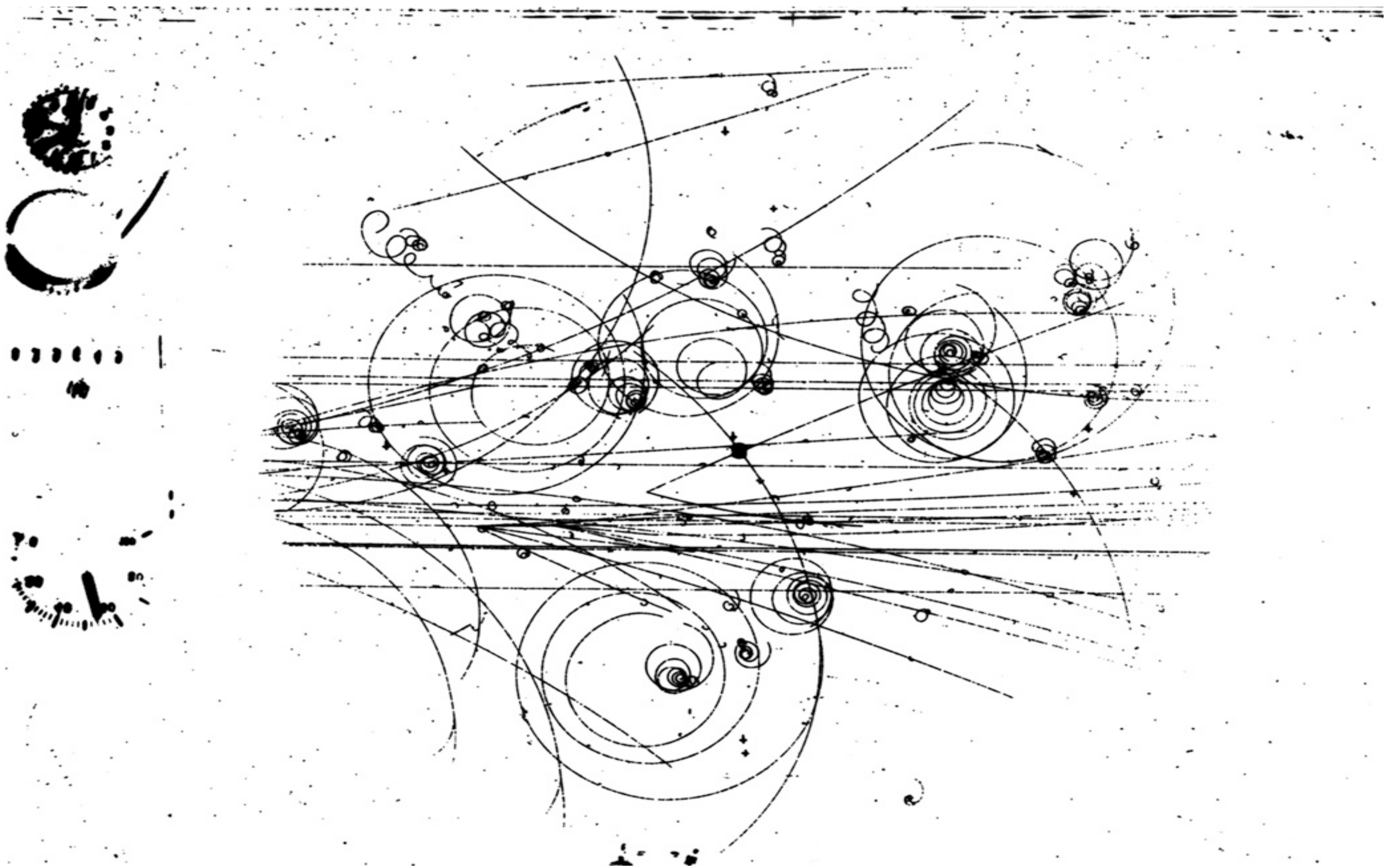
Beta particle: it's electron/positron
Small mass, charge +/-1 and generally low velocity

