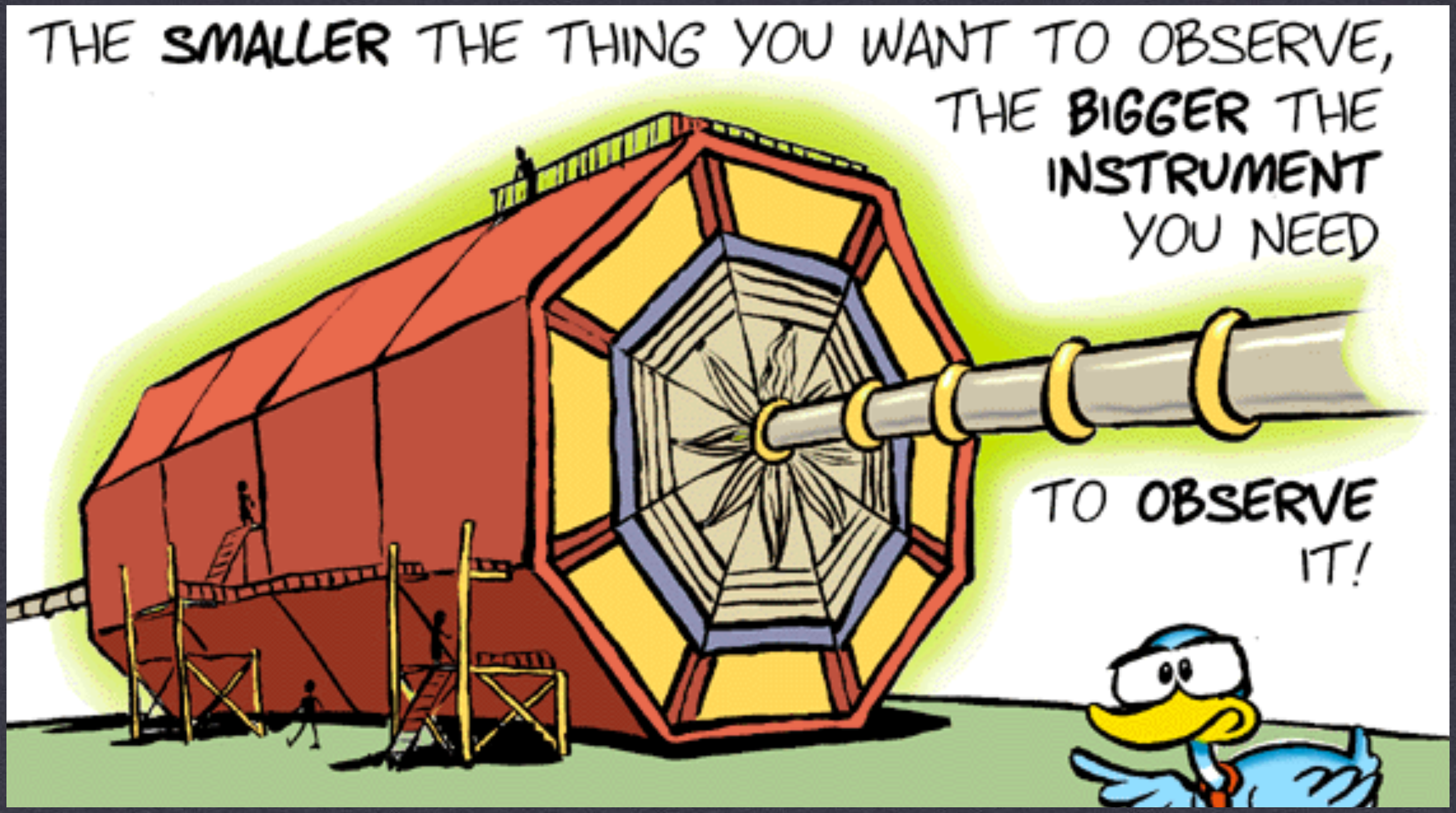


PARTICLE HUNTING

How and why?

August, 6th 2017

ANGELA FAVA

Theory or Experiment?

- Progress in Physics is the result of a symbiosis between theory and experiment.
- Is the majority of Nobel Prizes awarded for experimental work or theoretical work?

experiment

As of 2013, experimental discoveries outnumbered theoretical ones at about 5-2!

- Which fraction of the Nobel Prizes were awarded specifically for technical innovation?

20%

Almost as many as all the theoretical contributions!

https://quantumcoffee.wordpress.com/2014/06/08/nobel-prizes-in-physics-theorists-vs-experimentalists/

Origin of the scientific method

- The basis of the experimental investigation of nature dates back to the XVI century, with the actions of G. Galilei.
- Einstein named Galileo the "**father of modern science**". Galileo's great contribution: science based on careful observation, measurement, and controlled experiment, and made accessible to a wide audience.

" Io stimo più il trovar un vero,

benché di cosa leggiera,

che 'l disputar lungamente delle massime questioni

senza conseguir verità nissuna."

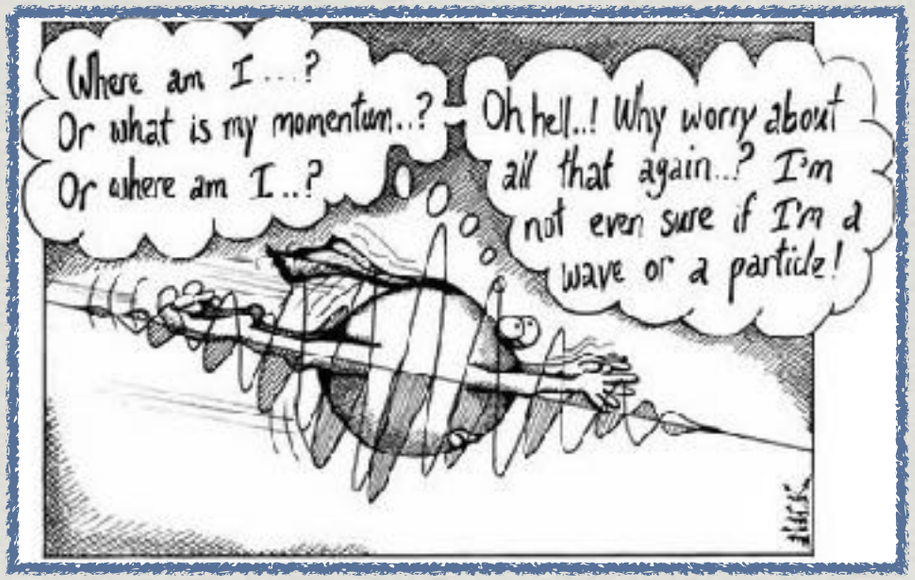
"I appreciate more discovering some truth,
although of minor relevance,
rather than abundantly discussing major topics
without getting to any results."

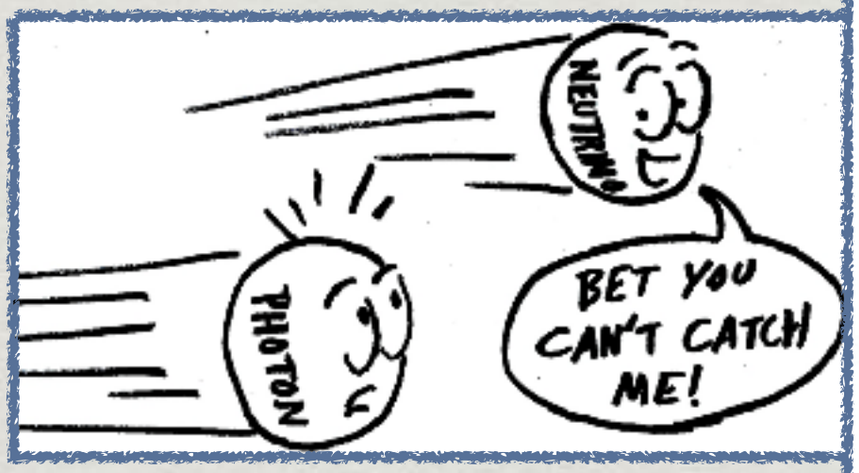
- Galilei's many discoveries were possible thanks also to the many instruments he invented, the telescope in primis.

