

# ***A Scientist's Story – from VASSAR College to Discovery of the Higgs Particle***



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**APS 2017 Conferences for Undergraduate Women in Physics,  
University of Wisconsin-Madison  
January 14, 2017**



## 2014 VASSAR Commencement Address

***On May 25, 2014, I gave a Commencement Address at Vassar College, Poughkeepsie, New York.***

***Title: From VASSAR to the Discovery of the Higgs Particle (on YouTube 2014)***

***I was told that I was the first research scientist in 23 years and the first physicist ever to deliver a Vassar commencement address.***

***In my commencement address, I told my story of my journey from Vassar college to the discovery of the Higgs Particle.***

***Part of today's speech is a recap of my VASSAR commencement address.***

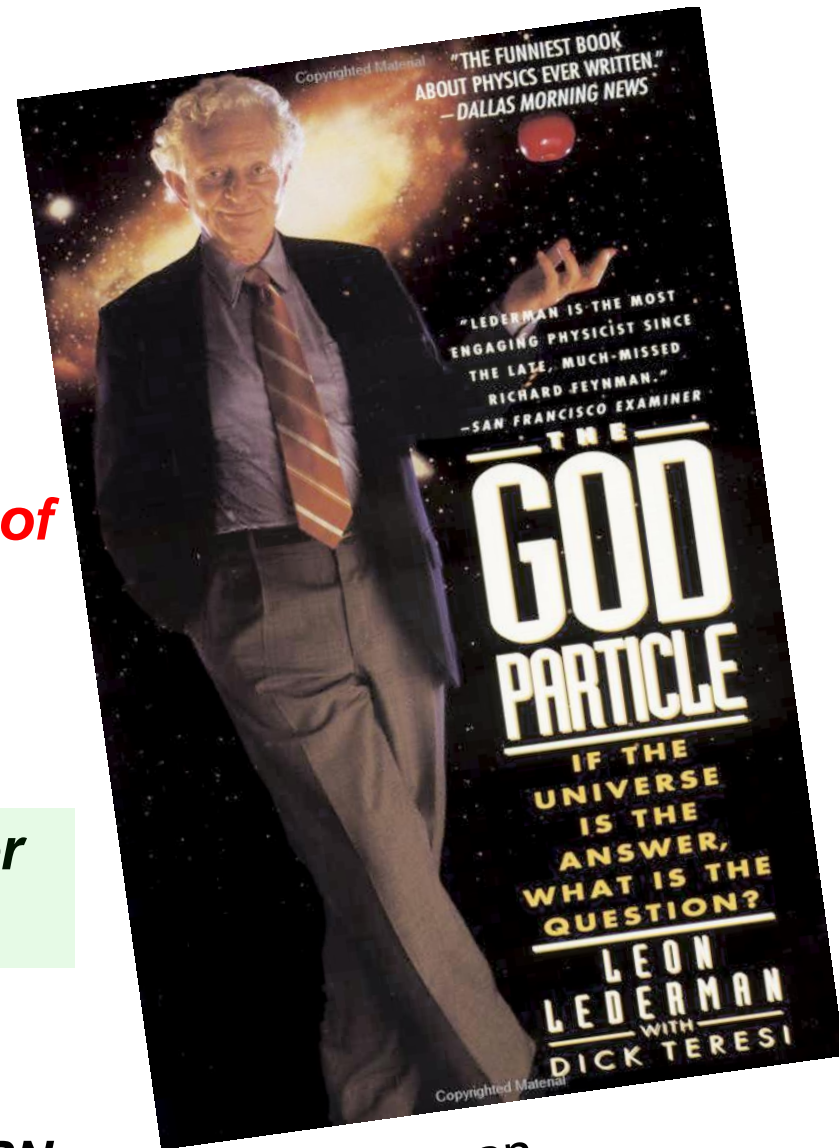
# *What is a Higgs particle?*

*The Higgs particle was the missing cornerstone of the **Standard Model of Physics**, a theory which describes how the known particles in the Universe interact with one another.*

*The Higgs particle is responsible for all masses in the Universe.*

*December 13, 2011, “tantalizing hints”*

*July 4, 2012, “Higgs Discovery!” at CERN.*



Leon Lederman  
Nobel Laureate, 1988

# ***Where and how was the Higgs particle discovered?***

***CERN is home to the world's biggest and most powerful particle accelerator – the 27-km (17 miles) Large Hadron Collider (LHC), where the discovery was accomplished.***



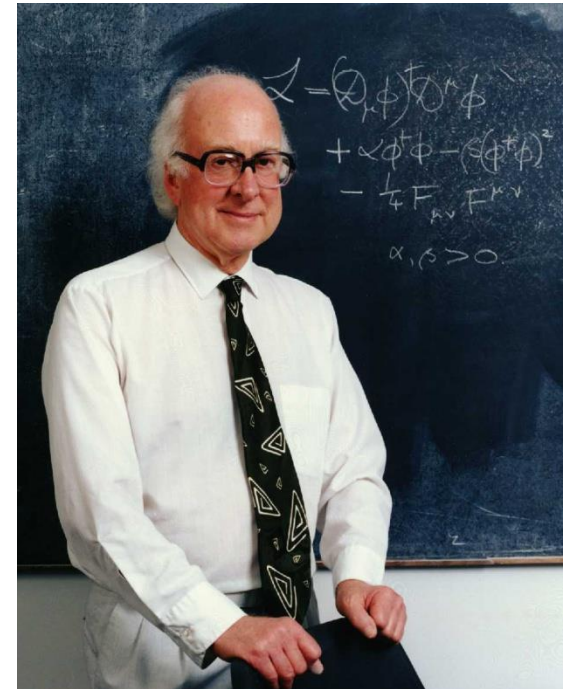
***Founded in 1954 (12 European States)  
Today: 22 Member States***

***CERN: Conseil Européen pour la Recherche Nucléaire  
[Official name: European Organization for Nuclear Research]***



# The Higgs Particle

- In his famous 1964 paper, Professor Peter Higgs of Scotland proposed **a new, massive boson of spin zero** to explain how elementary particles – the building blocks of the Universe – get their masses
- In the universe, there is a Higgs “field” that pervades all of space, turning mass-less particles moving through it into the massive ones
- Englert and Higgs were awarded the 2013 Nobel Prize in Physics; Brout unfortunately died two years earlier.



**1964:**

Englert and Brout

Higgs

Guralnik, Hagen and Kibble



# *If there were no Higgs field*

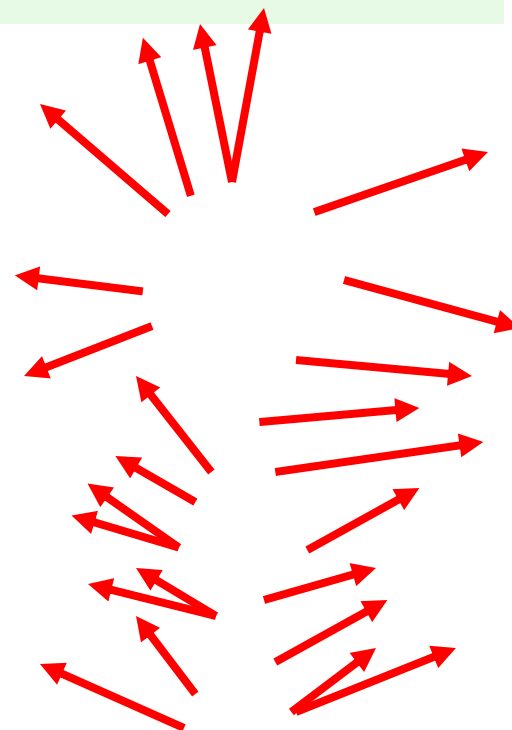
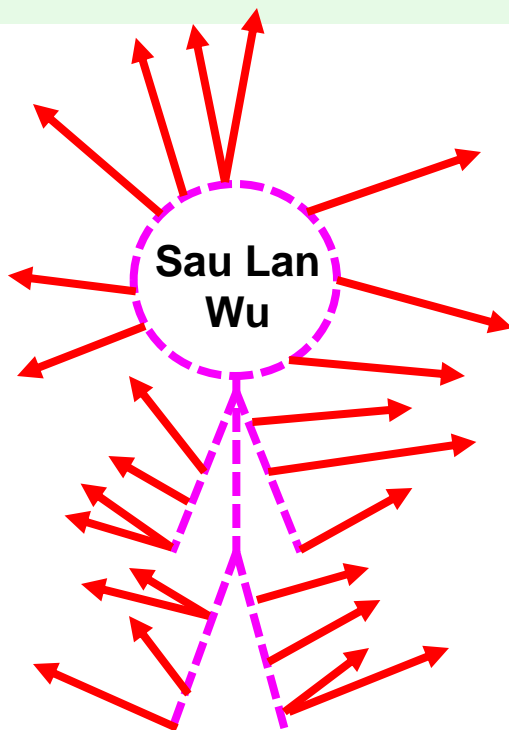
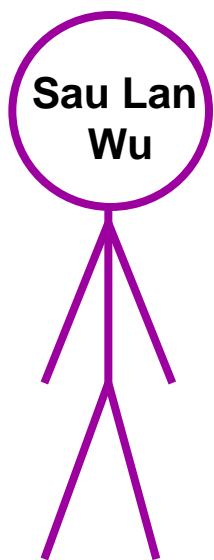
- *The Higgs boson is responsible for all masses, from electrons to humans to galaxies.*
- *Without this particle, the world would not be anything like what we know.*
- *There would be no ordinary matter as we know it; there would be no atoms, no molecules, no cells and, of course, no humans.*



