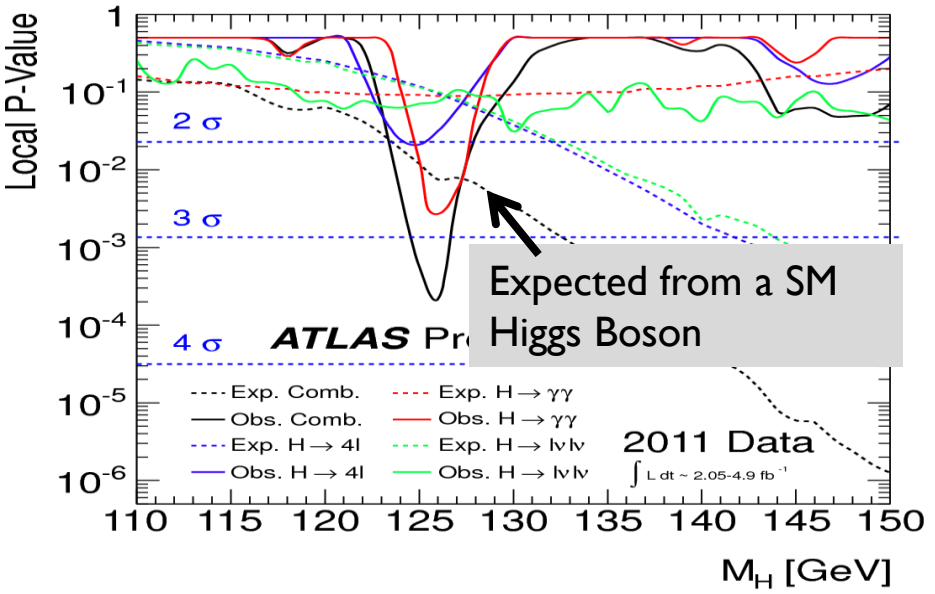
The Higgs Discovery and Media Coverage

April 09, 2018

Discovery First Hints of the Higgs boson

- On December 13, 2011, CERN held a public seminar to announce the first results of the Higgs searches: "Tantalizing hints"
- The ATLAS collaboration showed an intriguing excess at m_H~125 GeV, mainly due to the $H \to \gamma\gamma$ and $H \to 4$ *leptons* channels.
- ***The Wisconsin group made outstanding contributions in $H \to \gamma\gamma$ and $H \to 4$ leptons and in the Higgs combination effort.***

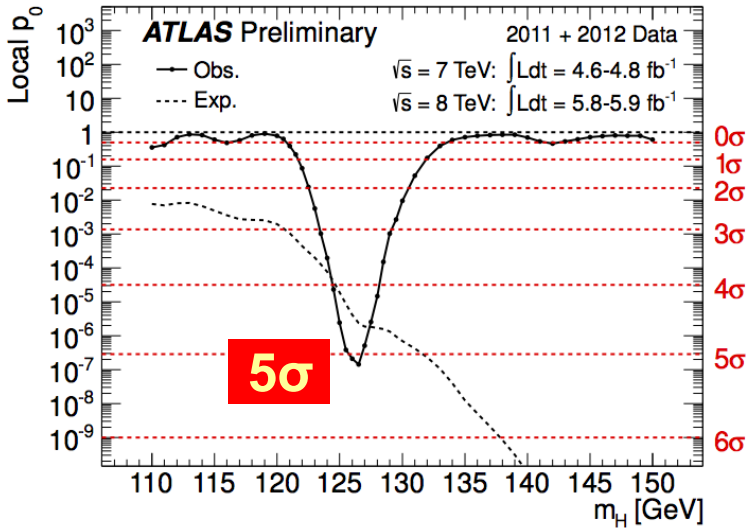
CERN Council Meeting, Dec 2011



Expected SM Significance: 2.4 σ
Observed Local / Global: 3.6 / 2.5 σ

Discovery The discovery of the Higgs boson

- July 4 2012, "Discovery!"



Expected SM Significance: 4.6 σ
Observed: 5.0 σ

The Discovery of the Higgs Boson

Armed with 5σ significance independently from the ATLAS and CMS experiments, the Director General of CERN, Rolf Heuer, declared:

"I think we have it"

"We have now found the missing cornerstone of particle physics. We have a discovery. We have observed a new particle that is consistent with a Higgs boson."

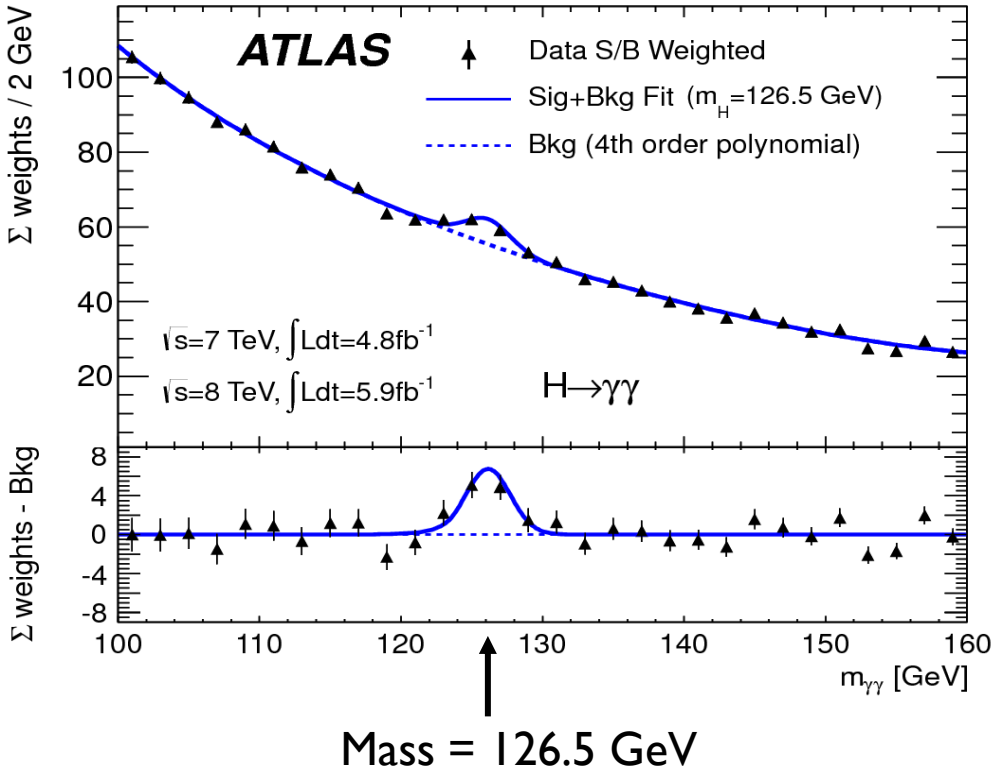
July 4, 2012, date of the discovery announcement

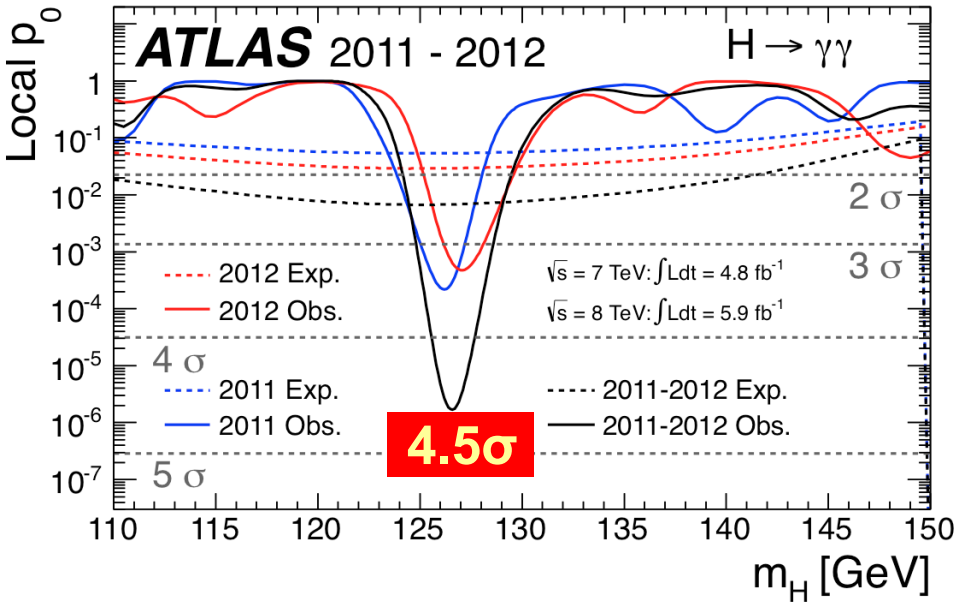
Wisconsin's contribution to the Higgs discovery

We made outstanding contributions to the discovery

(1) We are one of the only two groups of physicists who obtained the H→γγ results that led to the discovery

p_0: probability that the background fluctuates to the observed data (or higher)



