The Large Hadron Collider at CERN

How Secrets of the Universe are Revealed through Collaboration of Thousands of Scientists

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TU-Dresden Ringvorlesung
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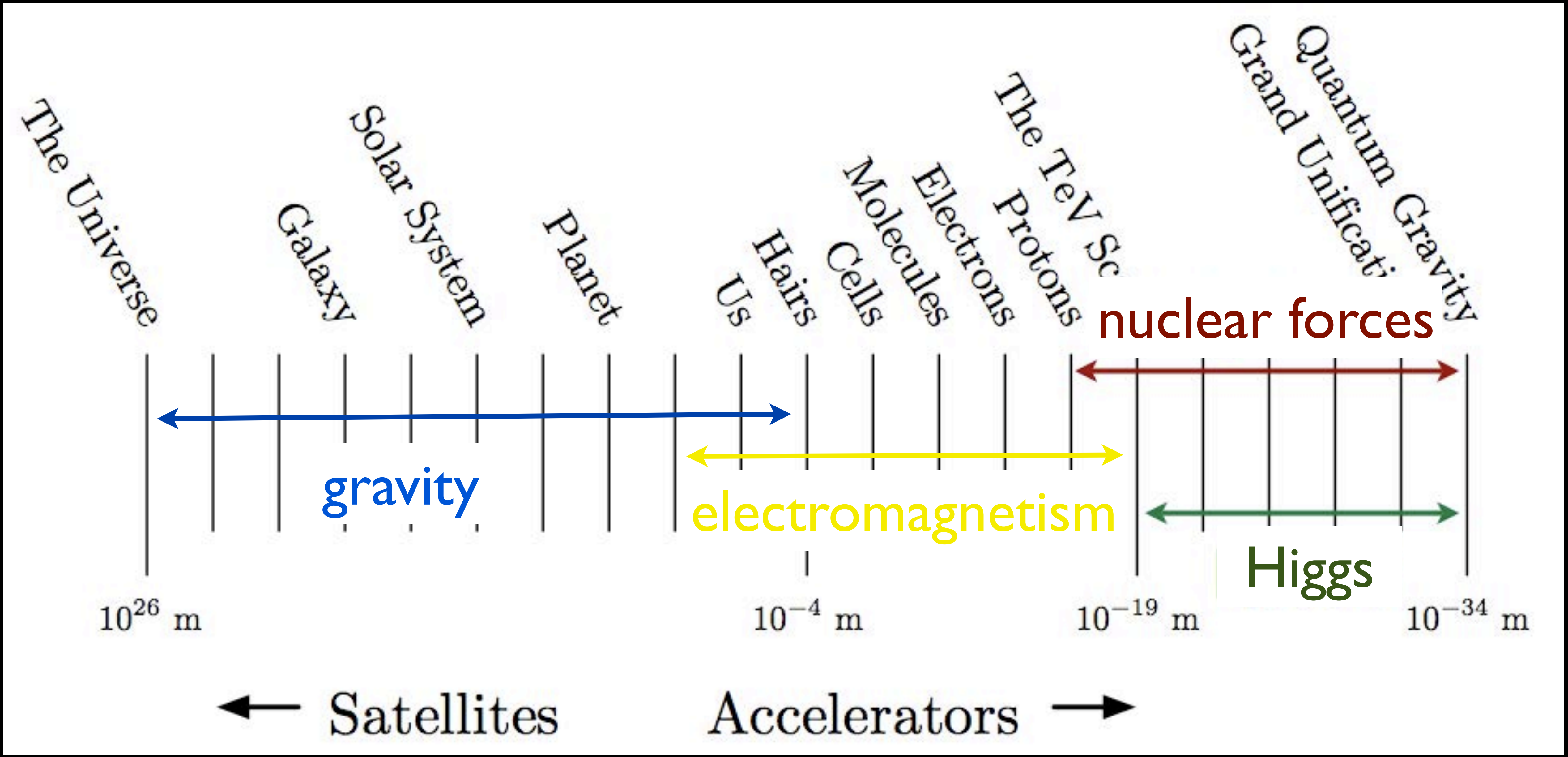
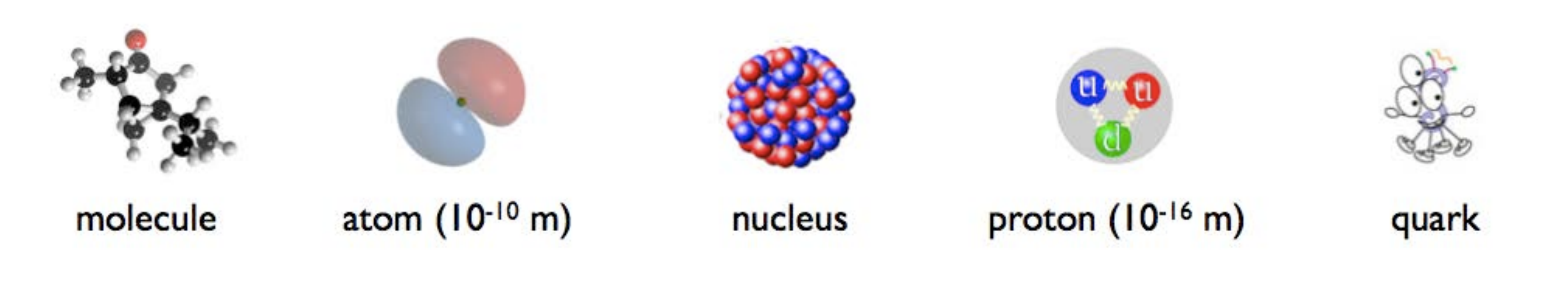
In this lecture, we will cover

- What is the Large Hadron Collider?
- How do high energy experiments work?
- What's so special about the Higgs Boson?
- What is it like to work on an experiment with 3000 other people?
- What other fundamental questions in physics could be answered at the LHC?
- Your questions!

The scales and forces of the universe

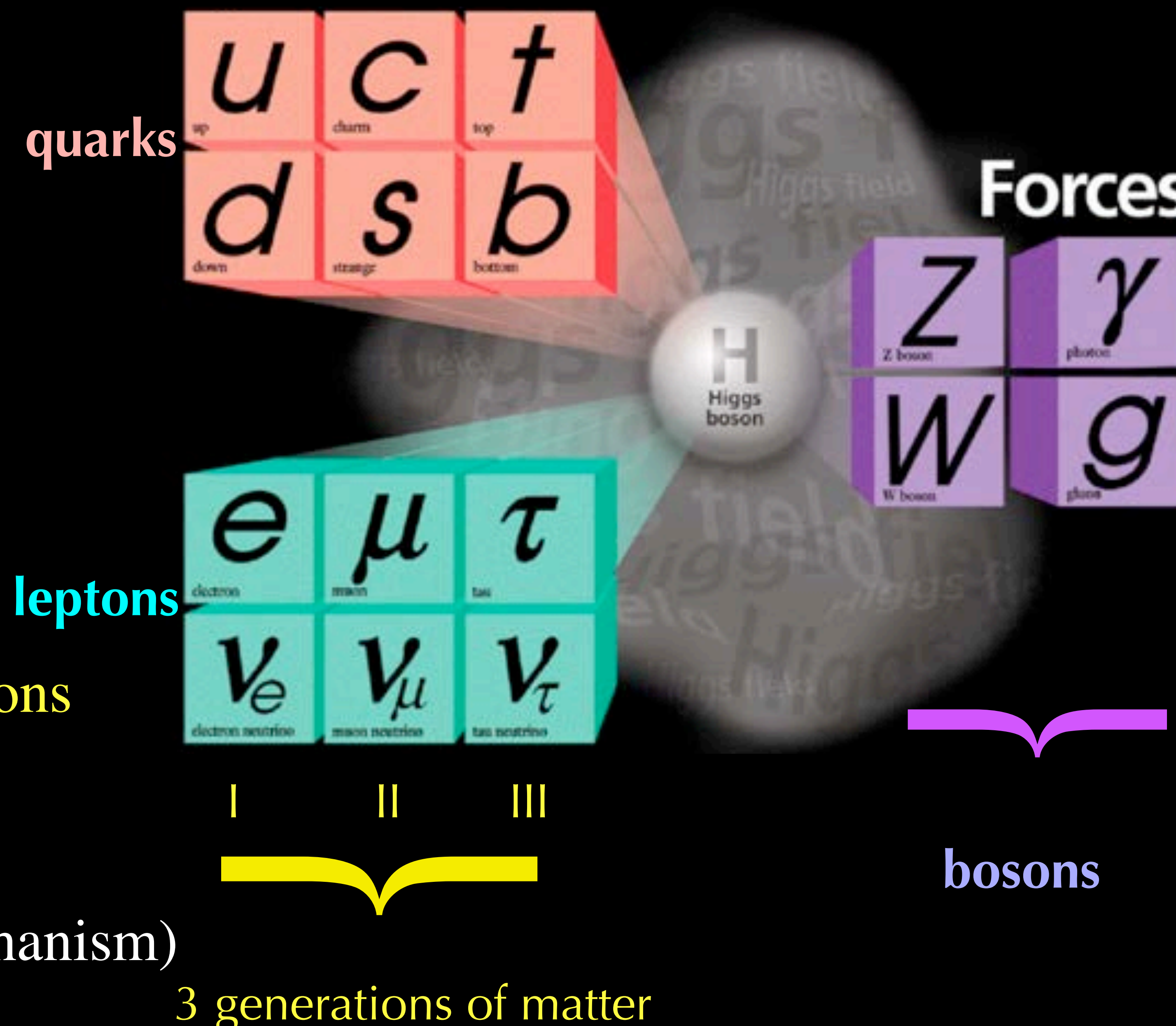




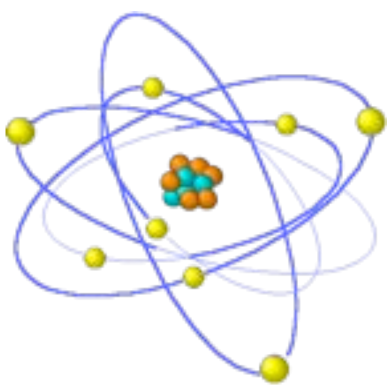
Standard Model of Particle Physics in 1 slide

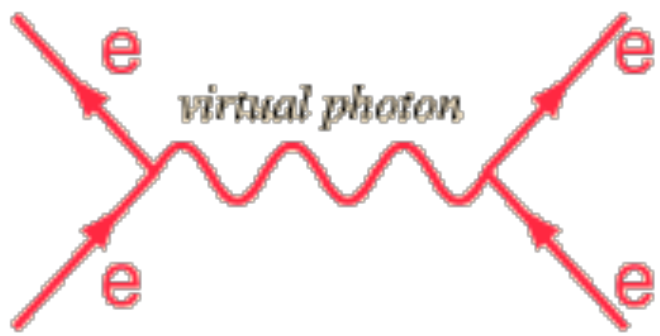
- The Standard Model is a Quantum Field Theory describing elementary particles and their interactions. It is a fusion of Special Relativity (Einstein) and Quantum Mechanics (Bohr, Planck, Heisenberg, Schrödinger, and many others), and was fully developed by Glashow, Weinberg and Salam in 1967 (Nobel Prize, 1979) .

- There are 3 main ingredients:
  - Forces: Electromagnetism(γ), Weak Nuclear Force($W^{\pm}$,Z), Strong Nuclear Force(g)
    - notice that gravity is missing!
  - Matter
    - 6 quarks, 6 leptons in 3 generations
  - Higgs Mechanism (bzw. BEH mechanism)

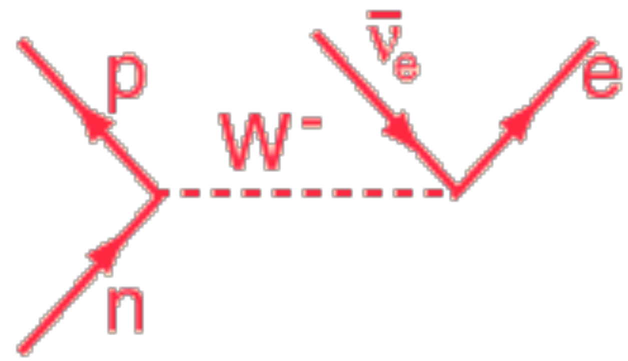


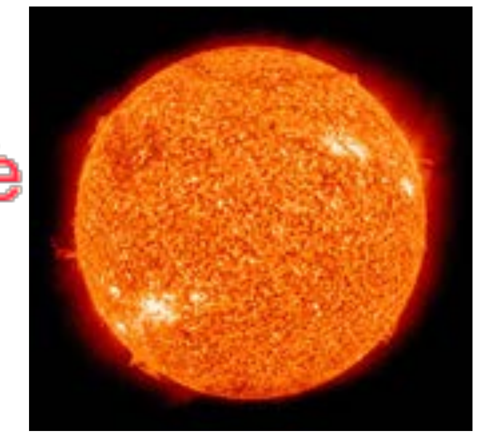
According to the Standard Model all known forces are due to the exchange of Bosons -the photon, gluon, W, Z, or the Higgs.
Richard Feynman showed how interactions represented in a quantum field theory could be drawn as an (infinite) series of diagrams.



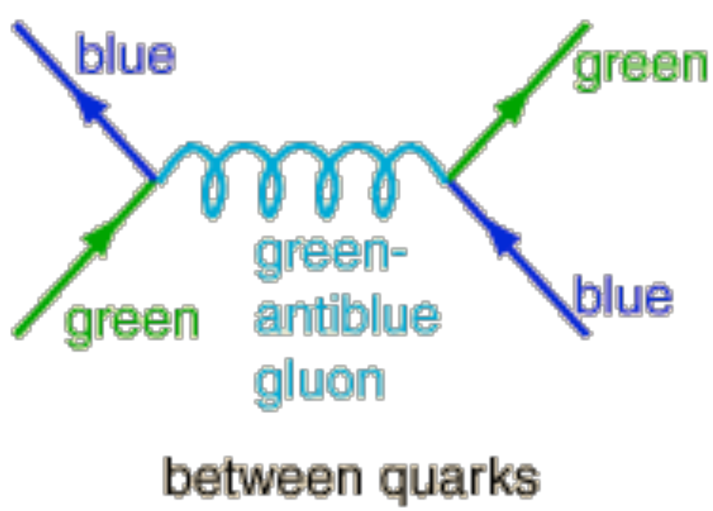


Electromagnetic Force

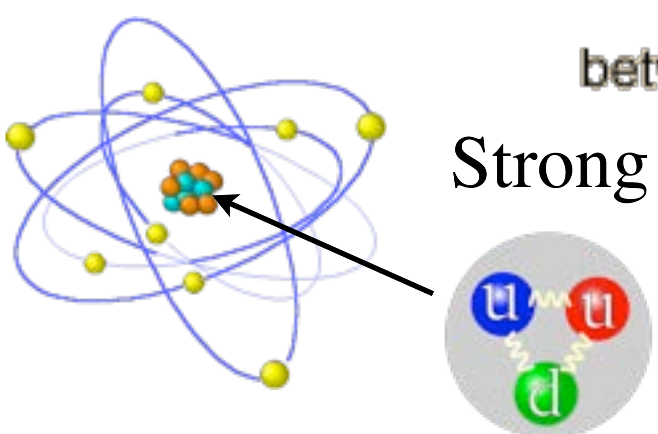


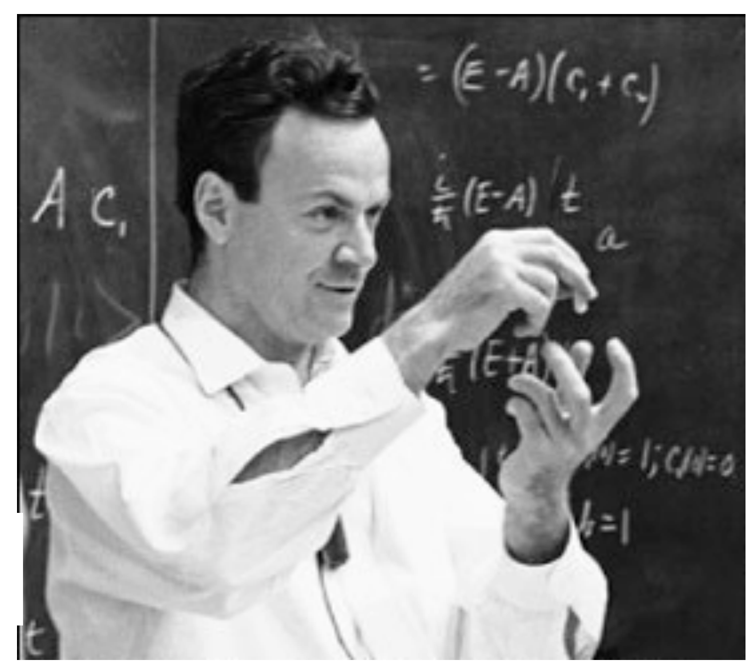


Weak Nuclear Force



Strong Nuclear Force





Nobel Prize
1965

2013 Nobel Prize in Physics

The Nobel Prize in Physics 2013
François Englert, Peter Higgs

The Nobel Prize in Physics 2013

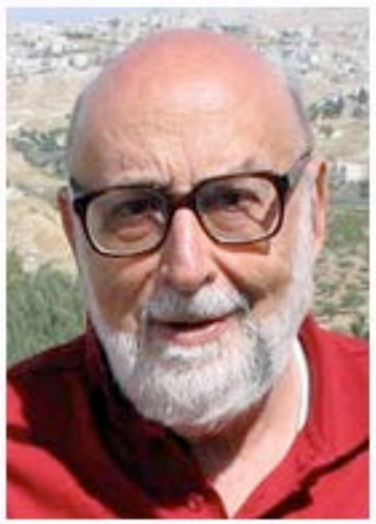


Photo: Pnicolet via Wikimedia Commons
François Englert

Photo: G-M Greuel via Wikimedia Commons
Peter W. Higgs

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

- This year's physics Nobel Prize was awarded to Francois Englert and Peter Higgs for laying the theoretical foundation of the Higgs Mechanism in the Standard Model and predicting the existence of the Higgs Boson.
- It was awarded nearly 50 years after the work was published, probably as a result of the discovery of the Higgs Boson last year.

What is the Higgs Boson?

It started out as a mathematical trick to make the massless particles in our Quantum Field Theory, appear to have mass, so that they would correspond to the particles that we see in our experiments.

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c. + \psi_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

To do this you have to assume that there is a new energetic field

- the Higgs Field -

that permeates the entire universe!

"Science is what we do to keep from fooling ourselves" R. Feynman

An excitation of the Higgs Field is the physical manifestation - the Higgs Boson.

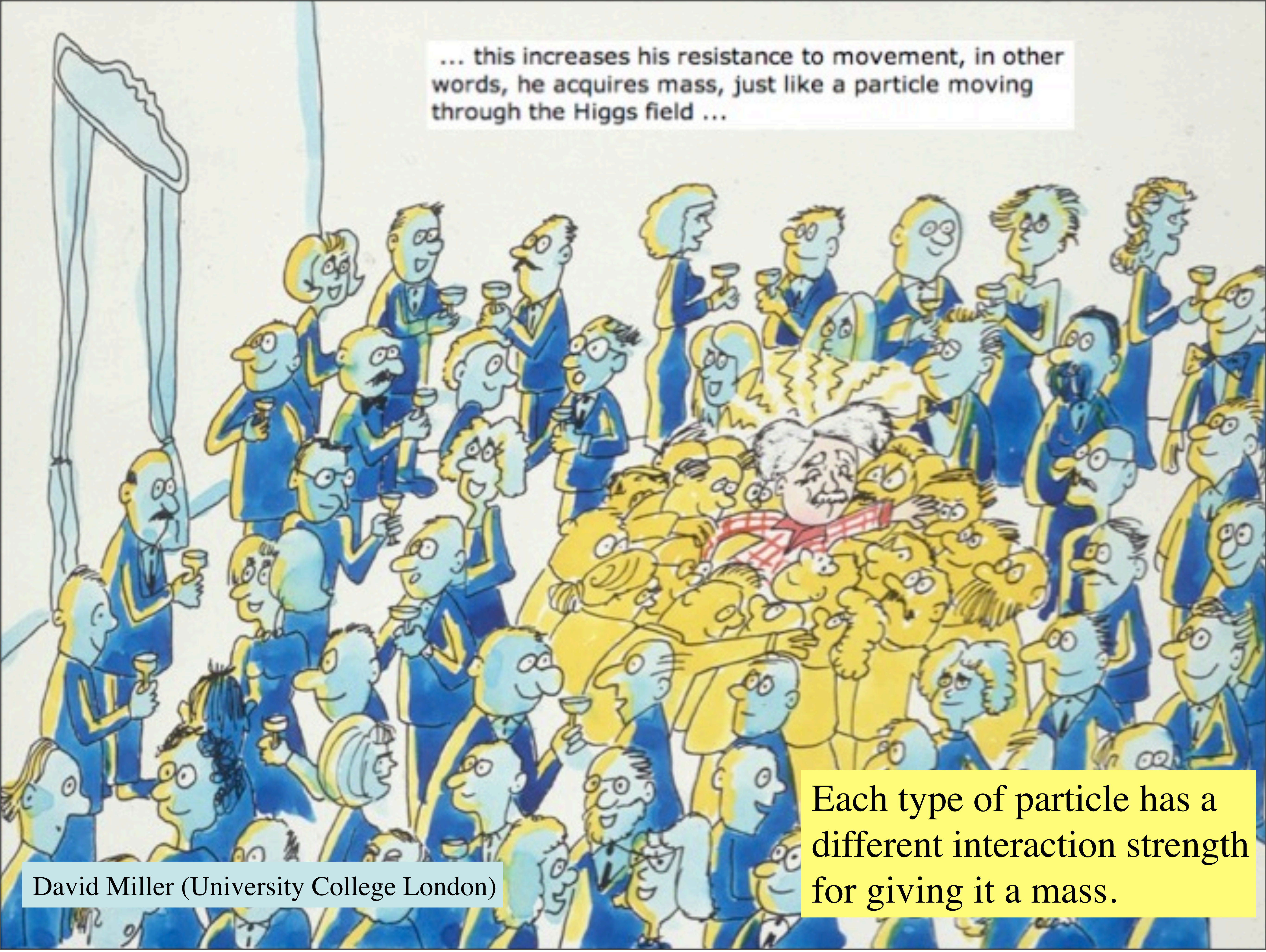
But is it true?