# *If there were no Higgs field*

***What would happen to me if there were no Higgs field?***

- I shall be massless; pieces of my constituents will fly out all over the place with the speed of light just like the photon***

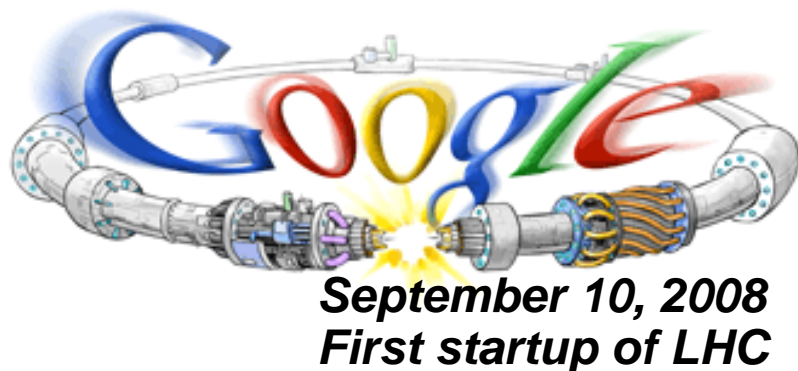
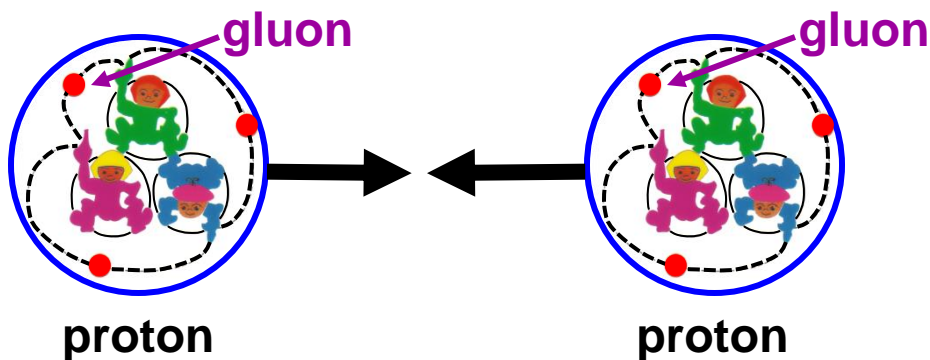






# The LHC – Where the Higgs is produced

- *The most effective way to produce a Higgs particle is by colliding two gluons*
- *Gluons are in protons. We therefore produce the Higgs particle by colliding two protons.*
- *(I played a leading role in the gluon discovery in 1979)*



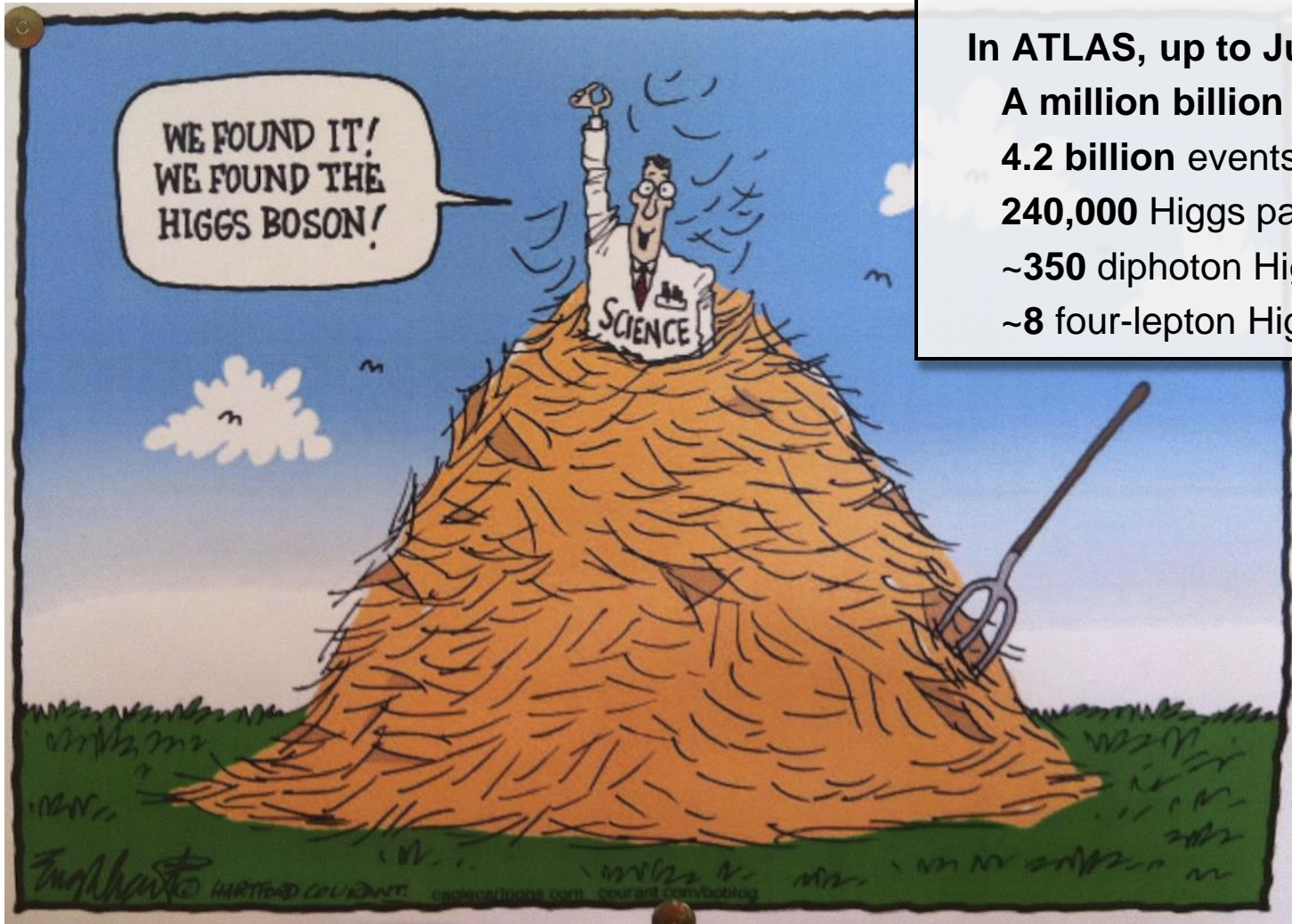
- *Very high energies are required to accomplish this*  
**→ Large Hadron Collider**  
**was built at CERN in Geneva, Switzerland.**





# How to search for a Higgs particle?

**Not so easy!**



## Needles in a **haystack**

In ATLAS, up to July 4, 2012:

**A million billion** collisions

**4.2 billion** events analyzed

**240,000** Higgs particles produced

~**350** diphoton Higgs events detected

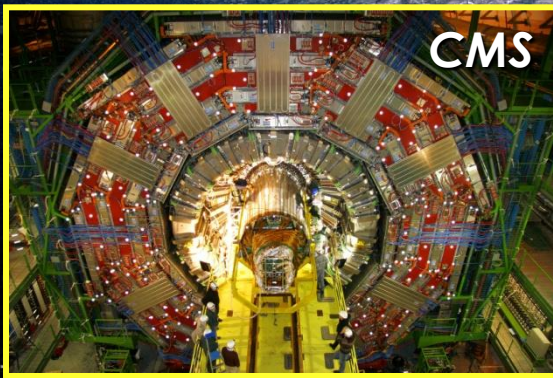
~**8** four-lepton Higgs events detected



