Title: Pauline Gagnon: Improbable Feats and Useless Discoveries

Date: Nov 08, 2017 07:00 PM

URL: http://pirsa.org/17110066

Abstract: As a child, Quebec native Pauline Gagnon dreamed of understanding what the universe was really made of.

<p style="margin: 0px 0px 10px; padding: 0px; color: rgb(59, 59, 59); text-transform: none; line-height: 20.52px; text-indent: 0px; letter-spacing: normal; font-style: normal; font-variant: normal; font-weight: normal; word-spacing: 0px; white-space: normal; font-size-adjust: none; font-stretch: normal; background-color: rgb(255, 255, 255); -webkit-text-stroke-width: 0px;">As an adult, she studied exactly that, working at the largest experiment ever built, CERNâ€™s Large Hadron Collider. In her role as a Senior Research Scientist, based at Indiana University and working at CERN, she searched for dark matter particles in the decays of the famous Higgs boson, in the form of hypothetical particles called dark photons.

Now retired from active research, Gagnon is dedicated to inspiring other curious minds of all ages to ponder the same big questions that fascinated her as a child. Having worked in the CERN Communications group, she is adept at explaining the complex science of particle physics in engaging, comprehensible ways. She has delivered nearly 100 presentations to audiences in nine countries on three continents.

Gagnonâ€™s popular science book, Who Cares about Particle Physics: Making Sense of the Higgs boson, the LHC and CERN, not only explains current issues in particle physics but also explores the importance of fundamental physics in shaping not only our understanding of the universe, but in shaping society as well.

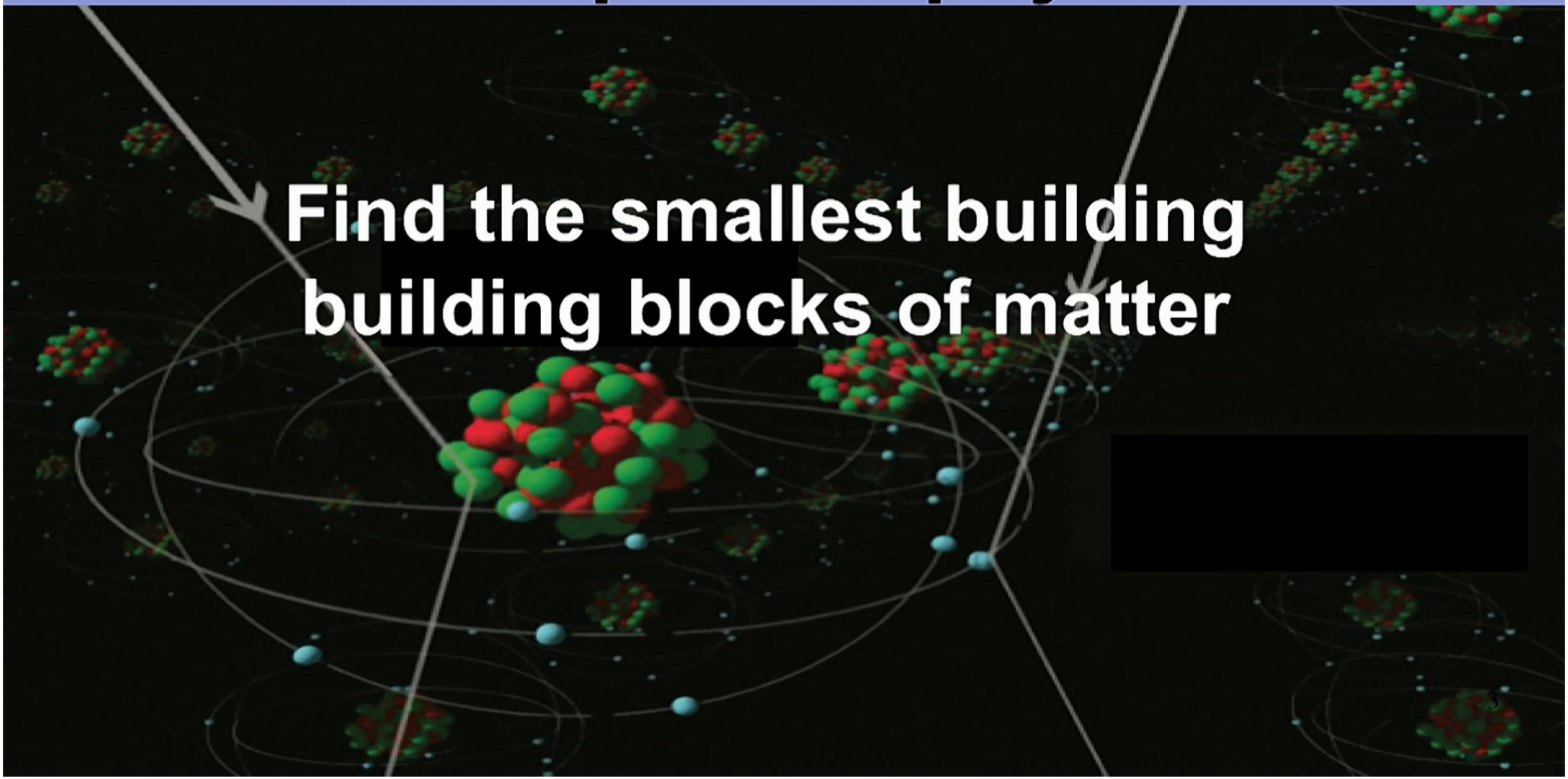
In her Perimeter Institute Public Lecture, Gagnon will explore the incredible (and improbable!) feats of ingenuity and cooperation that have led to one of humanityâ€™s greatest experiments, and why such pioneering research, albeit â€œuselessâ€• in terms of everyday practicality, has changed the way we live and is vital to our collective future.

Outline

- What is particle physics?
- How do we manage to achieve what may seem impossible
  - How do we work?
- Finding useless particles: Why do we do it?
- What is left to do?

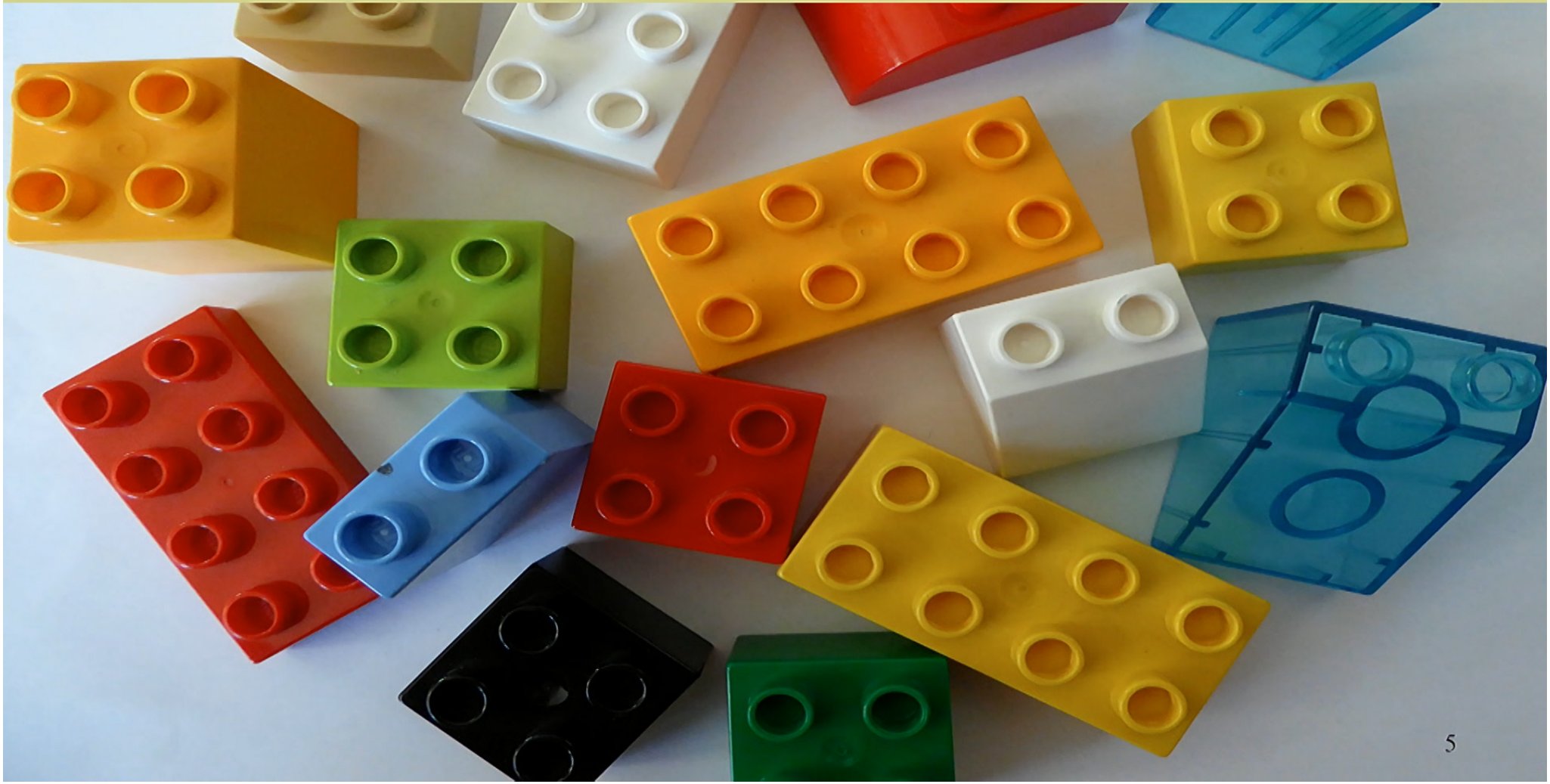



Aim of particle physics:

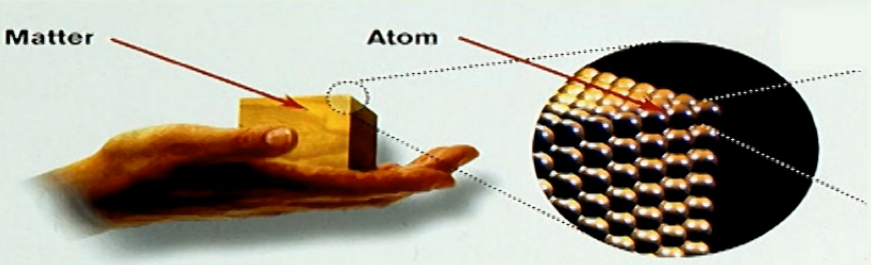


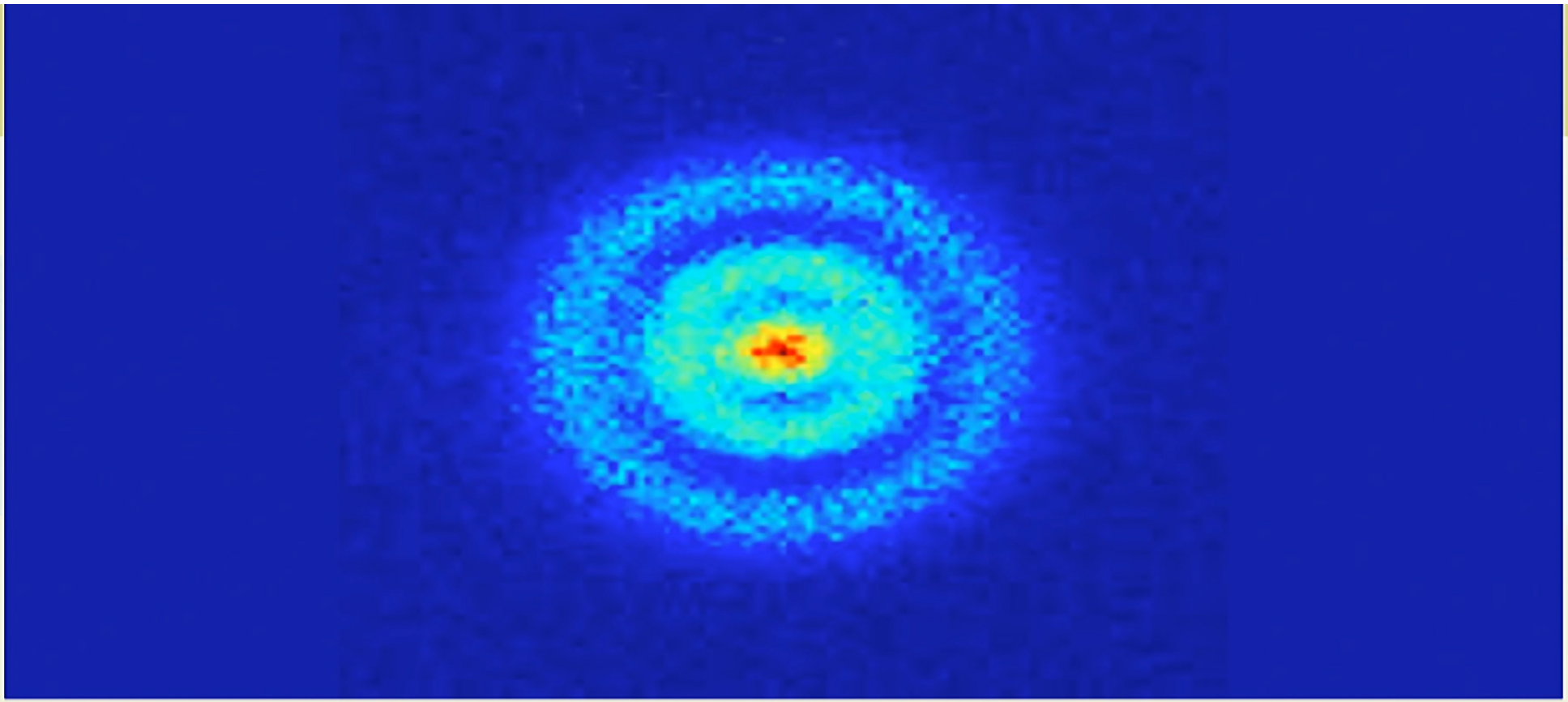
The Legoland version of Copenhagen

At Legoland, here are the fundamental particles



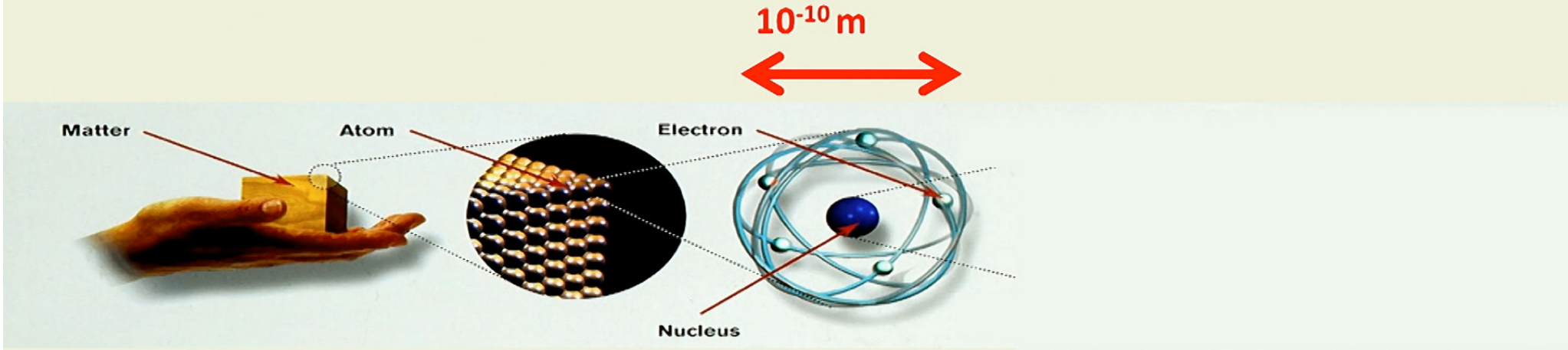
What are the smallest building blocks of matter?





An atom is a million times smaller than a hair

What are the smallest building blocks of matter?



