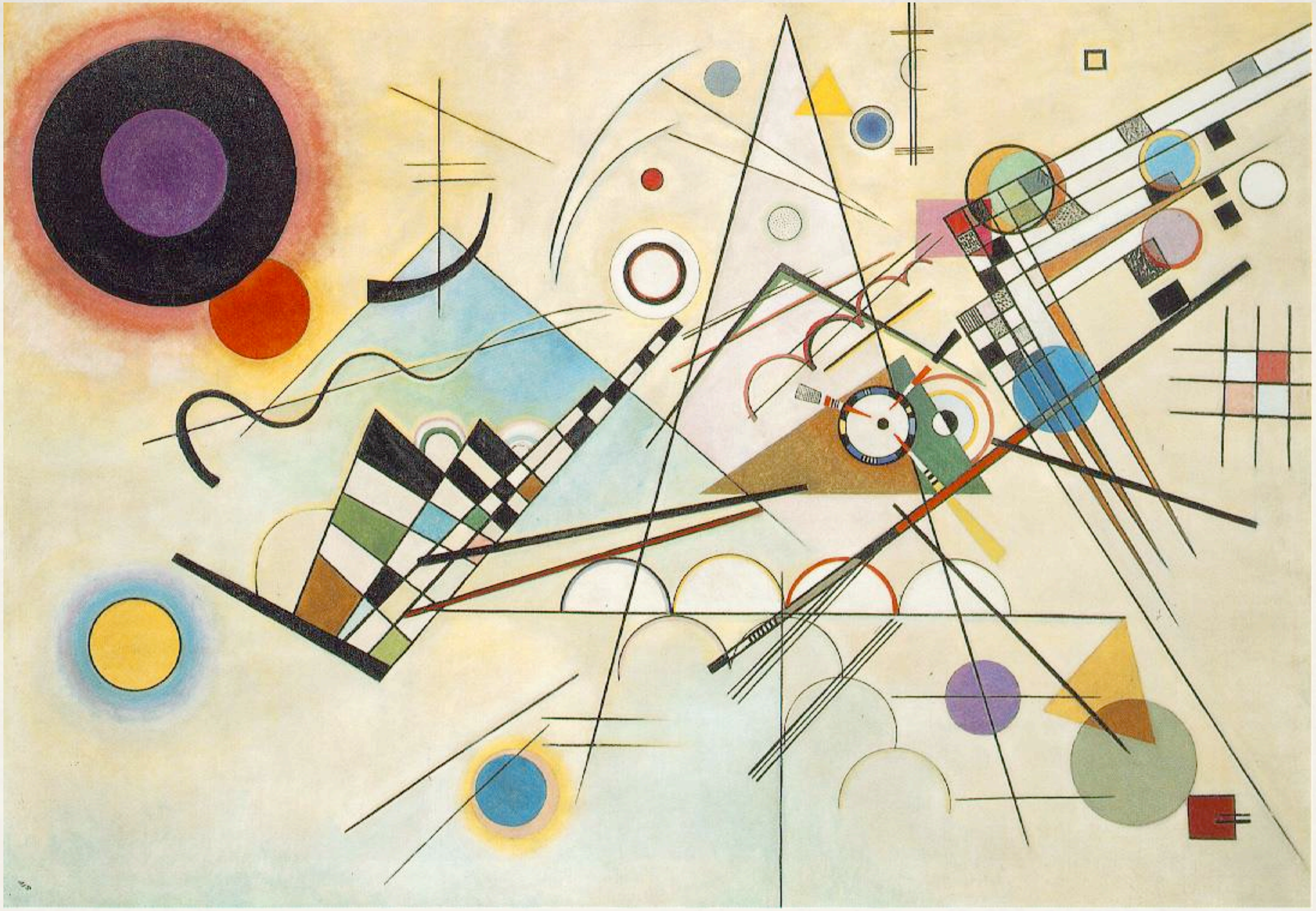
2013

Everyday Particle Physics

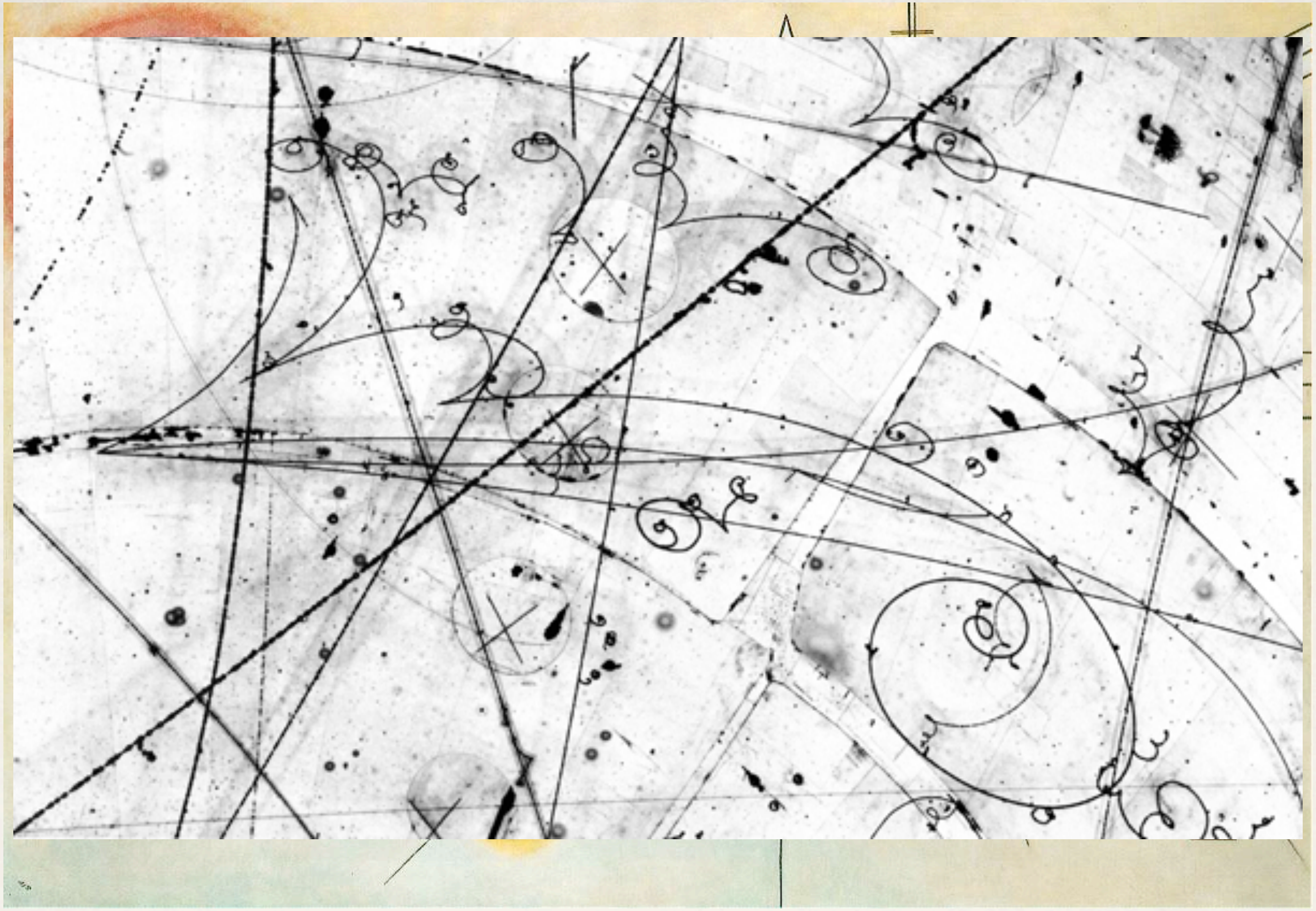
Andrea Pocar
University of Massachusetts - Amherst