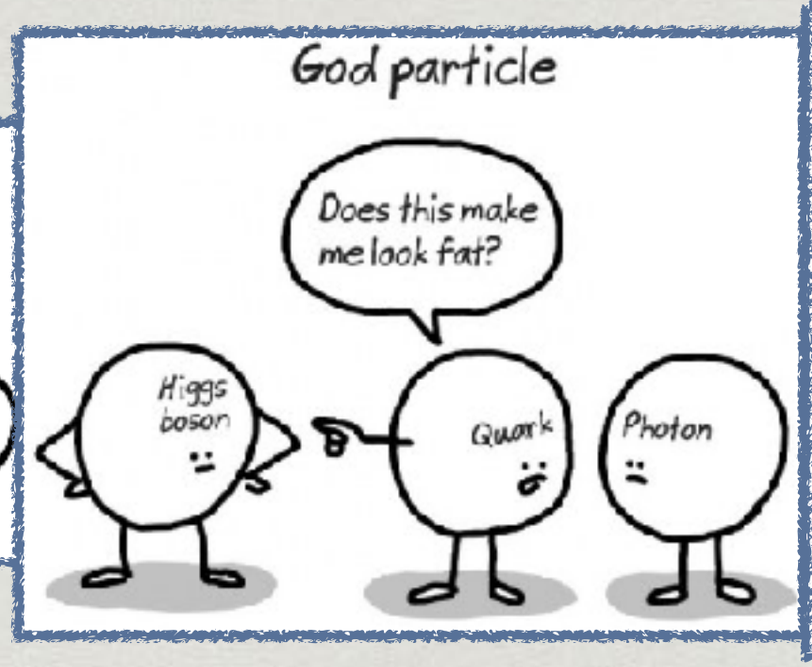
A UNIVERSE OF PARTICLES

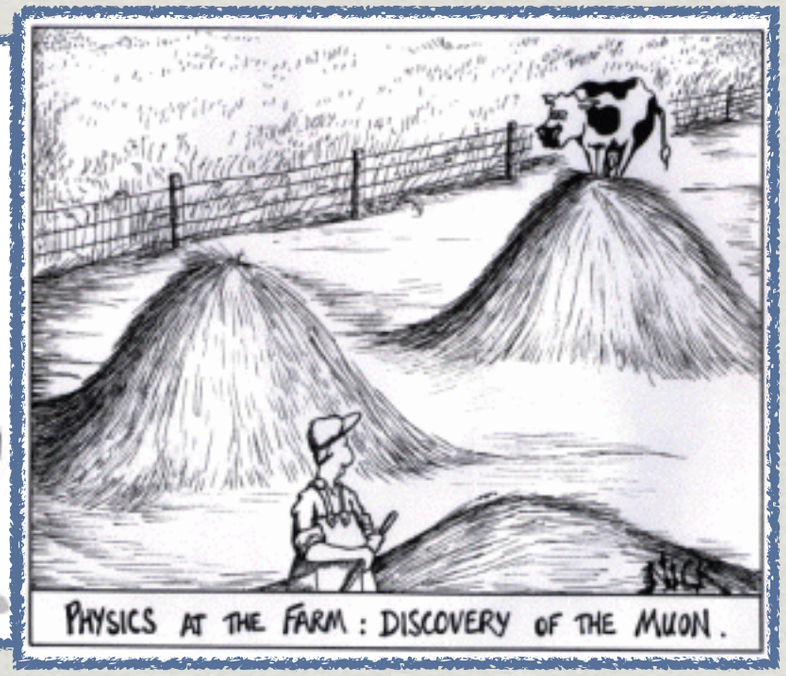
V.I.P.'s: Very Important Particles!

- It is a common belief that the fundamental particles are protons, electrons and neutrons, because they are the constituents of the atoms, of which the ordinary matter is made of.
- Light, or electromagnetic radiation more properly, is made of particles as well, besides its wave-like behaviour.
- A few more "famous" particles:
  - neutrinos
  - Higgs boson
  - muons



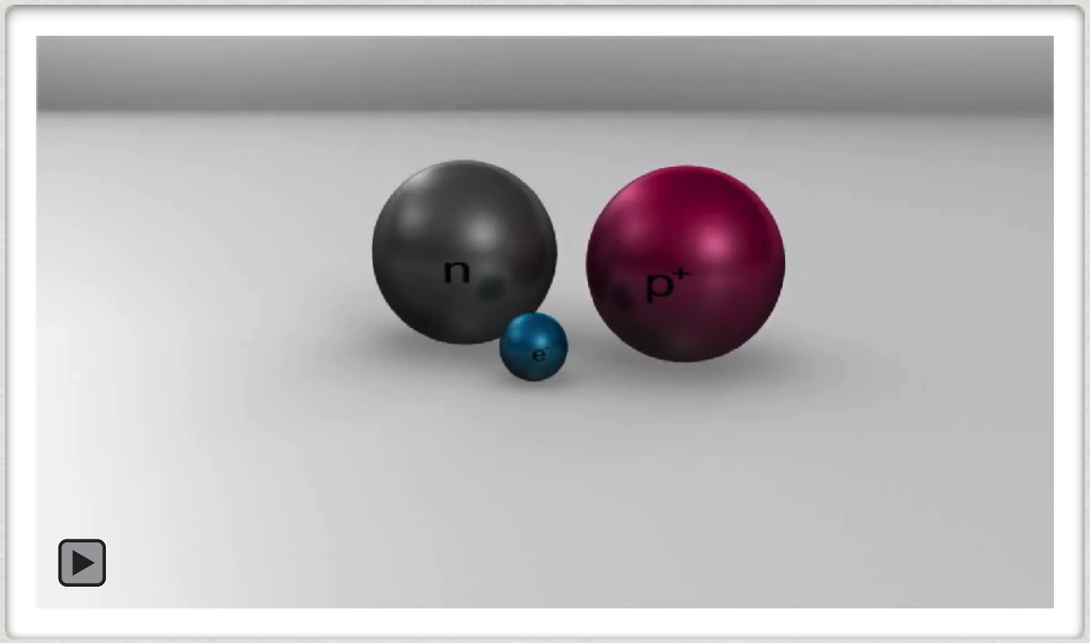






The particle zoo

- The situation became much more complicated since the beginning of the XX century. Observation of cosmic rays lead to the discovery of a multitude of particles!



From "CERN: The Standard Model Of Particle Physics" _ film produced as part of the CERN/ATLAS multimedia contest internship

- How many particles have been observed up to now?

200 ÷ 300

They are named after greek letters: we have almost run out of symbols!
And there might even exist many more than these...

- This is just for ordinary matter. Numbers double accounting for anti-matter.

Particle Data Group (www.pdg.lbl.gov): the bible of Particle Physics!

Tidying up the mess: the Standard Model

These are fundamental!

Special particles: they carry the information in the interaction!

What about protons & neutrons? They are made of quarks!!!

Unit of measurement in Particle Physics

- **Electronvolt (eV)**: energy acquired by an electron accelerating through a potential difference of one volt.

$$1\ \text{eV} = q_e \cdot V = (1.6 \times 10^{-19}\ \text{C}) \cdot (1\ \text{V}) = 1.6 \times 10^{-19}\ \text{J}$$

- Commonly adopted for masses as well.
  From the mass-energy equivalence $E = mc^2$, in the "natural units" framework ($c = 1$).

- 1 eV **B**

511 keV = electron mass

200 MeV **C**

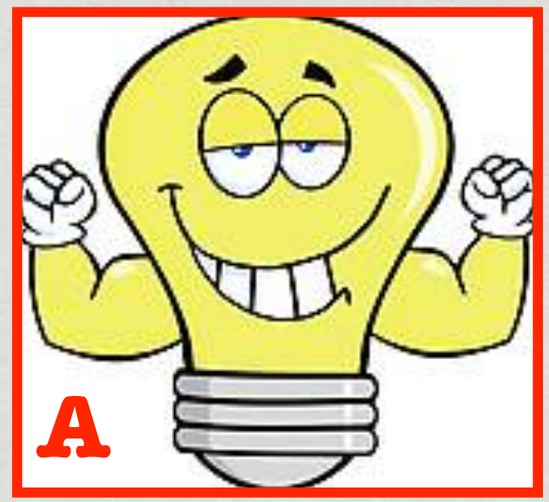
125 GeV = mass of the Higgs boson

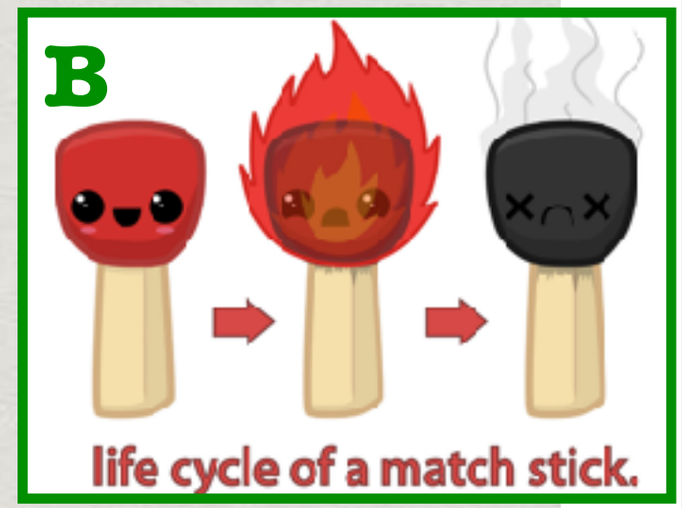
1 TeV **D**

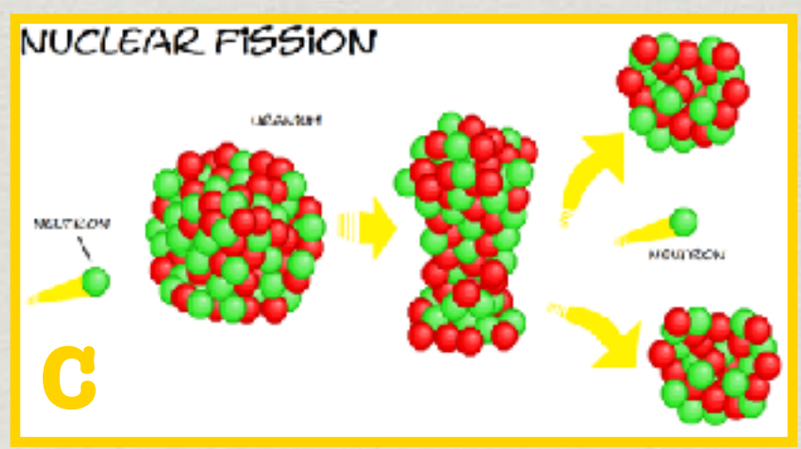
13 TeV = collisions at LHC

624 EeV **A**

10^{88} eV = estimated total mass-energy of the observable Universe







Particle Sources

NATURAL

Cosmic rays

- The first source for Particle Physics experiments.
- broad energy spectrum, up to 3 x 10^8 TeV ("Oh-My-God" particle).
- Interesting for cosmological studies.

