Quest for the Higgs Boson

Closing in on the origin of mass of fundamental particles

Bernd Stelzer

SFU

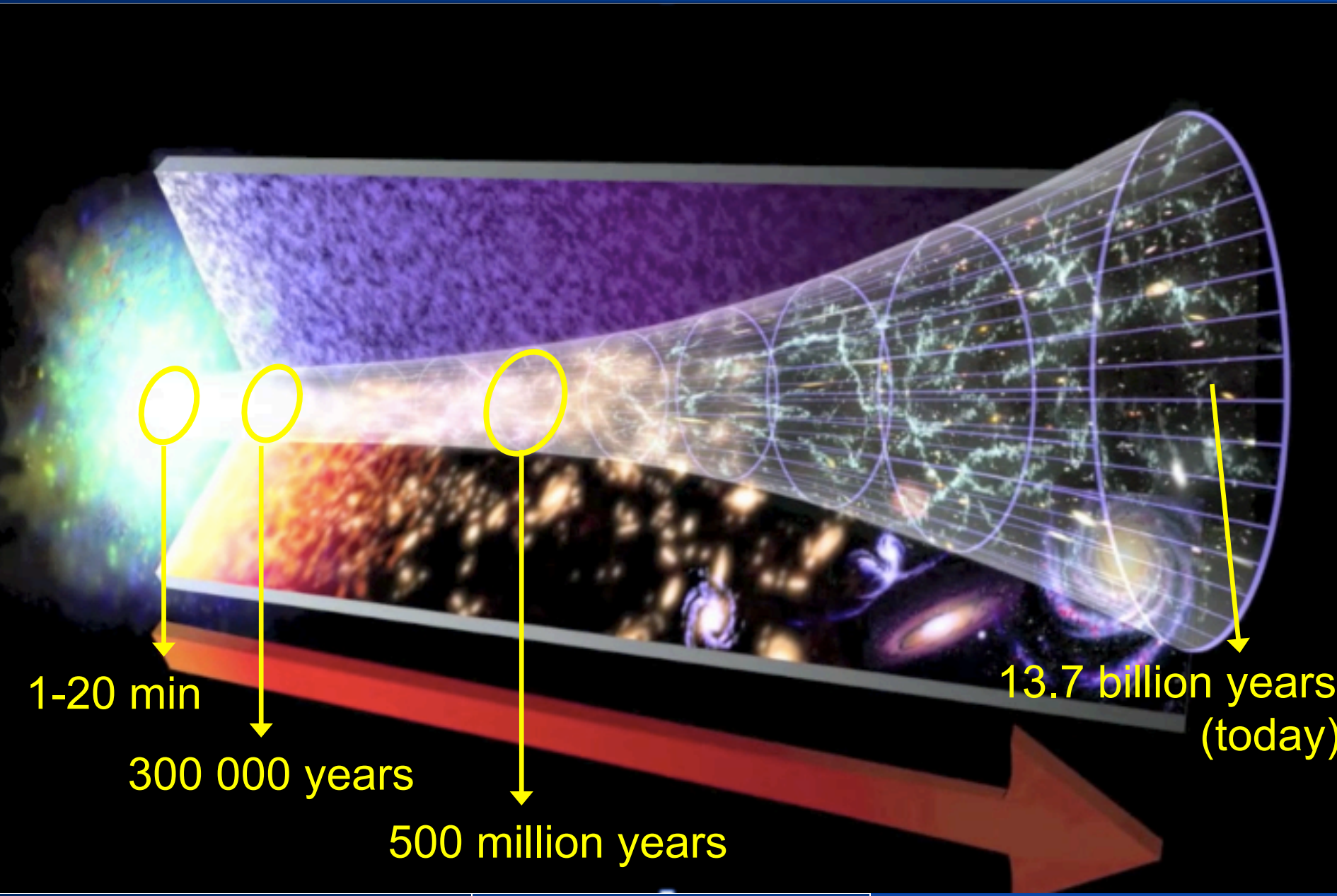
Big Bang Theory

Particle Physics:

Study of the *smallest building blocks of the universe,* their properties and interactions.

Big Bang Theory

Big Bang Theory



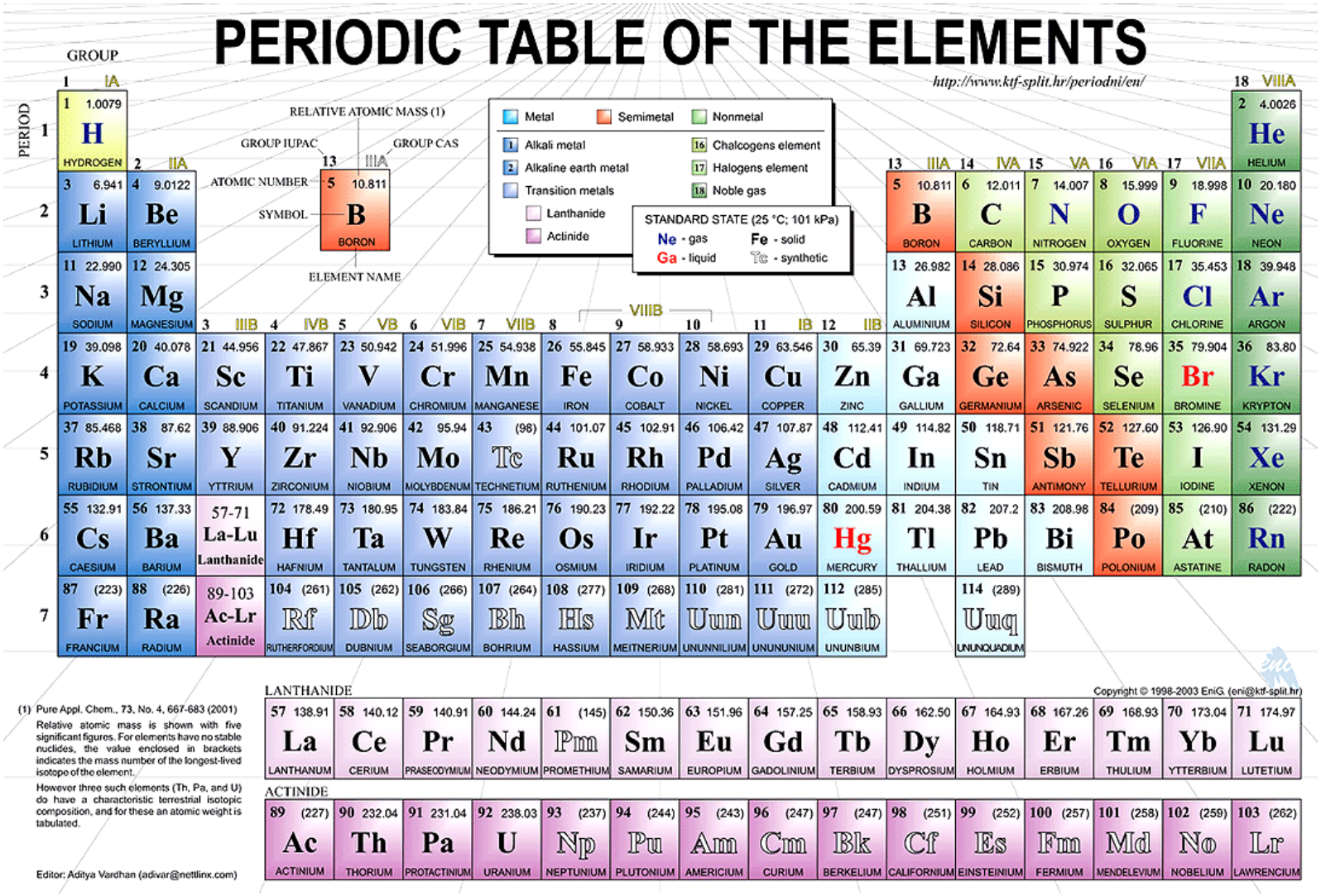
The Large Hadron Collider (LHC)

What is the Mass of Particles?

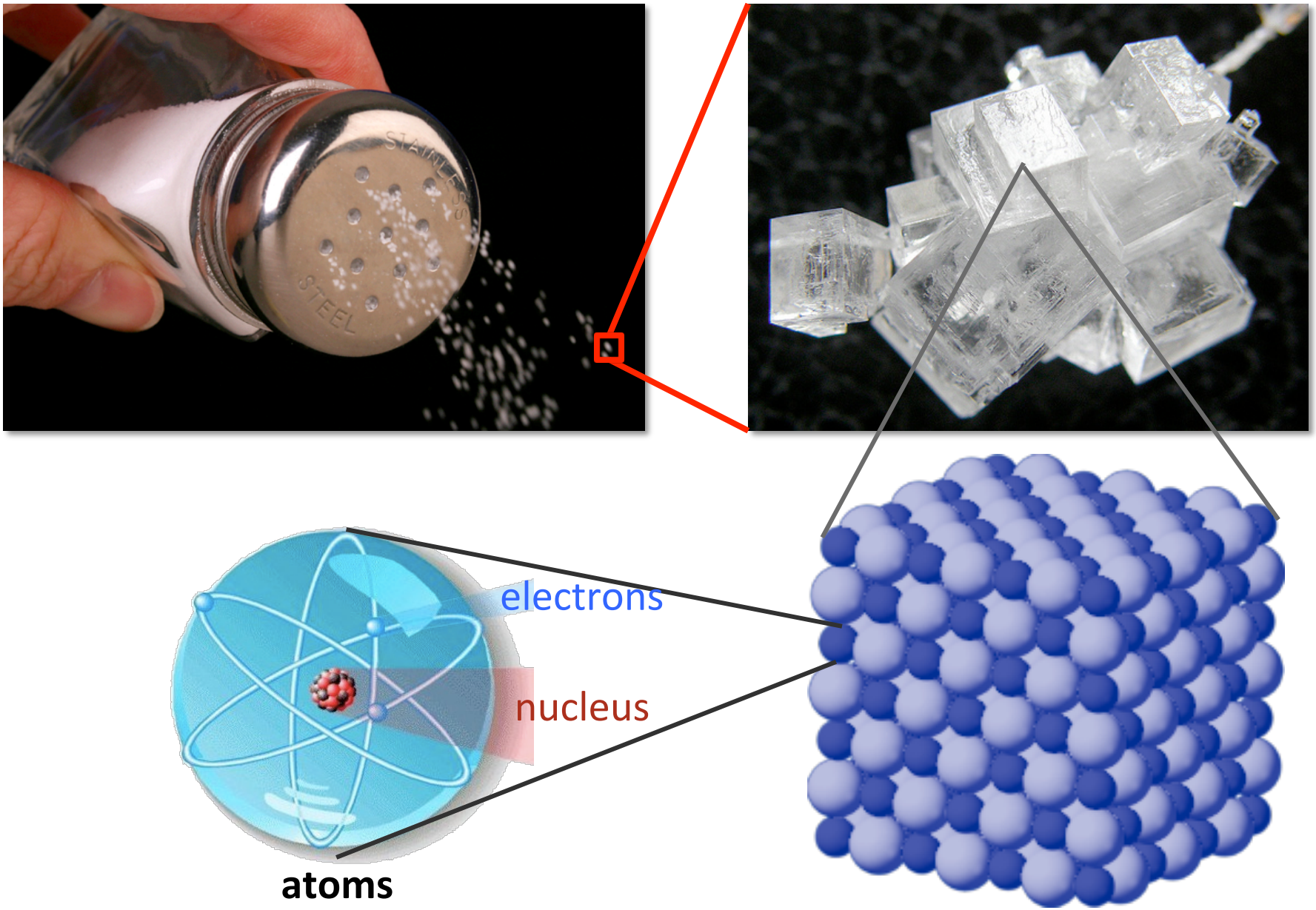
Isaac Newton

"*the property of a body that is a measure of its inertia and that is commonly taken as a measure of the amount of material it contains and causes it to have weight in a gravitational field*"

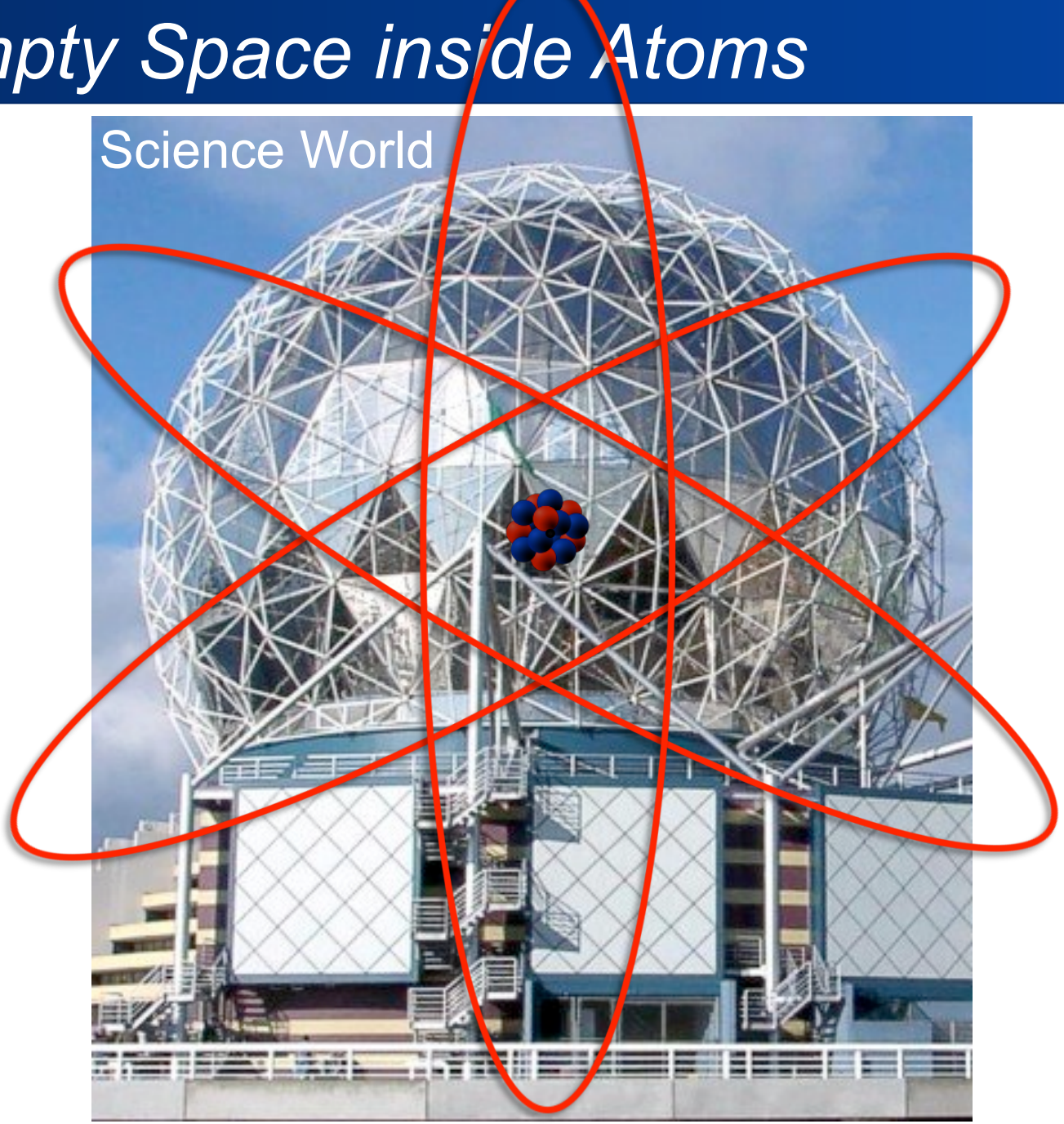
What is Matter?



