High Energy Physics Experiments: What? How? Why?

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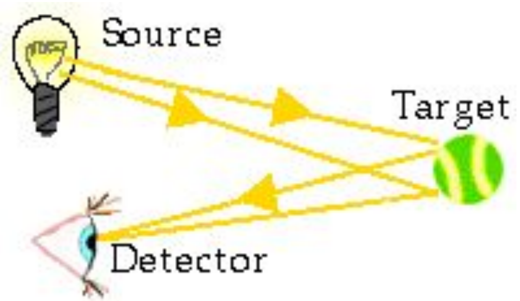
How do we search for new particles?

Before the particle accelerator

How do we “see” things

- By observing the things around

- Light waves, reflected from a target are detected by our eyes (colors, distance)



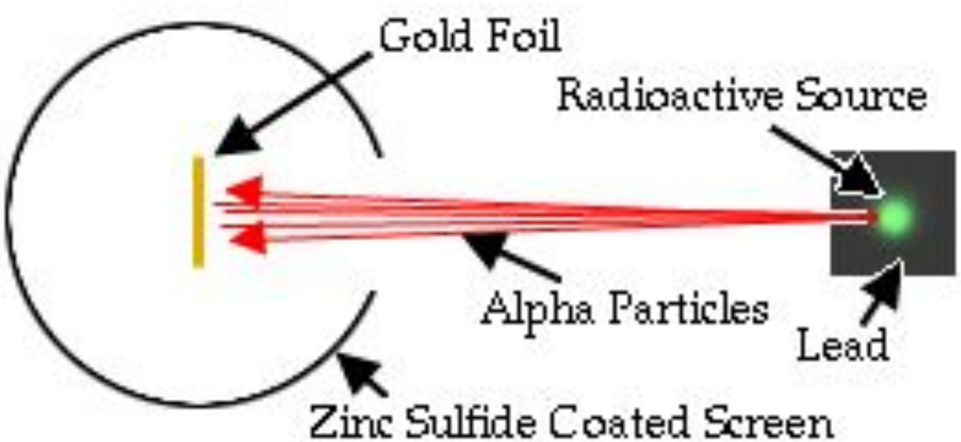
- Our brain analyses the information, and tells us if this is a ball
  - (If we have seen a ball before – so we build up on previous knowledge too)

In High Energy Physics

- We need

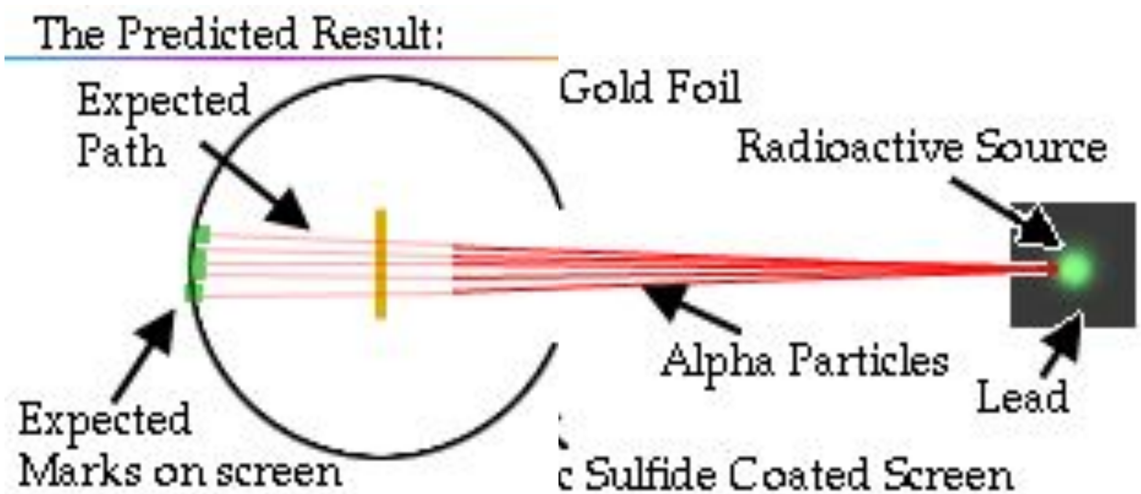
1) A beam of electrons, (anti-)protons, ions
2) A target – what we want to see and understand
3) A detector

- and often a theory !