# The LHC Experiments

*Four large detectors at the LHC to capture the head-on collisions between two proton beams (each 4 TeV)*

$1 \text{ TeV} = 10^{12} \text{ eV}$



**CMS**

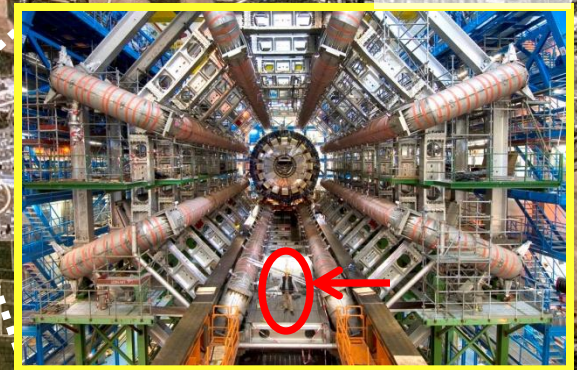
**12,500 tons**

Geneva  
Airport

**LHCb**

**ATLAS**

**ALICE**



**7,000 tons, 5 stories tall**

*The LHC crosses the French-Swiss border 4 times*





# Cathedrals of Science

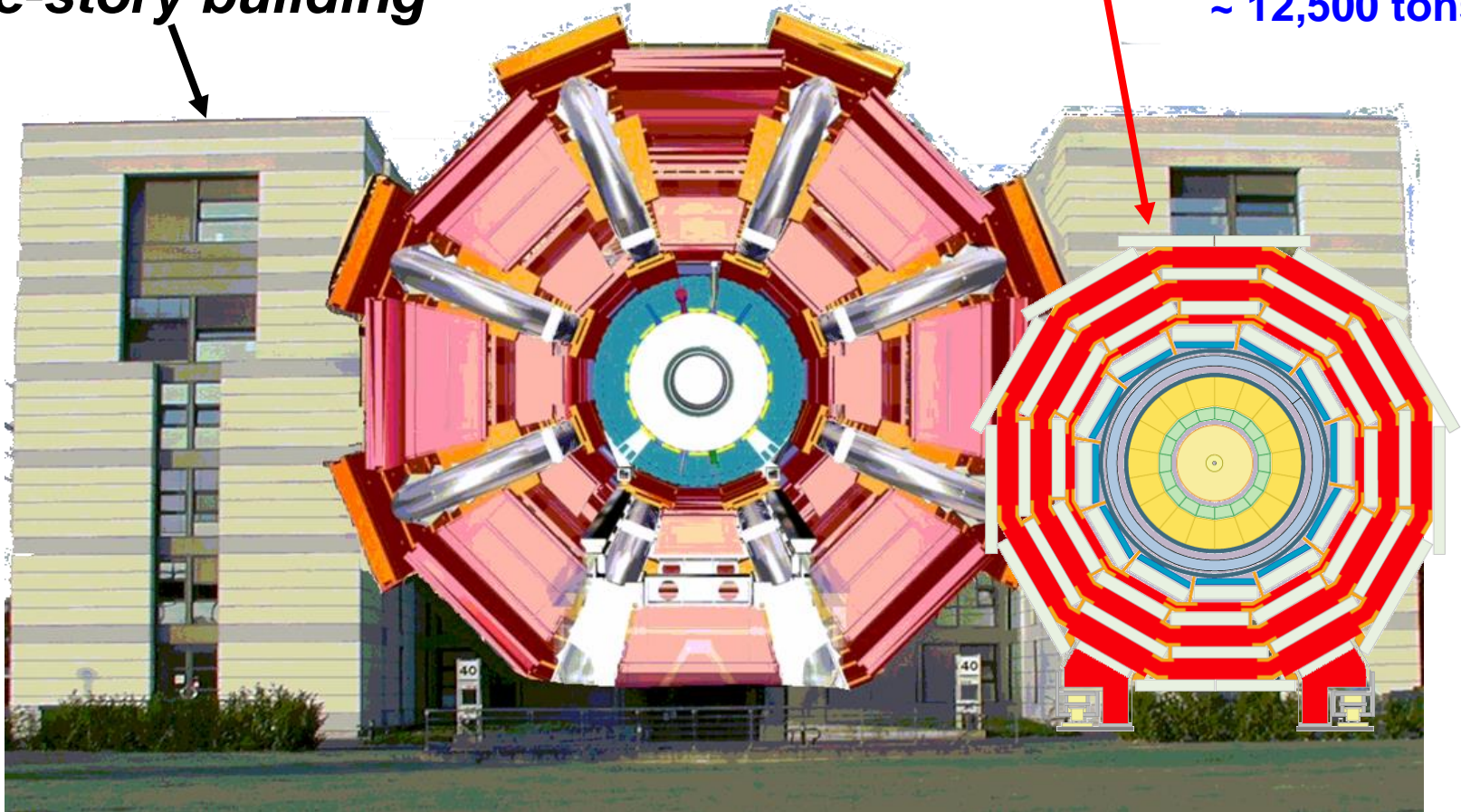
*Five-story building*

**ATLAS**

~ 25 m × 45 m  
~ 7,000 tons

**CMS**

~ 15 m × 21.5 m  
~ 12,500 tons



- *About 100 million “sensors” each*
- *Much above a 12 megapixel camera, taking 20 million pictures/sec*



# ***Discovery of the Higgs Particle***

***I set myself a goal of contributing to at least three major physics discoveries in my lifetime. So far I have participated in the discoveries of the charm quark, the gluon, and the Higgs particle.***

***My third eminent participation is in the discovery of the Higgs particle. On July 4, 2012, the discovery of the Higgs particle was announced; I am sure you have read about it in New York Times or CNN. This is a discovery in which my Wisconsin group members and I played a very active role.***



# ***Discovery of the Higgs Particle***

***This project is so gigantic that two independent teams of 3000 physicists each, the ATLAS and CMS collaborations, worked at the Large Hadron Collider at the laboratory CERN – the European Center for Nuclear Research here in Geneva, Switzerland.***

***The discovery was a culmination of two decades of hard work by more than 6000 scientists from 56 nations and about 200 institutions from all over the world.***

***Other groups in ATLAS and CMS Collaborations have their exciting moments in the discovery of the Higgs particle; They have their own stories to tell.***



# ***Discovery of the Higgs Particle***

***Let me now share with you the joy of discovery.***

***In early morning June 25, 2012, nine days before the announcement of the Higgs discovery, members in my Wisconsin group, after a number of sleepless nights, obtained a clear evidence of the Higgs particle.***



# ***Discovery of the Higgs Particle***

***At 3pm on the same day on June 25, 2012, there was a commotion in the Wisconsin corridor on the ground floor of Building 32 at CERN.***

***We heard my graduate student Haichen Wang saying, "Haoshuang is going to announce the discovery of the Higgs!" Our first reaction was to consider it as a joke, so when we entered my student Haoshuang Ji's office, we had smiles on our faces.***

***Those smiles suddenly became much bigger as we looked at his computer printout of a Higgs signal plot. Pretty soon, cheers were ringing down the Wisconsin corridor.***