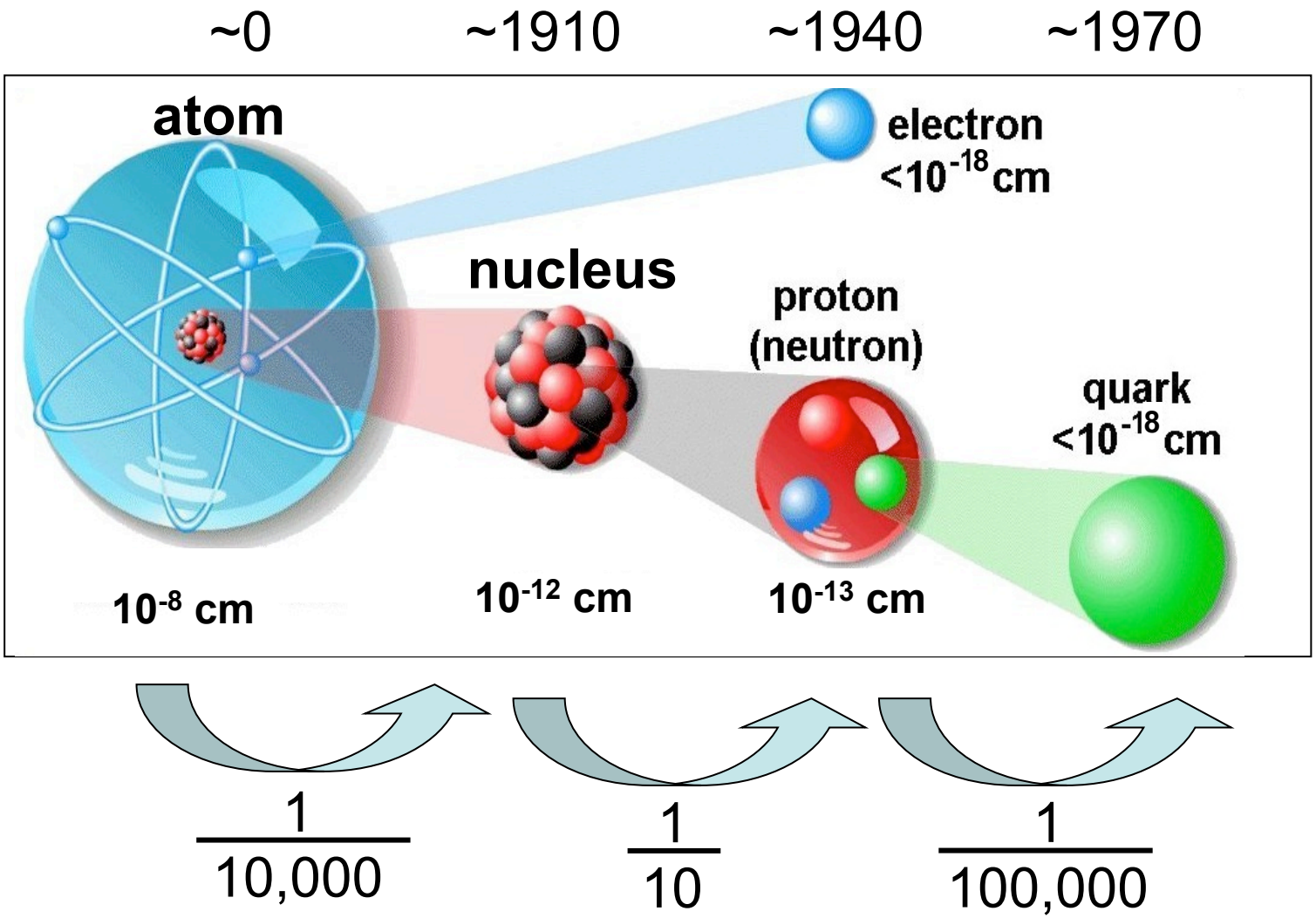
What is Matter made of?



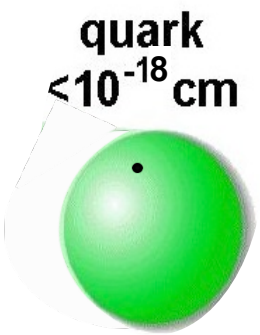
The Empty Space inside Atoms



Knowledge gained in the last Century

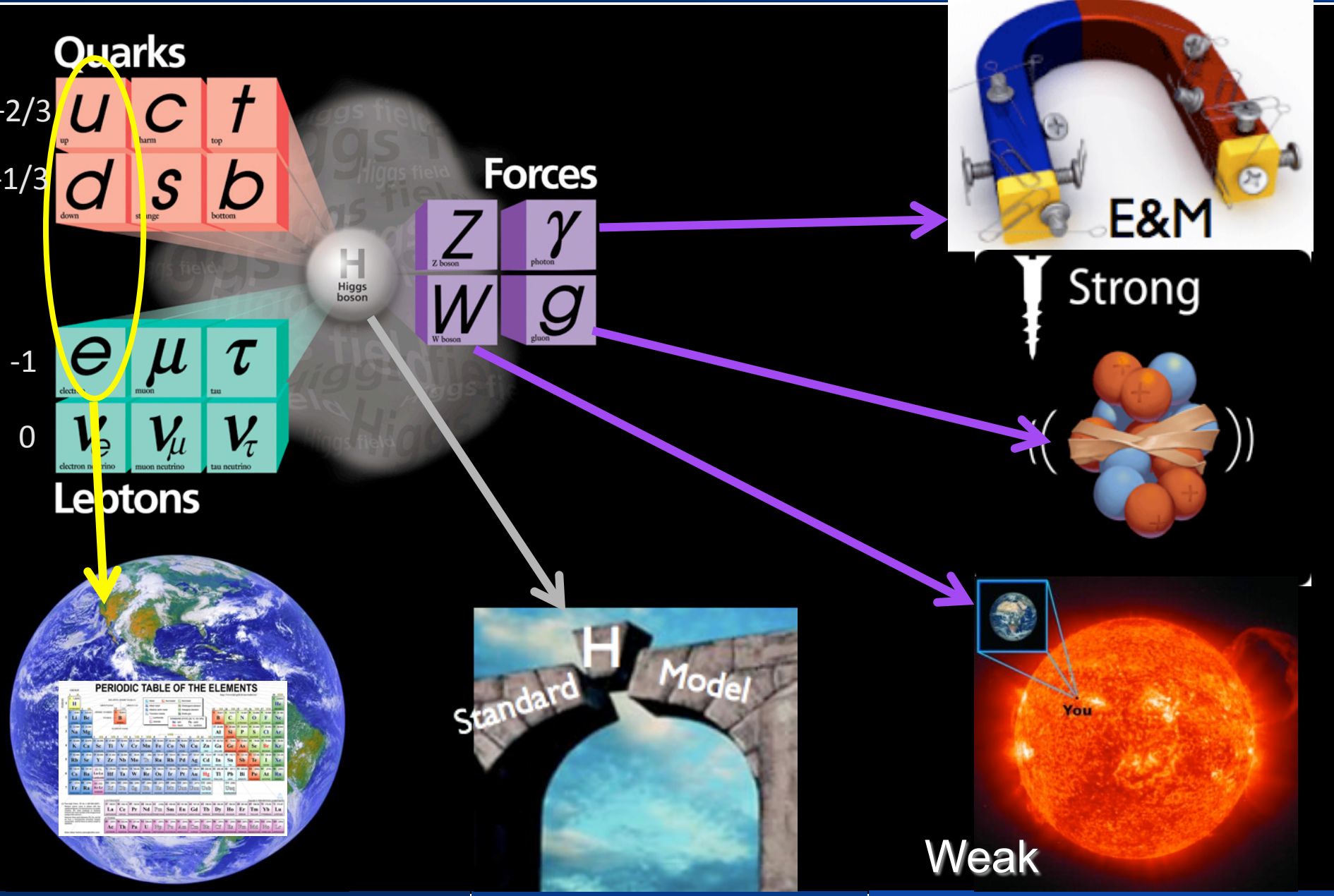


Knowledge gained in the last Century



The Standard Model of Particle Physics

The Standard Model of Particle Physics

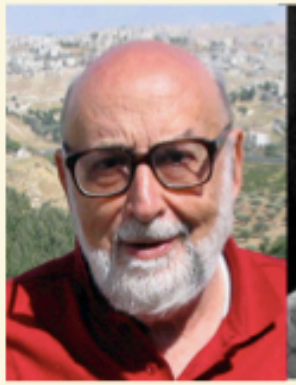


The Higgs Mechanism

Anderson

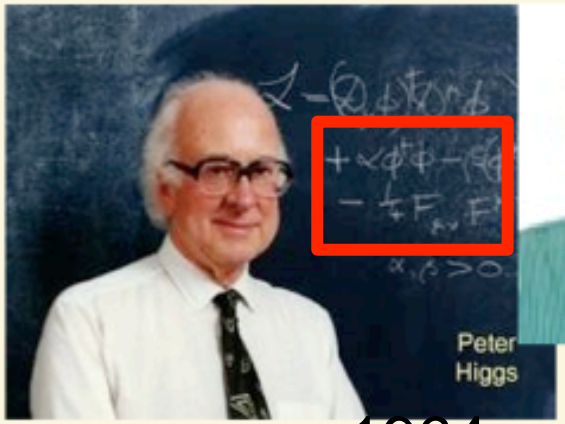
Nambu

Goldstone



Englert

Brout



1964

Guralnik

Kibble

Hagen

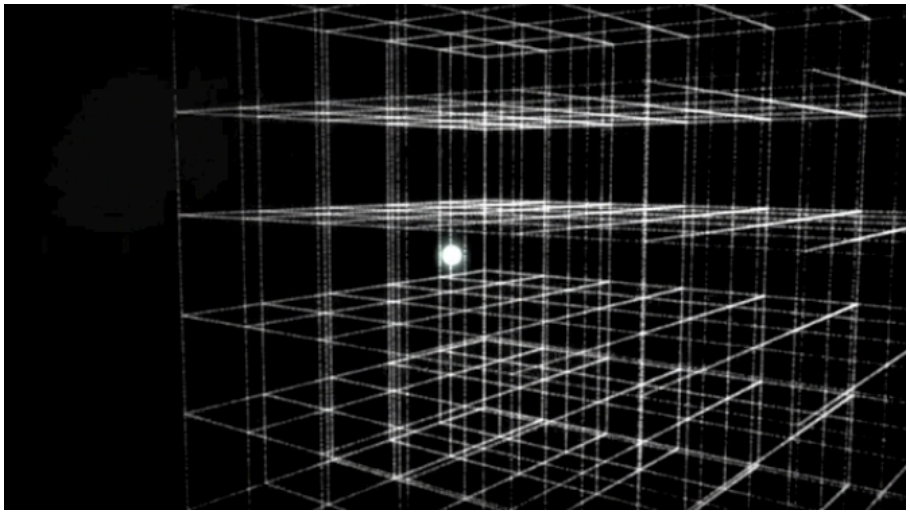
2010 J. J. Sakurai Theoretical Particle Physics

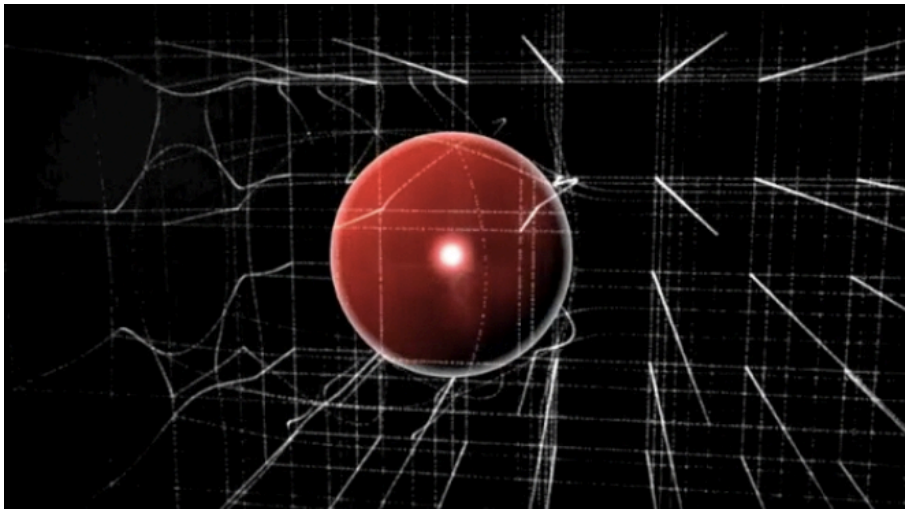
2013 Nobel Prize in Physics

Origin of Mass and Inertia – Higgs Field

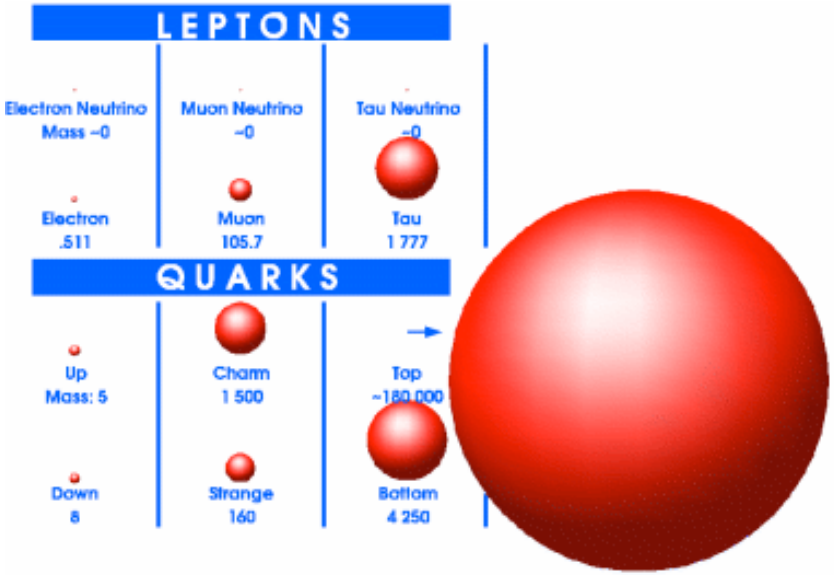
The Higgs Mechanism

Why do particles have mass?