For more discussion, see Prof. Arno Straessner's Ringvorlesung:

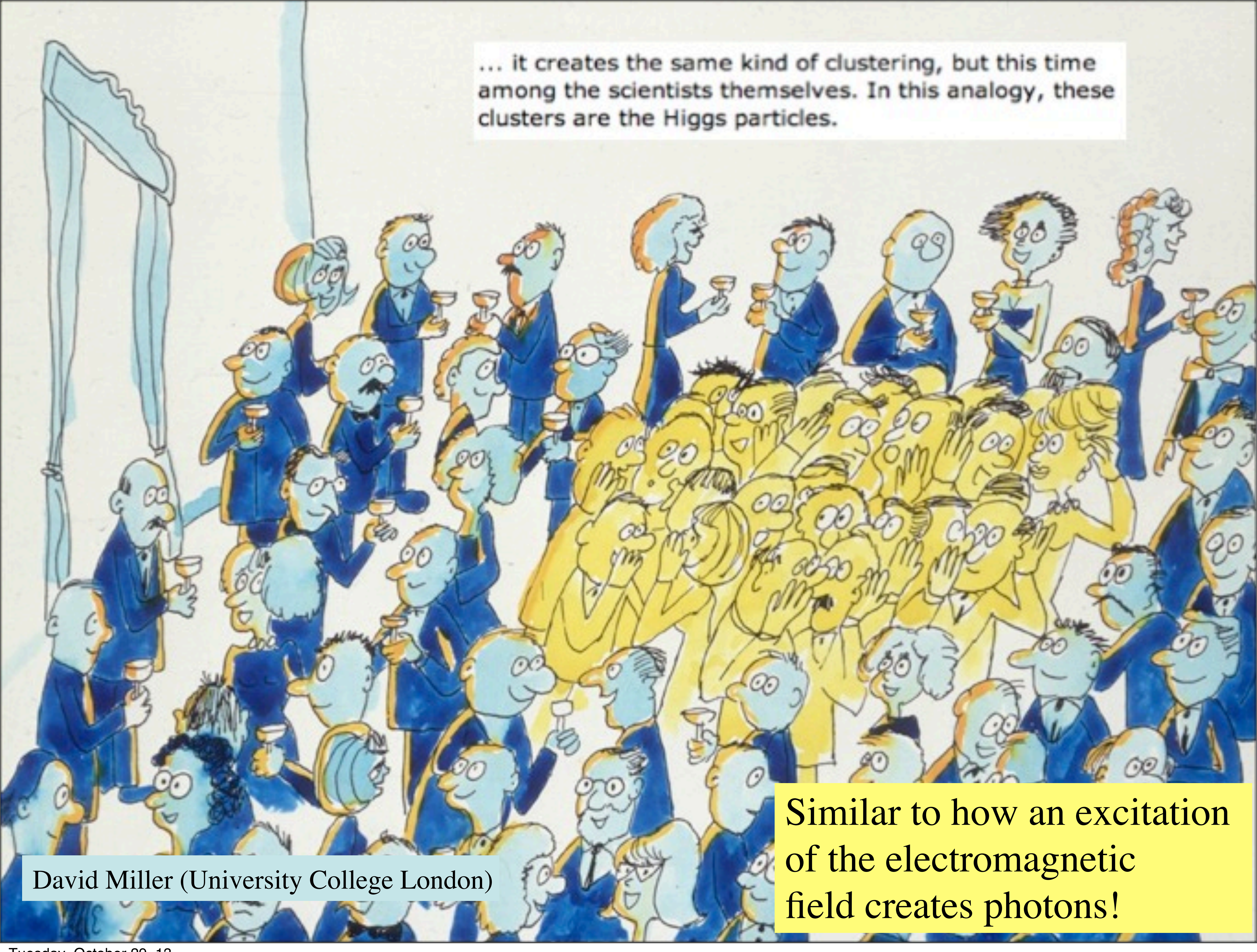
Ist das Rätsel der Masse gelöst? - Teilchenphysik am Large Hadron Collider


To understand the Higgs mechanism, imagine that a room full of physicists quietly chattering is like space filled only with the Higgs field....
David Miller (University College London)


... a well known scientist walks in, creating a disturbance as he moves across the room, and attracting a cluster of admirers with each step ...
David Miller (University College London)

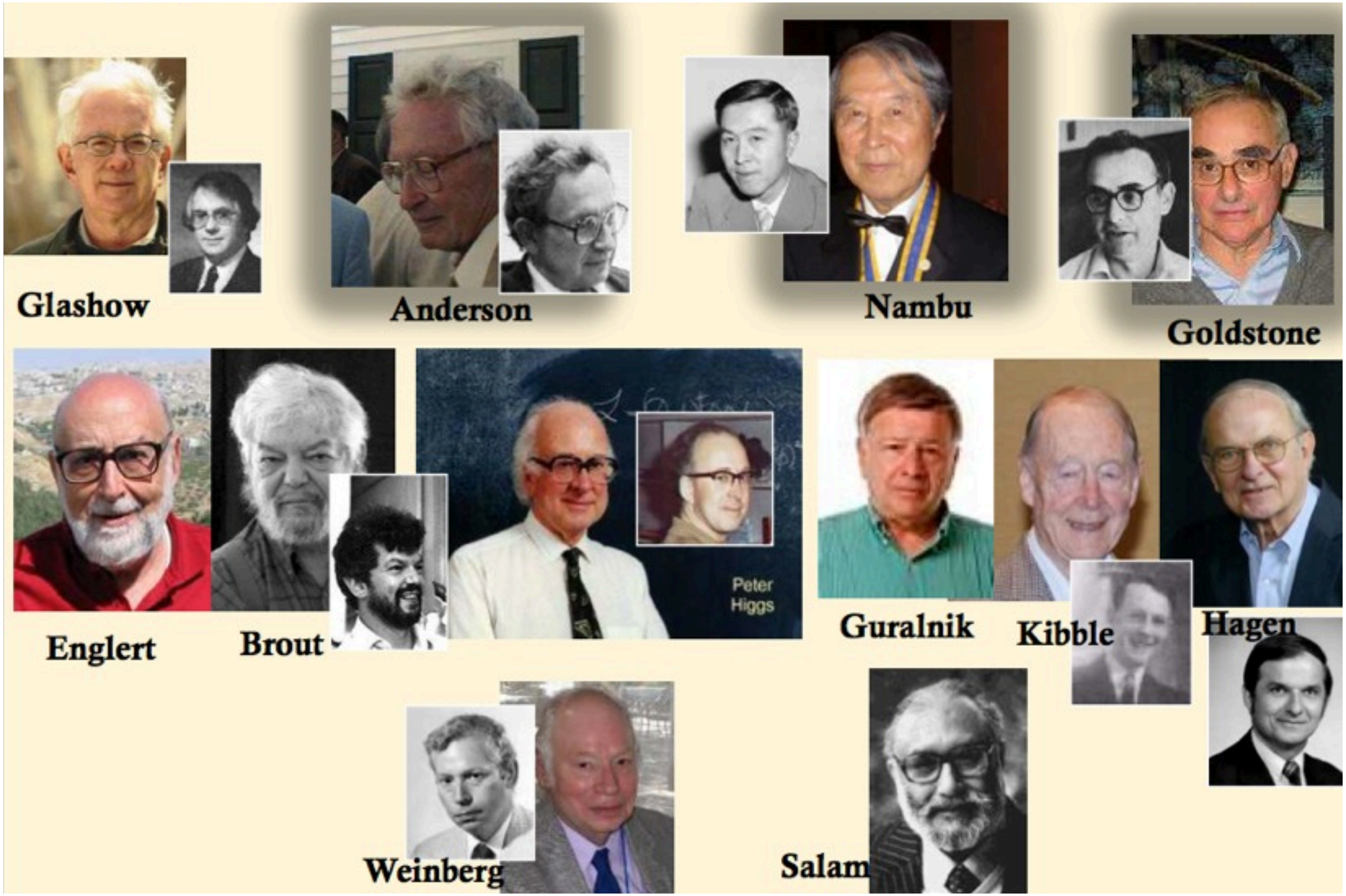

... this increases his resistance to movement, in other words, he acquires mass, just like a particle moving through the Higgs field ...
Each type of particle has a different interaction strength for giving it a mass.
David Miller (University College London)


... if a rumour crosses the room ...
David Miller (University College London)


... it creates the same kind of clustering, but this time among the scientists themselves. In this analogy, these clusters are the Higgs particles.
Similar to how an excitation of the electromagnetic field creates photons!
David Miller (University College London)

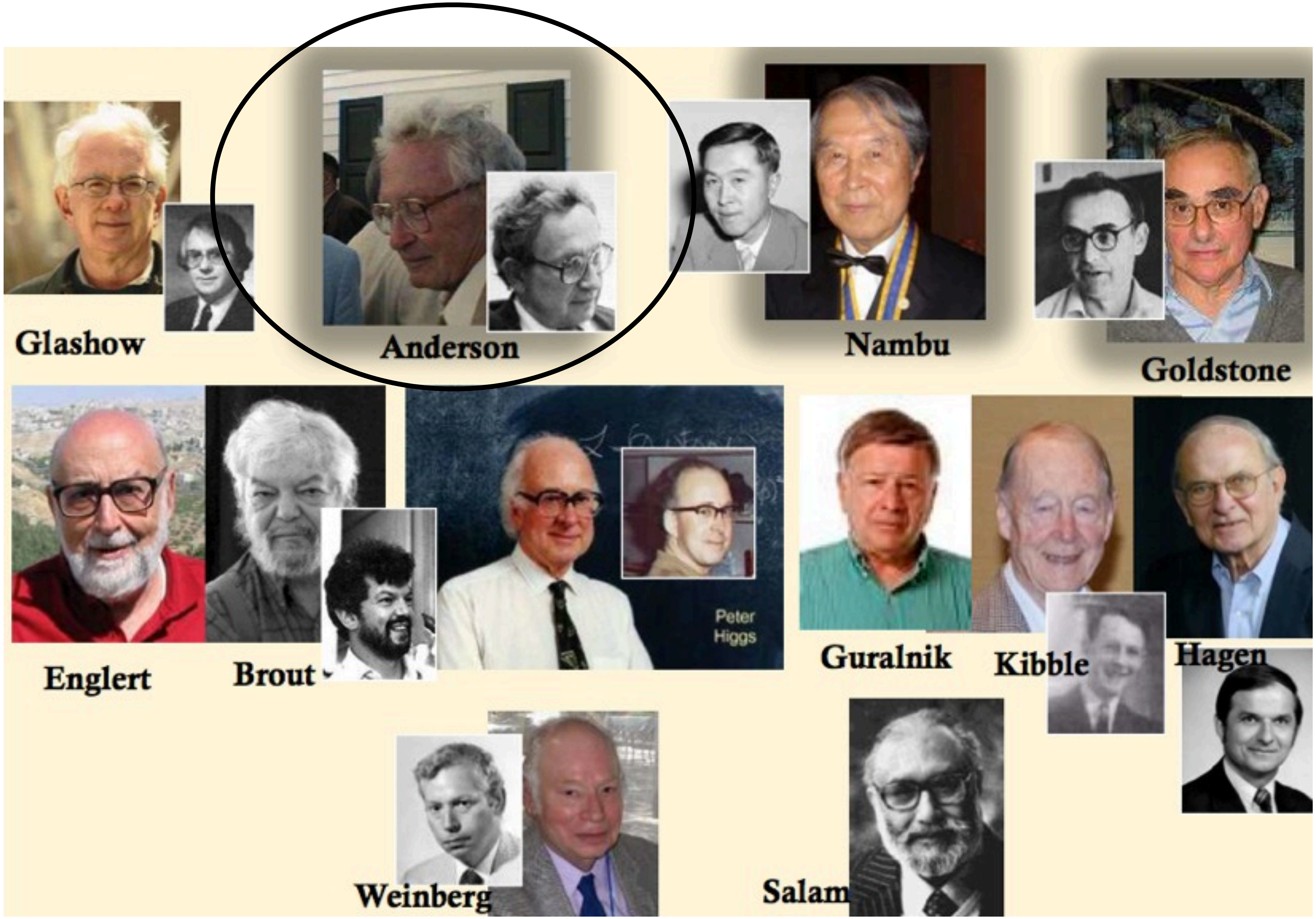
Who proposed the Higgs boson?

Although **Peter Higgs'** name is associated with the addition of a scalar field, there were several others who came up with the same idea about the same time.



Who proposed the Higgs boson?

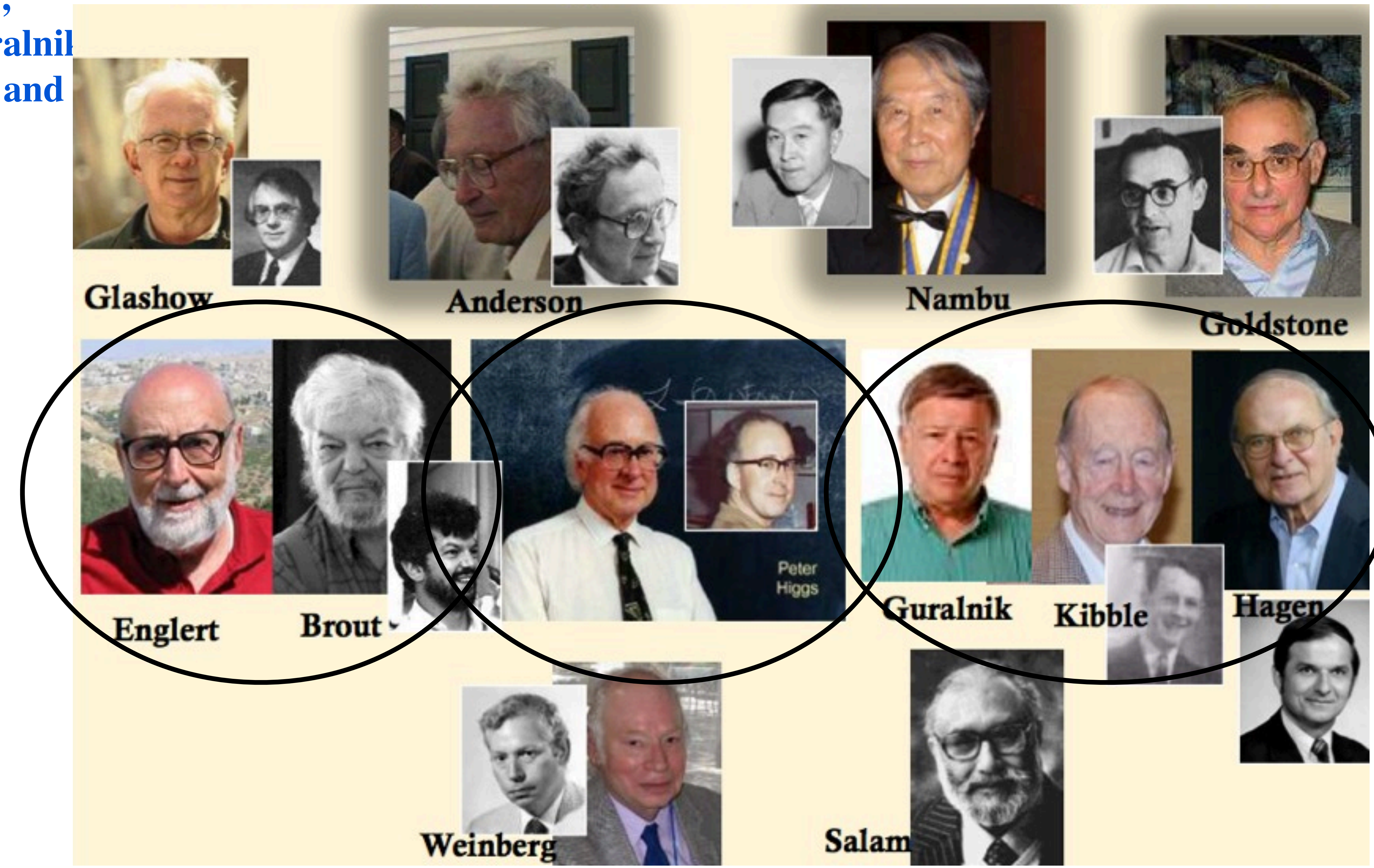
The basic method of adding a scalar field was proposed in 1962 by Philip Warren Anderson, a solid state theorist.



Who proposed the Higgs boson?

A relativistic model was developed in 1964 by three independent groups:

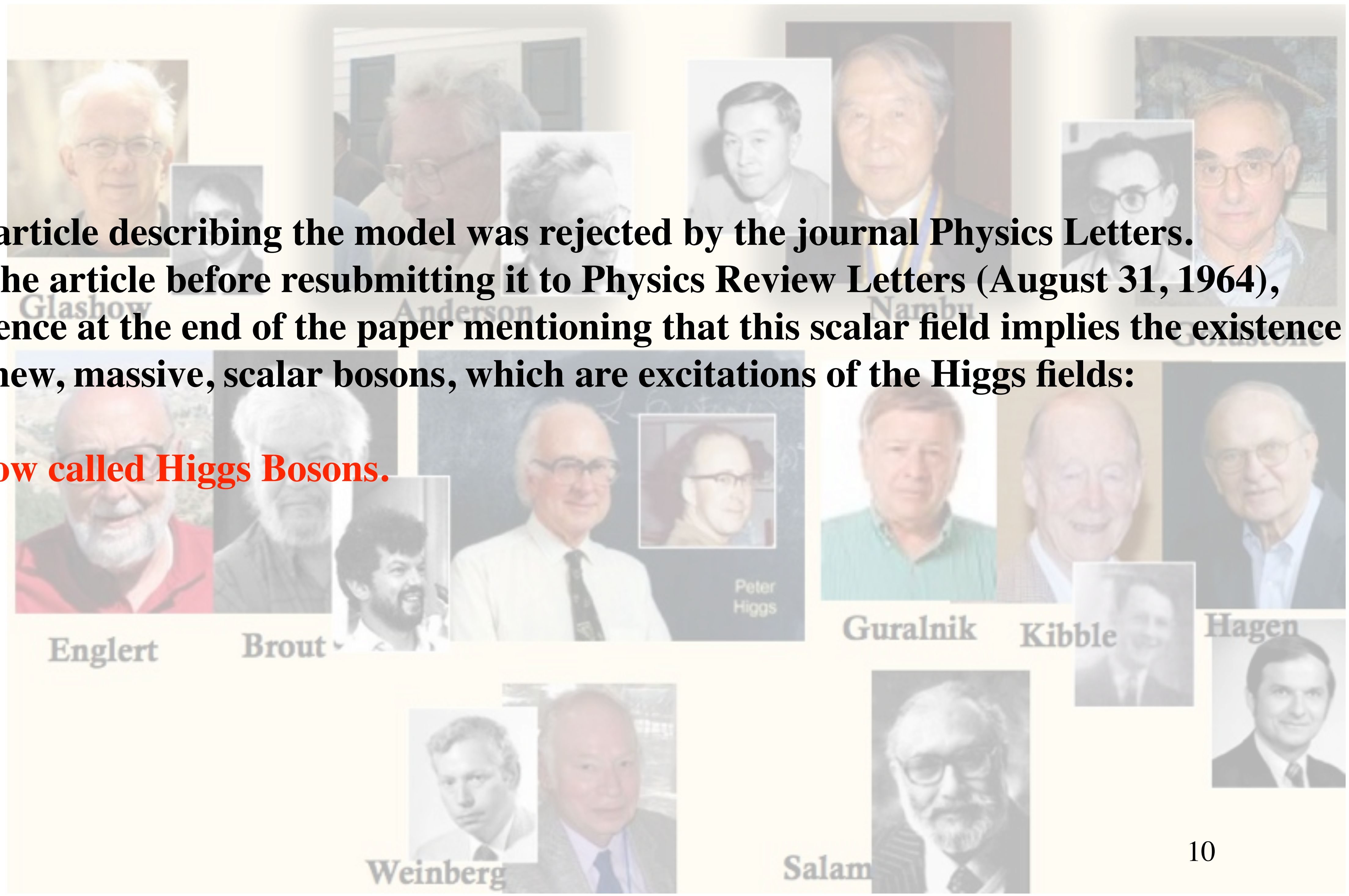
- **Francois Englert and Robert Brout;**
- **Peter Higgs;**
- **Gerald Guralnil C. R. Hagen, and Tom Kibble.**



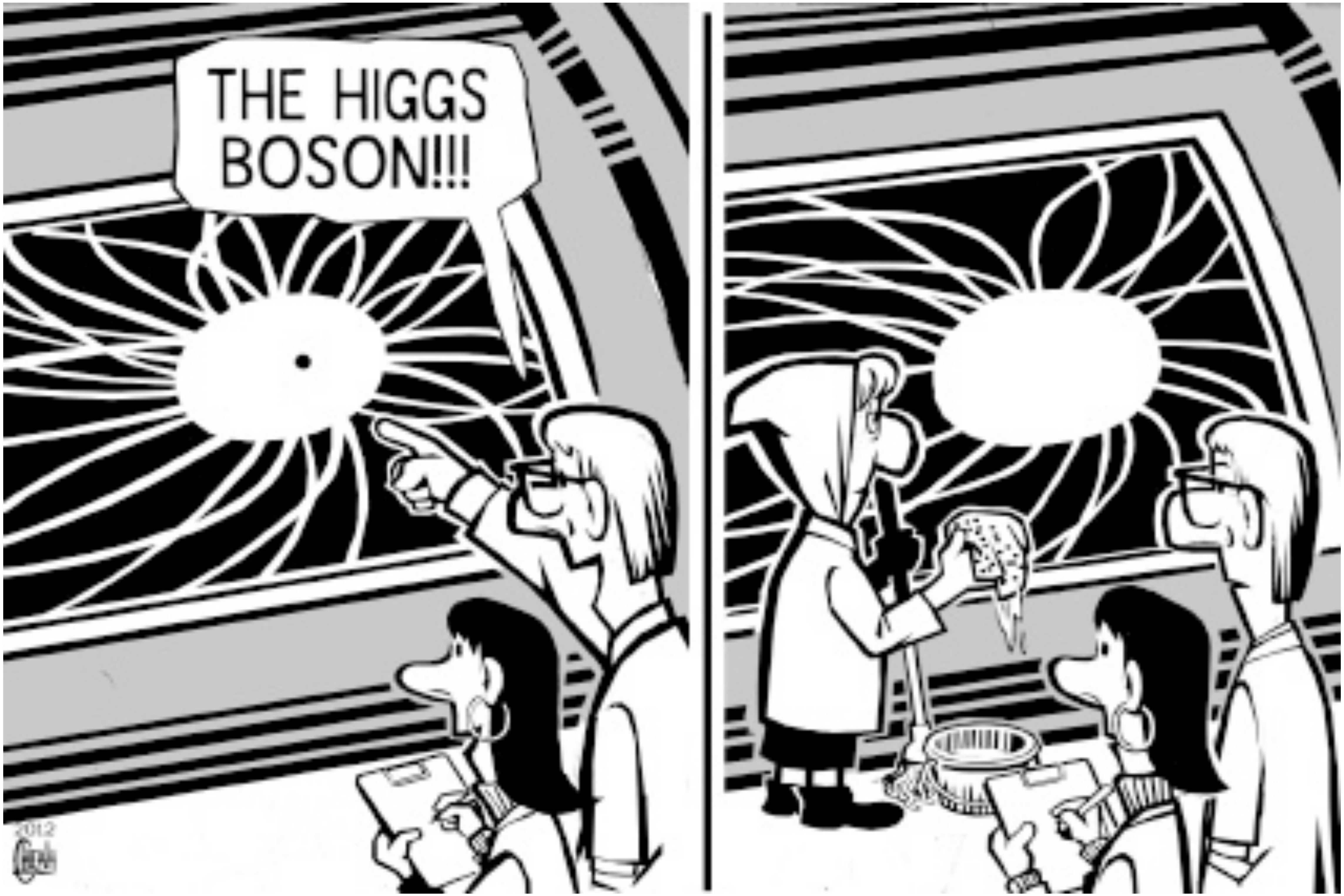
Who proposed the Higgs boson?

Higgs' original article describing the model was rejected by the journal Physics Letters. When revising the article before resubmitting it to Physics Review Letters (August 31, 1964), he added a sentence at the end of the paper mentioning that this scalar field implies the existence of one or more new, massive, scalar bosons, which are excitations of the Higgs fields:

These are the now called Higgs Bosons.