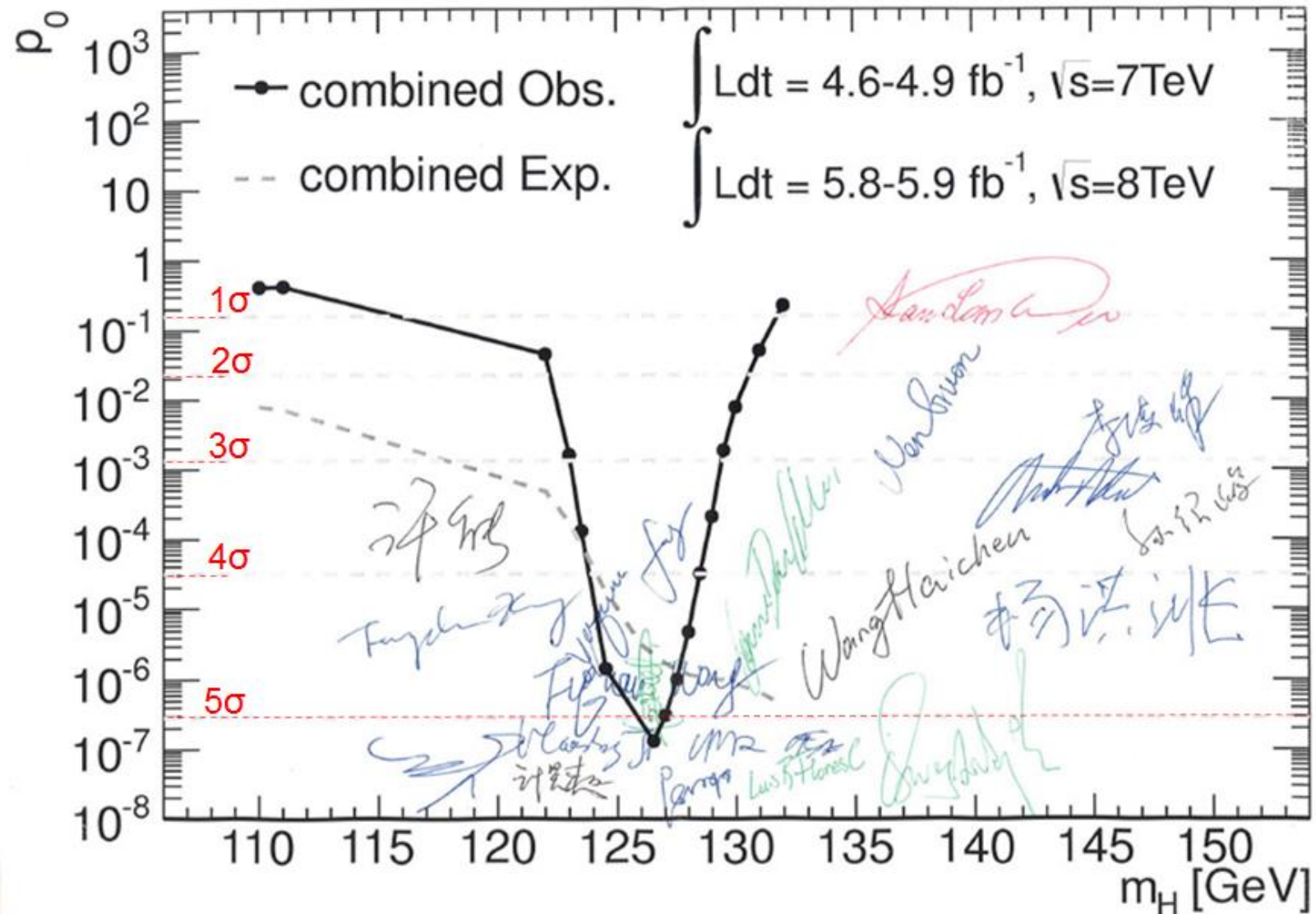


# *Discovery of the Higgs Particle*

*Haichen Wang was video recording the excitement. We made a large copy of this Higgs signal plot and all my group members signed on it.*

*This signed document is now displayed on the wall of the Wisconsin corridor at CERN.*

***The moment we got  $5\sigma$  (5 sigma) June 25, 2012, 3 pm***

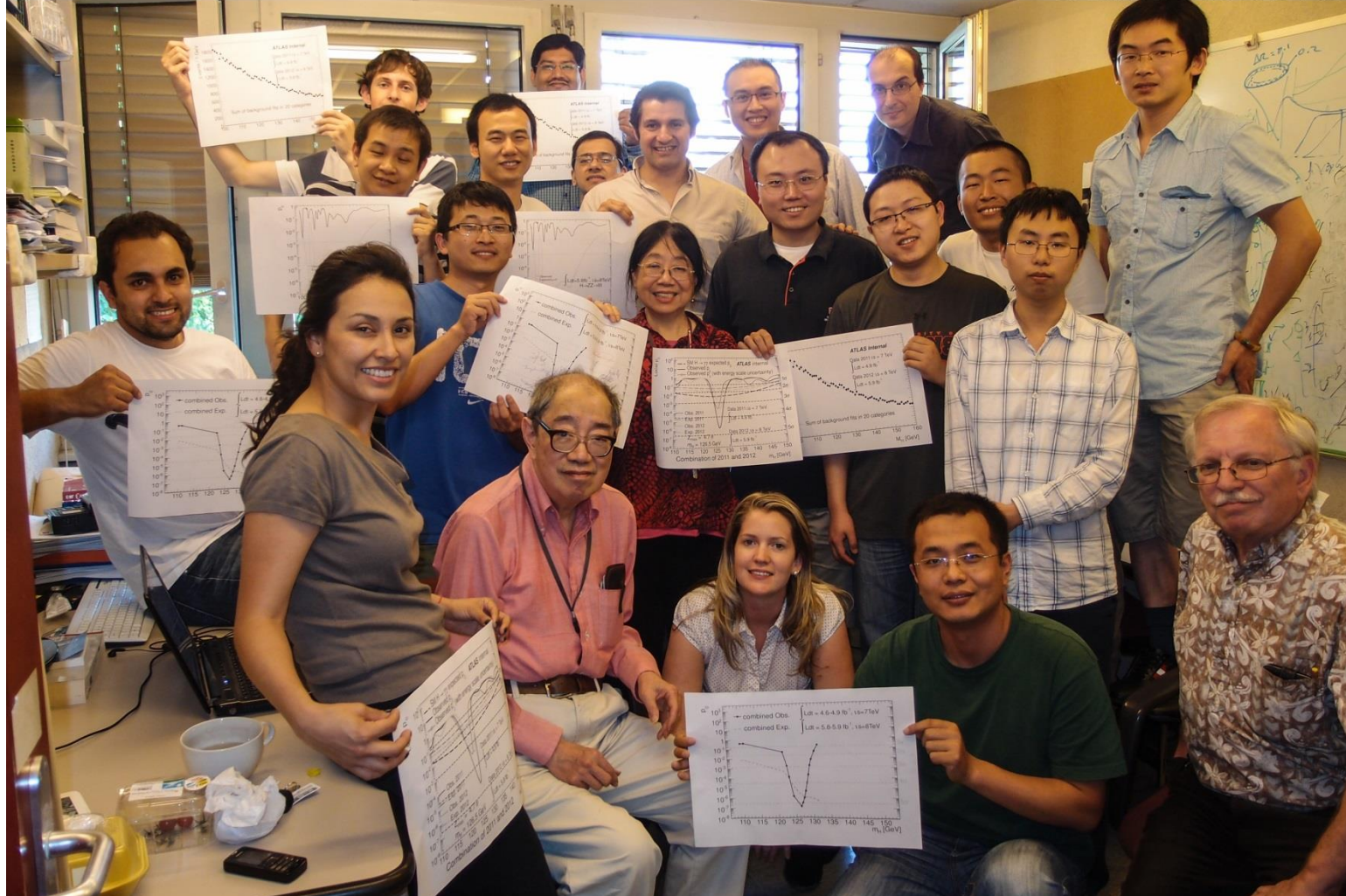


**5 $\sigma$ : chances that these events were the result of random fluctuations were less than one in three million.**

# The moment we got $5\sigma$ (5 sigma) June 25, 2012, 3 pm

June 25, 2012 Wisconsin group celebrating the discovery

Geneva time:  
6/25/2012 2:54:28 PM



OLYMPUS IMAGING CORP. XZ-1

6/25/2012 7:54:28 AM (Madison time)



## ***July 4, 2012 The Day of Pubic Announcement of the Discovery***

***Other groups in the two collaborations observed the same result, with the same excitement. They also have their own stories to tell.***

***On the day of the announcement of the discovery on July 4, 2012, the auditorium at CERN was locked until 9am. In order to encourage all the students and postdocs of my group to witness the scientific event of the century, I promised a reward of \$100 to whoever would line up outside the auditorium overnight. They all got in.***





# **July 4, 2012 The Day of Public Announcement of the Discovery**

- **July 4 2012, "Discovery!"**



**Scenes of jubilation in the CERN auditorium on July 4, 2012. Several former Director Generals of CERN are seen in this photograph.**



# *July 4, 2012 The Day of Public Announcement of the Discovery*



*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.*





**LHC ERA**

**July 4, 2012**

**The day of the CERN public  
announcement of the discovery**



**Professor  
Higgs**

**Professor  
Englert**

**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”. In fact, it had taken me thirty two years, from 1980 to 2012.**





## ***The New York Times – March 5, 2013***

***On March 5, 2013 the photo of five physicists appeared on the front page of New York Times.***

***The heading: **Chasing the Higgs** – Struggle, and finally triumph, in the search for physics' most elusive particle.***

***This article was written by the famous NYT science writer Dennis Overbye.***



"All the News  
That's Fit to Print"

# The New York Times

National Edition

How late tonight, tomorrow? Total  
8-12 inches north, 2-4 inches central,  
a soaking to 2 inches south. Higher in  
the 20s. Low to the 20s and 30s.  
Weather map, Page 30

VOL. CLXII...No. 56,066

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## ScienceTimes



### Chasing the Higgs

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

By DENNIS OVERBYE

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.