Particle Physics: a practical primer

Having fun with common manifestations of fundamental particles and interactions

Andrea Pocar, University Of Massachusetts, Amherst - Saturday February 2, 2013



Particle Physics: a practical primer

Having fun with common manifestations of fundamental particles and interactions

Andrea Pocar, University Of Massachusetts, Amherst - Saturday February 2, 2013

Outline and goals

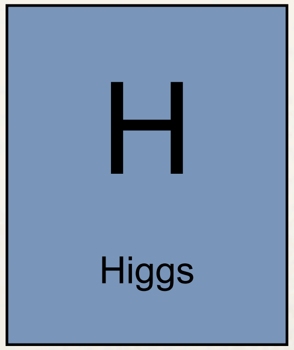
- Highlight particle physics phenomena encountered in everyday life
- Interplay with quantum physics and relativity
- Introductory remarks and examples
- Three/Four hands-on demonstrations, a couple of calculations
- List of fun examples
- Laundry list of much more!

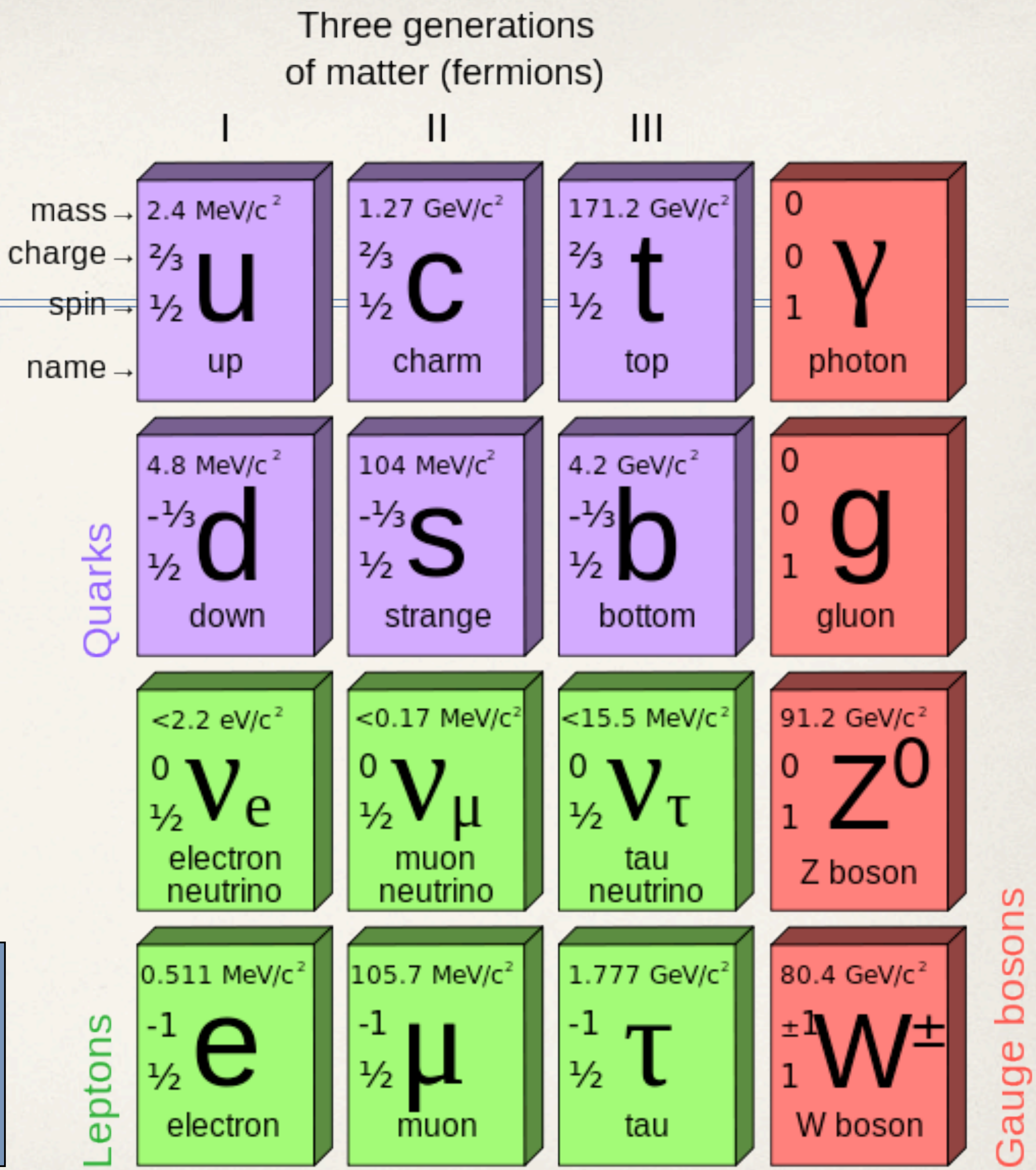
Fundamental Forces

- gravity
- electromagnetic
- nuclear forces: strong, weak
- examples of each, discussion