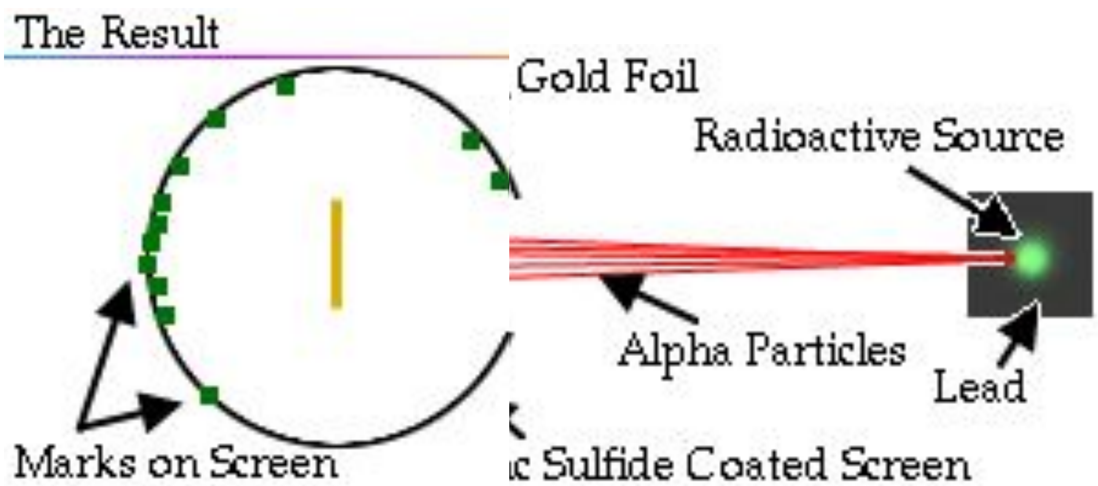
E. Rutherford (1909) shot a stream of alpha-particles on a gold foil.

In High Energy Physics



He expected the particles to go right through

In High Energy Physics



Found points everywhere around on the screen.

Discovery of the atomic substructure!

The first particle physics experiment ! Principles are still valid.

High Energy Physics

Small

Fast

	Classical Mechanics	Quantum Mechanics
Fast	Relativistic Mechanics	Quantum Field Theory

Units and Numbers in HEP

- Mass is measured in eV/c^2 where c = speed of light
  - $1\ eV/c^2 = 1.8 \times 10^{-36}\ kg$
  - $m_{proton} = 1\ GeV/c^2 = 2 \times 10^{-27}\ kg$
  - $m_{electron} = 0.5\ MeV/c^2 = 1 \times 10^{-30}\ kg$
  - $m_{sun} \sim 2 \times 10^{30}\ kg$
  - $m_{Higgs} = 125\ GeV/c^2 \sim 10^{-25}\ kg$

We will mostly use the unit “GeV”= Giga electronvolt

A bit of Special Relativity

value

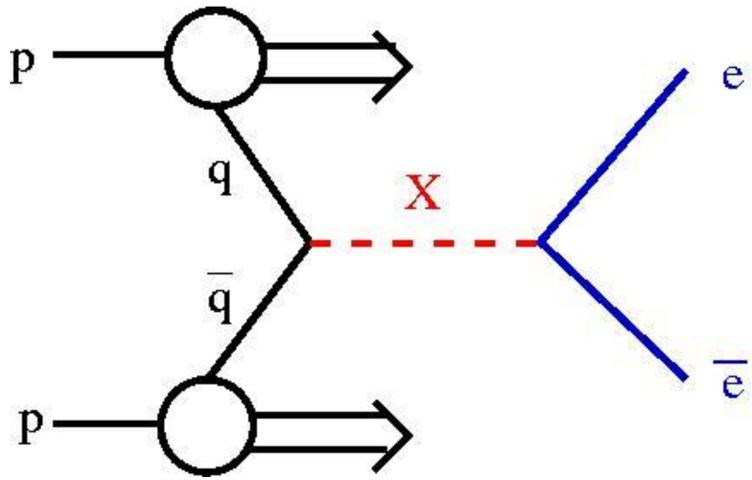
energy | mass | speed of light

$$E = mc^2$$

J | kg | 299,792,458 m/s

units

$c^2 = 89{,}875{,}517{,}873{,}681{,}800\ m^2/s^2$



- Collide 2 protons with E=3,500 GeV
  - Total energy: E=7,000 GeV
  - Can create particle X with mass $m_X < 7{,}000\ GeV/c^2$
    - Actual interactions occur between quarks and gluons that carry part of proton energy
    - Most particles we create live only for a very short fraction of a second and then decay

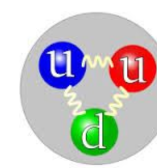
A bit of Quantum Mechanics

- de Broglie: the wavelength λ associated with a massive particle is related to its momentum p through the Planck const h:

$$\lambda = h/p$$

($h = 6.62607004 \times 10^{-34}\ m^2\ kg / s$
or $h = 4.135\ 667\ 662 \times 10^{-15}$ eV s)

- Fundamental relation to "seeing" smaller
- Resolution increases as energy (momentum) goes up
- For examples:
  - $p = 1$ GeV/c $\Rightarrow 10^{-15}$ m ≈ size of proton
  - $p = 1000$ GeV/c $\Rightarrow 10^{-18}$ m ≈ size of proton sub-structure

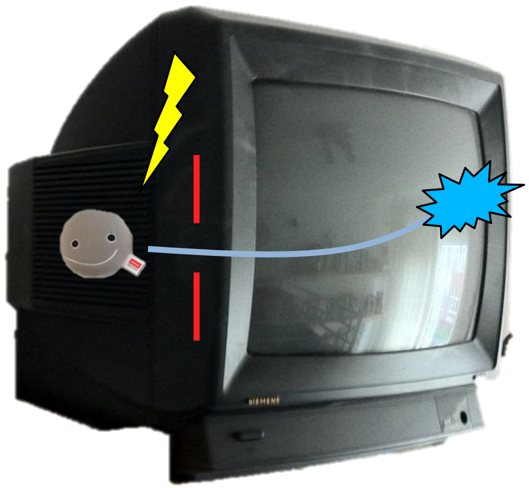


Why Colliders?