**Front page of New York Times, March 5, 2013**

**The heading: Chasing the Higgs – Struggle, and finally triumph, in the search for physics' most elusive particle.**

**By Dennis Overbye.**

**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 (University of Wisconsin), Joe Incandela (University of California-Santa Barbara), Guido Tonelli (University of Pisa) and Fabiola Gianotti (CERN).**



# The New York Times – October 9, 2013

"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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NEW YORK, WEDNESDAY, OCTOBER 9, 2013

\$2.50

### 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



9 Wisconsin  
members

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.





# ***From Vassar to Discovery of the Higgs Particle***

***Now, I would like to share with you my journey from Vassar to the Discovery of the Higgs particle.***



# Hong Kong

*I was a baby in Hong Kong during the Japanese occupation. My mother, with me in her arms, ran in and out of bomb shelters.*

*My mother was the sixth concubine of my father who was a well-known businessman in Hong Kong. However she was not the favorite of my father's wives. My mother and I were cast out and we were put to live in a slum.*

*My mother and my younger brother lived in a rented small bedroom and I had a rented bed in a corridor in a rice shop. I grew up with a strong determination to be financially independent of men.*



# Hong Kong

*At the end of each school day, we lined up to say good bye to our teacher with a whip in his hand.*

*I was in a school overcrowded with students. Every time when an officer from the Education Department came for inspection, I had to hide.*



## ***My Mother – Ying Lai***

***My mother grew up in a farm in China and girls were not allowed to go to school. Hence my mother could not read and could not write and had never worked. However my mother is the most inspiring person in my life. She realized early on in my childhood the tremendous value of education.***

***She did everything in her power to move me and my younger brother from schools in the slum to missionary schools in Hong Kong. I then moved on to a well-known Government High School.***





## **Getting Accepted by VASSAR College**

***When I graduated from high school in 1959, my father did not want me to go to college. "You should now earn your living, and support your mother." I secretly applied to 50 colleges and universities in USA, asking for a full scholarship.***

***There were only four colleges that said they would consider me, all women colleges – Agnes Scott College in Georgia, Randolph-Macon Woman's College in Virginia, Connecticut College and Vassar college.***

***I was rejected by the first three. So I was about to be rejected by the whole United States! While in despair, in April 1960, I was overjoyed to receive a telegram informing me that I was accepted by Vassar college with a full scholarship. Truly, God decided to send me to Vassar college.***



## Getting to VASSAR College

*I told my father I was accepted by Vassar college. He happened to be in New York at the time, staying with a friend whose daughter was about to graduate from Vassar college in May, class of 1960.*

*When he attended her commencement ceremony in May 1960, my father realized that **Vassar is a very prestigious college**. However he complained that during the reception only peanuts were served.*



## Getting to VASSAR College

***He was proud of my coming to Vassar. With \$300, he bought me tickets to go from Hong Kong to San Francisco by ship, President Wilson line, which took 17 days and then to New York by train. He gave me \$40 for pocket money. He warned me not to go to parties. If I were to lose my scholarship, that would be it!***

***The day I boarded the ship was the last time I saw my father.***



## Getting to VASSAR College

***During my trip from Hong Kong to San Francisco, we encountered several typhoons. Few people were in the dining room. I saw my apple rolling from one side of the ship to the other.***

***When the ship disembarked in San Francisco, several Vassar alumnae were waiting for me with home baked cakes. They were very kind. I then took the train from San Francisco to New York on a 5 days journey with their cakes as my only food. I did not want to spend any money on meals.***



## ***My Years at VASSAR (1960-1963)***

***At Vassar, I had a full scholarship with room and board, and the American girls donated clothes for foreign students, so I didn't have to go shopping.***

***Vassar even sent me to a summer school in Richmond, Virginia the first summer I was there because my English was so poor that I couldn't pass my requirement. Vassar really made sure I would succeed and graduate. They trained me to have perseverance, persistence, and if, you have that, you basically cannot fail.***



## ***My Years at VASSAR (1960-1963)***

***I buried myself in the library, forever avoiding weekend busloads of Yale men.***

***My adjustment to the United States was a difficult one. I was unable to see my family for nine long years. I wanted to invite my father to my Ph.D. graduation at Harvard but he died a year earlier.***





## ***My Years at VASSAR (1960-1963)***



***I buried myself in the Library, forever avoiding weekend busloads of Yale men.***





## ***My Years at VASSAR (1960-1963)***

***Also, in these early years, some aspects of American culture were unsettling. I visited the Supreme Court of Virginia with two other Chinese girls, and we looked for a restroom. We were confronted with the decision of whether to enter the door marked 'White' or 'Colored.'***

***We were confronted with that decision again when we got on a segregated bus. That was my first experience with racial discrimination. Of course, the United States has made tremendous progress since that time!***



## **Summer Internship at Brookhaven National Laboratory**

***I wanted to be an artist until I read Marie Curie's biography and decided to devote my life to science.***

***During my years at Vassar, I worked as a summer student in 1962 and 1963 at Brookhaven National Laboratory on Long Island where I became captivated by the study of particle physics. Those were exciting times, full of discoveries. There I first met my future husband, Tai Tsun Wu.***



# ***Applying to Graduate School***

***After graduating from Vassar in 1963 with Summa Cum Laude and Phi Beta Kappa, I was accepted by Harvard with a fellowship, and also got offers from Berkeley, Columbia and Yale.***

***Princeton wrote that they only accepted women if they were wives of faculty members. Caltech wrote that they did not have a women's dormitory, and would not accept women unless they were 'exceptional'!***



## **Graduate School at Harvard**

***My first year at Harvard was extremely difficult: boys did homework together in the men's dormitories; women were not allowed to go there. I was the only woman in physics in my class.***

***At the end of first year (1963-1964), I was awarded a Master's Degree – it was the first year when women were allowed to get a graduate degree from Harvard. Previously only Radcliffe College could award such a degree to women.***





## ***Kicked out of Harvard Yard (1964)***

***In May 1964, on graduation day for my Master degree, I joined some of my classmates for a free lunch offered to new graduates in the Harvard Yard. A guard asked me to leave and I was kicked out of the Harvard Yard. I was told that no woman had been allowed to this commencement lunch in 100 years; I left my friends with tears in my eyes.***

***At Harvard, “we shall overcome” by Joan Baez was my favourite song.***



## **MIT (1970-1977) and charm quark discovery (1974)**

***In 1970, with a Ph.D. degree from Harvard, I became a Post Doc. at MIT, participating in the charm quark discovery in 1974 at the Brookhaven National Laboratory in Long Island.***

***My supervisor, Prof. Ting, was awarded a Nobel Prize in 1976 together with Prof. Richter of Stanford.***



## **Wisconsin (1977) and Discovery of the Gluon (1979)**

- In 1977, I became an assistant professor at the University of Wisconsin-Madison. Another woman physicist and I were the first women professors of physics ever in this University, at that time already over a hundred years old.***
- In 1979, I was the leading figure in the gluon discovery. The gluon was a new particle that is a carrier of the nuclear force. It is responsible for binding quarks together to form protons and neutrons. This research was done in the German National Laboratory (DESY) in Hamburg.***
- I was the co-recipient of the 1995 European Physical Society Prize for High Energy Physics for the Gluon Discovery.***
- The following year, I was elected to be a fellow of the American Academy of Art and Sciences.***



# ***European Physical Society High Energy and Particle Physics Prize, 1995.***



***The four Prize Recipients at the ceremony of the 1995 European Physical Society High Energy and Particle Physics Prize in Brussels, Belgium. Front row: Günter Wolf and Sau Lan Wu; second row: Björn Wiik and Paul Söding.***





## ***My Primary Missions: Scientific Discoveries and Education of Young Scholars***

***Over 50 graduate students have received Ph.D. degrees under my supervision.***

***Many moved on to take postdoctoral positions at prestigious places – Harvard, MIT, Princeton and Stanford, for example. Some of them now occupy very important faculty positions in universities.***

***Thirty three of my former students and postdocs are now professors in the US and worldwide. An additional eleven have permanent positions in research laboratories. Others work in governments or in industries all over the world.***

***I am extremely proud of them and consider them as members of my family. Through them my inspiration has reached out all over the US and in other parts of the world.***



# ***Education of Young Scholars***

***My students work with me at CERN in Geneva, Switzerland, in an international environment, and they have a chance to participate in and witness major discoveries in physics.***

***They are constantly in a friendly competition with young physicists from many other countries. This type of training is especially important in the international, global arena.***