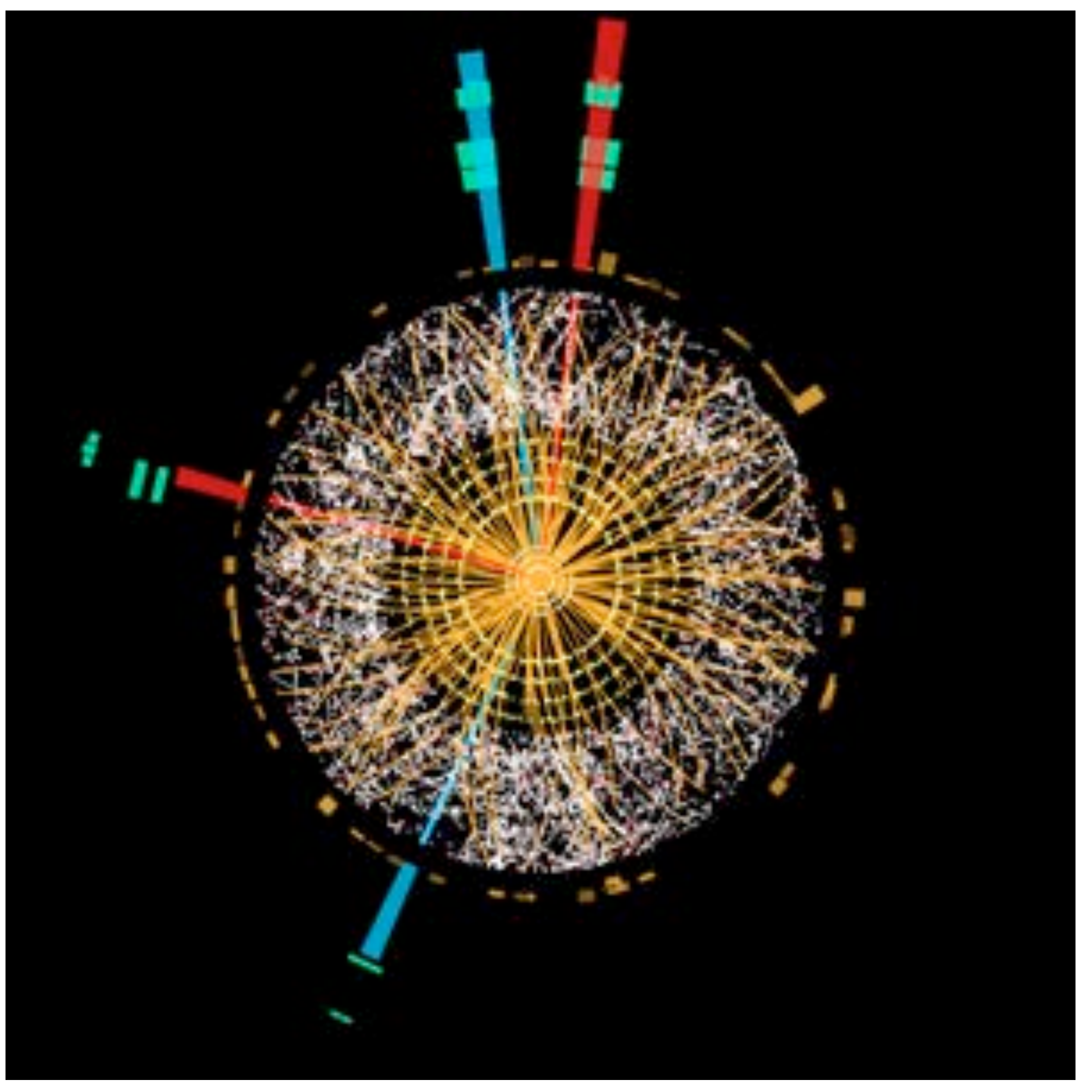


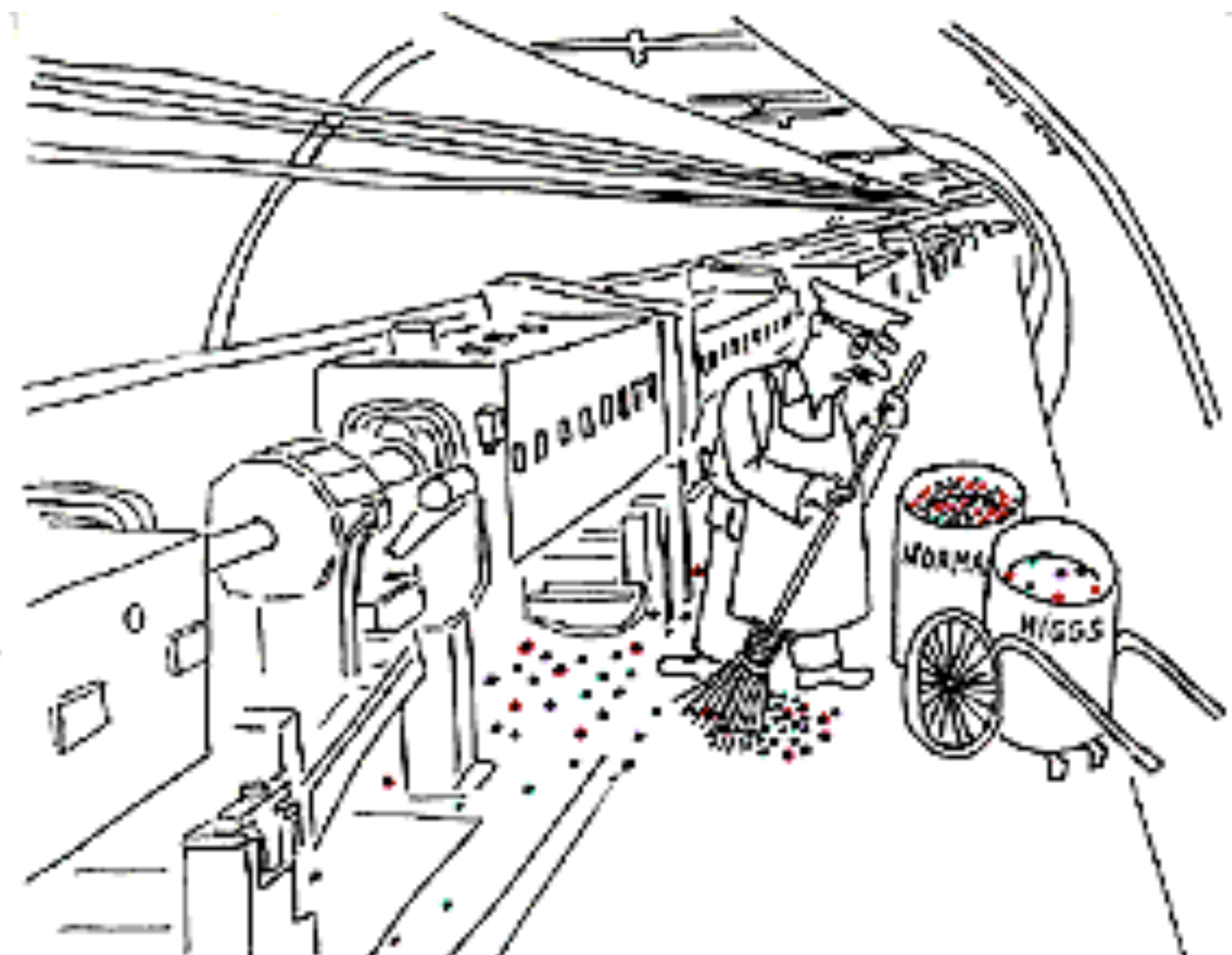
Have we seen the Higgs?



How do we look for the Higgs?

The standard model describes the possible decays of the Higgs Boson, and indicates that it will live for only ~ 10^{-21} seconds before it decays. So we will not directly "see" the Higgs, only its decay products. The decay modes are predicted by the standard model, even though the exact value of the mass is not!





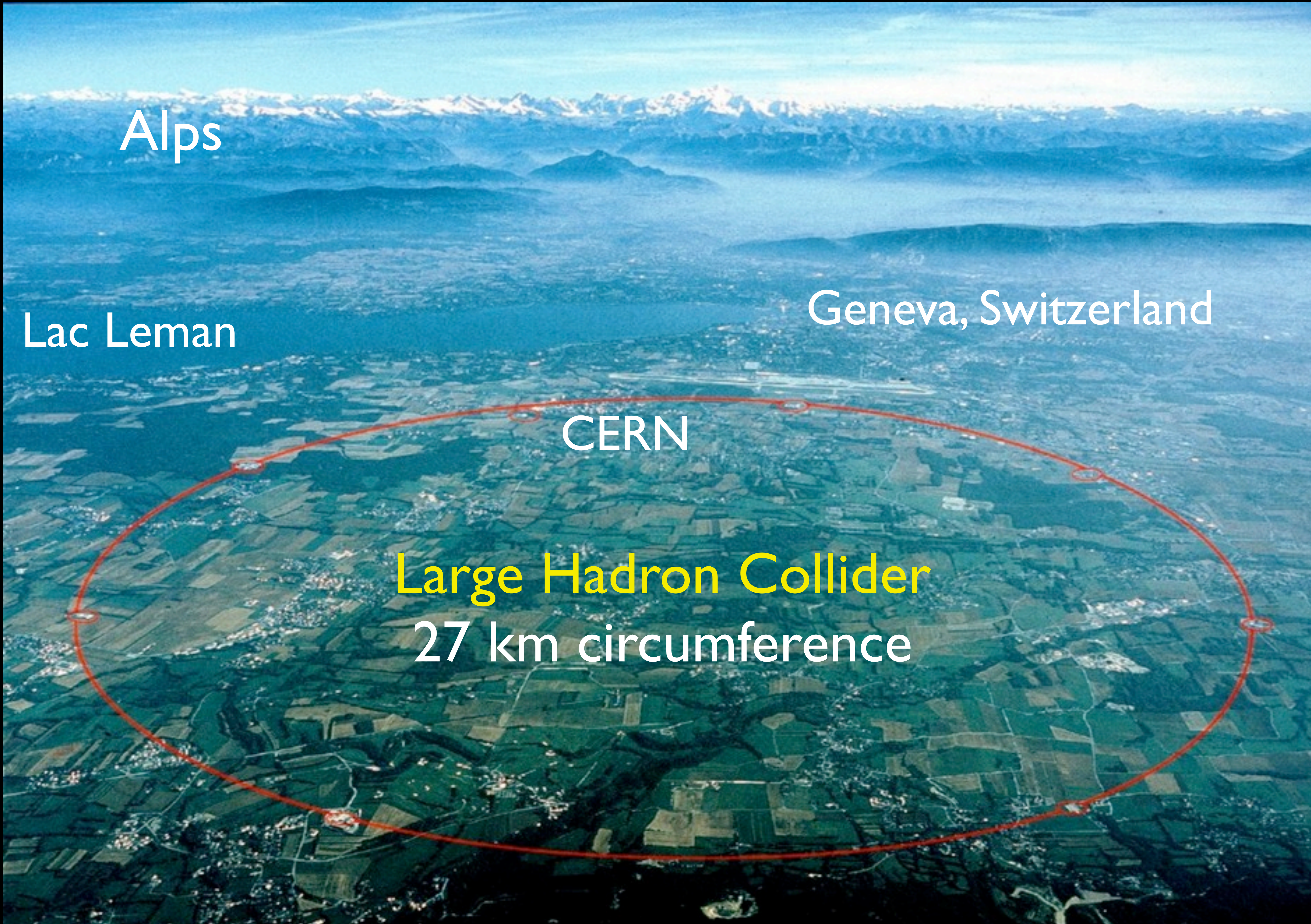
To find the Higgs we need to build colliding beam accelerators

Colliding beams?

Just like in a demolition derby a head on collision of two cars is much more destructive (has more energy) than a collision while going the same direction. This is the reason for colliding beams, we want to have the most energetic collisions possible- and use this energy to create new particles!

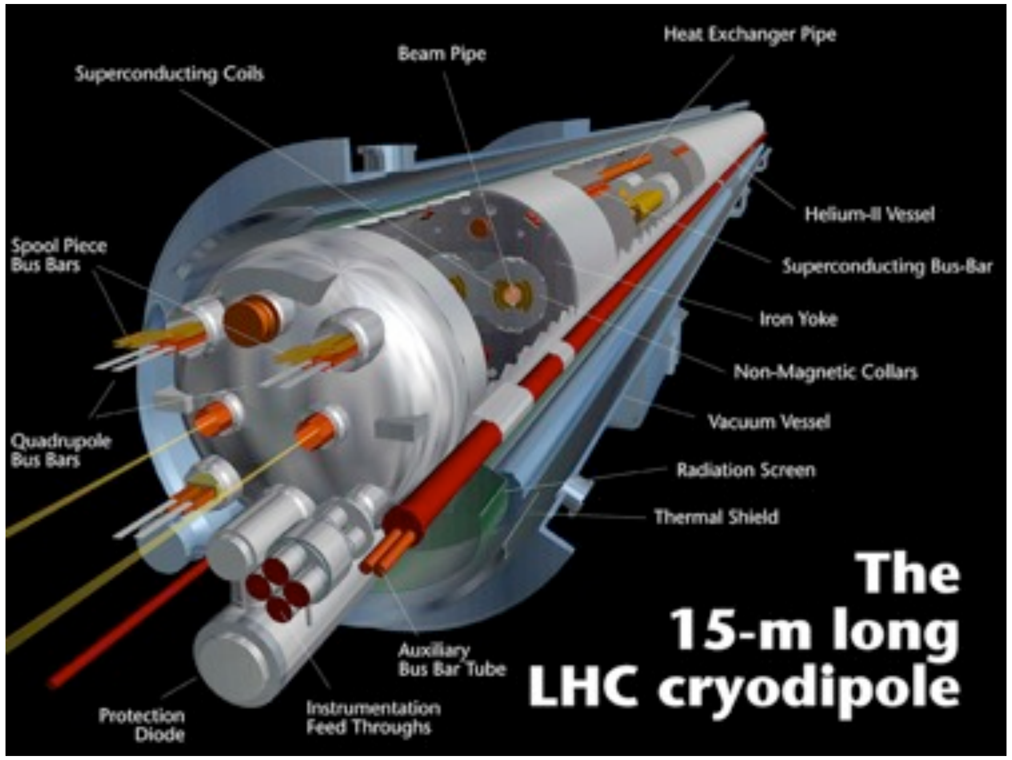
There is a long history of building colliding beam machines.
•ISR 1971-84 (proton-proton) 62 GeV
•LEP 1989-2000 (electron – positron) at > 100 GeV
•SSC 1993 (proton-proton) in Texas – cancelled- > 40000 GeV
•Tevatron 1983-2011(proton –antiproton) at Fermilab > 3000 GeV
•LHC 2010-Present (proton-proton) 14000 GeV

Searching for particles in the standard model, for gauge bosons, and the Higgs have been major goals of each of these colliders.


Alps
Lac Leman
Geneva, Switzerland
CERN
Large Hadron Collider
27 km circumference

A few milestones for LHC

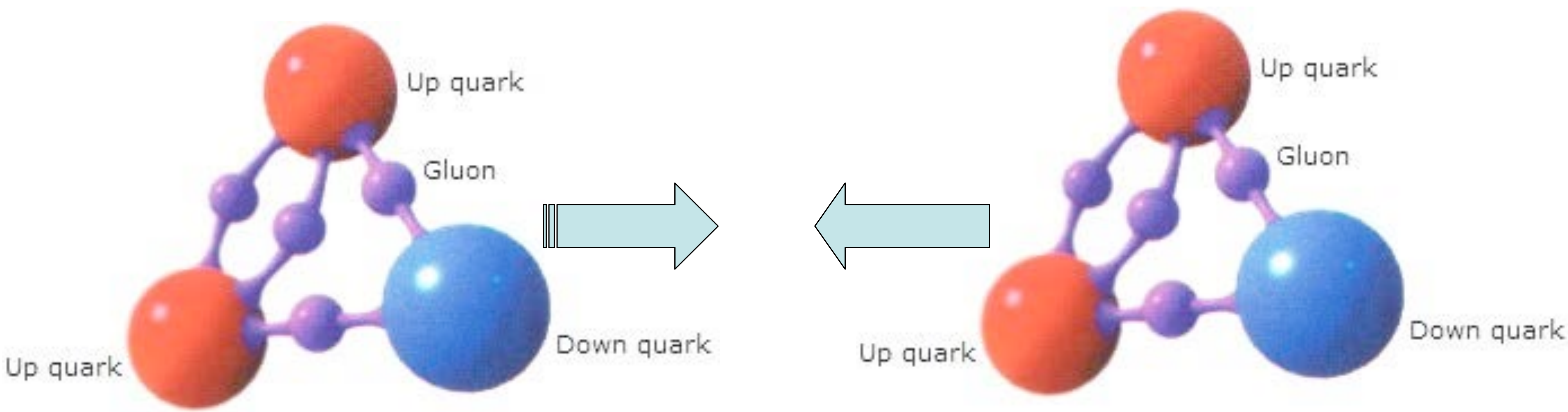
•Planning for the LHC began : 1993
•LEP accelerator closed and removed from tunnel-2000
•Last magnet installed in LHC- April, 2007
•Beam injected into one sector- August 2008
•First circulating beam – Sept 10, 2008
•Disaster! Magnet arc quench – Sept 19, 2008
•First collisions- Nov 23, 2009
•First collisions at 7.0 TeV , March 30, 2010
•Data taking 2010, 2011, 2012 (8 TeV)



Upcoming:
• Data taking 2015-2018 at full design energy (14 TeV)
• Upgrade of detectors 2018-2020
• Final dataset gathered 2020-~2030

What happens in a proton-proton collision at the LHC?

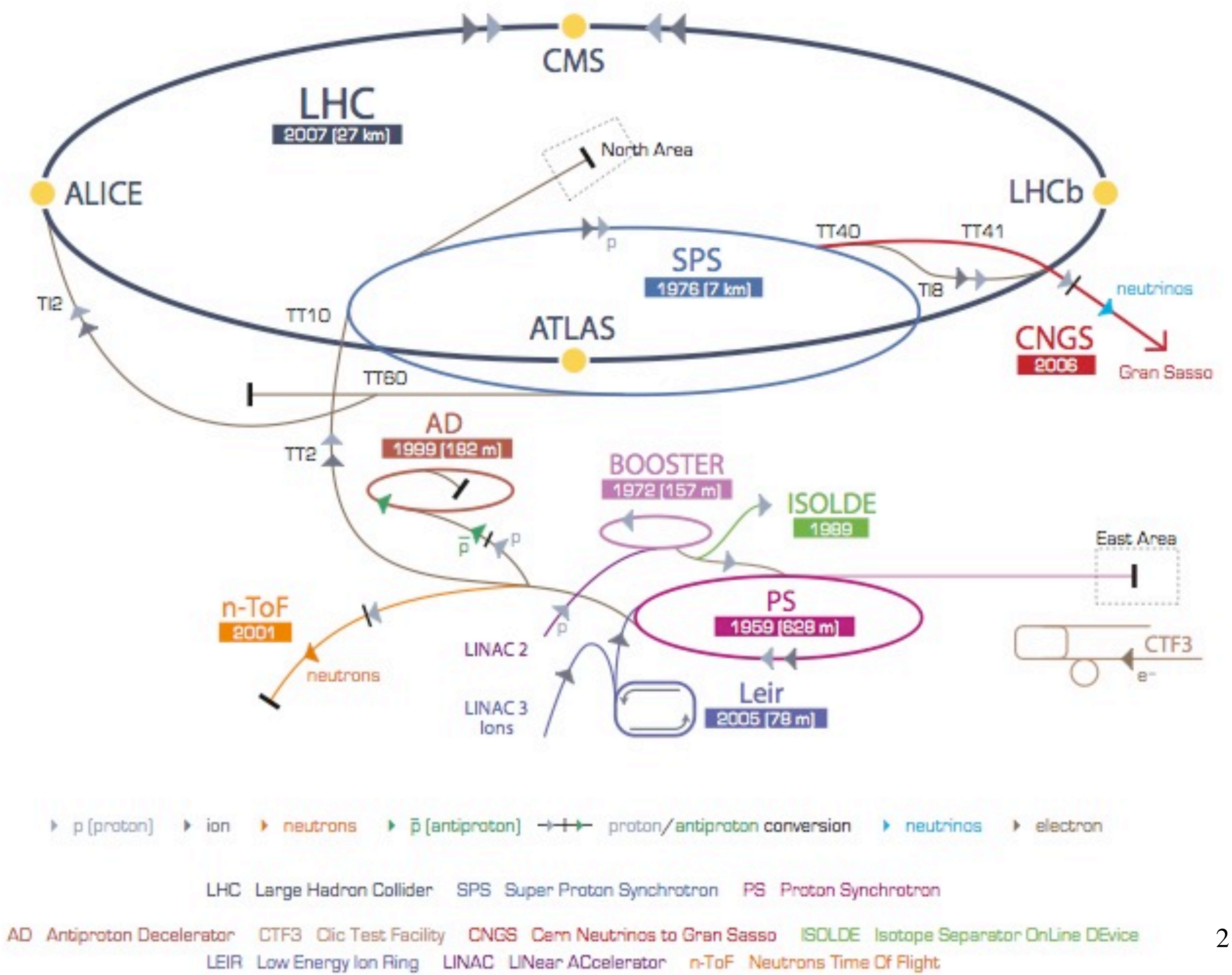
Protons collide at the interaction points around the LHC ring, but the proton is not a fundamental particle. The quarks and gluons that make up the proton are the particles that interact. At the LHC both quark-quark and gluon-gluon interactions are very important.