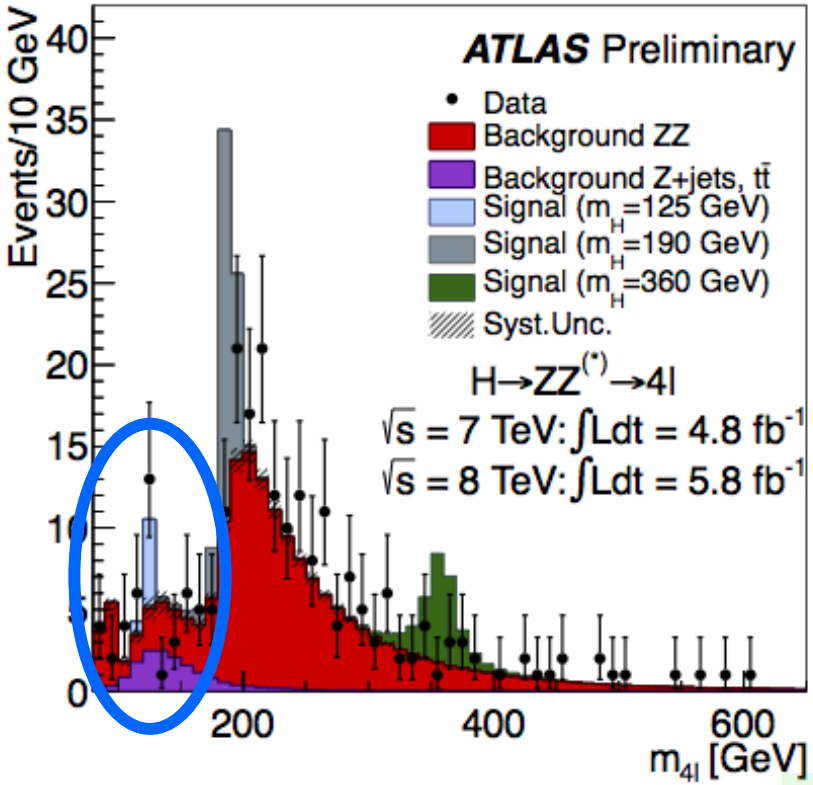


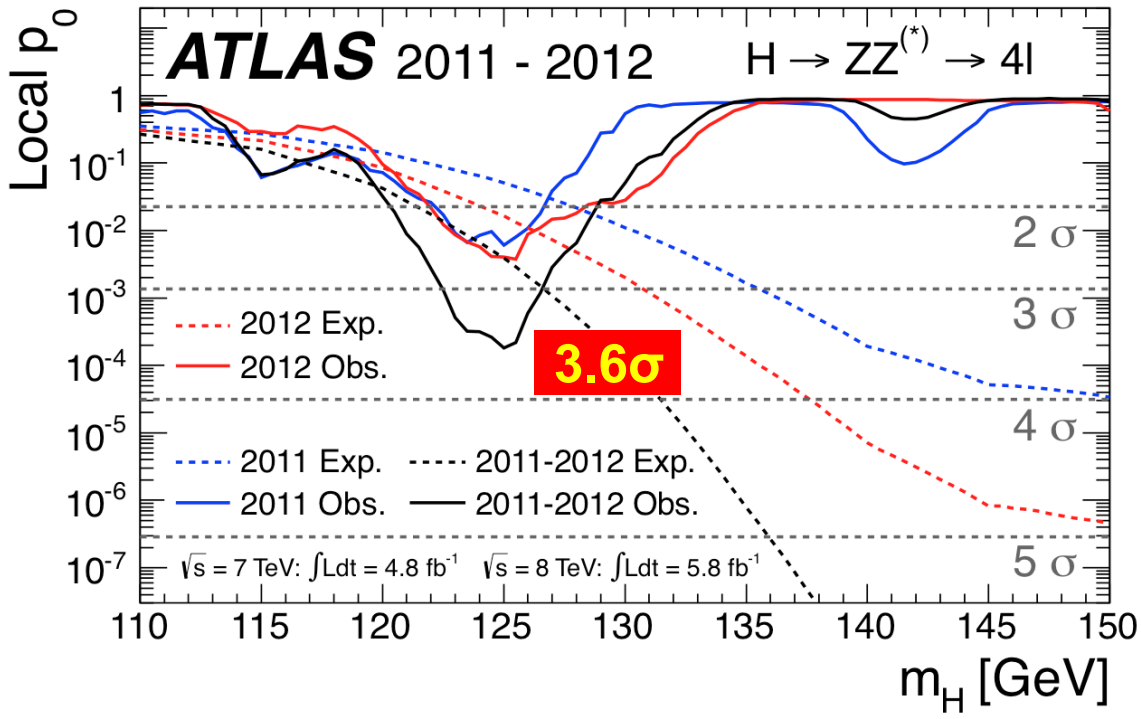
Results and plots made by our Graduate Student Haichen Wang

Wisconsin's contribution to the Higgs discovery

We made outstanding contributions to the discovery

(2) We played an outstanding role in obtaining the results of the 4-lepton channel



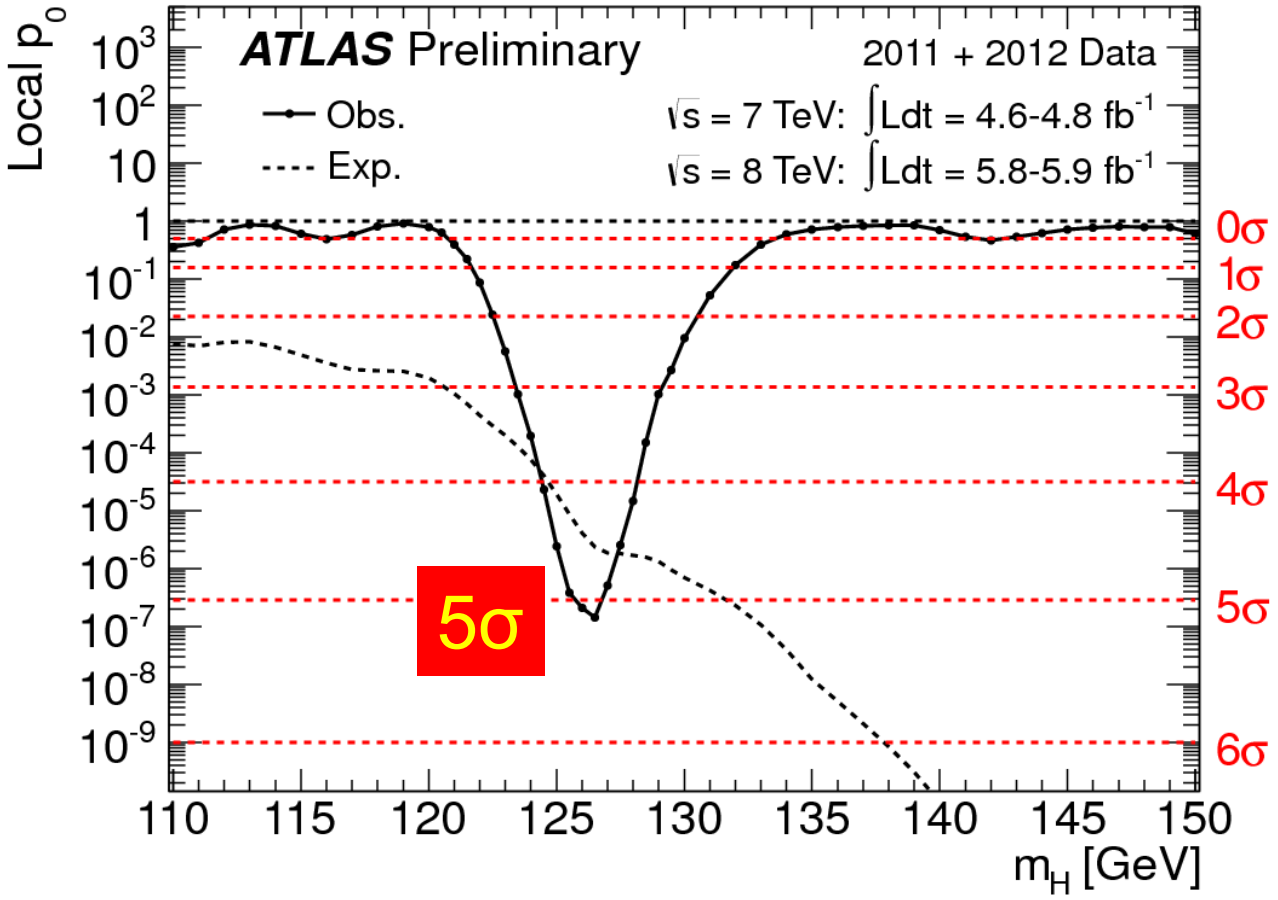


- ***Results and plots made by our Graduate Student X. Ju***
- ***ATLAS ICHEP CONF note co-edited by Assistant Scientist Luis Flores***

Wisconsin's contribution to the Higgs discovery

We made outstanding contributions to the discovery

(3) One of our graduate students is one of the two physicists who first obtained the significance of 5σ



Results and plot made by our Graduate Student Haoshuang Ji

p_0: ***probability that the background fluctuates to the observed data (or higher)***

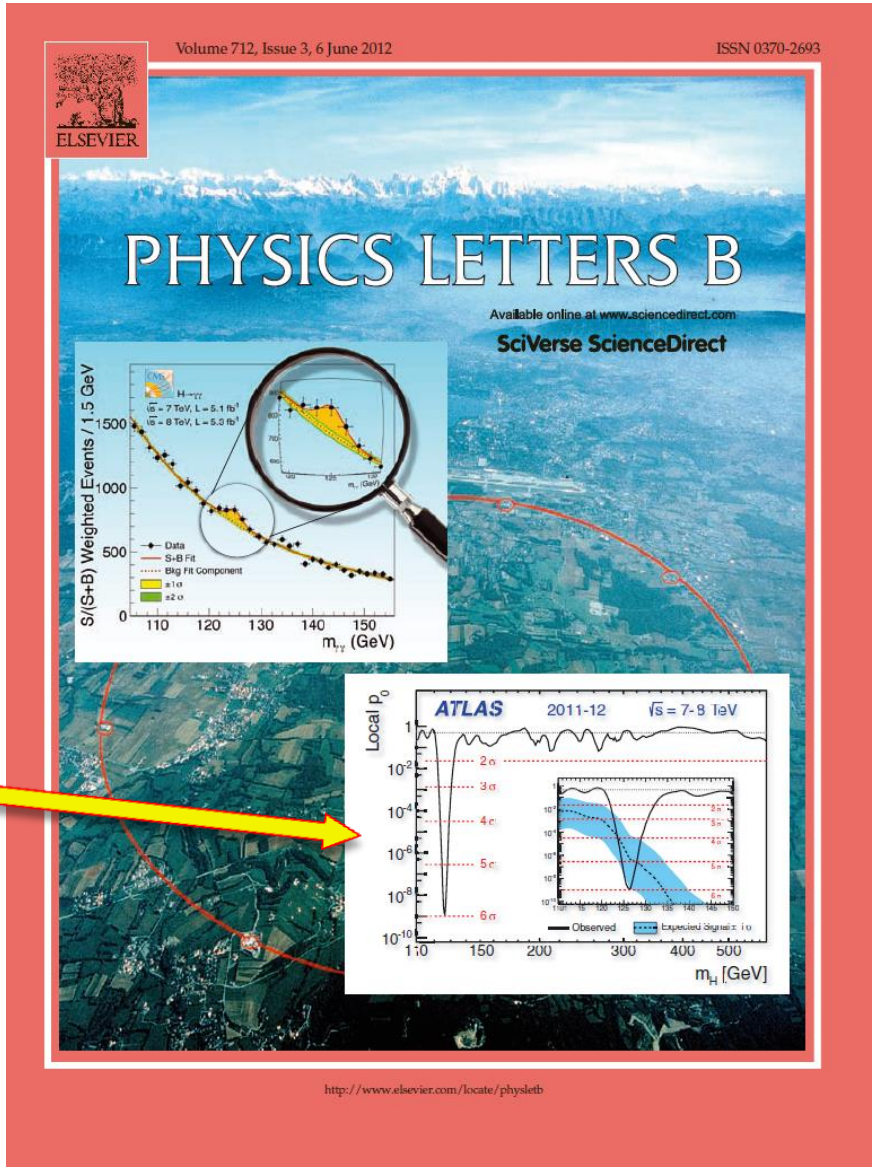
The chances that the events observed were due to random fluctuations are less than one in three million – corresponding to the stringent "five sigma" gold standard particle physicists insist on to claim a discovery.