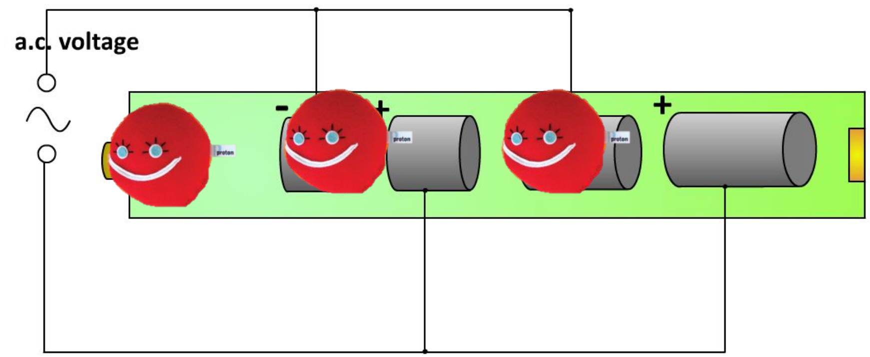
- Rutherford's experiment is a "fixed target" experiment
  - Center of Mass Energy ∝ √(Incoming Energy)
- Not as much energy as when colliding beams of particles: Center of Mass Energy ∝ Incoming Energy
- But you can also miss "target" more easily
- So put them in a ring – if you miss it once, you can re-use the same particles again ⇒ Birth of colliders!

Fermilab outside Chicago, p(antip) collision
Discovery of Top Quark

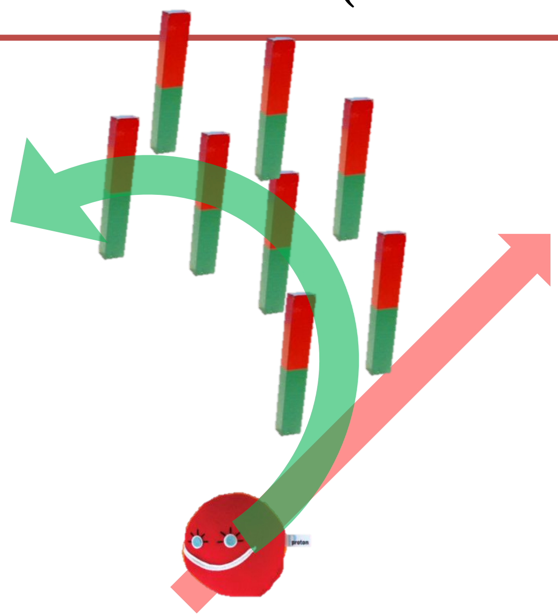
CERN, Previously e+e- collision (LEP)
Now p-p (LHC), Higgs Boson



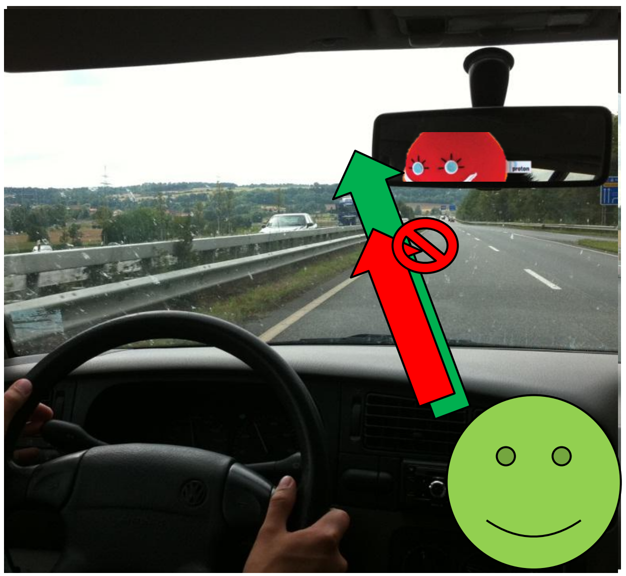
1. Electrical Field (→ accelerates)