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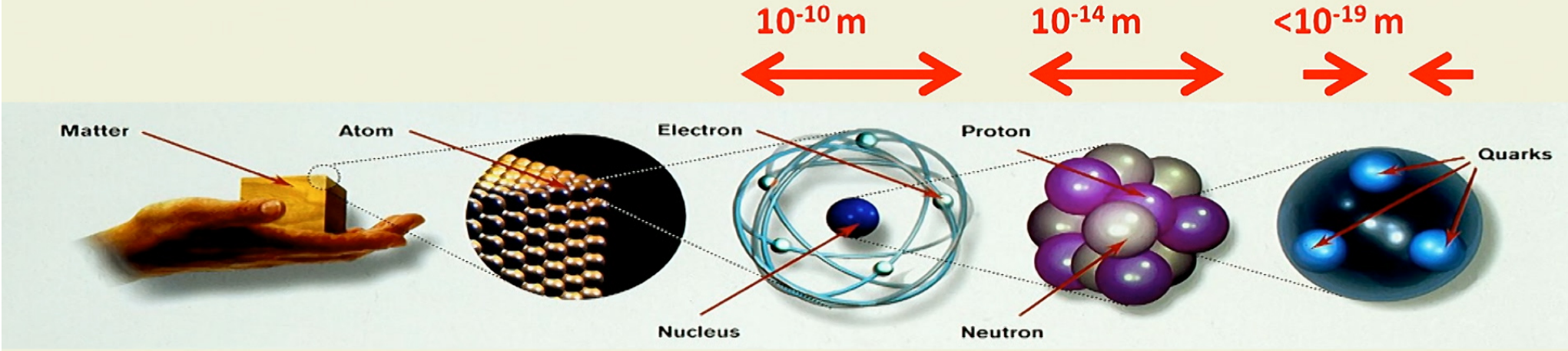


6

Protons and neutrons are made of quarks

Up :  (charge +2/3) and **down quarks:**  (charge -1/3)

7

Protons and neutrons are made of quarks

Up :  (charge +2/3) and **down quarks:**  (charge -1/3)

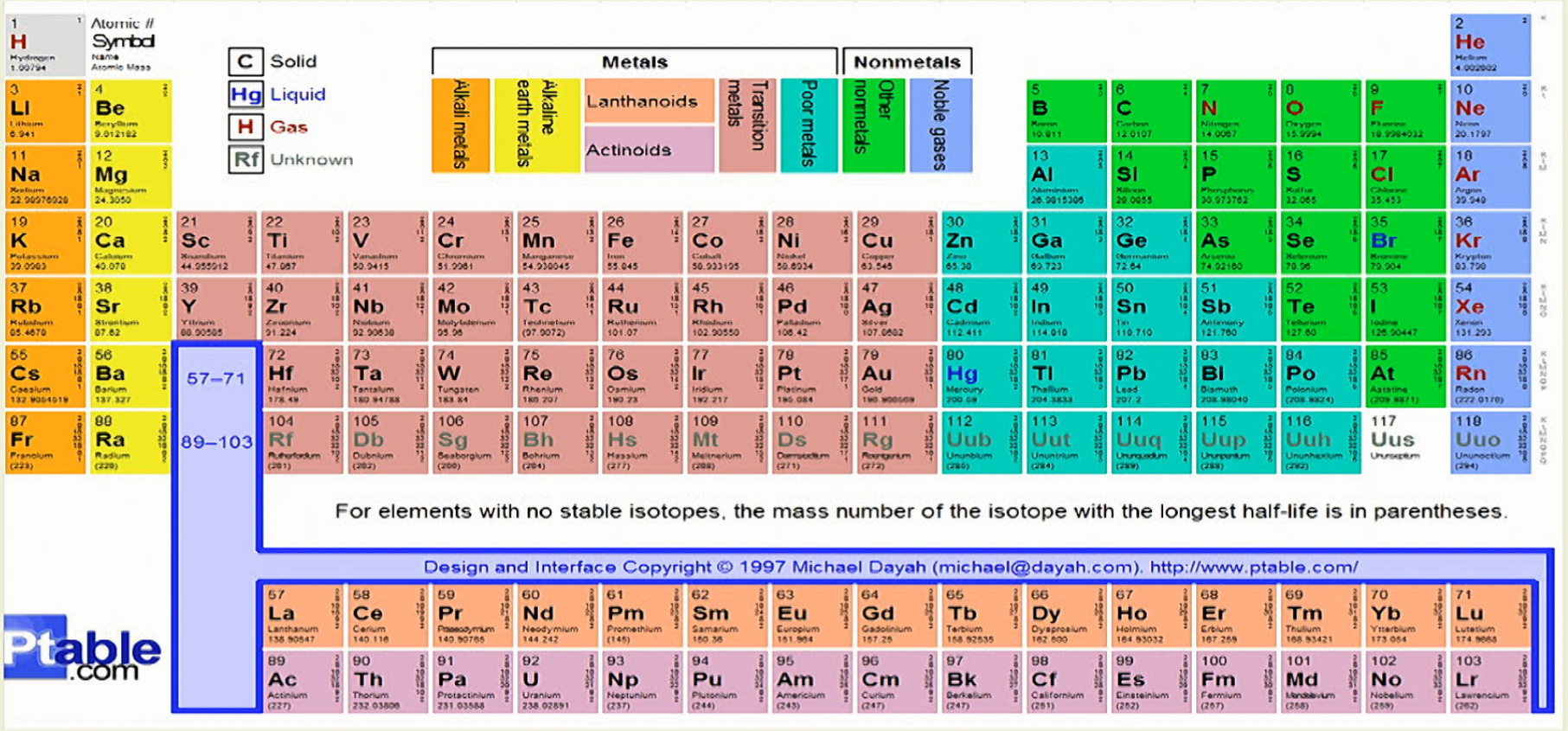
Proton:

up		up		down		proton
	+		+		=	
+2/3		+2/3		-1/3	=	+1

Neutron:

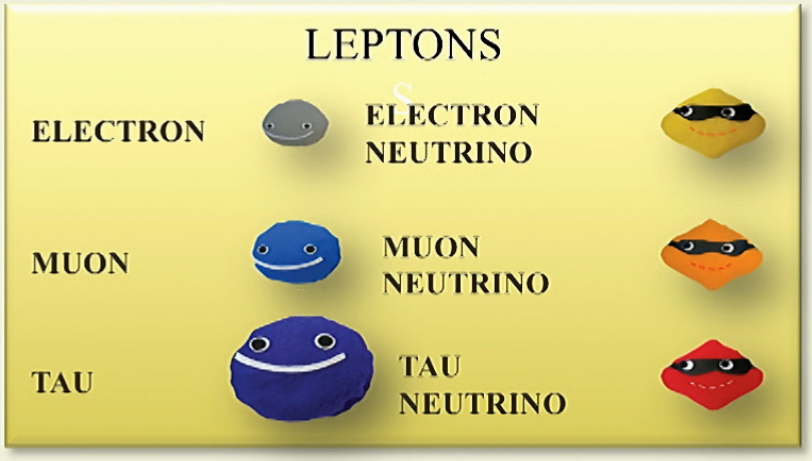
up		down		down		neutron
	+		+		=	
+2/3		-1/3		-1/3	=	0

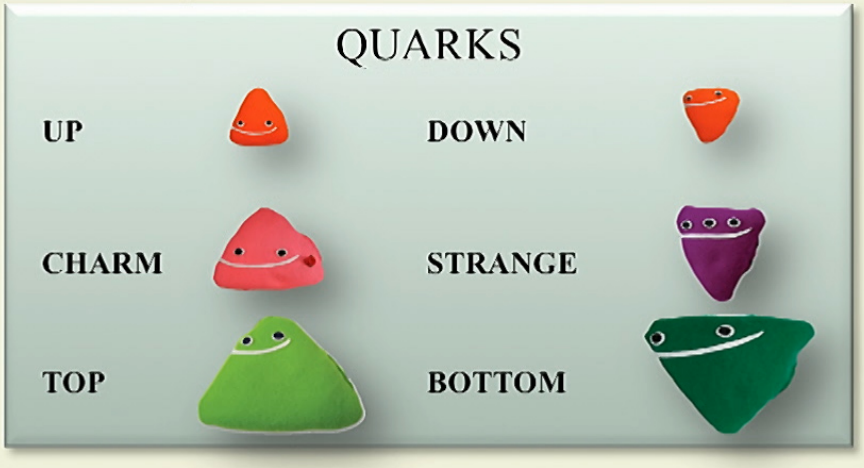
That's all you need to form all elements



The Standard Model

1. All matter is made of fundamental particles





www.particlezoo.net

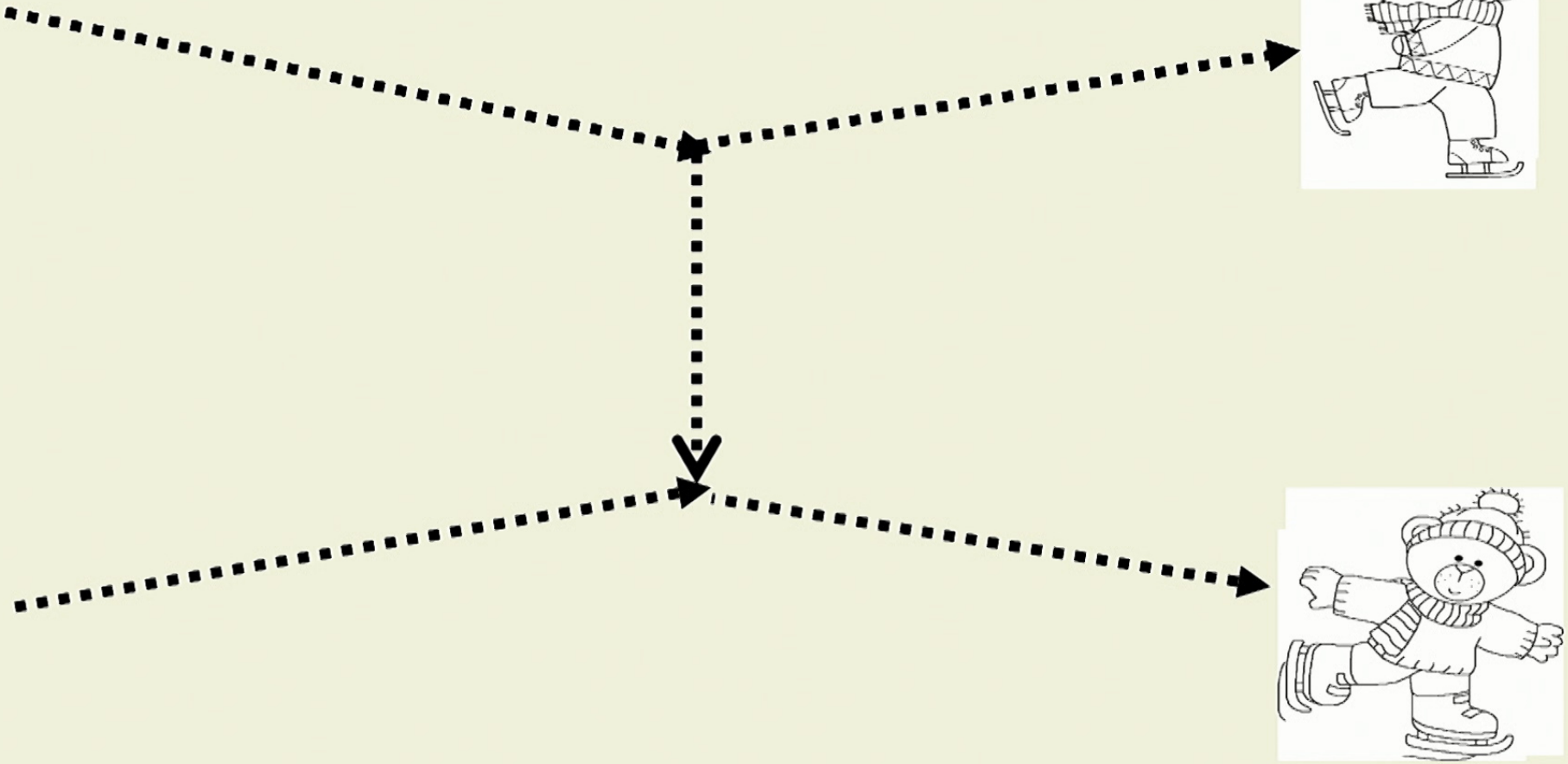
The Standard Model

1. All matter is made of fundamental particles

2. Exchange particles called **bosons** are associated to forces

www.particlezoo.net

Particles interact by exchanging other particles



How do these particles acquire a mass?

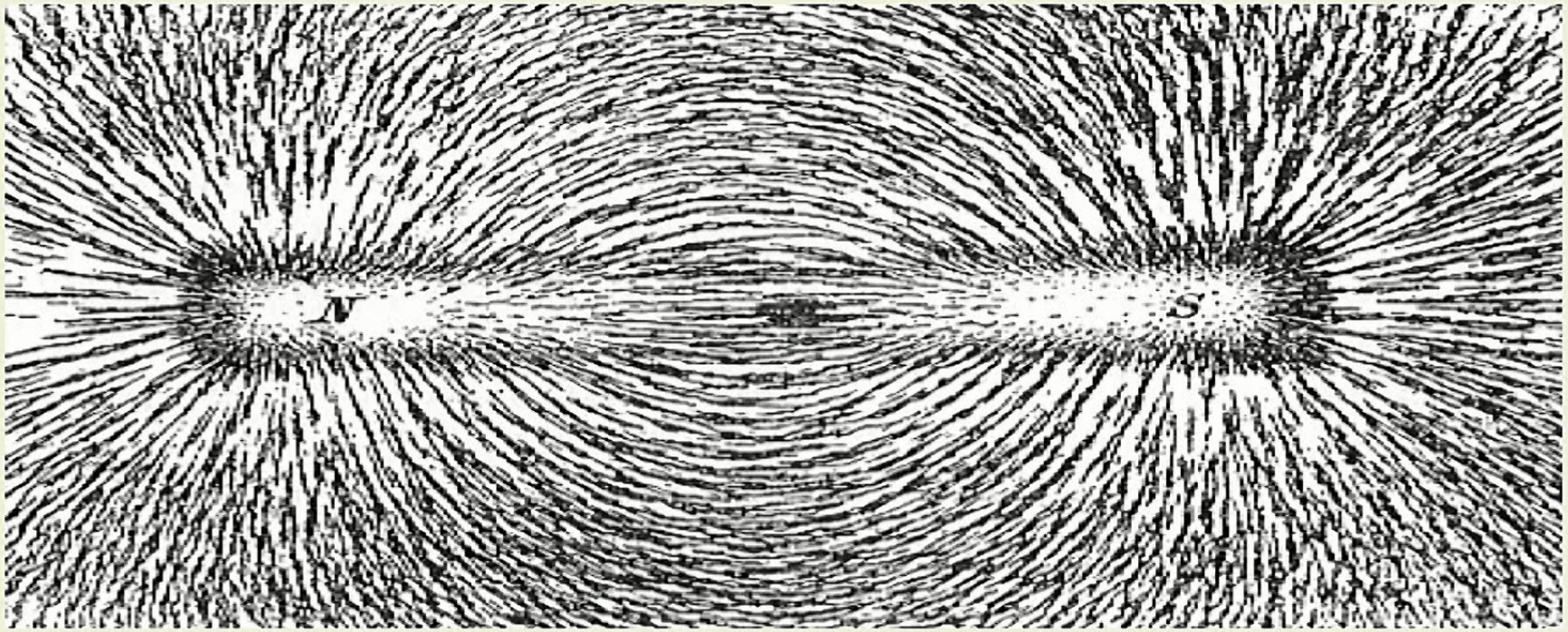
Tom Kibble, Gerald Guralnik, Carl Hagen, François Englert, Robert Brout, Peter Higgs

A mechanism to explain how particles acquire mass

This implied the existence of a new field

Particles acquire mass by interacting with this field

Magnetic field



To go further, we need three more concepts:

1. **Mass:**

   resistance to motion

2. **Energy and Mass are equivalent**

   $E = m c^2$

To go further, we need three more concepts:

1. **Mass:**

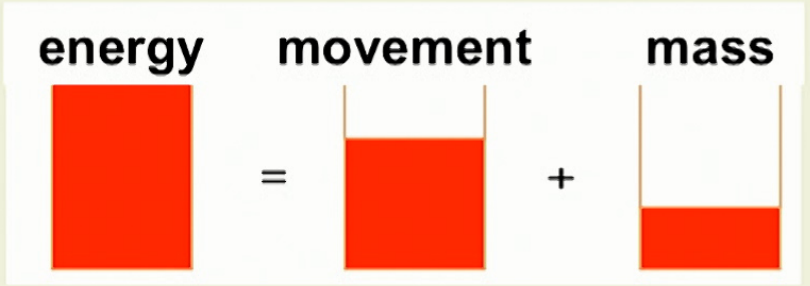
   resistance to motion

2. **Energy and Mass are equivalent**

   $E = m c^2$

3. **Energy conservation**

   Energy can take several forms but its sum is always conserved

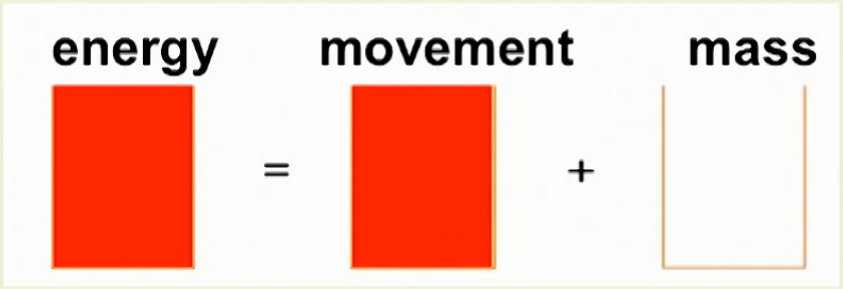


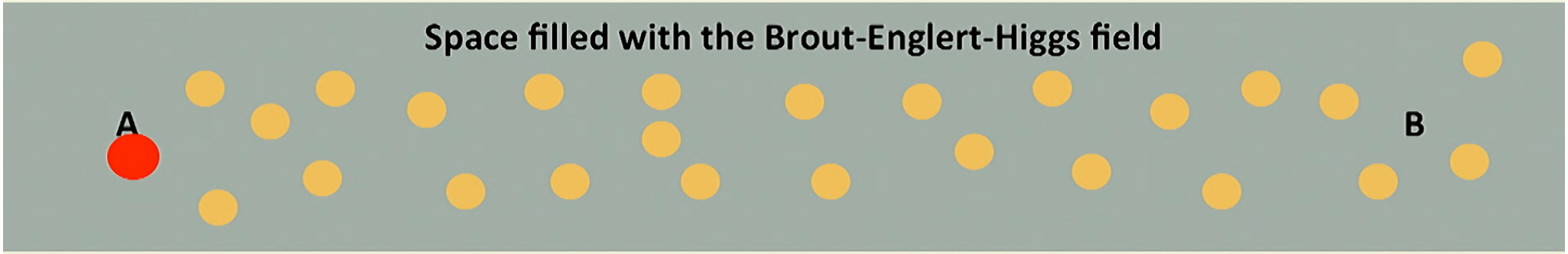
2. How does this field generate mass?