Wisconsin's contribution to the Higgs discovery

2011+2012 data

We made very strong contributions to the ATLAS plot shown in the cover of Physics Letters B

Our graduate student Haoshuang Ji is one of the two physicists who made the final results shown in this plot

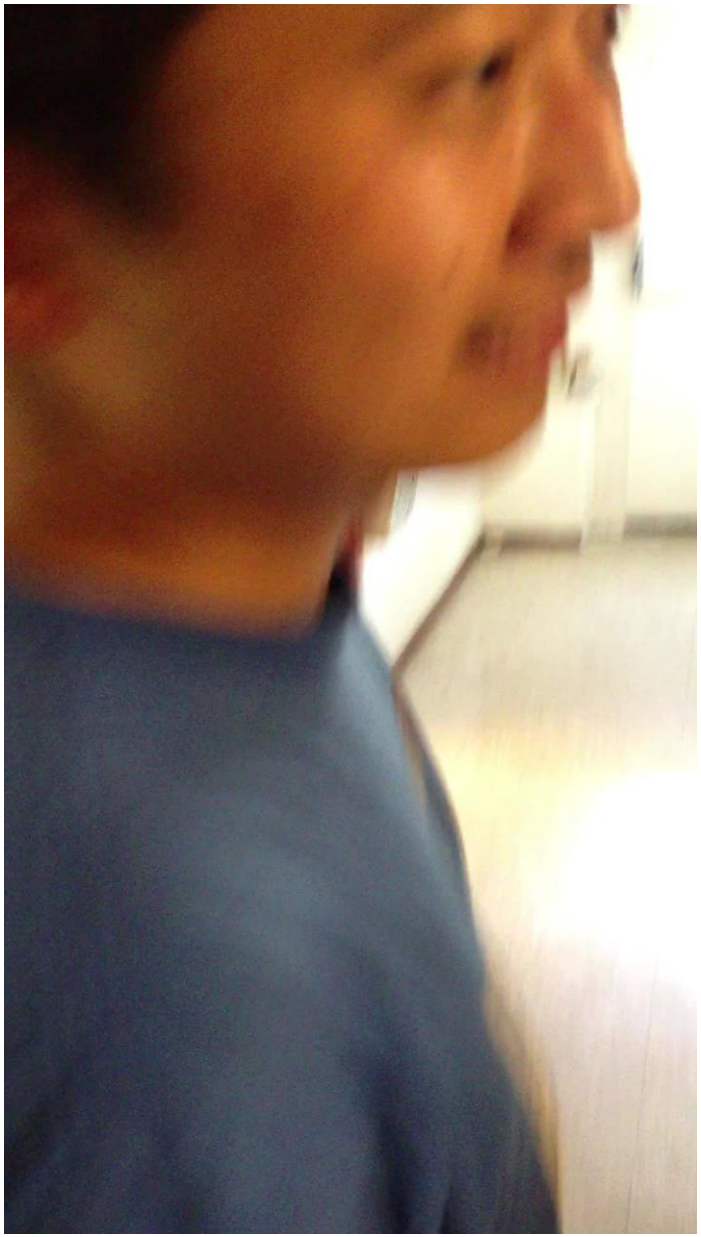


"Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC"

5.9σ

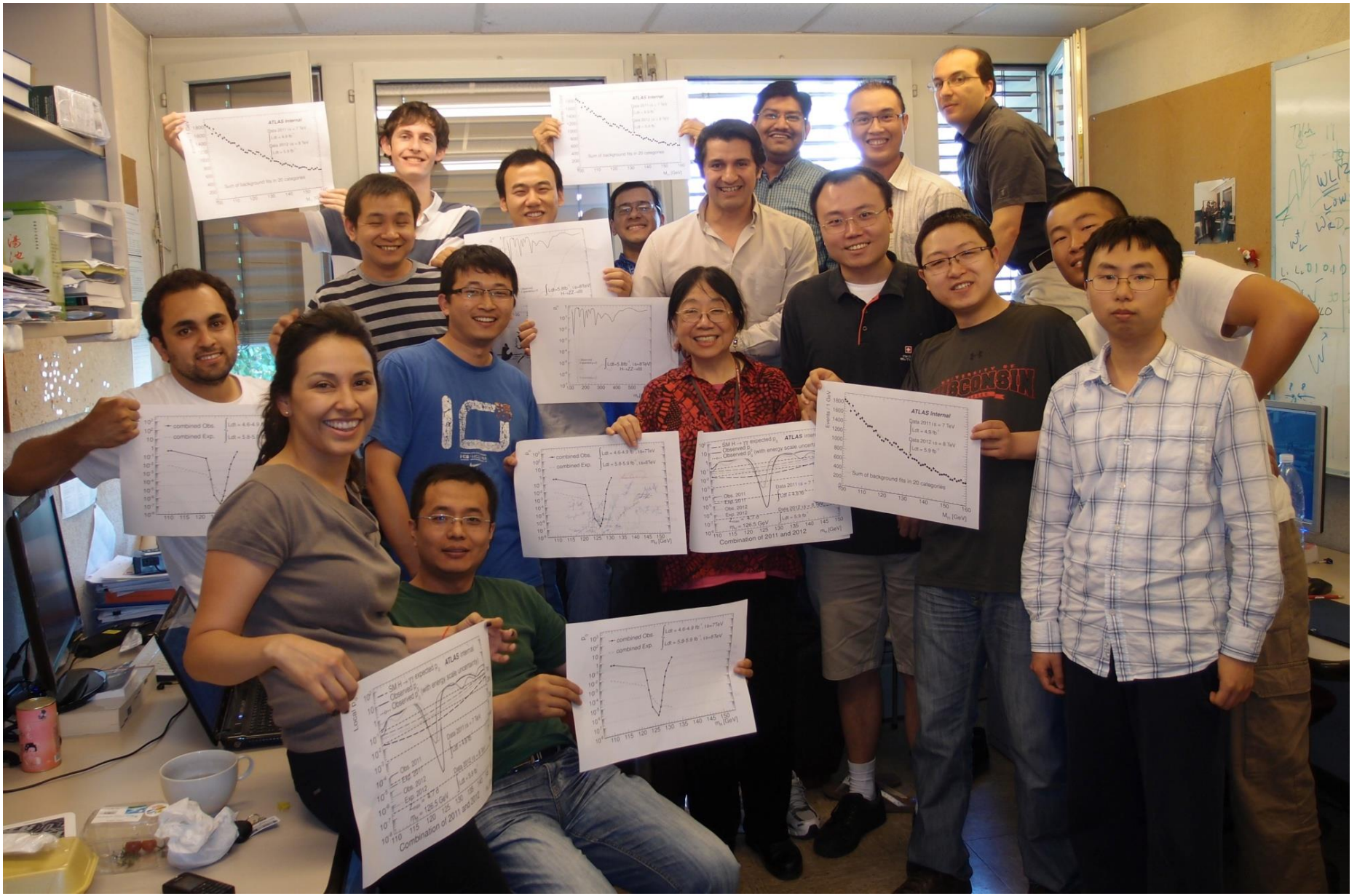
Physics Letters B
September 17, 2012

The moment we got 5σ June 25, 2012, 3 pm (Video)