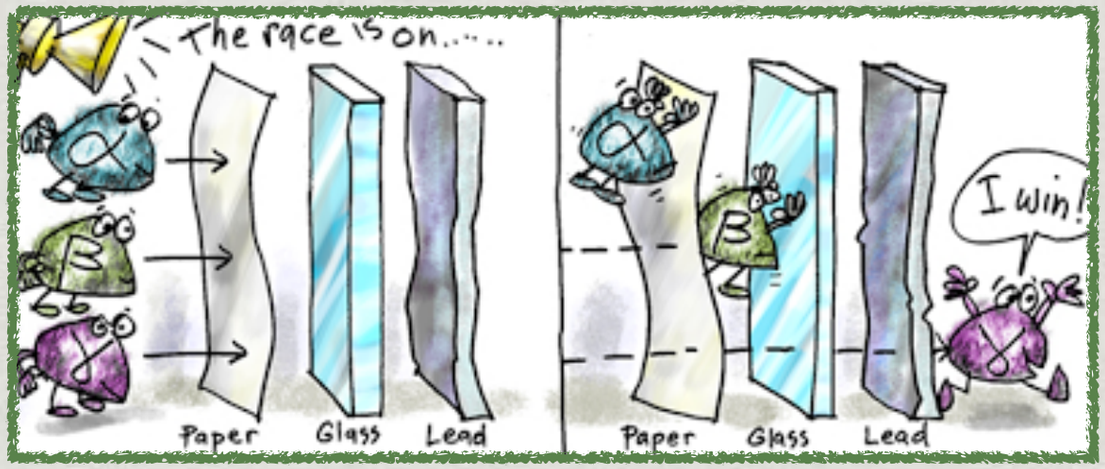
ARTIFICIAL

Accelerators

- Developed since 1930.
- Maximum energy obtained up to now: 13 TeV at LHC (CERN).
- Excellent for studies of rare particles thanks to very high intensity.

Radioactive decays.

- Low energies, in the keV - MeV range.
- Most famous applications in Particle Physics with neutrinos



Who is going to win the race?

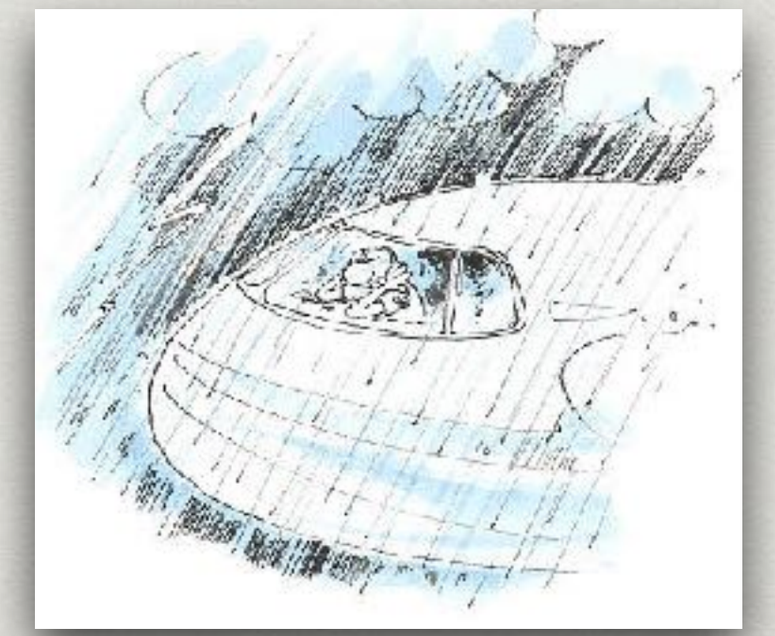
Photons

Cosmic rays: an invisible rainfall

100000 particles

cross the human body

in 1 hour!



At 33000 ft

almost **1 million particles**

cross one human body

in 1 hour!

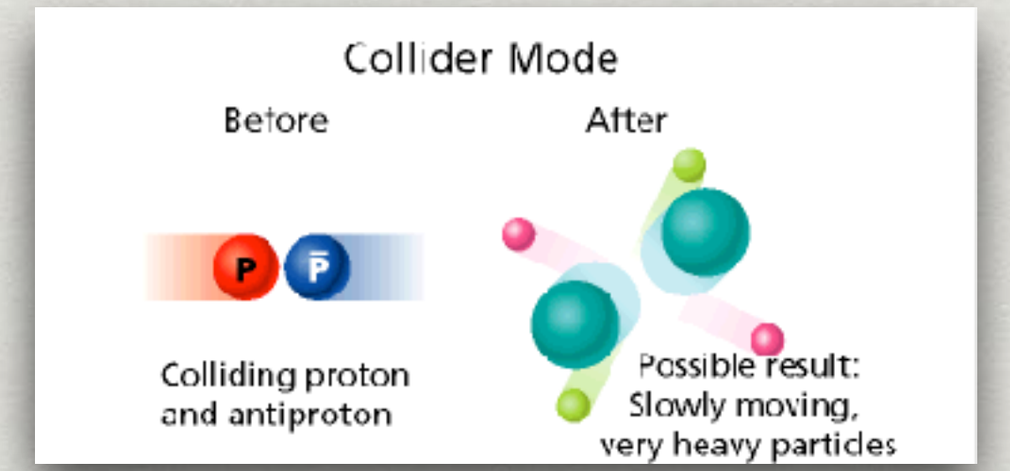
In the Gran Sasso National Laboratories (Italy),
at 1400 m depth,
human body is crossed by
only **1 particle every 10 hours!**

Who is hiding under the invisibility cloak?

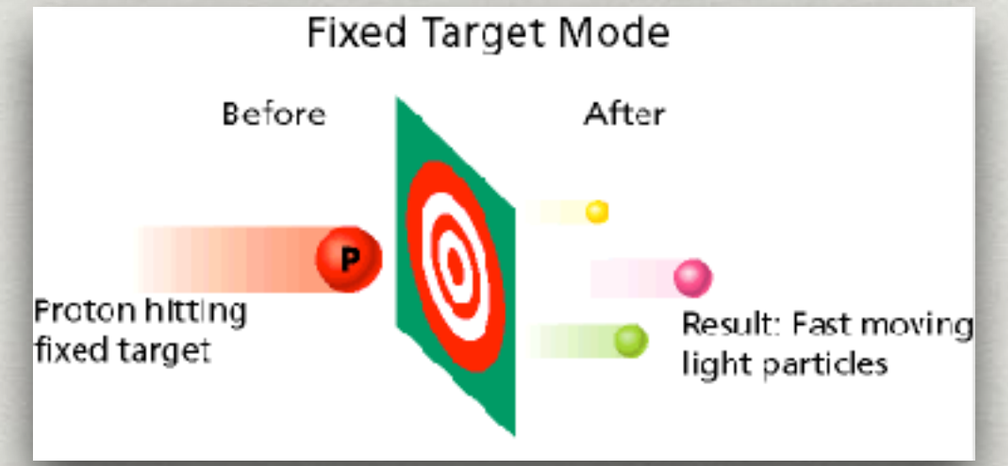
From “The fantastic voyage of Nino the neutrino” _
film produced by INFN (National Institute of Nuclear Physics), Italy

Particle production at accelerators

- **Colliding beams**.
  Maximisation of energy transfer.
  Most powerful: LHC (Large Hadron Collider)
  at CERN (Switzerland), 13 TeV!



- **Fixed target**.
  Production is forward with limited energy transfer.