Gluons holding quarks together to form a proton (diagram from *Scientific American*)

Gluons holding quarks together to form a proton (diagram from *Scientific American*)

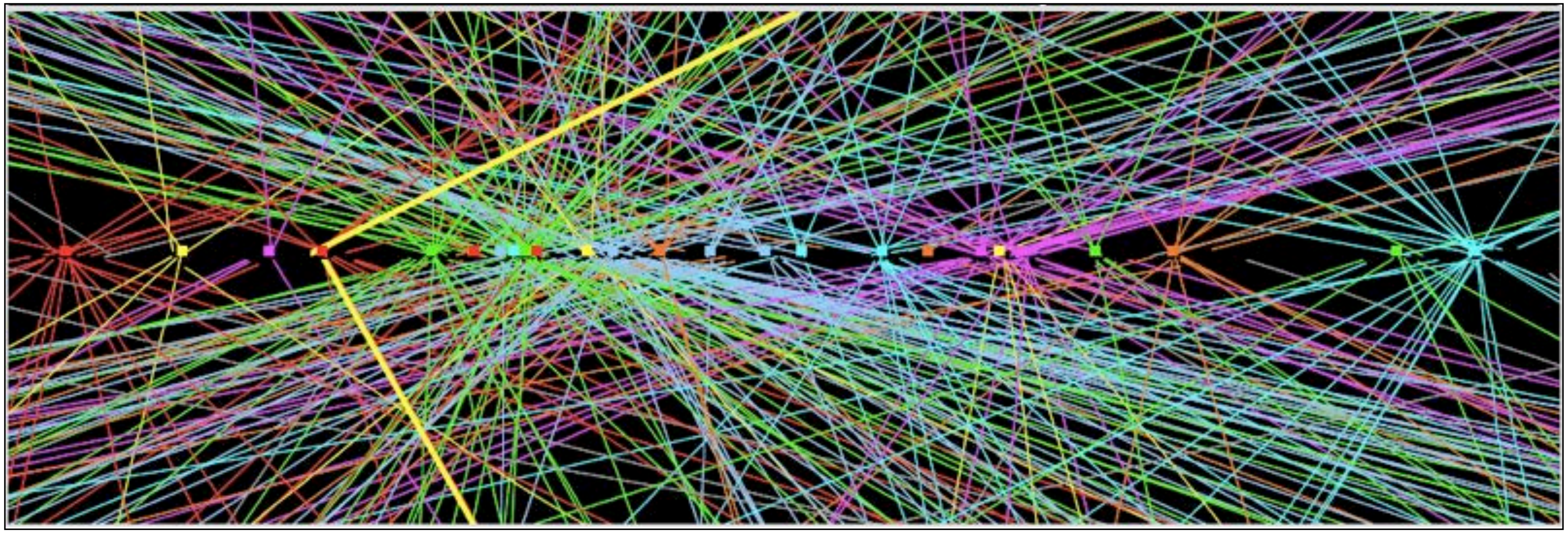
CERN Accelerator Complex



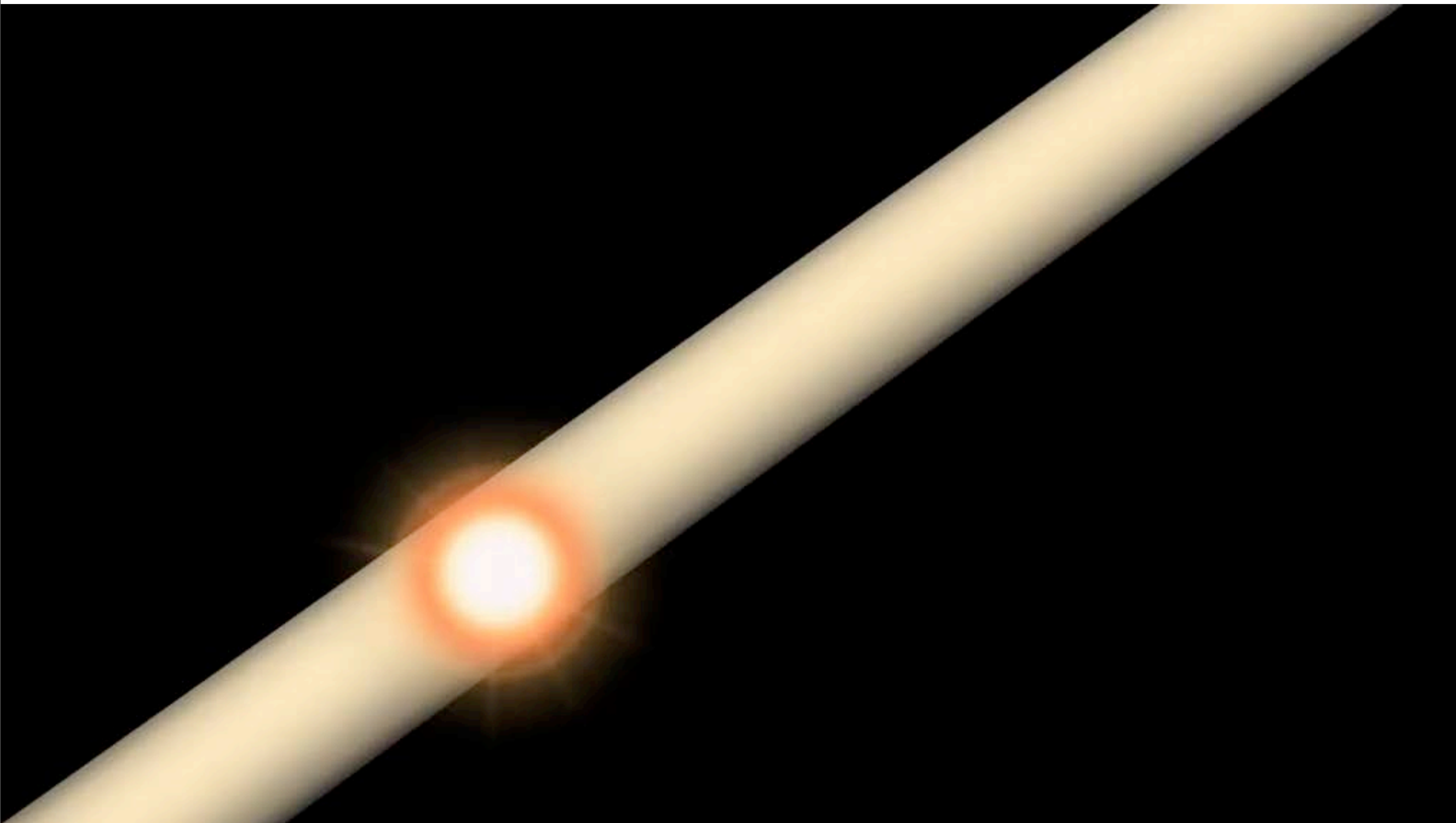
Proton collisions in the LHC

LHC has stored beams of 2 x 10^{13} (20 trillion) protons in a 16 micron diameter beam (half the size of a human hair). Each proton bunch is about 20 cm (8 in) long. We are running presently with about ~2000 bunches in each ring resulting in about 20 million crossings /sec!

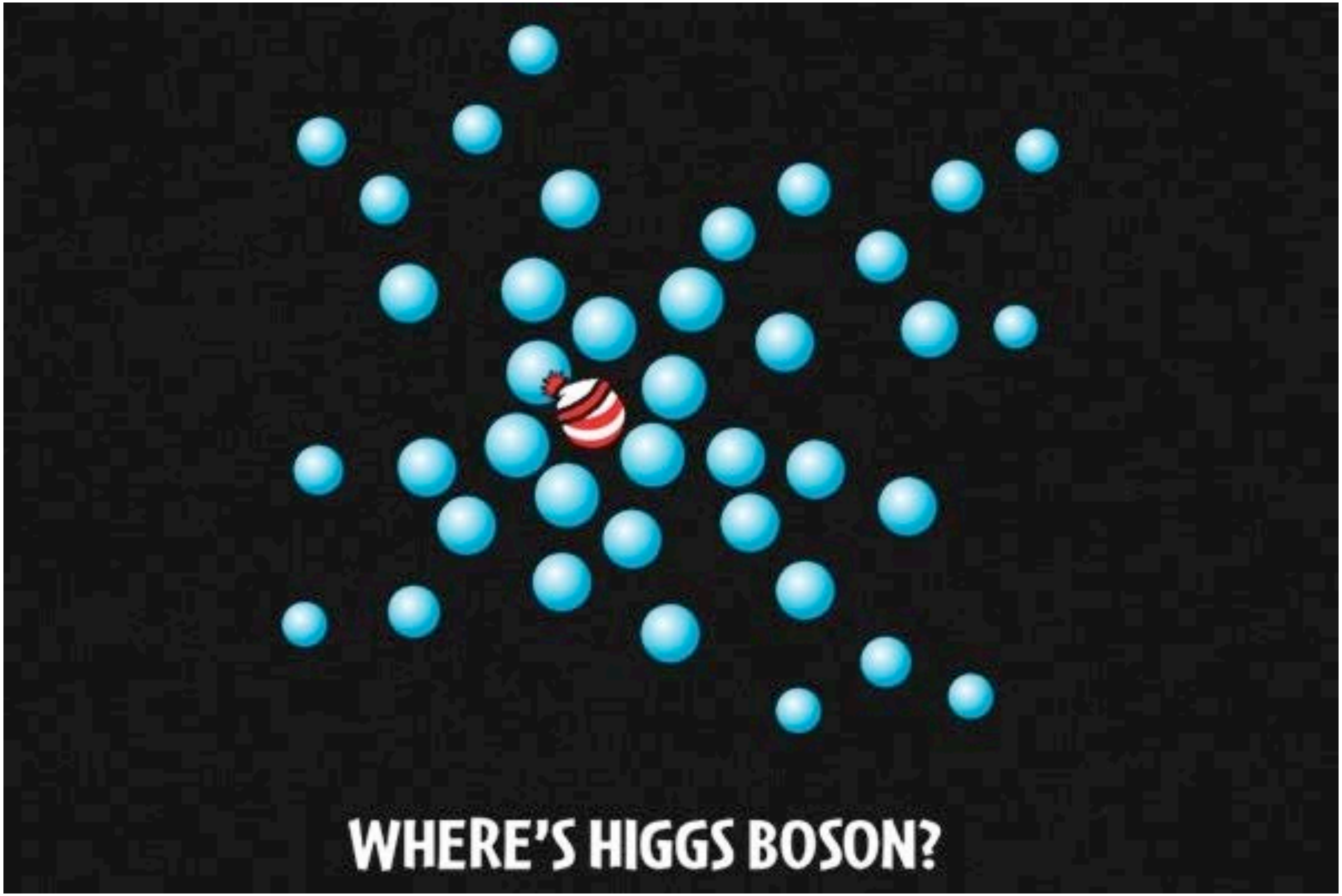
The two thin bunches pass through each other like two trains on the same railroad track, resulting about 30 proton-proton collisions.



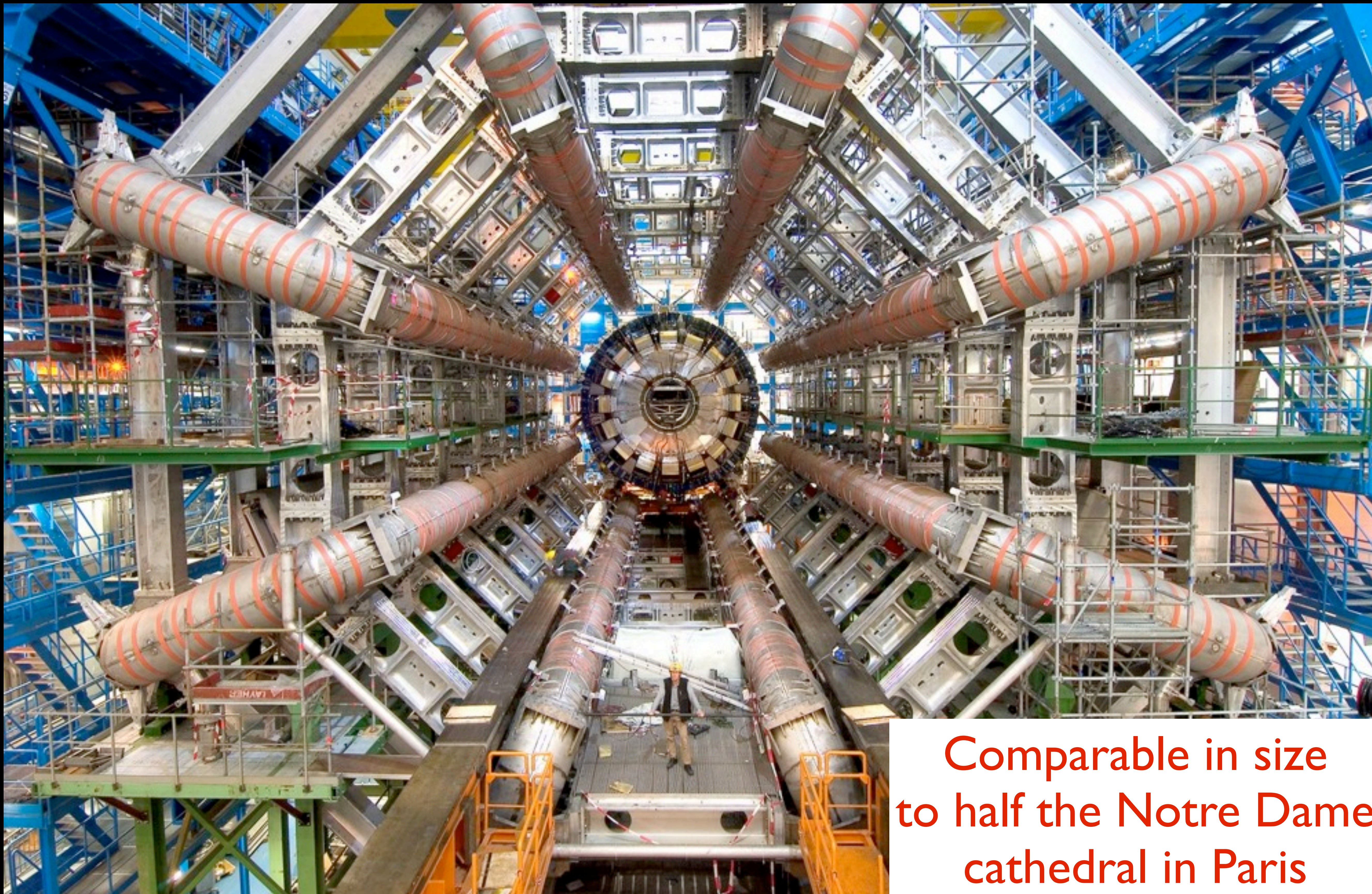
Collision Event



How do we identify the Higgs in the collisions?