Small ionising ability:
Long range
Medium penetrating power

Expect long, thin track
Easy scattered, hence wiggly

Low-sodium salt contains few % of ^{40}K

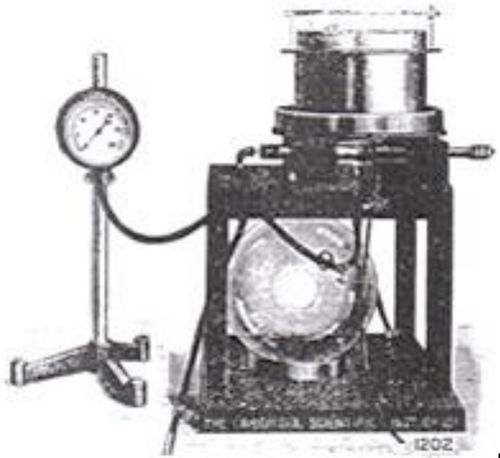
Collision-scene investigation



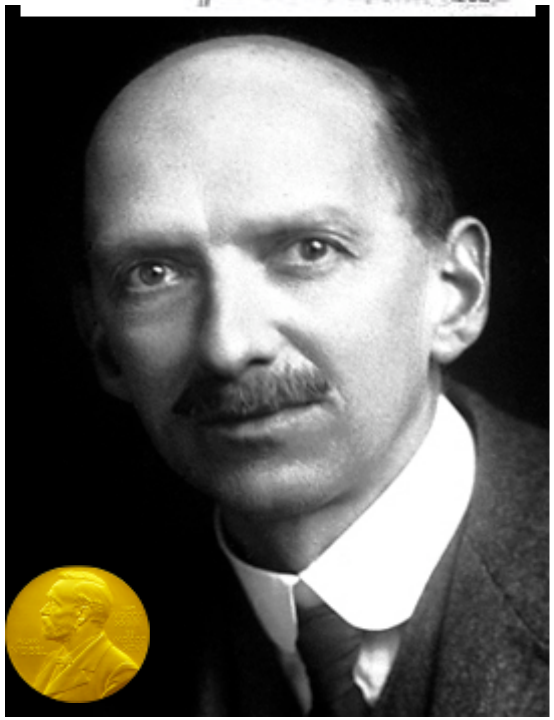
Closer to home

Something you can build: a cloud chamber !

Cloud Chambers



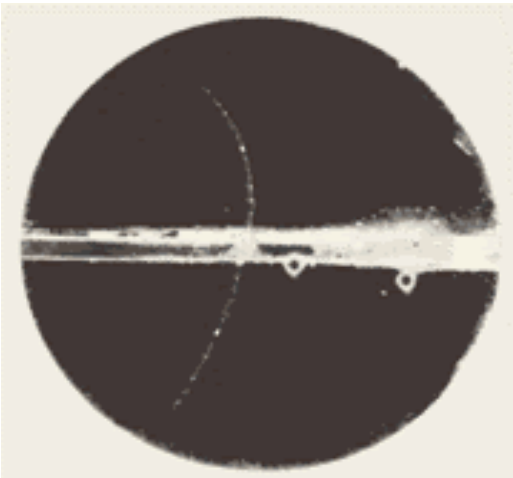
The Nobel Prize in Physics 1927 **was divided equally between Arthur Holly Compton "for his discovery of the effect named after him" and** *Charles Thomson Rees Wilson "for his method of making the paths of electrically charged particles visible by condensation of vapour".*

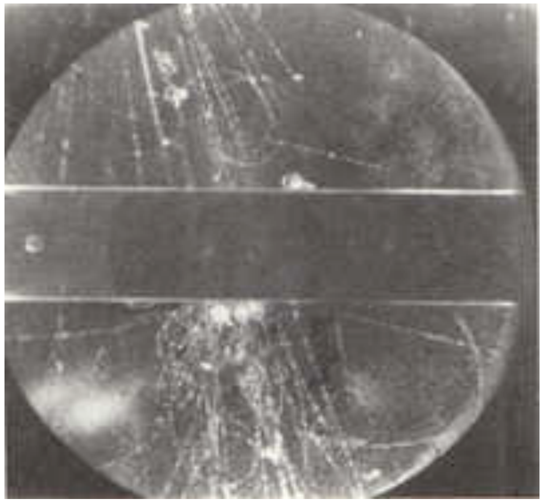


More Nobel Prizes…

The Nobel Prize in Physics 1936 was divided equally between Victor Franz Hess and Carl David Anderson "for their discovery of the positron" which they photographed in a cloud chamber.

The Nobel Prize in Physics 1948 was awarded to Patrick M.S. Blackett "for his development of the Wilson cloud chamber method, and his discoveries therewith in the fields of nuclear physics and cosmic radiation".