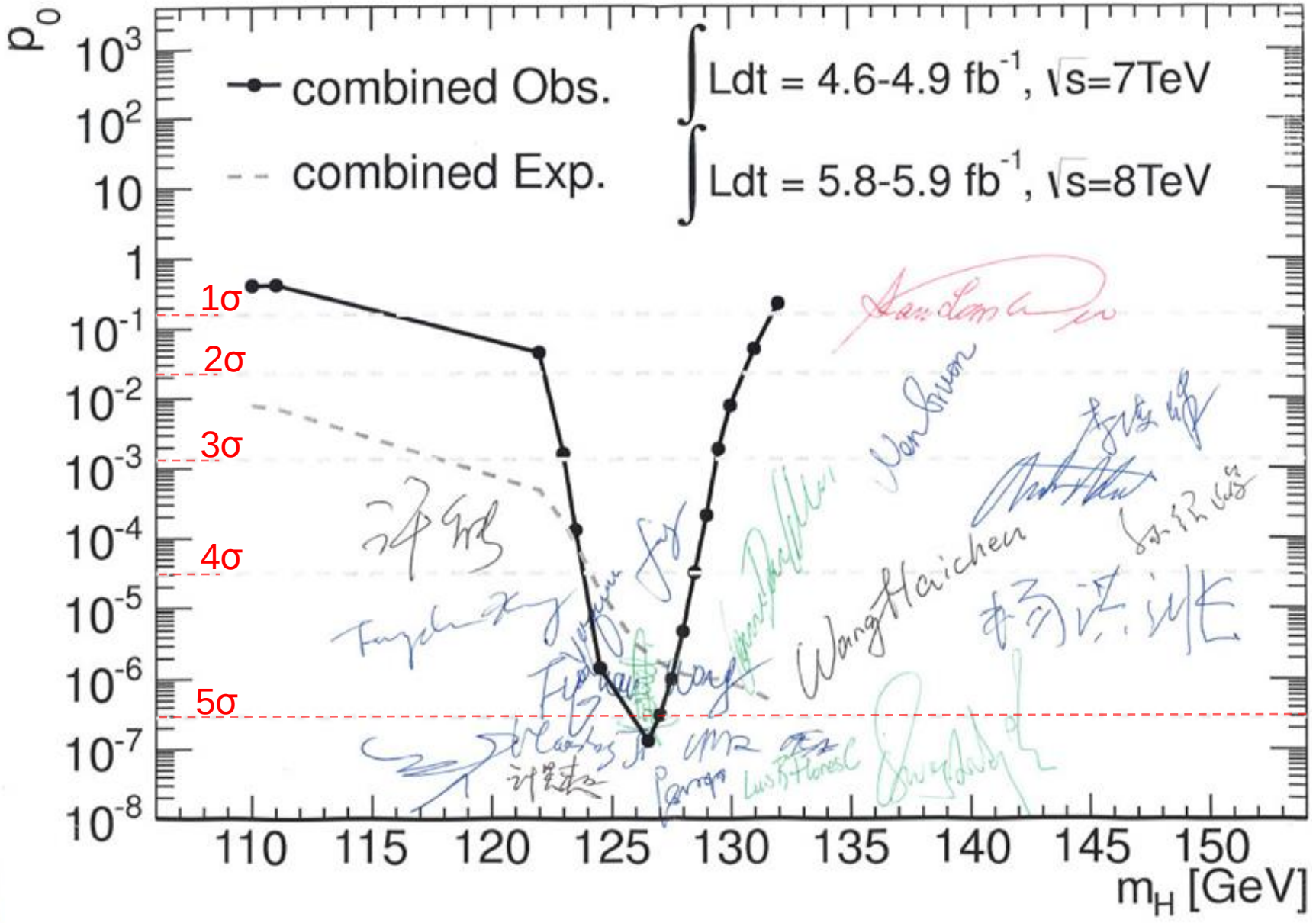


Graduate Student Haoshuang Ji announced 5σ

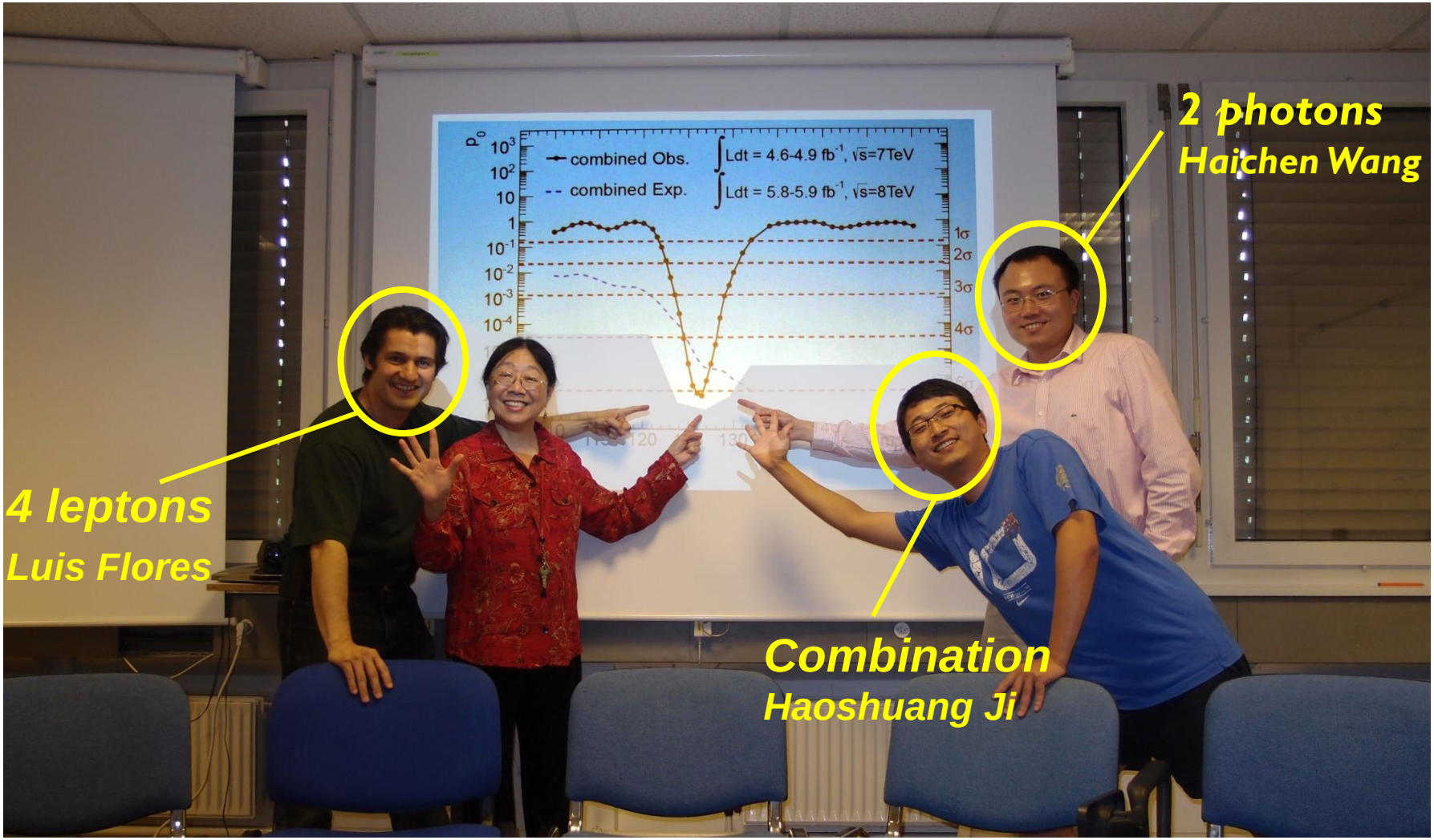
The moment we got 5σ June 25, 2012, 3 pm



The moment we got 5σ June 25, 2012, 3 pm



Celebrating 5σ July 1, 2012 Haichen's birthday



Photos to celebrate…

On July 4, 2012 the Higgs working group had a celebratory drink. Everyone is watching the corks of the champagne bottles flying up to the ceiling.

July 4, 2012 Meeting Professor Higgs

On July 4, at the end of the CERN seminar I went to shake hands with Prof. Higgs. I told him "I have been looking for you for over 20 years". He replied "now, you have found me".

Media coverage of Sau Lan Wu

The four Prize Recipients at the ceremony of the 1995 European Physical Society High Energy and Particle Physics Prize in Brussels, Belgium. Front row: G¨unter Wolf and Sau Lan Wu; second row: Bj¨orn Wiik and Paul S¨oding.

EUROPEAN PHYSICAL SOCIETY

1995

HIGH ENERGY AND PARTICLE PHYSICS
PRIZE

of the

EUROPEAN PHYSICAL SOCIETY

The 1995 High Energy and Particle Physics Prize of the European Physical Society is awarded to

Paul Söding
Björn Wiik
Günther Wolf
Sau Lan Wu

for the first evidence for three-jet events in e^+e^- collisions at PETRA.

Brussels, 27 July 1995

H. Schopper
President
European Physical Society

G. Jarlskog
Chairman
High Energy and Particle
Physics Division

To all Persons to whom these Presents shall come,

GREETING.

The American Academy of Arts and Sciences,

established by a Law of the Commonwealth of Massachusetts, at a Meeting held the tenth Day of April One Thousand Nine Hundred and Ninety-six for the purpose of promoting the design of their institution, elected

Sau Lan Yu Wu

a Fellow of their Society, and have granted unto her all the rights and privileges of a Member;

And In Testimony thereof, have affixed their Seal to this certificate, and caused the same to be duly attested.

Attest

Howard Hiatt Secretary

Jaroslav Pelikan President

K. Stephen Berg Vice Presid.t

Article published in the TRIBUNE DE GENEVE on July 31, and August 1, 2008 (translation)

In 1995, **Sau Lan Wu**, a University of Wisconsin-based CERN user, was awarded the European Physical Society Prize.

CERN, the feminine touch.

One woman, 89 men…

How many did you say? Two, five, ten, none at all? Since 1901, 178 people have won the Nobel Prize for Physics. And of these, just two women - Marie Curie in 1903 and Maria Goeppert-Mayer 60 years later. Forty years

Marie Curie needs no introduction. Born into a under-privileged family in Warsaw, through hard work and intelligence she succeeded in doing what no other woman has managed – win two Nobel Prizes ! After the physics prize for her discoveries on radioactivity, she received a second supreme distinction in 1911 for her work in chemistry. Her daughter, Irene Joliot-Curie, followed proudly in her mother's footsteps when she and her husband, Frédéric Joliot, discovered artificial radioactivity and were jointly awarded the Nobel Prize for Chemistry in 1935.

In 1948, Maria Goeppert-Mayer, an American of German origin, proposed the nuclear shell model of the atomic nucleus, publishing her findings at the end of 1949 at the same time as German physicist Hans Jensen published an article proposing the same theory. They would share the Nobel Prize for Physics in 1963.

Happily, other women have distinguished themselves in physics and science in general, and particle physics in particular, and have been justly rewarded with other, equally prestigious prizes. But women are still far outnumbered by men, simply because the two sexes don't embark in equal numbers on careers in these disciplines.

Article published in the TRIBUNE DE GENEVE on July 31, and August 1, 2008 *(translation)*

About 10 women have been distinguished in particle physics, mainly Americans. One of them - Sau Lan Wu – is currently working with CERN. Sau Lan Wu dreamed of being a painter but, after reading Marie Curie's biography, she decided to devote her life to physics. In 1995, she received the European Physical Society Prize for the first detection of three-jet events in e^+ e^- collisions at PETRA, which amounted to the first direct observation of the gluon. All a bit complicated, we agree. Today, Sau Lan Wu manages the group at the University of Wisconsin which is doing experiments at ATLAS , one of the detectors at the LHC, which will soon be switched on.

Famous or not, prize-winners or not, women are slowly making their mark on the field of particle physics and physics in general. At CERN in particular, more and more women are emerging. The reasons for inequality in science are complex, but intellectual capacity is certainly not one of them. In 2005, the former director of Harvard, Lawrence Summers, caused a scandal with the following remark: "I've noticed that men regularly achieve better results in exams and no-one knows why – perhaps it's biological."

Since then, the weight of evidence confirms there is no difference between men and woman when it comes to using the grey matter. Aptitude for science has nothing whatsoever to do with gender – or ethnic origin – but is shaped by education. Perhaps the real question we should be asking is to what extent our education is influenced by parental expectations and social prejudices.

Author : *Anne-Muriel Brouet*

The long road to the Higgs boson

Physics World
August 2012
by Michael Riordan

Feature: Particle physics — physicsworld.com

The long road to the Higgs boson

With the discovery of the Higgs boson seemingly accomplished, **Michael Riordan** looks back at how this long-sought particle was predicted and the first quarter century of experimental searches for it

Michael Riordan, author of *The Hunting of the Quark*, is based in Eastbound, WA, US, e-mail mriordan137@gmail.com

In a 1976 *Nuclear Physics* article, CERN theorist John Ellis, together with colleagues Mary Gaillard and Dimitri Nanopoulos, ended with "an apology and a caution". Their widely cited article, entitled "A phenomenological profile of the Higgs boson", concluded with the words:

"We apologize to experimenters for not having any idea what is the mass of the Higgs boson...and for not being sure of its couplings to other particles, except that they are very small. For these reasons, we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up."

Their admonition against "big experimental searches" did not, however, sink in. Governments have spent billions of dollars, euros and Swiss francs in this epic pursuit, involving many thousands of physicists and engineers worldwide. CERN, based in Switzerland, constructed the 27 km Large Electron–Positron (LEP) collider ring during the 1980s partly in the hope of tracking down this all-important quarry, which could help to explain the origin of mass in the universe. US physicists followed suit with the enormously expensive Superconducting Super Collider, only to watch Congress kill it in 1993, leaving a huge hole not just in Texas, but in the entire US high-energy-physics programme.

Tantalizing hints of a Higgs boson turned up at LEP and Fermilab's Tevatron over the past dozen years, but nothing was conclusive. Finally, the Large Hadron Collider (LHC), built at CERN by adding more than 1200 superconducting dipole magnets to the LEP tunnel, began producing something more substantive last year. Its mass, at 125 MeV, comes in close to that of 133 protons, or about that of a caesium atom. Based on evidence presented in July by LHC and Tevatron researchers at the International Conference on High Energy Physics in Melbourne, Australia, it seems that this long, arduous search is now over.

Out of the doldrums

Peter Higgs of the University of Edinburgh and several other theorists have been awaiting this discovery a long, long while. Ever since 1964, in fact, when novel subatomic particles were popping up almost weekly from proton accelerators at the Lawrence Berkeley and Brookhaven laboratories in the US and at CERN. That year quarks were just a fitful gleam in the eye of California Institute of Technology physicist Murray Gell-Mann. And the Stanford Linear Accelerator Center (SLAC), where their discovery was to occur over the following decade, was nearing completion in the foothills of the Santa Cruz Mountains south of San Francisco.

At the time, the quantum theory of fields, on which Higgs worked, was in the doldrums – a musty corner of particle physics where only a few stalwarts like him were sweeping dust. Far more popular then were S-matrix theory, Regge theory and Gell-Mann's own Eightfold Way, which vied to cope with and systematize the plethora of new mesons and baryons being disgorged by the proton machines. Although field theory had succeeded marvellously in accounting for the electromagnetic interactions of subatomic particles, it had fallen flat in attempts to describe their strong and weak nuclear interactions. Especially in California, working on the quantum theory of fields was considered harmful to a young physicist's career.

But a few theorists such as Higgs, along with Robert Brout and François Englert at the Free University of Brussels, ignored the fashions of the day. This was easier for the two Belgians, who had come to particle theory from condensed-matter physics, where the core idea of "spontaneous symmetry breaking", which now plays a crucial role in our understanding of the fundamental forces of nature, was spawned during the previous decade. Brout later recalled a 1960 Cornell University seminar by Victor Weisskopf of the Massachusetts Institute of Technology, who said "Particle physicists are so desperate these days that they have to borrow from the new things coming up in many-body theory." An early stab at applying these symmetry-breaking ideas to the strong nuclear force by theorists Yoichiro Nambu and Jeffrey Goldstone however predicted the existence of massless spin-0 particles (called Nambu–Goldstone bosons) that should have been easily detectable, but were nowhere to be found.

Here is where Brout, Englert, Higgs and a group of three other physicists at Imperial College Lon-

In the case of the Higgs boson search, where large ranges of particle masses are being surveyed, there is also the "look-elsewhere effect" to contend with. This refers to the fact that if you are examining many data bins in which an effect might show up, the chances of seeing *something* in one bin are multiplied by the number of bins under study. You have to adjust for that possibility.