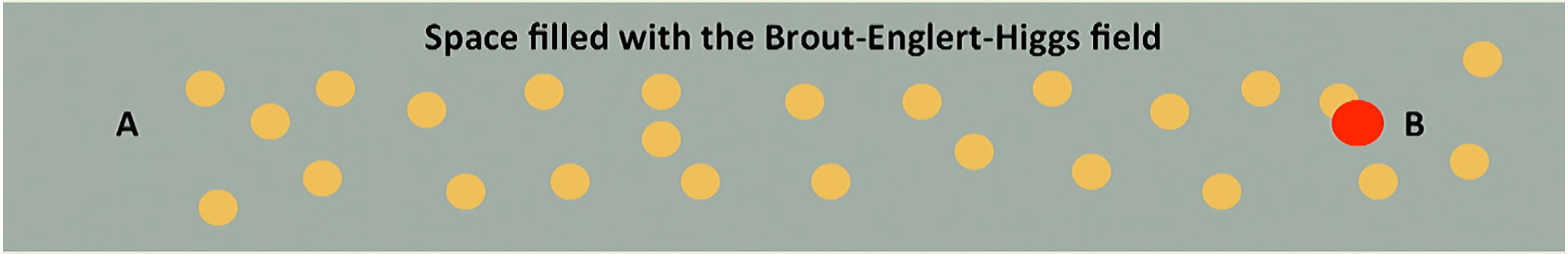
Empty space, without a Brout-Englert-Higgs field

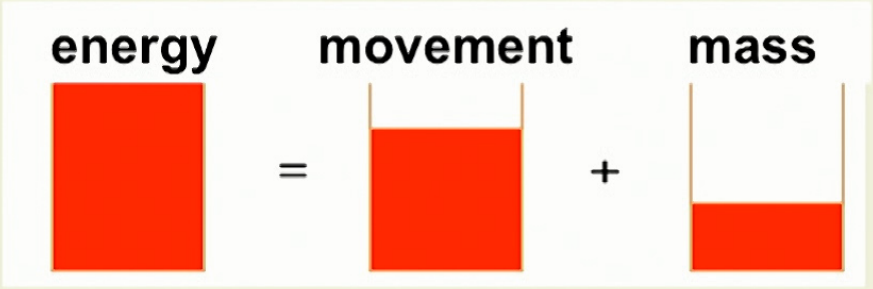
A

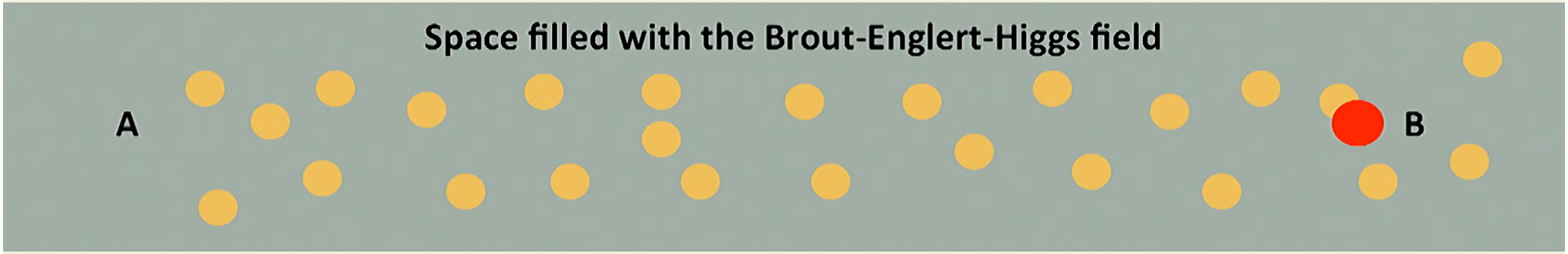
B

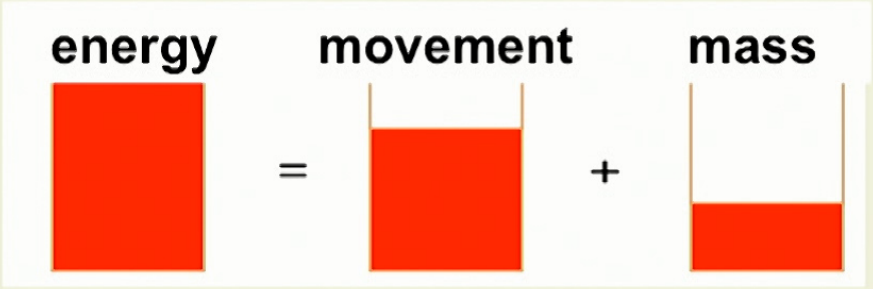



Space filled with the Brout-Englert-Higgs field
A
B


Space filled with the Brout-Englert-Higgs field
A
B


energy
movement
mass
=
+

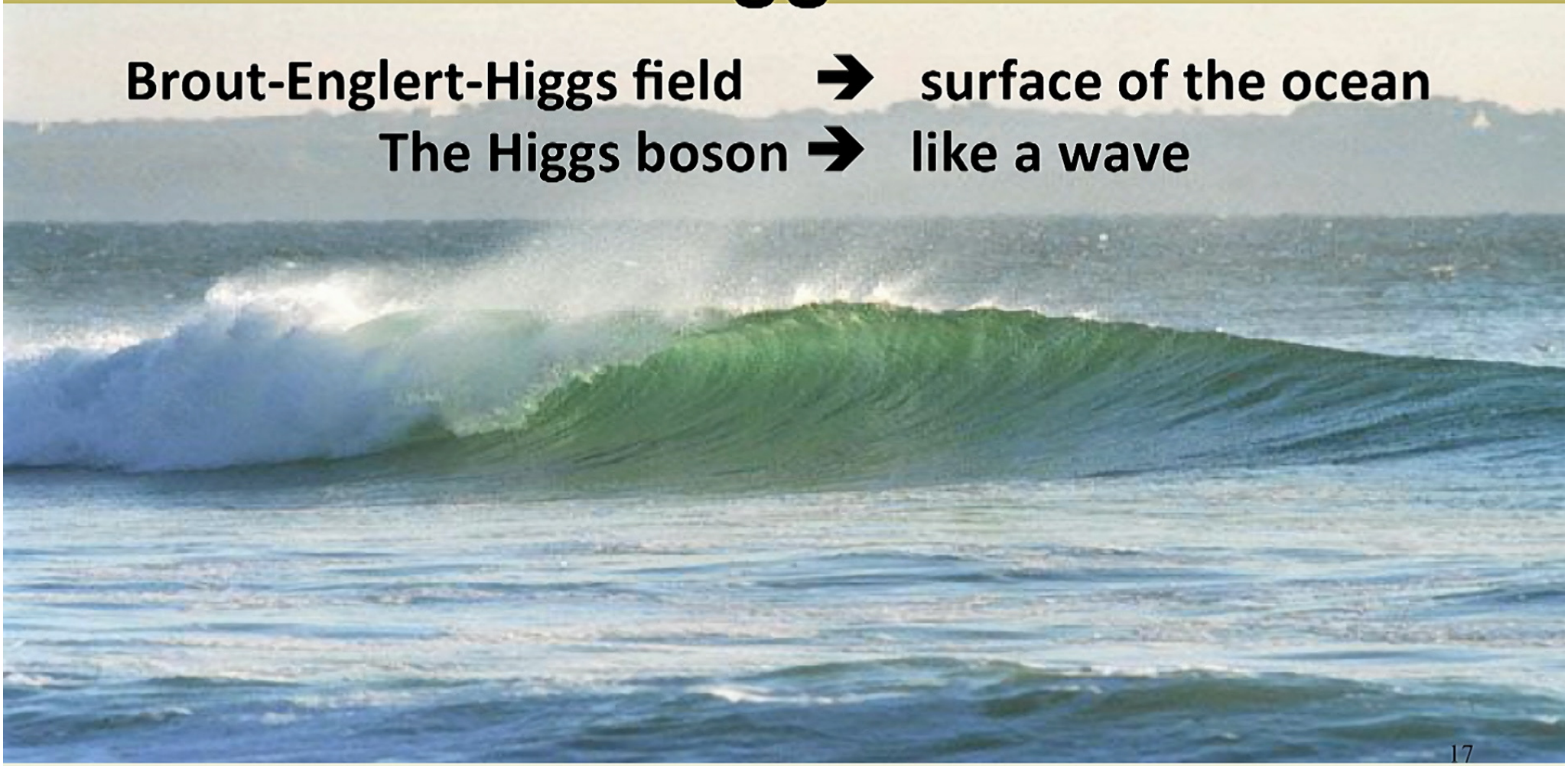




By interacting with this field, some of the particle's energy is transformed into mass

The Higgs boson

The Higgs boson



The Higgs boson

Brout-Englert-Higgs field → surface of the ocean

The Higgs boson → like a wave

Waves are excitations of the ocean surface

We can create Higgs bosons by exciting the BEH field

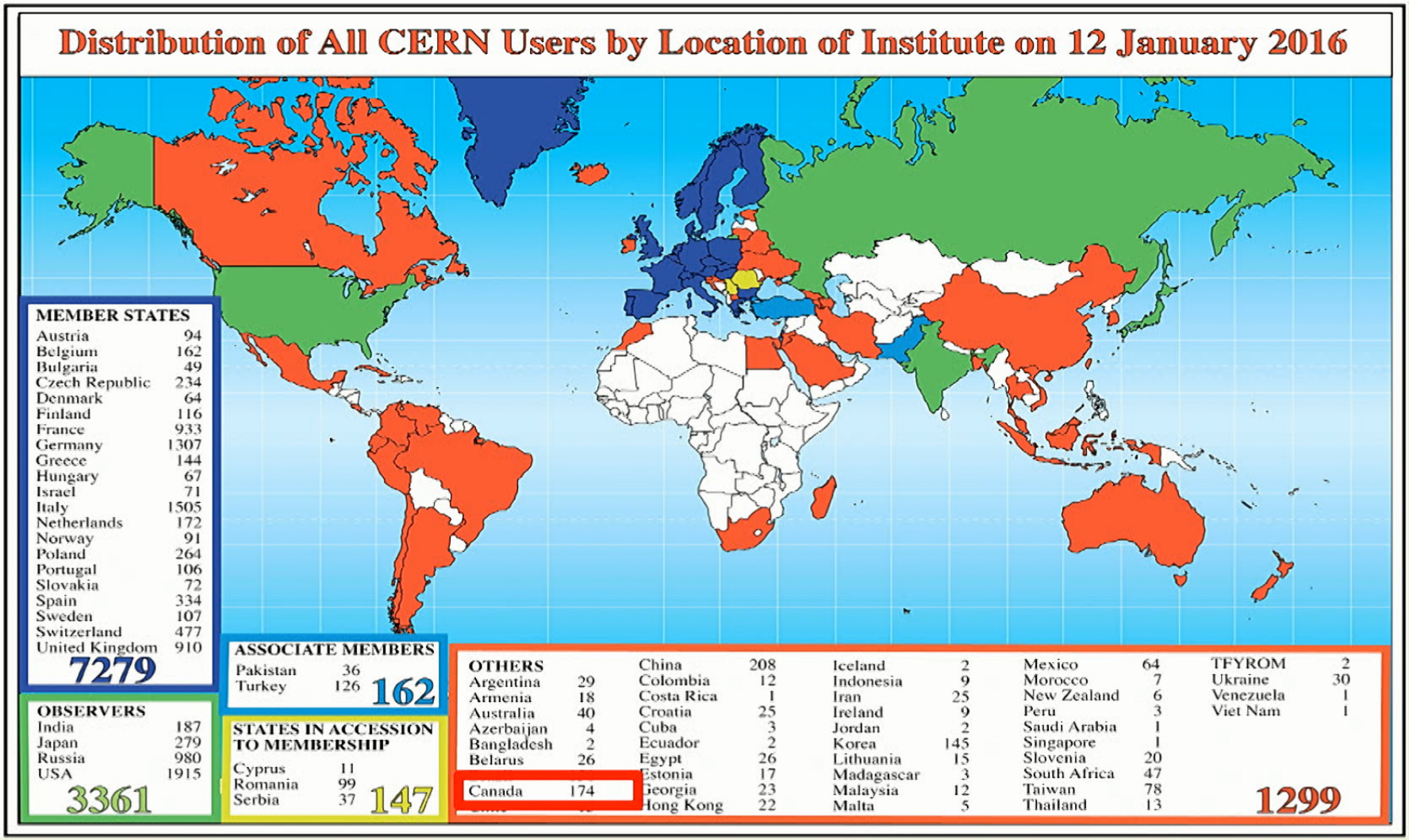
Where was the Higgs boson found?

CERN:
European Laboratory for Particle Physics

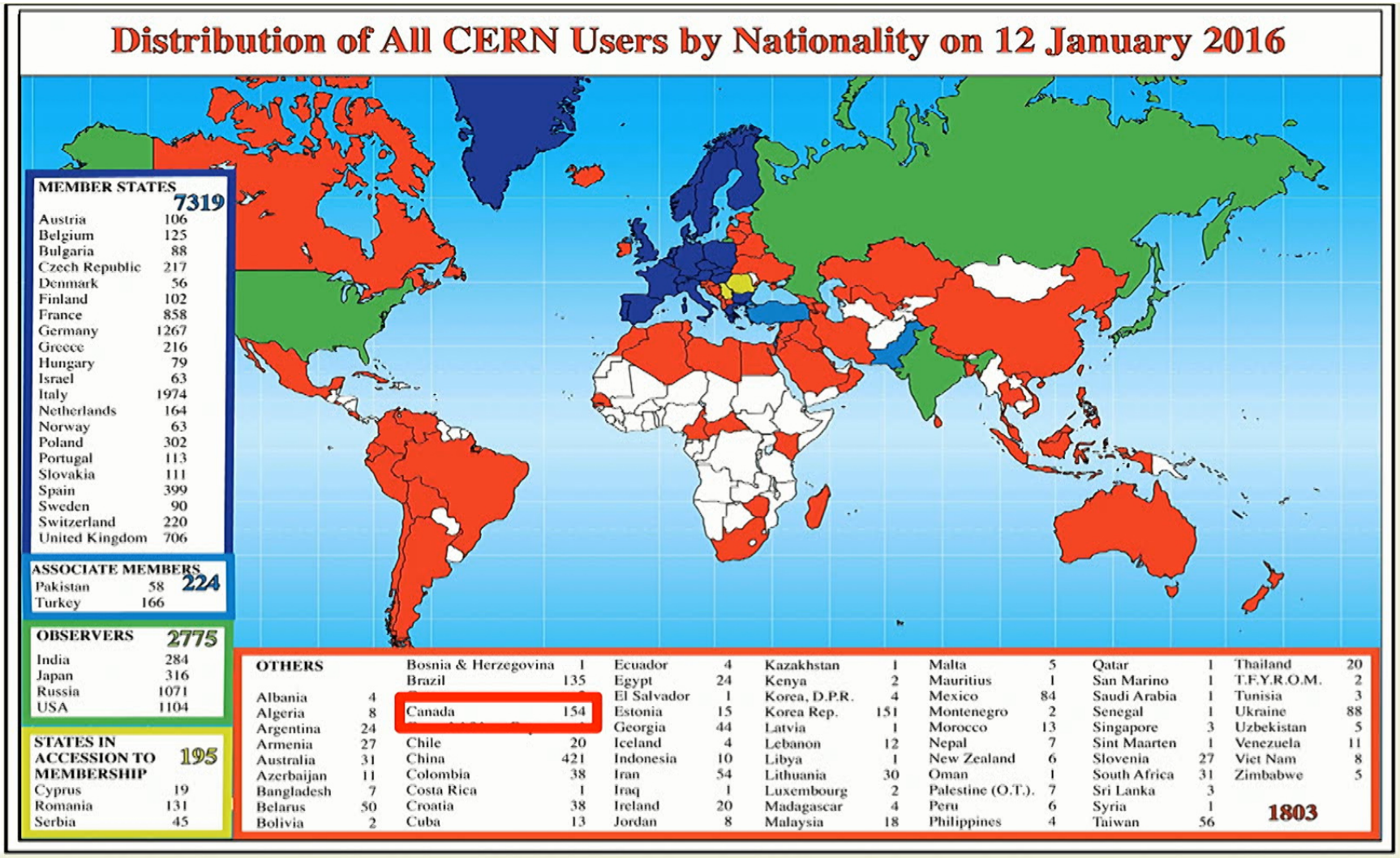
12000 researchers from 63 countries

- Founded in 1954 by UNESCO
- Financed by its 22 member states (most of Europe, Israel)
  - Serbia, Cyprus, Slovenia, Turkey, Pakistan, Ukraine and India