Elementary Particles

- mass
- charge
- spin

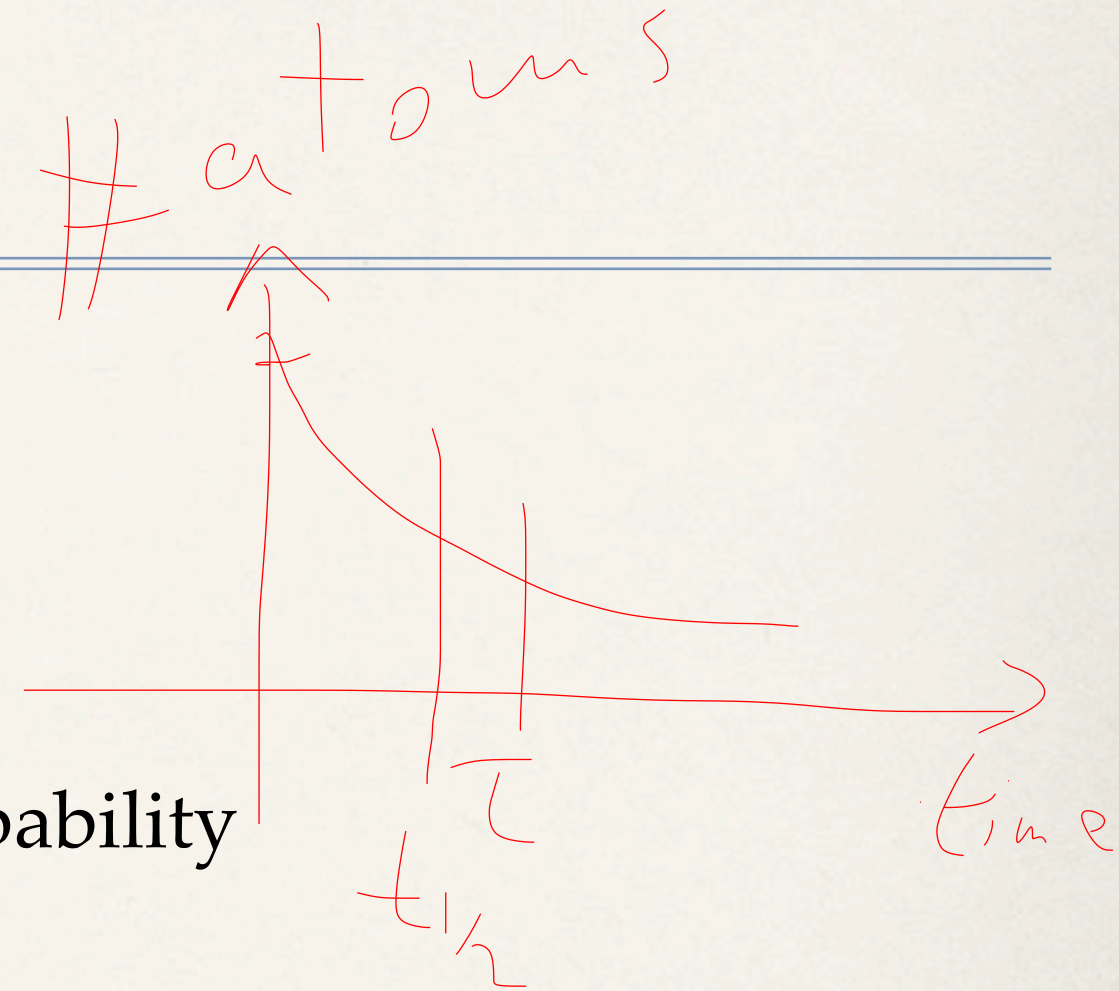




Quantum mechanics and relativity

- very high velocities/energies -----> special relativity
- particles ------> quanta of fields (very small scale)
- particles are also waves -----> “optical” phenomena (diffraction, interference, scattering)

Radioactive decays



- alpha, beta, gamma
- mean life (or half life): exponential probability
- table of isotopes:
  http://ie.lbl.gov/toi/perchart.htm
  http://www.nndc.bnl.gov/chart/reCenter.jsp?z=56&n=80

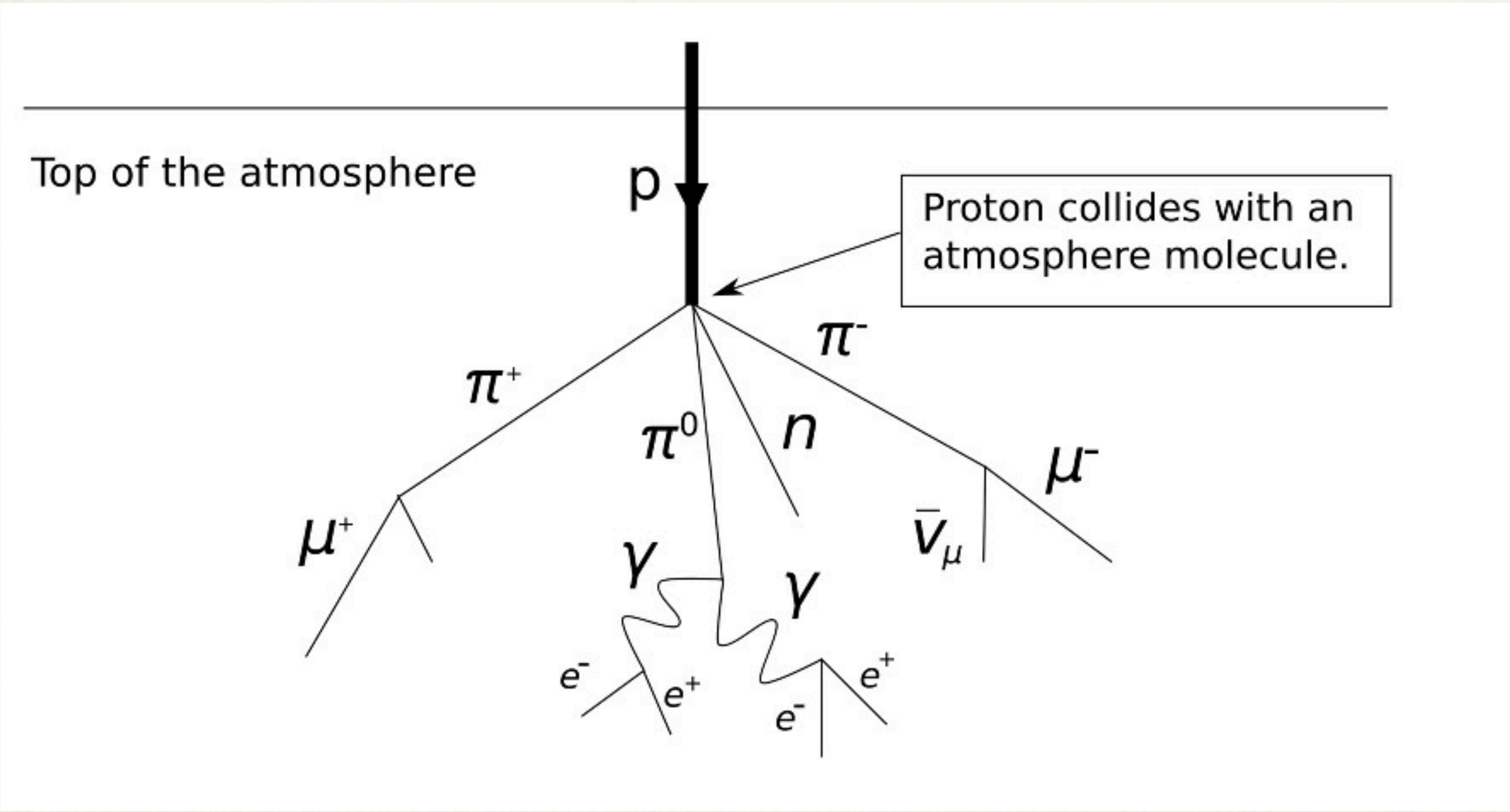
Demo 1: Geiger counter

- a few available sources
- mystery substance!

Muons

- muon production in cosmic rays
- ~200 per square meter every second hit the surface of Eart
- ~100 GeV average energy
- http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/muon.html

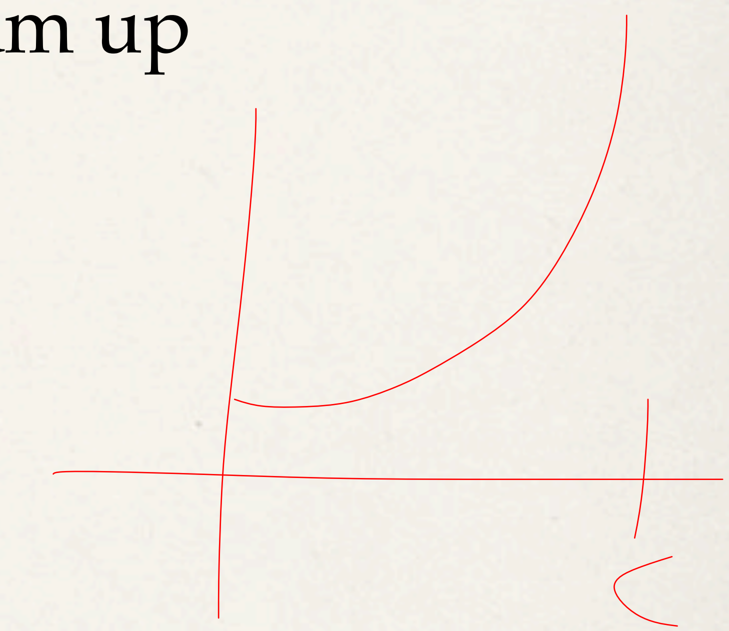
the Muon: the electron's cousin



Muons and relativity

- mean life (τ) = 2.2 microseconds
- produced in the upper atmosphere, up to tens km up
- time dilation: $$\Delta t = \frac{\Delta t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma\,\Delta t_0$$
- relativistic energy $$E = \frac{m\,c^2}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma\,m\,c^2$$