Thus twice-shy particle physicists have come to rely on the 5σ gold standard before they will begin to accept a possible result as real. And even then, it helps to have comforting corroboration from an independent experiment, which is one reason why Fermilab had two general-purpose detectors on the Tevatron.

at a mass close to 174 GeV. At more than 185 times the proton mass, this was (and still is) the heaviest known elementary particle.

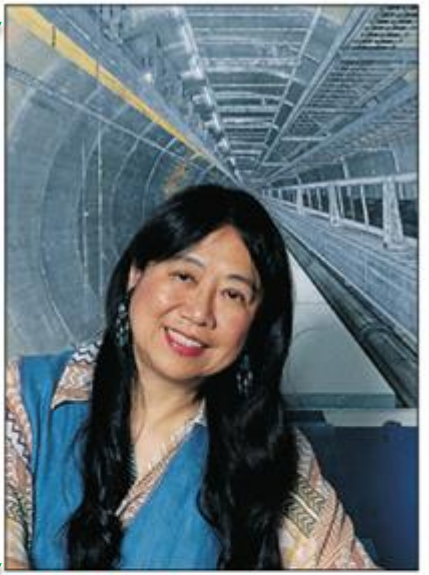
But such a heavy top quark, when considered within the Standard Model in tandem with the increasingly accurate measurements of the W and Z masses, implied a rather light Higgs boson, with a mass below 200 GeV. And theoretical arguments based on supersymmetry began to suggest that the lightest of its neutral, spin-0 bosons should come in above the Z mass but below 135 GeV. The SSC had been aiming far too high, that is. CERN and Fermilab might in fact have an outside shot at discovering it.

Full steam ahead

In 1996 LEP began its second phase of operation at energies above 160 GeV, at which pairs of W bosons appeared in profusion. Physicists began excluding ever-higher Higgs-boson masses as the LEP energy and luminosity, or collision rate, steadily increased during the late 1990s. CERN accelerator physicists and engineers achieved these gains by adding ever more superconducting microwave cavities to the machine to restore the energy lost by its electrons and positrons in every orbit as a result of synchrotron radiation (which grows as the fourth power of

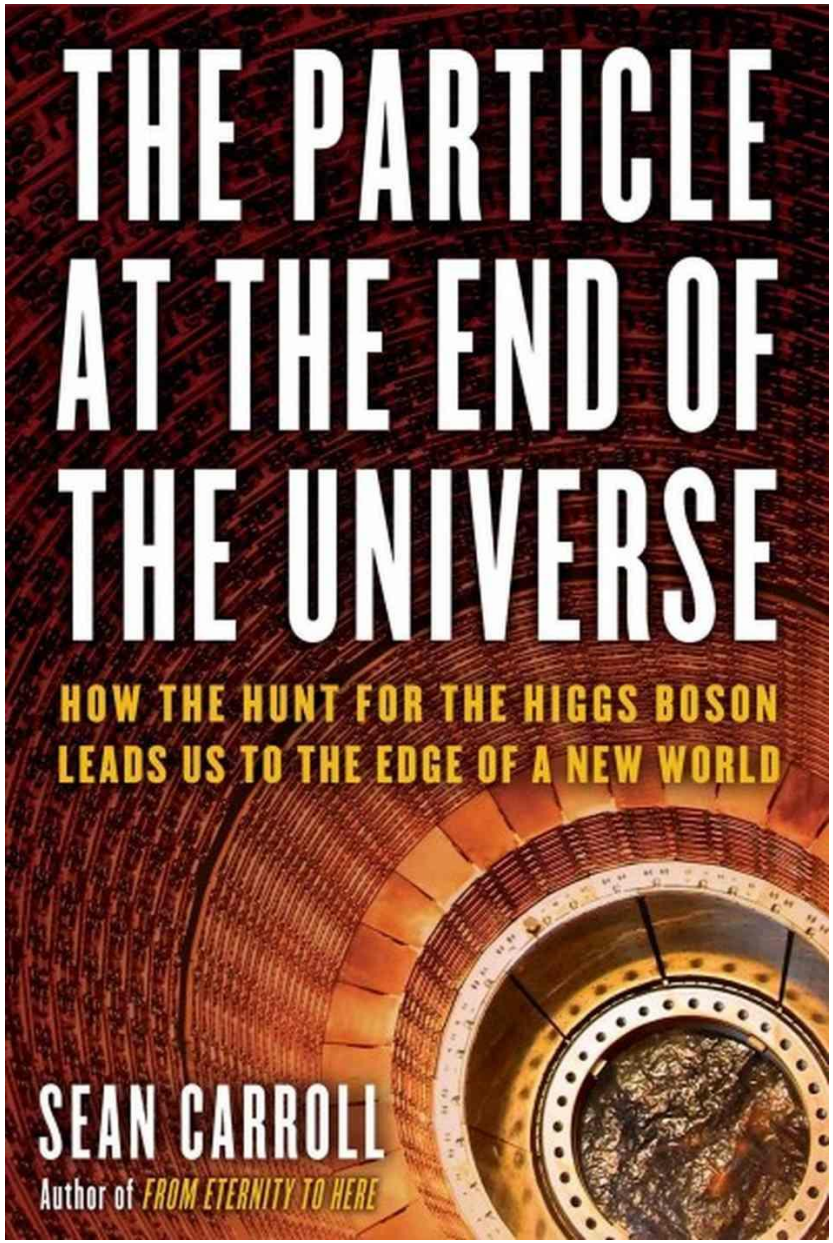
Vassar College

Big dreams Sau Lan Wu in the Large Electron–Positron collider tunnel at CERN. With others, she hoped this machine would help find the Higgs boson.

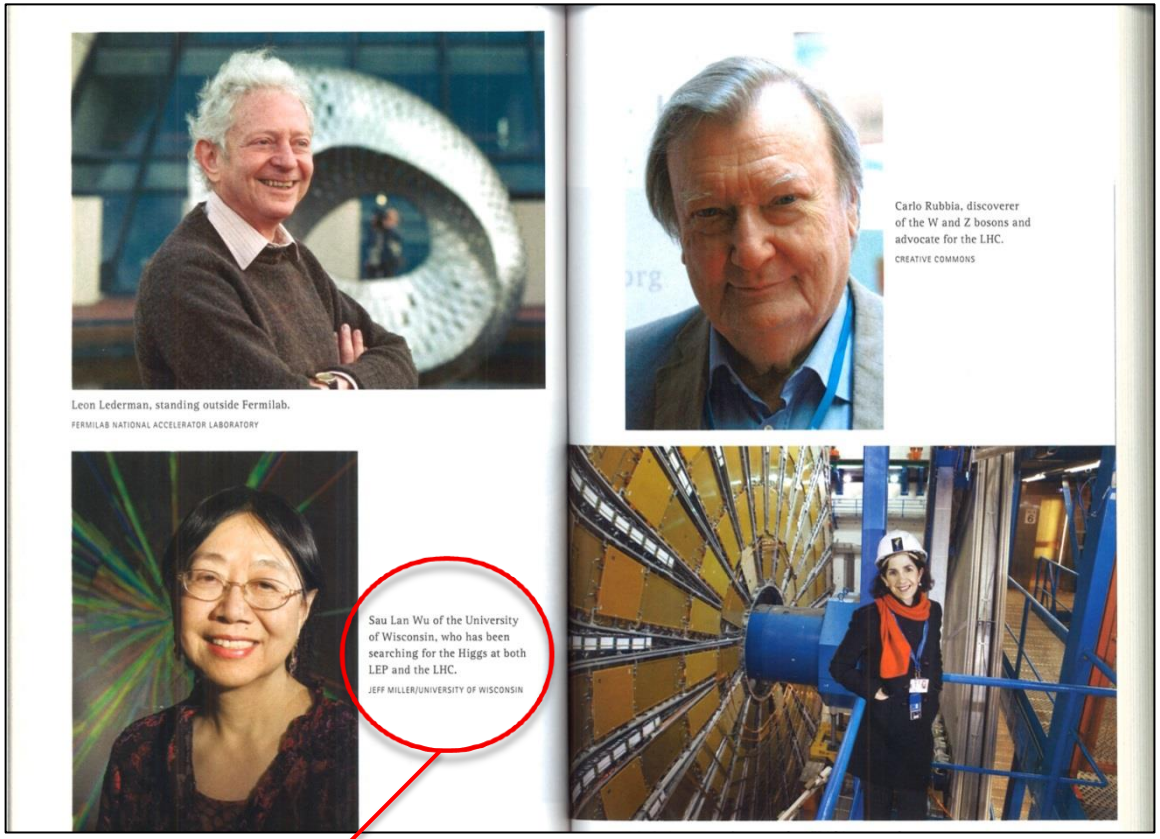


Big dreams Sau Lan Wu in the Large Electron–Positron collider tunnel at CERN. With others, she hoped this machine would help find the Higgs boson.

"The particle at the end of the Universe" Sean Carroll 2012



Hardcover, Dutton (Penguin group)



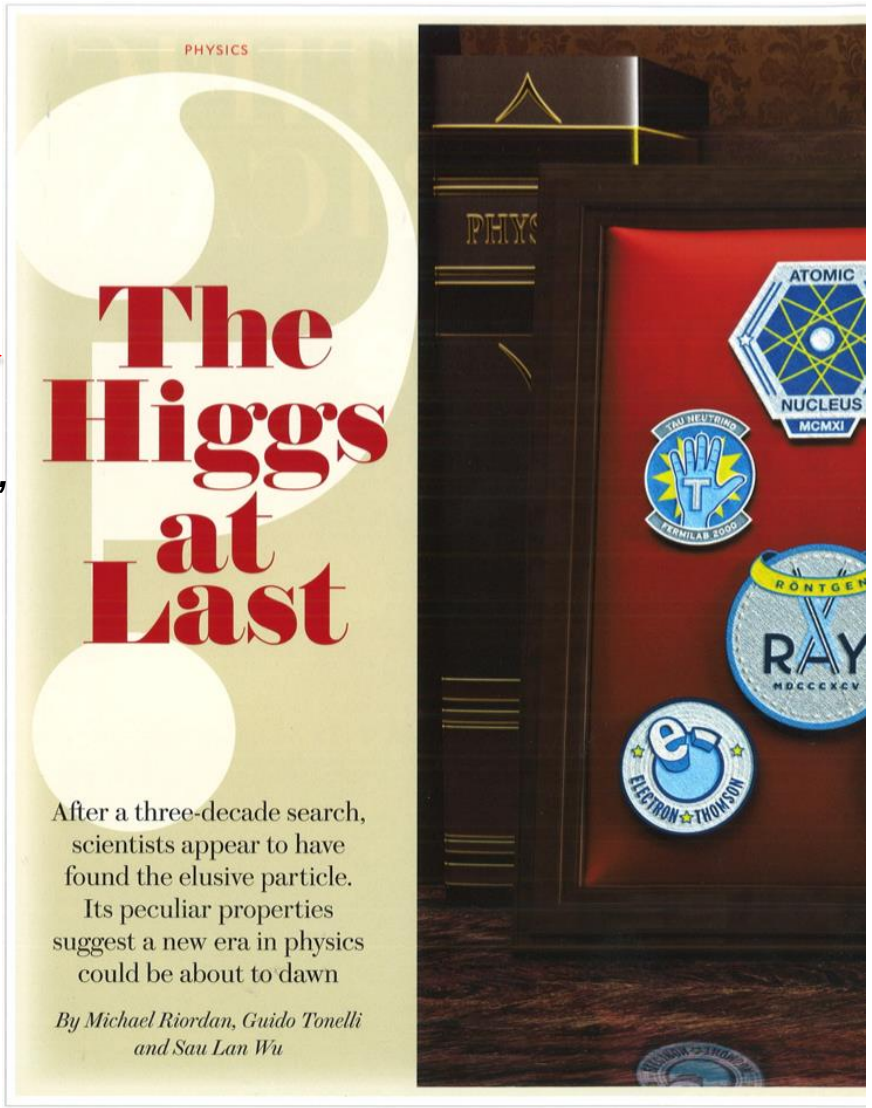
Sau Lan Wu of the University of Wisconsin, who has been searching for the Higgs at both LEP and the LHC