Distribution of All CERN Users by Location of Institute on 12 January 2016
MEMBER STATES
Austria 94
Belgium 162
Bulgaria 49
Czech Republic 234
Denmark 64
Finland 116
France 933
Germany 1307
Greece 144
Hungary 67
Israel 71
Italy 1505
Netherlands 172
Norway 91
Poland 264
Portugal 106
Slovakia 72
Spain 334
Sweden 107
Switzerland 477
United Kingdom 910
7279
ASSOCIATE MEMBERS
Pakistan 36
Turkey 126
162
OBSERVERS
India 187
Japan 279
Russia 980
USA 1915
3361
STATES IN ACCESSION TO MEMBERSHIP
Cyprus 11
Romania 99
Serbia 37
147
OTHERS
Argentina 29
Armenia 18
Australia 40
Azerbaijan 4
Bangladesh 2
Belarus 26
Canada 174
China 208
Colombia 12
Costa Rica 1
Croatia 25
Cuba 3
Ecuador 2
Egypt 26
Estonia 17
Georgia 23
Hong Kong 22
Iceland 2
Indonesia 9
Iran 25
Ireland 9
Jordan 2
Korea 145
Lithuania 15
Madagascar 3
Malaysia 12
Malta 5
Mexico 64
Morocco 7
New Zealand 6
Peru 3
Saudi Arabia 1
Singapore 1
Slovenia 20
South Africa 47
Taiwan 78
Thailand 13
TFYROM 2
Ukraine 30
Venezuela 1
Viet Nam 1
1299

Distribution of All CERN Users by Nationality on 12 January 2016



MEMBER STATES	7319
Austria	106
Belgium	125
Bulgaria	88
Czech Republic	217
Denmark	56
Finland	102
France	858
Germany	1267
Greece	216
Hungary	79
Israel	63
Italy	1974
Netherlands	164
Norway	63
Poland	302
Portugal	113
Slovakia	111
Spain	399
Sweden	90
Switzerland	220
United Kingdom	706

ASSOCIATE MEMBERS	224
Pakistan	58
Turkey	166

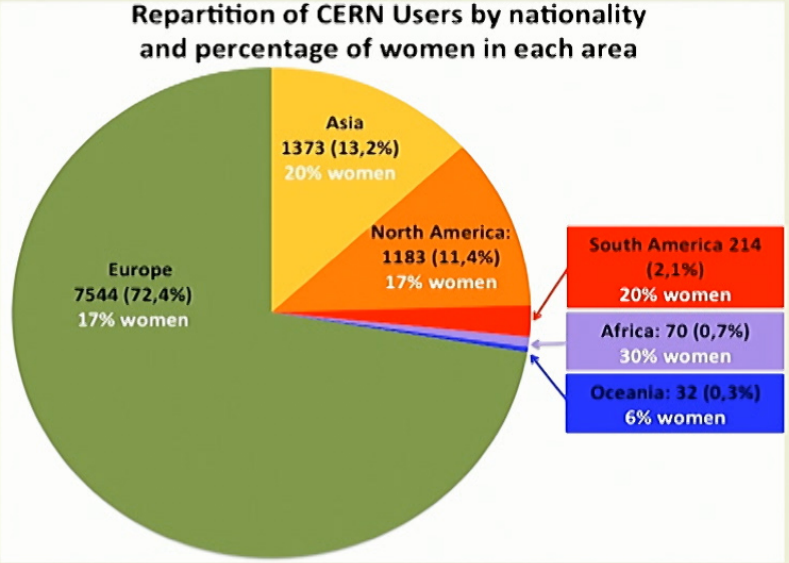
OBSERVERS	2775
India	284
Japan	316
Russia	1071
USA	1104

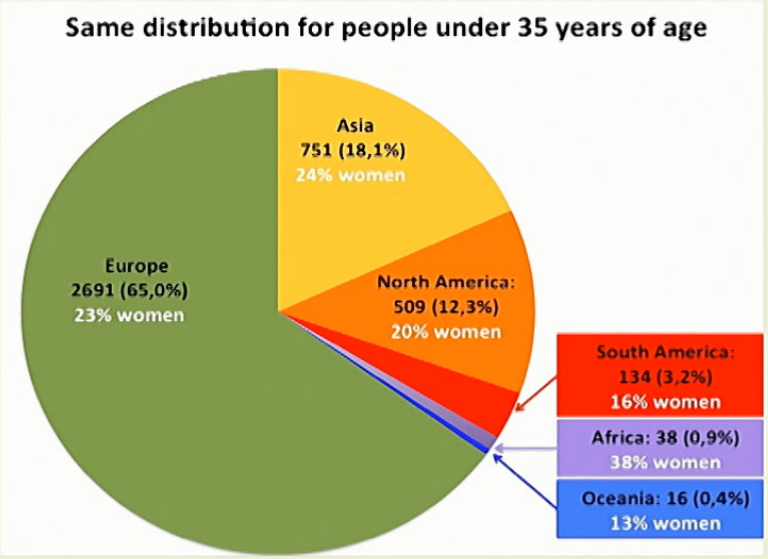
STATES IN ACCESSION TO MEMBERSHIP	195
Cyprus	19
Romania	131
Serbia	45

OTHERS																	
Albania	4	Bosnia & Herzegovina	1	Ecuador	4	Kazakhstan	1	Malta	5	Qatar	1	Thailand	20				
Algeria	8	Brazil	135	Egypt	24	Kenya	2	Mauritius	1	San Marino	1	T.F.Y.R.O.M.	2				
Argentina	24	Canada	154	El Salvador	1	Korea, D.P.R.	4	Mexico	84	Saudi Arabia	1	Tunisia	3				
Armenia	27	Chile	20	Estonia	15	Korea Rep.	151	Montenegro	2	Senegal	1	Ukraine	88				
Australia	31	China	421	Georgia	44	Latvia	1	Morocco	13	Singapore	3	Uzbekistan	5				
Azerbaijan	11	Colombia	38	Iceland	4	Lebanon	12	Nepal	7	Sint Maarten	1	Venezuela	11				
Bangladesh	7	Costa Rica	1	Indonesia	10	Libya	1	New Zealand	6	Slovenia	27	Viet Nam	8				
Belarus	50	Croatia	38	Iran	54	Lithuania	30	Oman	1	South Africa	31	Zimbabwe	5				
Bolivia	2	Cuba	13	Iraq	1	Luxembourg	2	Palestine (O.T.).	7	Sri Lanka	3						
				Ireland	20	Madagascar	4	Peru	6	Syria	1		1803				
				Jordan	8	Malaysia	18	Philippines	4	Taiwan	56						

A gathering of physicists at the Solvay Conference in 1927

Gender and racial diversity at CERN (2014)

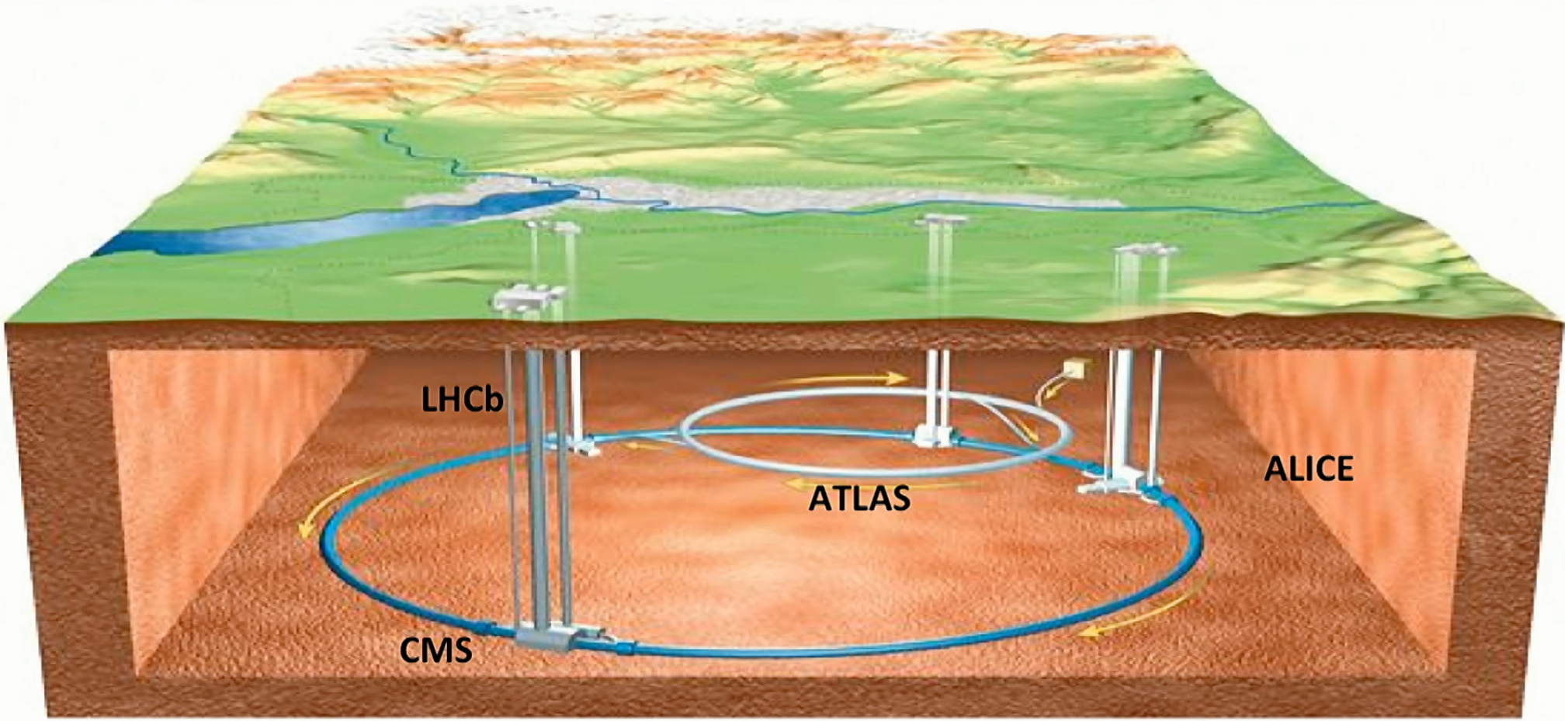




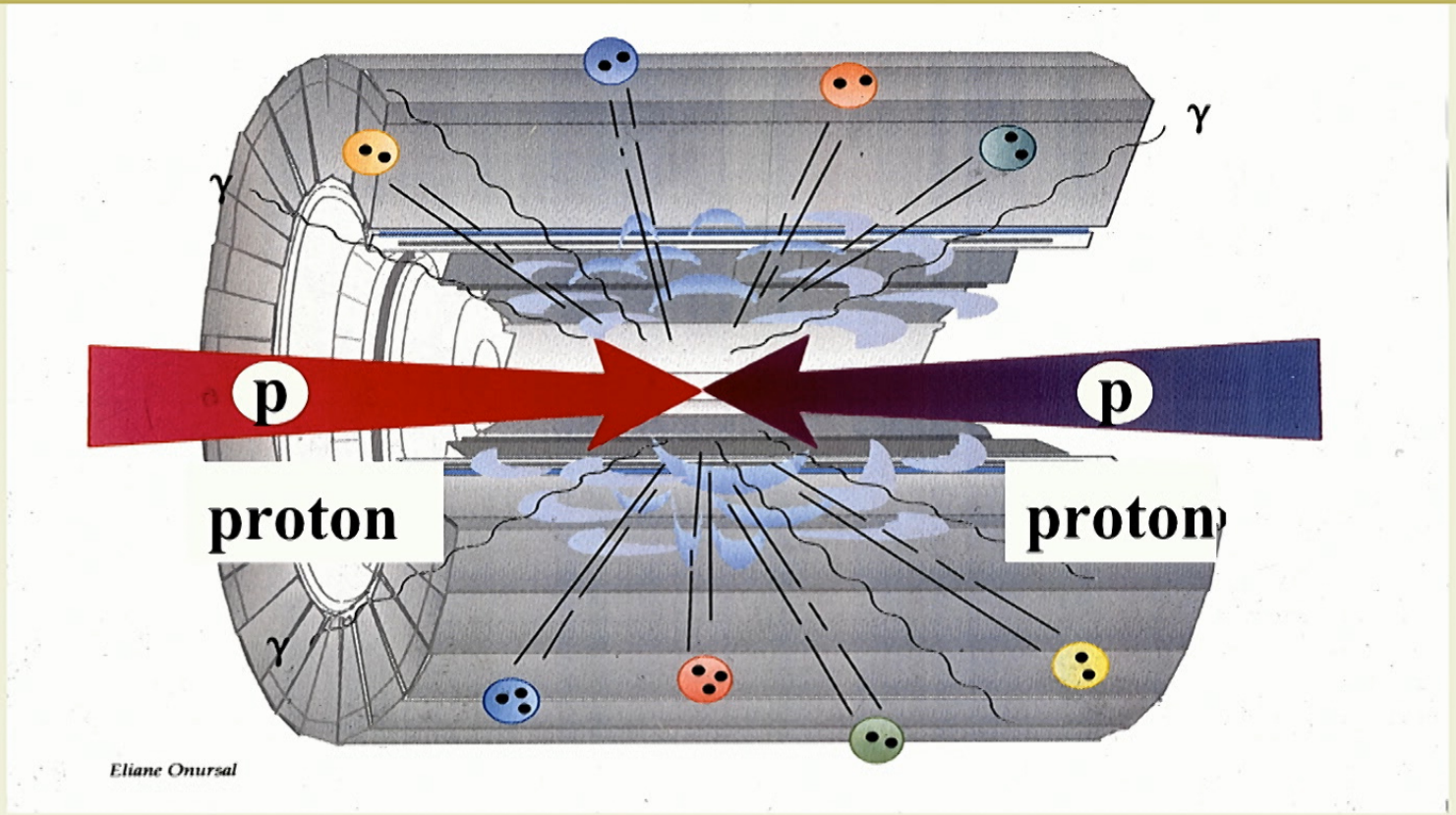
At CERN, roughly 80% of all scientists are male and 80% are white


4 large experiments on the LHC: ATLAS, CMS, LHCb, ALICE


The Large Hadron Collider (LHC)


LHCb
ATLAS
ALICE
CMS

The energy released during the collisions materialises to form new particles: $E=mc^2$