$c = 3 \times 10^8$ m/s
$\tau = 2.2 \times 10^{-6}$ s
$c\tau = 6.6 \times 10^2$ m



Calculate muon survival at the Earth's surface

- 1 GeV muons, produced at 10 km altitude:

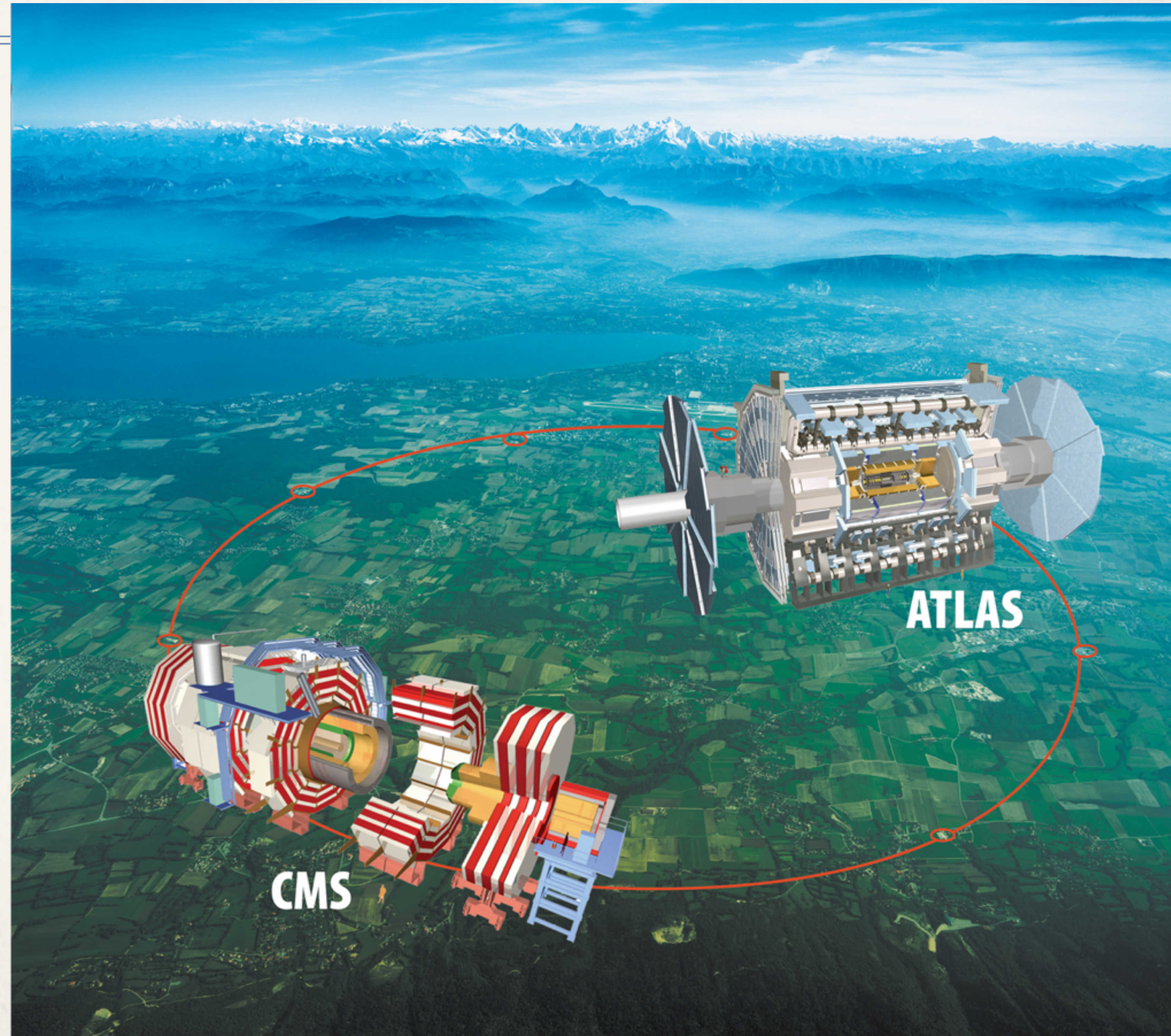
$m_\mu c^2 = 105\ MeV$ $m_e c^2 = 511\ keV$

$E = \gamma m c^2$

$1\ GeV = 10^9\ eV = \gamma \times 10^8$

$\gamma = 10$

Particle detectors



- general properties
- ionizing radiation

Discovery of the positron

MARCH 15, 1933 PHYSICAL REVIEW VOLUME 43

The Positive Electron

CARL D. ANDERSON, *California Institute of Technology, Pasadena, California*

(Received February 28, 1933)

Out of a group of 1300 photographs of cosmic-ray tracks in a vertical Wilson chamber 15 tracks were of positive particles which could not have a mass as great as that of the proton. From an examination of the energy-loss and ionization produced it is concluded that the charge is less than twice, and is probably exactly equal to, that of the proton. If these particles carry unit positive charge the curvatures and ionizations produced require the mass to be less than twenty times the electron mass. These particles will be called positrons. Because they occur in groups associated with other tracks it is concluded that they must be secondary particles ejected from atomic nuclei.

Editor

Discovery of the positron

MARCH 15, 1933 PI

T

CARL D. ANDERSON, Cal
(I

Out of a group of 1300 photographs of cosmi
in a vertical Wilson chamber 15 tracks were
particles which could not have a mass as grea
the proton. From an examination of the ener
ionization produced it is concluded that the cl
than twice, and is probably exactly equal to,
proton. If these particles carry unit positive