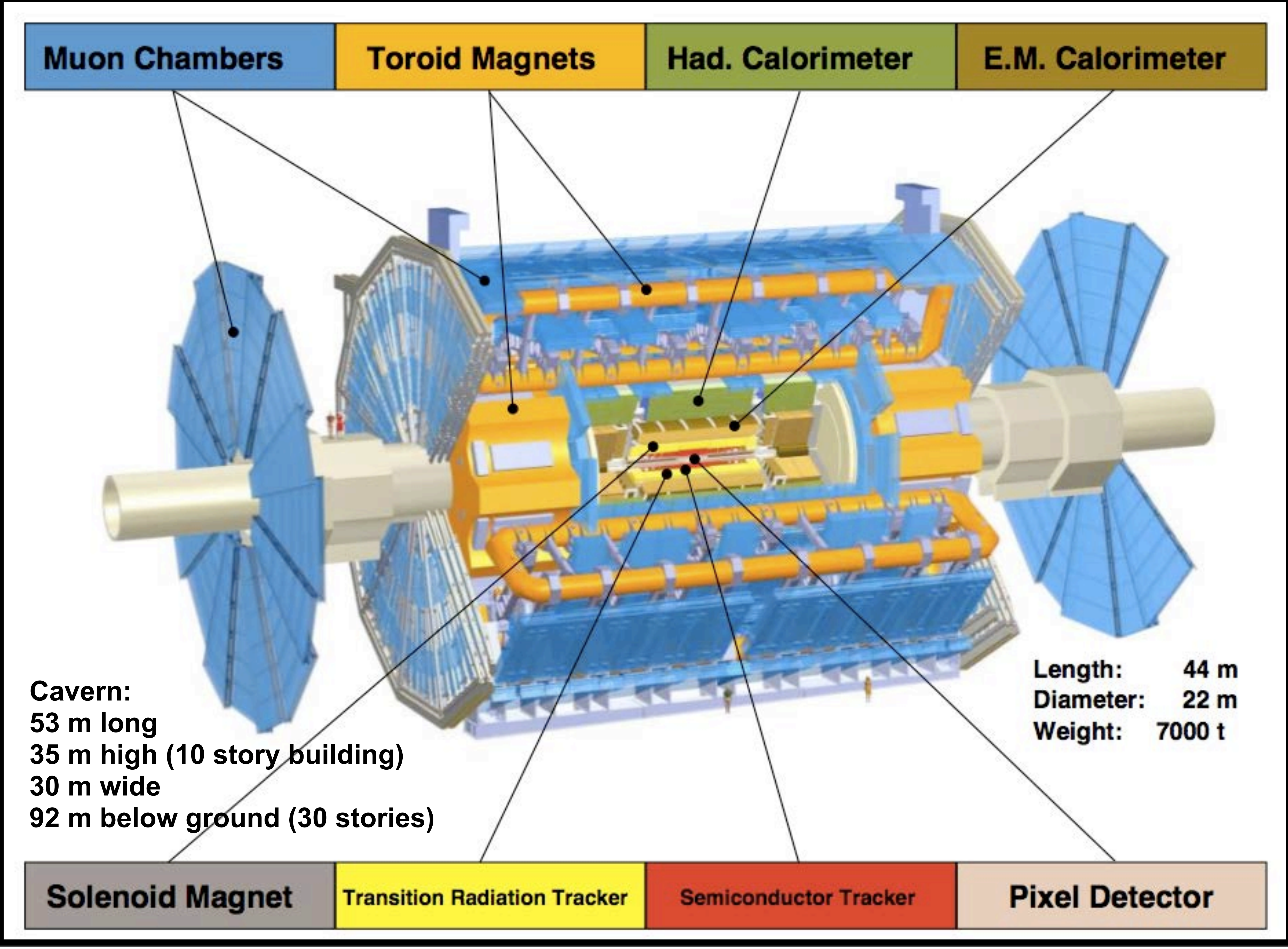


ATLAS

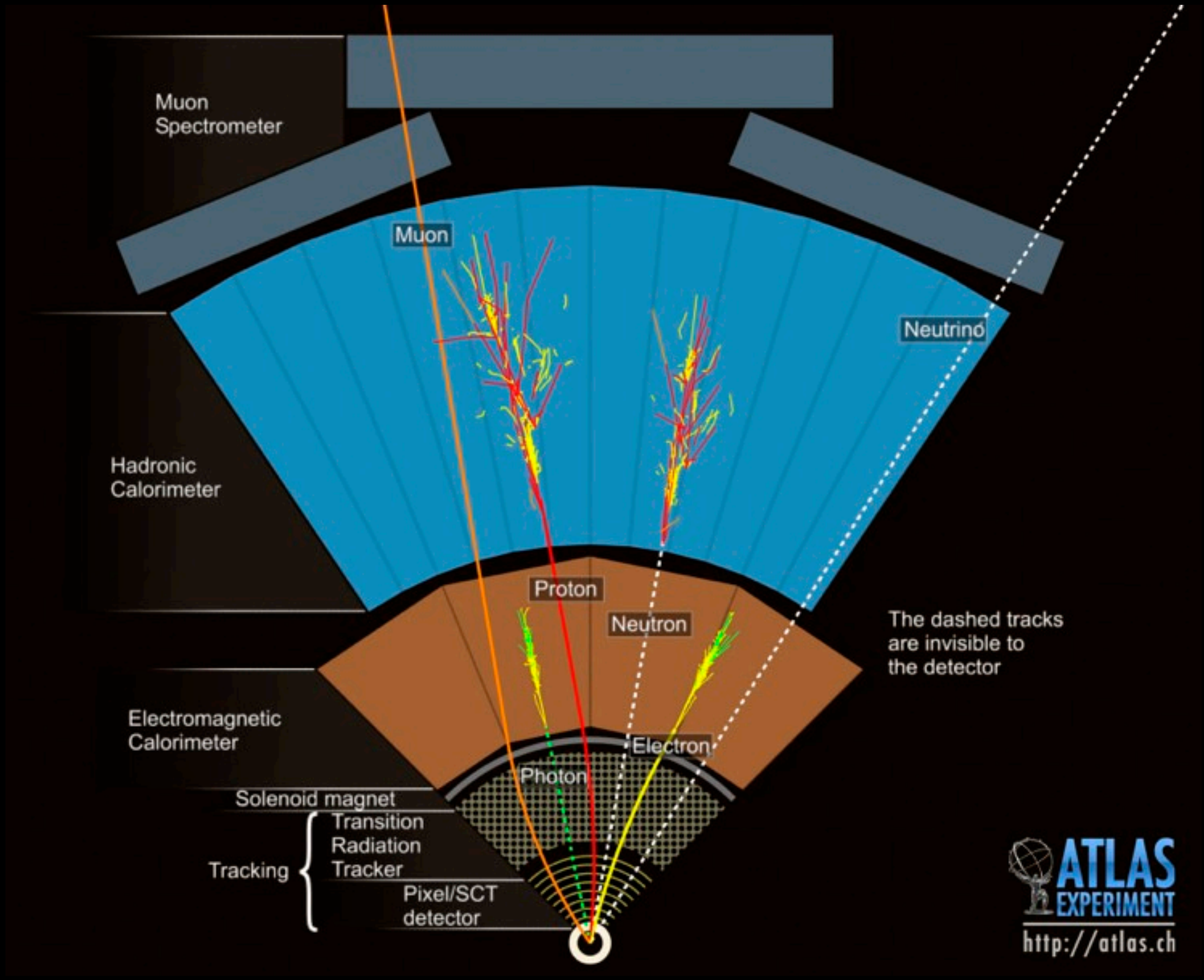


Comparable in size to half the Notre Dame cathedral in Paris

A Toroidal LHC Apparatus

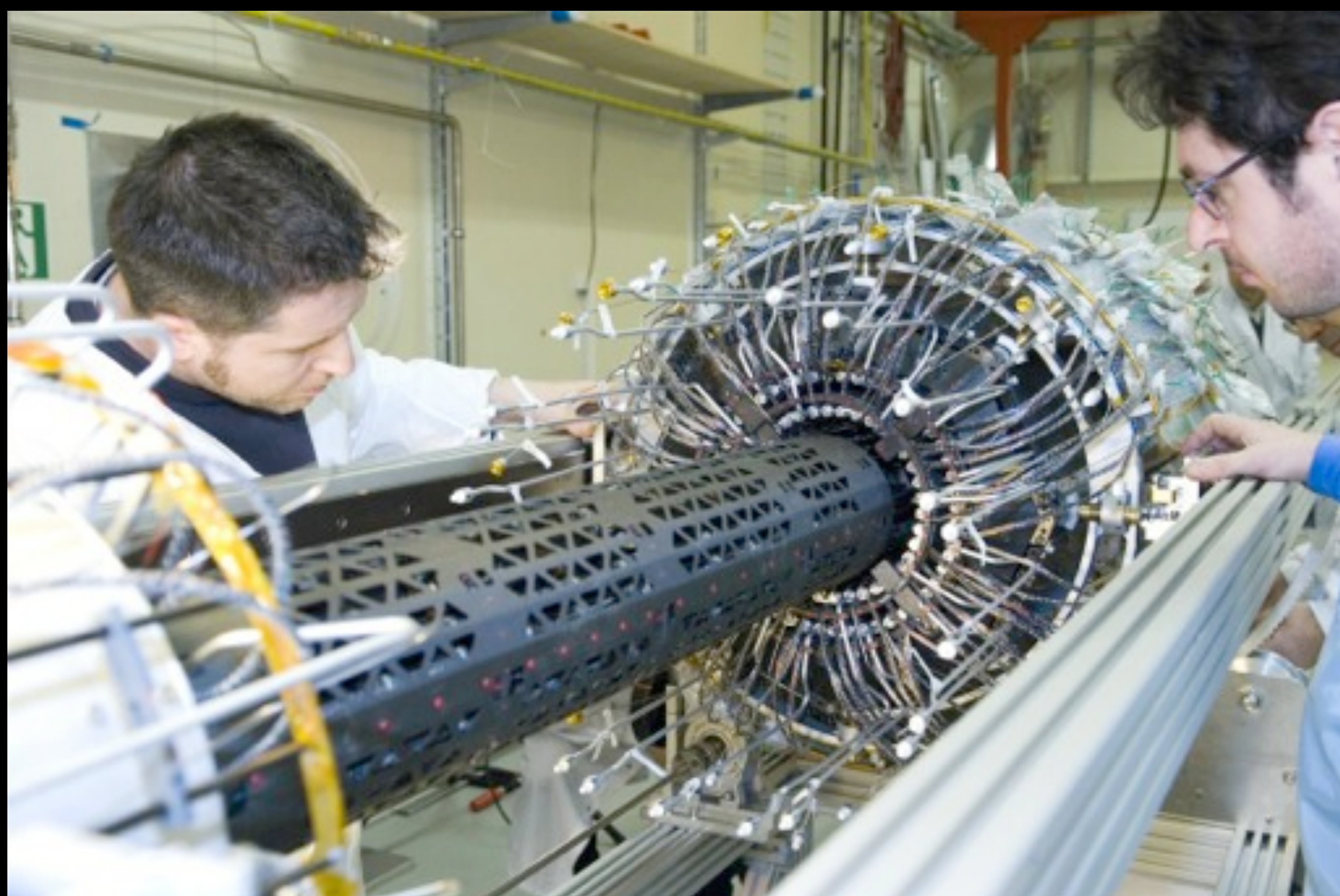


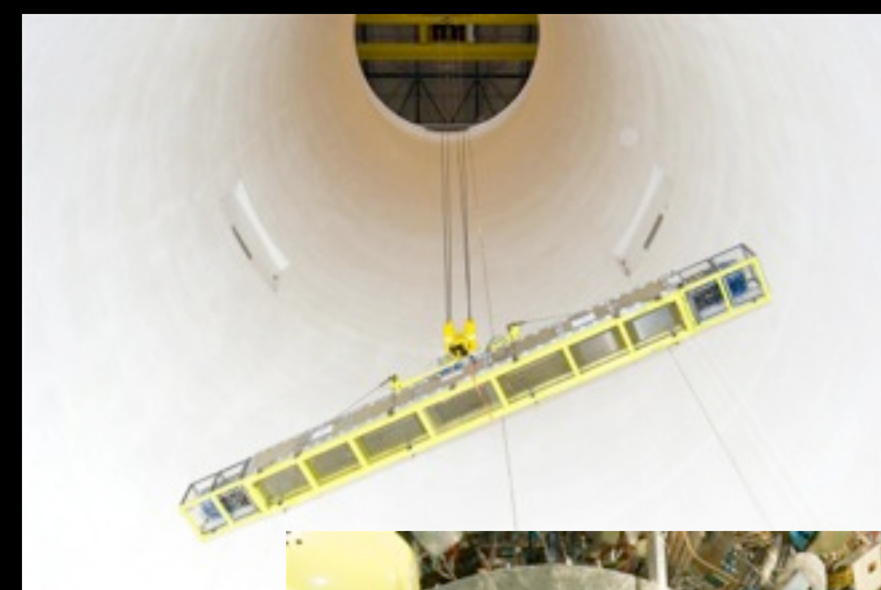
Particle Identification



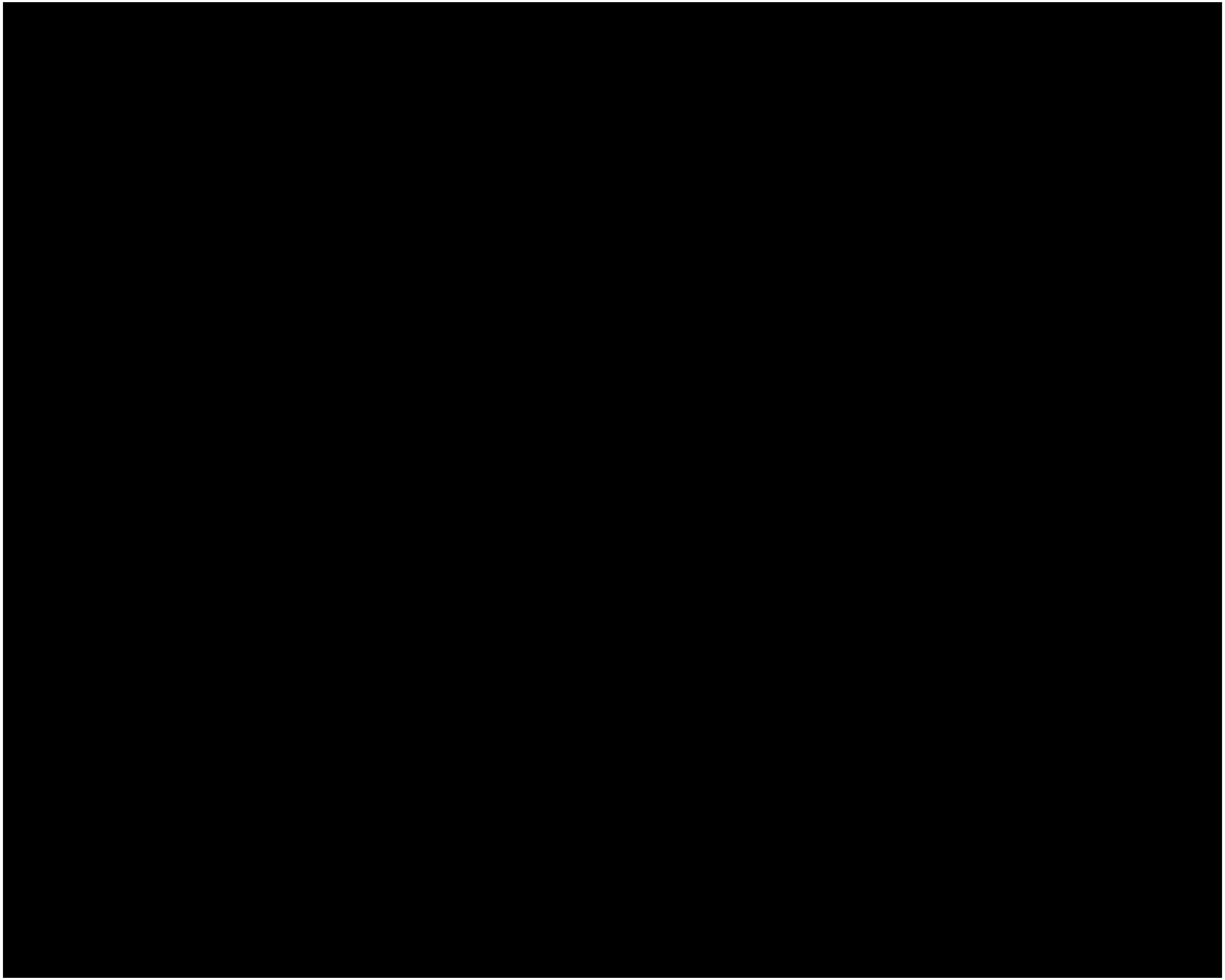
Constructing the ATLAS detector

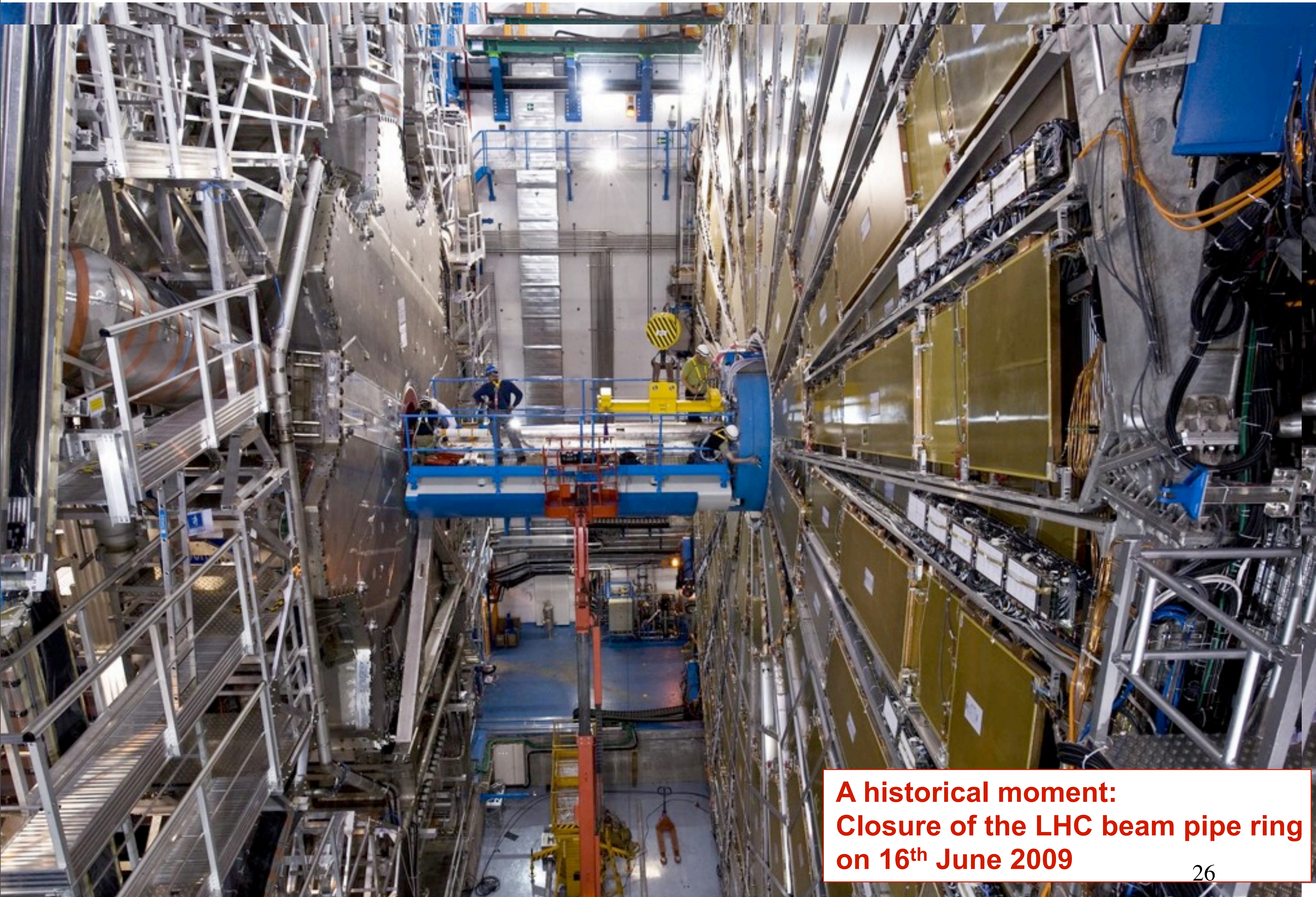
- Teams of physicists, engineers and technicians collaborate globally to design and build each detector component and sub-component
- Components are rigorously tested, usually by the institute that built the component, for functionality, ability to withstand the high radiation environment of the LHC, and communication with neighboring components
- Commissioning of the components takes place in-situ at CERN





Construction of ATLAS in 1 minute

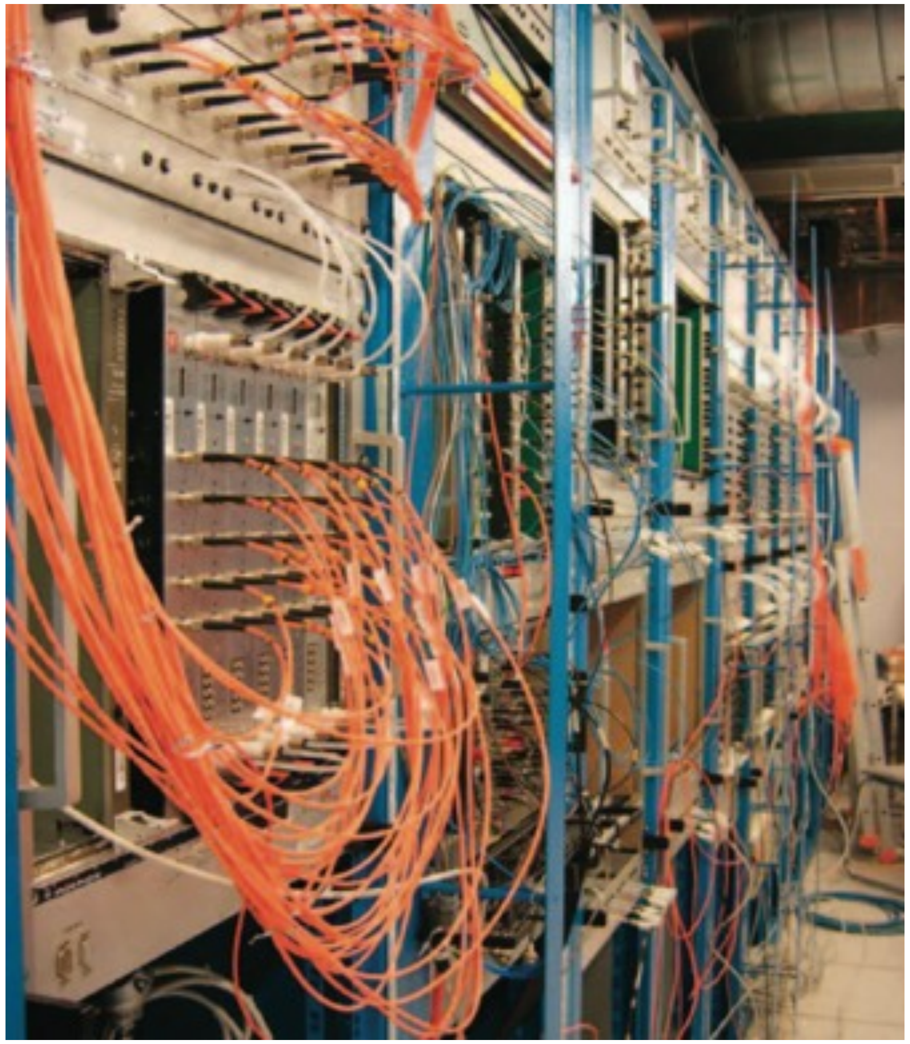




A historical moment:
Closure of the LHC beam pipe ring on 16th June 2009

Data Acquisition

Bunches of protons cross 40 million times per second.
Each bunch contains 10^{11} protons.
More than 1 proton-proton collision can occur in each crossing.
Number of proton-proton collisions in the detector: 1 billion/sec.
When any of the protons collide, the process is called an "event"



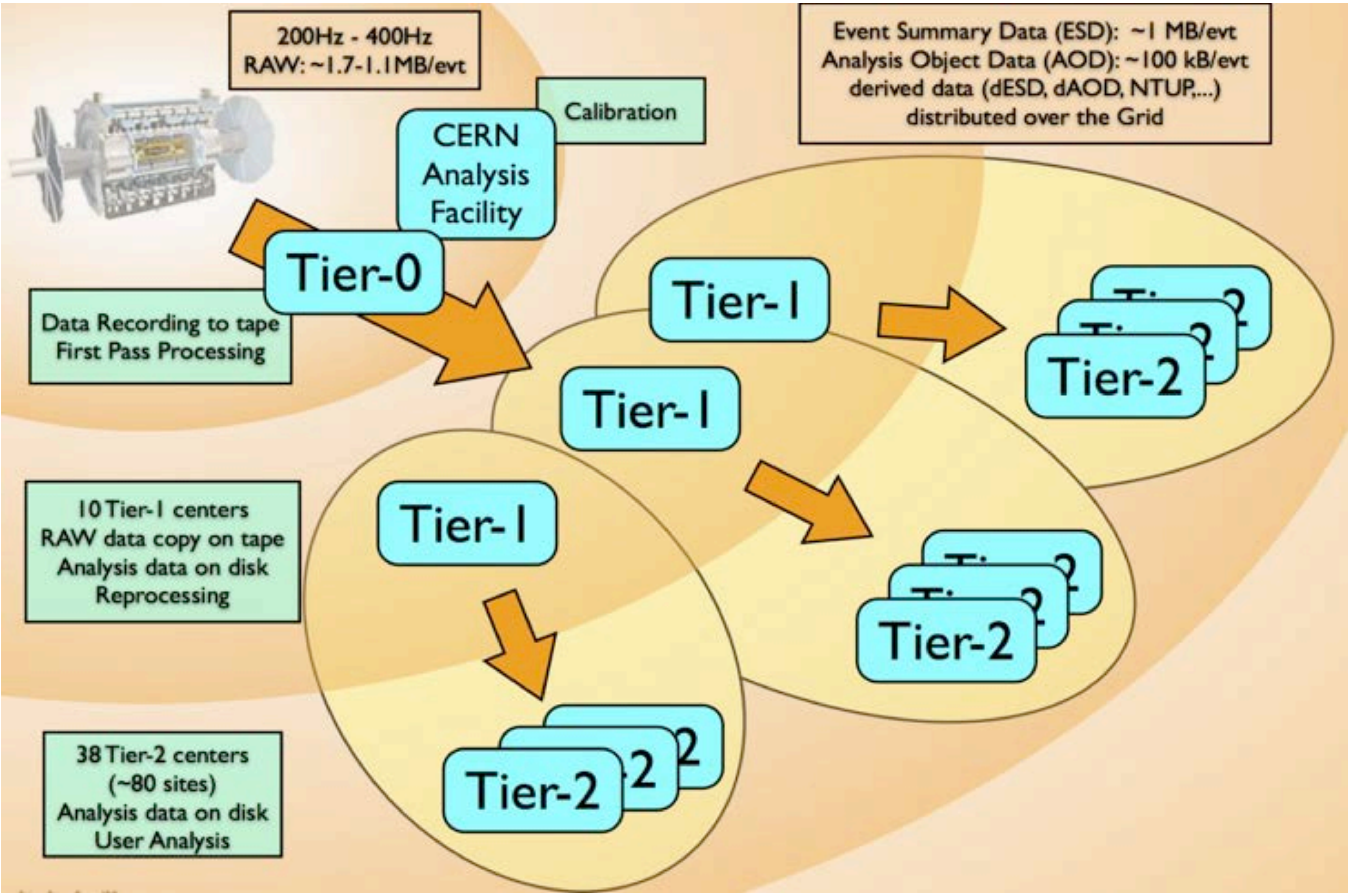
If all data were recorded, this would fill 100,000 CDs per second. This would create a stack of CDs 150 m high every second, which could reach to the moon and back twice each year. This data rate is also the equivalent to making 50 billion telephone calls at the same time.

To filter out the least interesting events, we have a 3-level triggering system, which reduces the amount of data we actually record to a manageable size - 320 MB/sec or 27 CDs per minute.

	Incoming event rate per second	Outgoing event rate per second	Reduction factor
Level 1	40 000 000	100 000	400
Level 2	100 000	3 000	30
Level 3	3 000	200	15

Physics Exploration = Computing

The data produced by the collisions is available to all collaborators via an international computing grid called the Open Science Grid (OSG). The data is disseminated in a 3-tier structure to efficiently access the data across the world. The OSG is also used by physicists to analyze the data.

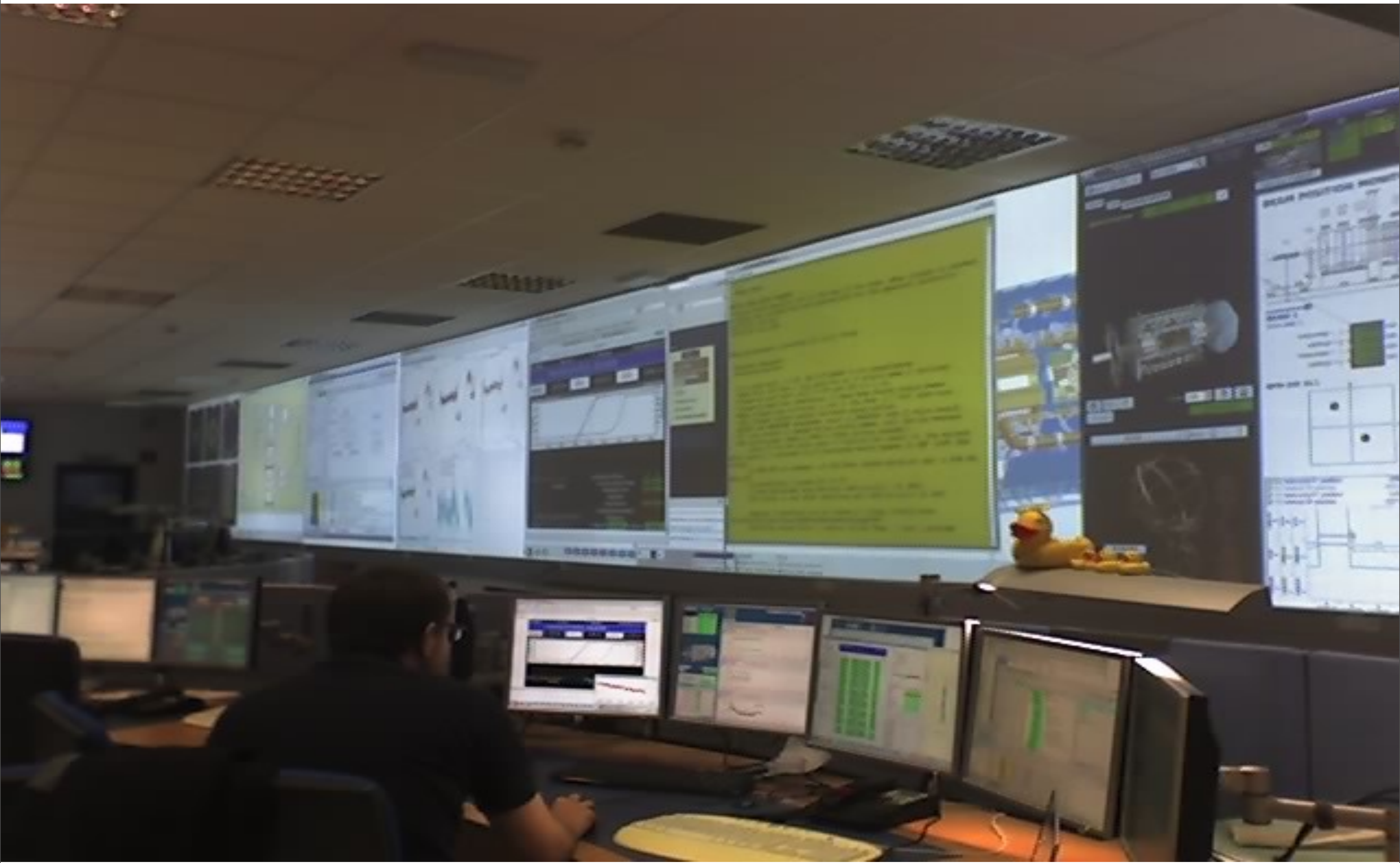


Exploring for new physics at the LHC

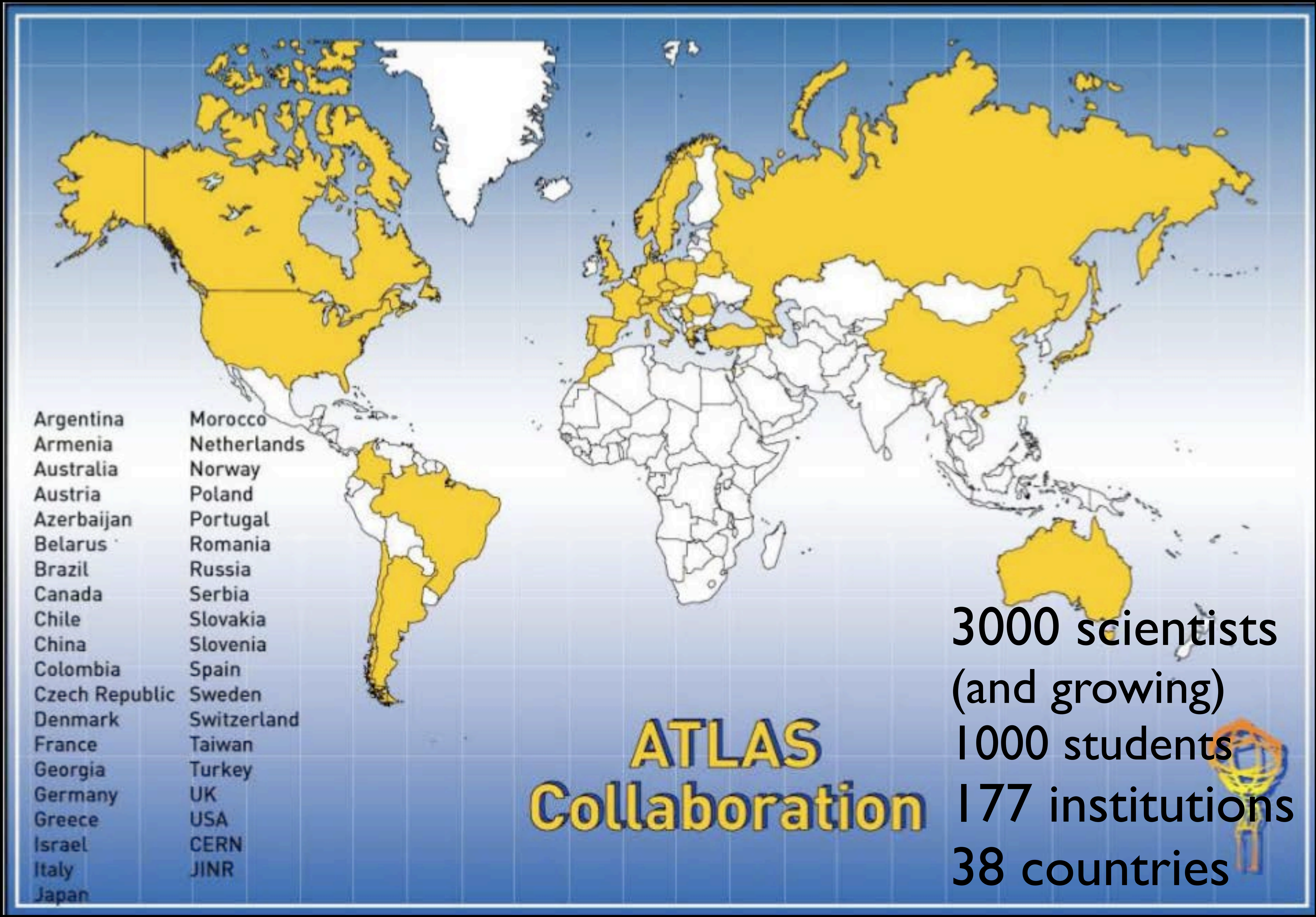
When LHC is running, ATLAS collects data 24 hours per day, 365 days per year. All collaborators share the shift duties.