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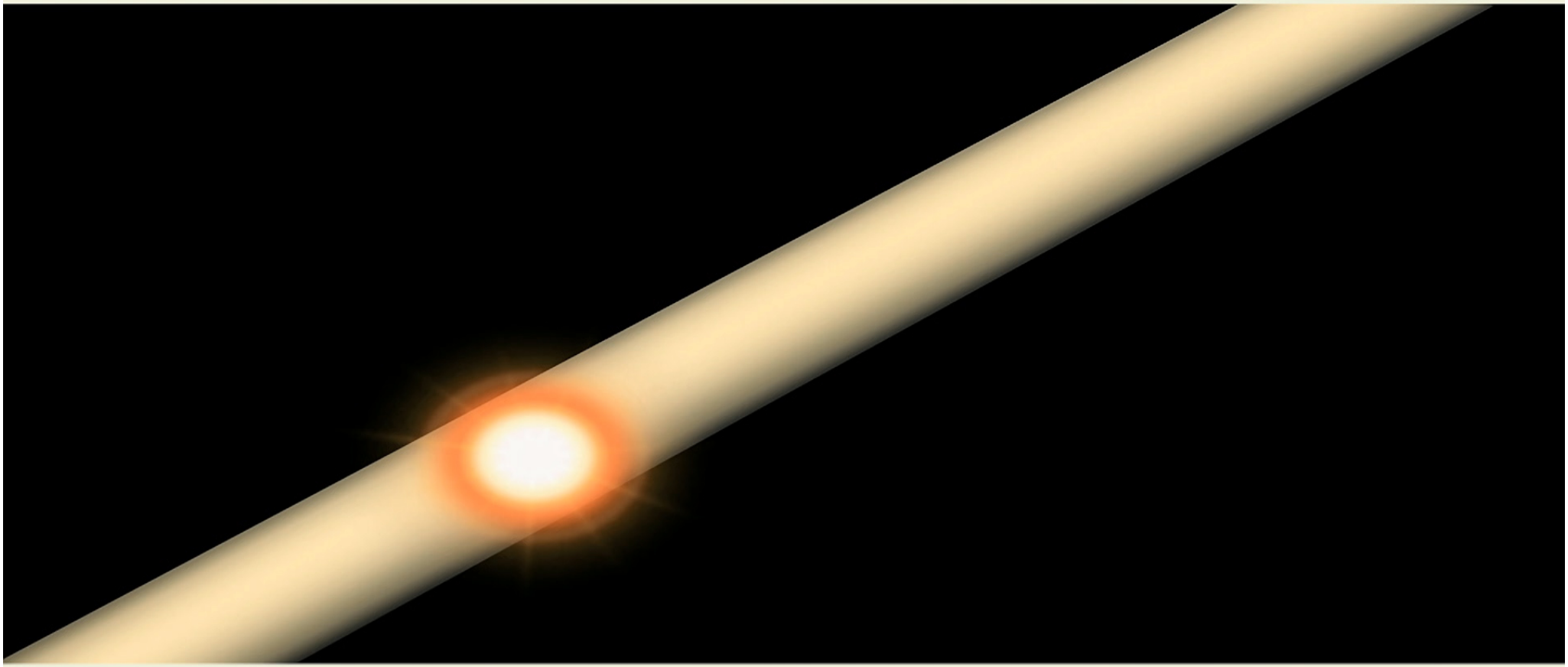
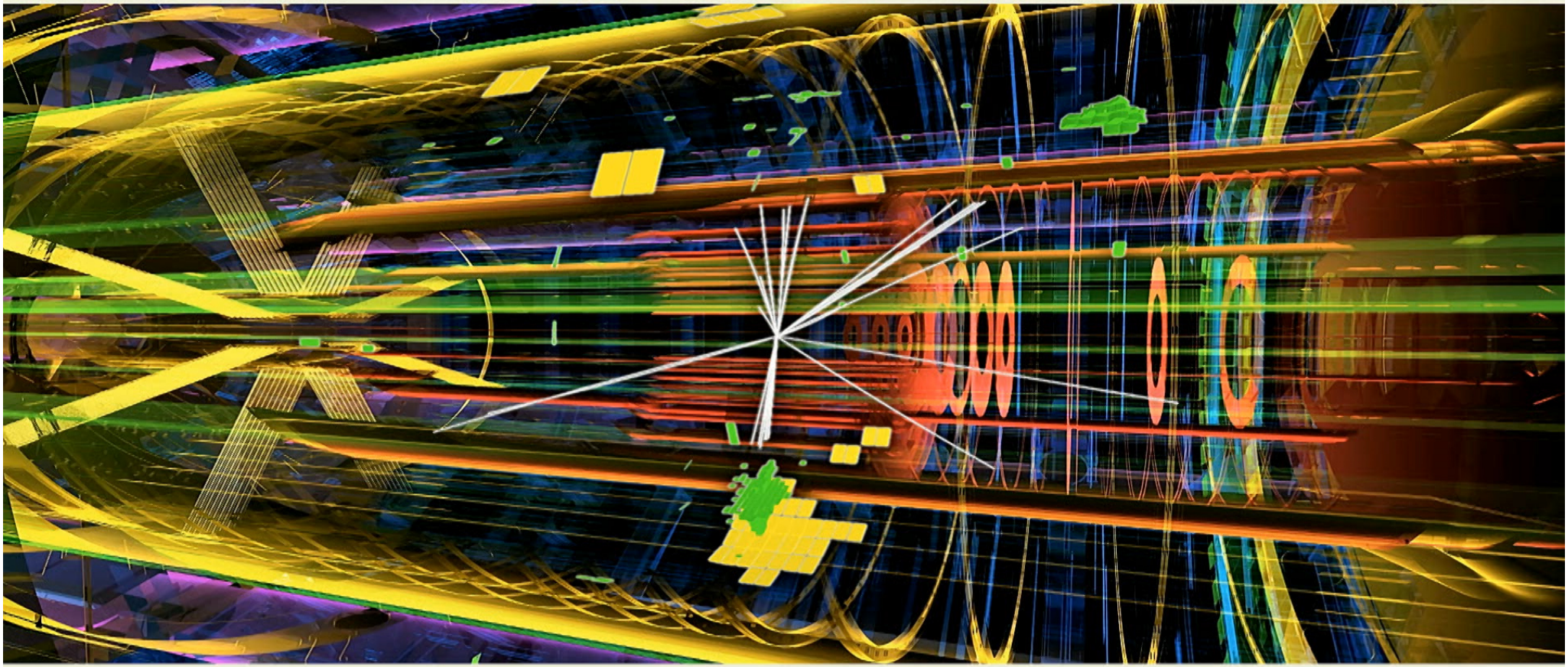
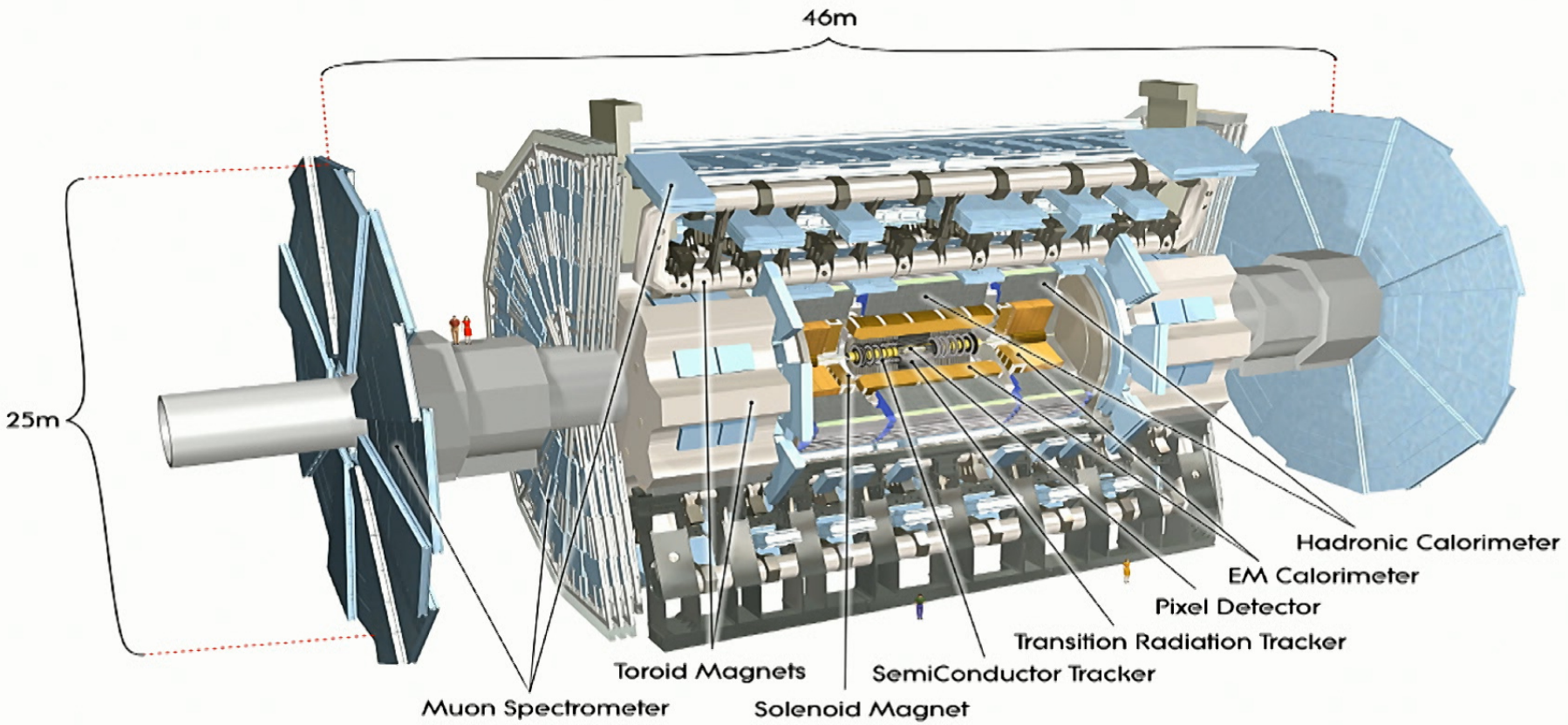




The ATLAS detector: like a giant camera



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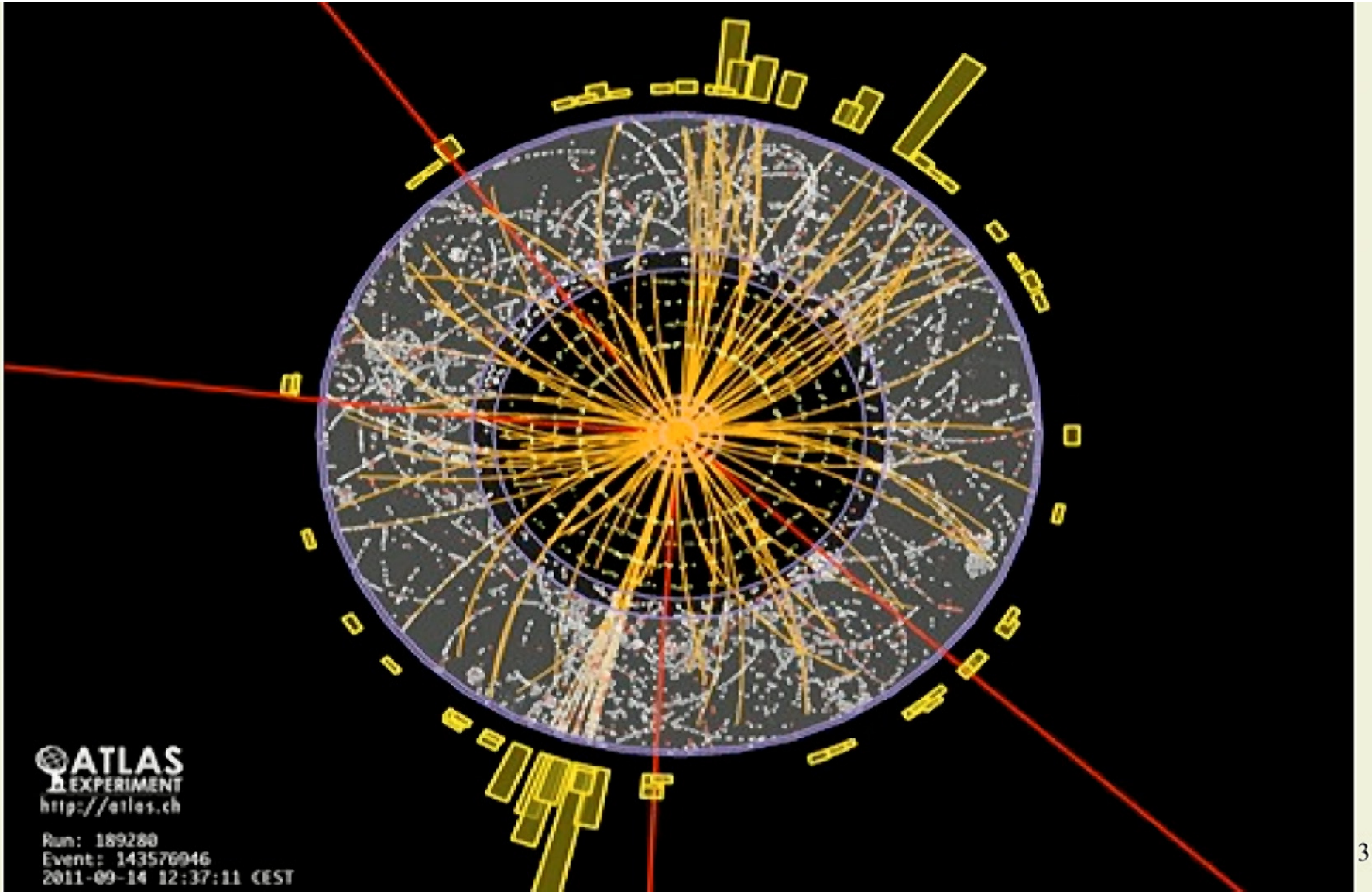
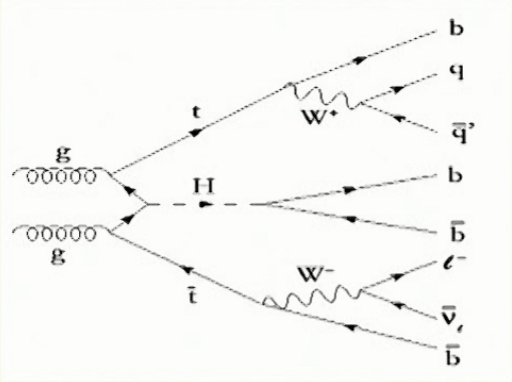

ATLAS
EXPERIMENT
http://atlas.ch
Run: 189280
Event: 143576046
2011-09-14 12:37:11 CEST

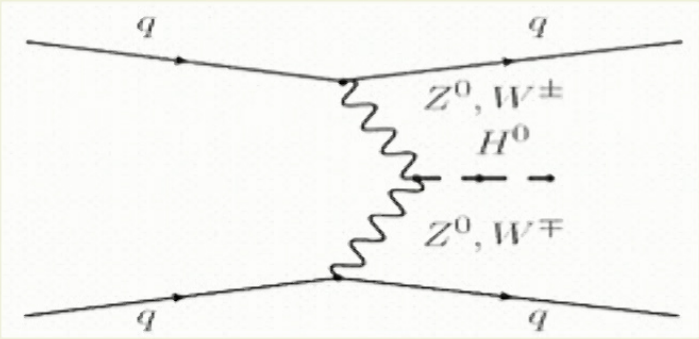
31

Where do we start?

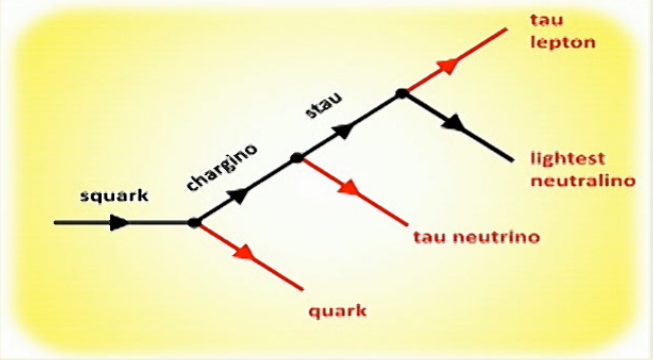
From theoretical predictions



- Sensitive to a variety of particles
- High granularity



- Sensitive in all directions
- Fast and precise



- Hermetic

First step: Technical Design

- The collaboration establishes what needs to be done
- The whole project is divided into sub-projects
- Each participating institute signs up for one of those projects
- Often times, several ideas are pursued in parallel

Everyone can say what they think

- Everyone can suggest new ideas or methods
- Each one must prove his or her ideas are better
- The best method is selected based on its merit
- The common goal always has the last word, even when the coordinator disagrees

Decisions by consensus

- Everything is discussed in meetings
- No top-down hierarchy
- No director, only coordinators
- Everyone chooses what they want to contribute

Everyone does as they please

- Like a huge picnic
- Each group volunteers for a task based on its taste and ressources, and the needs of the experiment
- Each person must figure out how to contribute to make sure the whole project is successful

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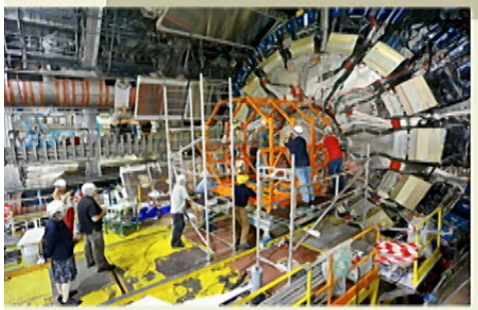
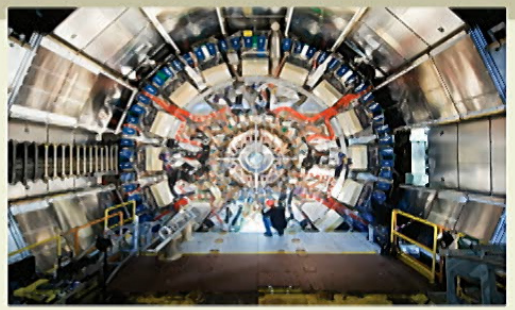
Motivation and creativity

Common goal: increase human knowledge

Individual benefits: participate in unique projects

- There are no bonus, no financial compensation
- The creative process is not blocked
- The whole project needs everyone's creativity