2. Every time (→ more energy)



3. Magnets (→ turn)

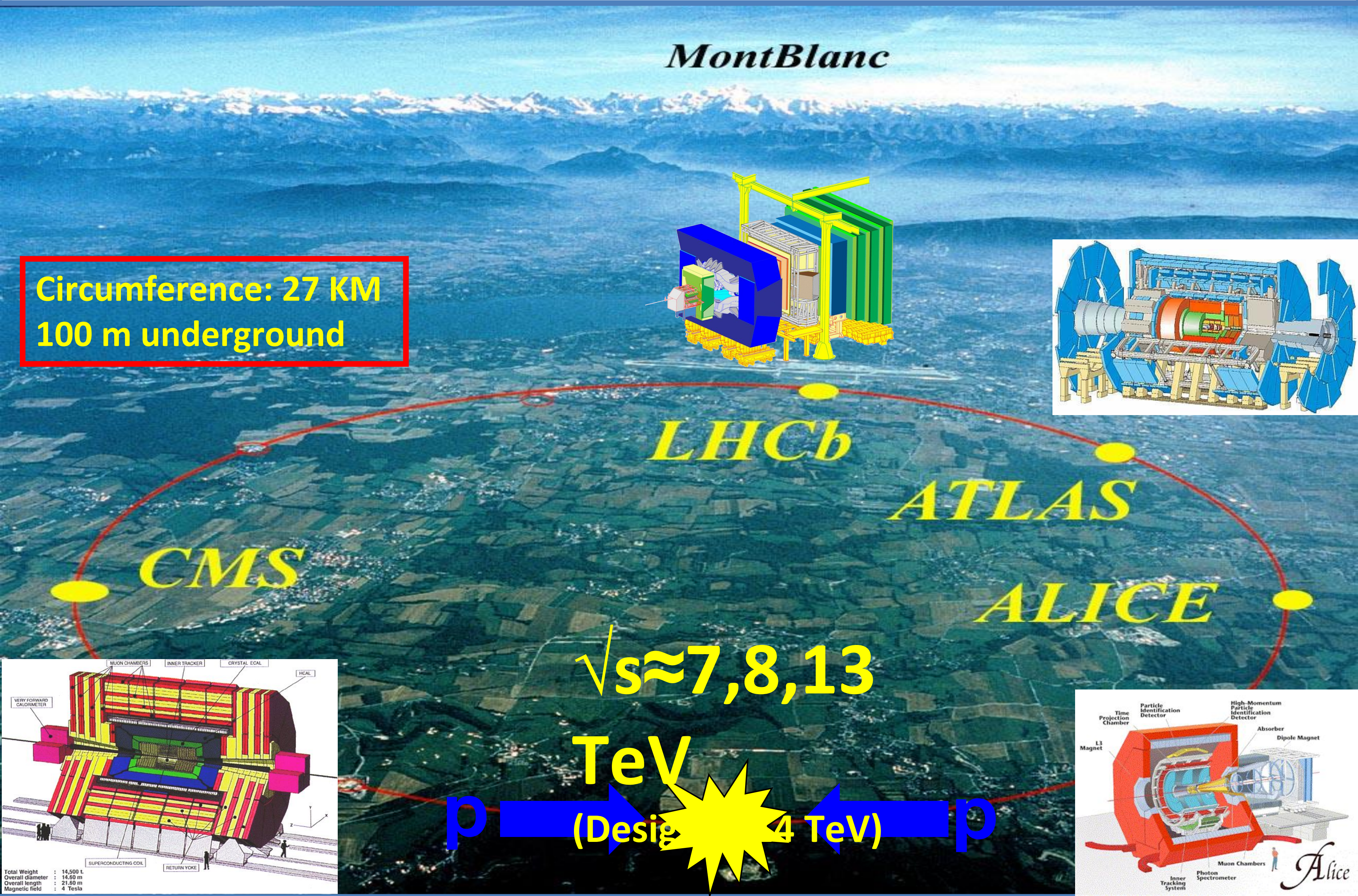


4. Vacuum (→ nothing on the way)

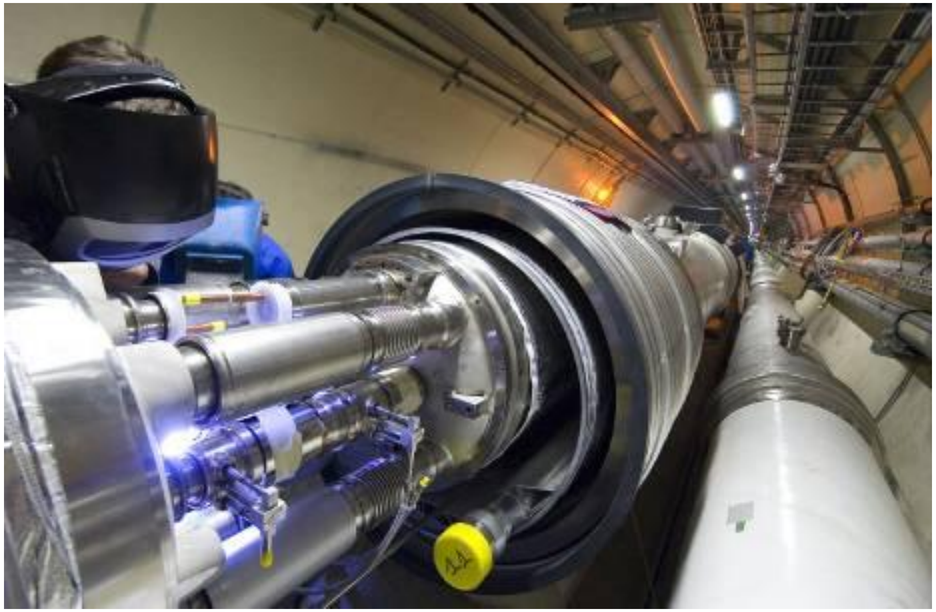
One of the **fastest** racetracks on the planet – the **L**arge **H**adron **C**ollider (LHC)

Several thousand billion protons travelling at 99.9999991% of the speed of light will travel round the 27km ring over 11000 times a second!