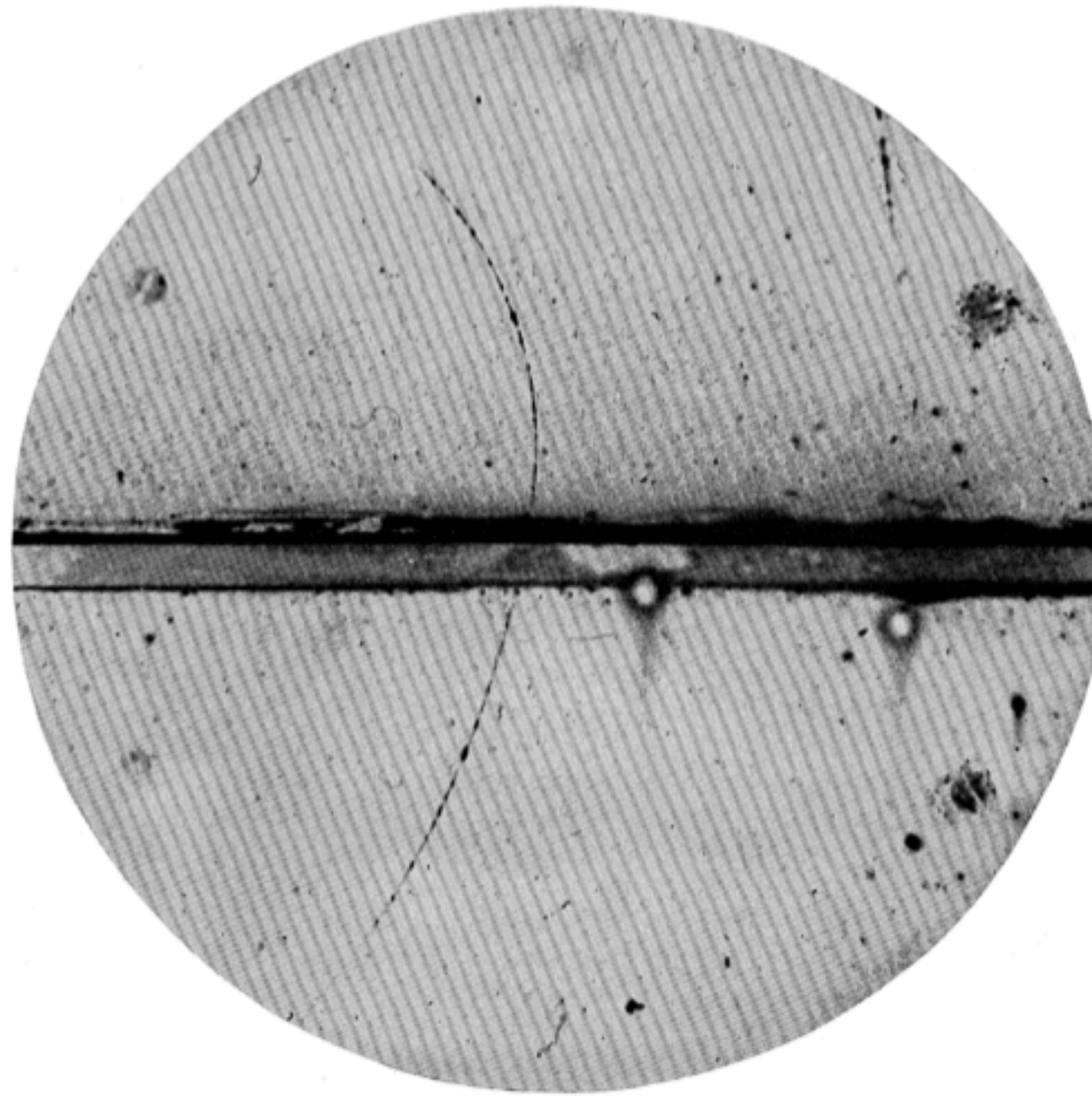


FIG. 1. A 63 million volt positron ($H\rho=2.1\times10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho=7.5\times10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

Demo 2: build a cloud chamber

- http://www.youtube.com/watch?v=400xfGmSlqQ
- follow handout
- use supercooled region to form droplets along the trail of ionization
- what do you see?
- how could you improve it?

Quarks

- 6 quarks, 3 pairs
- strong interactions, 3 colors (i.e. charges)
- never seen "bare", i.e. isolated; they always "hadronize"
- always form color-neutral particles: baryons and mesons
- how many combinations are there?
- how many possible protons are there?

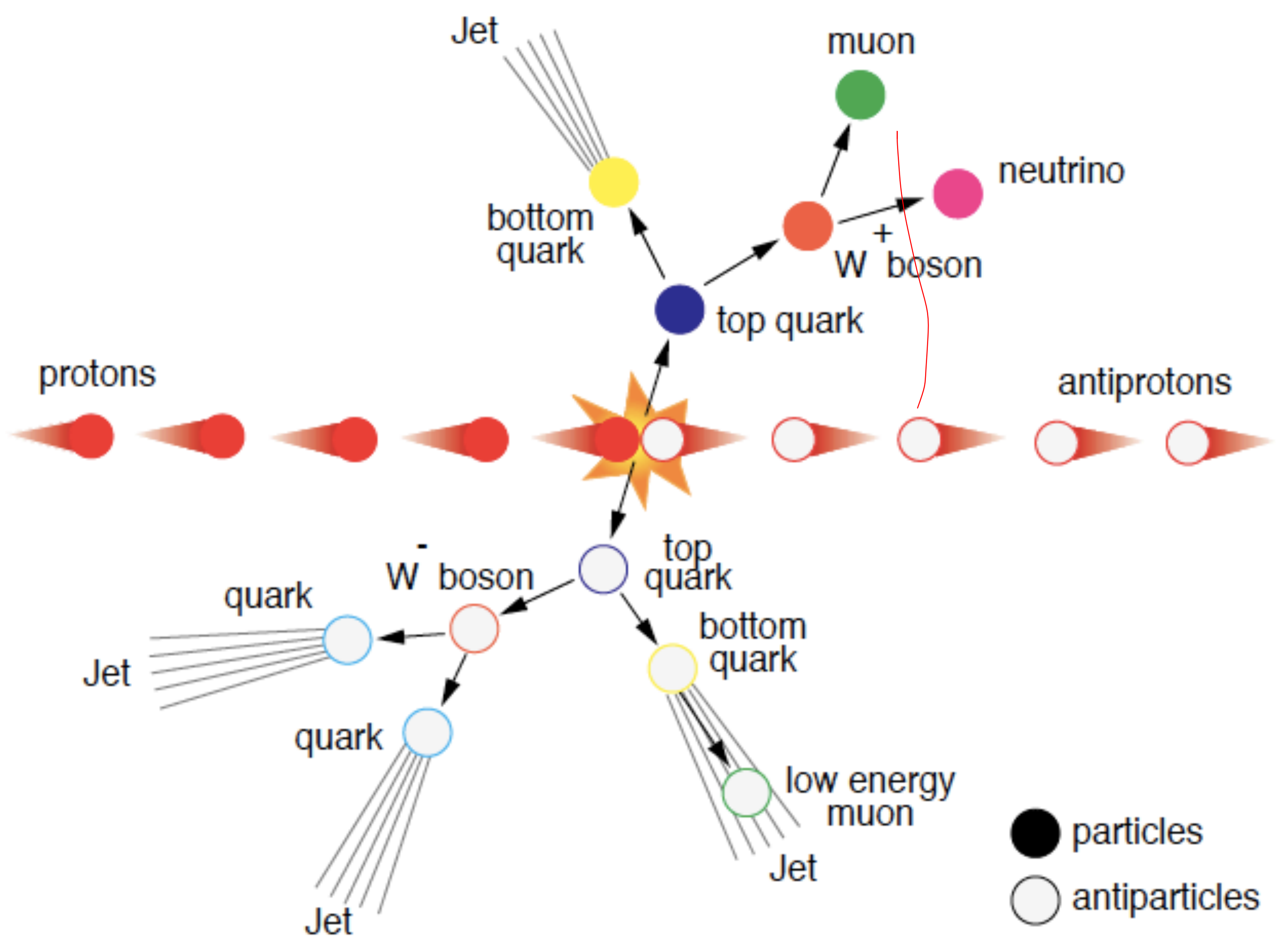
Demo 3: build baryons and mesons

- cut out shapes and make the baryon of your choice!