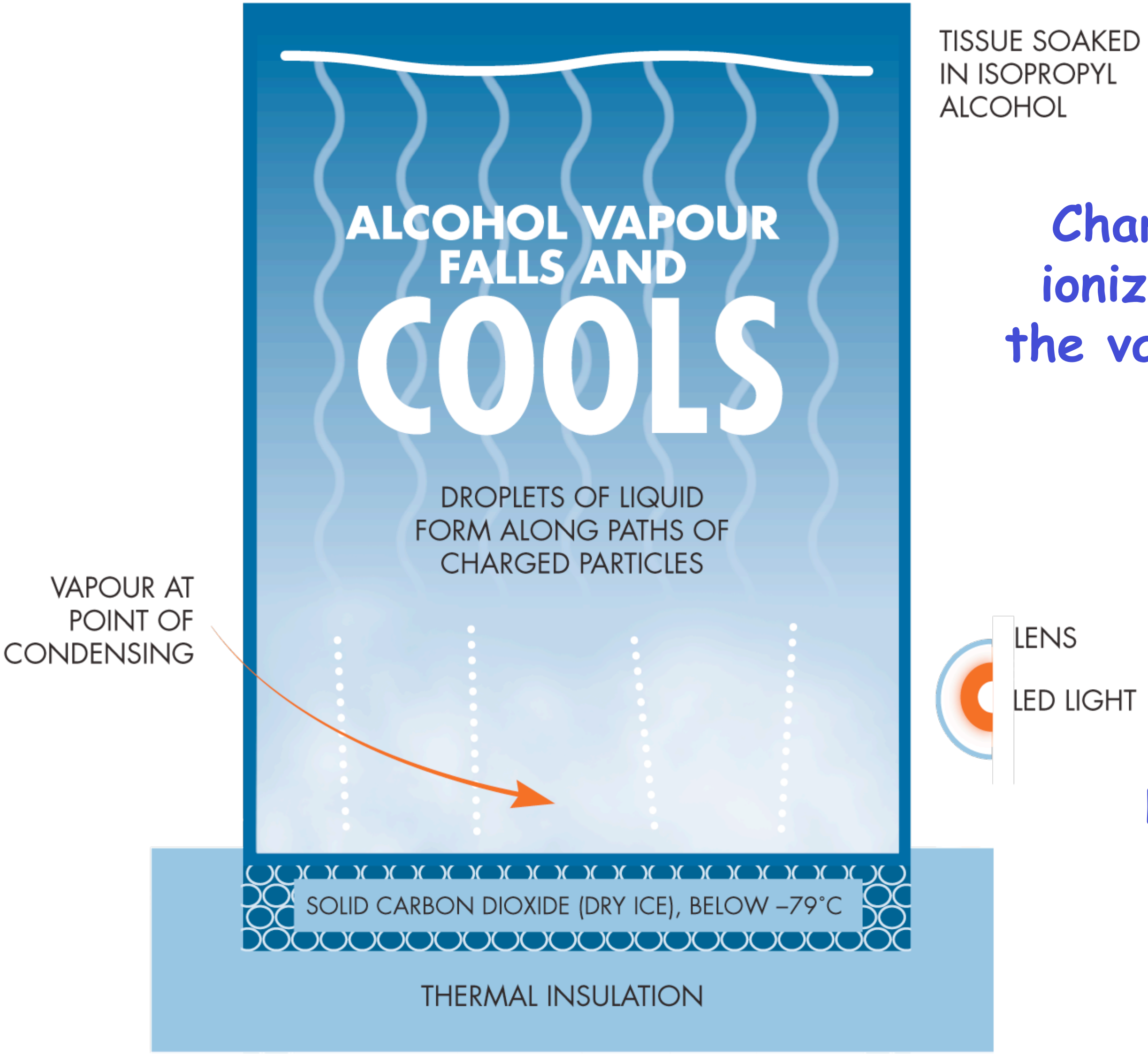
History of Cloud Chamber

Invented by Wilson in 1911 to study cloud formation and optical phenomena in moist air. Very rapidly he discovered that ions could act as centers for water droplet formation in such chambers. Wilson cloud chamber was based on adiabatic expansion.

The diffusion cloud chamber was developed in 1939 by Alexander Langsdorf. **The chamber differs from the expansion cloud chamber in that it is continuously sensitized to radiation, and in that the bottom must be cooled to a rather low temperature, generally as cold as or colder than dry ice.**

The **bubble chamber** was invented by **Donald A.Glaser** in 1952. Trails of bubbles in a superheated liquid, usually **liquid hydrogen.** Filled with much-denser liquid material, hence can reveal the tracks of much more energetic particles.