The Large Hadron Collider (LHC)



The **emptiest** space in the solar system

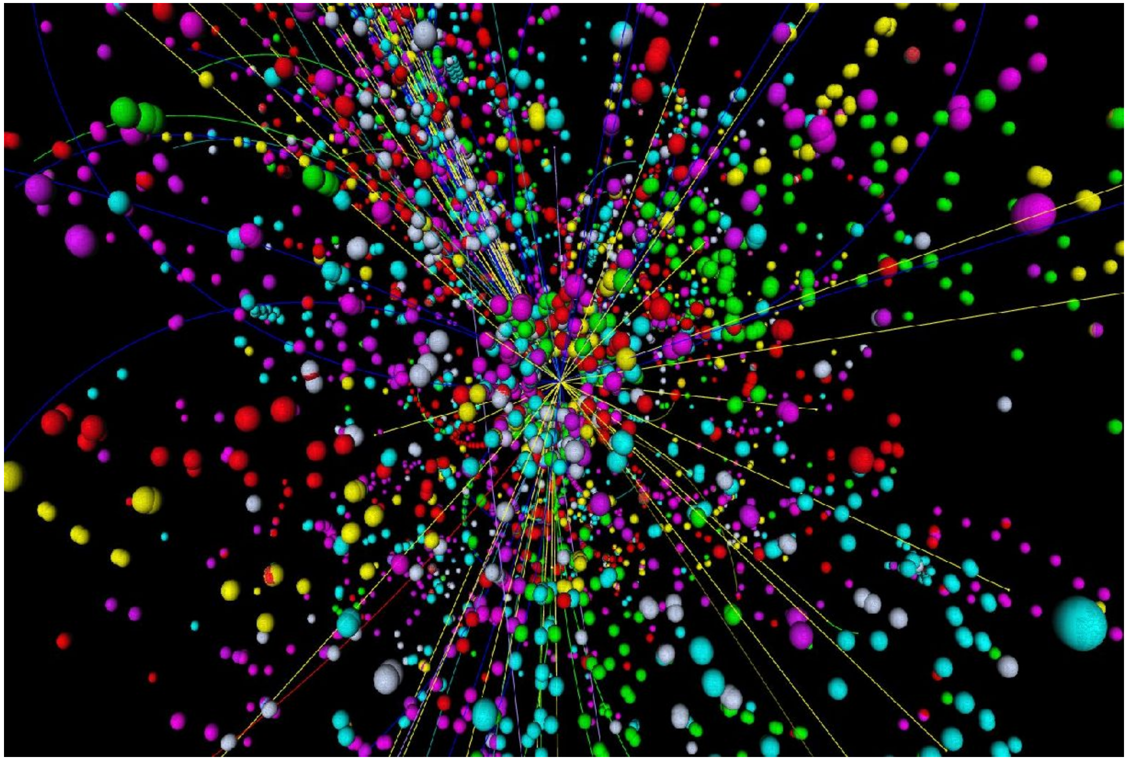


To accelerate protons to almost the speed of light, we need a vacuum similar to outer space. The pressure in the beam-pipes of the LHC will be about ten times lower than on the moon.

One of the **coolest** places in the Universe

With a temperature of around -271 degrees Celsius, or 1.9 degrees above absolute zero, the LHC is colder than outer space.

One of the **hottest** places in the Galaxy



When two beams of protons collide they generate, within a tiny volume and for a tiny fraction of a second, temperatures more than a billion times those in the very heart of the Sun.