The Higgs at Last

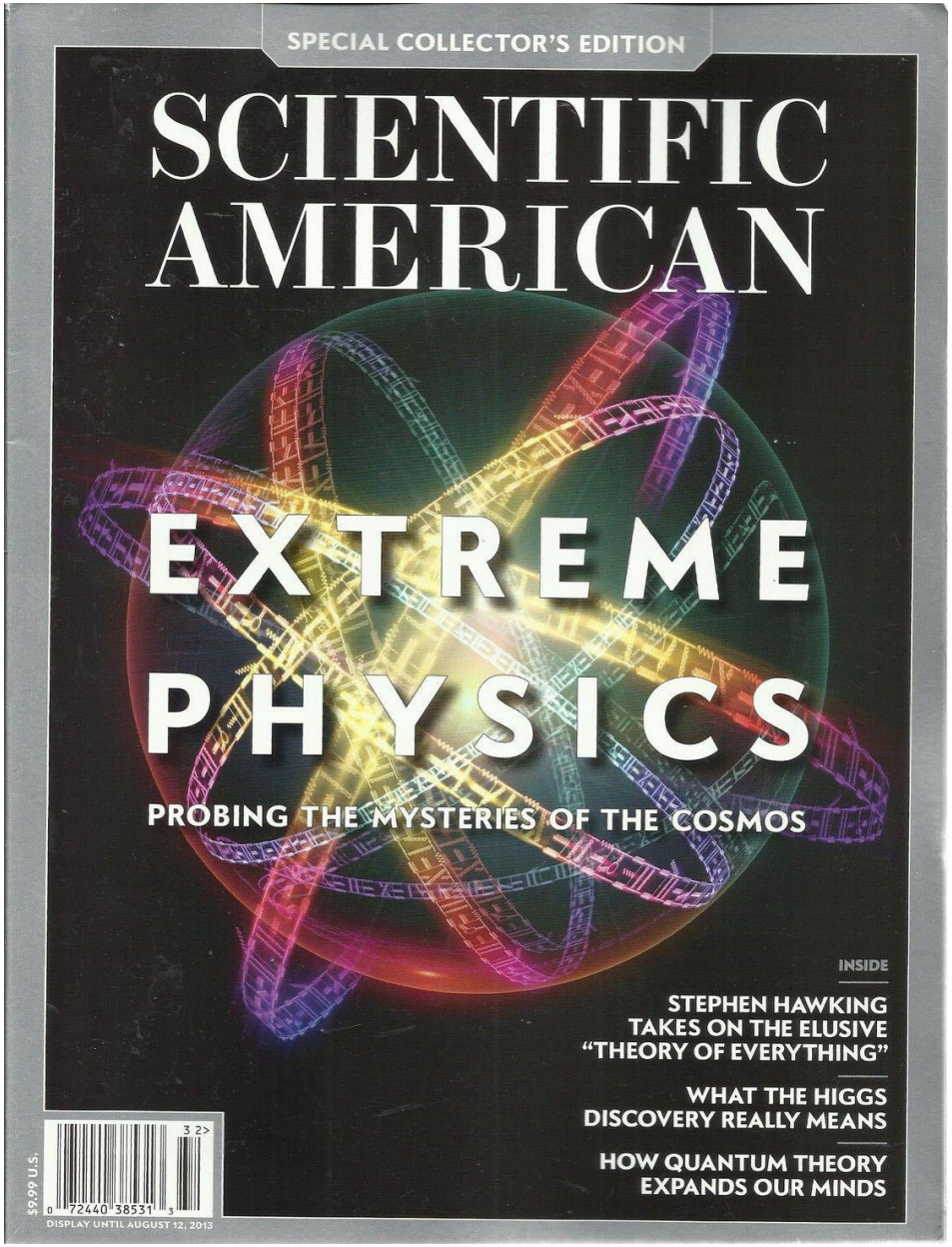
Scientific American October 2012

Translated (or in progress) into many languages.
German, French, Spanish, Italian, Chinese, Japanese, …

Co-authors by Michael Riordan, Guido Tonelli and Sau Lan Wu



Scientific American - Special Collector's Edition, August, 2013



"The Higgs at Last", is selected to be the first article in a special edition of Scientific American devoted to "extreme physics", containing 16 of the most intriguing articles that Scientific American has published in recent years.

Was published on August 12, 2013

Published editions (examples)

- Italian: “Il bosone di Higgs finalmente” (“Le Scienze”, italian edition of Scientific American). Front page:

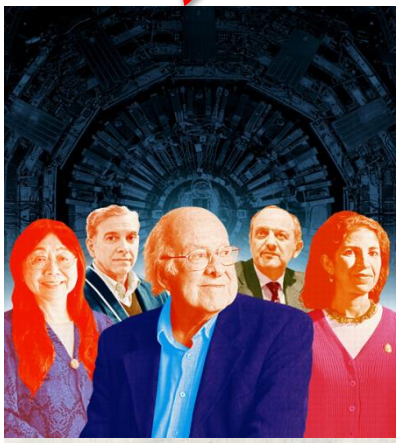
- German: Spektrum der Wissenschaft, November issue. "Der lange Weg zum Higgs" (The long road to Higgs)

- Chinese edition of Scientific American

The New York Times

Science Times
TUESDAY, MARCH 5,2013

Front page of the New York Times



Catching One Big Little Thing

A special issue tracks the toil and triumph in the hunt for physics' most elusive particle, the Higgs boson. PAGE D1

This photo is shown in the first page of the science section. It occupies most of the page.

8 pages devoted to The Higgs discovery

Chasing the Higgs

Struggle, and finally triumph, in the search for physics' most elusive particle.

By Dennis Overbye

Photo Caption

Peter Higgs, center, of the University of Edinburgh, was one of the first to propose the particle's existence. From left, physicists at CERN who helped lead the hunt for it: Sau Lan Wu, Joe Incandela, Guido Tonelli and Fabiola Gianotti.

The New York Times

Science Times
TUESDAY, MARCH 5,2013

Sections D6 / D7

The job of ultimately confirming the boson's discovery had been entrusted to another pair of graduate students, Haoshuang Ji , a Wisconsin student , and Aaron Armbruster of the University of Michigan — who had sent the plot that Dr. Gross had woken up to in November. They were each working to combine all the Higgs data from all the myriad ways it could fall apart and leave a trace in the detectors. This calculation would make or break the Higgs, because the boson had to behave properly in all its guises.

On the afternoon of June 25, Mr. Ji announced he had gotten a result of 5.08 sigma, causing cheers to go ringing down the corridor outside Dr. Wu's office; everybody ran to sign the printout. The next day, Mr. Armbruster arrived at the same result.

ATLAS was at 5-sigma.

International Herald Tribune March 6, 2013

BULL MARKET
THE DOW JONES HITS A RECORD
PAGE 17 | BUSINESS WITH REUTERS

RAFAEL NADAL
LOOKING READY TO PLAY AGAIN?
PAGE 15 | SPORTS

SUZY MENKES
STILLNESS AND GRACE FROM VALENTINO
PAGE 9 | FASHION PARIS

International Herald Tribune
WEDNESDAY, MARCH 6, 2013 THE GLOBAL EDITION OF THE NEW YORK TIMES GLOBAL.NYTIMES.COM

Chasing the Higgs

The professional rivalry that led to physics' missing link

The visionary and the discoverers Peter Higgs, center, of the University of Edinburgh, was one of the first to propose the existence of the Higgs boson. From left, physicists at the European Organization for Nuclear Research who helped lead the hunt for it: Sau Lan Wu, Joseph Incandela, Guido Tonelli and Fabiola Gianotti.

MEYRIN, SWITZERLAND

BY DENNIS OVERBYE

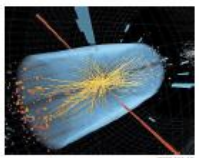
Vivek Sharma, a professor at the University of California, San Diego, had to spend months at a time away from home, coordinating a team of physicists at the Large Hadron Collider here, just outside Geneva. But on April 15, 2011, his daughter's seventh birthday, he flew to California. "We had a fine birthday, a beautiful day," he recalled.

Then Dr. Sharma was alerted that a rival team of physicists had beaten his team to the discovery of the Higgs boson — the long-sought "God particle."

If his rivals were right, it would mean that Dr. Sharma and his colleagues had missed one of nature's greatest prizes: to know something that nobody else has ever known.

He flew back to Geneva the next day and did not see his family again for months.

Dr. Sharma and his colleagues had every reason to believe that they were closing in on the Great White Whale of modern science: the Higgs boson, a particle whose existence would explain all the others then known and how they fit together into the jigsaw puzzle of reality.



CERN, VIA AP

Physicists at CERN sought the Higgs boson in the rubble of subatomic collisions.

For almost half a century, physicists had chased its quantum ghost through labyrinths of mathematics and logic, and through tons of electronics at powerful particle colliders.

Now it had come down to the Large Hadron Collider, where two armies of physicists, each 3,000 strong, struggled against each other and against nature.

In physics tradition, they were there to check and complement each other in

HIGGS, PAGE 8

Antitrust fine expected as E.U. zeros in on Microsoft

BRUSSELS

Penalty could be signal that companies violate settlements at their peril

BY JAMES KANTER

European antitrust officials were expected to impose a large fine on Microsoft on Wednesday for failing to give users of the company's Windows software the choice of competing Internet browsers.

It would be the first time the European Union has punished a company for neglecting to comply with the terms of an antitrust settlement. Microsoft and European antitrust officials reached a settlement over the browser-access issue in 2009. But last October, the Union's antitrust chief, Joaquín Almunia, charged Microsoft with failing to live up to the agreement.

The amount of the fine could not be learned on Tuesday. Mr. Almunia's office and Microsoft executives declined to comment. The company had previously emphasized that the failure was a mistake it regretted.

The significance of the action expected Wednesday could reach beyond Microsoft. It comes as Mr. Almunia's office is negotiating with Google to try to settle the commission's concerns about that company's dominance of the Internet search and advertising markets. Even if Google and the Union reach a settlement, a substantial fine for Microsoft would serve as a warning that a company violates such a settlement at its financial peril.

"It's important for the commission to show it's serious in this case because this will set a precedent, and because the commission increasingly uses settlements to help reach solutions more quickly, especially in the fast-moving technology sector," said Nicolas Petit, a professor of competition law and economics at the University of Liège in Belgium.