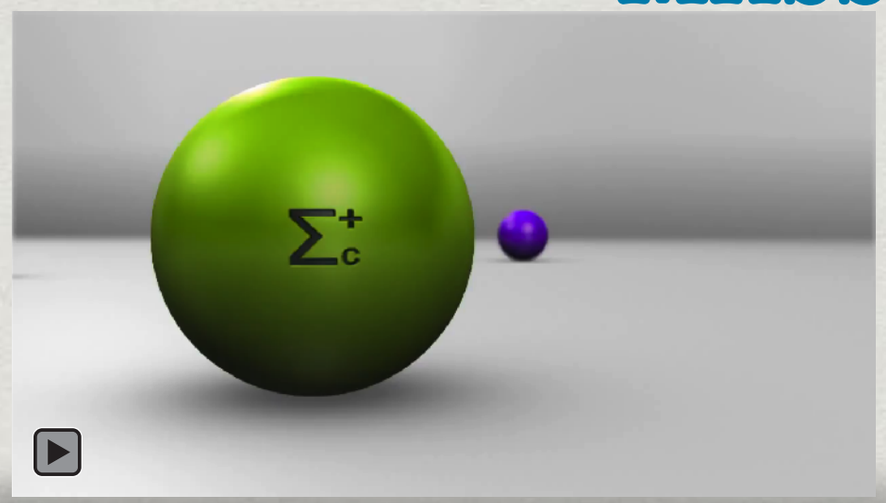


Neutrino beams examples of fixed target.
At Fermilab: BNB and NuMI!

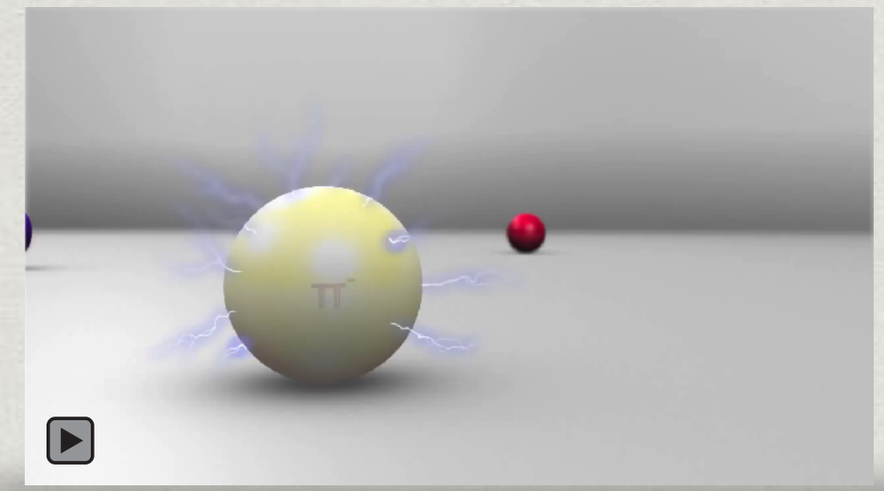
What to look for...

- PARTICLE (for theorist) = irreducible representation of Poincare group 😱
- PARTICLE (for experimentalist) = entity recognisable by measurable properties 👌

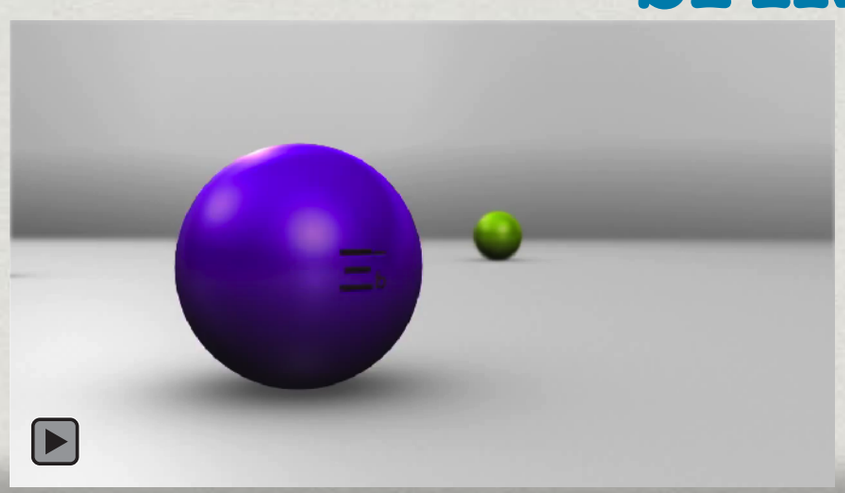
MASS



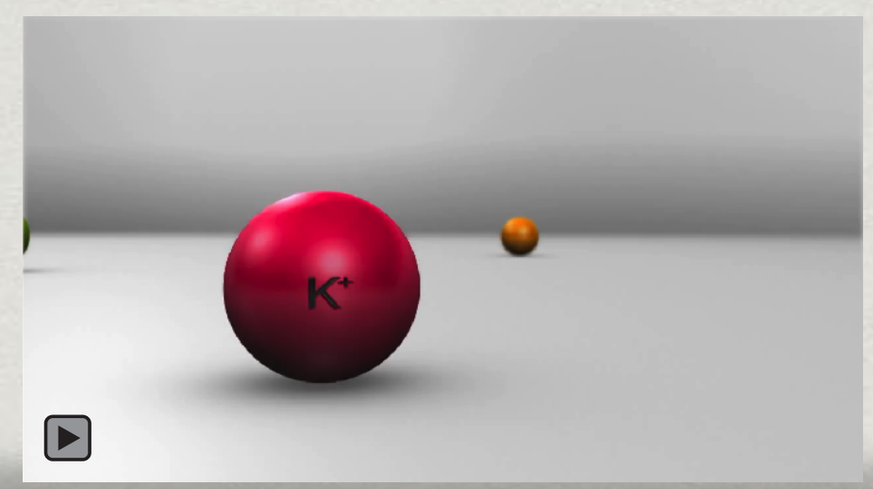
CHARGE



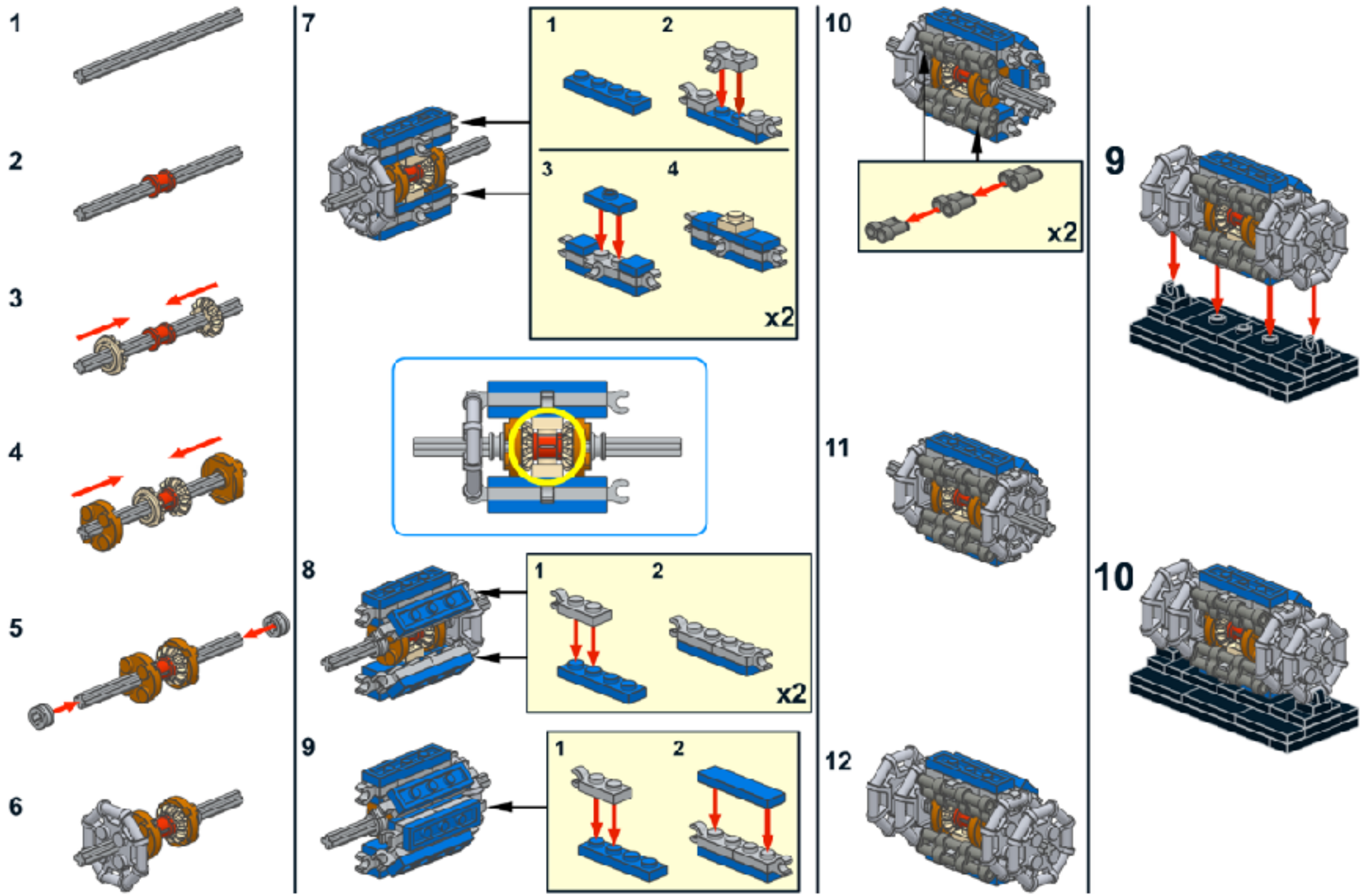
SPIN



LIFETIME



- Energy, momentum (mass x velocity) and position are additional handles.

