

# Finding the Higgs Boson

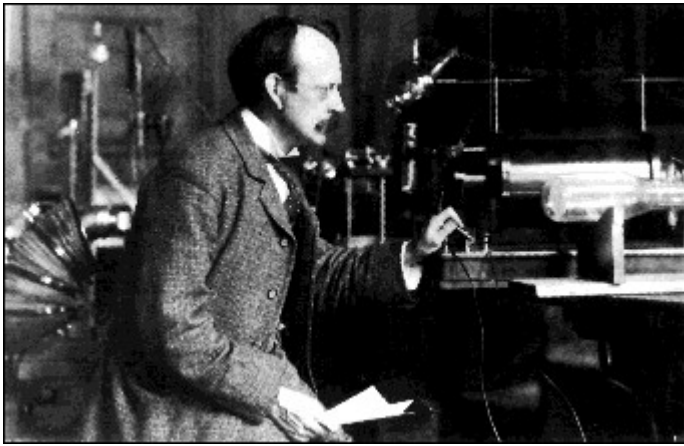
Peter Onyisi

*UT Physics Open House, 30 Oct 2012*

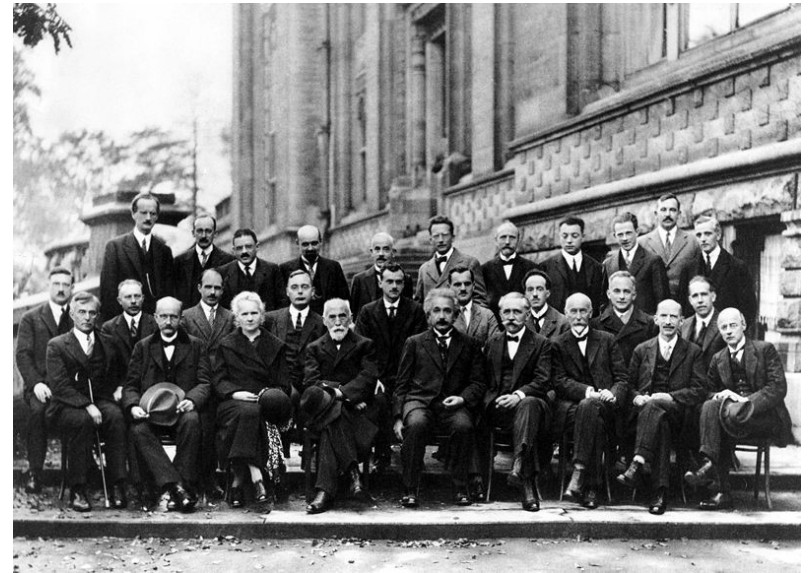
**THE UNIVERSITY OF TEXAS AT AUSTIN**

**WHAT STARTS HERE CHANGES THE WORLD**

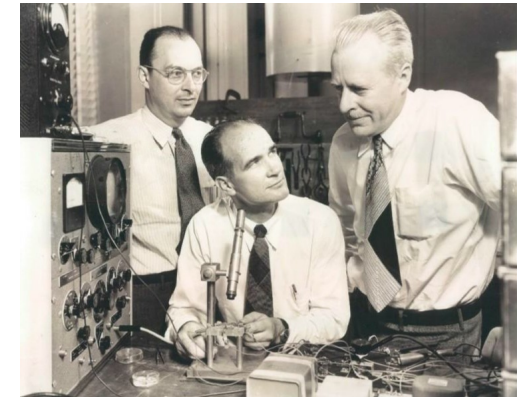
*Today's technology is the particle physics of the early 20th century*



J. J. Thomson & the cathode ray tube:  
discovery of the electron



1927 Solvay Conference

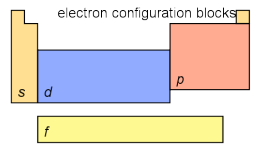


# The Periodic Table of the Elements

|          |                      |                       |                        |                            |                      |                         |                        |                       |                         |                           |                          |                          |                         |                           |                           |                          |                           |                          |
|----------|----------------------|-----------------------|------------------------|----------------------------|----------------------|-------------------------|------------------------|-----------------------|-------------------------|---------------------------|--------------------------|--------------------------|-------------------------|---------------------------|---------------------------|--------------------------|---------------------------|--------------------------|
| group 1  |                      |                       |                        |                            |                      |                         |                        |                       |                         |                           |                          |                          |                         |                           |                           |                          | 18                        |                          |
| period 1 | 1<br>H<br>Hydrogen   |                       |                        |                            |                      |                         |                        |                       |                         |                           |                          |                          |                         |                           |                           |                          |                           | 2<br>He<br>Helium        |
| 2        | 3<br>Li<br>Lithium   | 4<br>Be<br>Beryllium  |                        |                            |                      |                         |                        |                       |                         |                           |                          |                          | 5<br>B<br>Boron         | 6<br>C<br>Carbon          | 7<br>N<br>Nitrogen        | 8<br>O<br>Oxygen         | 9<br>F<br>Fluorine        | 10<br>Ne<br>Neon         |
| 3        | 11<br>Na<br>Sodium   | 12<br>Mg<br>Magnesium |                        |                            |                      |                         |                        |                       |                         |                           |                          |                          | 13<br>Al<br>Aluminium   | 14<br>Si<br>Silicon       | 15<br>P<br>Phosphorus     | 16<br>S<br>Sulfur        | 17<br>Cl<br>Chlorine      | 18<br>Ar<br>Argon        |
| 4        | 19<br>K<br>Potassium | 20<br>Ca<br>Calcium   | 21<br>Sc<br>Scandium   | 22<br>Ti<br>Titanium       | 23<br>V<br>Vanadium  | 24<br>Cr<br>Chromium    | 25<br>Mn<br>Manganese  | 26<br>Fe<br>Iron      | 27<br>Co<br>Cobalt      | 28<br>Ni<br>Nickel        | 29<br>Cu<br>Copper       | 30<br>Zn<br>Zinc         | 31<br>Ga<br>Gallium     | 32<br>Ge<br>Germanium     | 33<br>As<br>Arsenic       | 34<br>Se<br>Selenium     | 35<br>Br<br>Bromine       | 36<br>Kr<br>Krypton      |
| 5        | 37<br>Rb<br>Rubidium | 38<br>Sr<br>Strontium | 39<br>Y<br>Yttrium     | 40<br>Zr<br>Zirconium      | 41<br>Nb<br>Niobium  | 42<br>Mo<br>Molybdenum  | 43<br>Tc<br>Technetium | 44<br>Ru<br>Ruthenium | 45<br>Rh<br>Rhodium     | 46<br>Pd<br>Palladium     | 47<br>Ag<br>Silver       | 48<br>Cd<br>Cadmium      | 49<br>In<br>Indium      | 50<br>Sn<br>Tin           | 51<br>Sb<br>Antimony      | 52<br>Te<br>Tellurium    | 53<br>I<br>Iodine         | 54<br>Xe<br>Xenon        |
| 6        | 55<br>Cs<br>Caesium  | 56<br>Ba<br>Barium    | 57<br>Lu<br>Lutetium   | 71<br>Hf<br>Hafnium        | 72<br>Ta<br>Tantalum | 73<br>W<br>Tungsten     | 74<br>Re<br>Rhenium    | 75<br>Os<br>Osmium    | 76<br>Ir<br>Iridium     | 77<br>Pt<br>Platinum      | 78<br>Au<br>Gold         | 79<br>Hg<br>Mercury      | 80<br>Tl<br>Thallium    | 81<br>Pb<br>Lead          | 82<br>Bi<br>Bismuth       | 83<br>Po<br>Polonium     | 84<br>At<br>Astatine      | 85<br>Rn<br>Radon        |
| 7        | 87<br>Fr<br>Francium | 88<br>Ra<br>Radium    | 89<br>Lr<br>Lawrencium | 103<br>Rf<br>Rutherfordium | 104<br>Db<br>Dubnium | 105<br>Sg<br>Seaborgium | 106<br>Bh<br>Bohrium   | 107<br>Hs<br>Hassium  | 108<br>Mt<br>Meitnerium | 109<br>Ds<br>Darmstadtium | 110<br>Rg<br>Roentgenium | 111<br>Cn<br>Copernicium | 112<br>Uut<br>Ununtrium | 113<br>Uuq<br>Ununquadium | 114<br>Uup<br>Ununpentium | 115<br>Uuh<br>Ununhexium | 116<br>Uus<br>Ununseptium | 117<br>Uuo<br>Ununoctium |

atomic mass or most stable mass number: 55.845  
 1st ionization energy in kJ/mol: 762.5  
 chemical symbol: Fe  
 name: Iron  
 electron configuration: [Ar] 3d<sup>6</sup> 4s<sup>2</sup>  
 atomic number: 26  
 electronegativity: 1.83  
 oxidation states: +6, +5, +4, +3, +2, +1, -1, -2 (most common are bold)

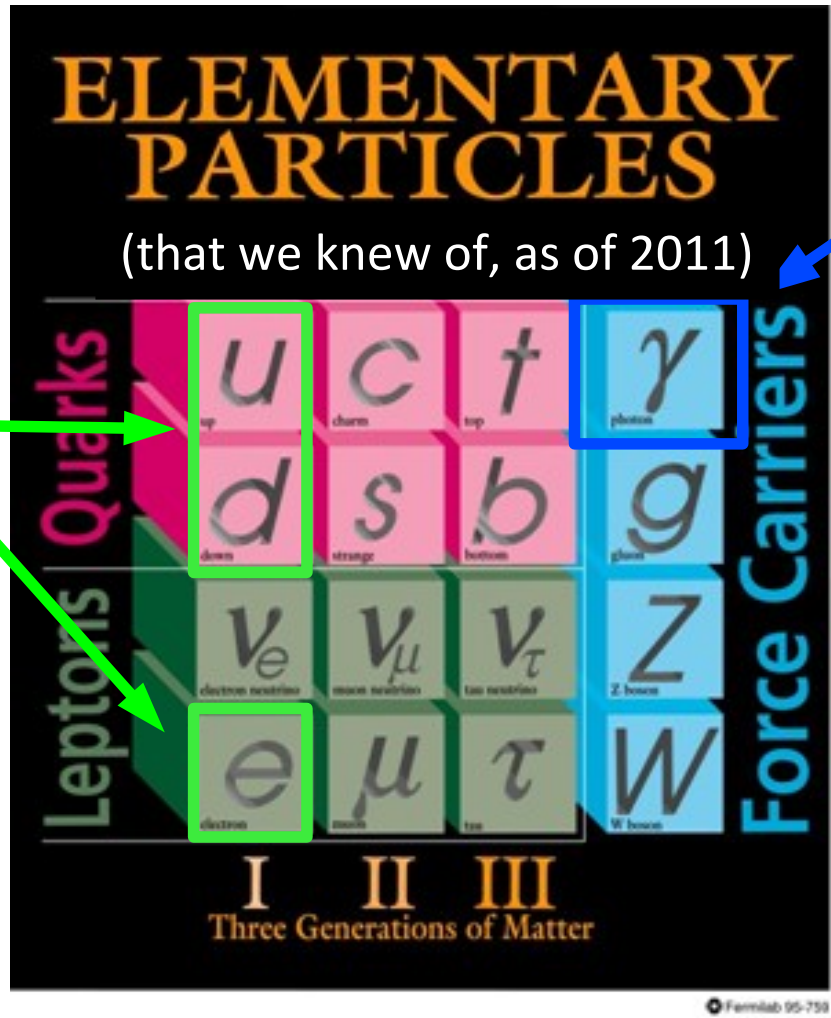
- alkali metals
- alkaline metals
- other metals
- transition metals
- lanthanoids
- actinoids
- metalloids
- nonmetals
- halogens
- noble gases
- unknown elements
- radioactive elements have masses in parenthesis



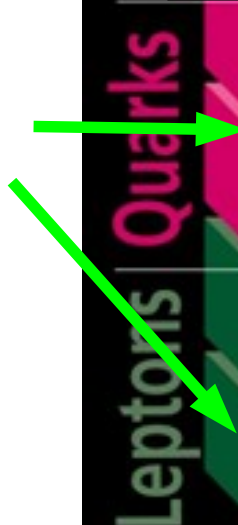
- notes
- as of yet, elements 112-118 have no official name designated by the IUPAC.
  - 1 kJ/mol = 96.485 eV.
  - all elements are implied to have an oxidation state of zero.