The cloud chamber

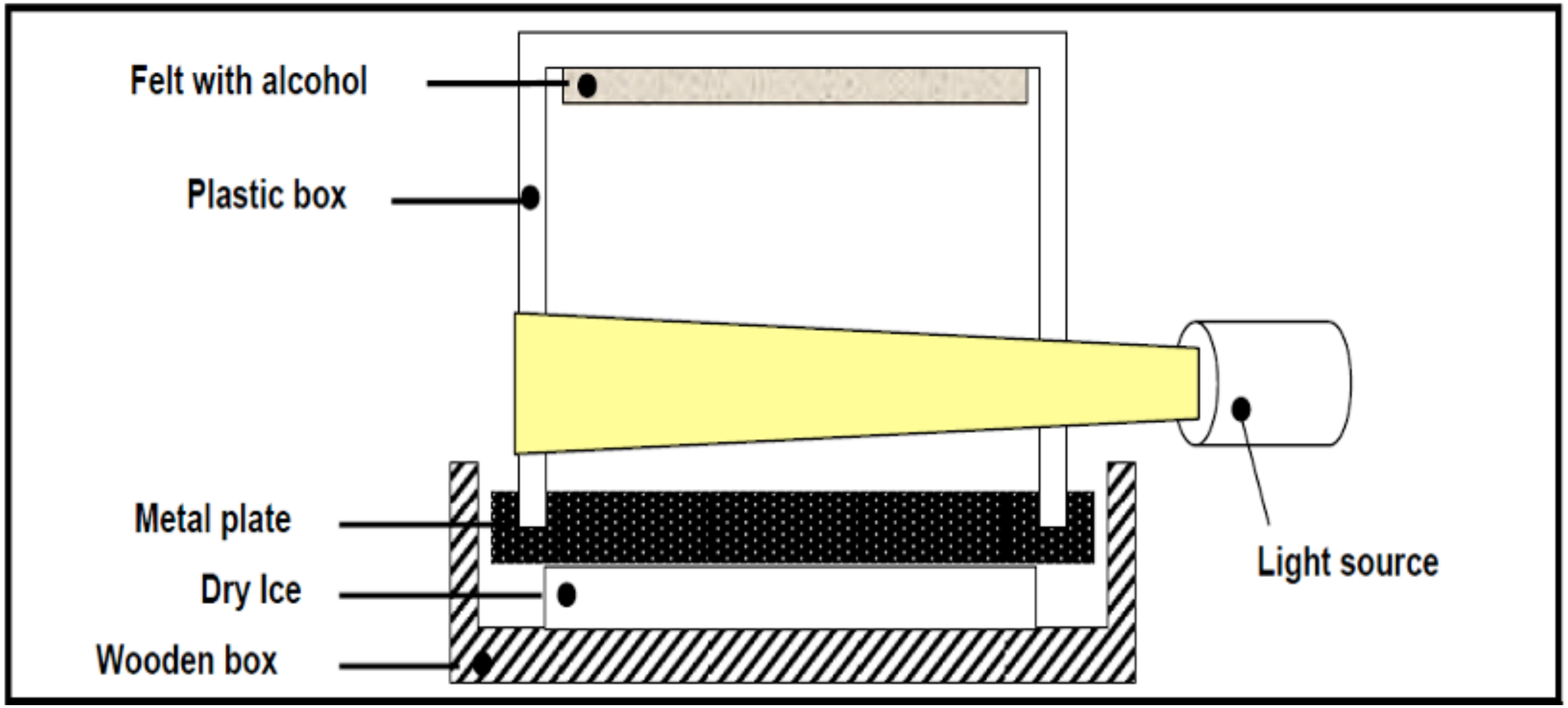


Charged particle causes ionization along its path: the vapour condenses about the ions !

Discovery of positron in 1932

Discovery of kaon in 1953

Making a Cloud Chamber



http://epweb2.ph.bham.ac.uk/user/lazzeroni/outreach/cloud-chamber/

Making a Cloud Chamber

1. Cut a 2 cm wide length of felt about 1m long.
2. Stick to the "bottom" of the plastic fish tank.
3. Cut the lid of the fish tank.
4. Put tape along the slots left in the lid.
5. Tape the baking tray to the lid.