Demo 3:
Calculate the top quark mass!

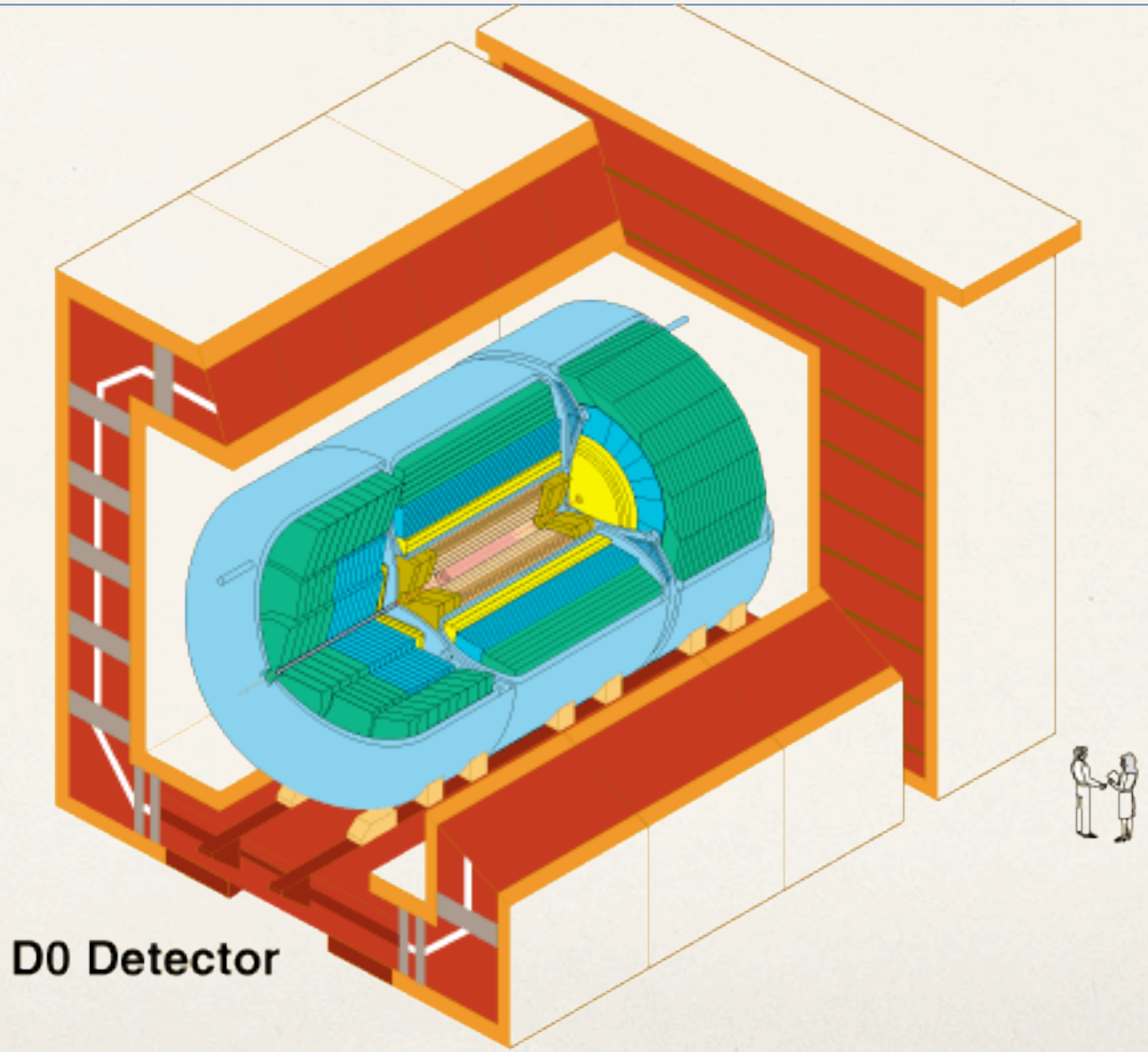
- real data from the D0 experiment at Fermilab
- “pencil and paper”
- http://ed.fnal.gov/samplers/hsphys/activities/top_quark_intro.html

Demo 4:
Calculate the top quark mass!

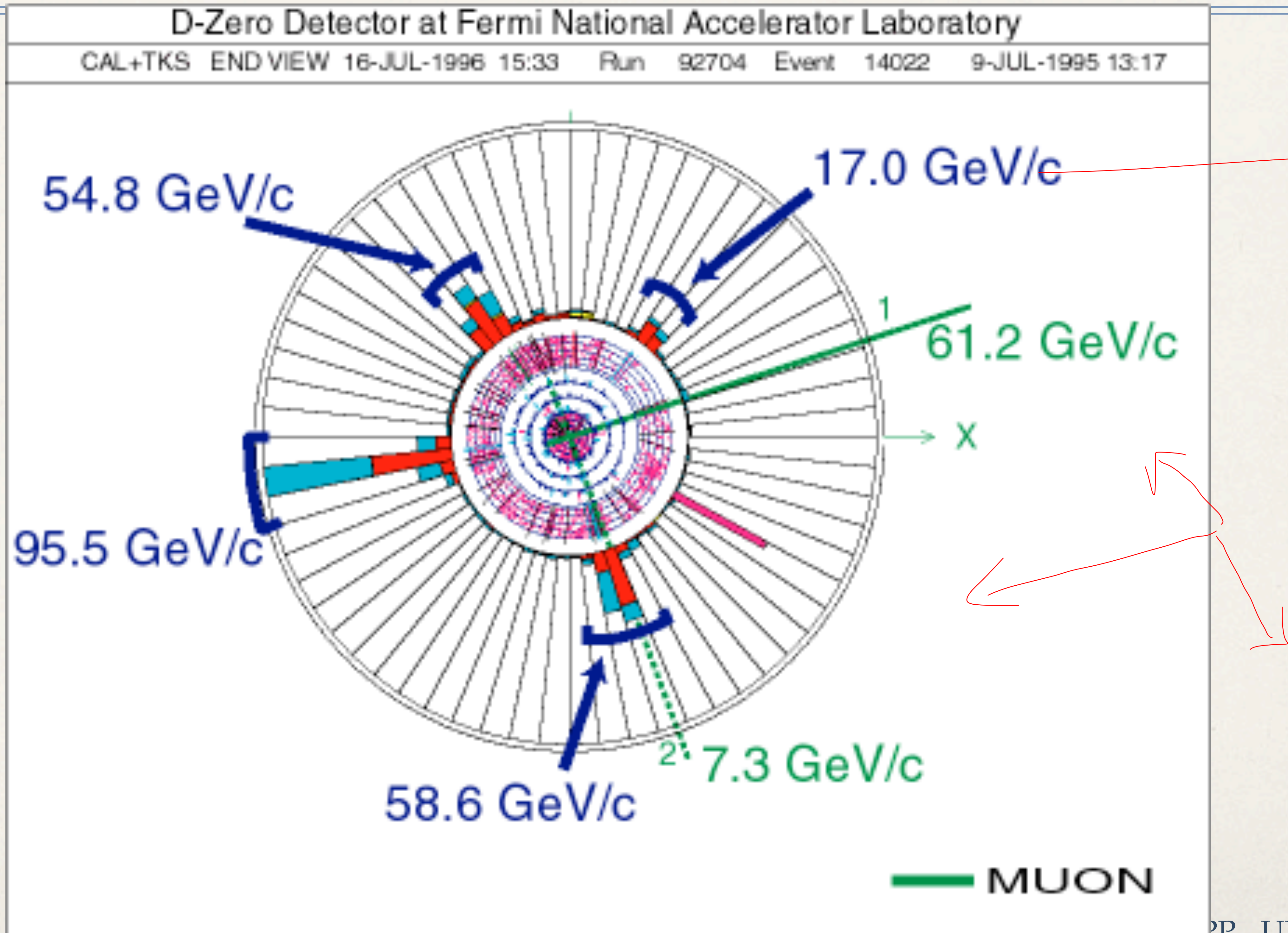


A Top Antitop Quark Event from the D-Zero Detector at Fermilab

Demo 4: D0 detector at Fermilab



Demo 4:
Calculate the top quark mass!