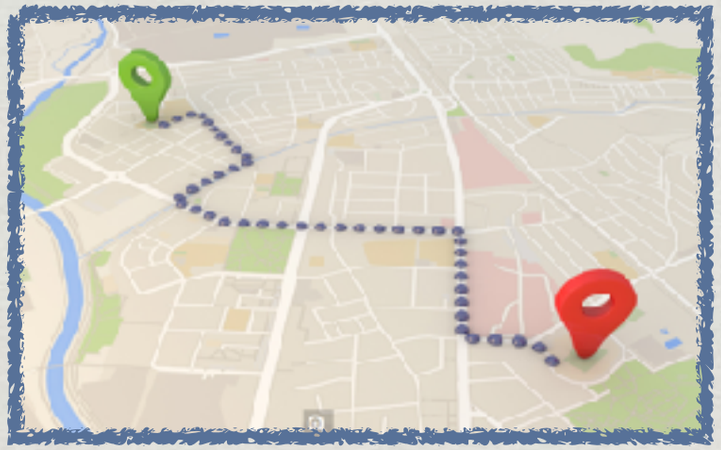


BUILDING A REAL DETECTOR

Detectors functionalities

- **TRACKING**

  High resolution measurement of the particle tracks.
  Ex: charge sign and momentum measurement by
  track curvature in a magnetic field.



- **PID (Particle Identification)**

  Measurement of β, γ, v or dE/dx that, combined with the momentum, allow to reconstruct the mass and therefore to identify the particle.

- **CALORIMETRY**

  Energy measurement by completely absorbing it.

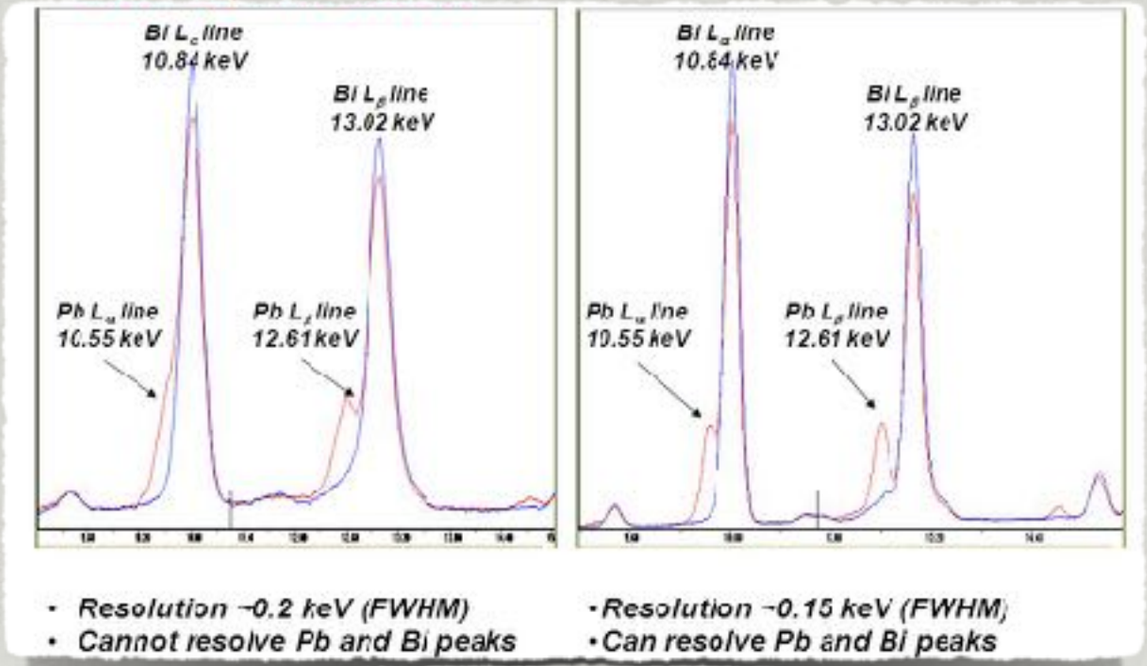
- **TRIGGER/VETO**

  Selection of interesting events / background rejection.

Performance

- **RESOLUTION**

  Accuracy in the measurements (energy, time, position, etc).
  Expressed in terms of width of the distribution, usually Gaussian, of measured values around the average.



- **EFFICIENCY**

  Probability of detecting the signal of each incoming particle.

- **RESPONSE TIME**

  Time needed for generating a signal since the primary interaction.

- **DEAD TIME**

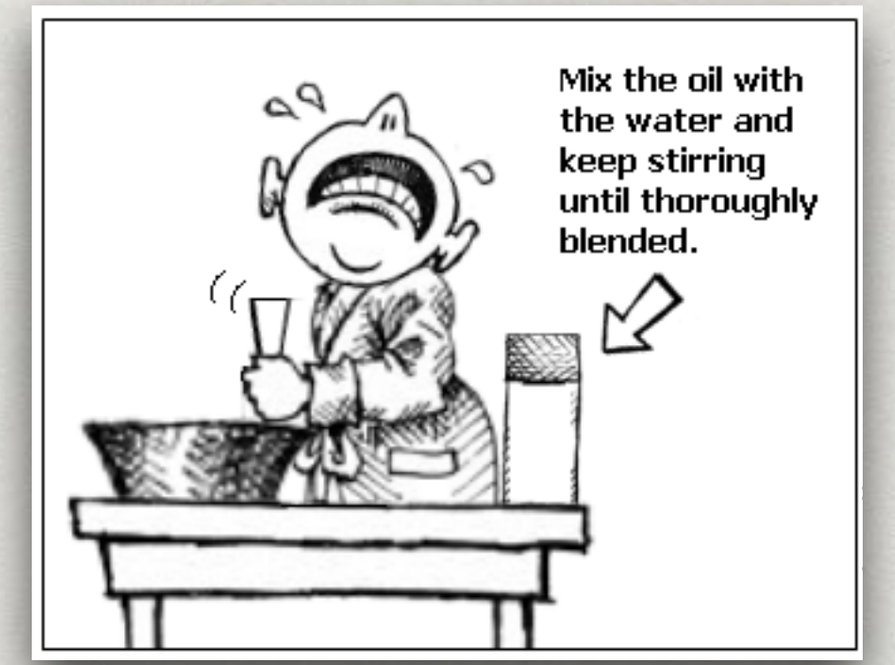
  Period of time after each signal in which no other signals can be generated.

- **STABILITY IN TIME**

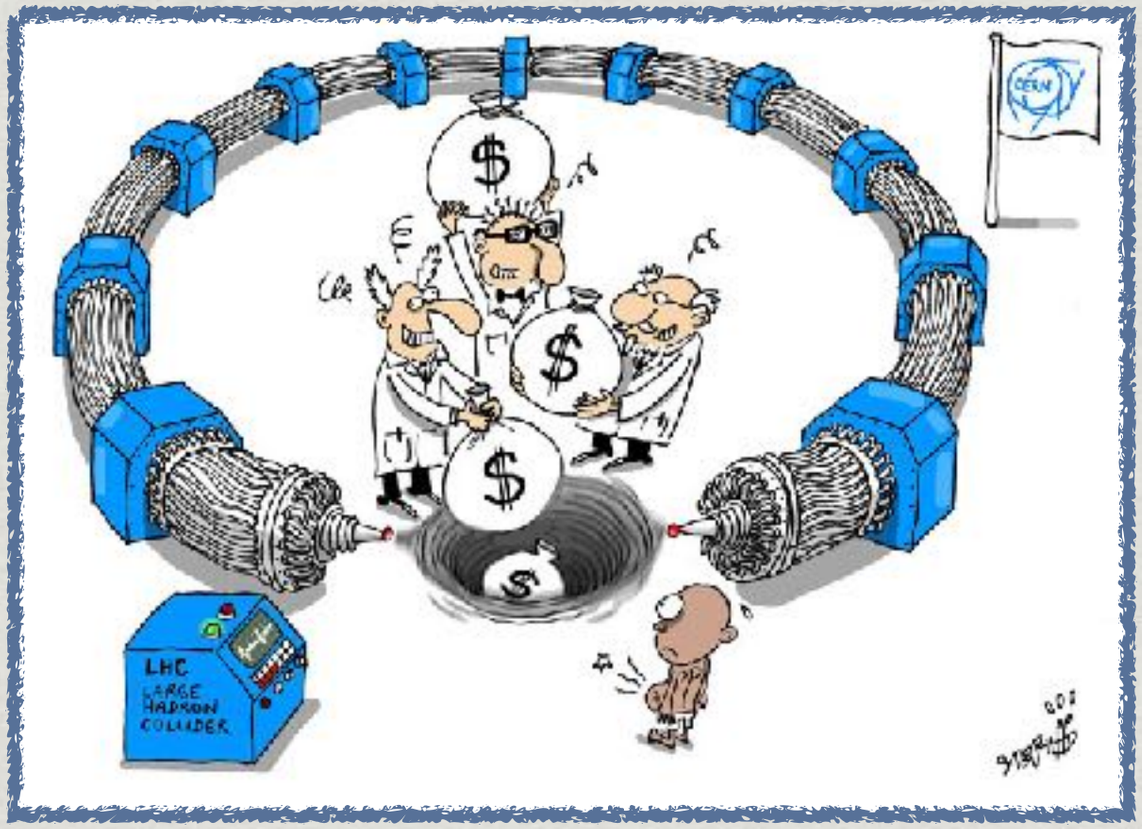
- **RADIATION HARDNESS**

- etc...