|                                   |                                 |                                      |                                  |                                 |                                |                                 |                                  |                                 |                                   |                                  |                               |                                   |                                  |
|-----------------------------------|---------------------------------|--------------------------------------|----------------------------------|---------------------------------|--------------------------------|---------------------------------|----------------------------------|---------------------------------|-----------------------------------|----------------------------------|-------------------------------|-----------------------------------|----------------------------------|
| 138.9054<br>57<br>La<br>Lanthanum | 140.116<br>58<br>Ce<br>Cerium   | 140.9076<br>59<br>Pr<br>Praseodymium | 144.242<br>60<br>Nd<br>Neodymium | (145)<br>61<br>Pm<br>Promethium | 150.36<br>62<br>Sm<br>Samarium | 151.964<br>63<br>Eu<br>Europium | 157.25<br>64<br>Gd<br>Gadolinium | 158.9253<br>65<br>Tb<br>Terbium | 162.500<br>66<br>Dy<br>Dysprosium | 164.9303<br>67<br>Ho<br>Holmium  | 167.259<br>68<br>Er<br>Erbium | 168.9342<br>69<br>Tm<br>Thulium   | 173.054<br>70<br>Yb<br>Ytterbium |
| (227)<br>89<br>Ac<br>Actinium     | 232.0380<br>90<br>Th<br>Thorium | 231.0358<br>91<br>Pa<br>Protactinium | 238.0289<br>92<br>U<br>Uranium   | (237)<br>93<br>Np<br>Neptunium  | (244)<br>94<br>Pu<br>Plutonium | (247)<br>95<br>Am<br>Americium  | (247)<br>96<br>Cm<br>Curium      | (247)<br>97<br>Bk<br>Berkelium  | (251)<br>98<br>Cf<br>Californium  | (252)<br>99<br>Es<br>Einsteinium | (257)<br>100<br>Fm<br>Fermium | (258)<br>101<br>Md<br>Mendelevium | (259)<br>102<br>No<br>Nobelium   |

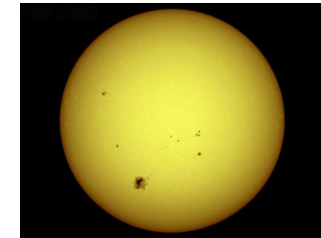
Overwhelming complexity of substances → smaller set of atoms  
 Overwhelming complexity of atoms → electronic structure, nuclei



What you're made of



Photon  
Particle of light

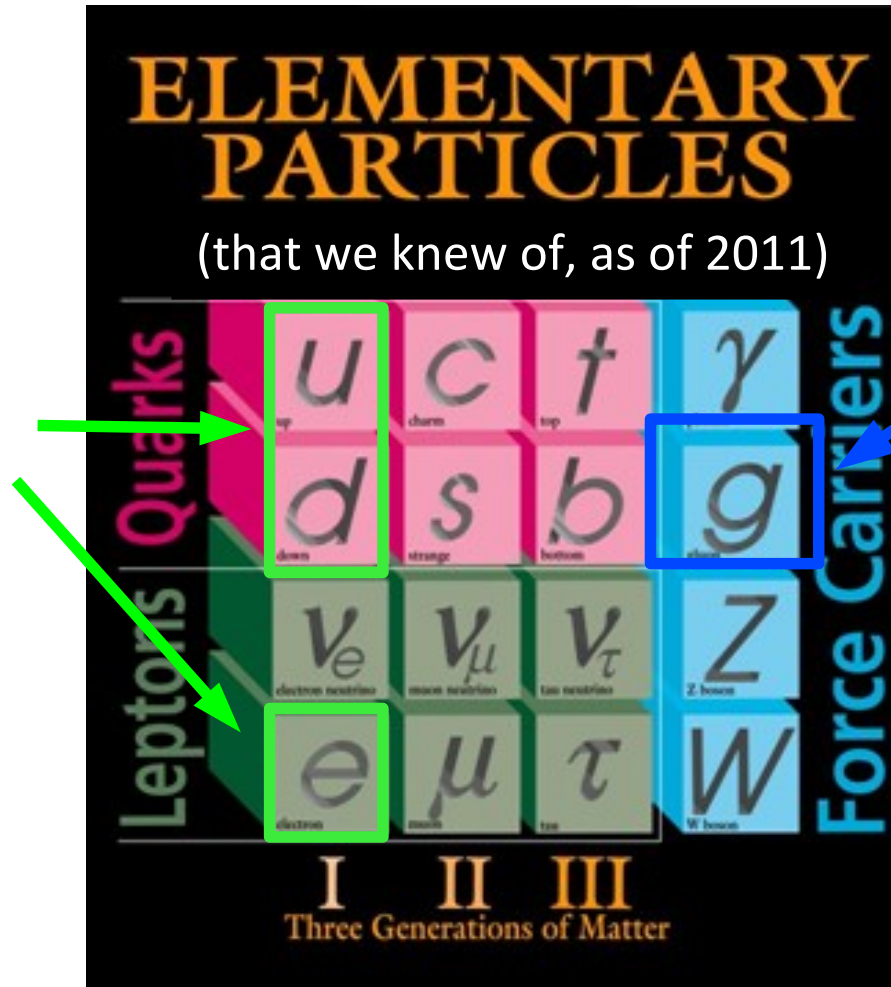


Overwhelming complexity of particles and forces → fundamental particles  
 “matter” and “forces”: both are particles (different kinds)

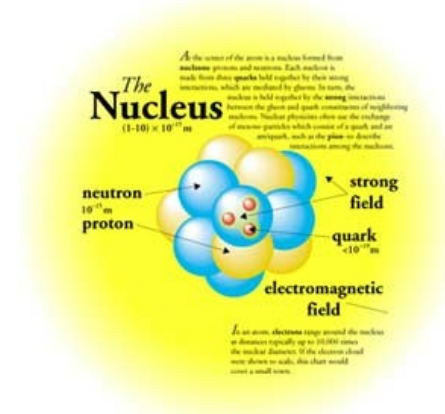
# ELEMENTARY PARTICLES

(that we knew of, as of 2011)

What you're made of



**Gluon**  
Particle of the strong nuclear force

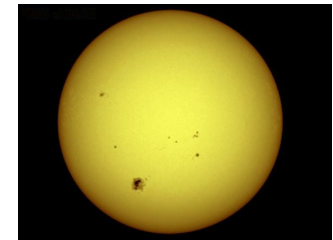
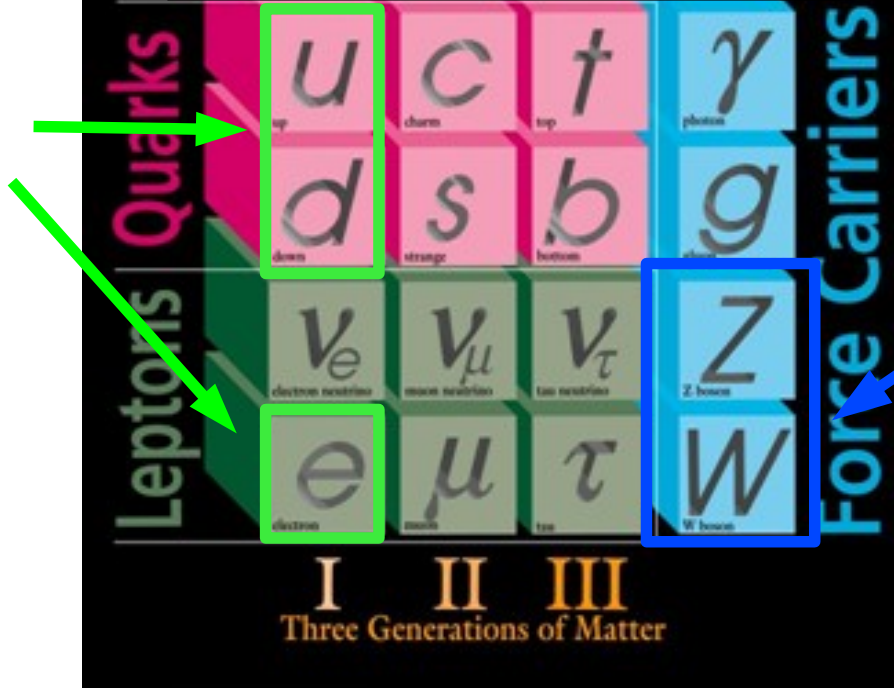


Fermilab 95-759

# ELEMENTARY PARTICLES

(that we knew of, as of 2011)