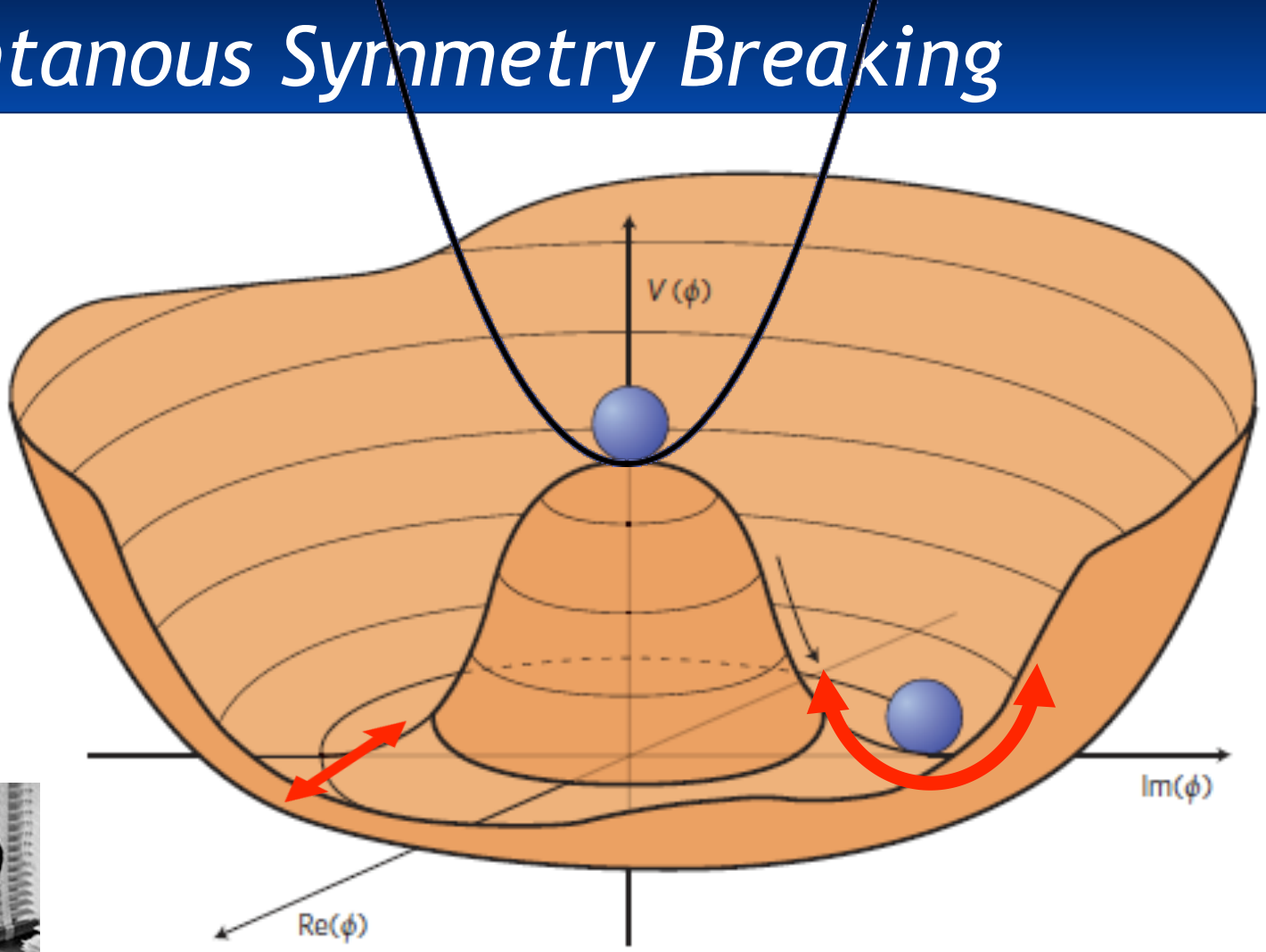




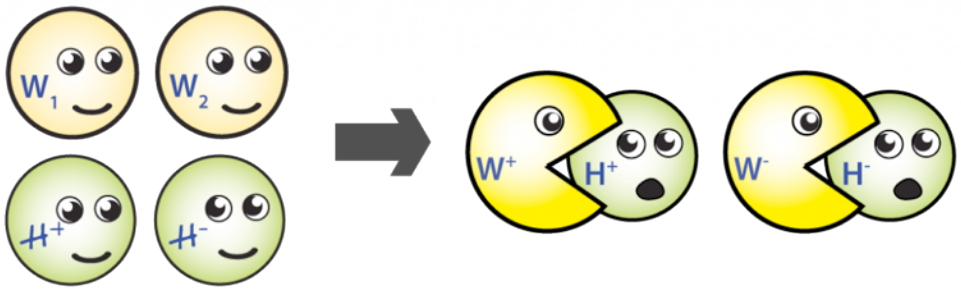
- Higgs field permeates all space and interacts with particles
- Strong interaction ⇔ large mass



Spontanous Symmetry Breaking

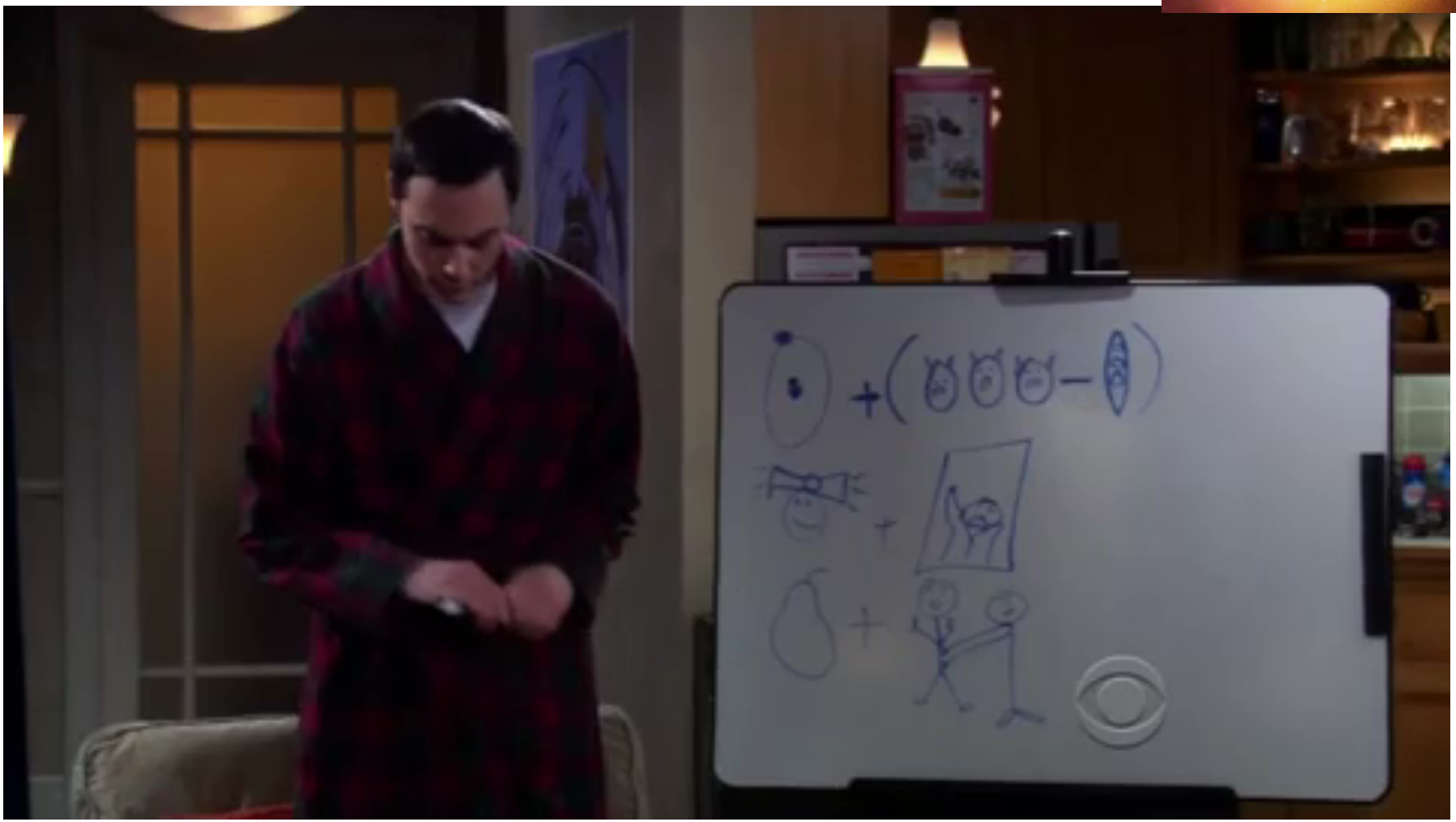


Nambu-Goldstone

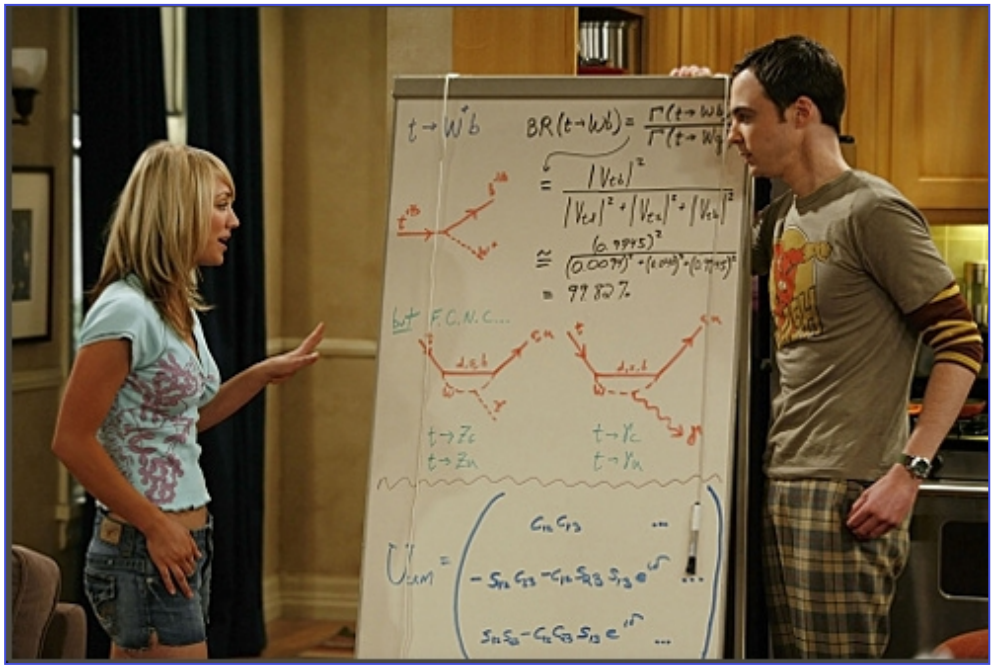


Higgs boson

Sheldon and the Higgs Boson

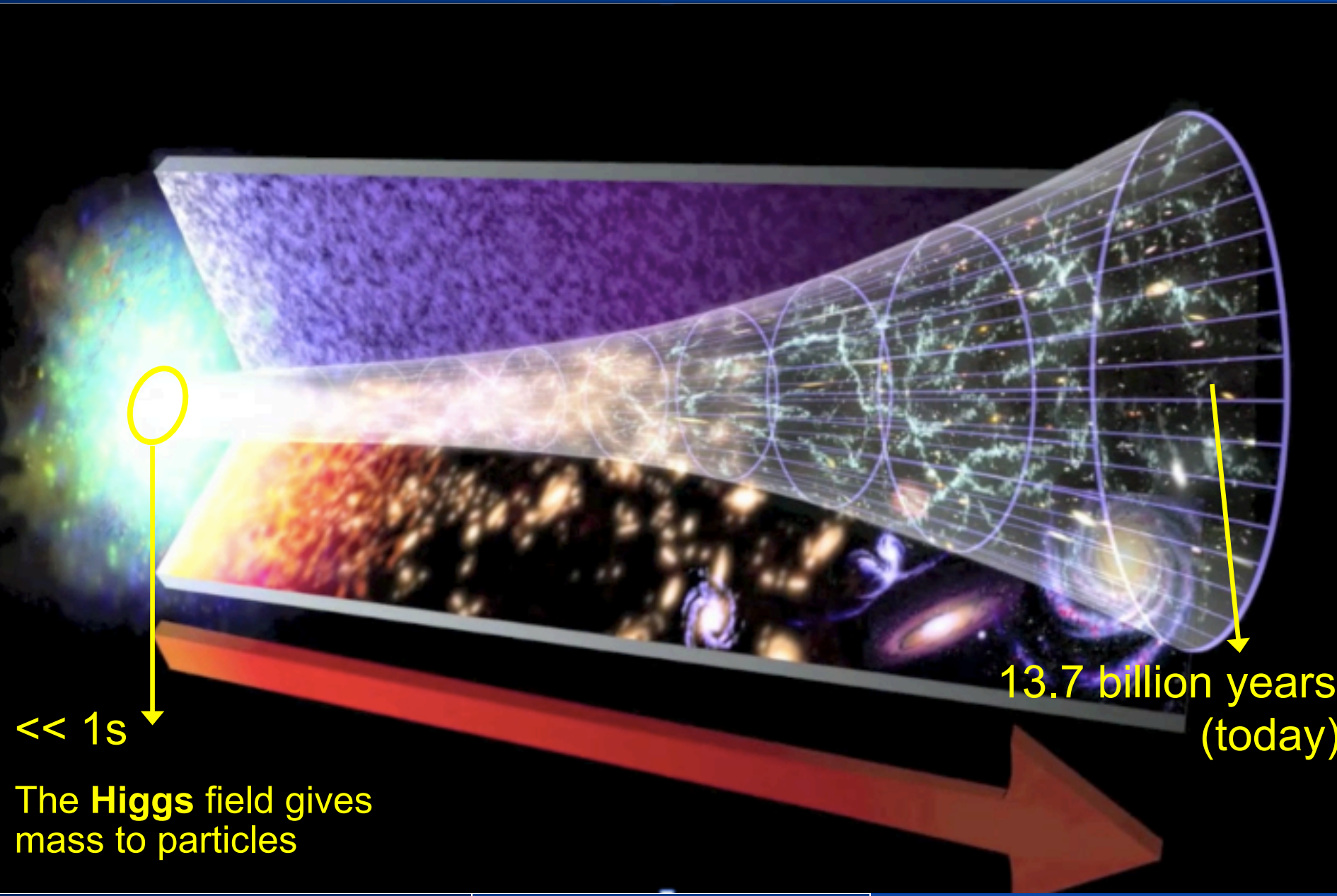


Big Bang Theory



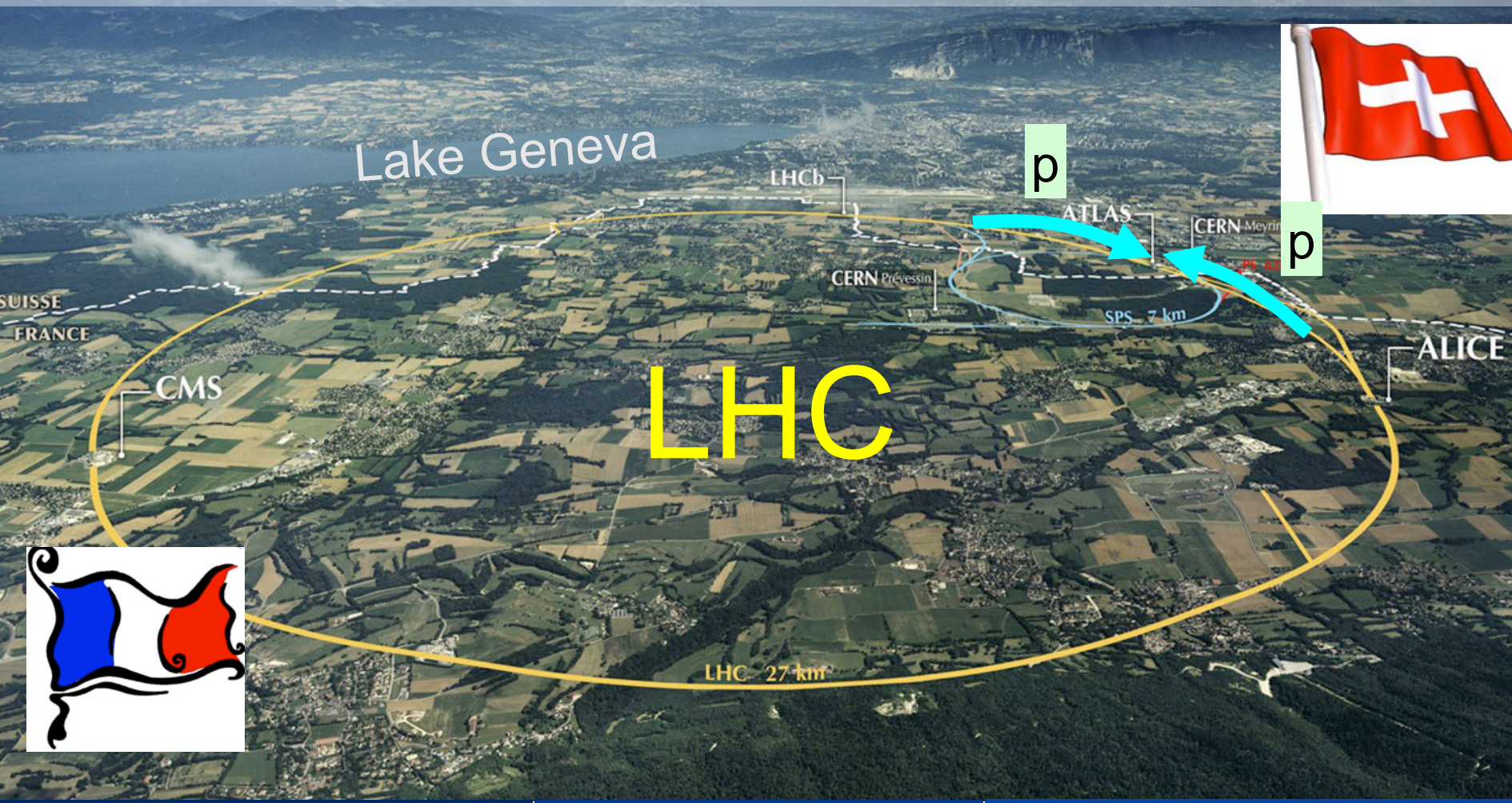
Making a ripple in the Higgs Field

Big Bang Theory

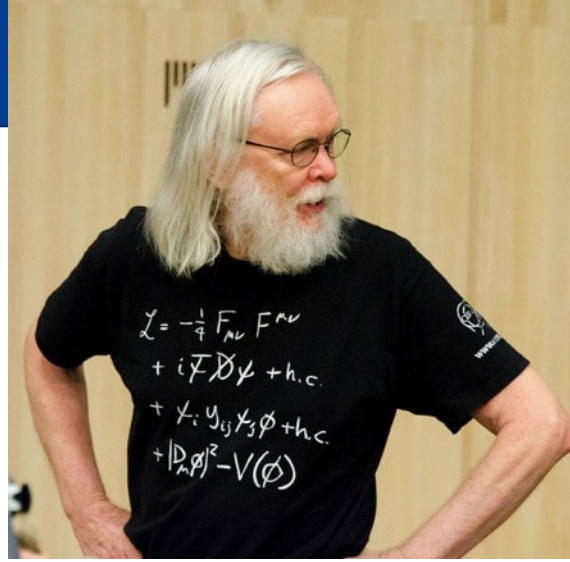


The Large Hadron Collider (LHC)

Air at room temperature:	0.04 eV	~20 °C
TRIUMF cyclotron:	500 000 000 eV	~10^{11} °C
Large Hadron Collider:	8 000 000 000 000 000 eV	~10^{15} °C



The Higgs Boson Mass



A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

Nucl. Phys. B 106, 292 (1976).