A fish tank
A baking tray

Scissors
Knife
Snips
Tape
Metre stick

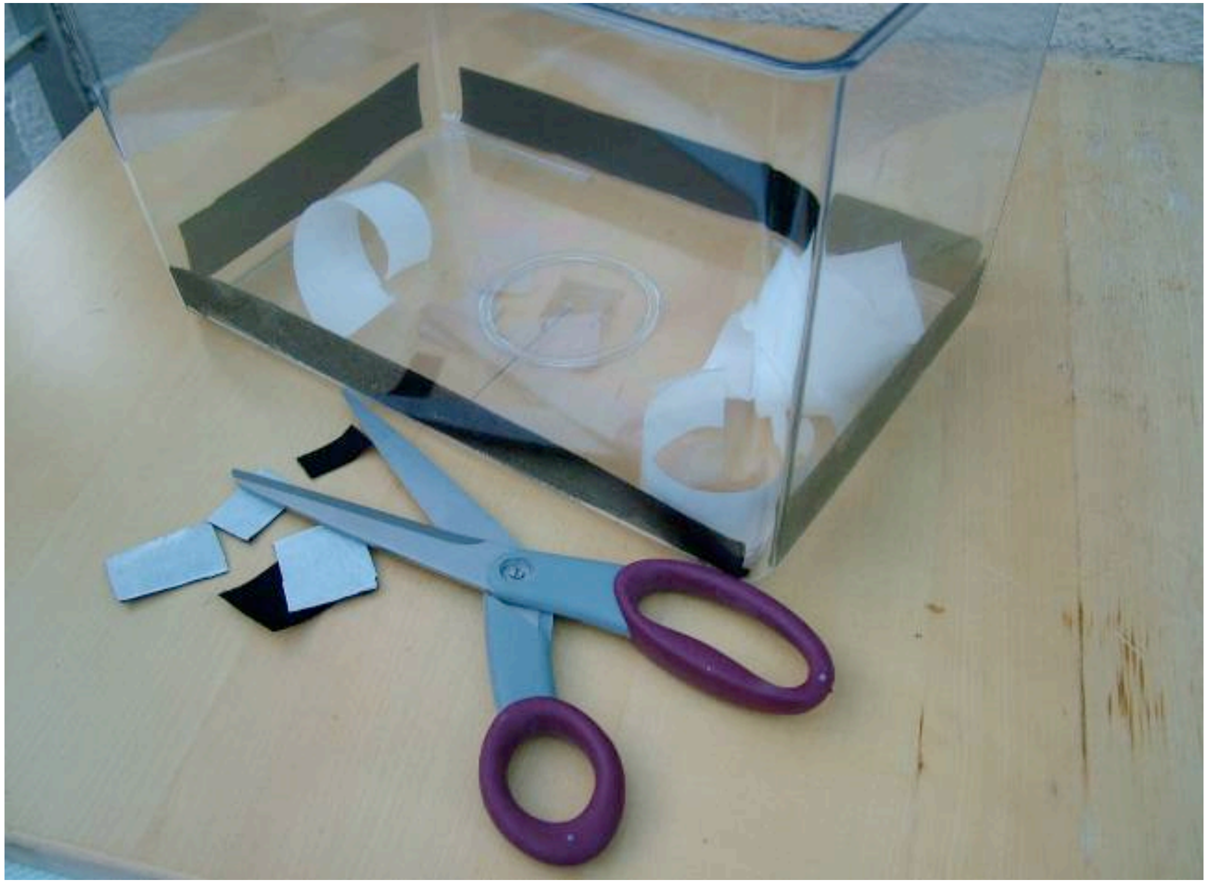
Roll of felt
A marker pen
Hot water bottle

Stick felt around the "bottom" of the fish tank

Mark two 2.5 cm wide bands the width of the roll of felt and cut them off.

Then cut these two strips so that you have pieces that fit the ends and sides of the tank.

Peel the backing off the felt and stick it in place in the “bottom” of the fish tank.



Cut out the central part of the "lid"

You should end up with something like this:

Cover the slits along the sides with tape:

Stick the lid to the baking tray with more tape:

Put it all together:

Dry ice Solid carbon dioxide. Subliming at -78.4°C

Isopropyl alcohol

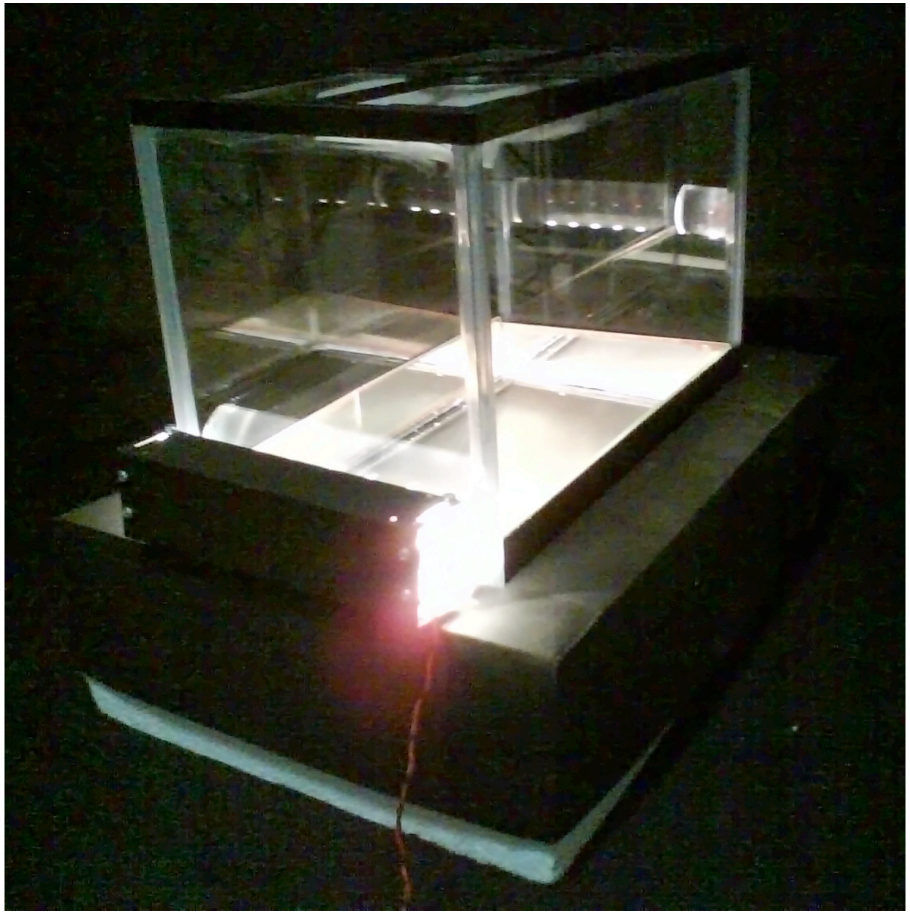
Particle sources

For these, you need help from people from Jammu University !

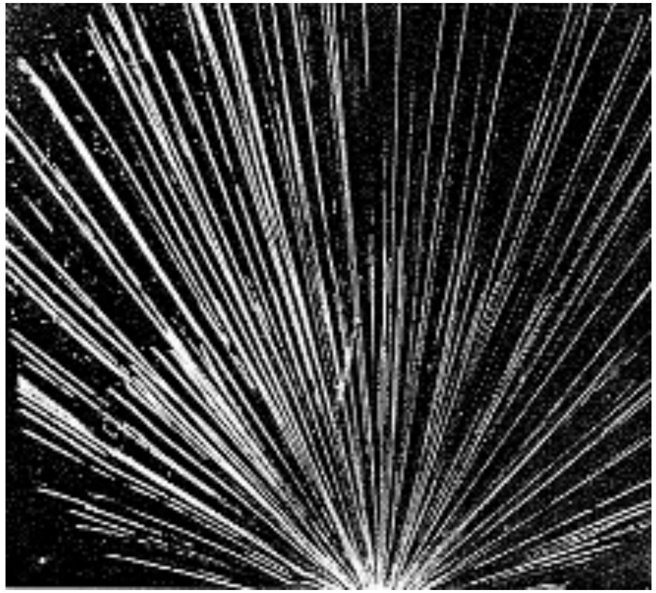
Using the Cloud Chamber

- 1. Soak the felt in the chamber with Isopropyl alcohol.
- 2. Get blu tac and a source and put them at one end of the cloud chamber. Use the blu tac to have the source about 5mm above the base.
- 3. Put dry ice in a tray. (With gloves)
- 4. Put the cloud chamber on the dry ice.
- 5. Put hot water bottle on top.
- 6. Arrange the lighting so trails will be lit from the side.

The Chamber at Birmingham

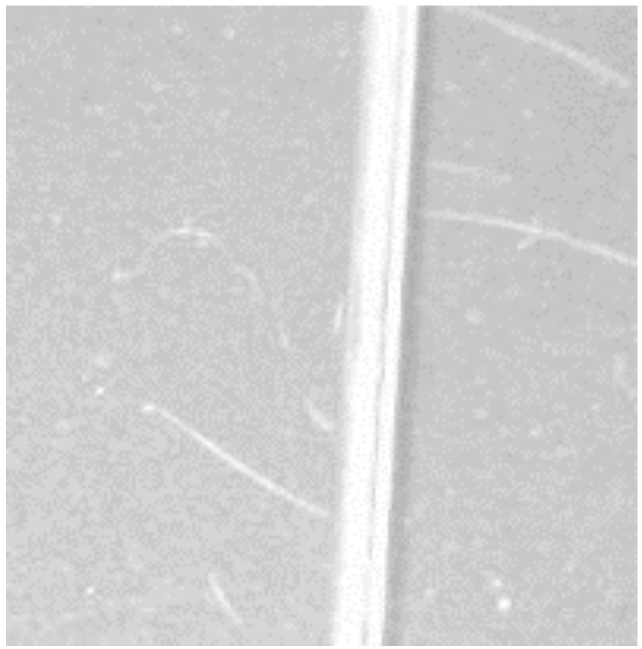


What do you see?