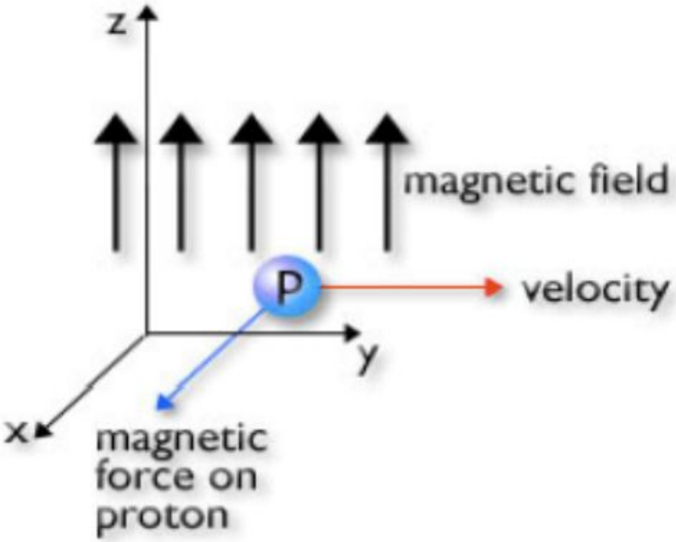
LHC the Accelerator

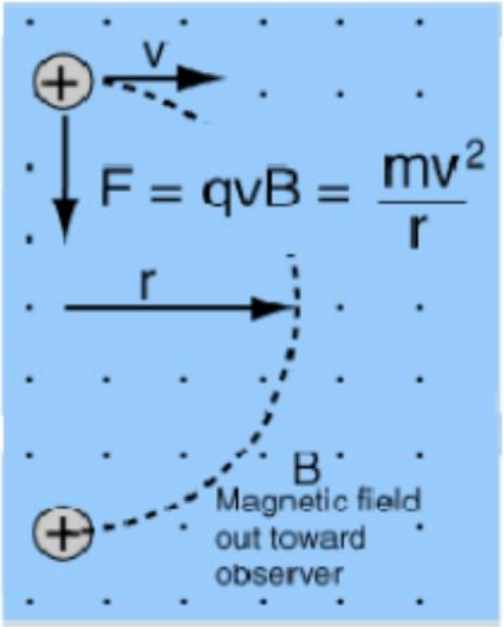
- 30,000 tons of 8.4T dipole magnets (1232 magnets)
- Cooled to 1.9K with 96 tons of liquid helium
- Energy of beam = 362 MJ
  - 15 kg of Swiss chocolate

Protons in the Accelerator

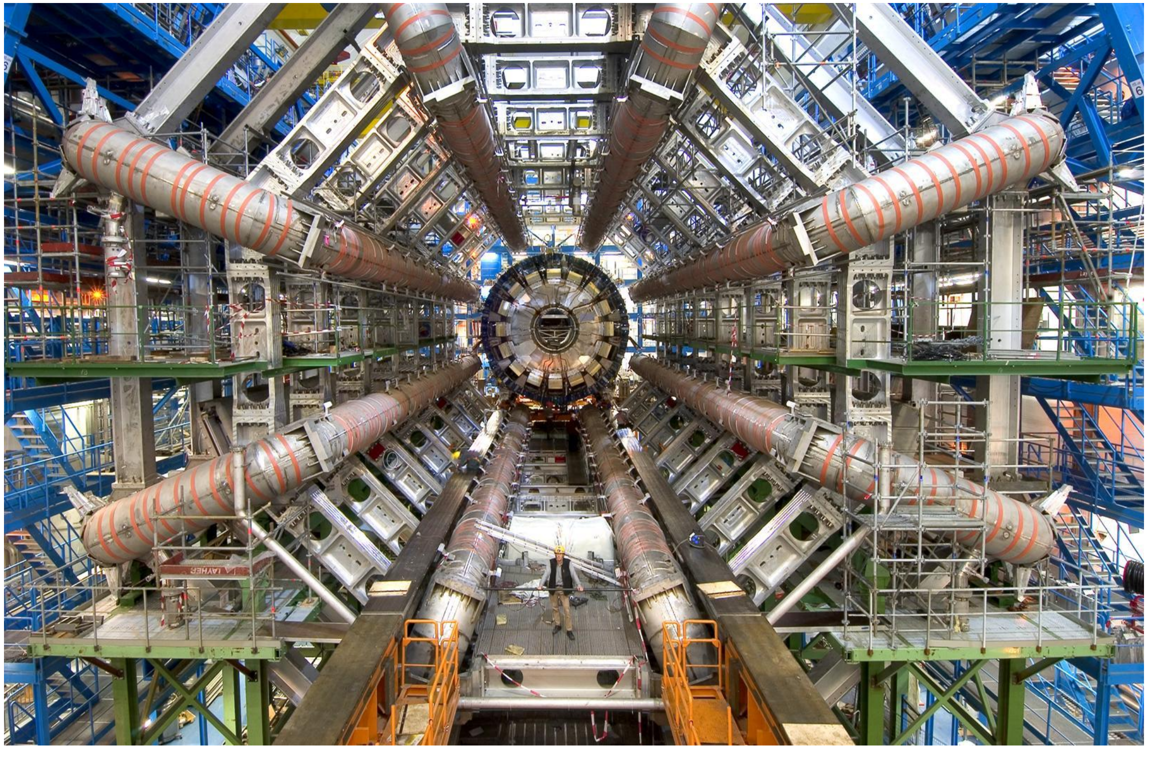
With F=qE (Maxwell) and F=ma (Newton)
Acceleration: a = qE/m

Magnets are used to steer proton beams in circle using
Lorentz Force ($F=qvB=mv^2/r$)