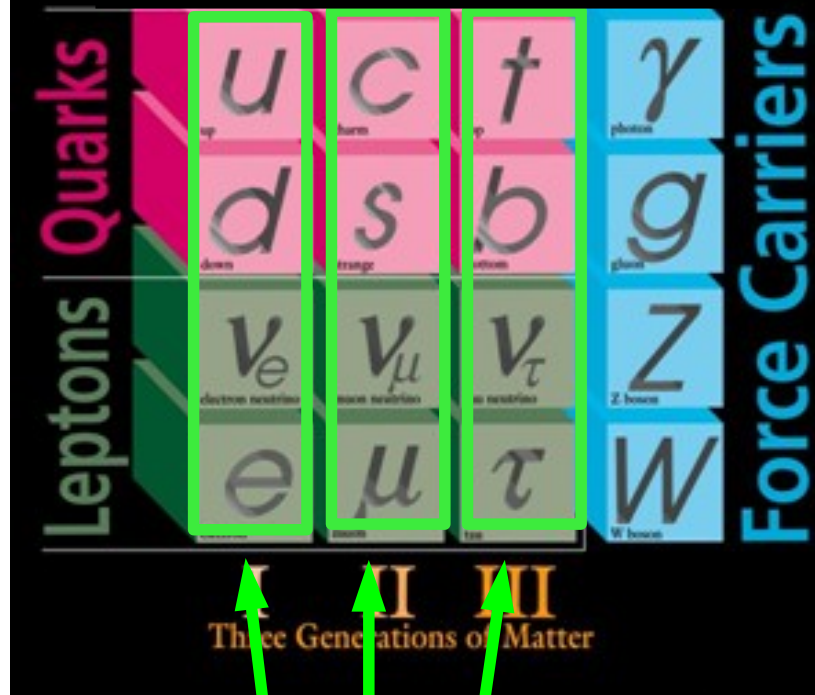
What you're made of



**W and Z**  
Particles of the  
weak nuclear force

# ELEMENTARY PARTICLES

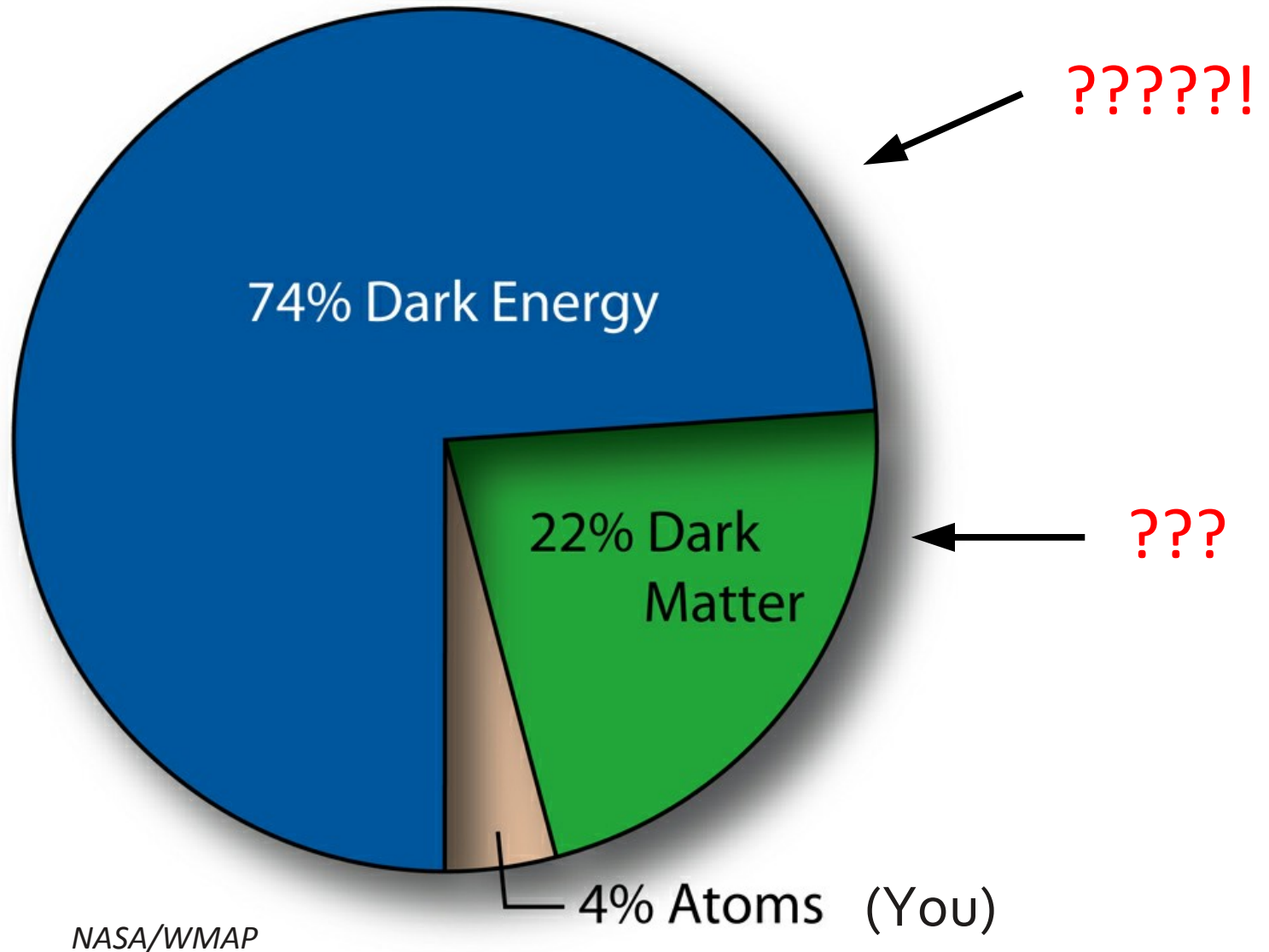
(that we knew of, as of 2011)



Three “generations” of matter particles

Units of energy and mass  
1 GeV = 1.07 protons  
125 GeV  $\approx$  1 cesium atom

# The Modern Universe





# What does the Higgs boson do?

The Higgs *field* fills all of space. It's like a gravitational or electric field, but it doesn't need a source to exist; it's just there.

It gives masses to all the fundamental particles that we know of, essentially by sticking to them.

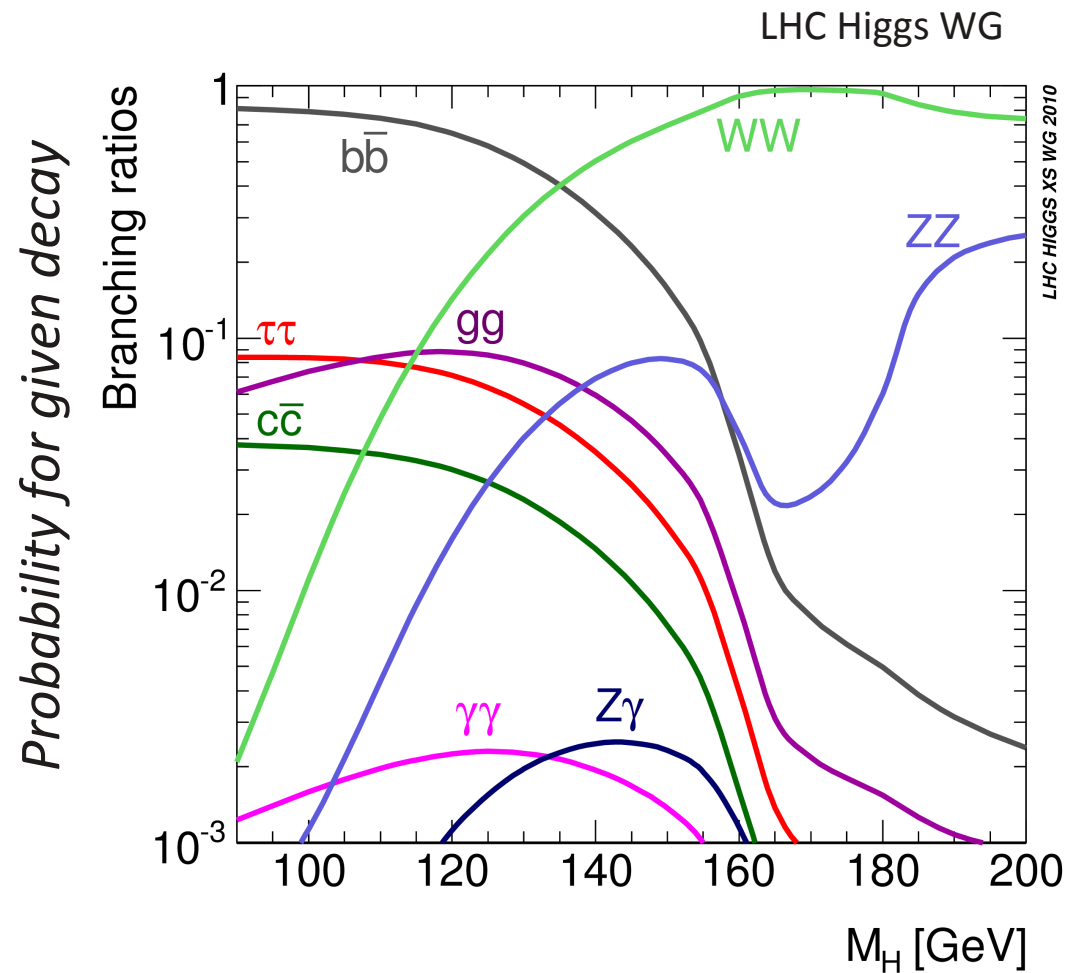
How can we see it? By shaking the field a bit and seeing the wobbles.



Higgs Field

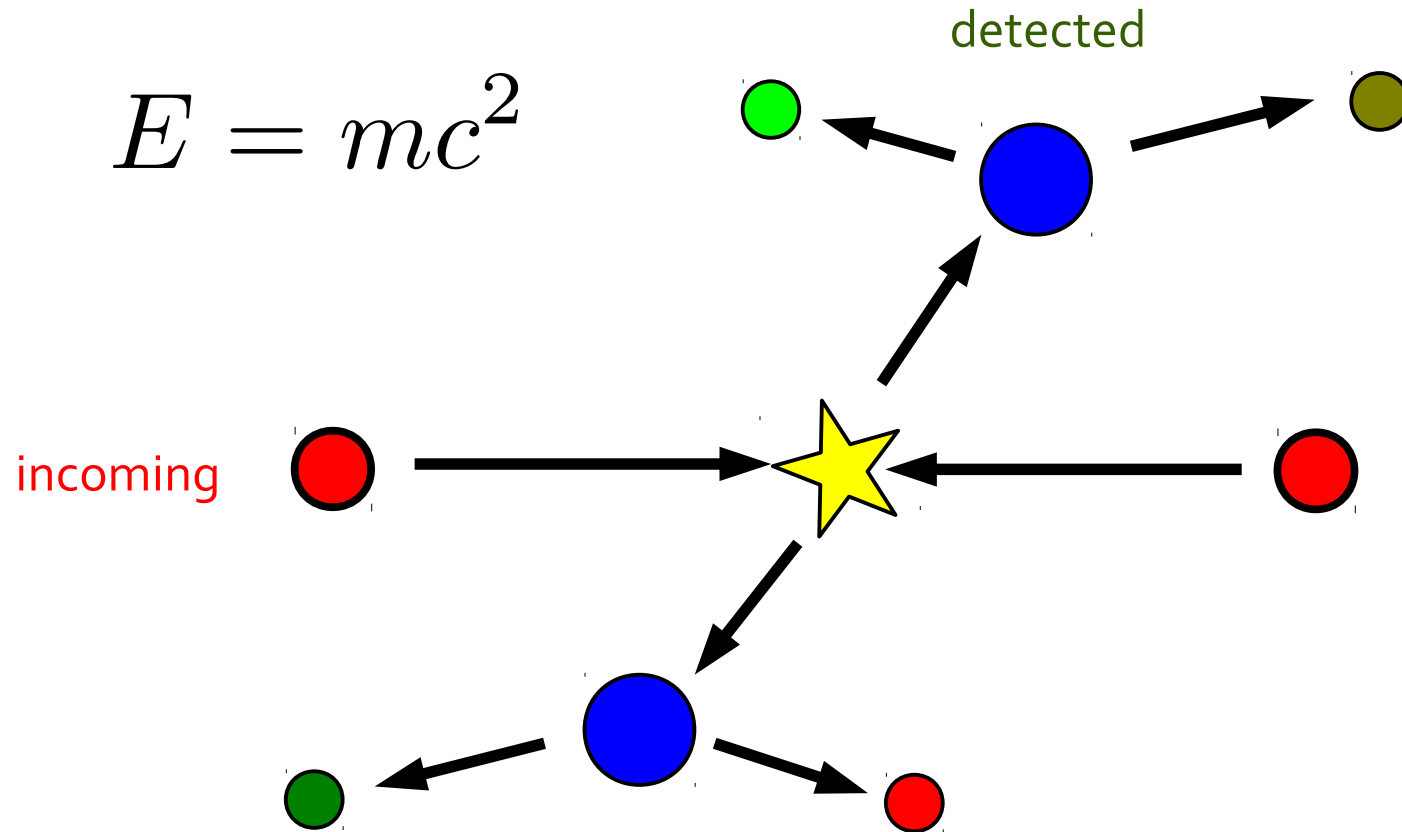
Higgs Bosons

# Theoretically well understood



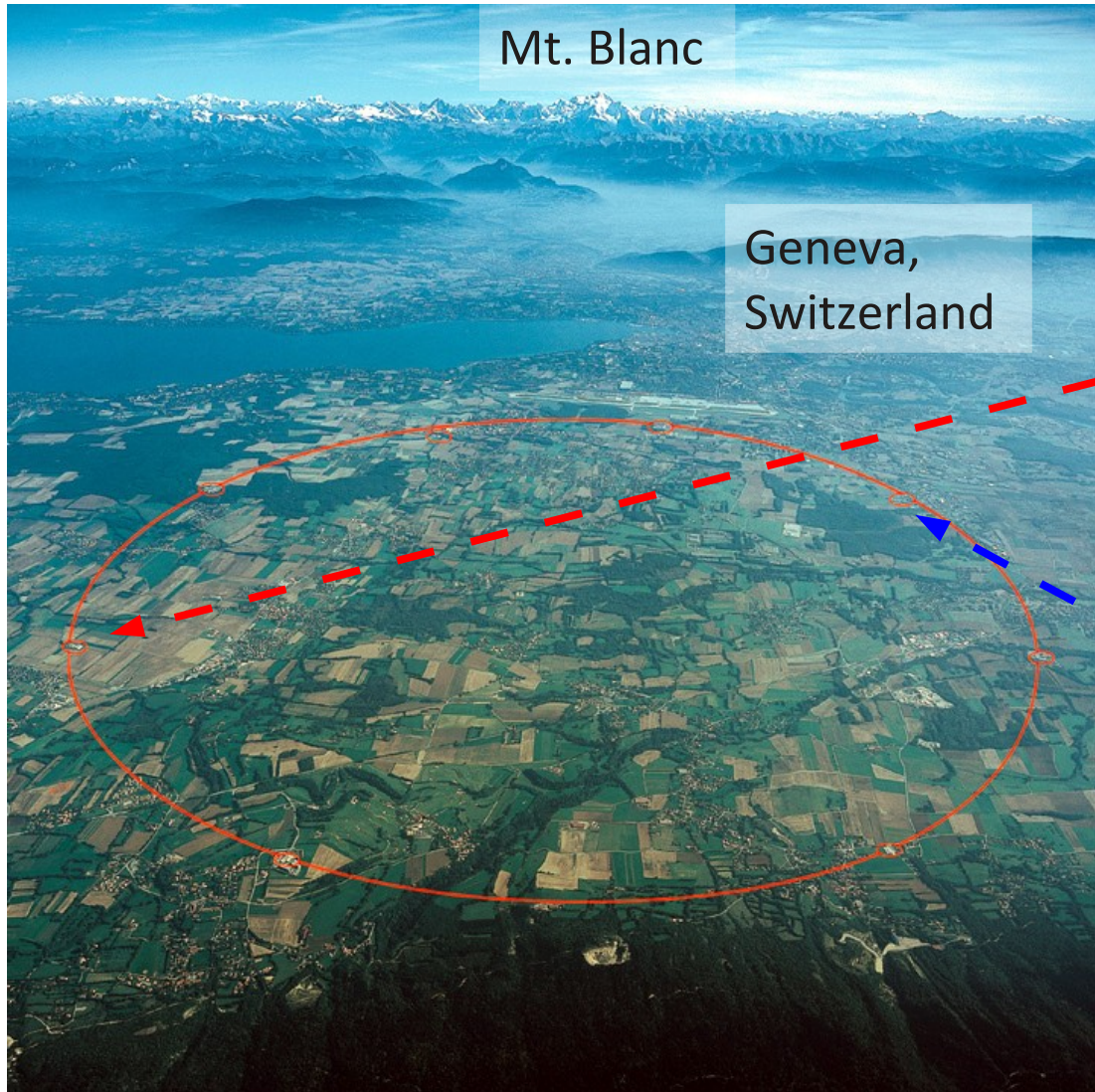
We knew exactly what to look for (except how heavy it was!)