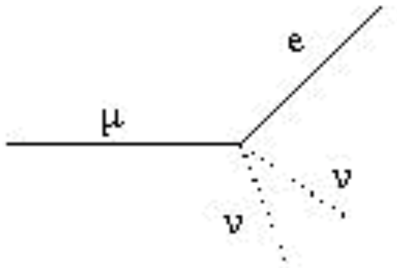
Mostly alpha

The tracks from beta are much fainter; low-energy beta emissions produce very irregular tracks.

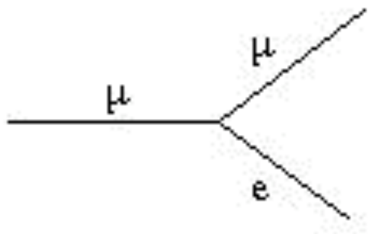


Another way to identify beta tracks is to take a number of photographs at 1 second intervals with a digital camera and flash, say 10 or so, and then download the images to a computer. Zoom in on the photographs and with luck you may be able to pick out some images that show beta tracks. The contrast may be better if the pictures are changed to greyscale.

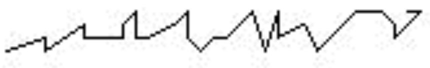
Other "things"



A straight track that sharply "kinks" off to the left or right. This is a decay of a muon particle. The two dashed lines are particle called neutrinos that your chamber is not able to detect.



Three tracks that meet at a single point. In these events, one track is an incoming cosmic ray, a particle called muon. This particle hits an atomic electron. The electron and the outgoing cosmic track are the two other tracks.



A very windy, chaotic track. This is "multiple scattering", as a low-energy cosmic ray bounces off of one atom in the air to the next.

Experiments: Cloud study

It is called cloud chamber after all……

Cosmic rays could aid the cloud formation
in the atmosphere !

Varying cosmic radiation with time
could change the Earth cloud cover

Cloud formation investigated
at CERN (CLOUD) and at Boulby Mine (SKY-ZERO)

Conclusions

"Seeing" a particle with your own eyes
is a an amazing experience

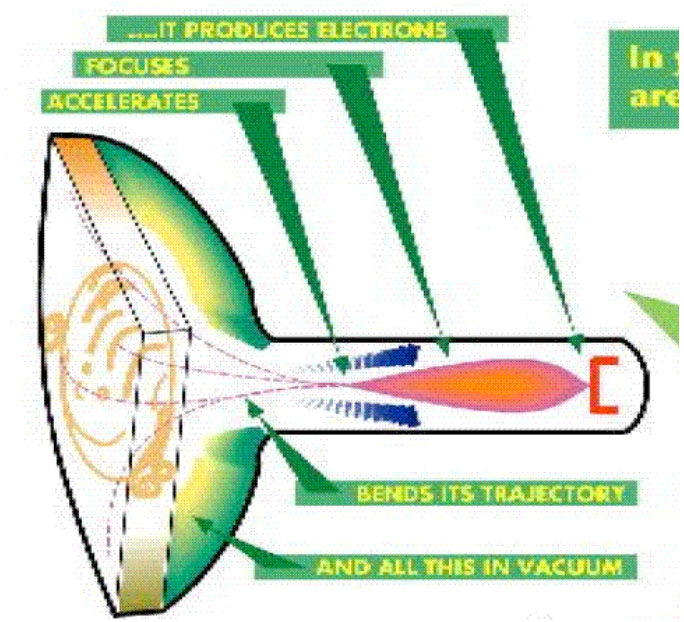
Real-science experiments can be done
with the detectors shown

Great way to start with particle
physics !

Spares

Particle Accelerators

- Basic design is just like an <u>old</u> TV
  - i.e. apply accelerating voltage
  - Magnets can be used to steer and focus the particles



- A charged particle (q Coulombs) dropping through a potential, V Volts, acquires energy E=qV (1 Volt gives energy of 1eV).
- Unlike a TV (V ~ 10,000 Volts) the LHC at CERN will accelerate particles to 14 Trillion Volts.