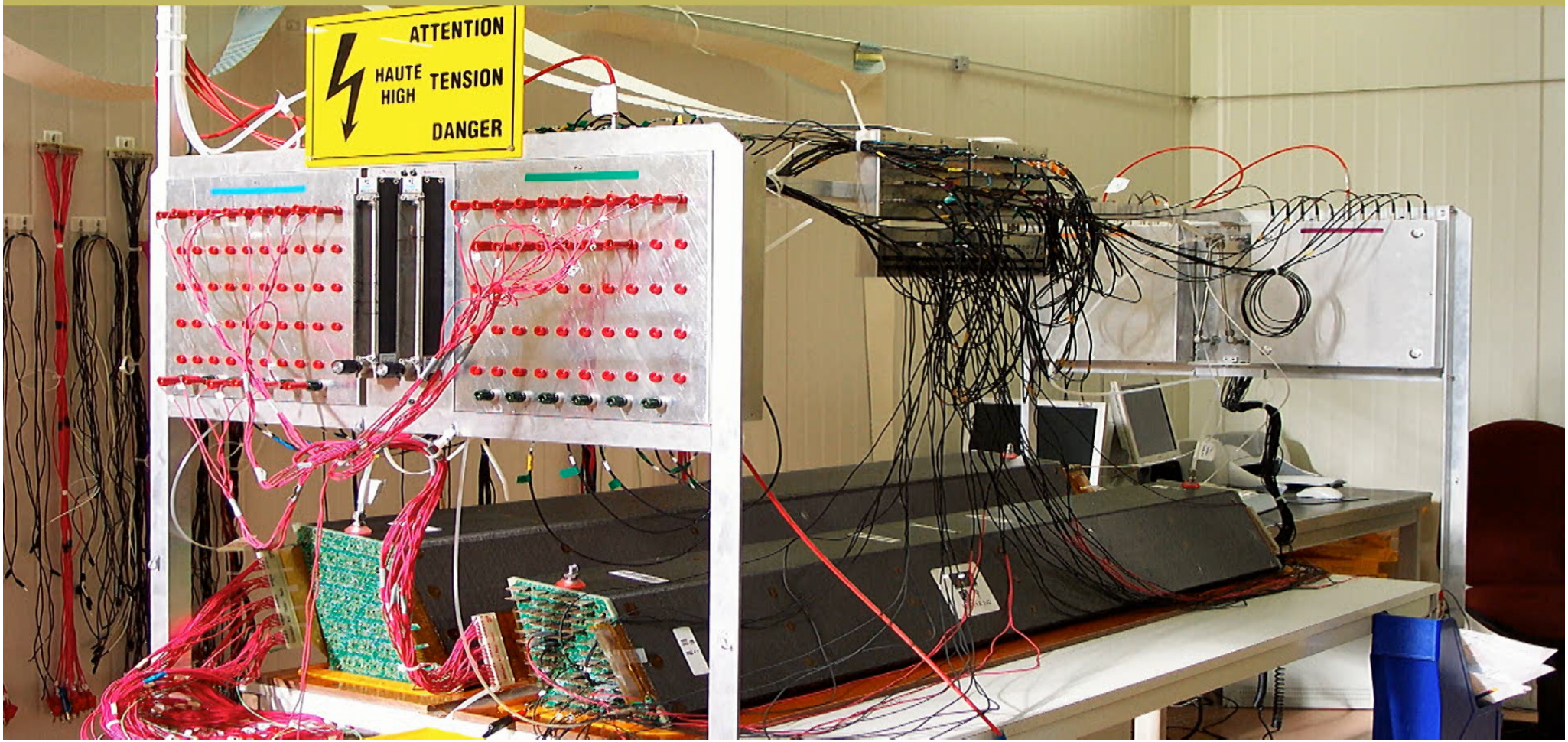





Collaboration and competition

- If one group fails, everyone fails
- Hence, we must help each other
- But we also compete for jobs

We tested over 110 000 wires



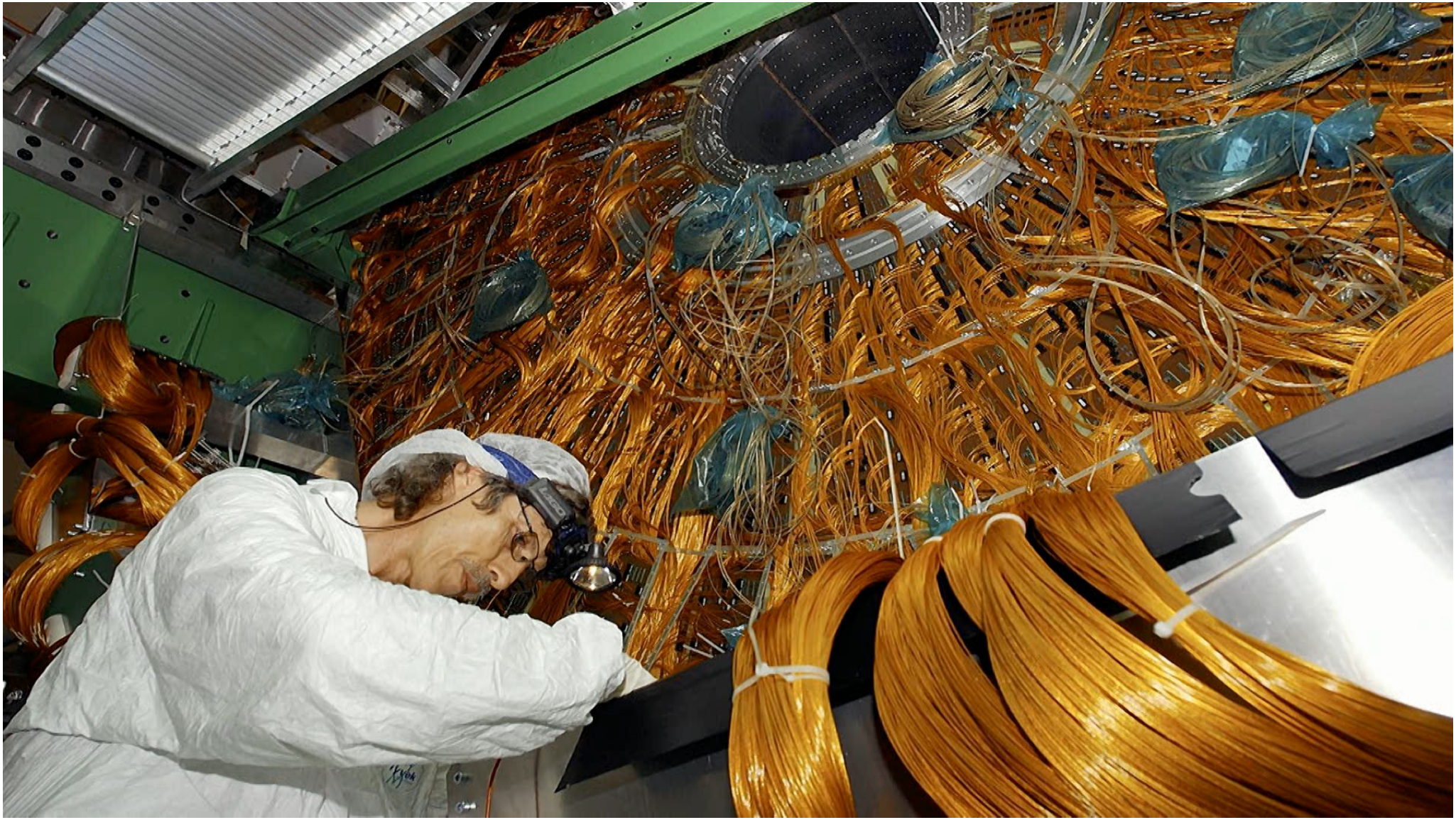
Not obvious at the start…

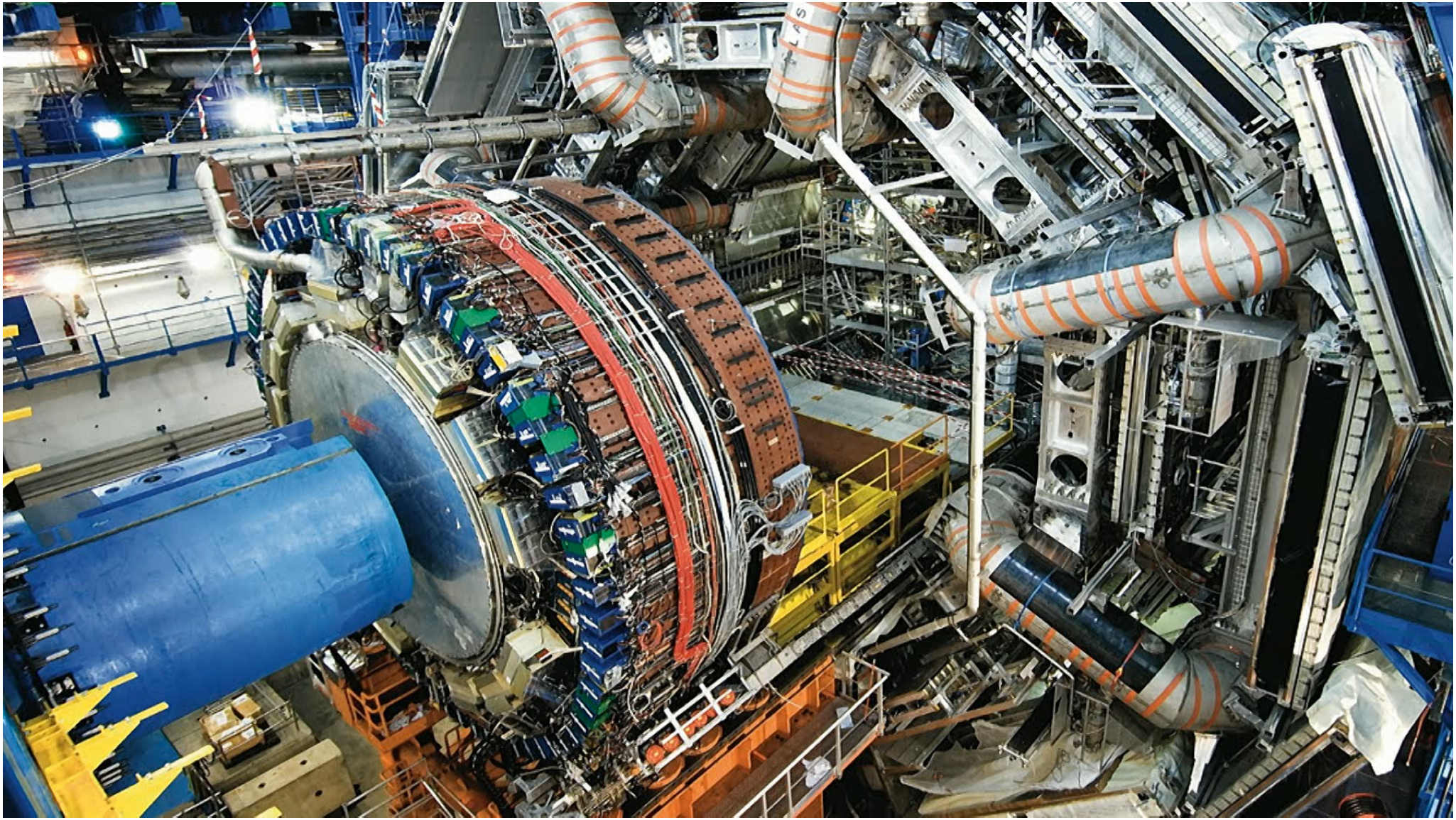
41

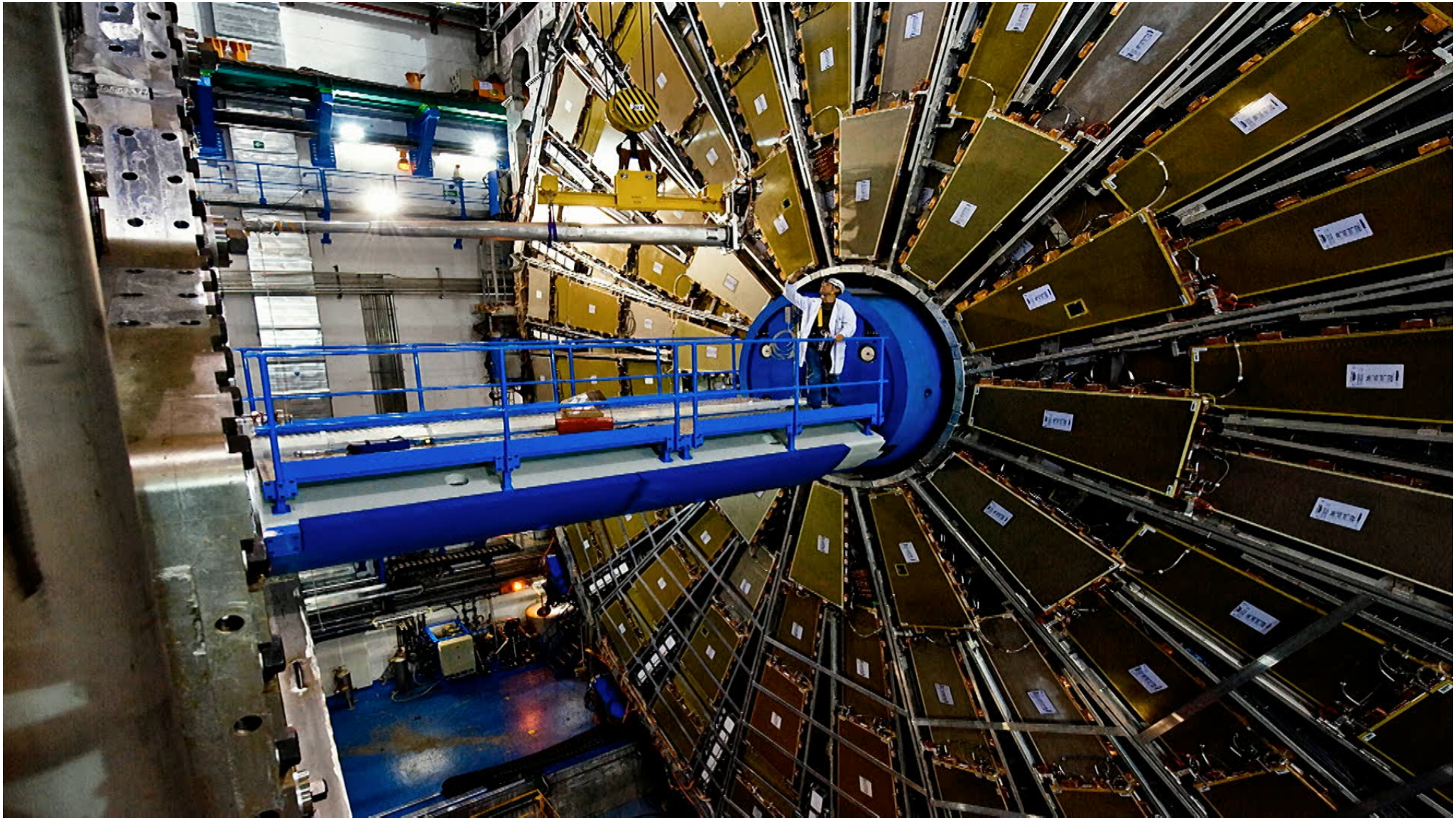
… and 18 months later

Brings out the best out of people

Maria and Giuseppe Fidecaro







How did we manage to make it work?