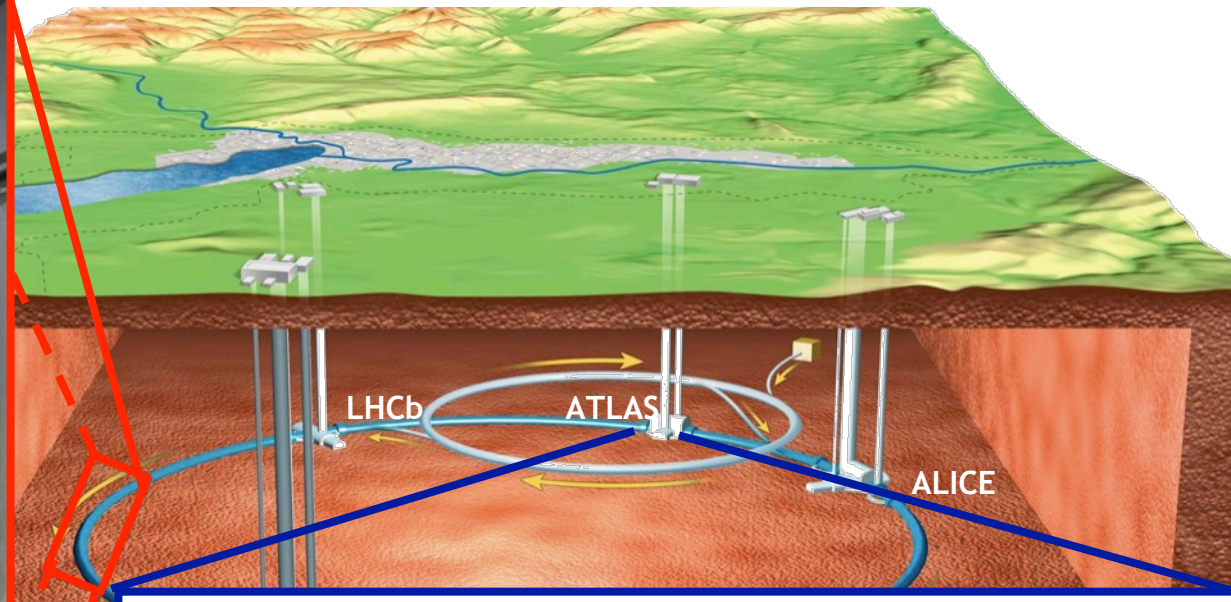
Received 7 November 1975

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all 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.

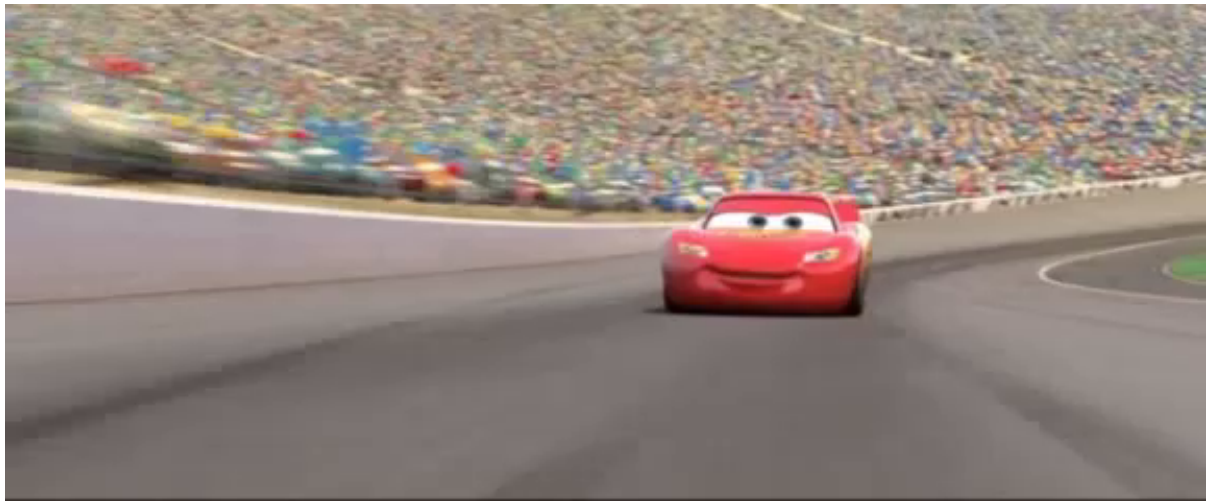
The Large Hadron Collider (LHC)

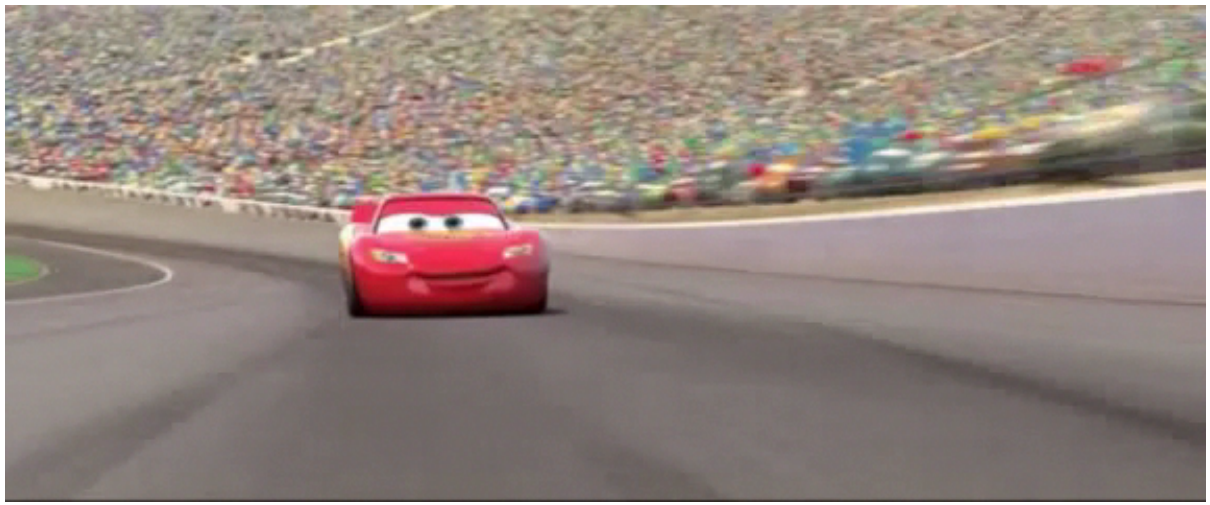
- protons go fast: 99.999999% of the speed of light
- make a full turn 11254 times per second

The Large Hadron Collider (LHC)



Large Hadron Collider – Race Track

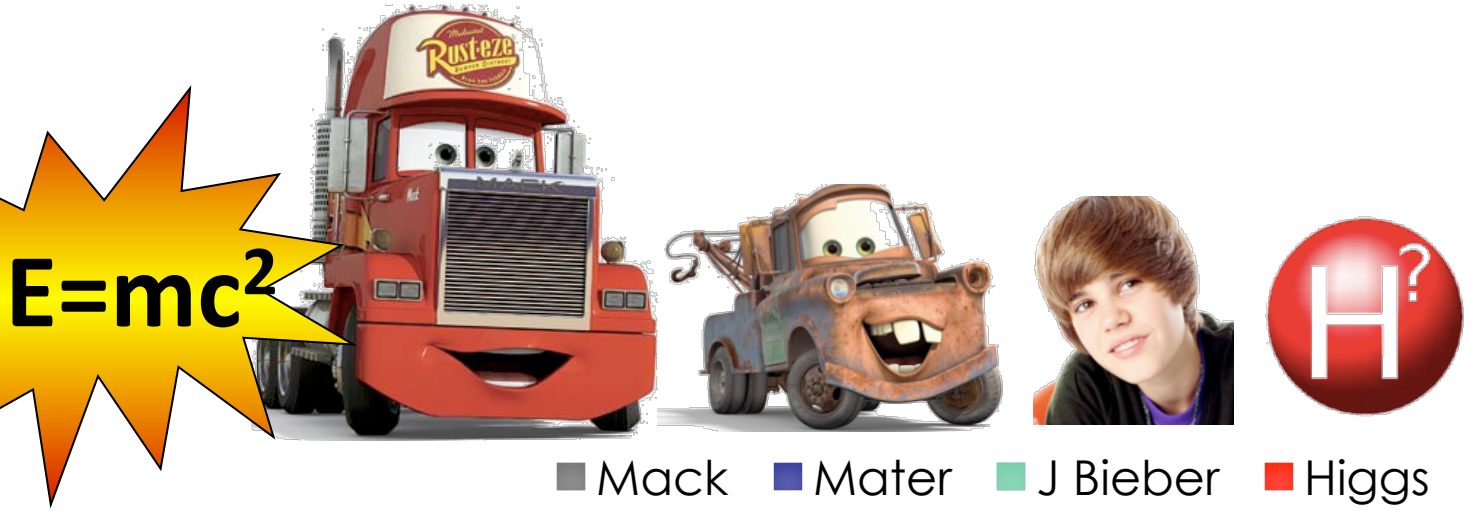


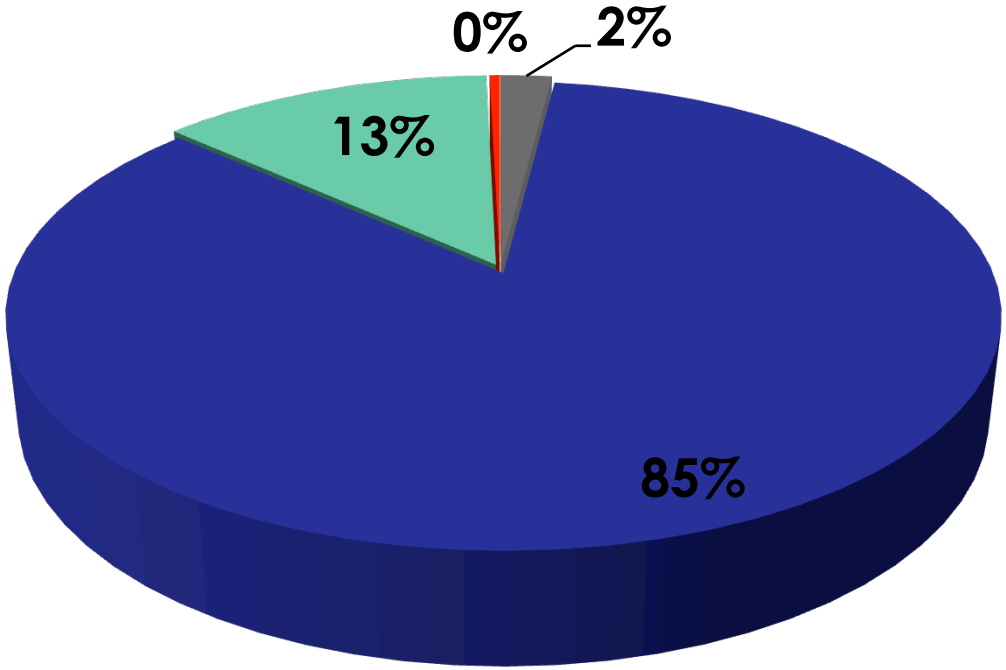


Collision Experiment - Typical Experience

Collision Experiment – Quantum Experience

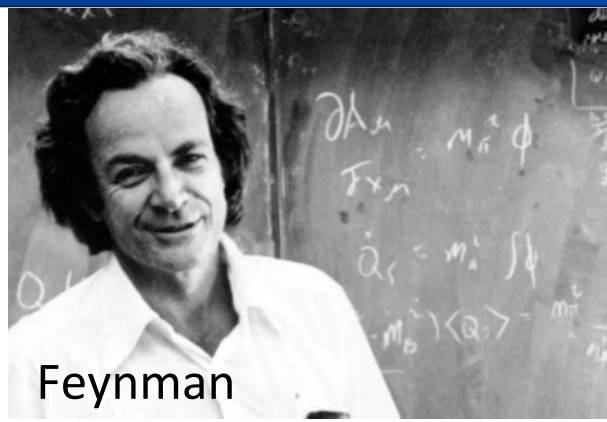
Collision Experiments – Quantum Probability

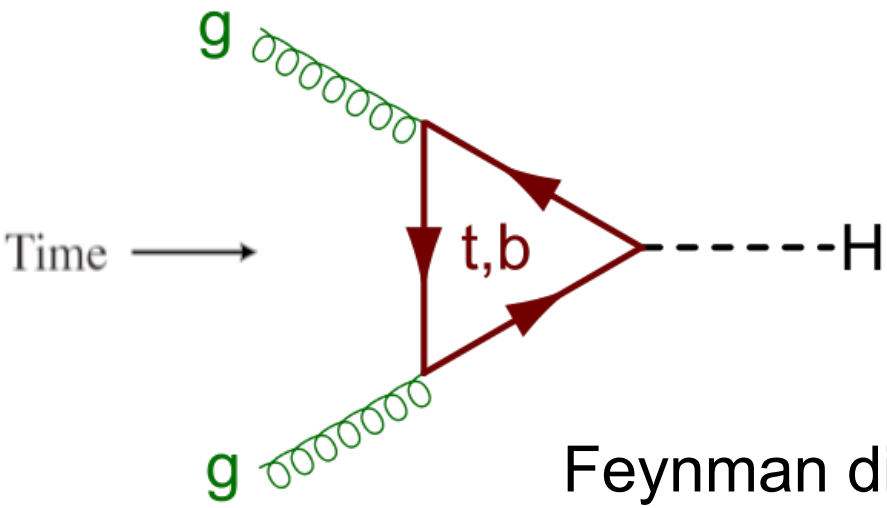


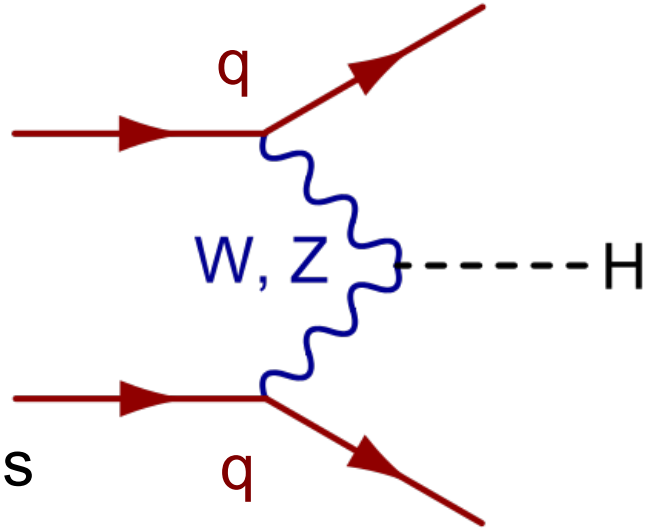


Higgs Boson Production

Higgs boson couples to massive particle.
But constituents of the proton are light.
Requires more complex interactions – Feynman tells us, these will occur *very rarely*, only once for every Trillion proton collision!