Examples

- How the sun burns
- Heavy elements: we are stardust!
- Carbon dating
- Radio-isotope batteries (betacells)
- X-rays: inspection of welds
- Smoke detectors
- Muon tomography
- Analytics with neutrons
- Neutron doping of silicon
- Much more (list)

How the Sun burns

p-p Solar Fusion Chain

$p + p \rightarrow {}^{2}H + e^{+} + \nu_e$ $p + e^{-} + p \rightarrow {}^{2}H + \nu_e$

$^{2}H + p \rightarrow {}^{3}He + \gamma$

$^{3}He + {}^{3}He \rightarrow {}^{4}He + 2\,p$ $^{3}He + p \rightarrow {}^{4}He + e^{+} + \nu_e$

$^{3}He + {}^{4}He \rightarrow {}^{7}Be + \gamma$

$^{7}Be + e^{-} \rightarrow {}^{7}Li + \gamma + \nu_e$ $^{7}Be + p \rightarrow {}^{8}B + \gamma$

$^{7}Li + p \rightarrow \alpha + \alpha$ $^{8}B \rightarrow 2\,\alpha + e^{+} + \nu_e$

CNO Solar Fusion Cycle

$^{12}C + p \rightarrow {}^{13}N + \gamma$

$^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$

$^{13}C + p \rightarrow {}^{14}N + \gamma$

$^{14}N + p \rightarrow {}^{15}O + \gamma$

$^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$

$^{15}N + p \rightarrow {}^{12}C + {}^{4}He$

$$4p \longrightarrow \mathrm{He}^4 + 2e^+ + 2\nu_e + 26.7\mathrm{MeV}$$

Image: bbc.co.uk

Heavy elements: we are stardust!

- large stars, supernovae

Carbon dating

- C-14 dating (half life = 5730 years)

Radioactive space propulsion

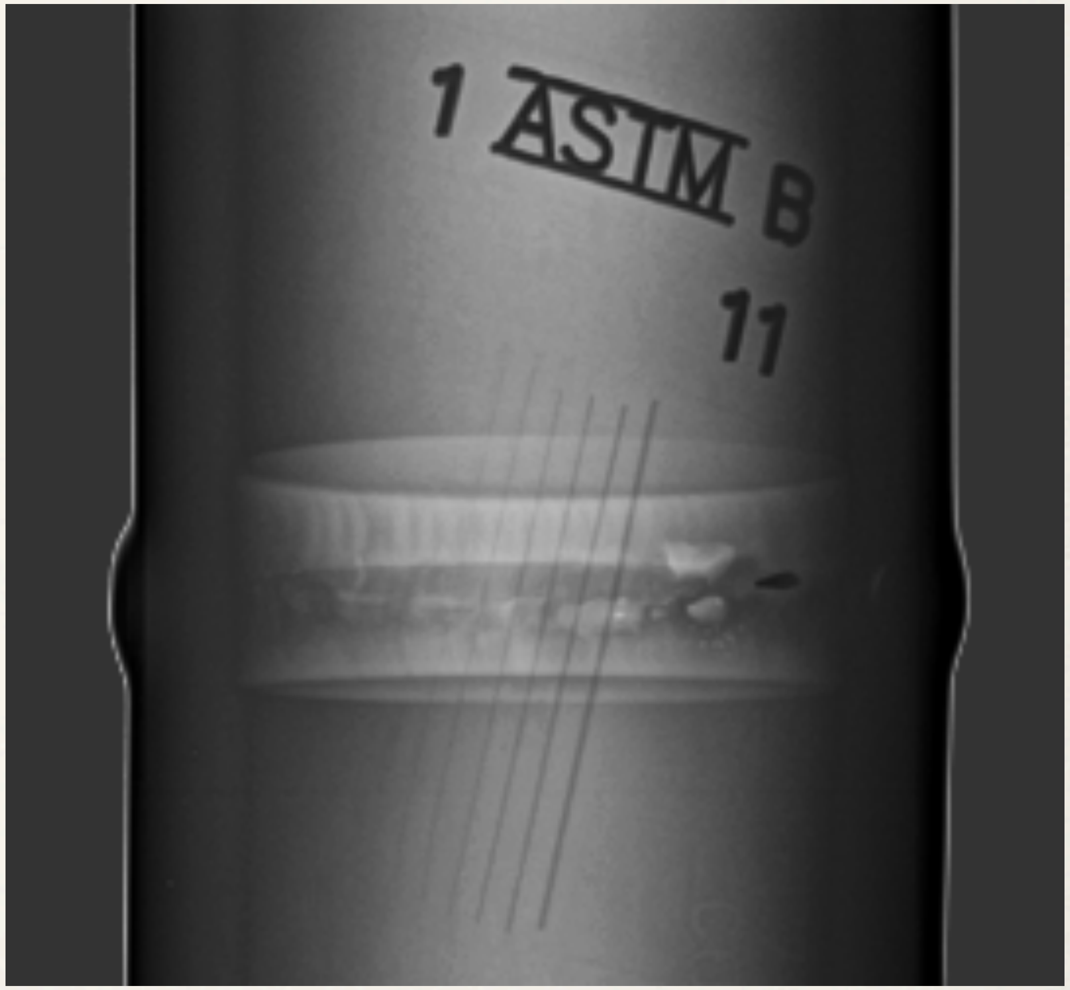
- Pu-238
  (α-decay of 5.6 MeV, rare spontaneous fission; 90 year half life)

- heat up fluid that is then exhausted through a nozzle

Radio-isotope batteries (betacells)

- relatively old idea (pacemakers), back in fashion
- based on beta decays on silicon devices: low power, long-lasting