# How do we look for new particles?



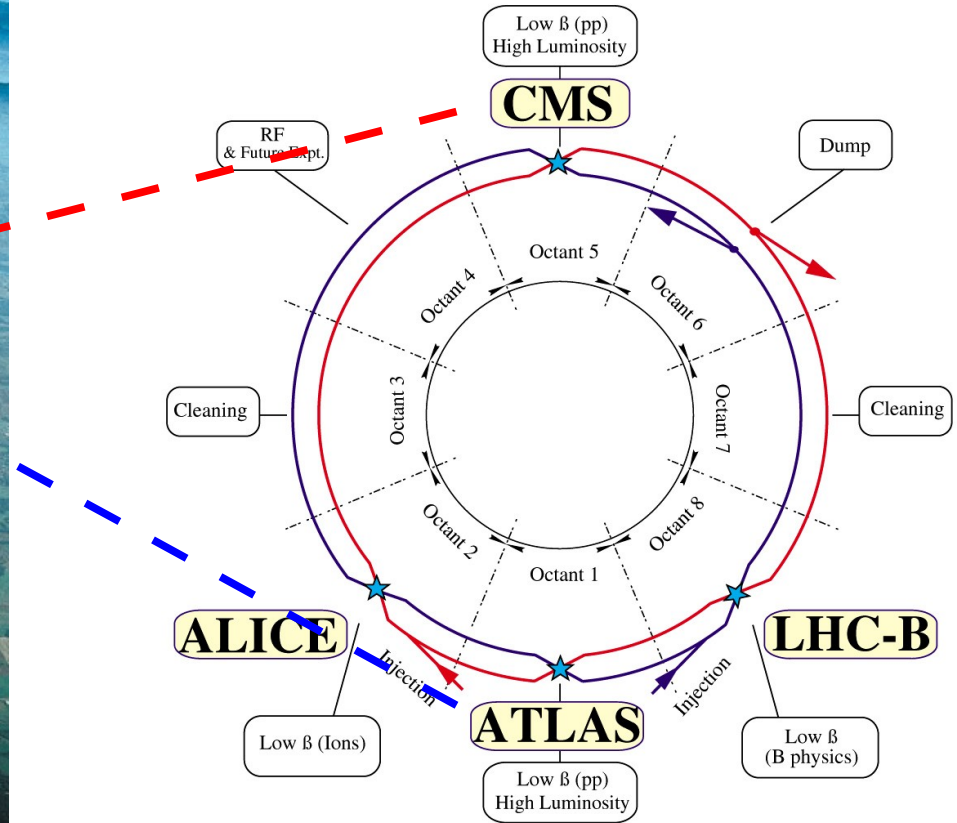
convert **kinetic** energy to **mass** energy of new particles