Using the **largest and most complex detectors** ever built

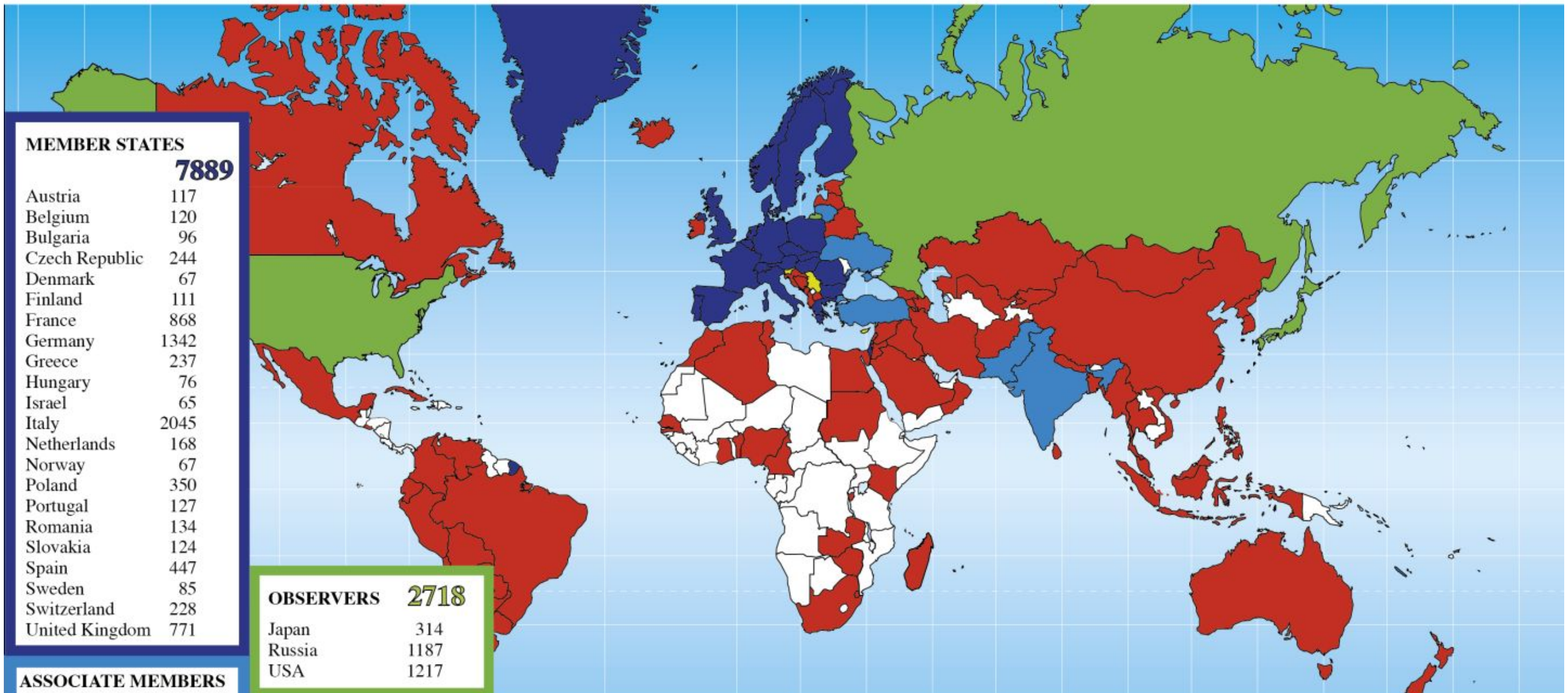


ATLAS detector during construction (see the person there?)

To select and record the signals from the 600 million proton collisions every second, CERN scientists are building huge detectors to measure the tiny particles to an extraordinary precision.

Every day more than **10000 scientists** work at CERN

Distribution of All CERN Users by Nationality on 24 January 2018



MEMBER STATES 7889

Austria	117
Belgium	120
Bulgaria	96
Czech Republic	244
Denmark	67
Finland	111
France	868
Germany	1342
Greece	237
Hungary	76
Israel	65
Italy	2045
Netherlands	168
Norway	67
Poland	350
Portugal	127
Romania	134
Slovakia	124
Spain	447
Sweden	85
Switzerland	228
United Kingdom	771