"The commission also has an incentive to slap on a big fine in this case to ensure that companies, which are hard to monitor, get the message that it will be costly down the road if they get caught defying settlement orders," Mr. Petit said.

In theory, Mr. Almunia can levy a fine totaling up to 10 percent of a company's

MICROSOFT, PAGE 18

China backs U.S. efforts to penalize North Korea

NEW YORK

Proposed U.N. sanctions target 'illicit' activities after latest nuclear test

BY RICK GLADSTONE AND JERRY MULLANY

Bolstered by support from China, the United States moved on Tuesday to intensify sanctions on North Korea because of its nuclear test last month, targeting North Korean banking activities and what the U.S. ambassador to the United Nations called illicit activities by North Korean diplomats.

A draft resolution introduced at the United Nations Security Council — the fourth against North Korea — drew a furious reaction from the country even before it was formally distributed among the 15 council members. The move follows three weeks of delicate back-and-forth negotiations between the United States, the resolution's principal sponsor, and China, North Korea's major benefactor, which has nevertheless grown increasingly impatient with the North's nuclear activities.

"North Korea will be subject to some of the toughest sanctions imposed by the United Nations," the U.S. ambassador, Susan E. Rice, said Tuesday.

She added that the scope of the sanctions, aimed at denuclearizing the Korean Peninsula, "is exceptional and demonstrates the strength of the international community's commitment."

CRAIG RUTTLE/AP

Ambassador Susan E. Rice said Tuesday that the sanctions had "exceptional" scope.

The resolution will punish "the illicit activities of North Korean diplomatic personnel, North Korean banking relationships, illicit transfers of bulk cash," Ms. Rice said.

The full text of the draft was not made immediately available outside the Council.

Photo Caption

The visionary and the discoverers

Peter Higgs, center, of the University of Edinburgh, was one of the first to propose the existence of the Higgs boson. From left, physicists at the European Organization for Nuclear Research who helped lead the hunt for it: Sau Lan Wu, Joseph Incandela ,Guido Tonelli and Fabiola Gianotti.

The New York Times March 14, 2013

CERN Physicists See Higgs Boson in New Particle

By DENNIS OVERBYE
Published: March 14, 2013

Physicists at CERN, the European Organization for Nuclear Research, said Thursday that the new particle discovered with enormous fanfare last summer definitely looks like a Higgs boson, the particle famously predicted by Peter Higgs and others to imbue elementary particles with mass. But they said they still needed more data to understand how it works and what it means for the universe.

Special Section

Chasing the Higgs
How two armies of scientists closed in on physics' most elusive particle.

"The preliminary results with the full 2012 data set are magnificent," Joe Incandela, a professor at the University of California, Santa Barbara, and leader of one of the discovery teams, said in a statement released by CERN. "To me it is clear that we are dealing with a Higgs boson, though we still have a long way to go to know what kind of Higgs boson it is."

After rummaging through the data from some 2,000 trillion collisions of subatomic particles in the Large Hadron Collider — more than twice as much data as led

"All the News That's Fit to Print"

The New York Times

Late Edition

Today, partly sunny, breezy, seasonably cool, high 67. Tonight, cloudier, low 55. Tomorrow, mostly cloudy, rain likely, breezy, high 62. Weather map appears on Page A26.

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For Nobel, They Can Thank the 'God Particle'

FRONT PAGE NY TIMES Oct. 9, 2013

By DENNIS OVERBYE

The "God particle" became the prize particle on Tuesday.

Two theoretical physicists who suggested that an invisible ocean of energy suffusing space is responsible for the mass and diversity of the particles in the universe won the Nobel Prize in Physics on Tuesday morning. They are Peter W. Higgs, 84, of the University of Edinburgh in Scotland, and François Englert, 80, of the Université Libre de Bruxelles in Belgium.

The theory, elucidated in 1964, sent physicists on a generation-long search for a telltale particle known as the Higgs boson, popularly known (though not among physicists) as the God particle. The chase culminated last year with the discovery of this particle, which confers mass on other

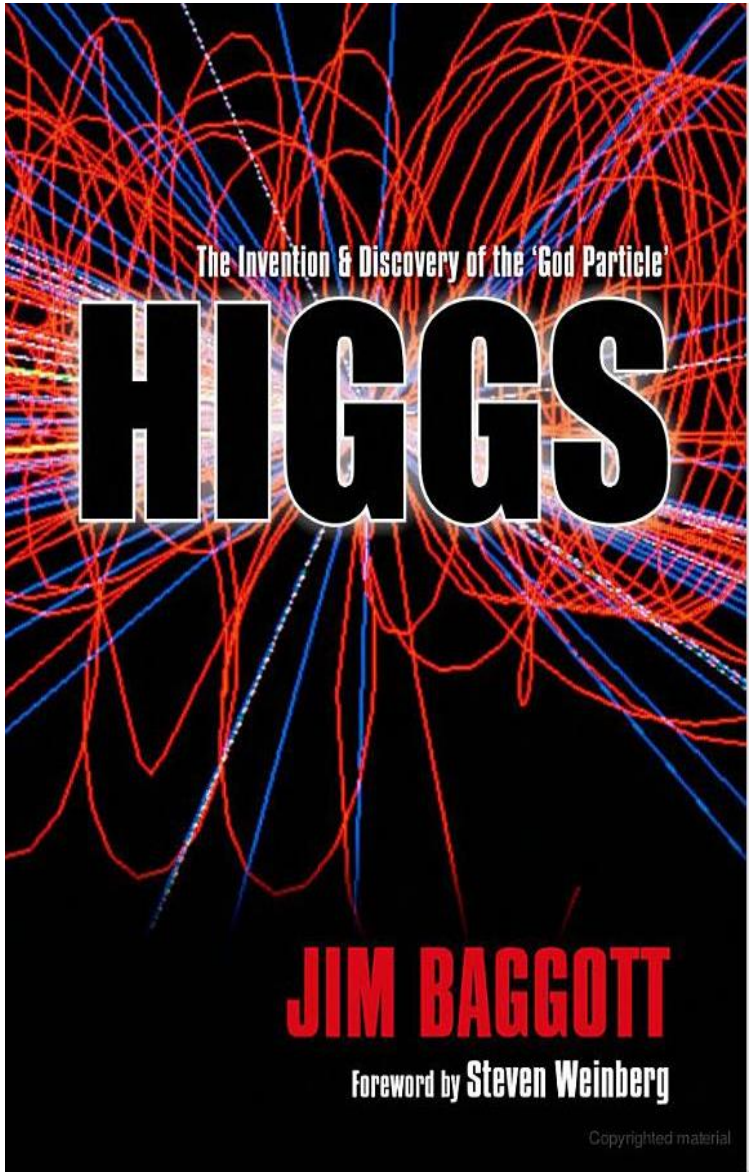
FABRICE COFFRINI/AGENCE FRANCE-PRESSE — GETTY IMAGES

Scientists at CERN near Geneva on Tuesday after the announcement of the winners of the Nobel Prize in Physics.

9 Wisconsin members

Other coverage

Sau Lan Wu was mentioned in:



Physics world October 2012

Michael Riordan

Cornering the Higgs boson

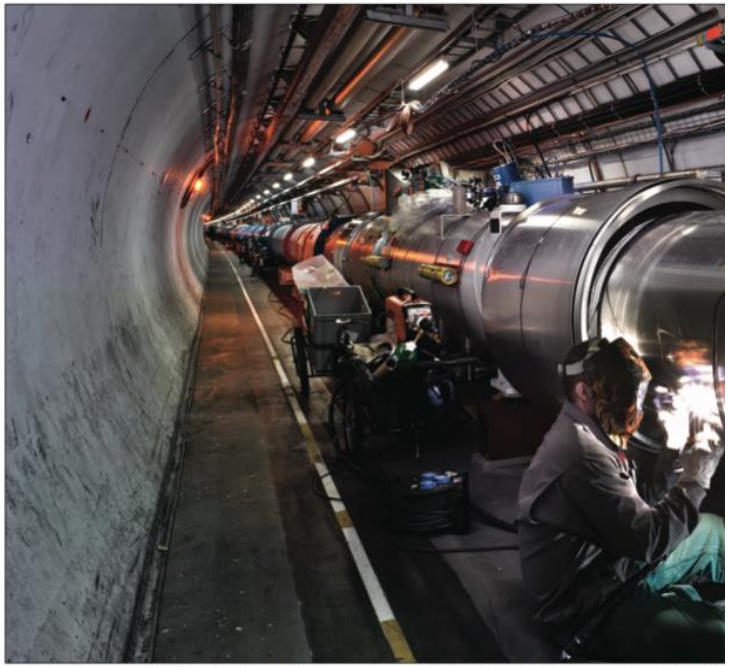
Michael Riordan continues his look back on the Higgs boson search with the early attempts to hunt it down at the Tevatron and the Large Hadron Collider

Michael Riordan, author of *The Hunting of the Quark*, is based in Eastbound, WA, US, e-mail mriordan137@gmail.com.
This feature continues on from "The long road to the Higgs boson", which described the hunt for the Higgs up to the year 2000 (August pp22–26)

In one sense, the Large Electron–Positron (LEP) collider at CERN could have been considered a failure. Although LEP had cost about a billion Swiss francs (CHF) to build, and even more than that to operate from 1989 to 2000, researchers did not discover a single new elementary particle using it. Sure, they made tremendous refinements of the properties of the massive W and Z bosons – the weak-force-bearing particles that had been discovered at CERN in the early 1980s – as well as precision measurements of other important parameters of the Standard Model of particle physics. But during that 12-year period, only Fermilab could claim a fundamental particle discovery – of the top quark in 1995.

In another sense, however, LEP was a major success. For physicists had excluded a huge range of masses in which any Higgs bosons would have been almost impossible to discover by experiments at proton colliders. A particle that remotely resembled the Higgs boson predicted by the Standard Model should have appeared in electron–positron collisions at LEP had its mass been up to as high as 114 billion electron volts (114 GeV), according to a combined analysis of the four LEP experiments published in 2003 (*Phys. Lett. B* **565** 61). But nothing new had cropped up in this range. And the precision LEP measurements, taken together with the top-quark mass as determined at Fermilab, required that any Standard Model Higgs boson had to show up at a mass below 193 GeV (at a confidence level of 95%). As nobody could have said anything much about its mass before 1989, LEP researchers had thus taken a giant step on the long road to cornering the Higgs boson.

And many physicists on the ALEPH experiment at LEP, which had recorded the most telling candidate events, argued that they had witnessed good evidence for it at 115 GeV. In December 2000 they published a paper entitled "Observation of an excess in the search for the Standard Model Higgs boson at ALEPH" (*Phys. Lett. B* **495** 1), claiming a 3σ excess of Higgs-like events at this energy. But the other three LEP experiments did not confirm these results. Therefore the combined analysis allowed only that such a signal *might* have occurred – in other words, the signal-plus-background hypothesis fitted all the data better than no signal at all, but not by much. In late 2000 CERN finally shut LEP down after a heated debate and began construction of the Large Hadron Collider (LHC).