Feynman diagrams

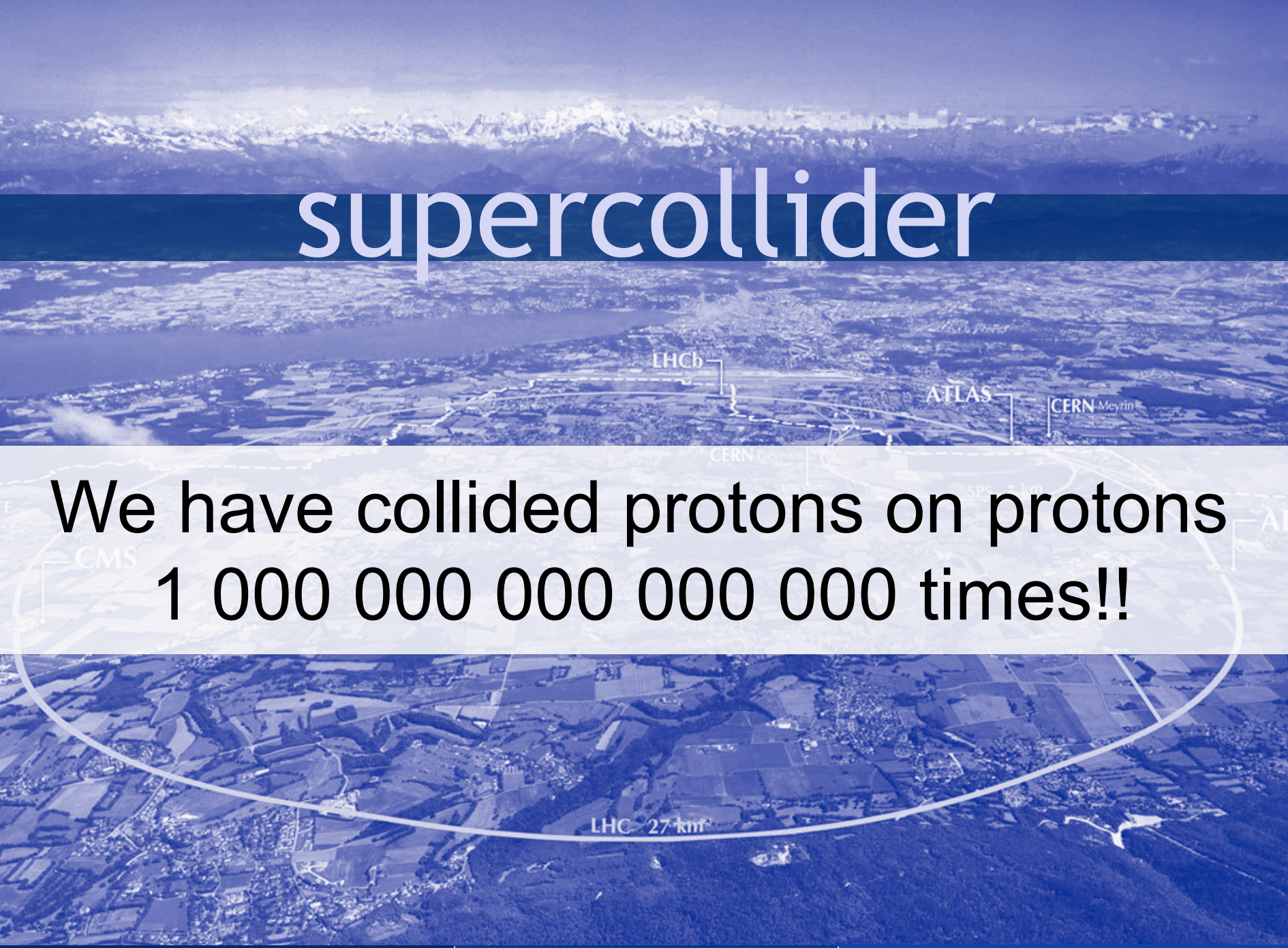
"Gluon fusion"

"Vector boson fusion"

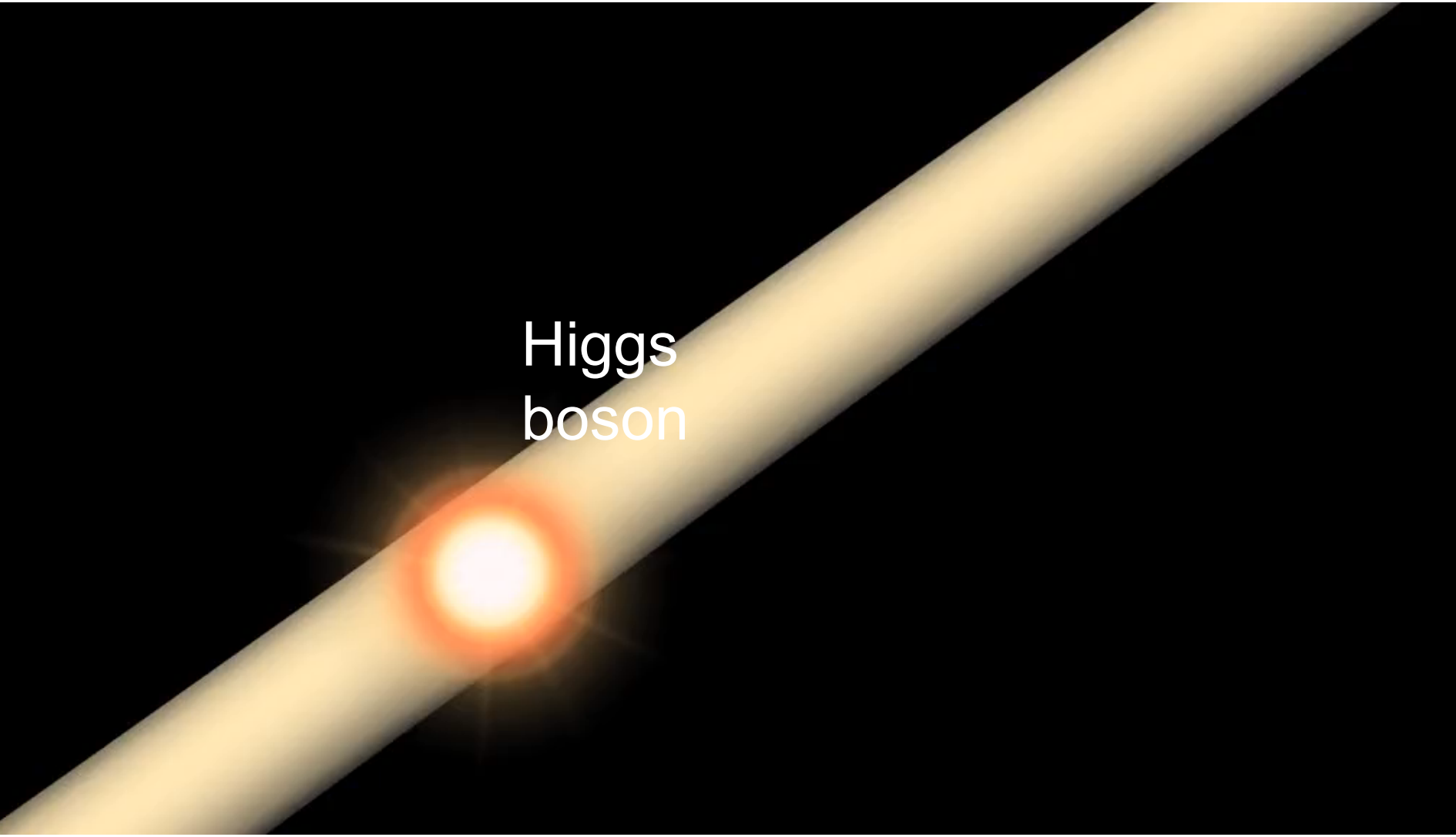
Requires many collisions (*many chances to produce a Higgs*)

supercollider

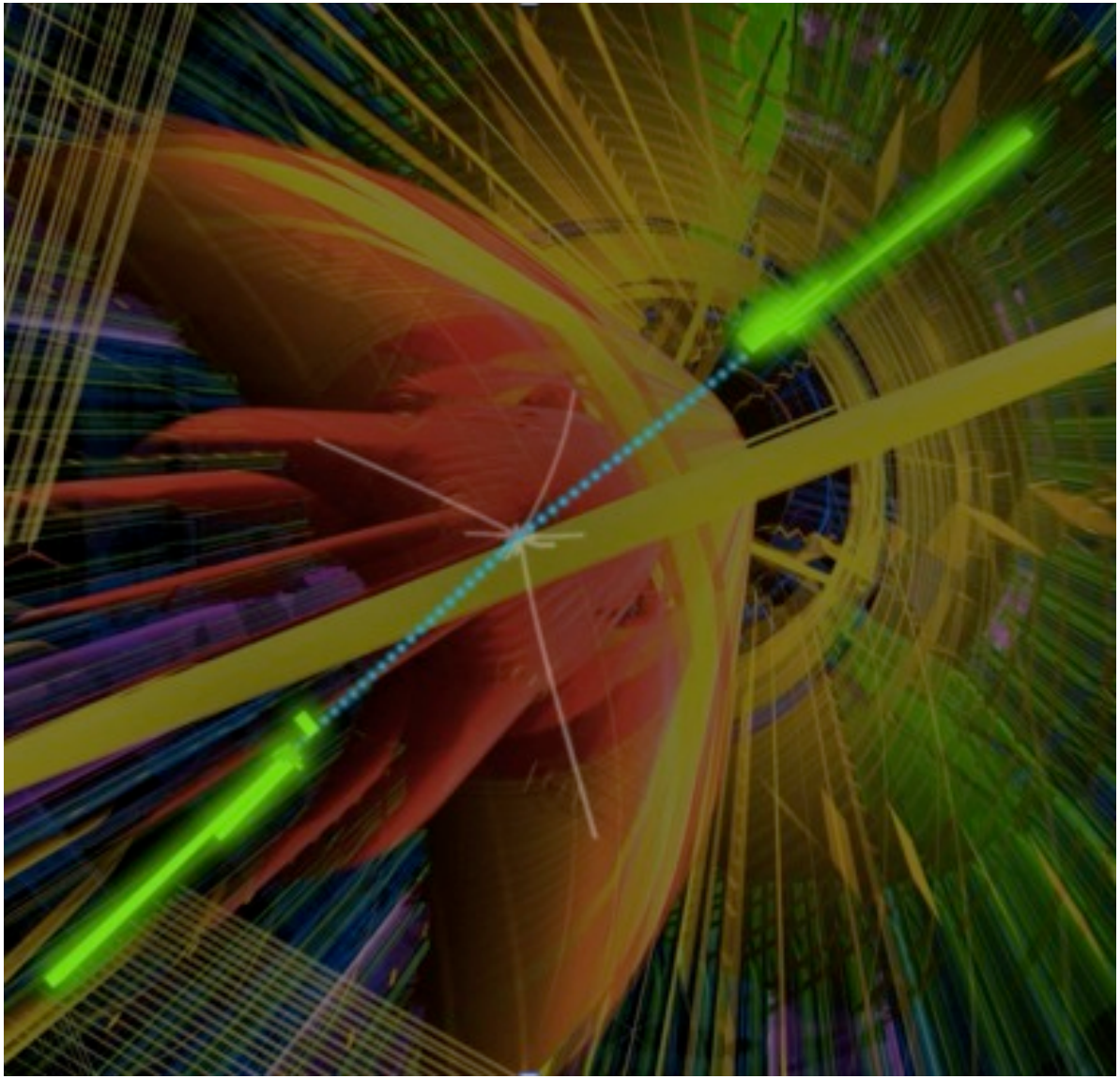
We have collided protons on protons
1 000 000 000 000 000 times!!



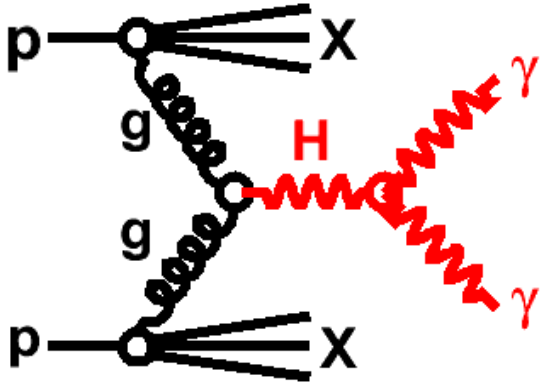
LHC is a Supercollider



Finding the Higgs with Photons

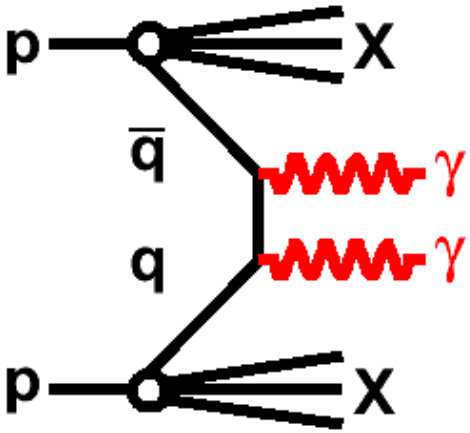


Higgs Production



or

Background ?

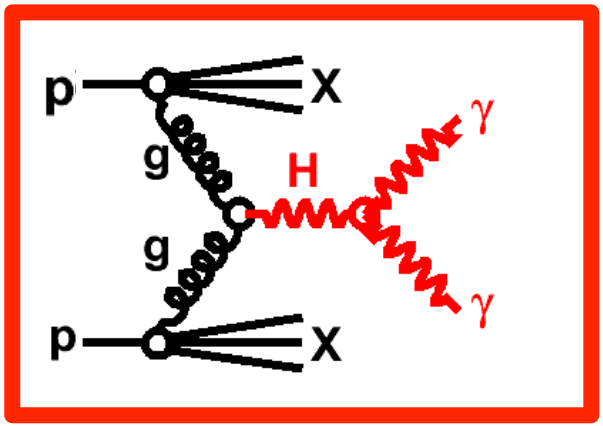


Finding the Higgs with Photons

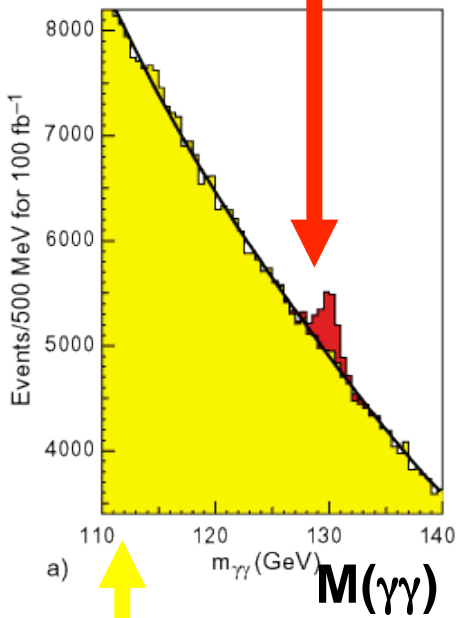
- Higgs boson decays to two energetic photons
  - Higgs mass can be determined from decay kinematics

- Background process looks identical
  - many times larger probability

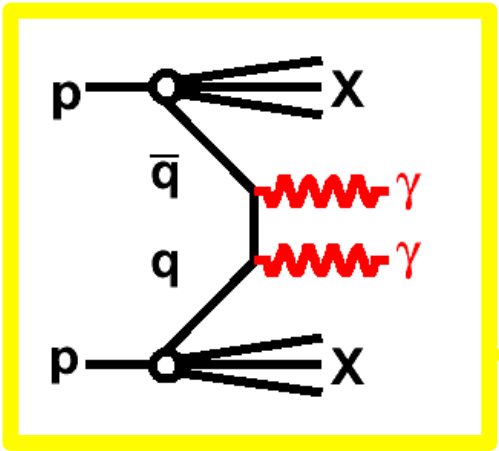
Higgs →γγ



This is what we look for!