The recipe for the perfect detector... 🤔



... doesn't exist 😧

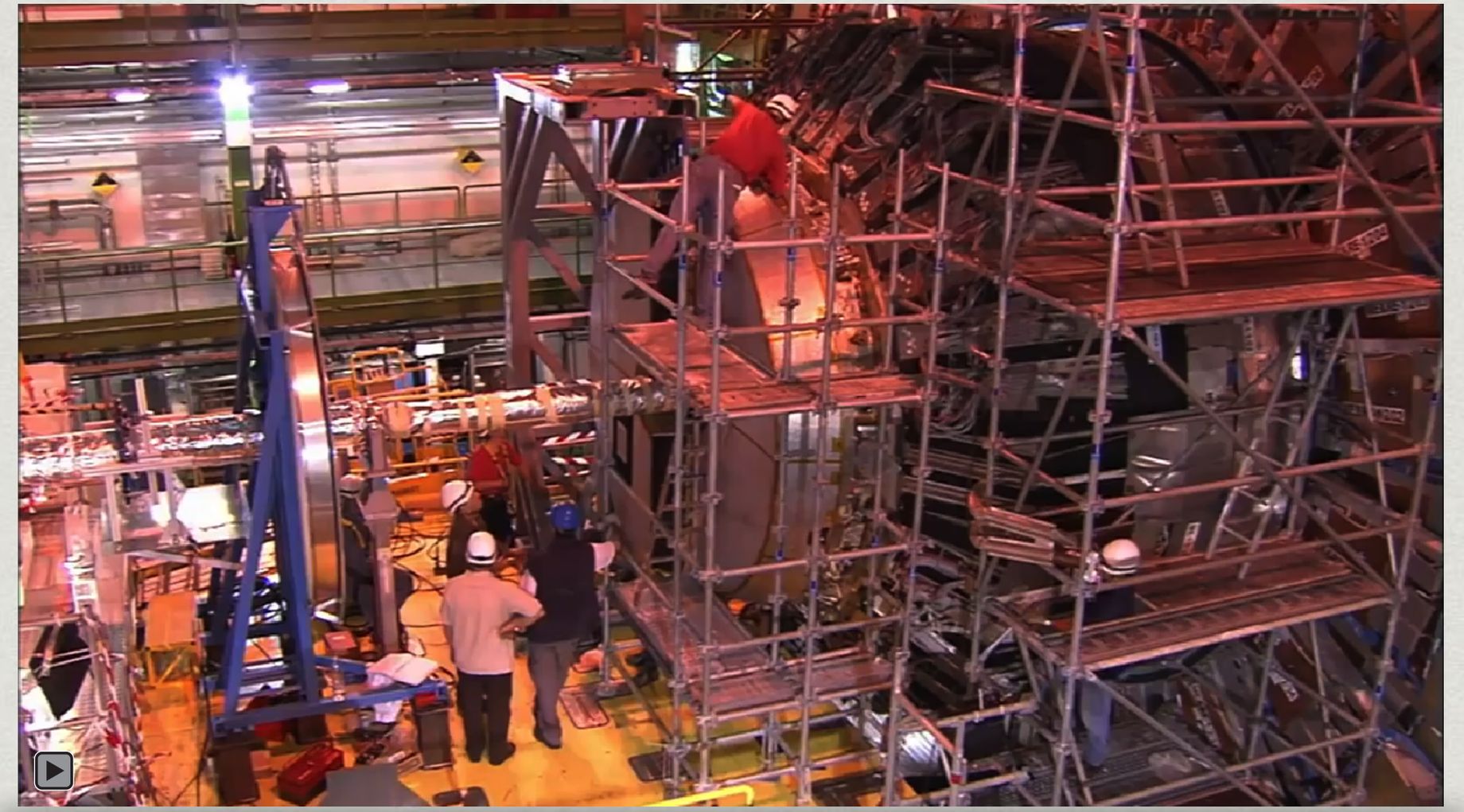


- The choice for the detector design is driven by the PHYSICS CASE:
  Which functionalities are needed?
  Which performance is required?
  But also by the COST $$$

- Usually detectors, especially nowadays, are made of several sub-detectors.

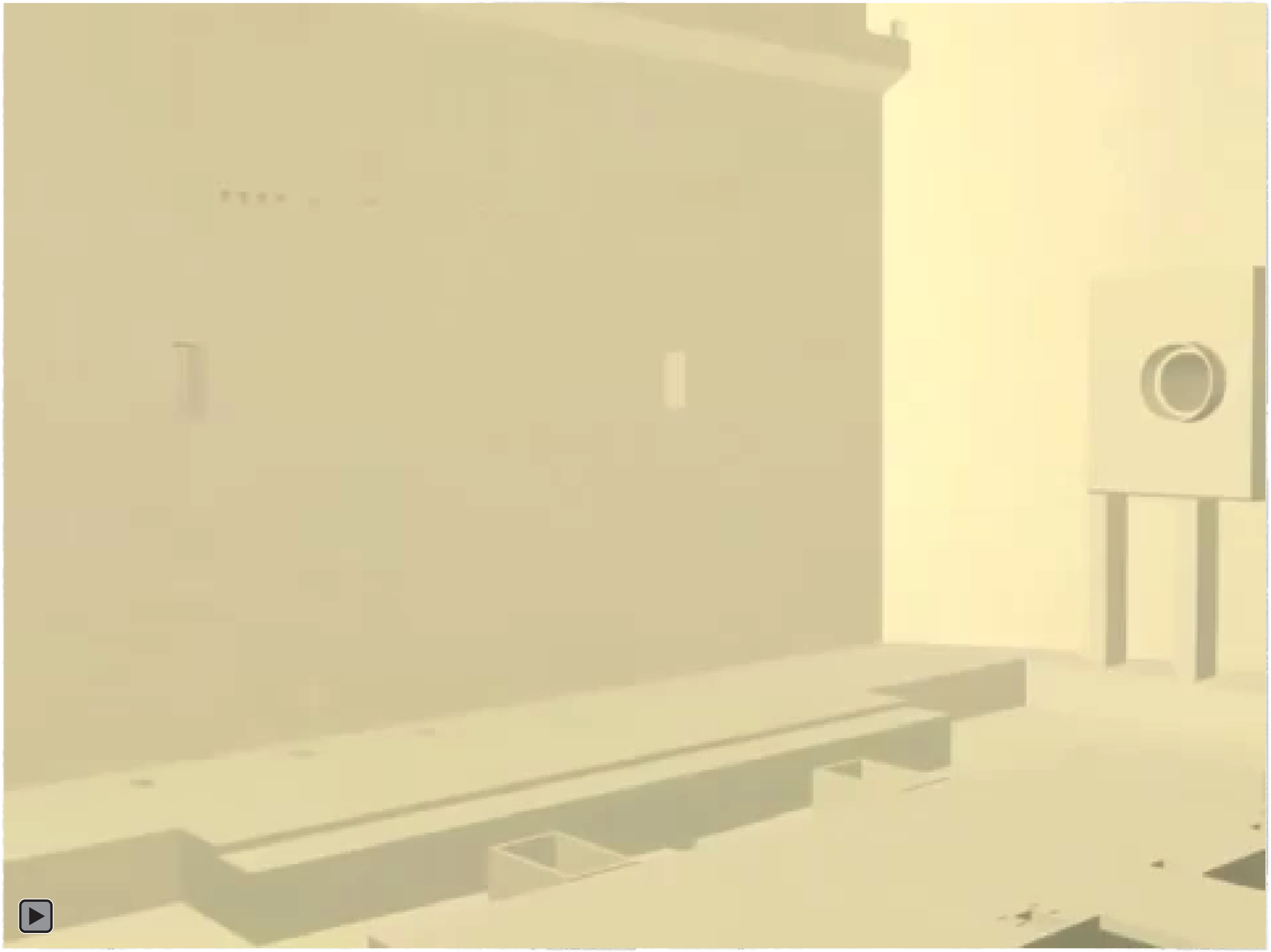
The Big Friendly Giants

- The two biggest detectors installed at the LHC accelerator: ATLAS and CMS.
  - **ATLAS** is 45 m long and 25 m wide, but weighs "only" 7000 t;
  - **CMS** is smaller, 21 meters long and 15 meters wide, but heavier, 12500 t.
- Installed in shafts at 100 m depth: big technological challenges for the installation!