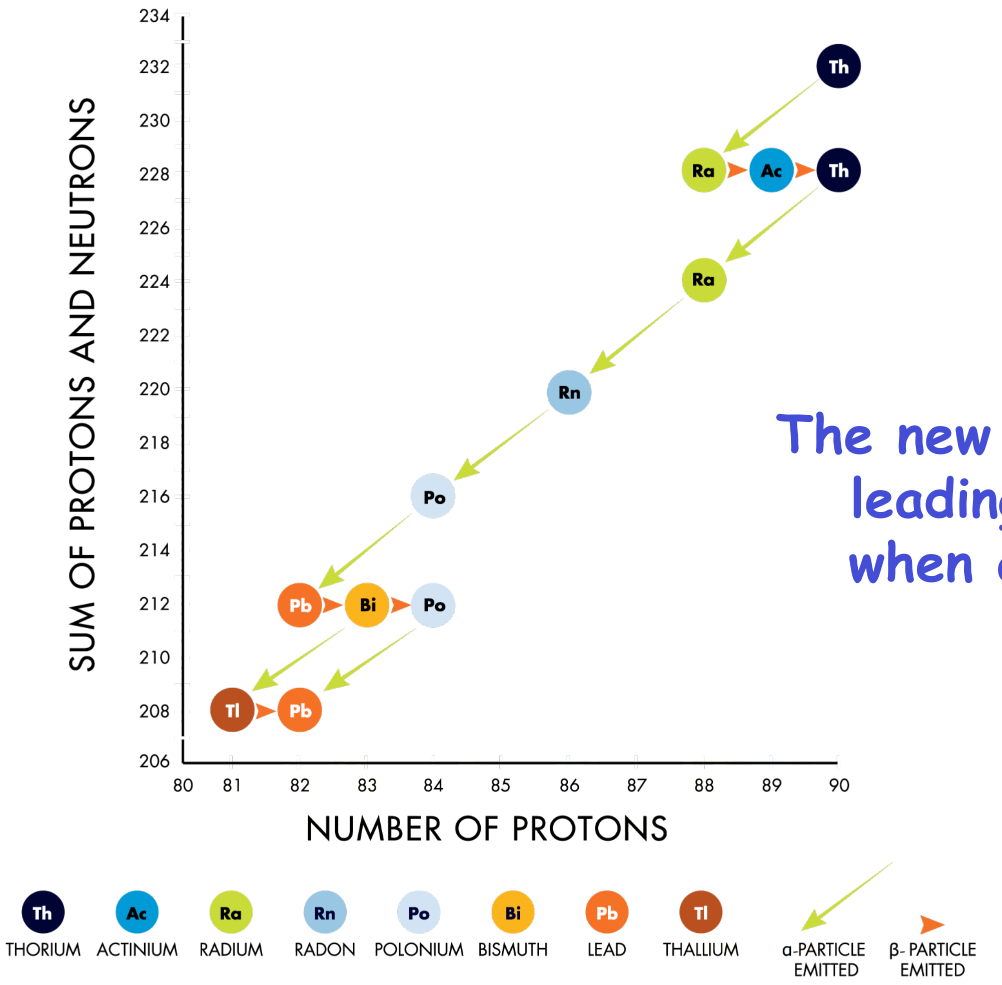
Cosmic showers measurements

- We want for example to know:
  - How many cosmic particles with an energy above 10^{16} eV reach the earth?
  - Where do they come from? Are there sources in our Milky Way?
  - Can one determine the GZK-cut-off?
  - Are there long range correlations between showers (Zatsepin-Gerasimova effect)?
  - Variation with latitude, altitude

Further research

- HiSPARC is not “only” limited to measurements of flux and sources. Lots of science to be done:
  - Shower models are not so good yet
  - Understanding the charge particle/gamma fraction
  - Understanding variations as a function of time, altitude and latitude
  - Long range correlations
  - Influences from the atmosphere
  - Some detector systems have a weather station as well: test models making predictions about thunderstorms and lightning being linked to cosmic rays

Thorium



The new atom may also be radioactive leading to decay chains that end when a stable isotope is reached

Antimatter

- Every fundamental particle has its antiparticle.
  - These have the same mass but opposite charge.

electron	e^-	e^+	positron
up quark	$u^{+2/3}$	$\bar{u}^{-2/3}$	up anti-quark

Etc.

Other School experiments

- www.youtube.com/watch?v=SmR3lqC81lg