OBSERVERS 2718

Japan	314
Russia	1187
USA	1217

ASSOCIATE MEMBERS 745

India	357
Lithuania	35
Pakistan	65
Turkey	173
Ukraine	115

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP 118

Cyprus	26
Serbia	57
Slovenia	35

OTHERS 1872

Afghanistan	1
Albania	3
Algeria	14
Argentina	27
Armenia	19
Australia	31
Azerbaijan	10
Bangladesh	11
Belarus	48
Benin	1
Bolivia	4
Bosnia & Herzegovina	2
Brazil	135
Burundi	1
Cameroon	1
Canada	161
Chile	20
China	510
Colombia	45
Croatia	41
Cuba	12
Ecuador	6
Egypt	31
El Salvador	1
Estonia	15
Georgia	46
Ghana	1
Hong Kong	1
Iceland	3
Indonesia	11
Iran	51
Iraq	1
Ireland	16
Jordan	1
Kazakhstan	5
Kenya	3
Korea Rep.	185
Kyrgyzstan	1
Latvia	2
Lebanon	23
Luxembourg	2
Madagascar	4
Malaysia	15
Malta	9
Mauritius	1
Mexico	82
Mongolia	2
Montenegro	11
Morocco	20
Myanmar	1
Nepal	10
New Zealand	5
Nigeria	3
North Korea	1
Oman	3
Palestine (O.T.)	7
Paraguay	2
Peru	7
Philippines	3
Saint Kitts and Nevis	1
Saudi Arabia	2
Senegal	1
Singapore	4
South Africa	56
Sri Lanka	6
Sudan	1
Swaziland	1
Syria	1
Taiwan	51
Thailand	22
T.F.Y.R.O.M.	2
Tunisia	5
Uruguay	1
Uzbekistan	4
Venezuela	10
Viet Nam	13
Zambia	1
Zimbabwe	2

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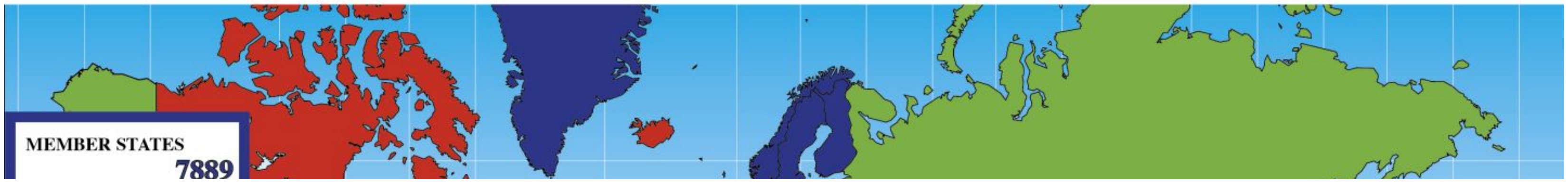
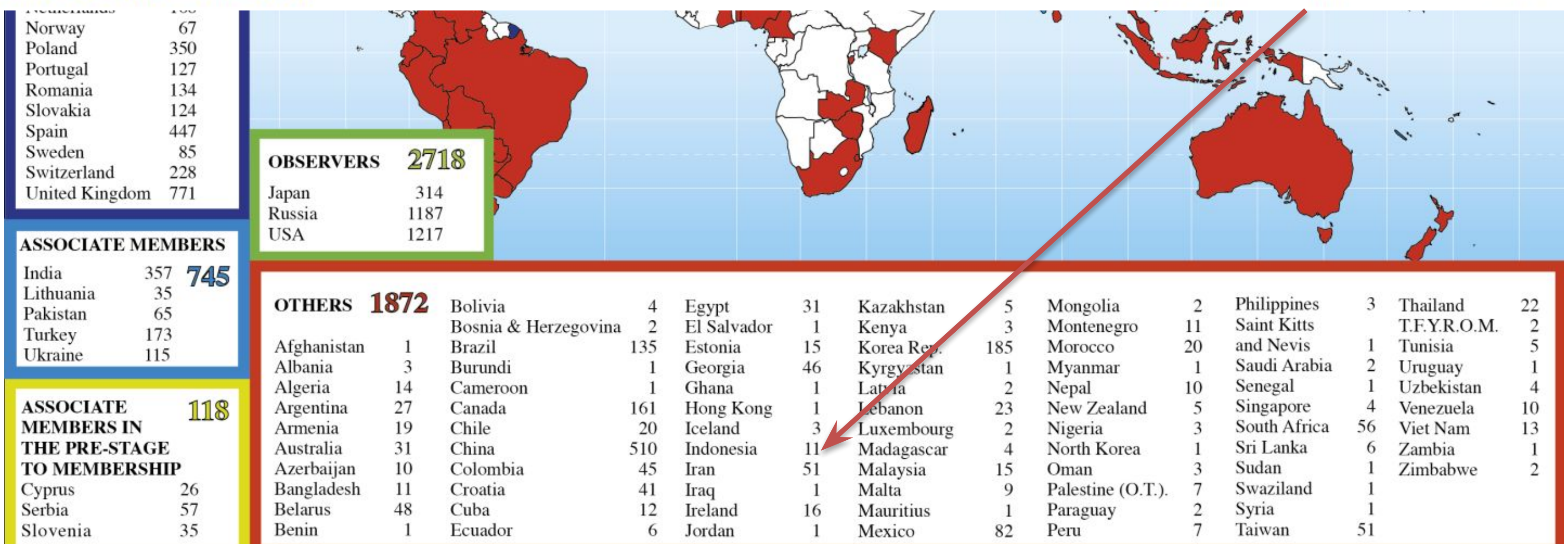


Institute Name	Institute Parent Name	Town	Country	Experiment Name
Institute for Research in Fundamental Sciences		Teheran	Iran	CMS
K.N Toosi University of Technology		Teheran	Iran	ISOLDE
K.N Toosi University of Technology		Teheran	Iran	IS492



QUESTIONS