from "An introduction to CMS experiment at CERN"

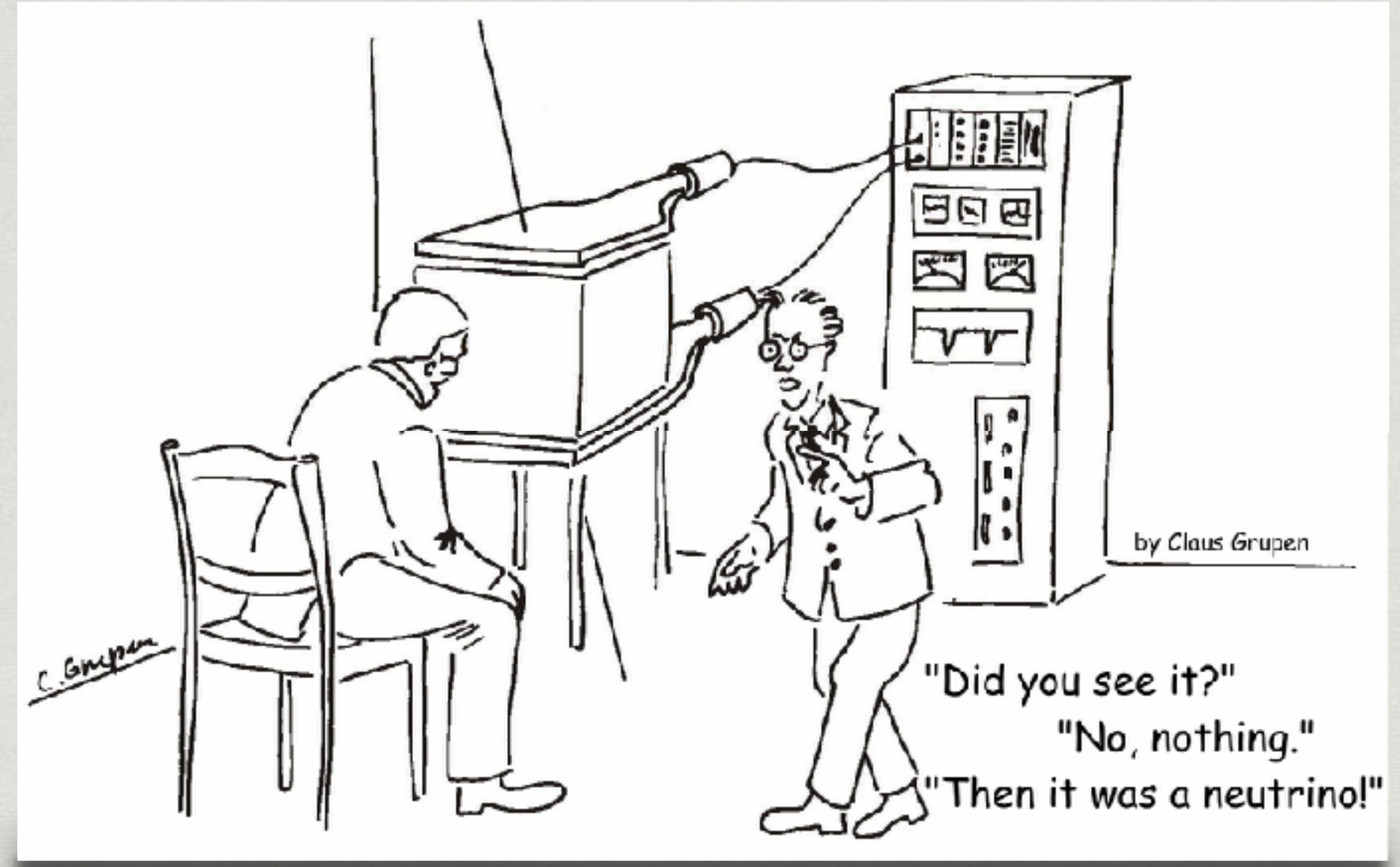
An insight into ATLAS detector



from “ATLAS - Episode 1 -A New Hope”

The ghosts catchers

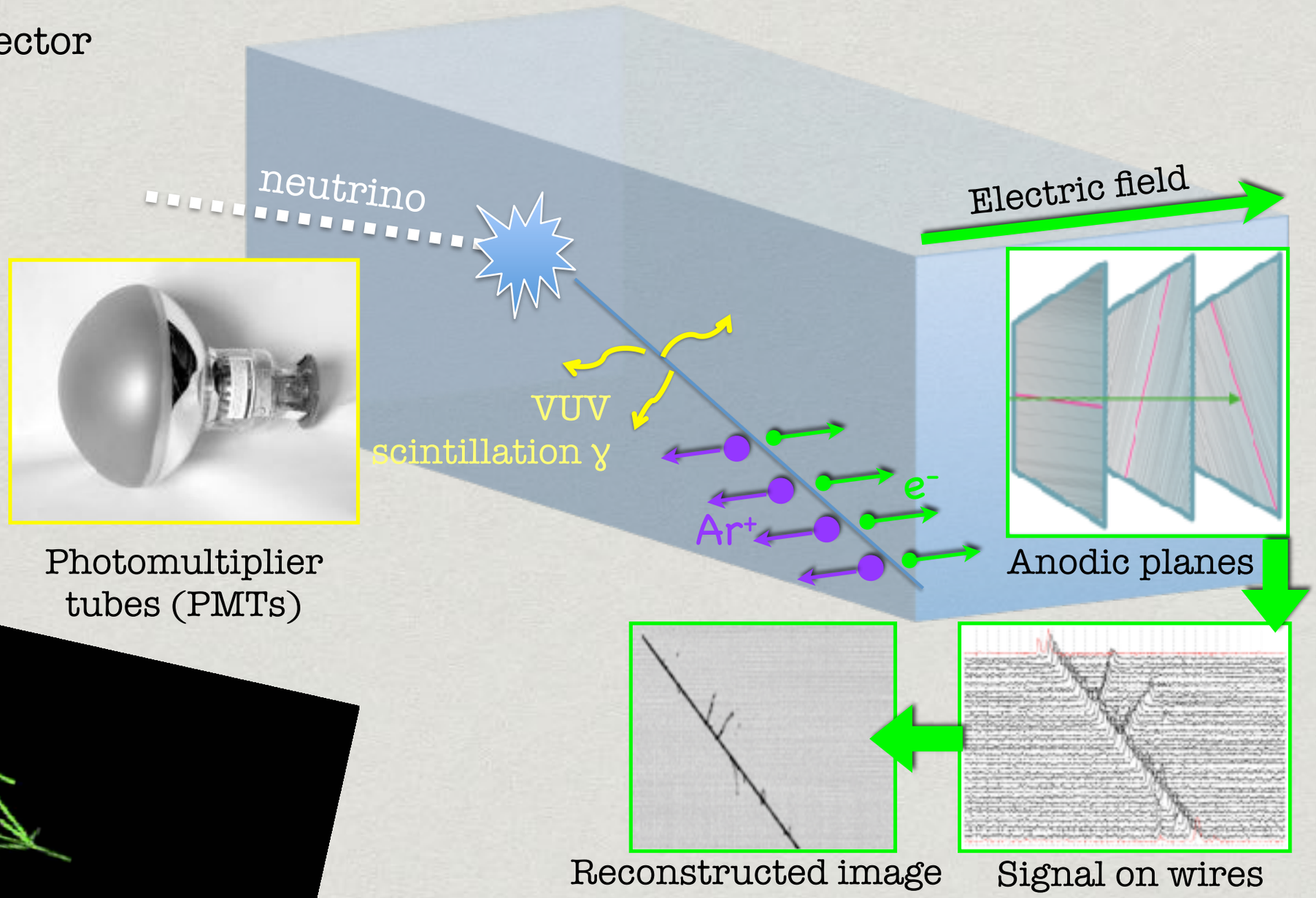
- Another big challenge is the search for rare events: neutrino interactions, dark matter, neutrino less double beta decay, proton decay, etc.