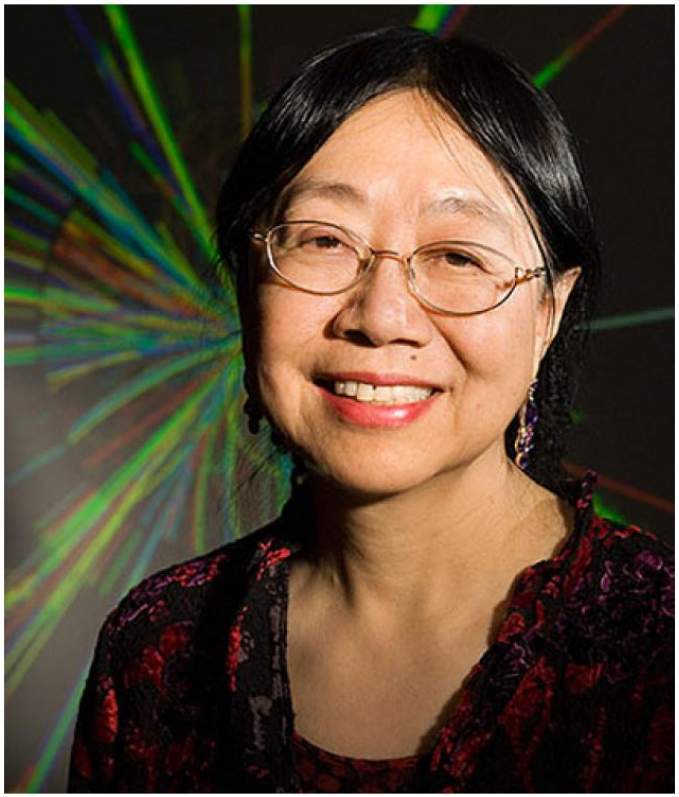
Focus on Fermilab

As the new century dawned, physicists at Fermilab could look forward to more than five fruitful years during which they had no competition at all in the Higgs search. It would take at least that long (and as it turned out, much longer) to build and install the LHC in the 27 km LEP tunnel. Boasting a collision energy of almost 2×10^{12} eV (2 TeV), Fermilab's Tevatron proton–antiproton collider was then the most powerful machine on Earth – and the only one able to generate exotic new particles with masses above 100 GeV. But would it have a sufficiently high collision rate, or luminosity, to create enough of the expectedly rare Higgs events?

A daunting problem with hadron colliders such as the Tevatron or the LHC is that they also produce lots of extraneous debris because protons and antiprotons are not elementary but composite particles made of quarks and gluons. Indeed, Caltech theorist Richard Feynman once compared proton collisions to "smashing garbage cans into garbage cans". A lot of garbage comes bursting out, some of it looking a lot like the expected decay products of Higgs bosons. At LEP this was not a problem because it collided electrons and positrons, which are essentially point particles with well-understood electromagnetic interactions. Its candidate Higgs events had only two or four tightly packed "jets" of hadrons, corresponding to emerging quarks, and little else. These events could be recognized rather easily.

But at the Tevatron and the LHC, such Higgs-like signals would be swamped by the immense backgrounds of ordinary hadron events. It is not unlike trying to detect a fire-fighter smoking a cigarette in the midst of a forest fire from the two different smoke patterns emitted. If you happen to have a strong, distinctive signal, digging it out from such

Wisconscience Wall in the Town Center of the Wisconsin Institutes for Discovery



Inside the heart of the atom, physicist Sau Lan Wu is mapping the very structure of our universe. In 2012, Wu, the leader of the UW-Madison contingent at the ATLAS experiment at the Large Hadron Collider in Europe, played a major role in identifying the wake of the Higgs boson – an elusive subatomic particle believed to give all matter its mass. It was yet another landmark in a career that includes being the leader in the discovery of the gluon - which "glues" together pieces of an atom's nucleus - and contributing to finding a particle called J/psi that confirmed the existence of another subatomic piece, the charm quark.

From VASSAR to the Discovery of the Higgs Particle.

VASSAR College Commencement Address, May 25, 2014

Sau Lan Wu

Enrico Fermi Professor of Physics and Vilas Professor

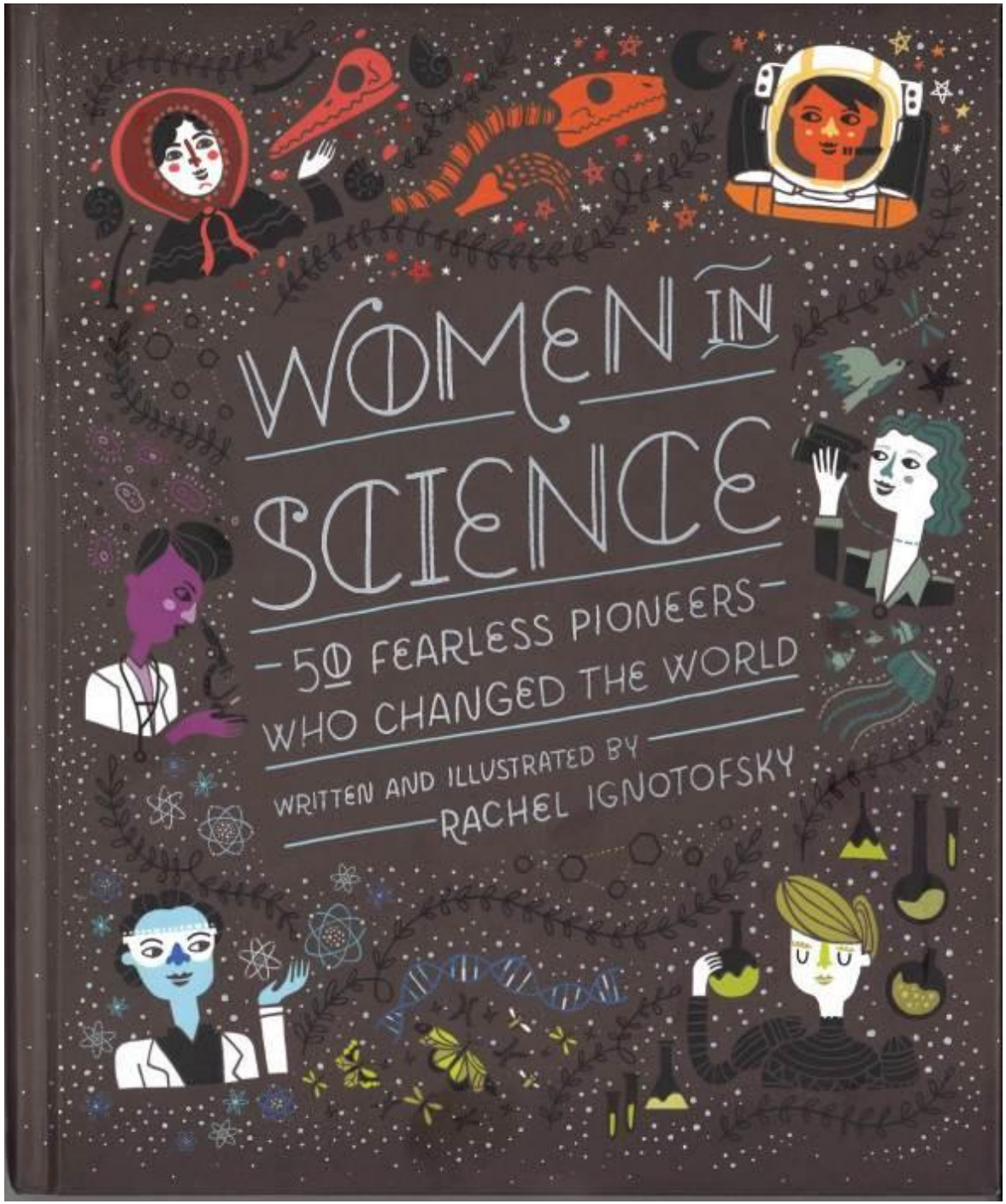
University of Wisconsin-Madison, 1150 University Avenue Madison, WI 53706, USA

President Hill, Professor Feroe, the Board of Trustees, the eminent faculty, proud parents and grandparents and Vassar graduates of the class of 2014:

Thank you for giving me this great honor and wonderful opportunity to address today's 150 commencement ceremony.

Professor Feroe tells me that I am the first research scientist in 23 years and the first physicist ever to deliver a Vassar commencement address.

Video link: http://commencement.vassar.edu/ceremony/2014/address/


WOMEN IN SCIENCE
50 FEARLESS PIONEERS WHO CHANGED THE WORLD
WRITTEN AND ILLUSTRATED BY
RACHEL IGNOTOFSKY


WAS A KEY SCIENTIST IN THE DISCOVERY OF THE HIGGS BOSON.
SHE WAS PART OF THE TEAM THAT DISCOVERED THE CHARM QUARK.
MADE IMPORTANT CONTRIBUTIONS IN THE DISCOVERY OF THE GLUON.
"I GREW UP WITH A STRONG DETERMINATION TO BE FINANCIALLY INDEPENDENT OF MEN."—SAU LAN WU

SAU LAN WU

PARTICLE PHYSICIST

Sau Lan Wu was born in the early 1940s during the Japanese occupation of Hong Kong. Although Sau Lan Wu's mother was illiterate and uneducated, she did whatever it took to make sure that Sau Lan Wu and her brother got a good education.

Against her father's wishes, Sau Lan Wu applied to 50 different colleges in America. She was accepted to Vassar College with a full scholarship in 1960—the school provided her with room, board, clothing, and books. She graduated summa cum laude and was accepted into Harvard's masters program in physics—the only woman admitted that year in her field.

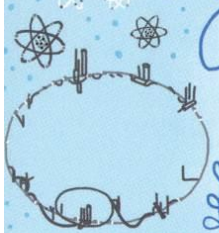
After earning a PhD from Harvard, Sau Lan Wu started researching particle physics—the study of matter and how it works—at MIT, DESY, and the University of Wisconsin-Madison. Atoms are made out of protons and neutrons, which are made of quarks. Sau Lan Wu was fascinated by these particles and has dedicated her life to discovering their secrets.

With a research team led by Samuel Ting, Sau Lan Wu helped to discover the charm quark, a type of elementary particle, in 1974. After that first achievement, she became the lead on a research team that discovered the gluon, a particle that holds the quarks together.

One unanswered question in physics was how the tiny particles that make up an atom have mass. In 1964, a theory was created that mass depended on a subatomic particle named the Higgs boson—a unit of the Higgs field, which exists everywhere. The way particles interact with the field gives them more or less mass. To prove this theory, researchers faced the difficult task of finding a Higgs boson. Sau Lan Wu said, "It is like looking for a needle in a haystack—the size of a football stadium."

With a particle collider, Wu led one of the teams working to find proof of these teeny tiny subatomic particles. In 2012, her team was instrumental in observing the Higgs boson.

Sau Lan Wu is one of the most important particle physicists in her field and has made many groundbreaking discoveries. She continues to teach and research what all the stuff in the universe is made of.



THE LARGE HADRON COLLIDER PARTICLE ACCELERATOR IS 17 MILES LONG.

WON THE EUROPEAN PHYSICAL SOCIETY PRIZE FOR HIGH-ENERGY PHYSICS IN 1995.

FELLOW OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES.

SHE HAS MET HER OWN PERSONAL GOAL TO MAKE AT LEAST THREE MAJOR DISCOVERIES.

THE HIGGS BOSON IS CALLED THE "GOD PARTICLE."

SUMMER SCHOOL AT THE BROOKHAVEN NATIONAL LABORATORY INTRODUCED HER TO PARTICLE PHYSICS.

HER HERO IS HER MOTHER.

A BIOGRAPHY OF MARIE CURIE INSPIRED HER TO BECOME A SCIENTIST.