the particles you can make are determined by the forces they feel



## LHC LAYOUT

27 km circumference



CERN AC \_ E12-4A \_ V18/9/1997

**CERN:** the European laboratory for particle physics

**LHC:** collides protons with kinetic energy  $> 4000$  times their rest mass

PREINJECTEUR  
LINAC 2

ATTENTION  
HAUTE TENSION  
HIGH TENSION  
100 KV DANGER

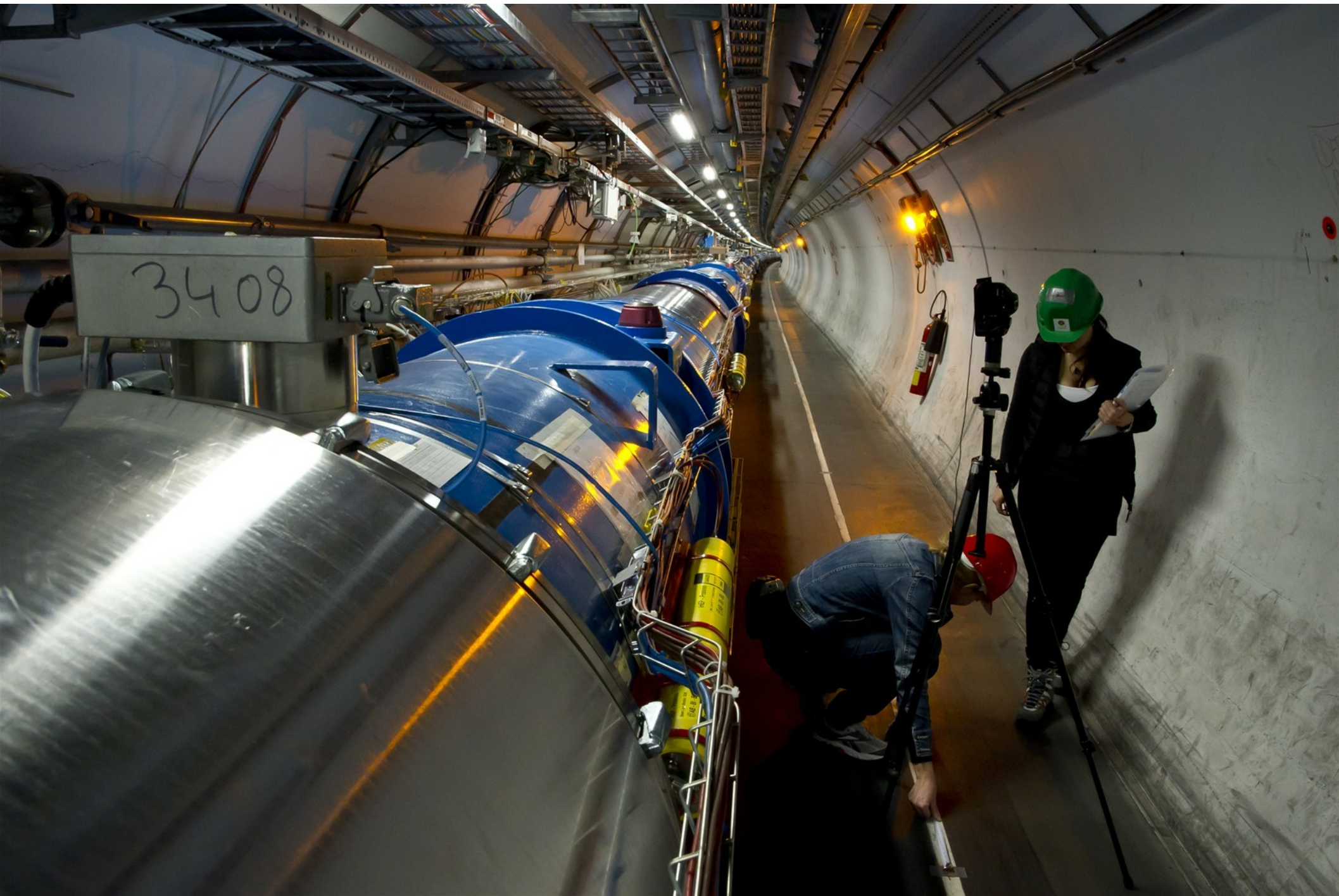
H<sub>2</sub>

where it all begins

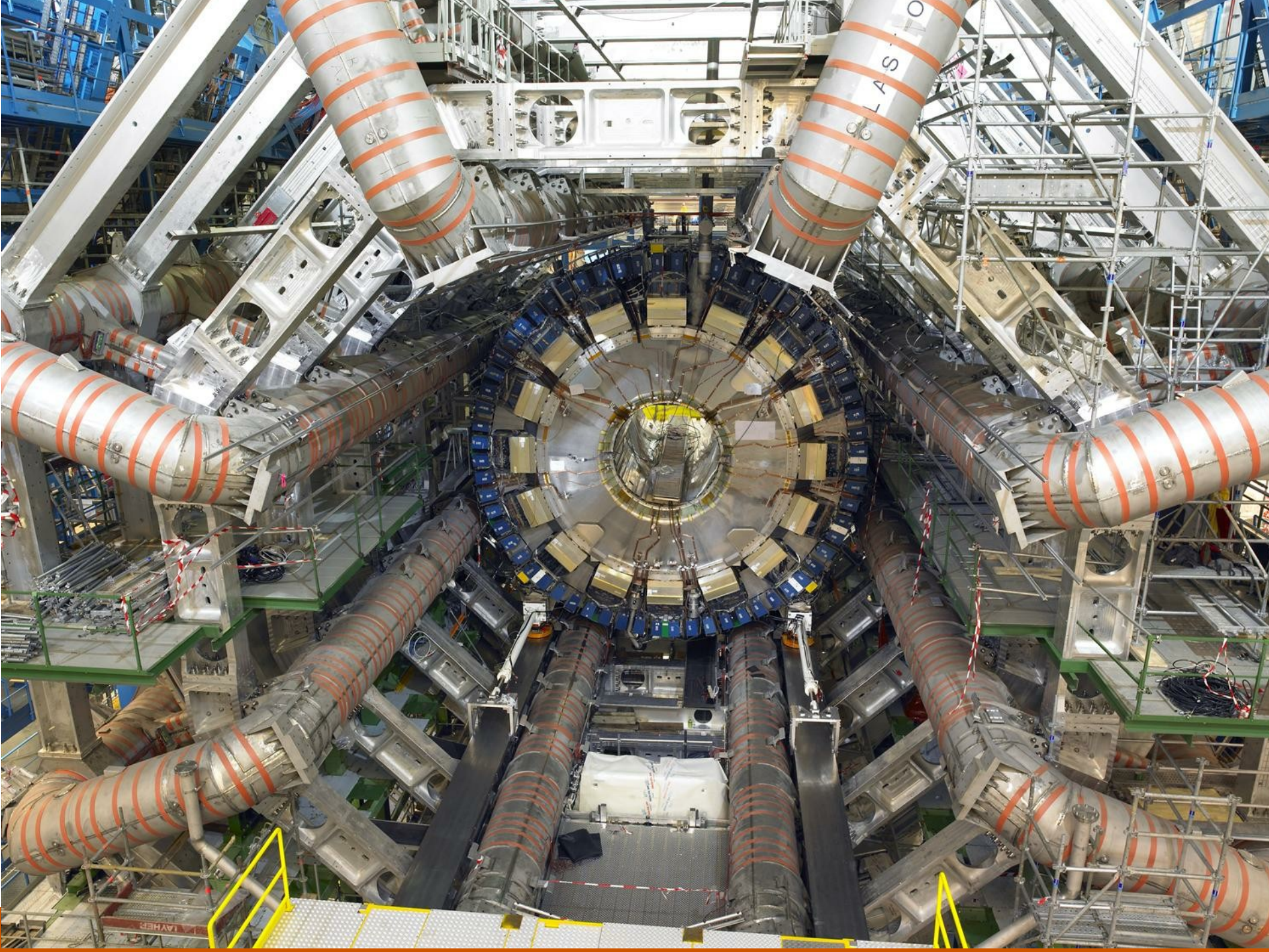
consumption per day  
≈ 2 nanograms

A PROTON SOURCE

Flammable gas - Gaz inflammable



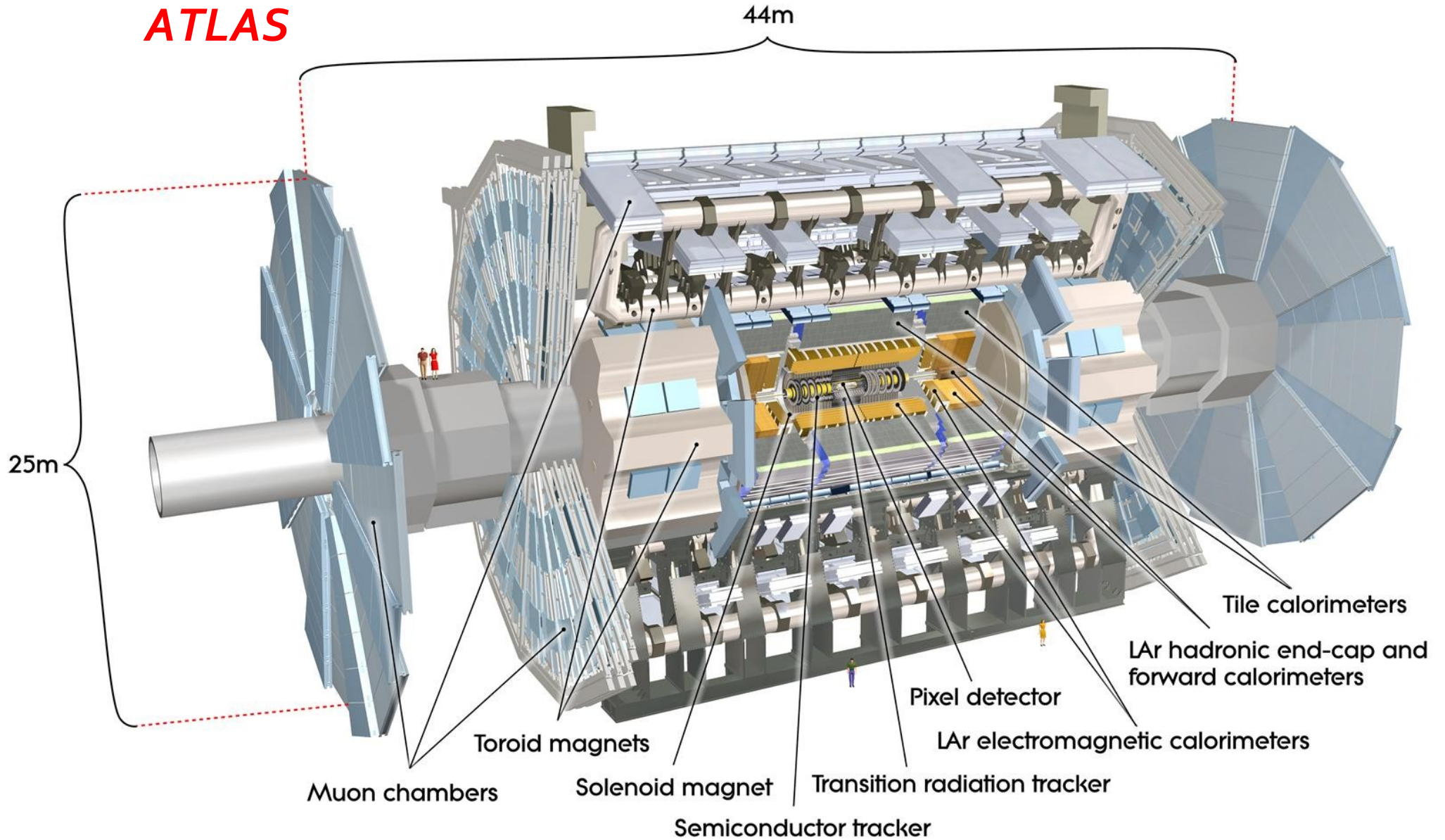
## Inside the LHC tunnel







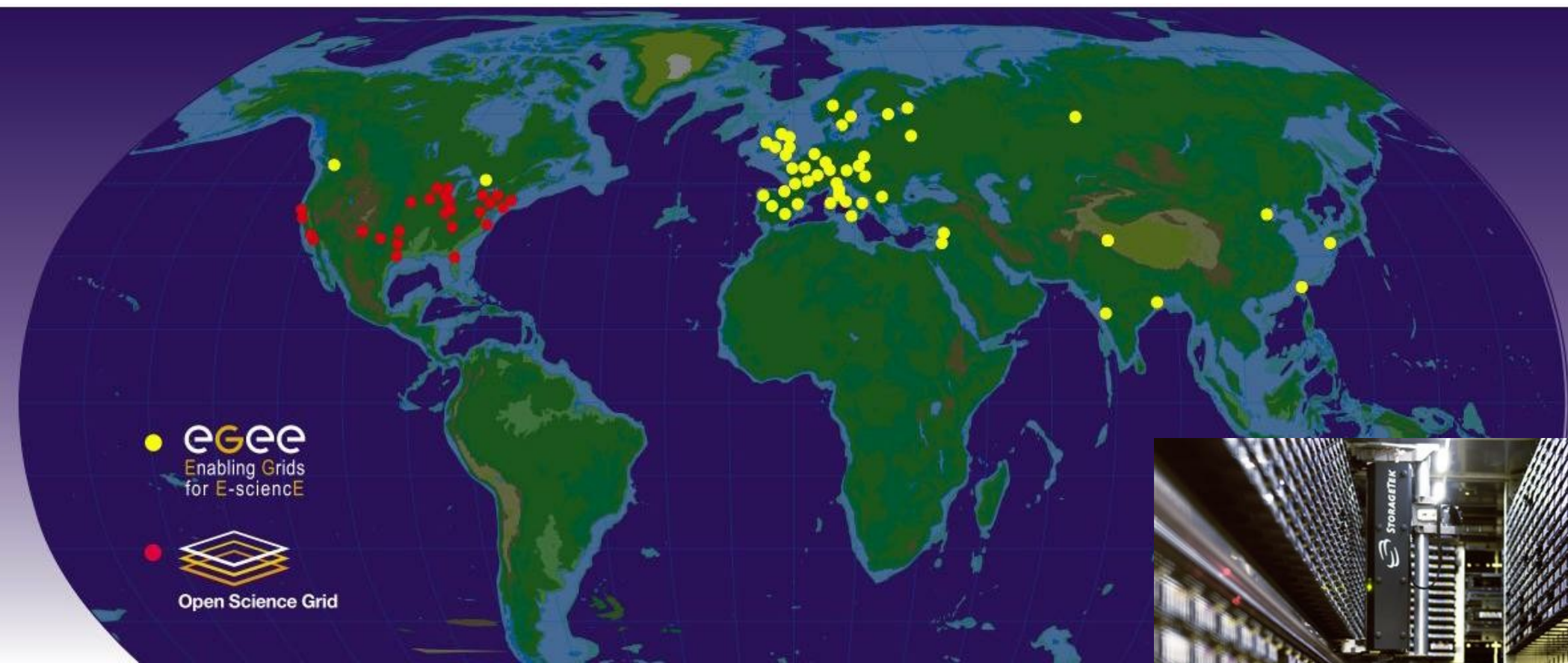
# ATLAS



## How ATLAS detects particles



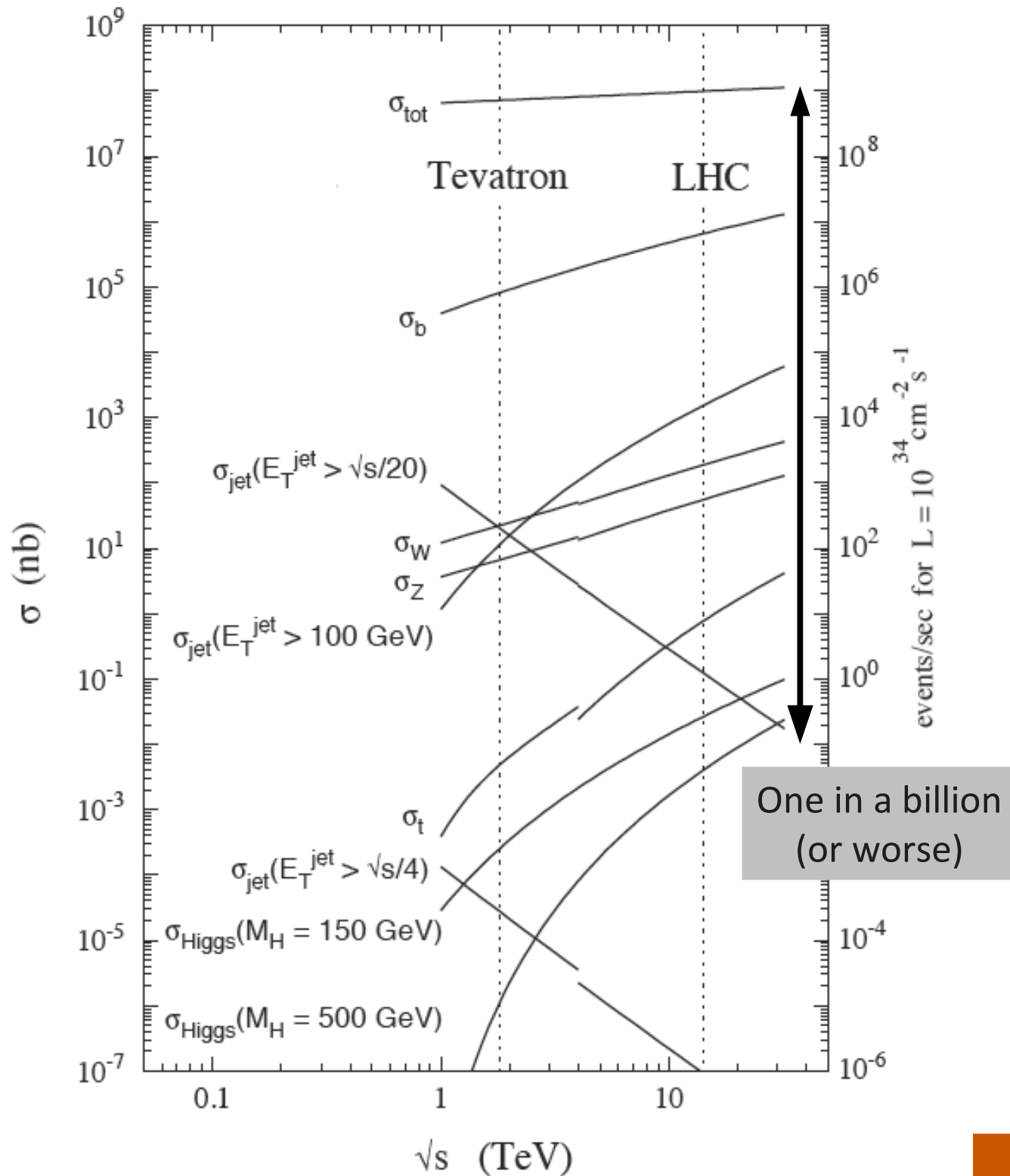
Over 3000 people work on ATLAS... here are a few (at the Higgs party!)