X-rays: inspections of welds



Smoke detectors

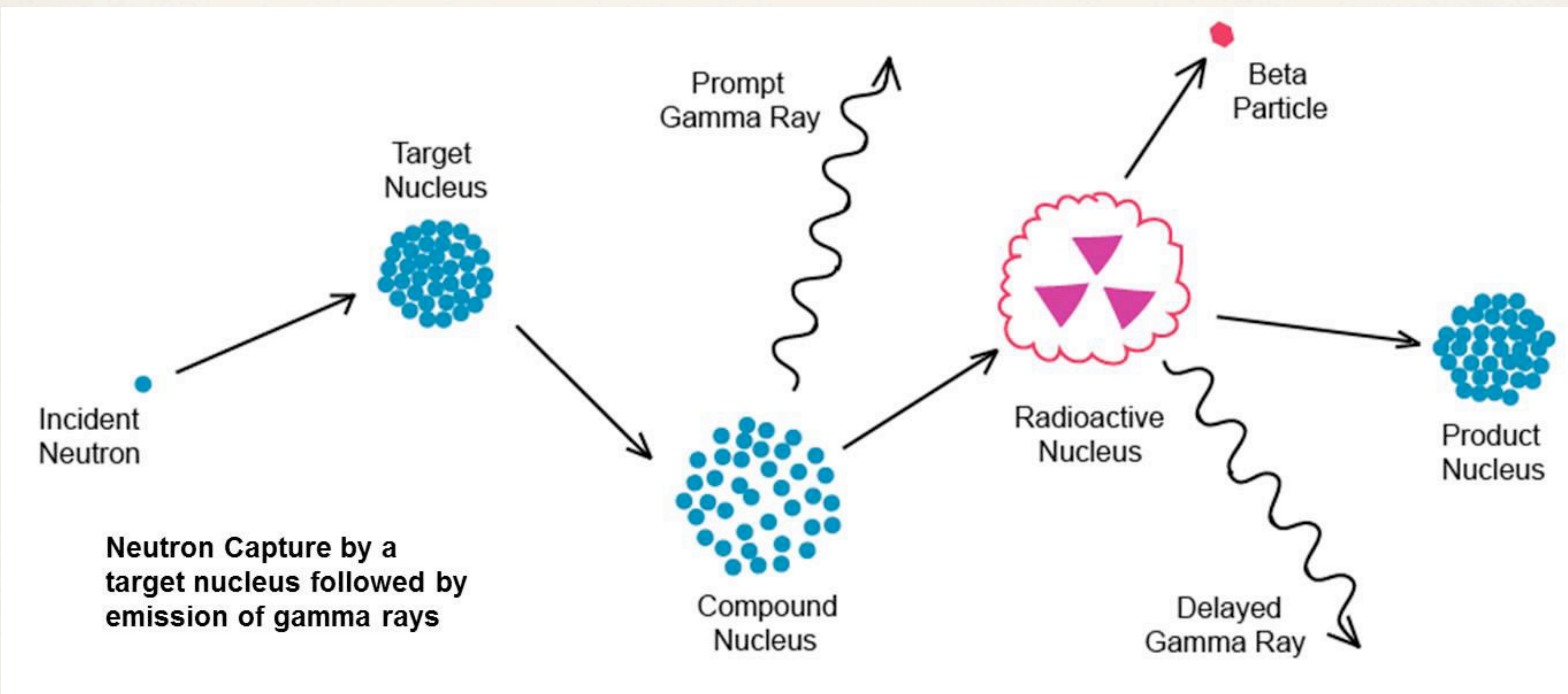
- air ionization between electrodes ----> current
- Am-241 source (430 years)

Muon tomography

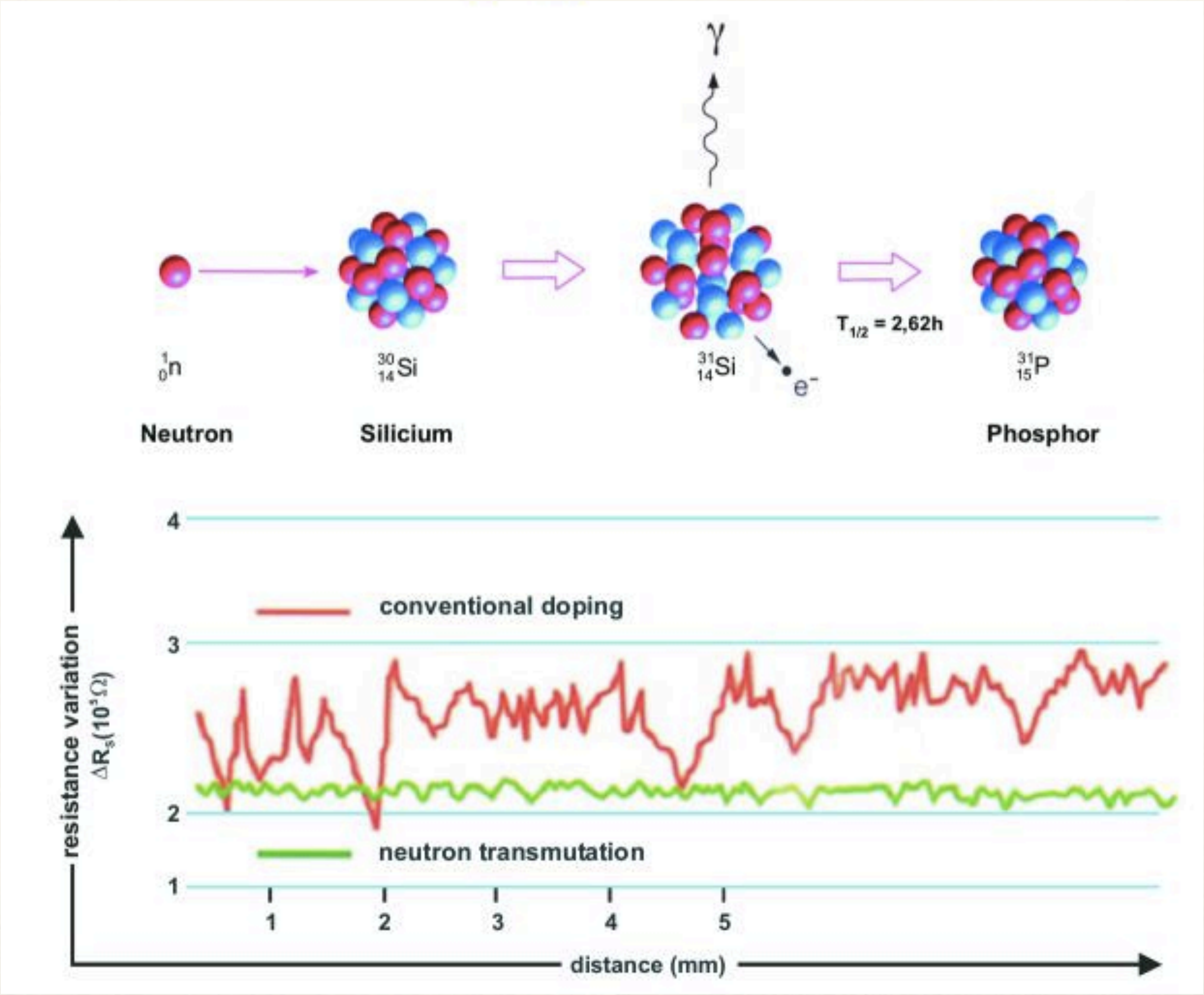
- hidden chambers in Egyptian and Mayan temples
- http://www.hep.utexas.edu/mayamuon/aboutus/
  http://www.ph.utexas.edu/spw/schwitters_061111.pdf
- fight contraband

Analytics with neutrons

- neutron activation analysis to measure trace elements
- use in non-invasive sampling of works of art



Neutron doping of silicon



Much more

- dark matter
- gravitational waves
- the Higgs boson
- dark energy
- inflation and cosmological evolution
- ....