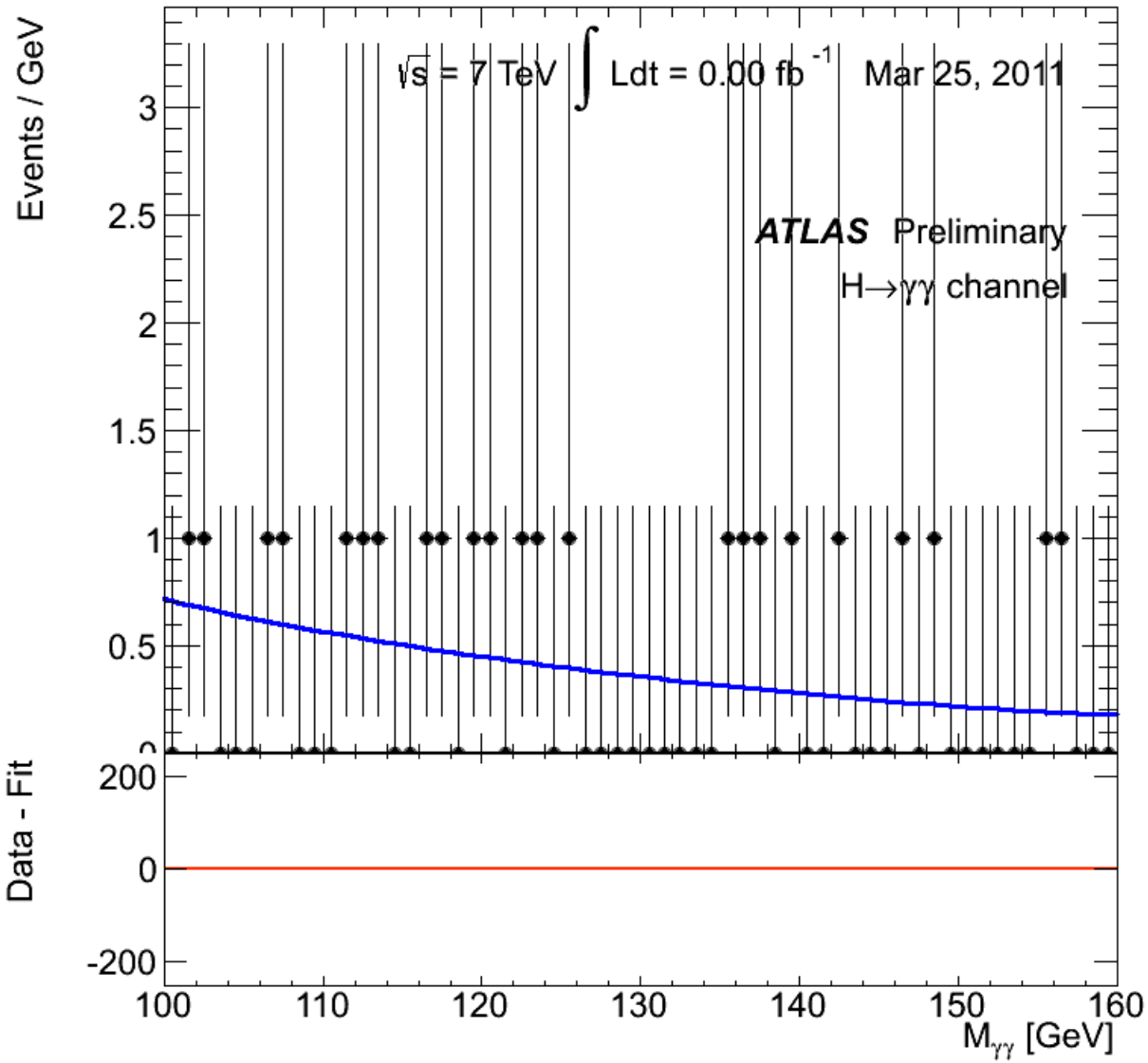
background



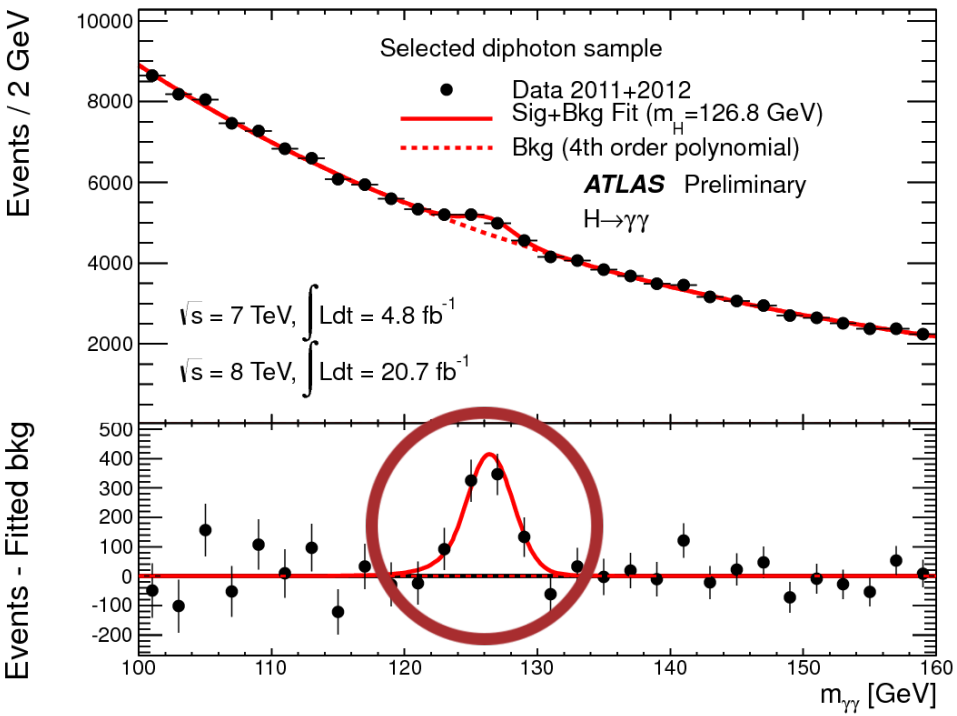
from relativity:

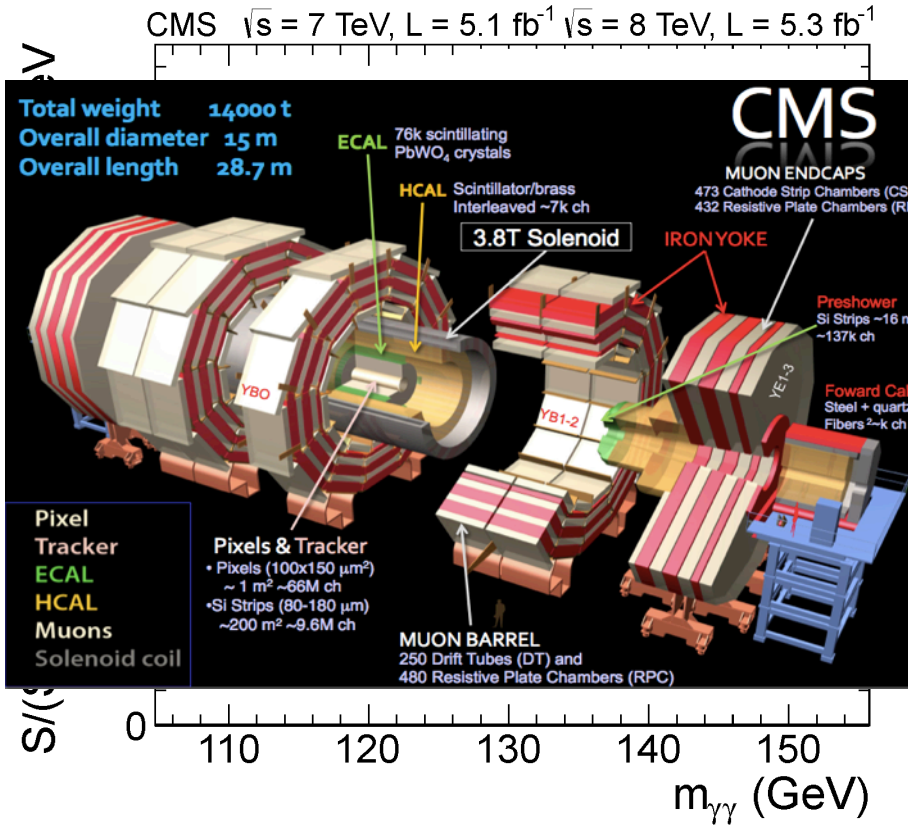
$$M_H^2 c^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 c^2$$

Finding the Higgs with Two Photons

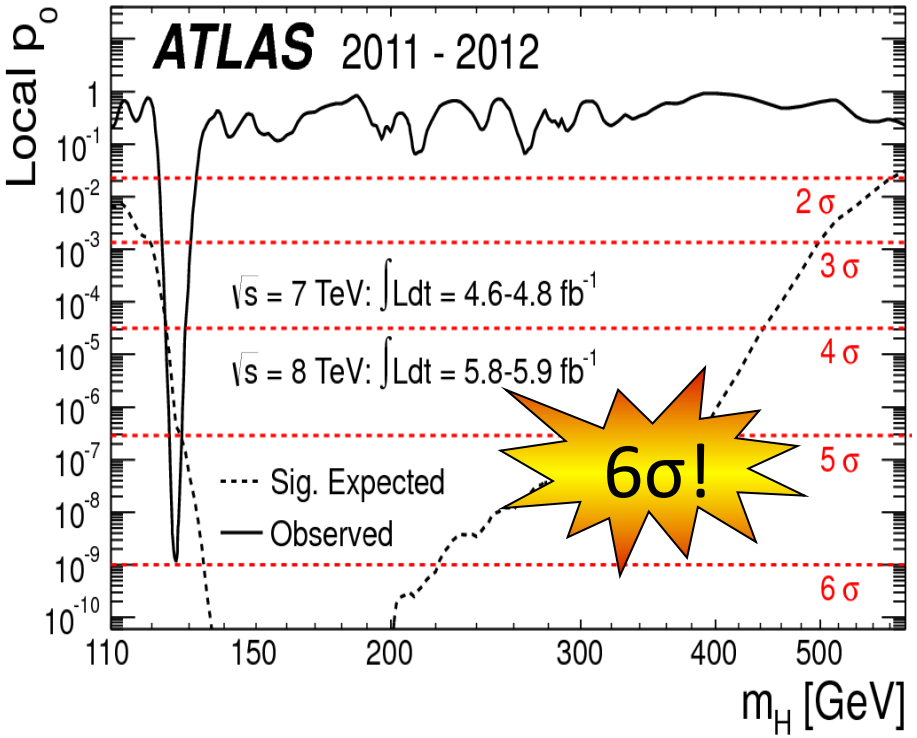


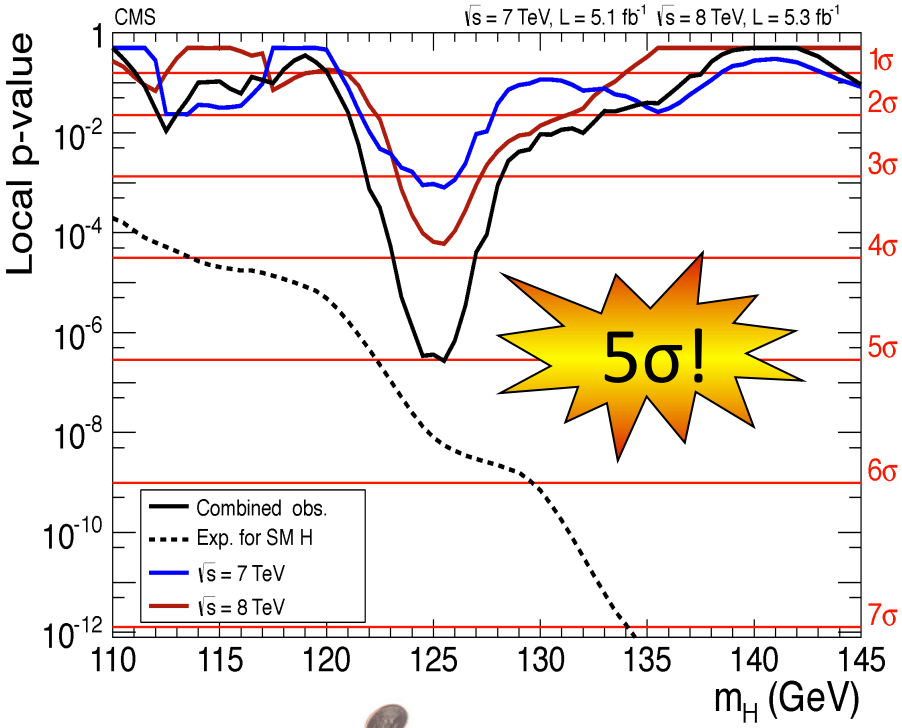
LHC is a Supercollider



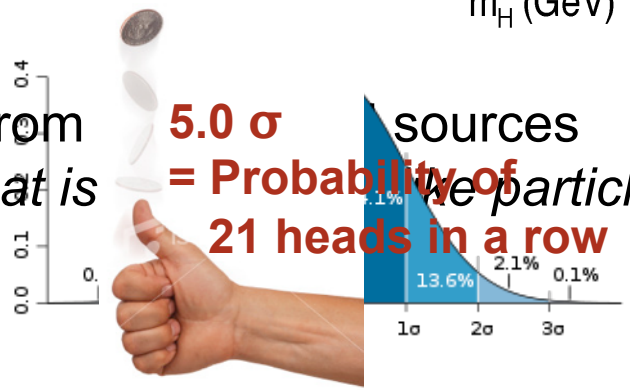


All LHC Results





p_0: Probability that the observed data originated from sources or measurement uncertainty (*i.e. probability that is* *we particle*)