## ***A Career in a Field Dominated by Males***

***As you can imagine, it was not always easy for a woman to be in the scientific field in the 60s, 70s and even 80s.***

***I remember reading in Life magazine that, if you are a man, people assume you are competent until you prove you are not. If you are a woman, people assume you are not competent until you prove you are.***



## ***A Career in a Field Dominated by Males***

***I was warned that it would be hard for an Asian female to have a career in a field dominated by white males; but my Vassar and Harvard degrees in physics provided me with the self-confidence and credentials necessary for this challenge.***

***In particular, Vassar College gave me the exclusive opportunity to come to America. Vassar and Harvard have played a pivotal role in my life and has paved my way to a successful career.***





# ***My Closing Remarks for Class 2014 at my commencement address***





# ***My Closing Remarks for Class 2014***

***In 1963, I was here by the Sunset Lake, just like you. I was overjoyed. Right here, I made the resolution to devote my life to science and to make a significant contribution to humanity.***

***Since then I have experienced the joy of discoveries, in life as in science. The search may be long or difficult. Often times, it is long and difficult. But when obstacles strike, you fall down and you get back up. We need you in every aspect of our world, from science to society to the arts and everything in between. You believe in yourself. You hold true to your determination. And you will do something great.***



# ***My Closing Remarks for Class 2014***

***You must believe where others do not.***

***You must act where others cannot.***

***You must lead where others will not.***

***You cannot wait for someone to invite you!***

***Live with integrity and let your conscience be your guide.  
Be a pioneer and follow your heart, contributing to future  
human kind. Have faith and luck will follow you.***

***These closing remarks also apply to you.***

***I wish you a very bright future in the years to come.***



# ***BACKUP SLIDES***





# The Standard Model

Fundamental building blocks of the Universe  
-the elementary particles

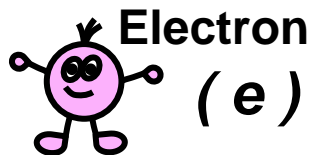
## The elementary particles – Fermions (spin $\frac{1}{2}$ )

First generation

up



down



Electron  
( $e$ )



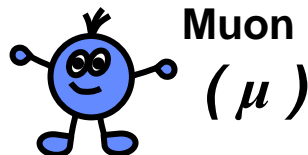
Electron  
neutrino  
( $\nu_e$ )

Second generation

charm



strange



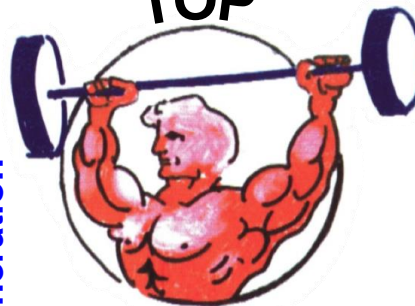
Muon  
( $\mu$ )



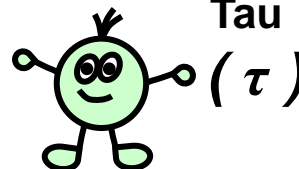
Muon  
neutrino  
( $\nu_\mu$ )

Third generation

TOP



bottom



Tau  
( $\tau$ )



Tau  
neutrino  
( $\nu_\tau$ )

Only the first generation of elementary particles is needed to account for all the matter we see in the world around us

up quark

down quark

electron

electron-neutrino



# How to discover the Higgs particle?

**The Higgs particle is not stable**

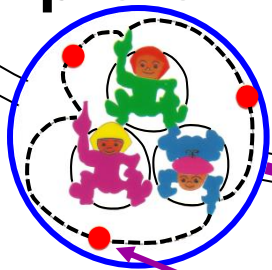
**The only way we can observe it is to detect its decay products**