Success is shared

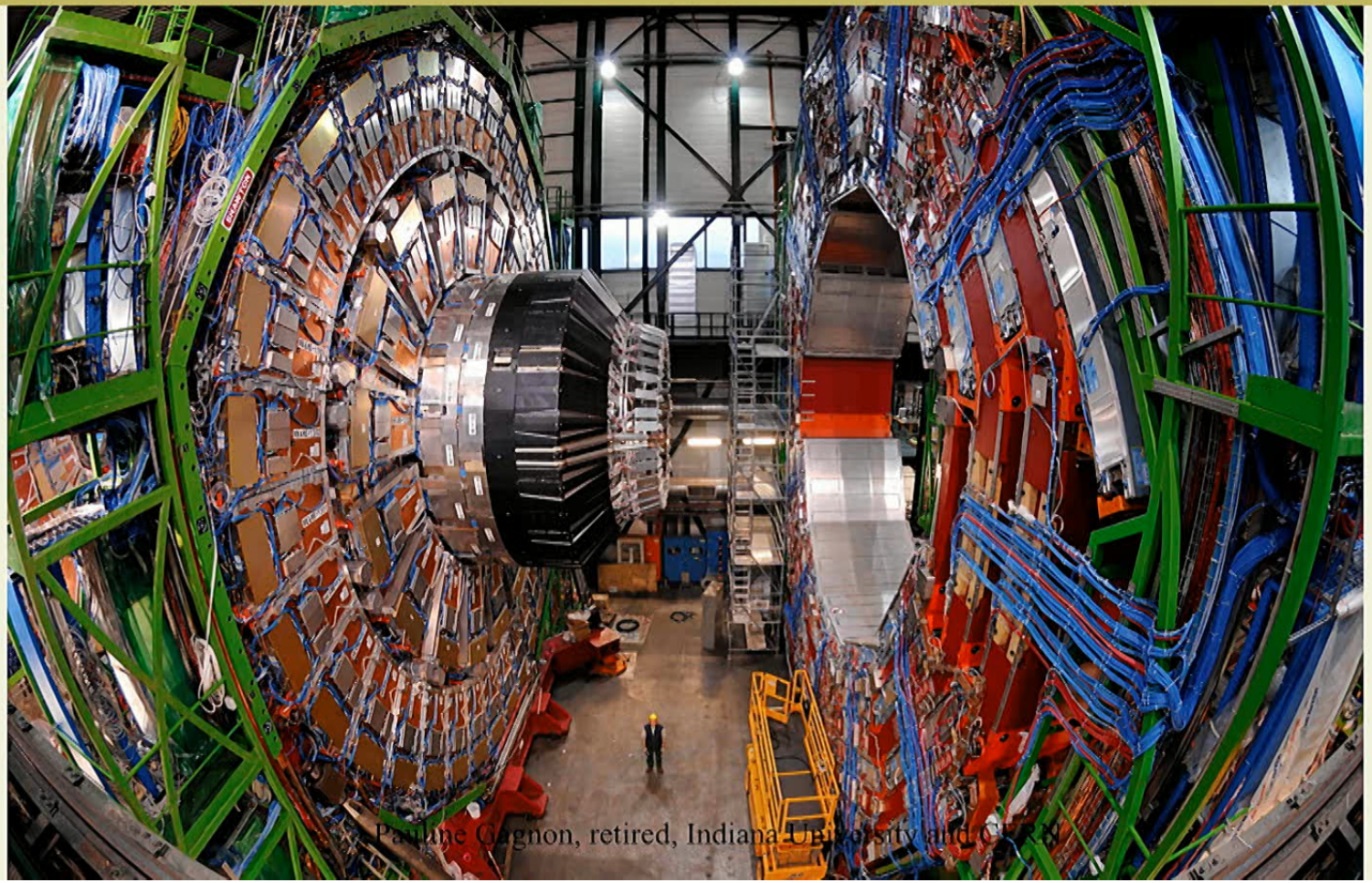
Pauline G[illegible]on, retired, Indiana University and CE[illegible]

We will probably never find any practical application for the Higgs boson

Lifetime: 10^{-22} seconds

1. Increase human knowledge

2. Develop technology



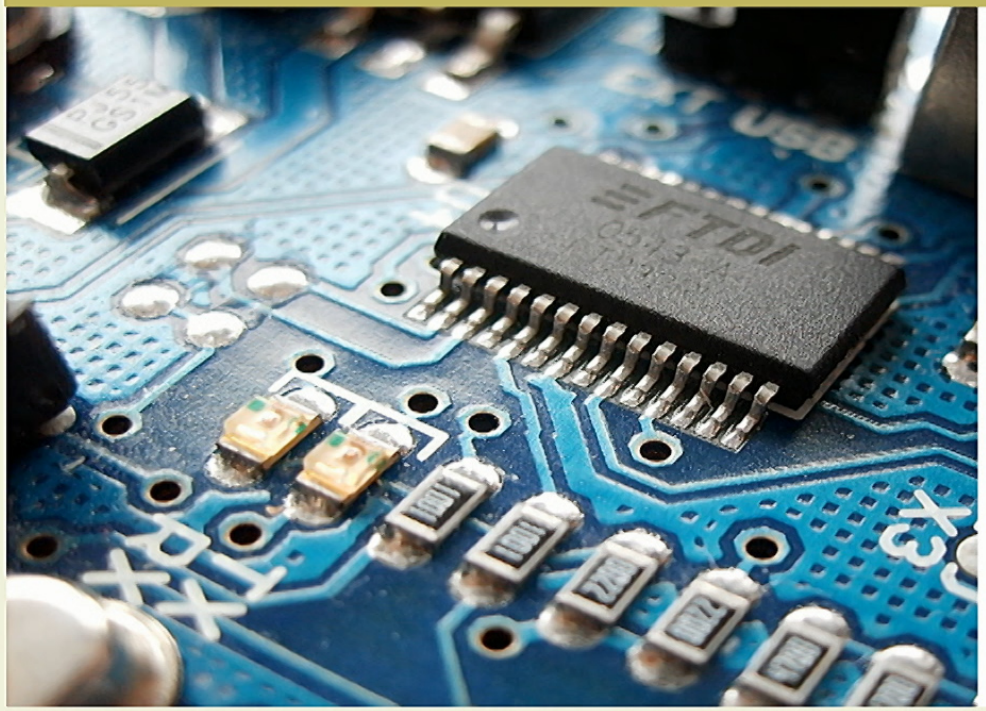
3. Train highly qualified people

4. Contribute to world peace through international collaboration

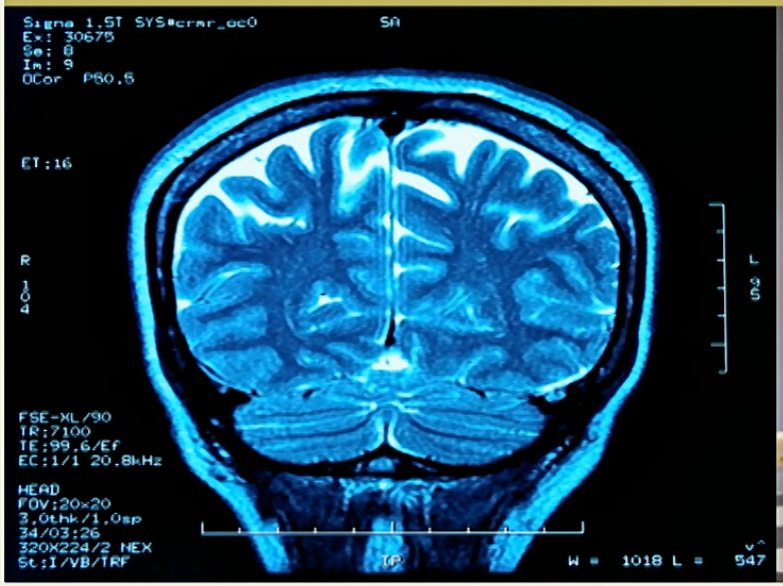
Pauline Gagnon, Retired, Indiana University and CERN

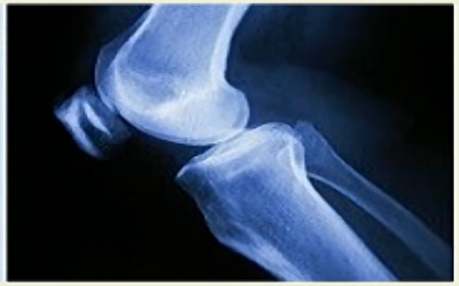
Benefits for Humanity?

Computers and electronic devices



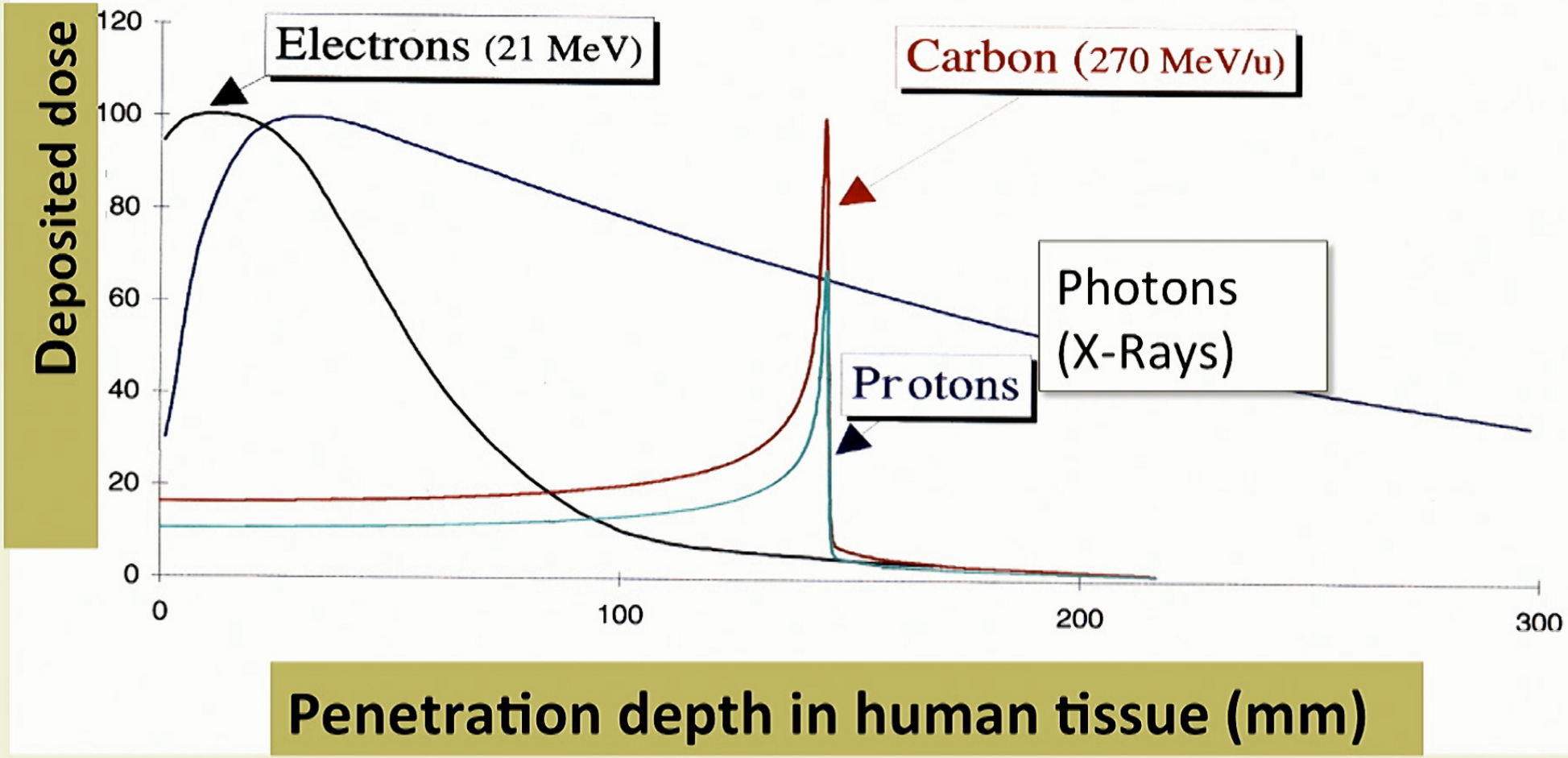
Medical imaging





Pauline Gagnon, retired, Indiana University and CERN 60

Hadrontherapy



Hadrontherapy

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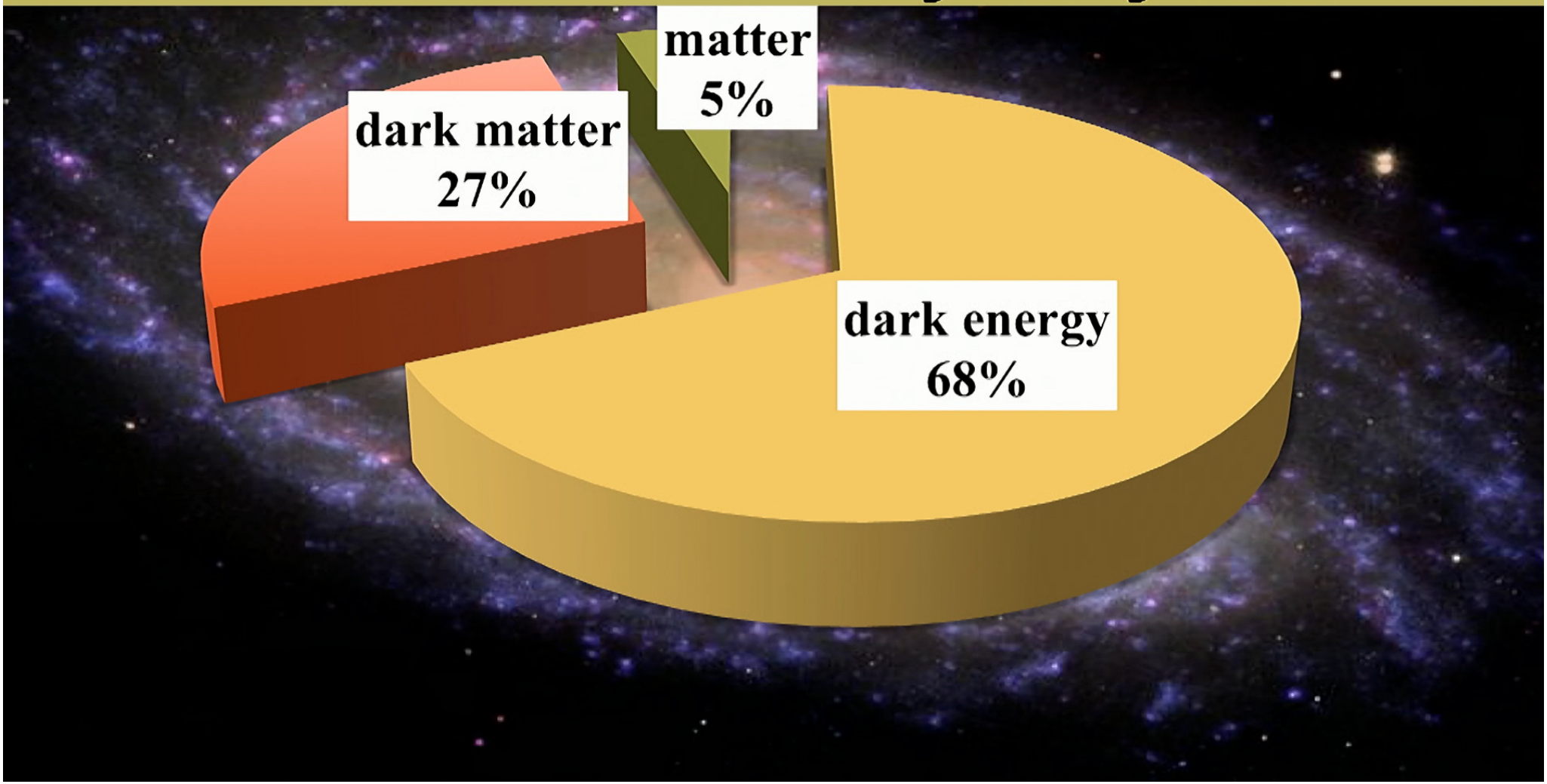
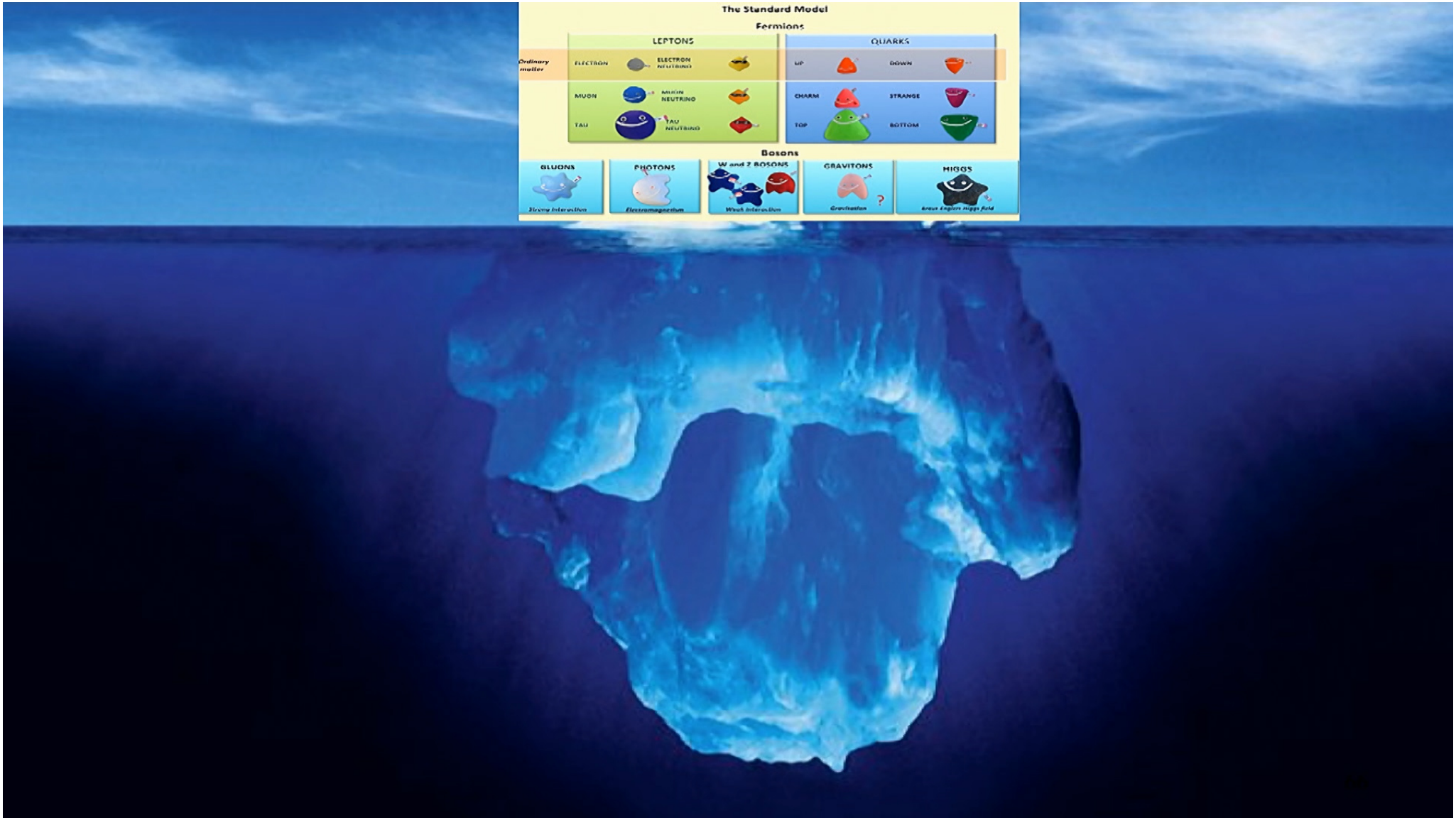
Hadrontherapy