Exploring for new physics at the LHC

Exploring for new physics at the LHC



ATLAS Collaboration



3000 scientists (and growing)
1000 students
177 institutions
38 countries

ATLAS Collaboration

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2012-218

Accepted by: Physics Letters B

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

The ATLAS Collaboration

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

Abstract

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H\to ZZ^{(*)}\to 4\ell$, $H\to\gamma\gamma$ and $H\to WW^{(*)}\to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H\to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H\to ZZ^{(*)}\to 4\ell$ and $H\to\gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4\ (\mathrm{stat}) \pm 0.4\ (\mathrm{sys})$ GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

The ATLAS Collaboration

G. Aad[48], T. Abajyan[21], B. Abbott[111], J. Abdallah[12], S. Abdel Khalek[115], A.A. Abdelalim[49], O. Abdinov[11], R. Aben[105], B. Abi[112], M. Abolins[88], O.S. AbouZeid[158], H. Abramowicz[153], H. Abreu[136], B.S. Acharya[164a,164b], L. Adamczyk[38], D.L. Adams[25], T.N. Addy[56], J. Adelman[176], S. Adomeit[98], P. Adragna[75], T. Adye[129], S. Aefsky[23], J.A. Aguilar-Saavedra[124b,a], M. Agustoni[17], M. Aharrouche[81], S.P. Ahlen[22], F. Ahles[48], A. Ahmad[148], M. Ahsan[41], G. Aielli[133a,133b], T. Akdogan[19a], T.P.A. Åkesson[79], G. Akimoto[155], A.V. Akimov[94], M.S. Alam[2], M.A. Alam[76], J. Albert[169], S. Albrand[55], M. Aleksa[30], I.N. Aleksandrov[64], F. Alessandria[89a], C. Alexa[26a], G. Alexander[153], G. Alexandre[49], T. Alexopoulos[10], M. Alhroob[164a,164c], M. Aliev[16], G. Alimonti[89a], J. Alison[120], B.M.M. Allbrooke[18], P.P. Allport[73], S.E. Allwood-Spiers[53], J. Almond[82], A. Aloisio[102a,102b], R. Alon[172], A. Alonso[79], F. Alonso[70], A. Altheimer[35], B. Alvarez Gonzalez[88], M.G. Alviggi[102a,102b], K. Amako[65], C. Amelung[23], V.V. Ammosov[128,*], S.P. Amor Dos Santos[124a], A. Amorim[124a,b], N. Amram[153], C. Anastopoulos[30], L.S. Ancu[17], N. Andari[115], T. Andeen[35], C.F. Anders[58b], G. Anders[58a], K.J. Anderson[31], A. Andreazza[89a,89b], V. Andrei[58a], M-L. Andrieux[55], X.S. Anduaga[70], S. Angelidakis[9], P. Anger[44], A. Angerami[35], F. Anghinolfi[30], A. Anisenkov[107], N. Anjos[124a], A. Annovi[47], A. Antonaki[9], M. Antonelli[47], A. Antonov[96], J. Antos[144b], F. Anulli[132a], M. Aoki[101], S. Aoun[83], L. Aperio Bella[5], R. Apolle[118,c], G. Arabidze[88], I. Aracena[143], Y. Arai[65], A.T.H. Arce[45], S. Arfaoui[148], J-F. Arguin[93], E. Arik[19a,*], M. Arik[19a], A.J. Armbruster[87], O. Arnaez[81], V. Arnal[80], C. Arnault[115], A. Artamonov[95], G. Artoni[132a,132b], D. Arutinov[21], S. Asai[155], S. Ask[28], B. Åsman[146a,146b], L. Asquith[6], K. Assamagan[25], A. Astbury[169], M. 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CERN - Building 40

How ATLAS collaborates

How does one become an ATLAS author?

Every scientist should complete a task that benefits the entire experiment and requires 1/2 of their available research time for one year.

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How is the leadership structured?

Due to the size of the collaboration, a management structure not unlike one you would find in a company is in place. The top leaders are elected by the authors. Mid-level managers are usually made by appointment after calling for nominations from the authors.

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How do important decisions get made?

Key experts in the collaboration usually make proposals and their recommendations are discussed in the ATLAS Executive Board and presented in ATLAS plenary meetings in which all authors are invited to contribute their thoughts. A concensus is usually formed through discussion, although in rare cases the ATLAS management makes an executive decision.

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How does one apportion the tasks?

ATLAS tries to match the interests and resources of the participating team to the tasks. This can only succeed if everyone is also willing to share the less interesting but necessary tasks. This works because the physicists are motivated by the prospect of the exciting results to be obtained, and know that these depend on having a complete working detector system.

How ATLAS collaborates

How does one collaborator get credit for his/her contributions?

Internal publications within the collaboration will document the individual contributions, as they are typically written by small teams. Leading contributions are often recognized by asking the person in question to present results at conferences. But often, major results are possible only through the collective work of tens if not hundreds of people.

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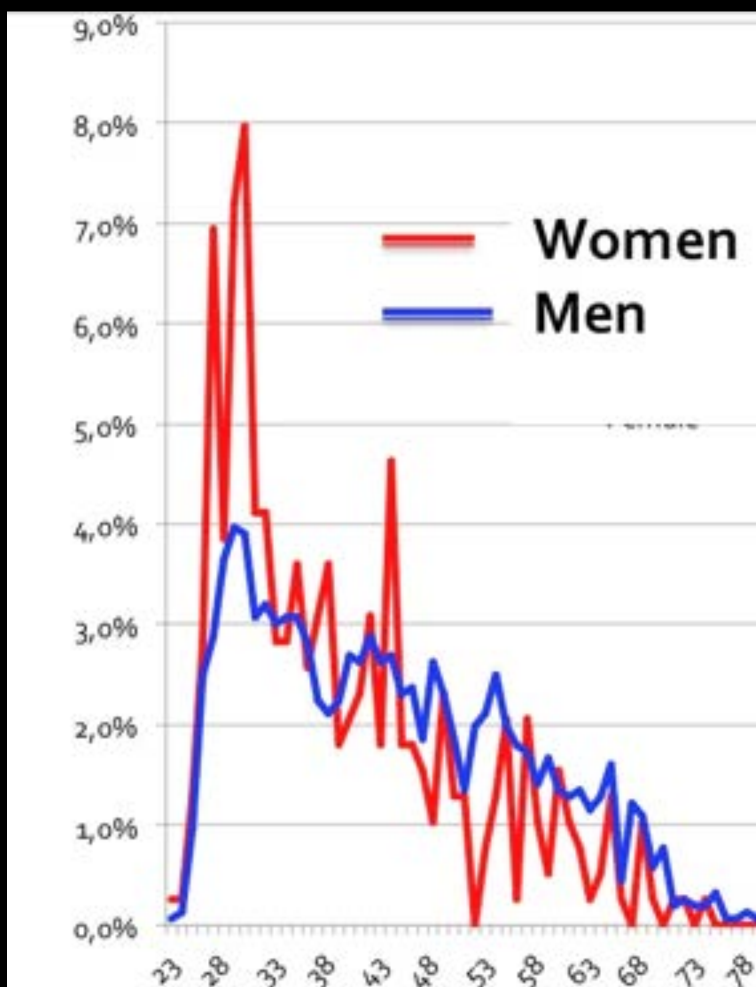
Where does the money come from?

Large project funds come from science funding agencies of the various participating countries. There are also direct contributions from CERN and the various individual university funds.

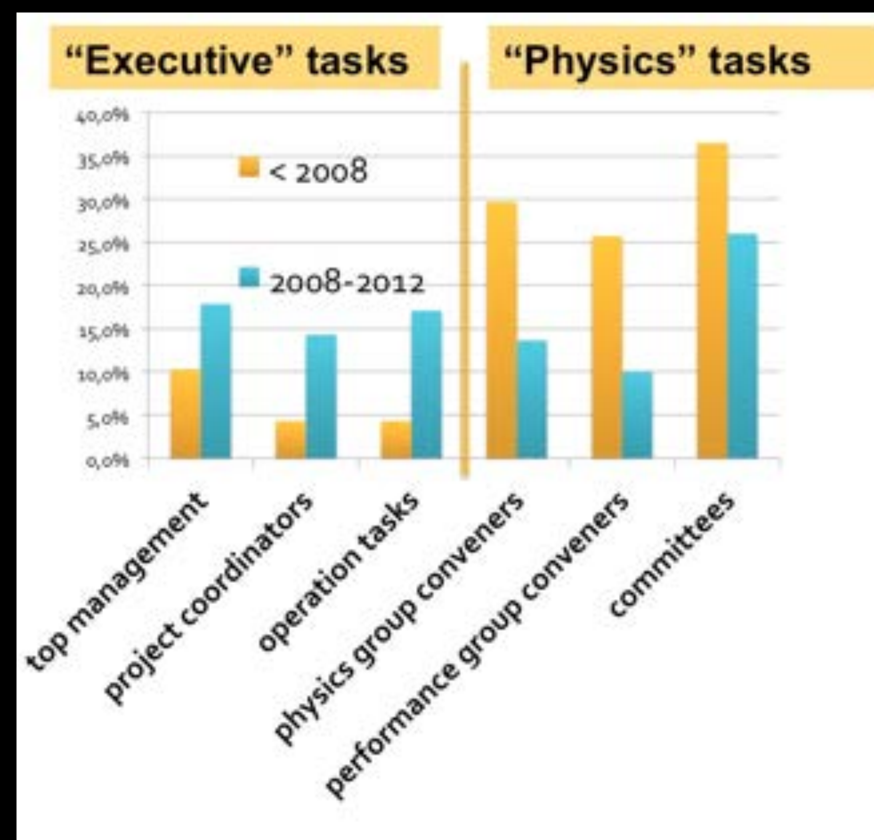
Demographics

- 3000 scientists and growing (15% women)
- 1/3 of the authors are graduate students

Percentage of men, women by age



Breakdown of women in ranks



Women are making strides in ATLAS (and HEP, generally), although a recent study by American Institute of Physics indicates this isn't a global trend in physics.

National affiliation

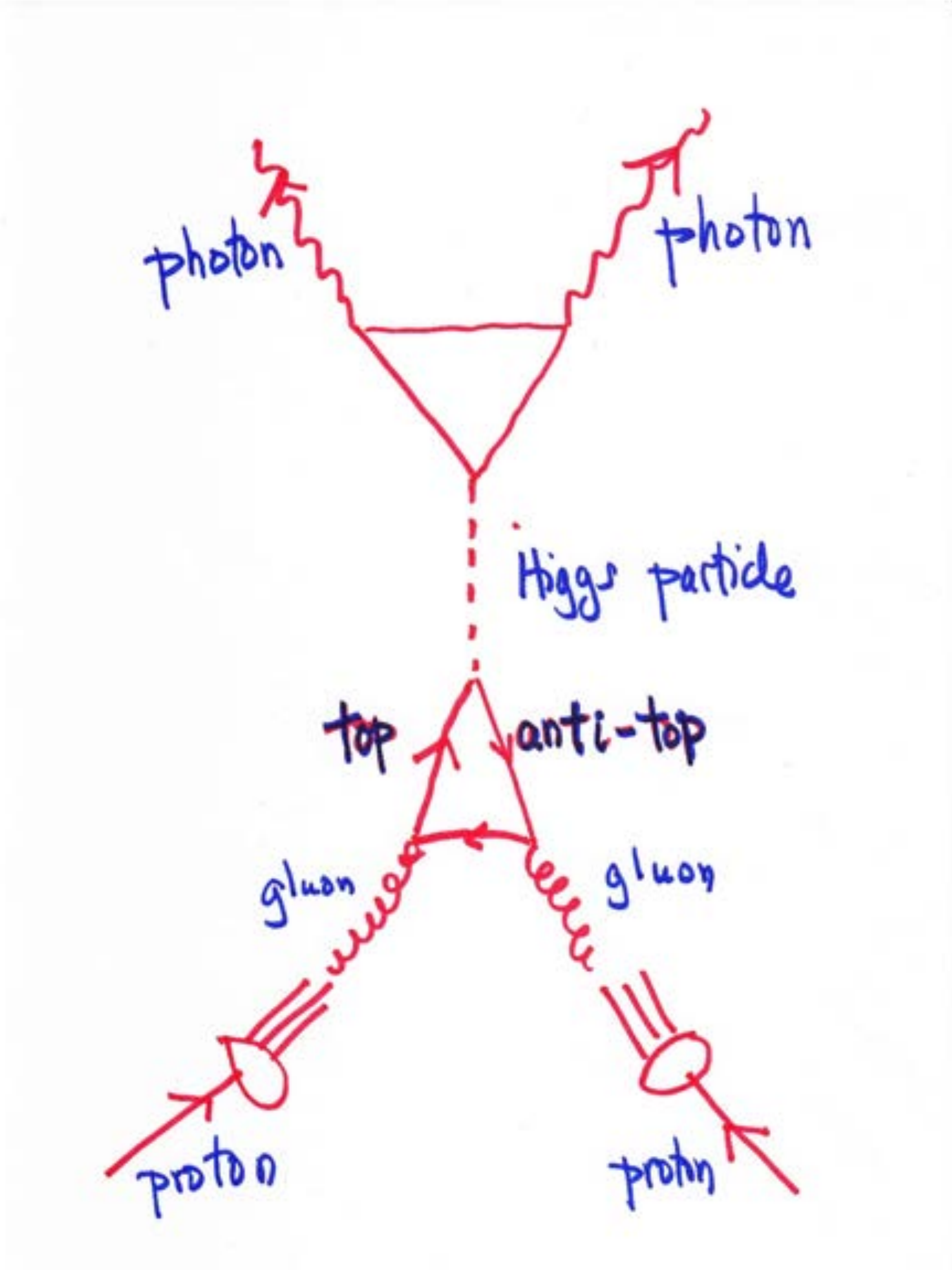
affiliation	% in ATLAS	% women by affiliation	% women by nationality
USA	18,2%	16,1%	11,3%
Germany	13,9%	20,7%	15,2%
UK	10,1%	23,2%	18,1%
Italy	7,7%	25,8%	31,9%
France	7,0%	29,2%	23,6%
CERN	5,1%	14,1%	
Japan	4,1%	4,9%	7,5%
Canada	3,8%	20,0%	22,2%
Russia	3,4%	6,1%	6,1%
Spain	2,9%	35,7%	35,6%
Czech	2,5%	6,3%	8,9%
Netherland	1,9%	27,0%	11,1%
Sweden	1,8%	25,7%	26,7%
Israel	1,6%	18,8%	19,2%
JINR	1,5%	3,4%	
Switzerland	1,4%	25,9%	16,0%
Greece	1,3%	34,6%	40,5%
China	1,3%	8,0%	12,0%
Poland	1,2%	30,4%	31,3%
Norway	0,9%	27,8%	28,6%
Portugal	0,9%	22,2%	20,8%
Romania	0,8%	46,7%	42,9%
Australia	0,7%	7,1%	0,0%
Turkey	0,7%	21,4%	26,3%
Denmark	0,6%	16,7%	9,1%
Brazil	0,5%	30,0%	23,1%
Slovak Rep	0,5%	10,0%	18,2%
Morocco	0,5%	11,1%	18,2%
Slovenia	0,5%	0,0%	11,1%
Taiwan	0,5%	0,0%	25,0%
Argentina	0,4%	25,0%	42,9%
Serbia	0,4%	71,4%	72,7%
Chile	0,3%	16,7%	50,0%
South Afric	0,3%	20,0%	
Belarus	0,2%	0,0%	0,0%
Georgia	0,2%	50,0%	23,1%
Austria	0,2%	0,0%	0,0%
Columbia	0,2%	66,7%	40,0%
Azerbaijan	0,1%	0,0%	0,0%
Armenia	0,1%	0,0%	25,0%

Higgs production and decay

The Standard Model predicts the number of Higgs events we should see and what the Higgs will decay into (as a function of the unknown mass).

There are many ways to produce a Higgs, and many ways in which it decays.   We use Feynman diagrams to help us visualize these processes.

The decay mode determines what we measure in our detector.



What is the signature of a Higgs?

The signal with the least background is Higgs decaying to two photons.

How do we calculate the Higgs mass?
If the Higgs were stationary, we just add up the energy of each of the two photons since Energy = Mass * c^2, we can calculate the mass.

If the Higgs is moving , then we also need to take into account the directions of the photons.
Excess events at one particular mass above a "background" indicate the presence of a new particle.

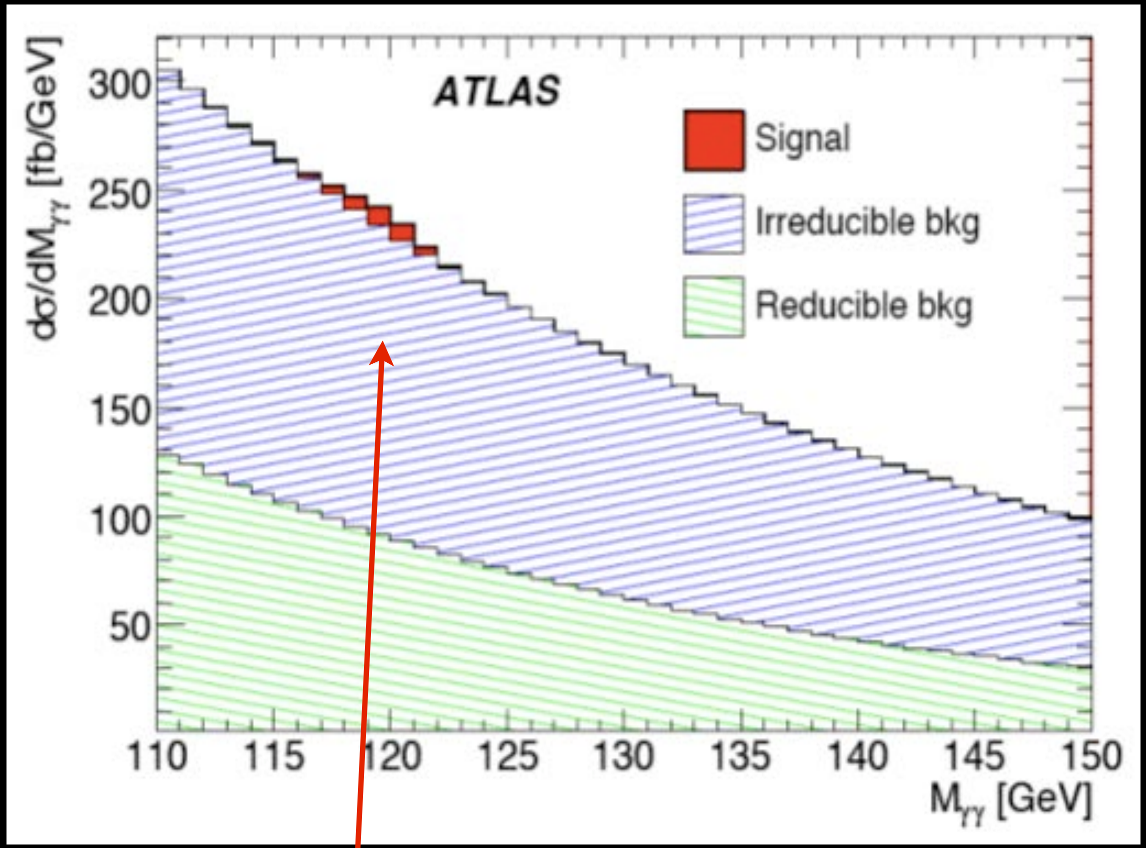
"Take a look at this everyone - it just could be the signature we've been looking for!"

How do we “discover” the Higgs?

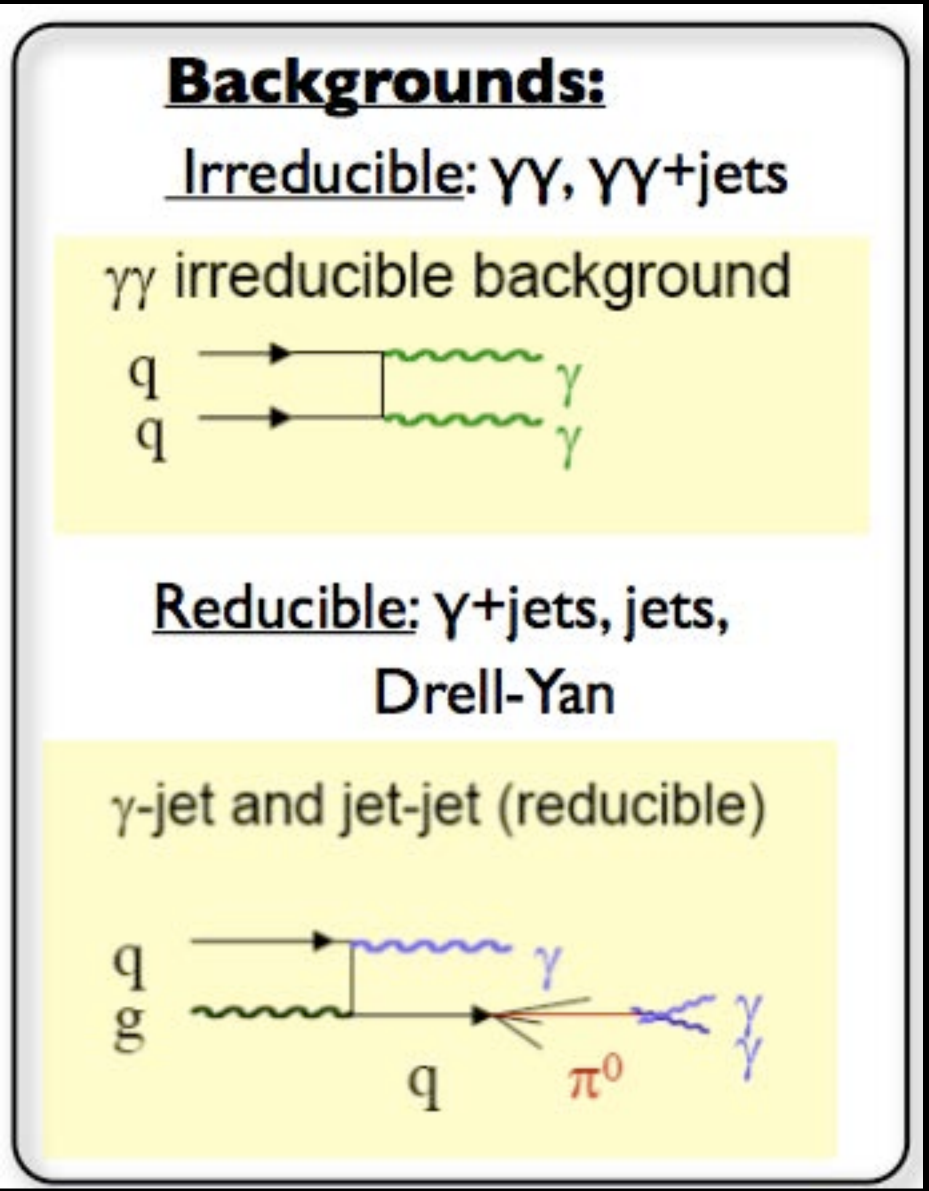
We count events!