**Higgs decays into  
2 photons,  
or 4 leptons,  
or other “channels”**

1600 high-tech  
superconducting magnets  
**LHC**

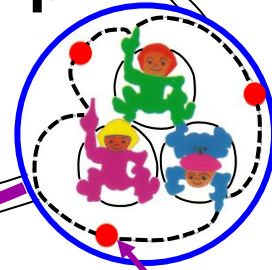


**proton**



**gluon**

**proton**



**gluon**

**About one Higgs every minute**

**ATLAS detector**



# Higgs discovery channel #1

$H \rightarrow \text{two photons}$

**LHC**

**proton**

gluon

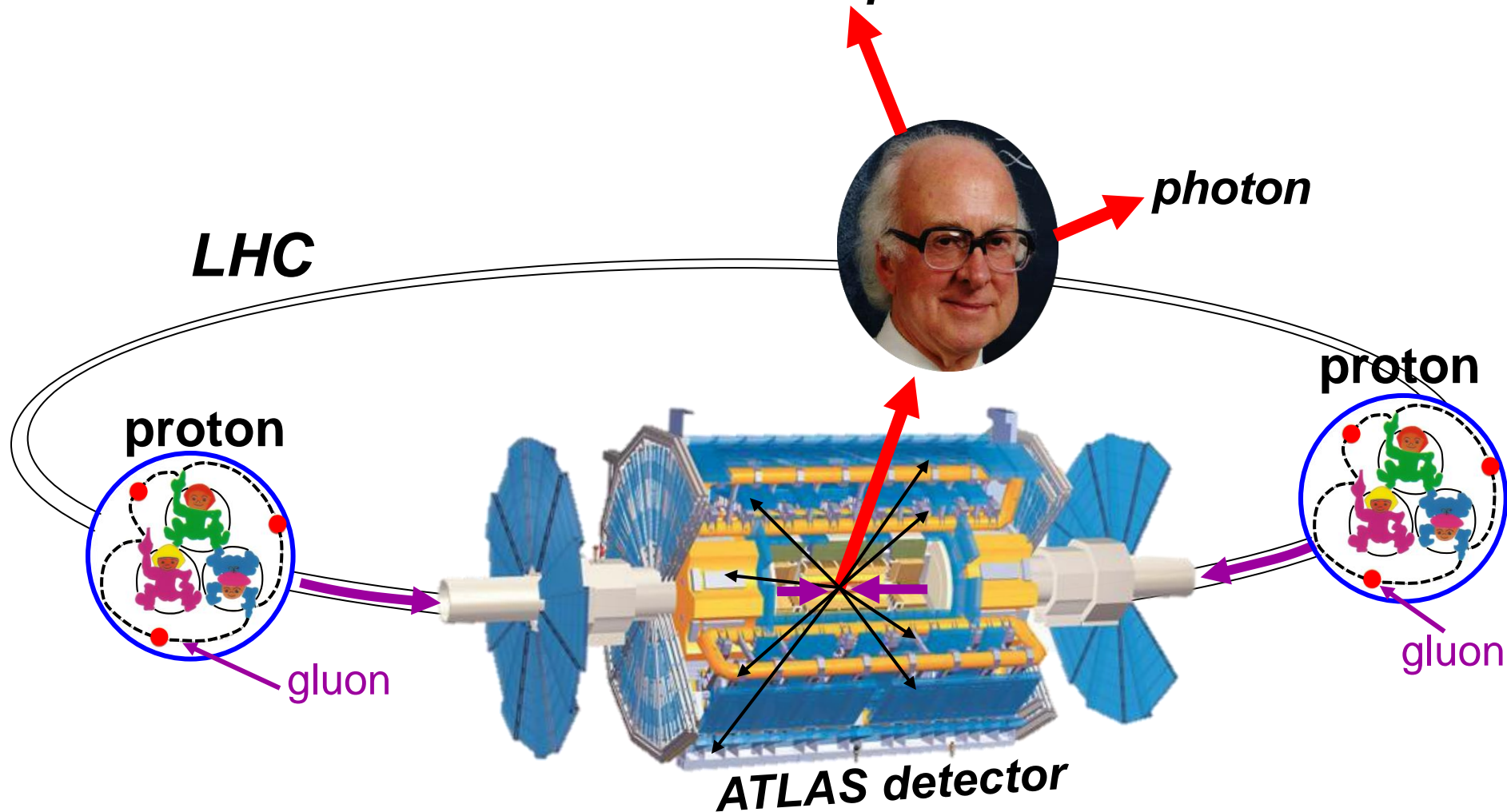
*photon*

*photon*

**proton**

gluon

**ATLAS detector**

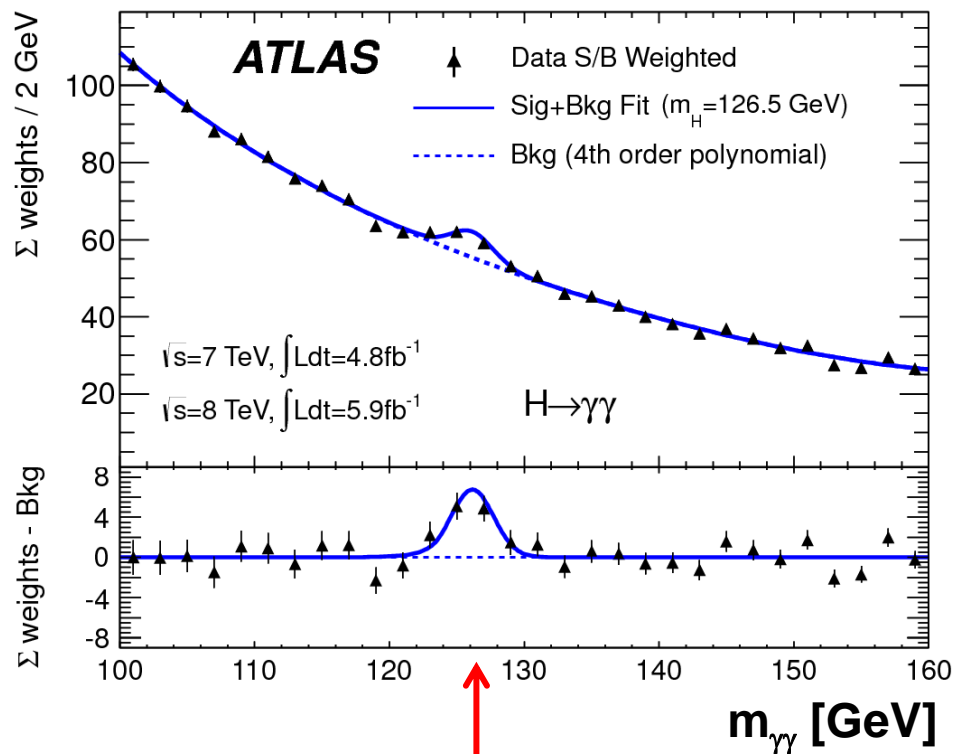




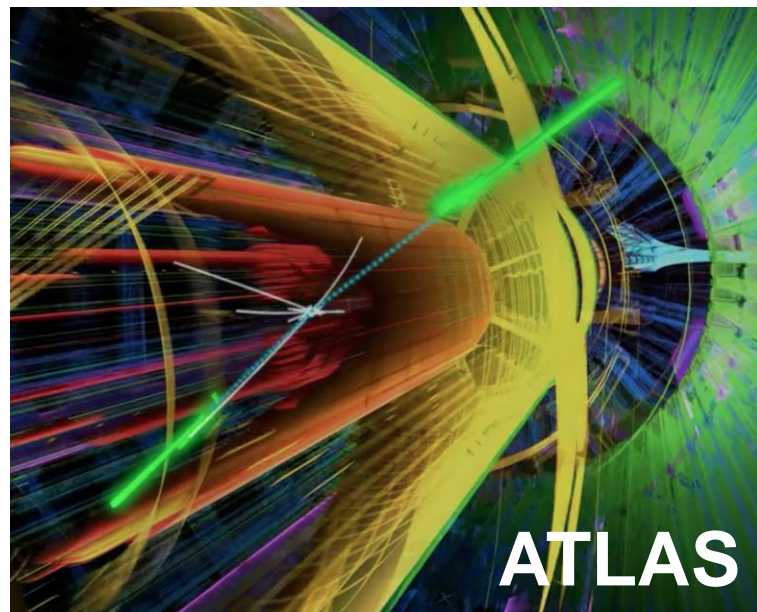


# Higgs discovery channel #1

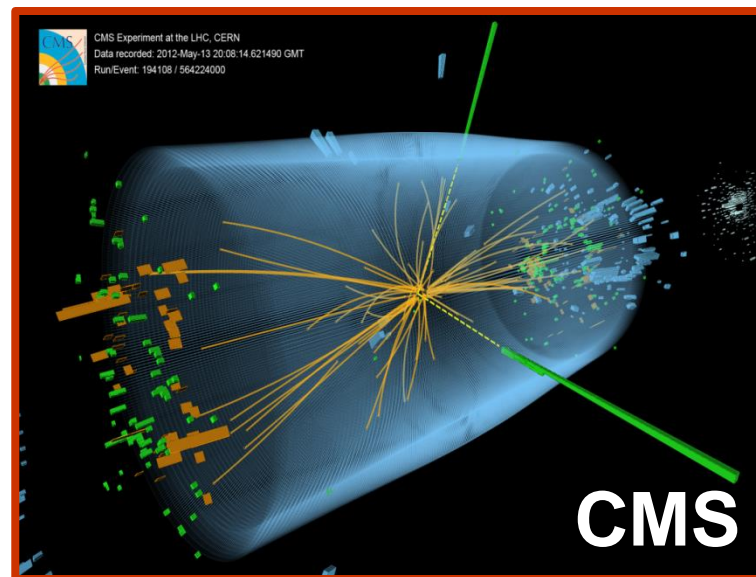