62

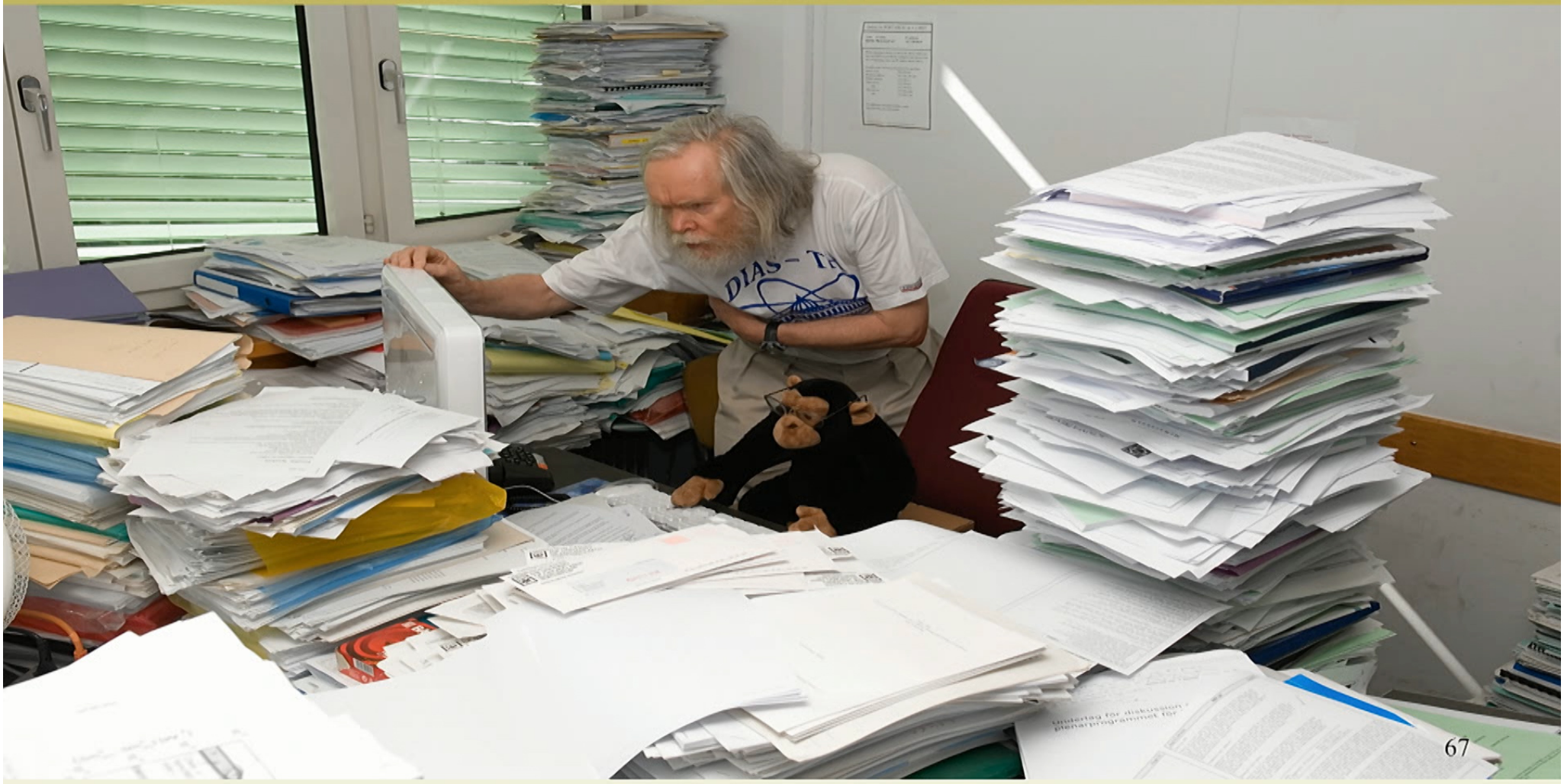

Have we already found everything?

Dark matter mystery

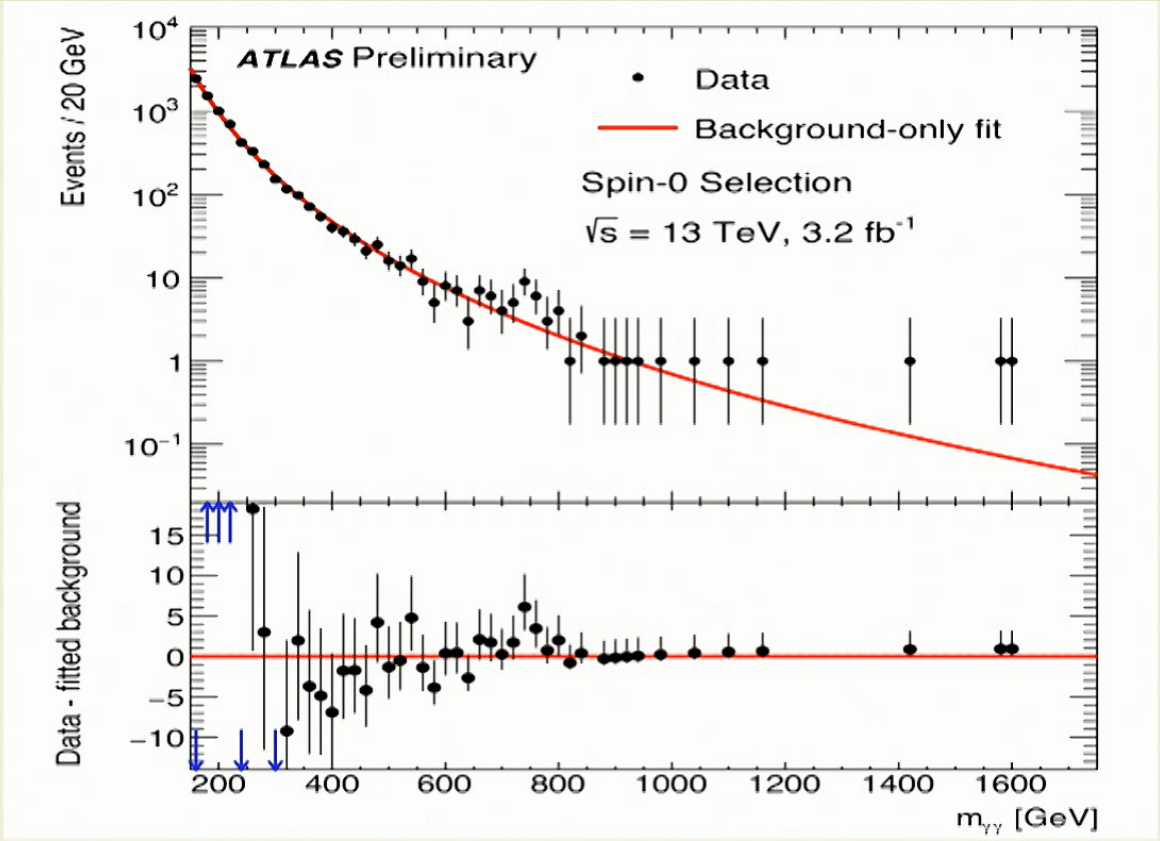



The Standard Model
Fermions
LEPTONS
QUARKS
Ordinary matter
ELECTRON
ELECTRON NEUTRINO
UP
DOWN
MUON
MUON NEUTRINO
CHARM
STRANGE
TAU
TAU NEUTRINO
TOP
BOTTOM
Bosons
GLUONS
PHOTONS
W and Z BOSONS
GRAVITONS
HIGGS

Best theorists are hard at work

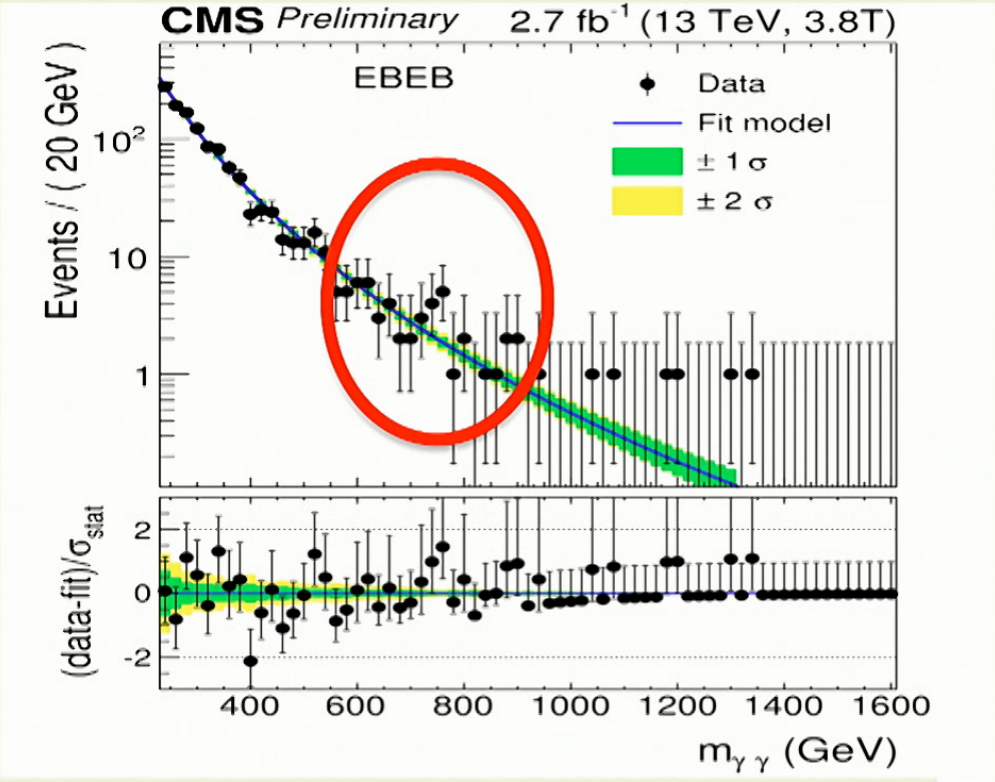


One way is to look for an excess of events



ATLAS data, first seen in Dec 2015

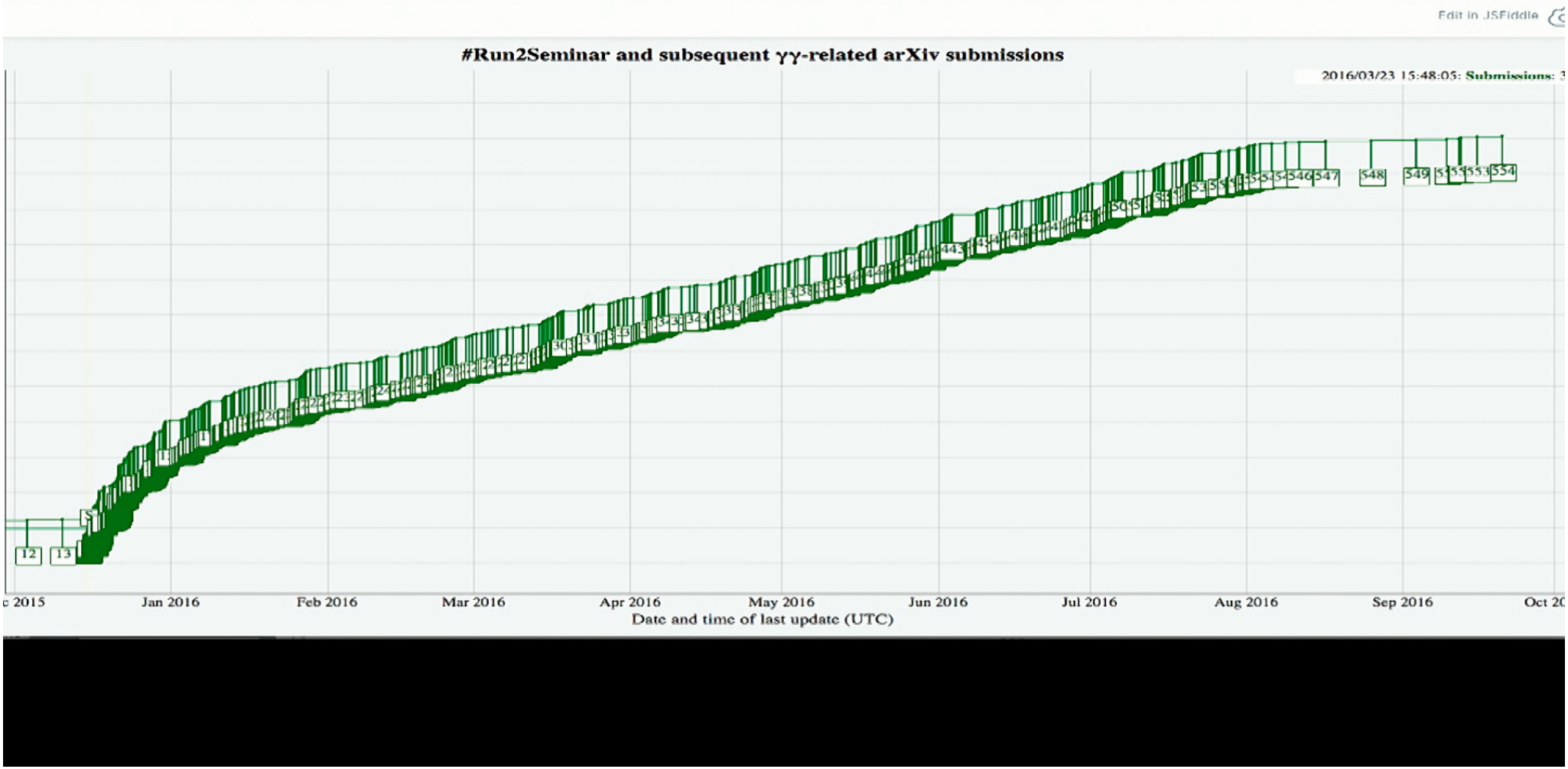
It looked like a new particle at 750 GeV



CMS data

August 2016

554 theory papers on … nothing!



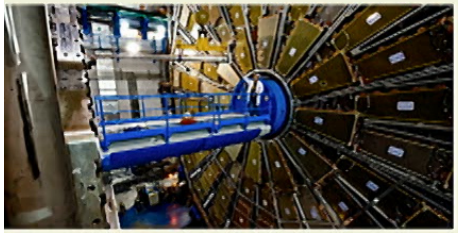
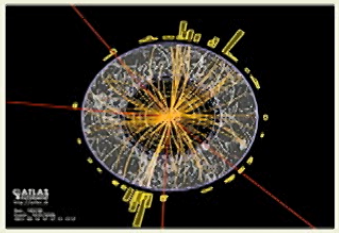
What could it have been?

papers describing the new boson properties	30
supersymmetry	20
dark matter	15
2HDM models and extensions	14
new gauge symmetry	14
hidden sector	10
extra dimension, graviton, inflaton, dilaton	8
heavy or new fermion, vector-like fermions loops	7
heavy or composite axion	7
composite Higgs model	6
Grand Unification Theory	6
weak singlet scalar or pseudoscalar	5
Higgs-like resonances, new Higgs boson	4
D3-brane, light stringy states, heterotic string	4
radion in the Bulk-higgs scenario	3
singlet extension of SM	3
seesaw model	2
left-right symmetry model	2
vector resonance or leptoquark	2

New particles would reveal the secret passage to the bigger theory

Take-home messages

- We can achieve incredible feats by getting the best out of highly motivated and diverse people who are allowed to do as they please
- There will probably never be any application for the Higgs boson but fundamental research drives economic development and has completely changed how we live
- Any new particle or new phenomenon found from now on will revolutionize our understanding of the Universe


Thank you for your attention