LHC experiments record billions of collisions, tens of petabytes of data per year

Need to search through them with computers throughout the globe





**Quantum mechanics:**  
We only have *probabilities*

Every collision is a *random occurrence*

We're looking for things happening less often than once in a trillion collisions

# The Pace of Higgses

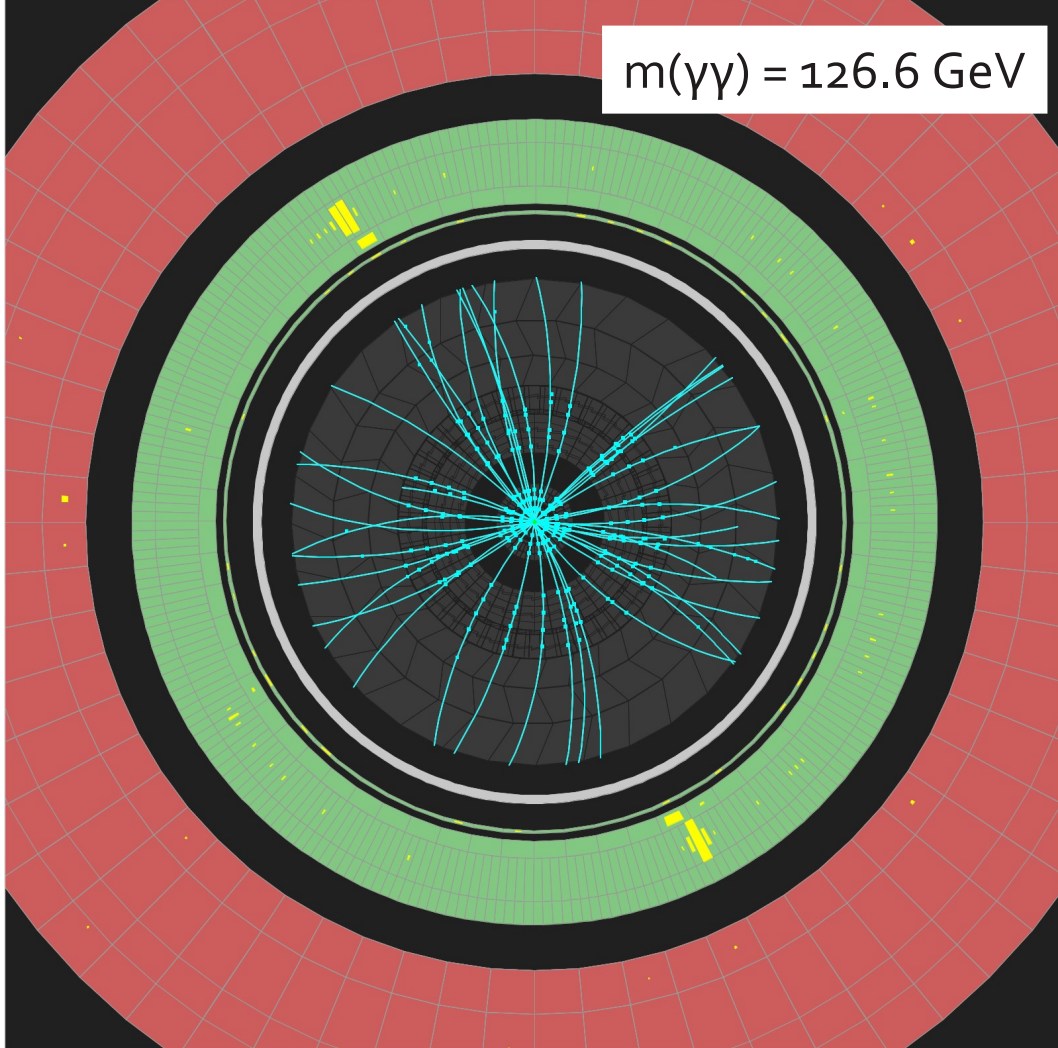
The collisions produce

- a  $H \rightarrow WW \rightarrow \ell\nu\ell\nu$  event every 20 minutes
- a  $H \rightarrow \gamma\gamma$  event every 45 minutes
- a  $H \rightarrow ZZ \rightarrow 4\ell$  event every 13 hours

We're not 100% efficient at catching them, and we need a lot to separate them from other processes

In short, it takes a long time to accumulate data.

$m(\gamma\gamma) = 126.6 \text{ GeV}$

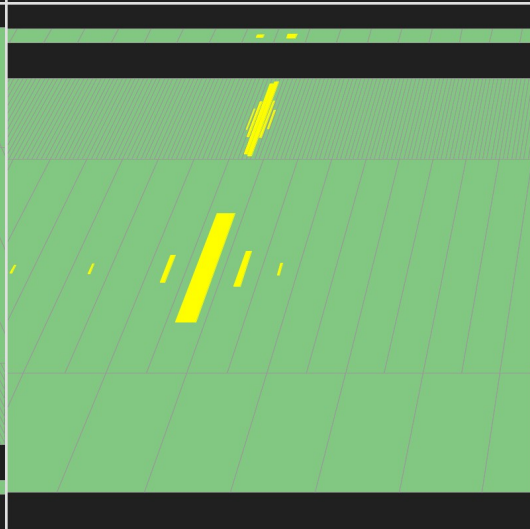
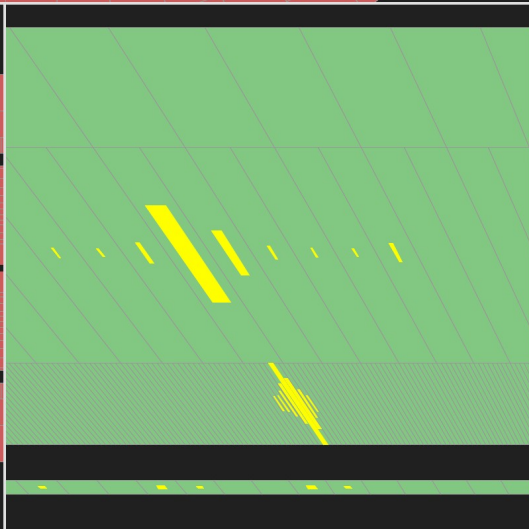
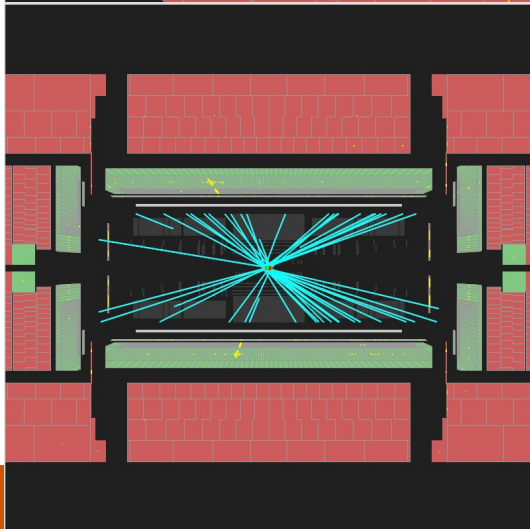
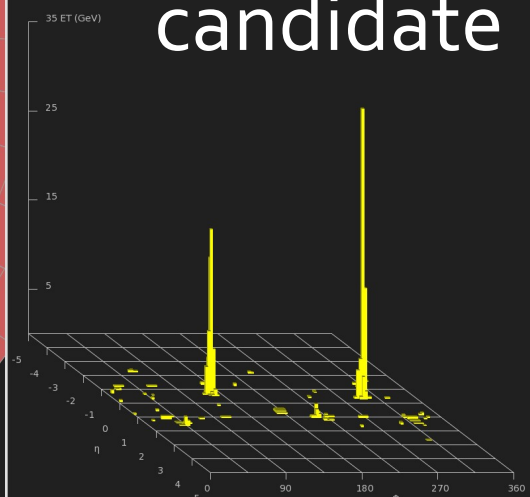


Run Number: 191426, Event Number: 86694500

Date: 2011-10-22 15:30:29 UTC

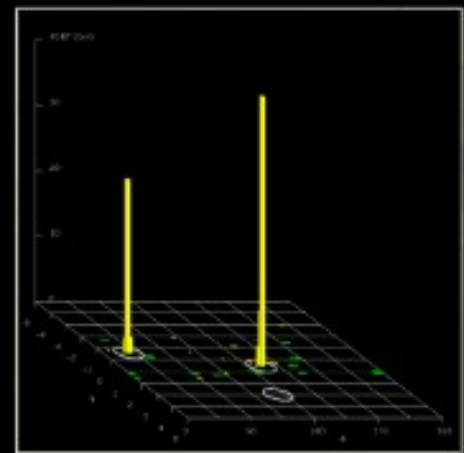
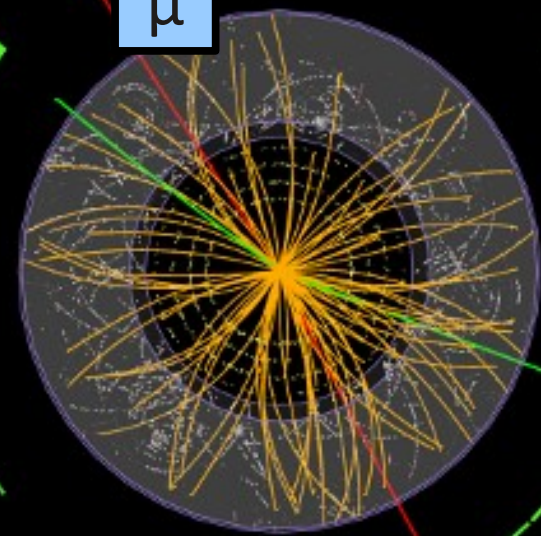
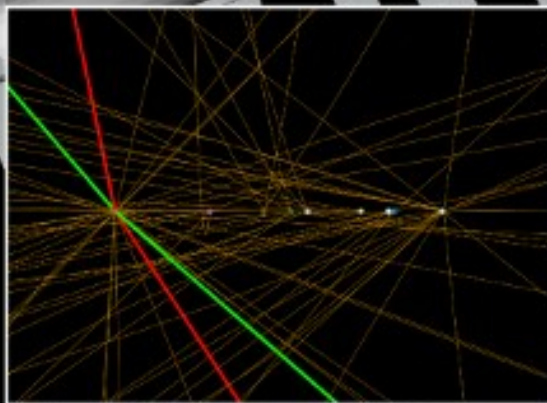
$H \rightarrow \gamma\gamma$