## $H \rightarrow \text{two photons}$



**Mass = 126.5 GeV**  
(1 GeV =  $10^9$  eV)



**ATLAS**



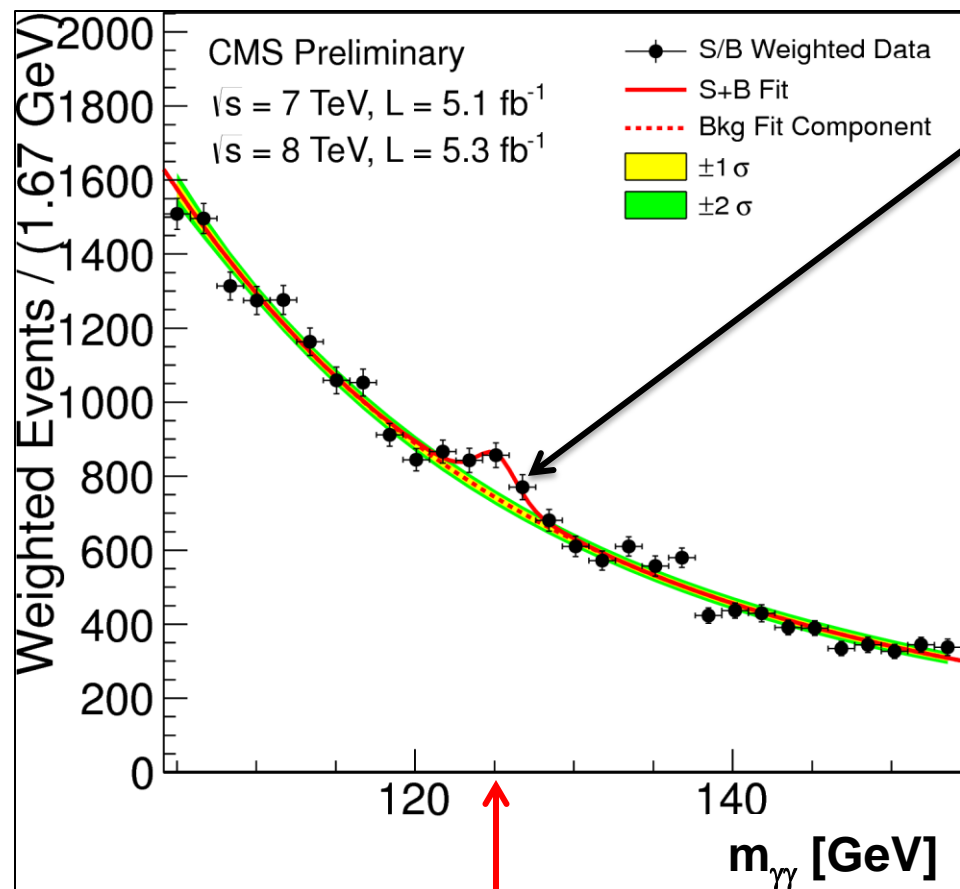
**CMS**



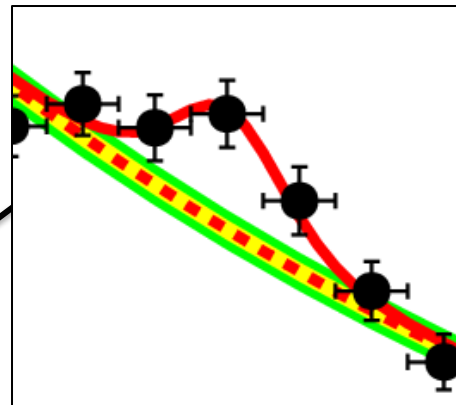


# Higgs discovery channel #1

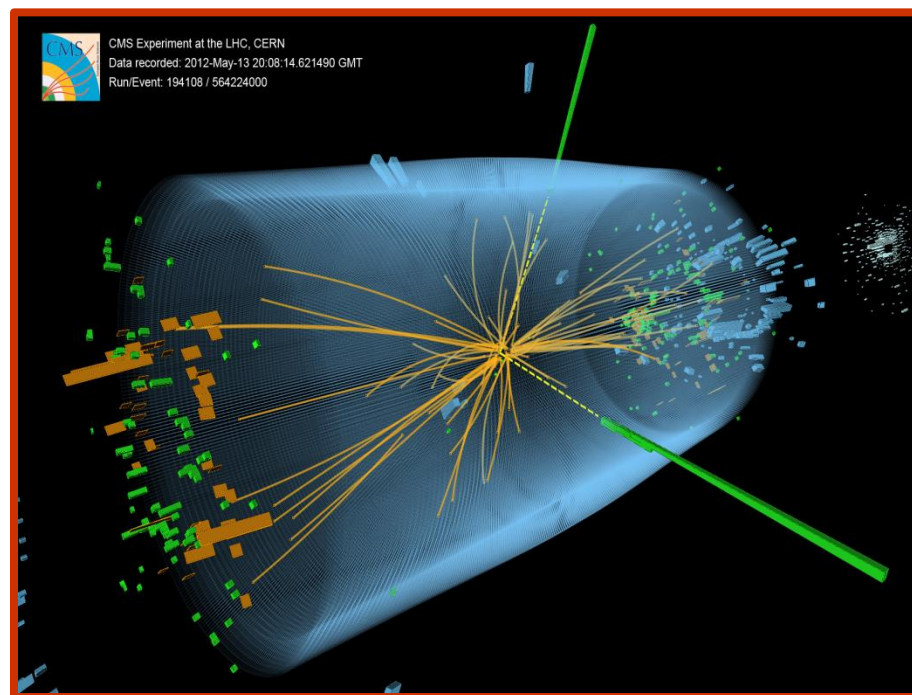
## $H \rightarrow \text{two photons}$



**Mass = 125 GeV**  
(1 GeV =  $10^9$  eV)



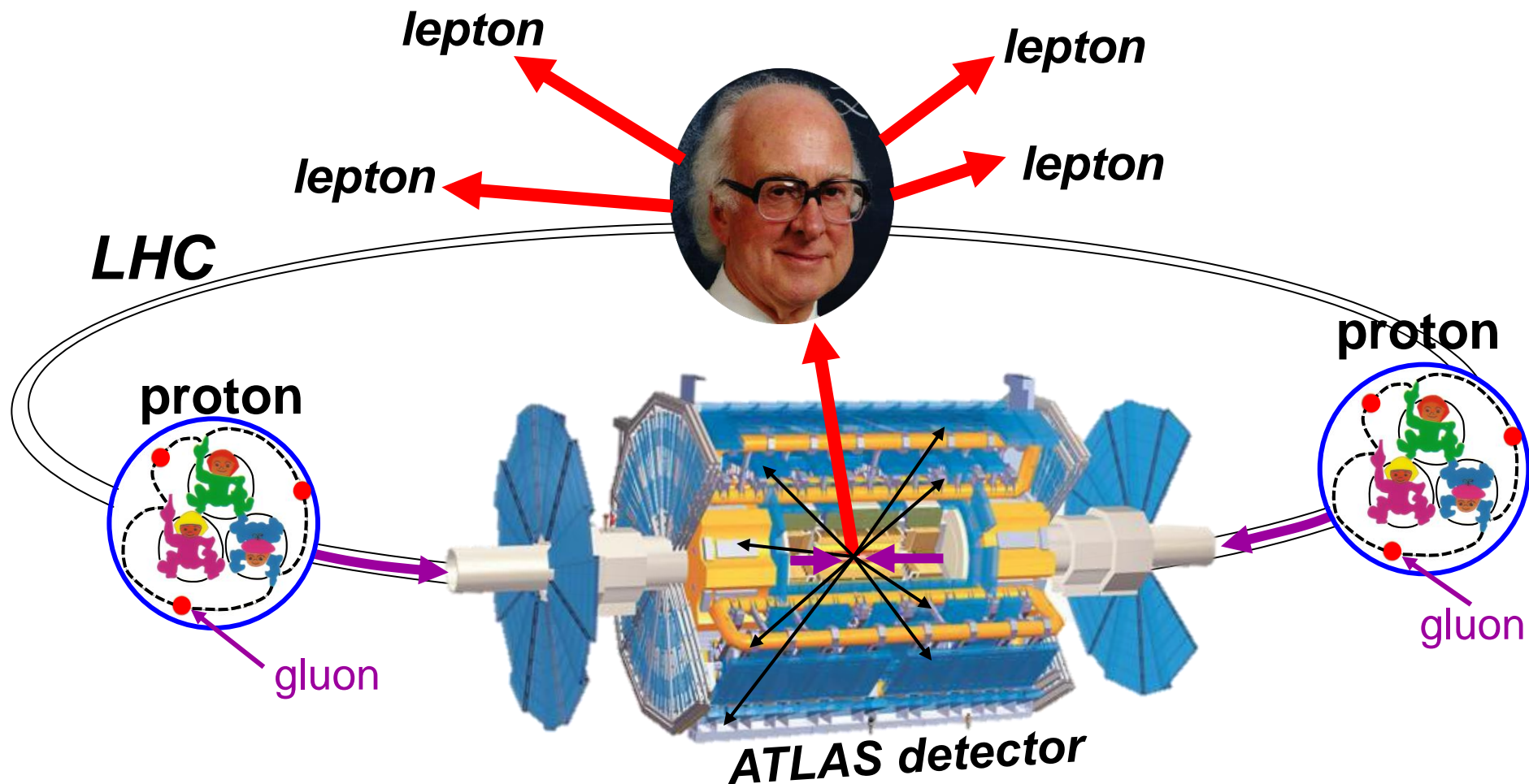
**CMS**





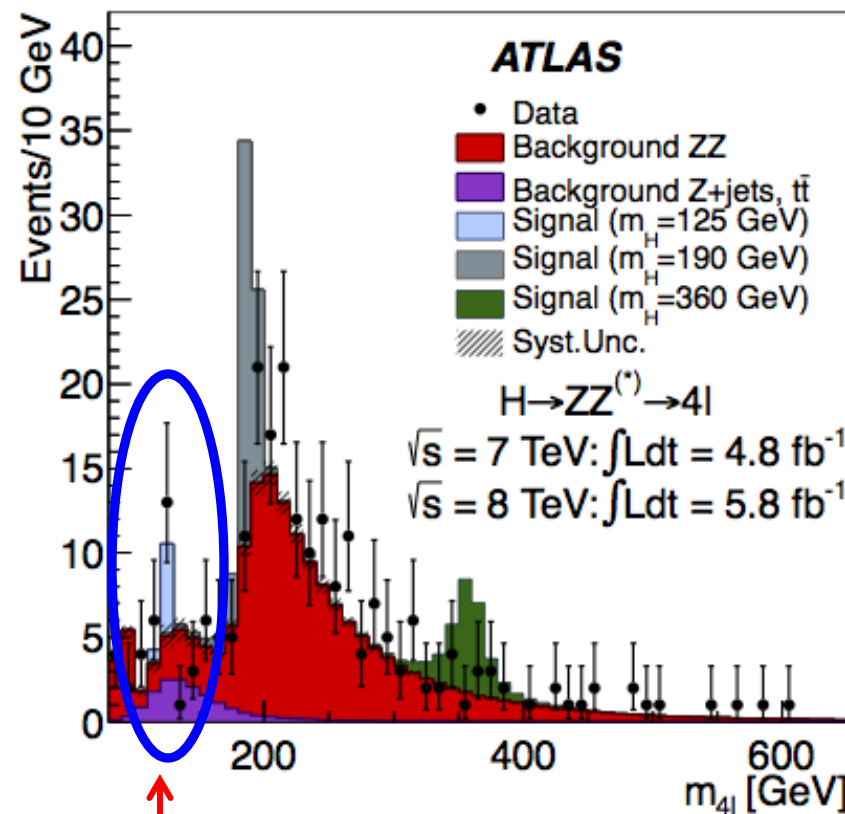
## Higgs discovery channel #2

$H \rightarrow$  four leptons ( $e^+e^-e^+e^-$ ,  $e^+e^-\mu^+\mu^-$ ,  $\mu^+\mu^-\mu^+\mu^-$ )





# Higgs discovery channel #2: $H \rightarrow 4$ leptons



**Mass = 125 GeV**

**Higgs  $\rightarrow$  4 muons**