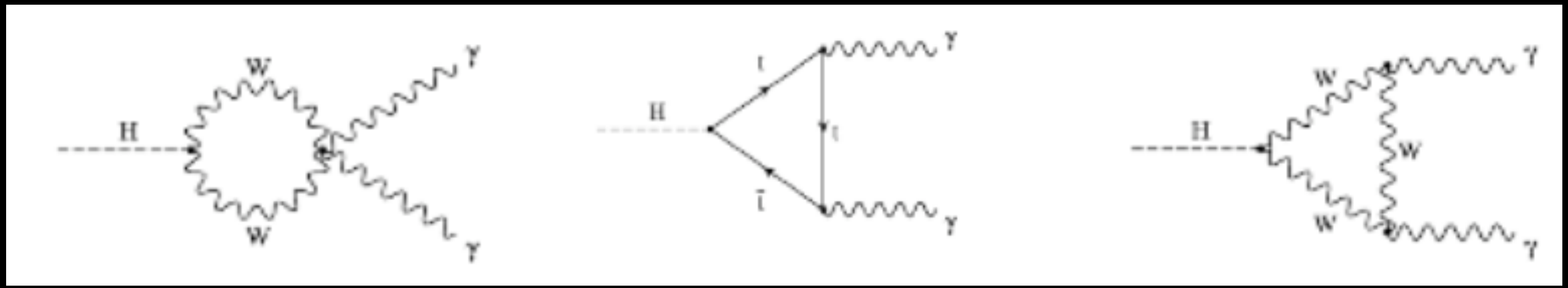
Some events are real Higgs events, and some are fake, or background, events

Excess events above background at one particular mass indicate presence of a new particle



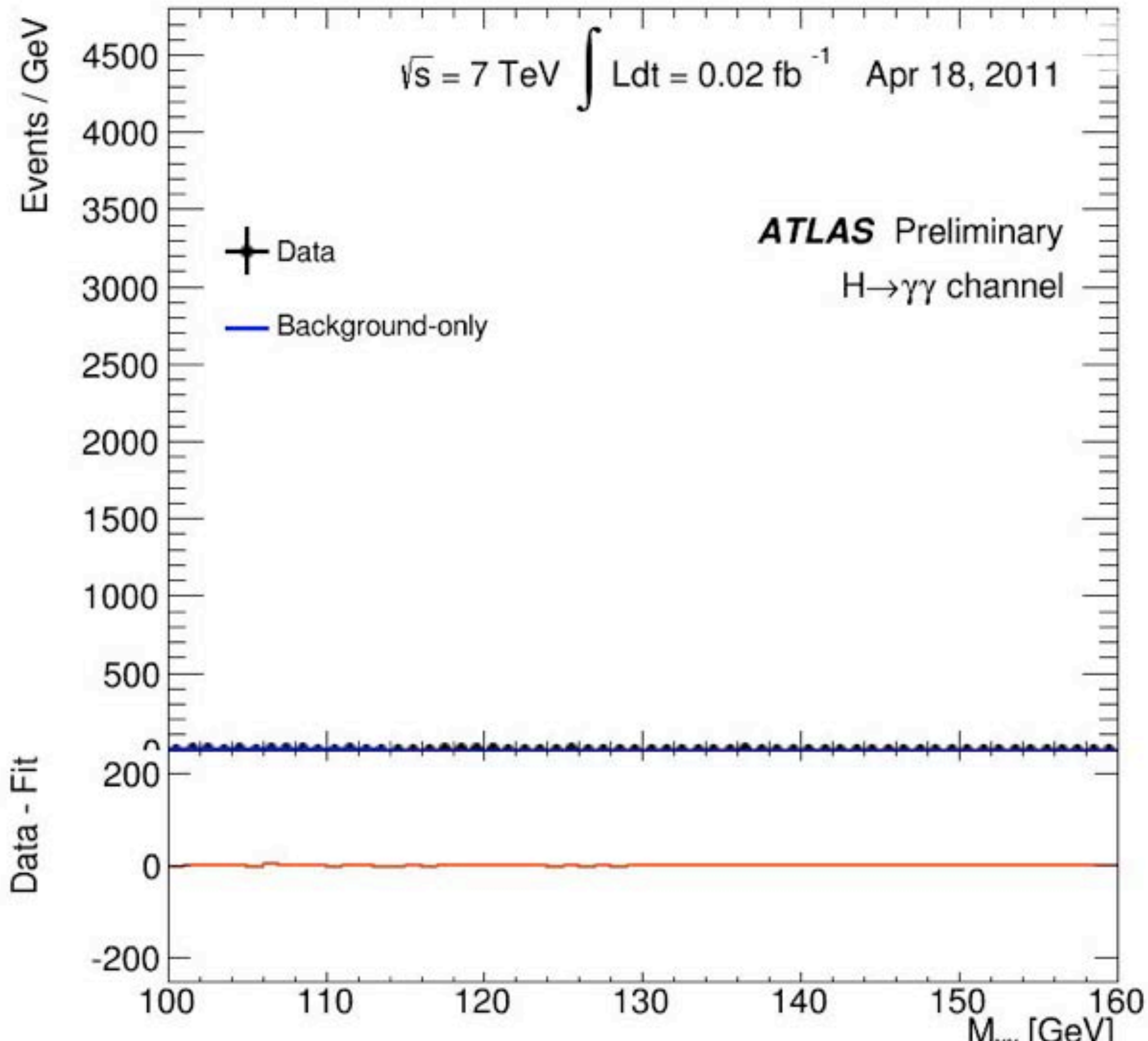
Simulation of possible Higgs signal and background





Discovery of Higgs decay to two photons

After two years of accumulating events, the following plot of the two-photon mass spectrum from ATLAS presents evidence of the Higgs particle.



Announcement of Higgs discovery at CERN - July 4, 2012

We have looked for a SM Higgs over the mass region 110-600 GeV in 12 channels

We have excluded at 99% CL the full region up to 523 GeV except 121.8< m_H<130.7 GeV

We observe an excess of events at m_H ~ 126.5 GeV with local significance **5.0 σ**

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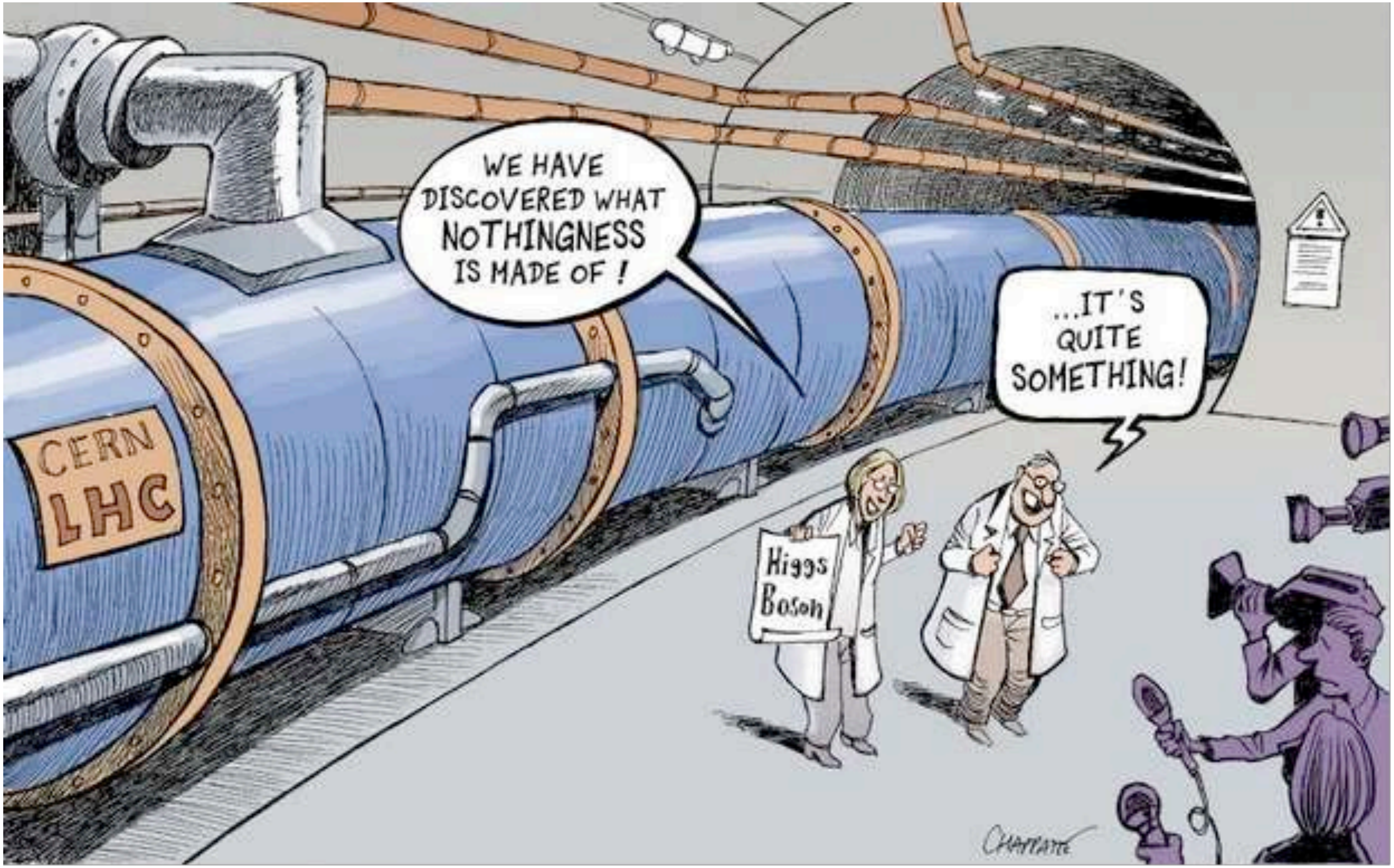
At last --- a picture of a Higgs

Peter Higgs
Rolf Heuer - Director of CERN
Joe Incandela – CMS spokesperson
Fabiola Gianotti - ATLAS spokesperson


CERN
LHC
WE HAVE DISCOVERED WHAT NOTHINGNESS IS MADE OF !
...IT'S QUITE SOMETHING!
Higgs Boson
CHAPPATTE

But is this the one and only Standard Model Higgs?

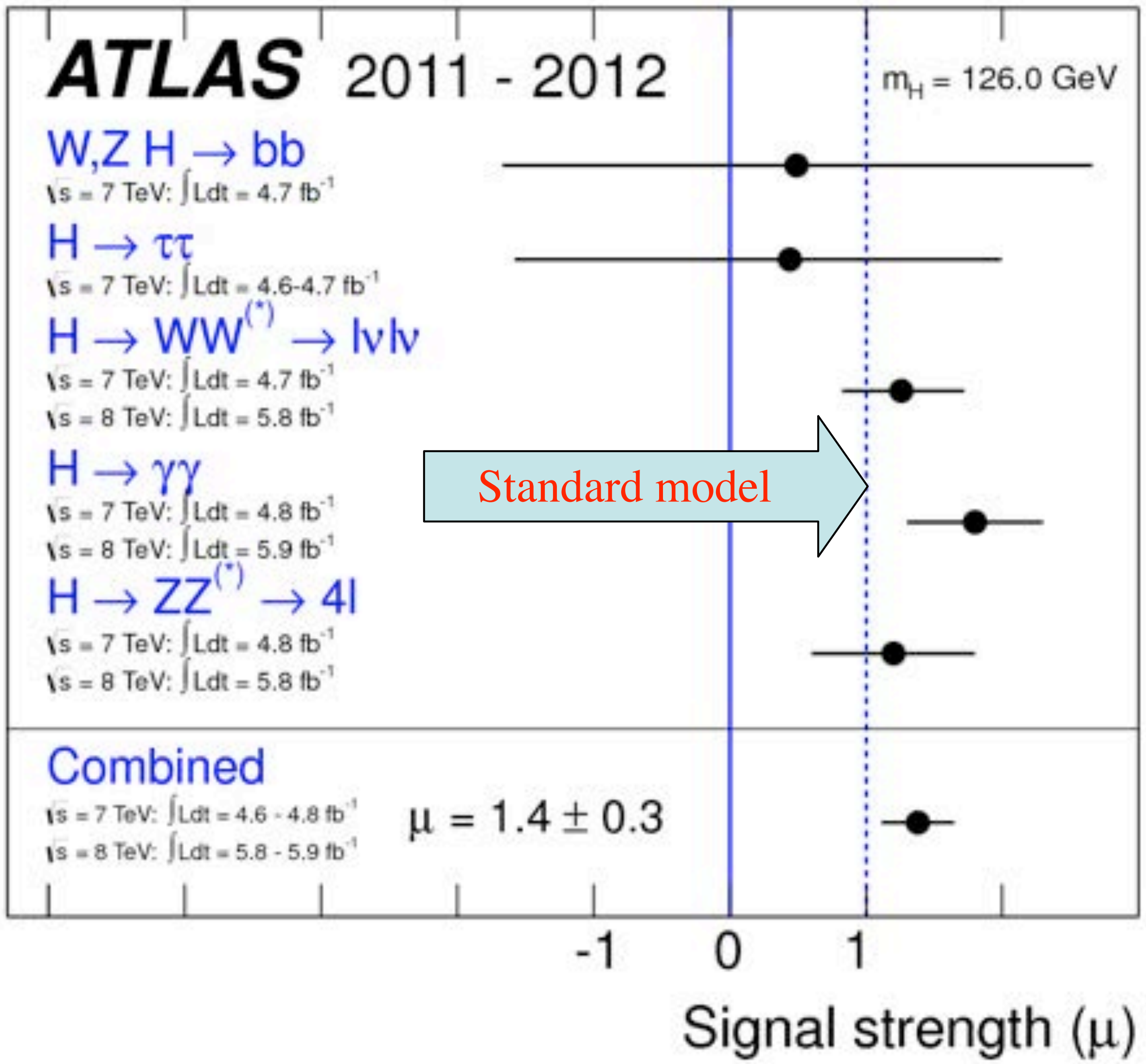
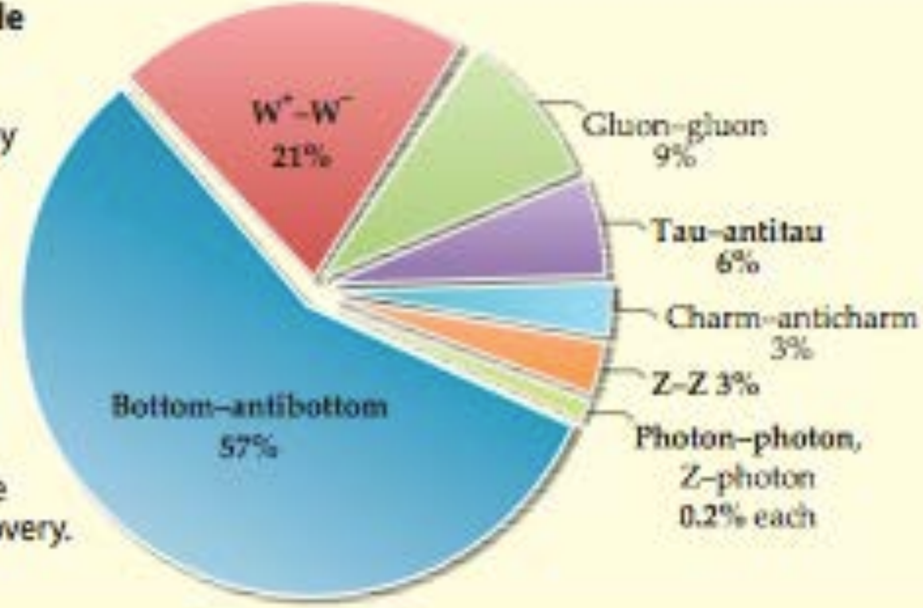


Figure 2. Decay-mode branching fractions of a 125-GeV Higgs boson, as predicted by the standard model. The five modes in bold constituted the ATLAS and CMS teams' searches. Specifically, the two rarest modes they considered, Z-Z and photon–photon, were the basis for the discovery.



For the next decade we will be increasing the number of measurements of this Higgs particle and improving our determination of it's coupling to other particles, its quantum properties and its decay modes.

Why is this important?

- Physicists: With the observation of a Higgs the Standard Model is now complete and it may suggest the ways this model must be modified in the future.
- Everyone: Your tax money has contributed to a fundamental discovery. It now appears that what we had called empty space - the vacuum - is much more interesting than we could have dreamed. This will now have ramifications for cosmology and for understanding the workings of our universe.

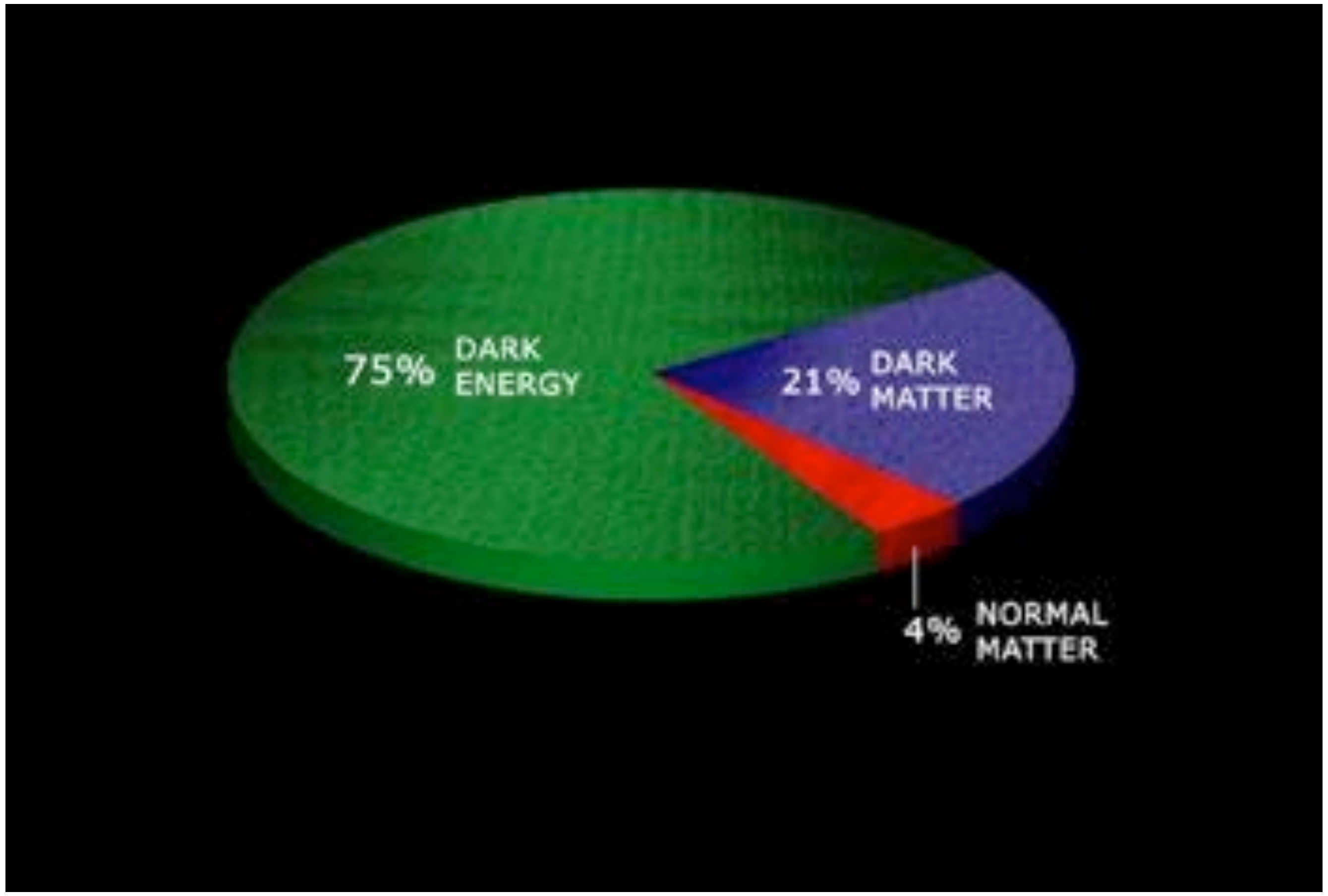
What is left for ATLAS to do?

The Higgs particle was the only undiscovered particle in the standard model. Although it explains why the fundamental particles acquire mass, it does not explain dark matter, dark energy or gravity.

Dark Matter and Dark Energy

Only 4% of the mass-energy density of the universe appears to be made of Standard Model particles,

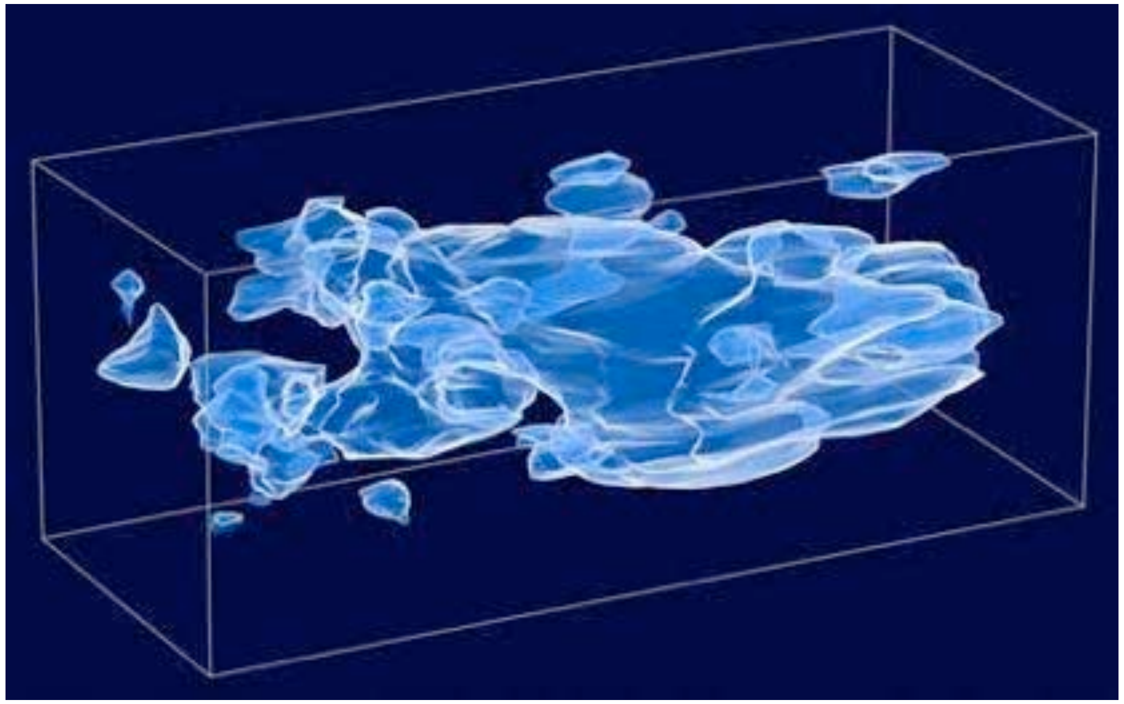
21% appears as neutral, gravitationally interacting, unknown particles (?) surrounding each galaxy - **Dark Matter.**



75% is unknown, energy that is believed to be causing the universe to expand- **Dark Energy.**

Searches for Supersymmetry or Dark Matter at ATLAS

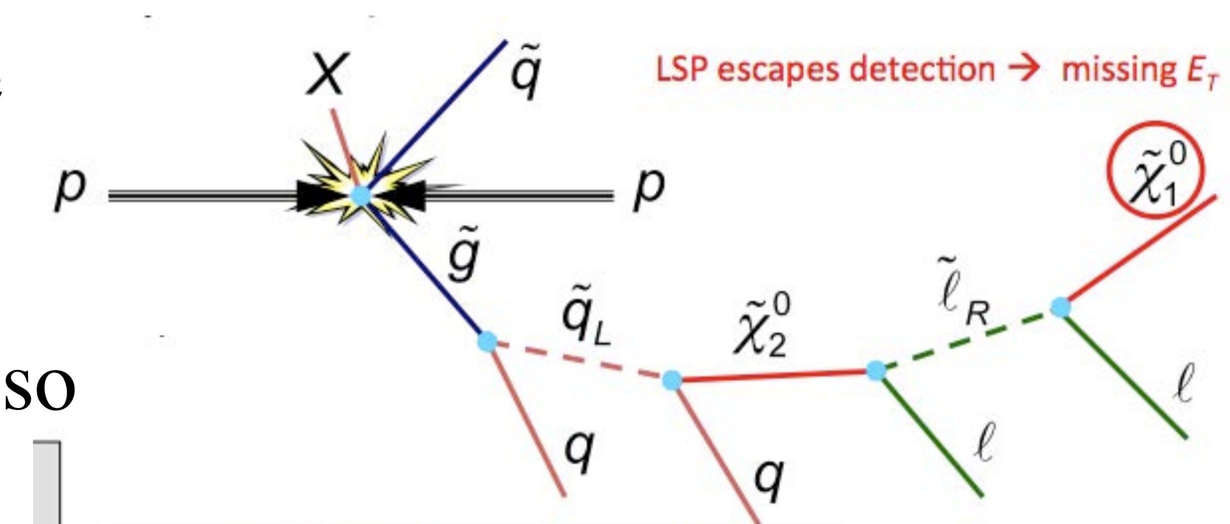
At the LHC we may be able to discover Dark Matter, if it takes particle form. We know that it surrounds galaxies like a giant, clumpy cloud.