candidate



$H \rightarrow ZZ \rightarrow ee\mu\mu$   
candidate

$m_{4\ell} = 124.3 \text{ GeV}$



Run: 182796  
Event: 74566644  
2011-05-30 07:54:29 CEST

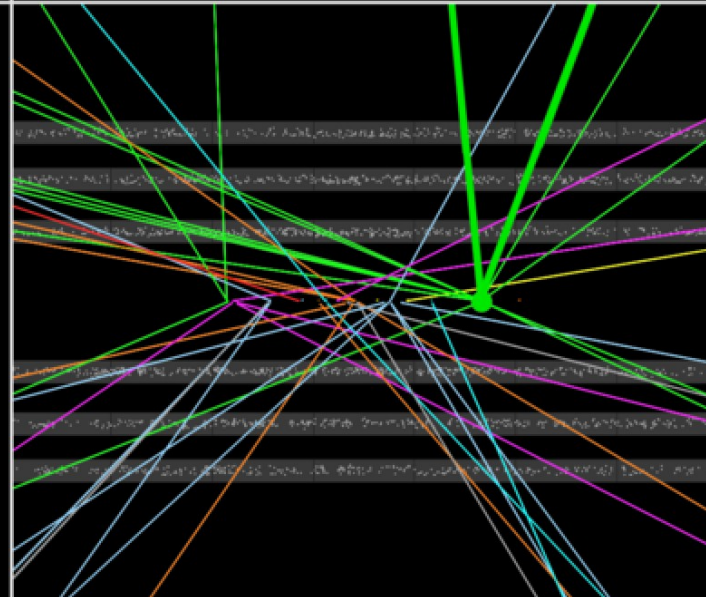
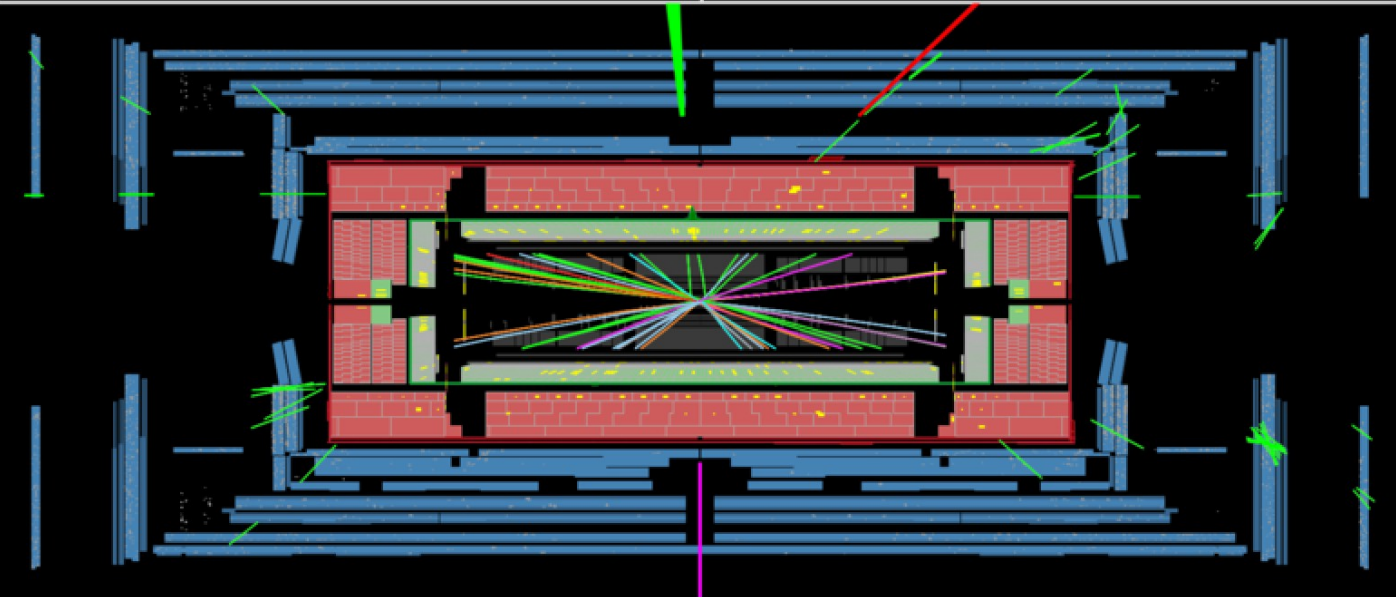
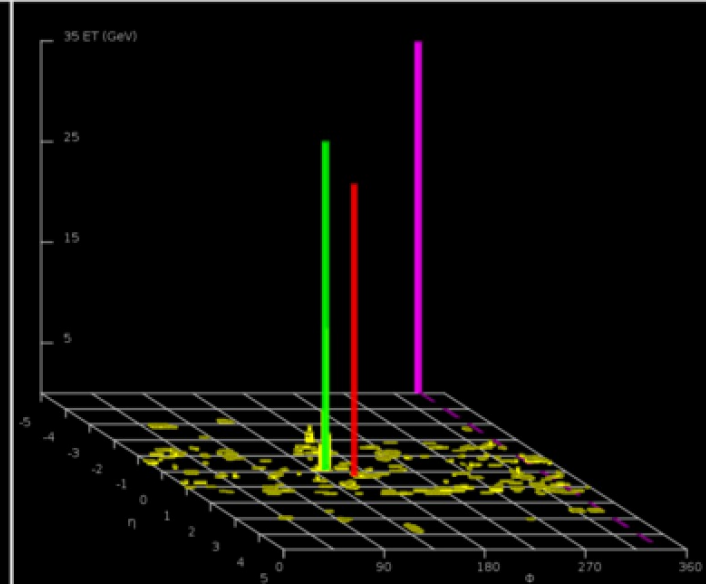
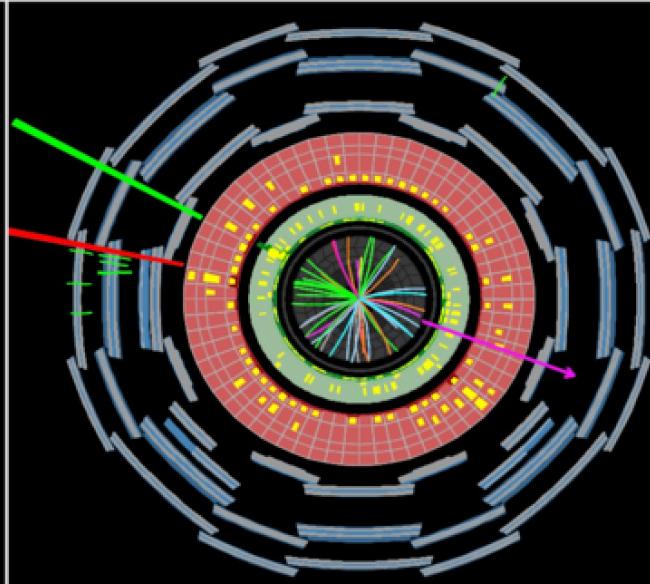




# ATLAS EXPERIMENT

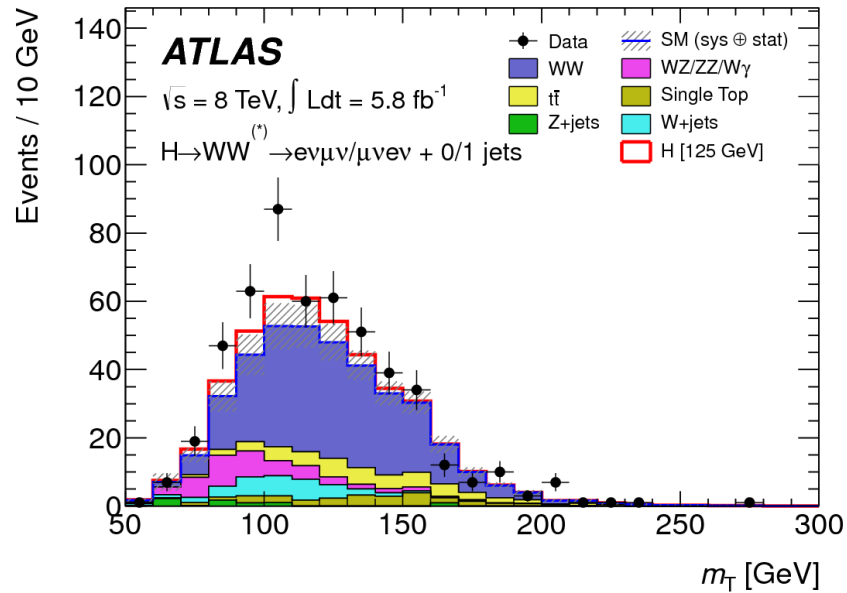
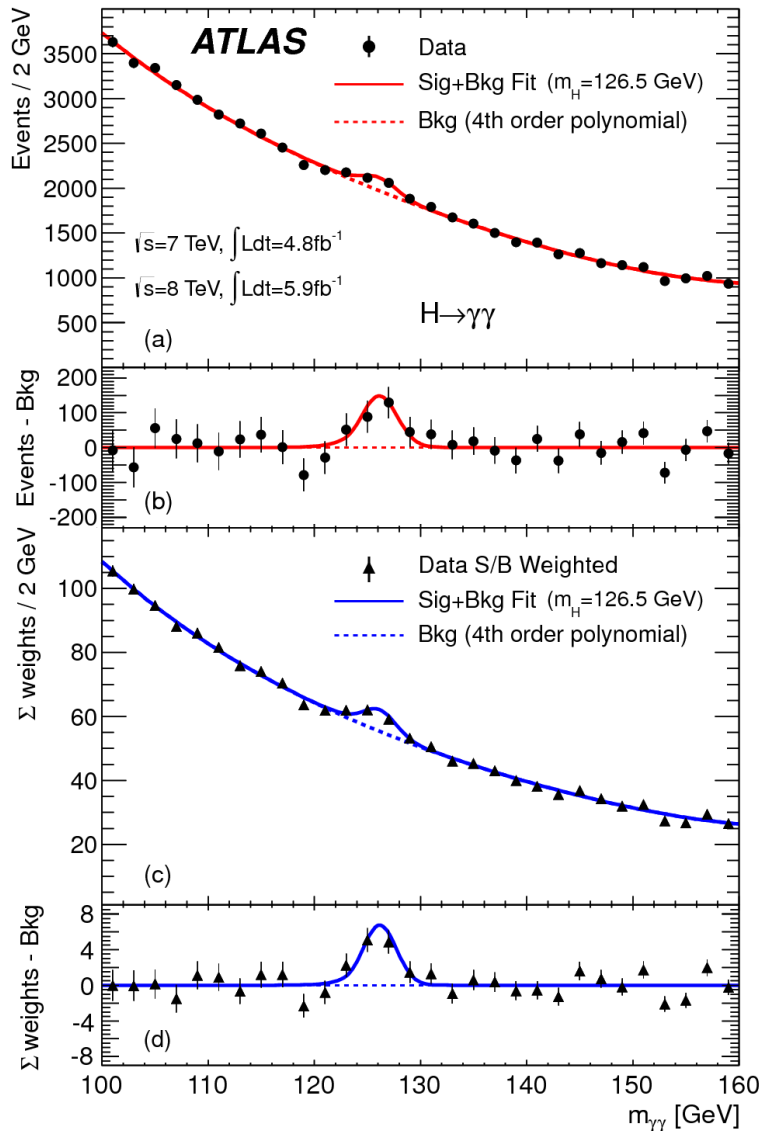
Run Number: 204026, Event Number: 33133446