LHC is a Supercollider

A Day to Remember

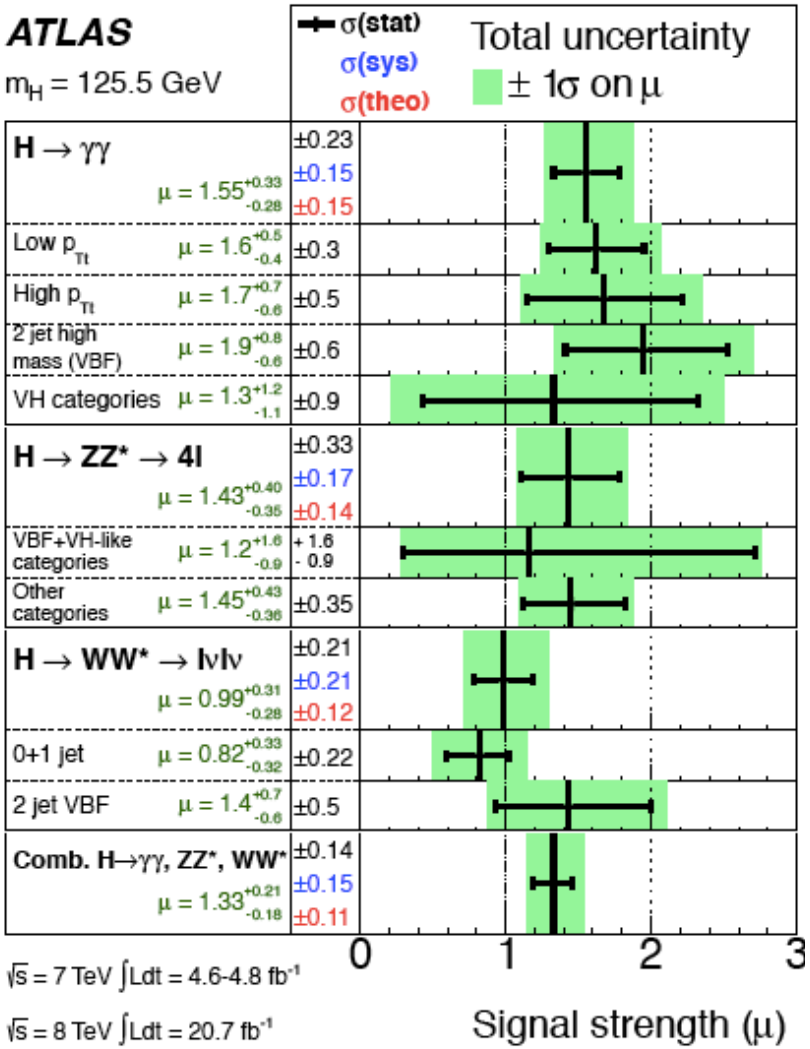
An historical day : 4th July 2012

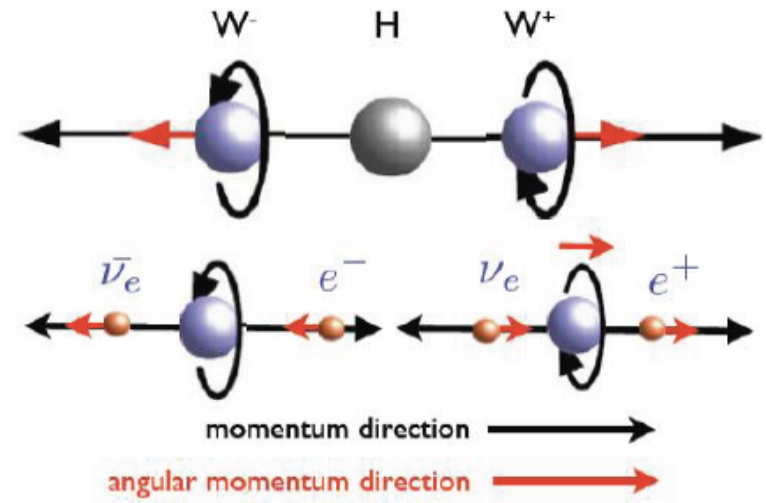
News Stories – What are they about?

- On July 4th, media was headlining stories about the Higgs boson

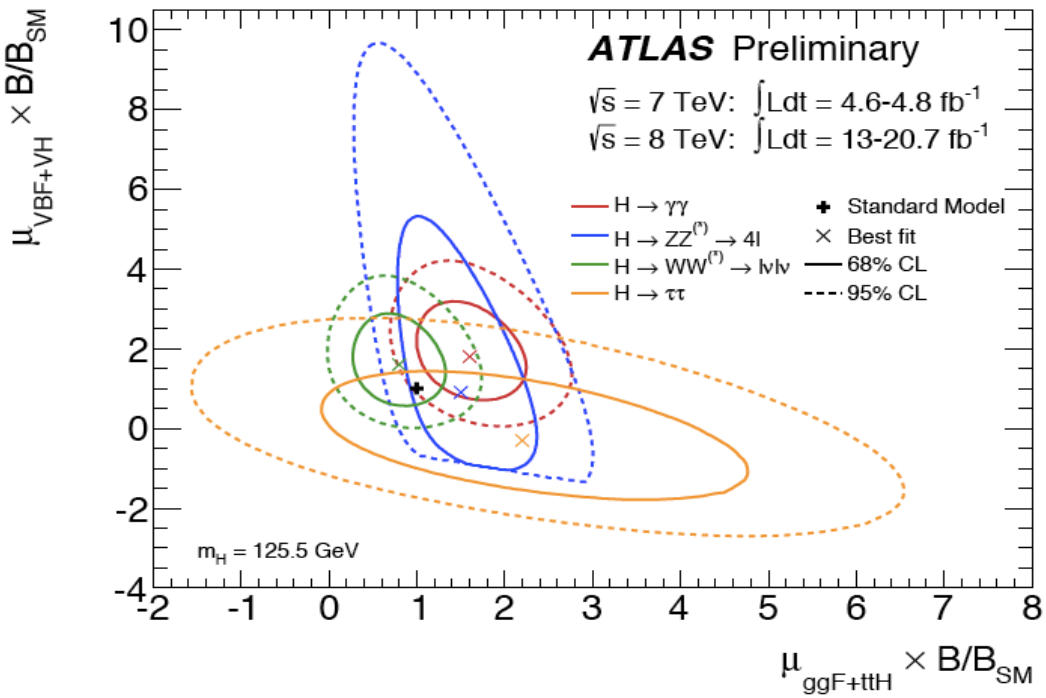
Many New Results since last year!

New particle is *now confirmed* to be *a Higgs* boson particle!





Bu
firs



Higgs Boson – One Year Later

theguardian

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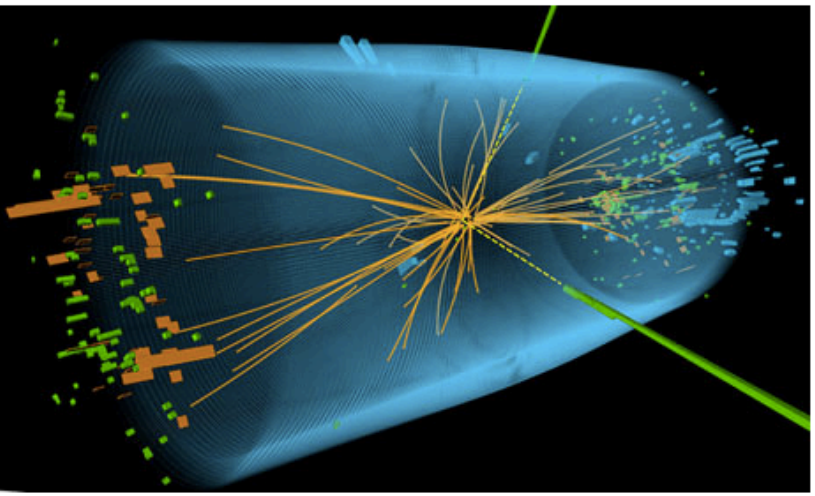
News > Science > Higgs boson

Cern scientists believe newly discovered particle is the real Higgs boson

Results of analysis at Cern in Switzerland show particle behaves precisely as expected

Ian Sample, science correspondent
The Guardian, Friday 15 March 2013



A representation of traces of a proton-proton collision issued by Cern as part of its efforts to find the elusive Higgs boson. New data strengthens the belief that a subatomic particle discovered last year is the Higgs boson, European scientists said. Photograph: Cern/AFP/Getty Images

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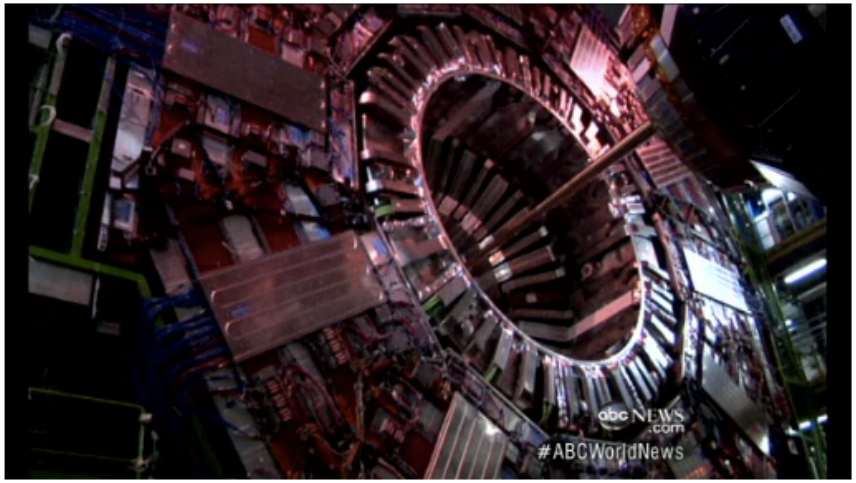
'God Particle': The Higgs Boson One Year Later

July 4, 2013

By JON M. CHANG via WORLD NEWS



Real CMS proton-proton collision events in which 4 high energy electrons (green lines and red towers) are observed.

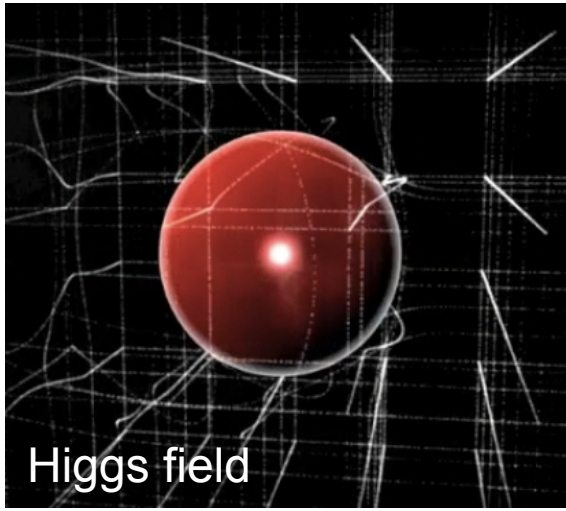
Thomas McCauley and Lucas Taylor/CMS/CERN

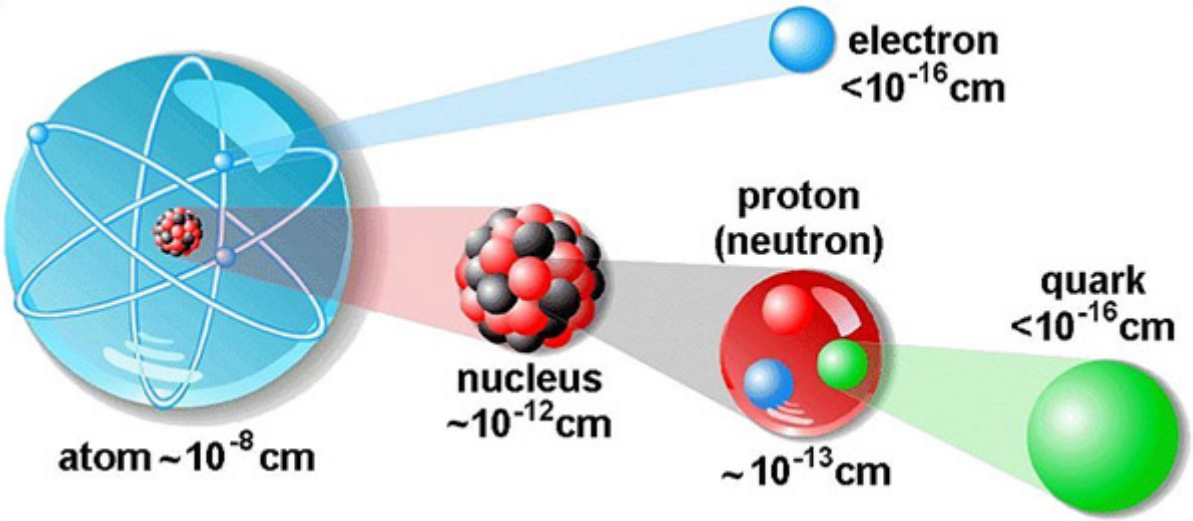
One year ago, several hours before cities across the United States started their annual fireworks displays, a different type of fireworks were set off at the European Center for Nuclear Research (CERN) in Switzerland. At 9:00 a.m., physicists announced to the world that they had found something they had been searching for for nearly 50 years: the elusive Higgs boson.

Why the Higgs Field Matters?

What if we could switch off the Higgs field?

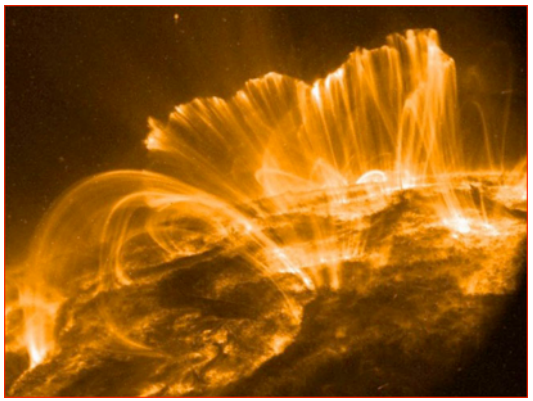
1. Good news: we loose some weight!
2. Bad news: there will be no atoms!





Bohr radius:

$$a_0 = \frac{4\pi\varepsilon_0\hbar^2}{m_e e^2}$$



3. Protons will not be stable, but decay
4. No nuclear fusion *no suns – dark universe*

ATLAS Collaboration

3000 Physicists from 38 countries and 174 institutes

ATLAS Canada Collaboration

Rob McPherson, Spokesperson (University of Victoria, IPP)
Richard Teuscher, Deputy Spokesperson (University of Toronto, IPP)
Reda Tafirout, Computing Coordinator (TRIUMF)
Bernd Stelzer, Physics Coordinator (Simon Fraser University)
stelzer@sfu.ca

University of Alberta
University of British Columbia
Carleton University
McGill University
Université de Montréal
Simon Fraser University
University of Toronto
TRIUMF, Vancouver
University of Victoria
York University

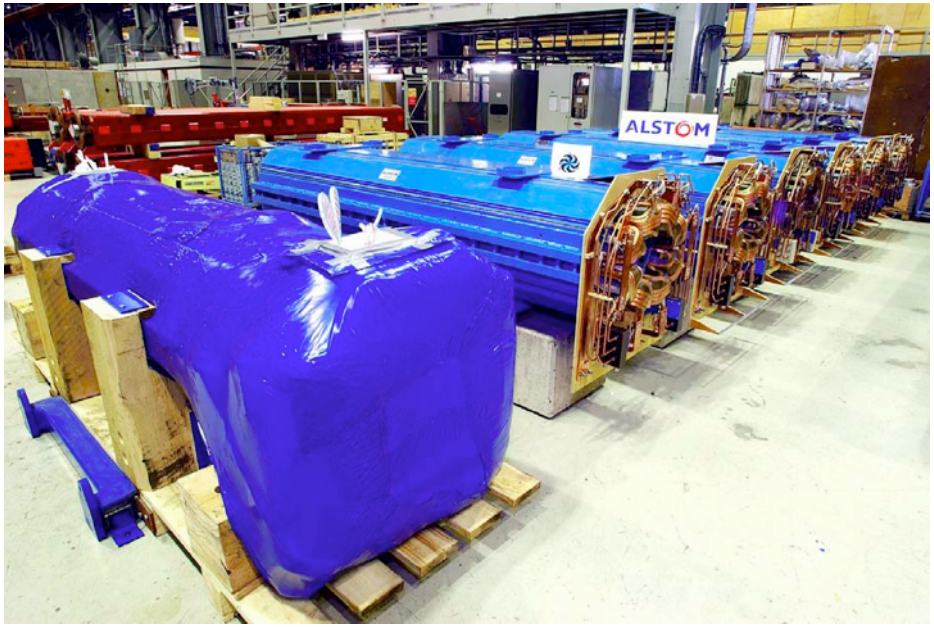
(150 Canadians from 10 institutes)

Large Hadron Collider - Years in the Making

- About 10 000 magnets (15m long, 35 tons, 8.4 Tesla)
- Operated at colder than outer space (superconductors)