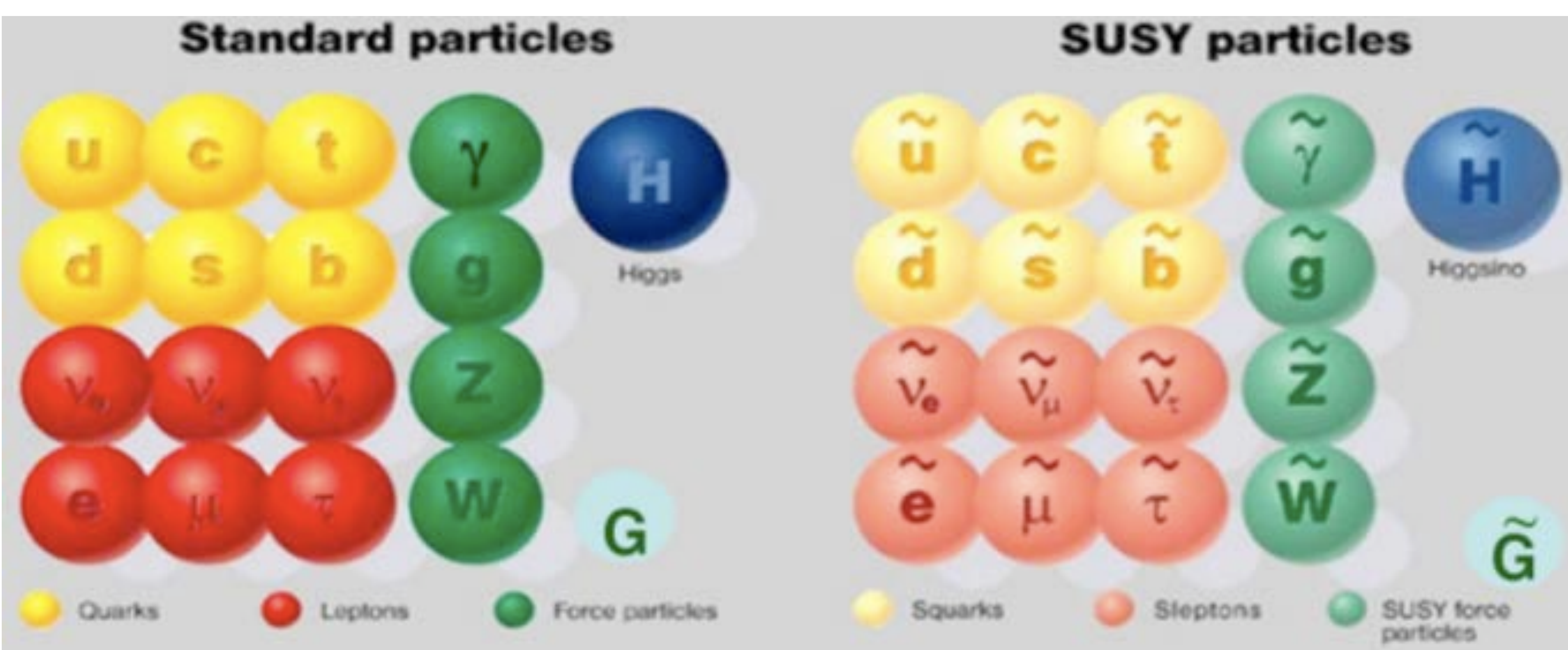
We know about the existence of dark matter from galactical observations, such as the Bullet Cluster.

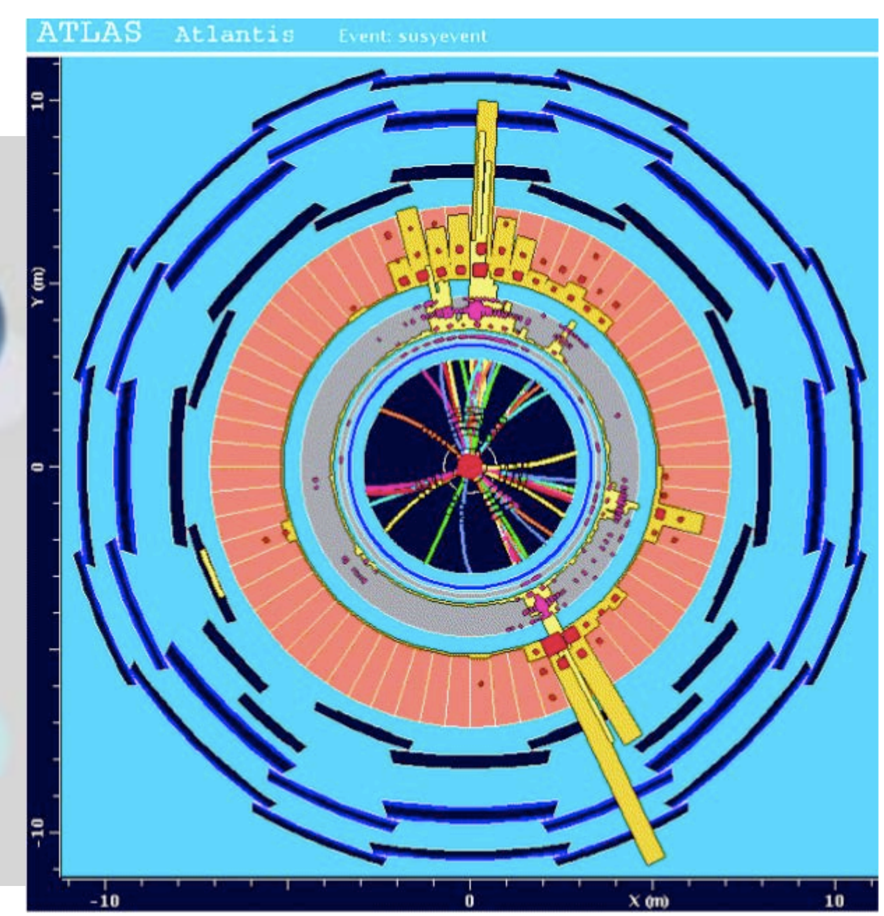
Searches for Supersymmetry or Dark Matter at ATLAS

One speculation is that dark matter is the lightest of a large collection of "supersymmetric" (SUSY) particles. We have searched for these at the LHC, but so far have not seen any. Higher energy running after 2014 may reveal this particle.



"Typical" SUSY decay chain at the LHC





Conclusion

I hope I have given you some inkling of the what/how/where/who/why of High Energy Particle Physics at the LHC.

The discovery of the Higgs Boson is a major milestone in our field.

We do this work out of a genuine curiosity about nature, what we are made of and how we got to be here (and also because we want to make a living doing something we enjoy). There are applications of this research, such as radiation treatment for cancer, data transfer protocols that became the foundation of the internet, but applications or economic considerations are not the driving reason.

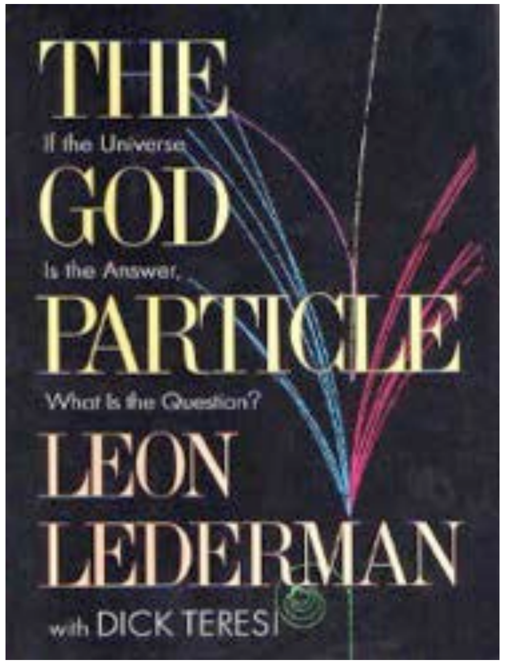
Exchange between Robert Wilson (first director of Fermi National Accelerator Lab - precursor to the LHC) and Senator John Pastore of Rhode Island:

JP: *Is there anything connected with the hopes of this accelerator that in any way involves the security of the country?*
RW: *No, sir. I don't believe so.*
JP: *Nothing at all?*
RW: *Nothing at all.*
JP: *It has no value in that respect?*
RW: *It has only to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with, are we good painters, sculptors, great poets? ... It has nothing to do directly with defending our country except to make it worth defending.*

Back-up Slides

God Particle?

Leon Lederman, the former director of Fermilab near Chicago, titled his 1993 book “The God Particle”.

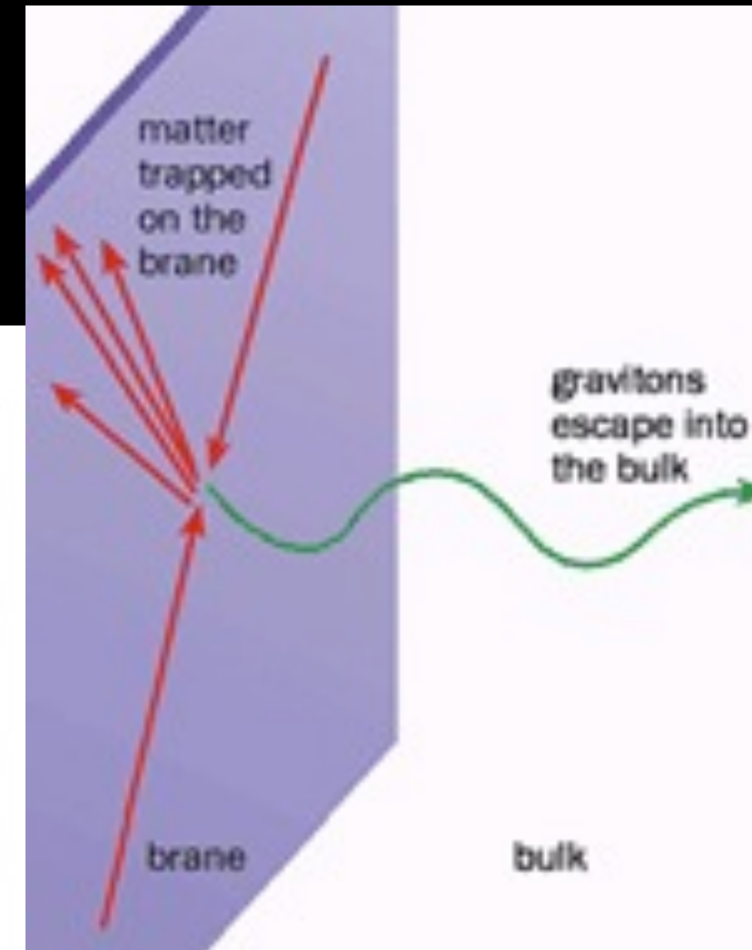


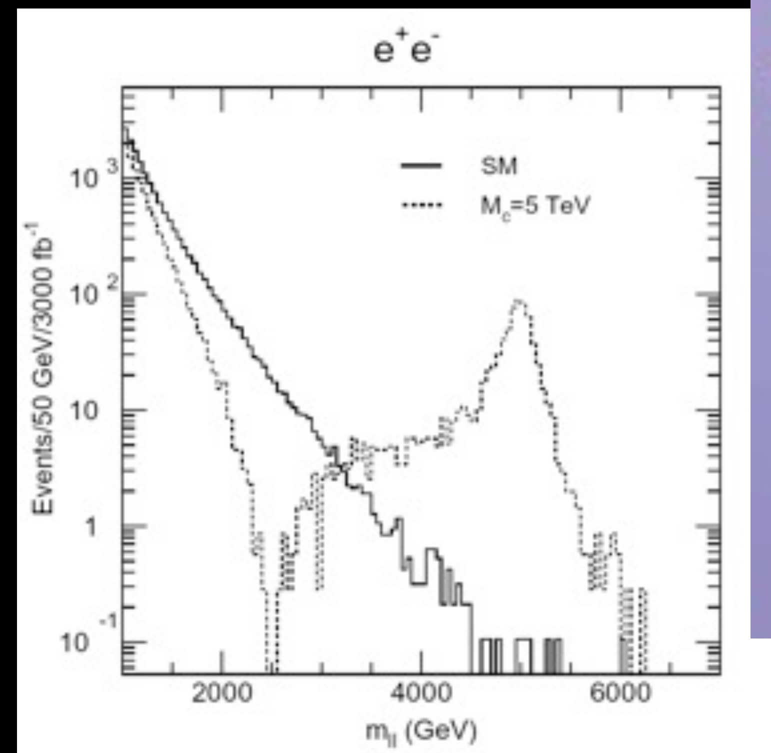
The Higgs has no religious implications, the only reason that Lederman used this expression, is that the Higgs field is a pervasive field throughout our universe, and that it is the basic reason that all elementary particles have mass. (and we would not be here without it!)

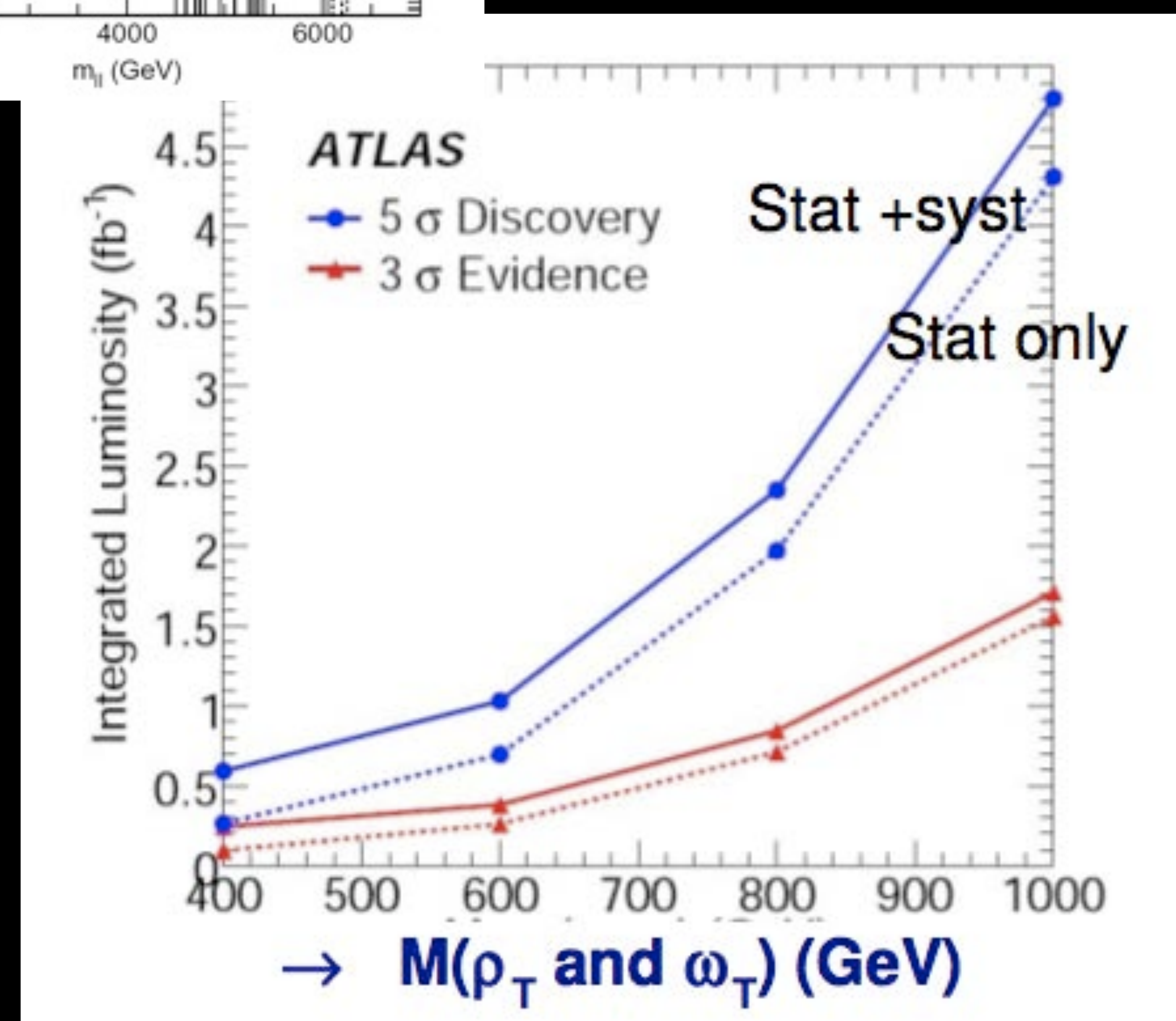
Note, however:
Most of our mass is due to the mass of protons and neutron that we contain, and this mass is mainly due to the kinetic energy (Fermi energy) of the bound quarks and gluons ($M= E/c^2$). However, if the quarks had zero mass they would never form protons or neutrons!

Other Sources?

- Strong dynamics, ADS/CFT
- Extra Dimensions
- Kaluza-Klein resonances
- Unmotivated theories
  - Unparticles, Hidden Valley, Quirks
- ... (too numerous to list them all)
- And can we find the source for dark matter??







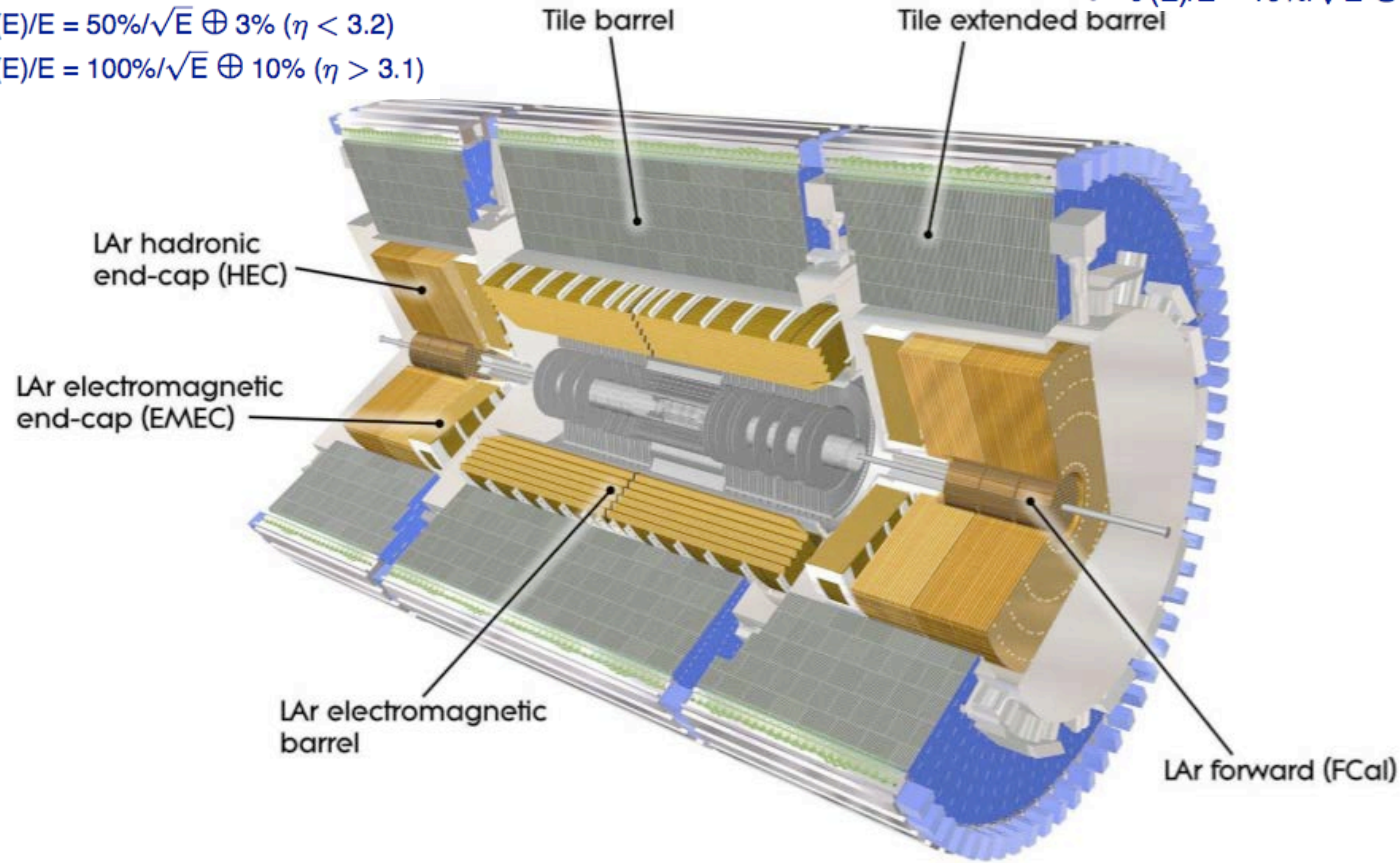
Calorimeter

Hadron Calorimeter

- Barrel: iron-scintillator tiles
  (3 longitudinal samples)
  Endcap/forward: Cu/W-LAr
  (4/3 longitudinal samples)
- 20 K channel
- $\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\%$ ($\eta < 3.2$)
  $\sigma(E)/E = 100\%/\sqrt{E} \oplus 10\%$ ($\eta > 3.1$)

Electromagnetic Calorimeter

- Pb-LAr accordion geometry
- 3 longitudinal samples $\eta < 2.5$
- Preshower detector $\eta < 1.8$
- 173 K channel
- $\sigma(E)/E = 10\%/\sqrt{E} \oplus 0.7\%$



Complete azimuthal symmetry, coverage $\eta < 4.9$

LHC Schedule

Current Schedule:
(always subject to change)

2012	8 TeV run
2013-2014	shutdown
2015-2017	14 TeV run
2018	shutdown
2019-2021	14 TeV high luminosity run
2022	shutdown

Celebrating first beams

ATLAS control room
during first LHC collisions