Date: 2012-05-28 07:23:47 CEST

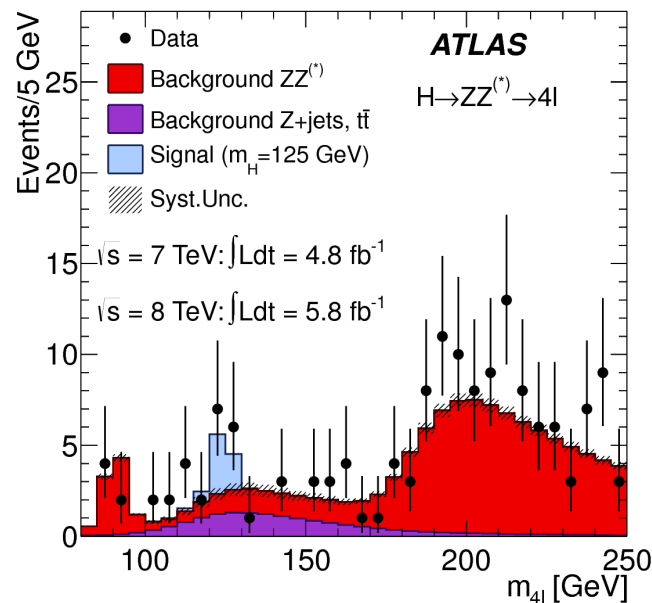


$H \rightarrow WW \rightarrow e\nu\mu\nu$  candidate

# The Discovery Plots

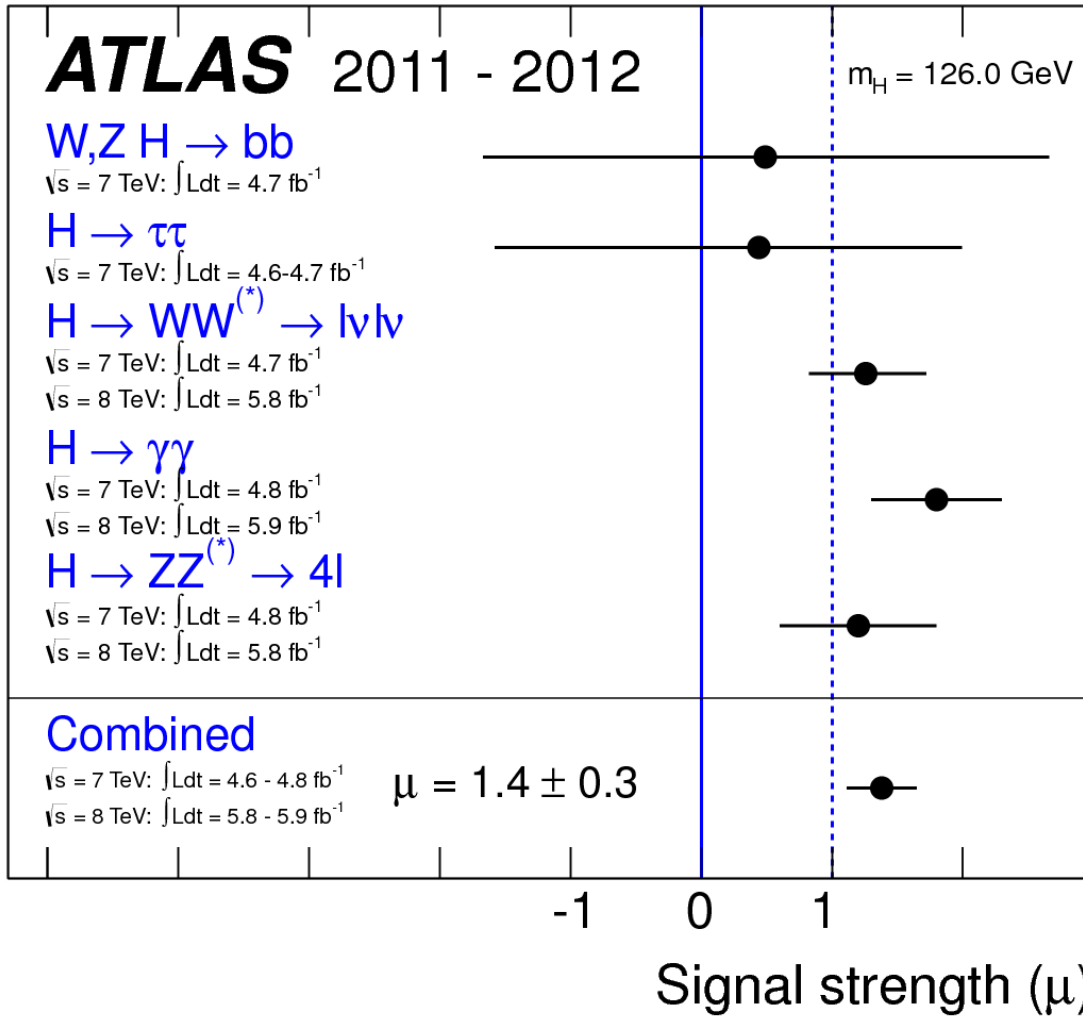


+ equivalent plots from our competitors, CMS

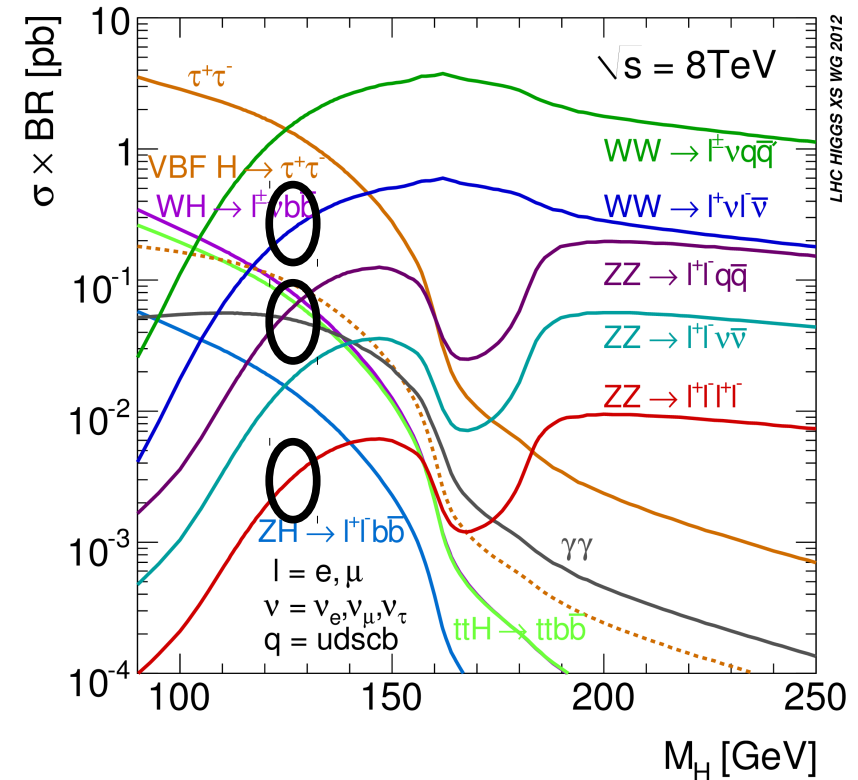


**"5.9 $\sigma$ ":**  
probability of fluctuation  
is  $1.7 \times 10^{-9}$

# Is it what we expect?



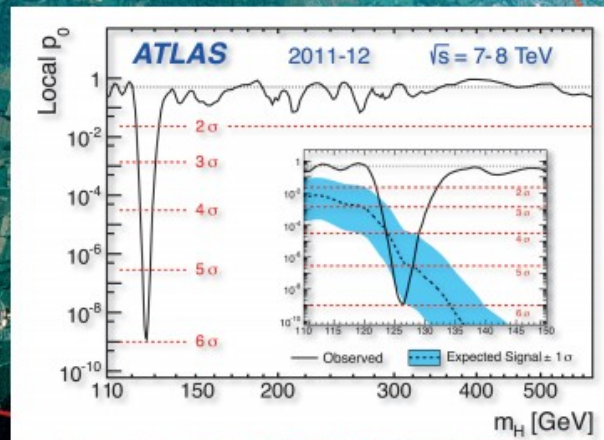
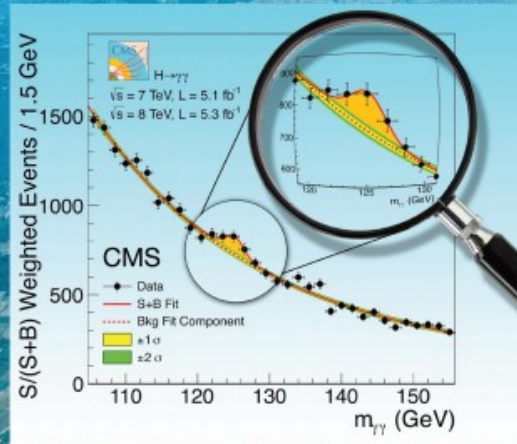
Signal strength = observed/expected rate



# PHYSICS LETTERS B

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

SciVerse ScienceDirect

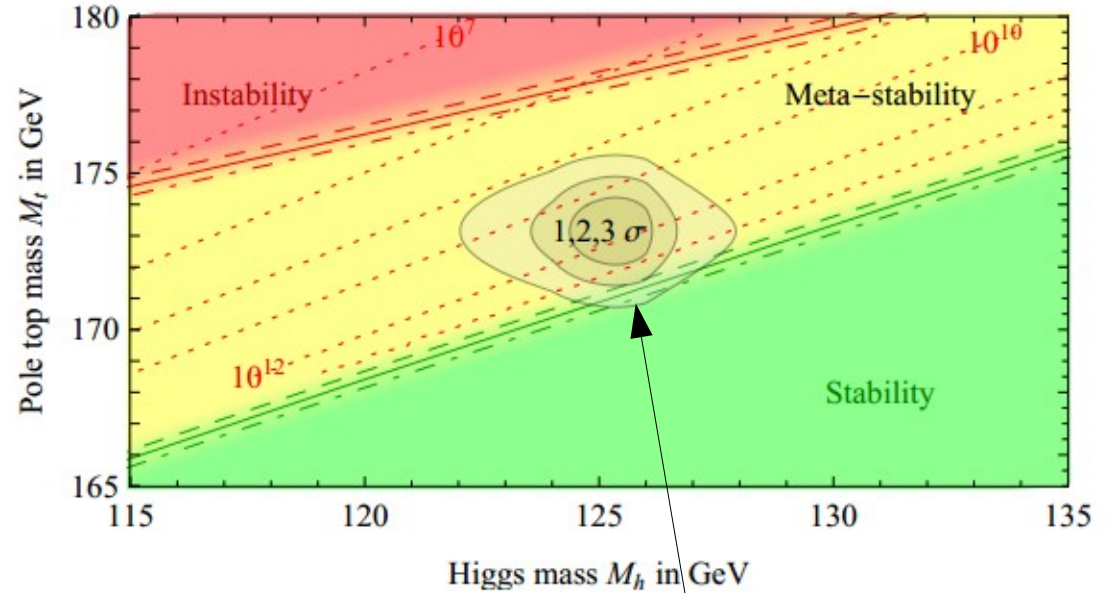
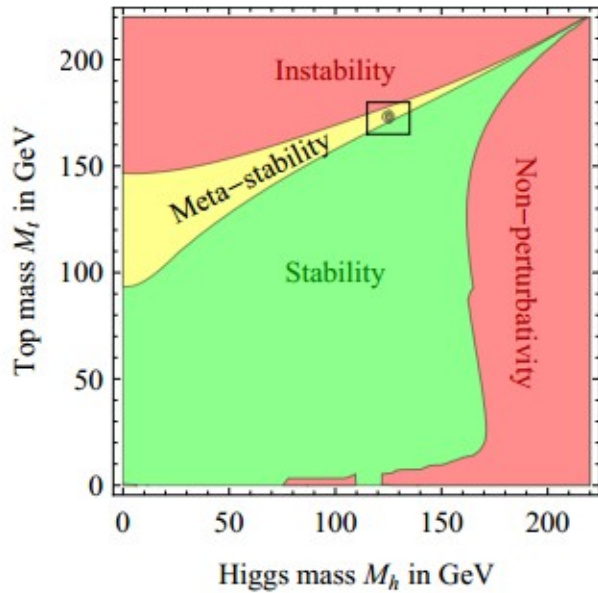


# Towards the Future

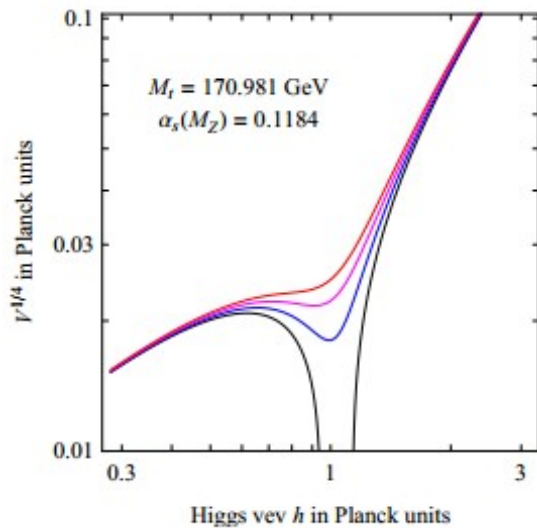
## What else do we need to study about the Higgs?

- Is it “the” Higgs, or something that just looks like it? Study its behavior!
- Does it have partners? Many theories predict so!
- What, precisely, is its own mass? Is our picture of how the Higgs field comes to be correct?
- Does it have implications for the evolution of the universe?

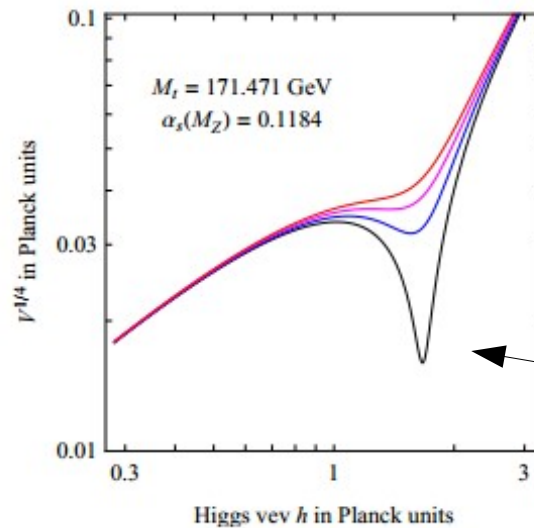
# Is our vacuum stable?



SM Higgs potential,  $M_h = 125$  GeV



SM Higgs potential,  $M_h = 126$  GeV



Perhaps we are not in the true minimum of the Higgs potential?

Could the SM Higgs drive primordial inflation?

Degrassi et al, arxiv:1205.6497

# Unsolved Mysteries

There are questions that may be related to new forces and matter particles with mass around the TeV scale.

- What about **dark matter**?
- The Higgs mass is “unstable” in the Standard Model (very sensitive to initial theoretical parameters) – does something stabilize it? (e.g. “**supersymmetry**”, “**composite Higgs**”)
- Are there differences between **matter and antimatter** beyond those in the Standard Model?

Also, keep our eyes open for something unexpected!

# HIGGS BOSON

# H



The **HIGGS BOSON** is the theoretical particle of the Higgs mechanism, which physicists believe will reveal how all matter in the universe gets its mass. Many scientists hope that the Large Hadron Collider in Geneva, Switzerland, which collides particles at 99.99% the speed of light, will detect the elusive Higgs Boson

**\$10.49** PLUS SHIPPING



*Wool felt, fleece with gravel fill for maximum mass.* MADE IN CHINA.