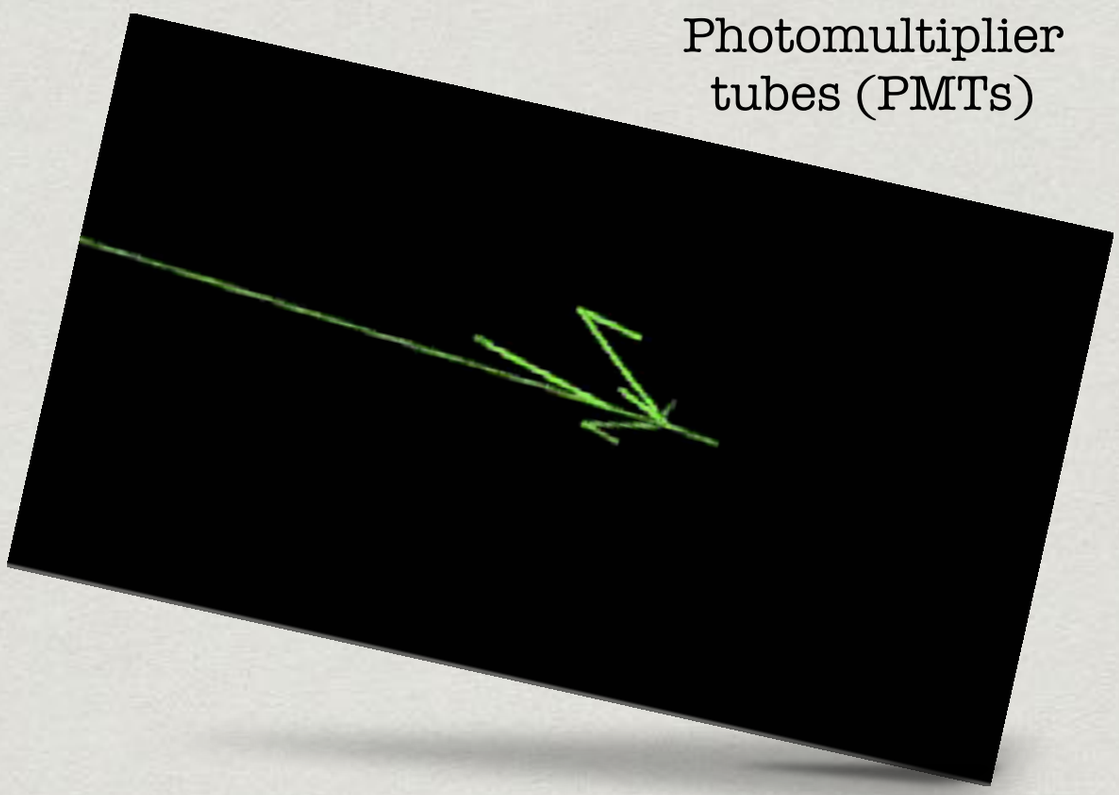


- The trick consists in exploiting extremely massive detectors, still with excellent tracking and calorimetric properties.
- Typically installed deep underground for shielding the cosmic radiation.

Liquid argon TPC

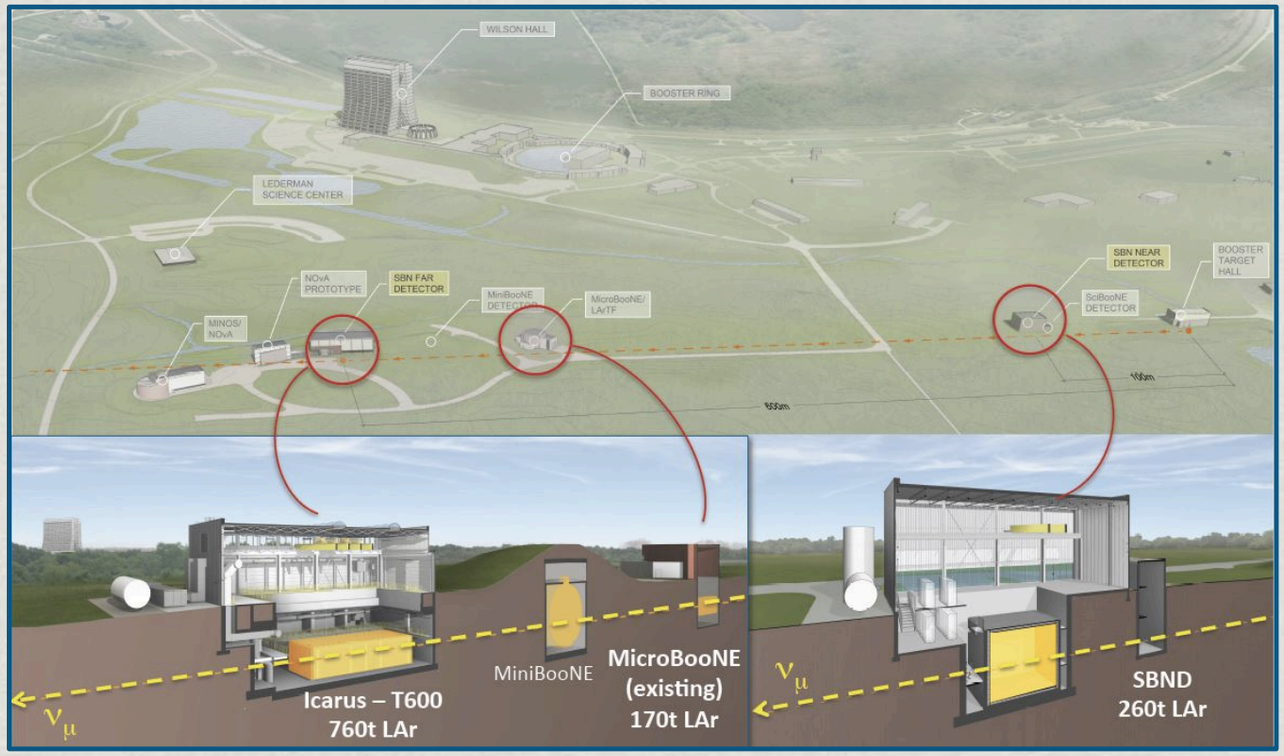
- "New" technique: H. Chen (1976) [FNAL P-496], C. Rubbia (1977) [CERN-EP/77-08]
- Both scintillation detector and TPC





Special 3x1 deal: the SBN Program @ FNAL

- An experiment will be held at Fermilab starting in 2018, for investigating the possible existence of a 4th sterile ν.
- It will exploit 3 LAr-TPC detectors:
  - **SBND**, 112 t of LAr active mass at 110 m from target, to be built anew;
  - **MicroBooNE**, 87 t at 470 m, already installed and taking data;
  - **ICARUS**, 476 t at 600 m, operated in 2010-2013 in Italy, refurbished at CERN and just arrived at Fermilab!

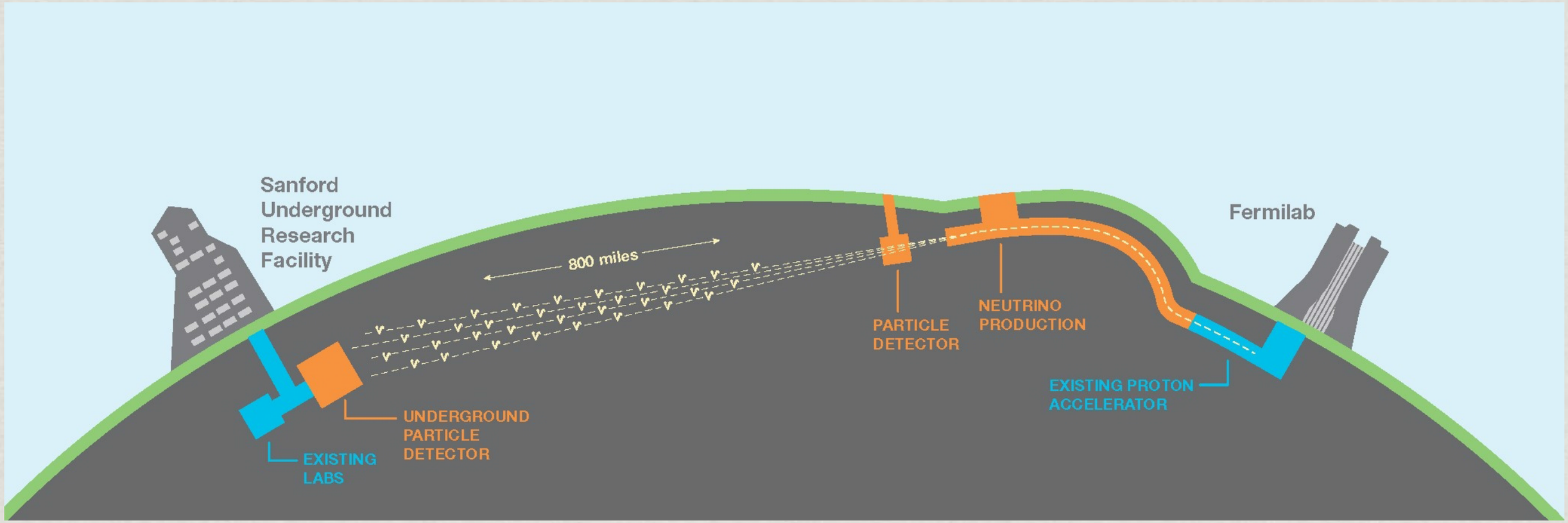


A DUNE-ish future

960 scientists,
163 institutions

- Ultimate ? experiment.
- Broad Physics Programme:
  - MH, δ_{CP}, θ_{23}, θ_{13} from ? oscillation;
  - core collapse supernova neutrinos;
  - baryon number non conservation.
- Near detector + 40 ktons LAr-TPC Far detector on 1300 km ? beam.
- Data taking expected starting in 2026.

31 countries



DETECTING @ FERMILAB