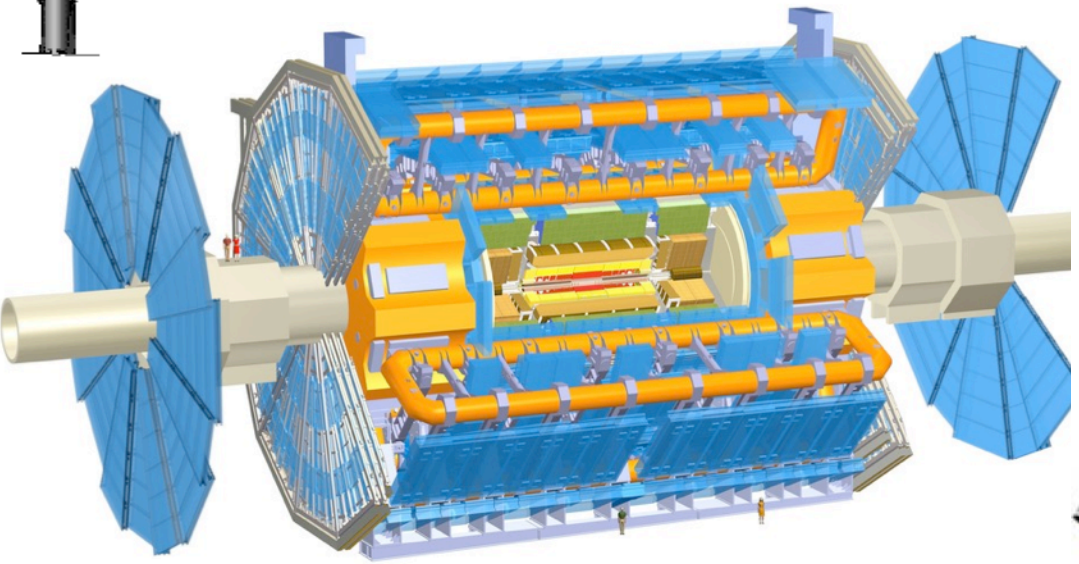
Canada and the LHC

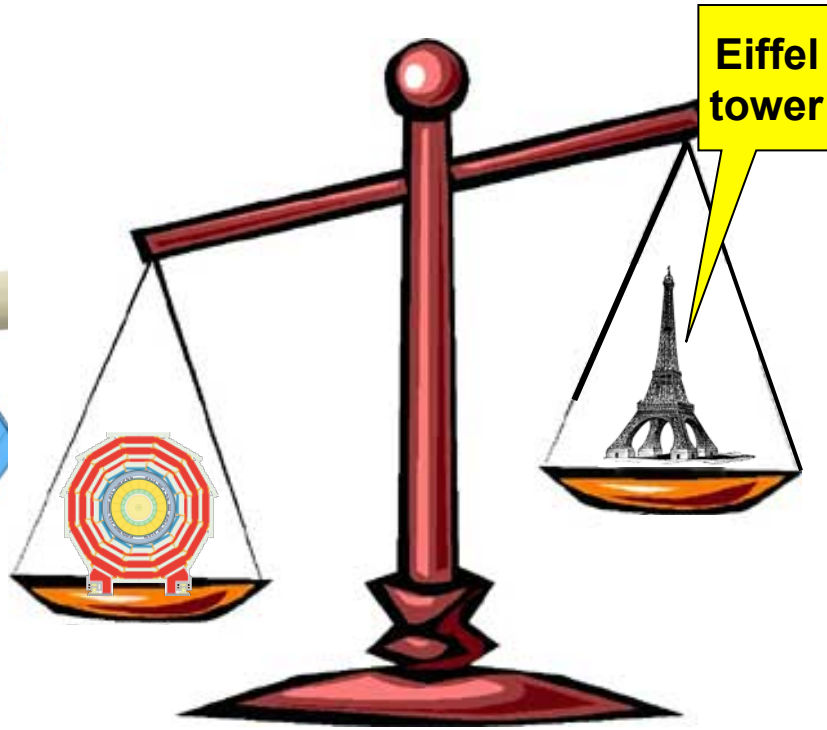
- Canada made important contributions to the LHC machine



Canadians made substantial contributions to the construction of the LHC through TRIUMF. This involved upgrades to the *injector synchrotrons to provide the LHC beams with higher brightness*, ferrite rings and high voltage power supplies for the PS booster upgrade, booster to PS transfer lines, *twin-aperture quadrupole magnets* for beam injection cleaning, pulse forming networks and injection kicker magnets to the LHC and beam position monitors

ATLAS and CMS Detectors



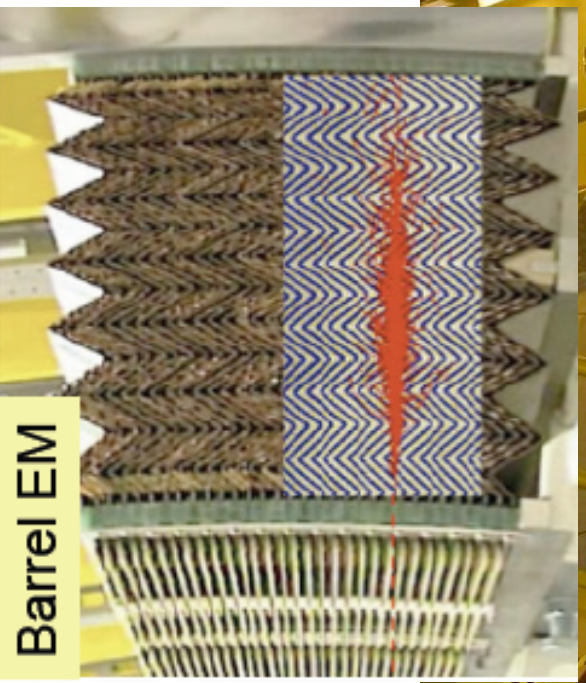


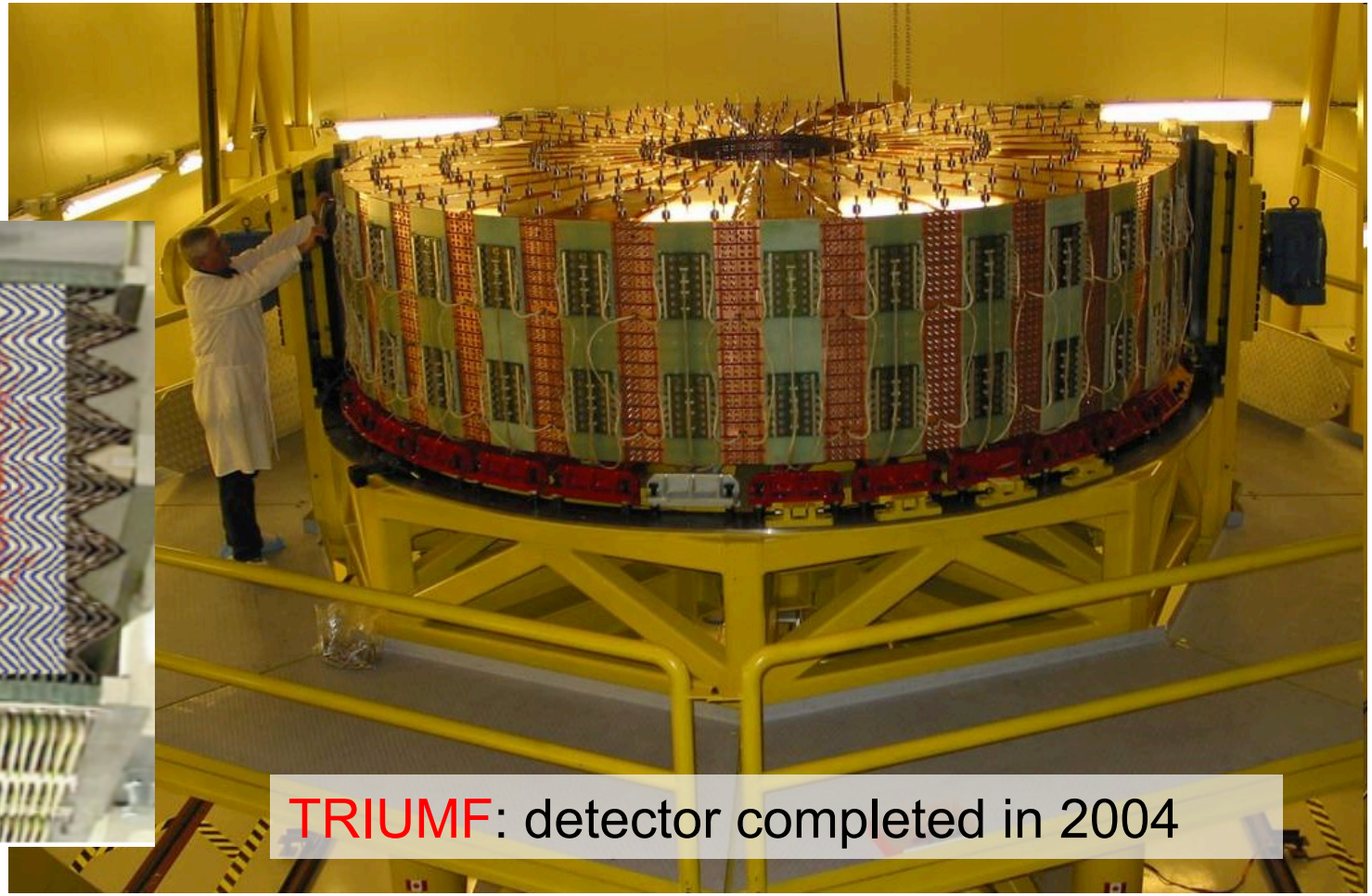
100 million electronic signals (“pixel”)

3000 km of wires

	Weight (tons)	Length (m)	Height (m)
ATLAS	7,000	42	22
CMS	12,500	21	15

Canadian Contribution to ATLAS

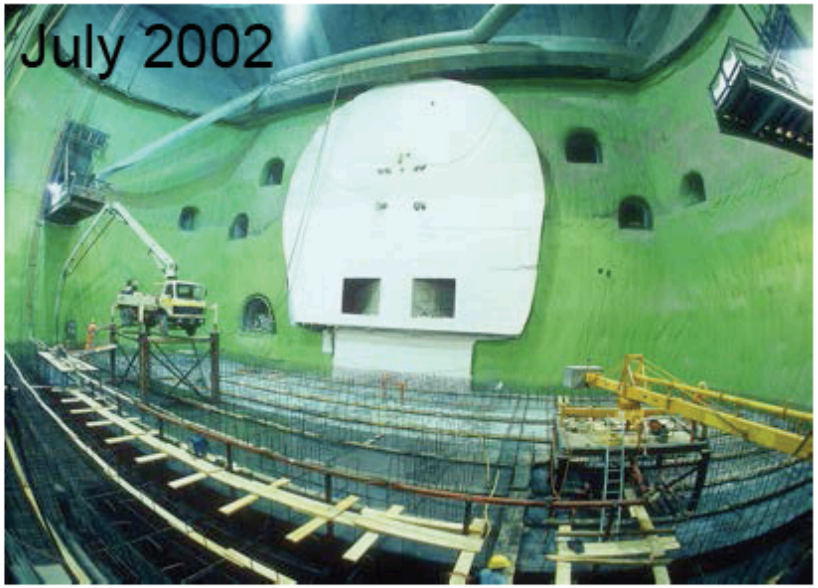


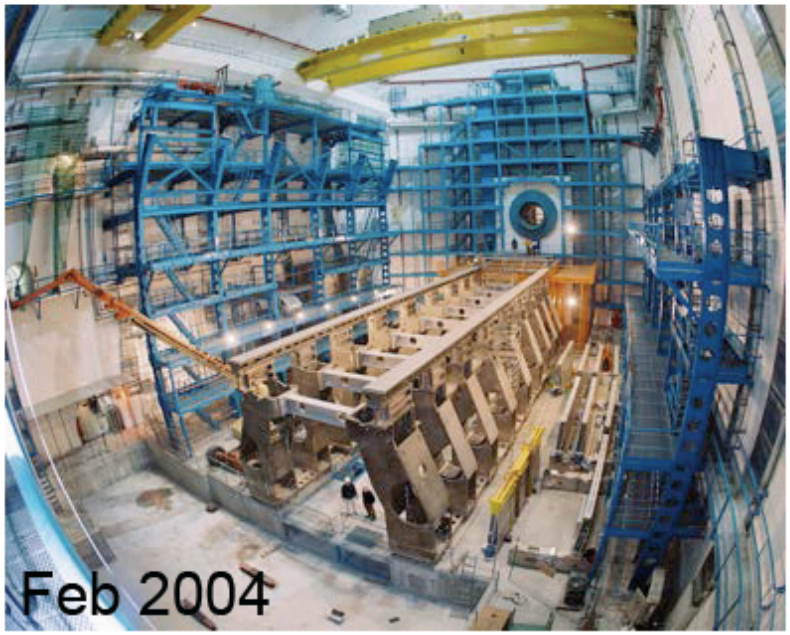


TRIUMF: detector completed in 2004

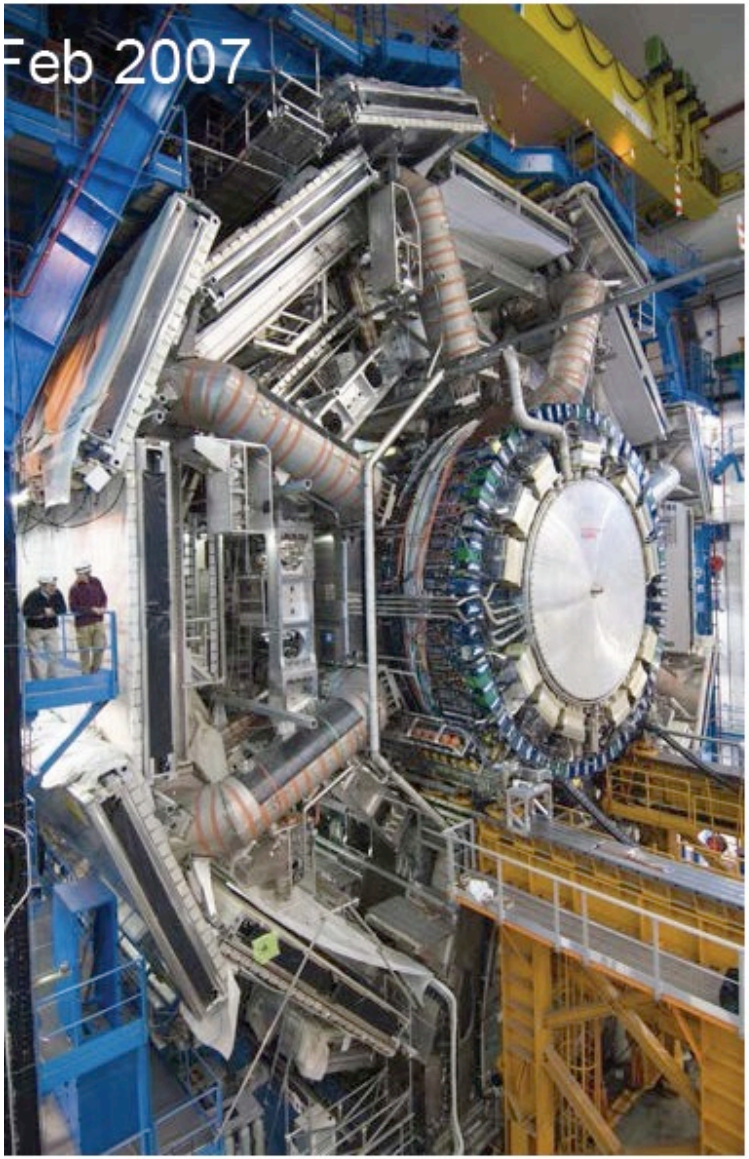
Calorimeter measure energy of particles

Building the ATLAS Experiment





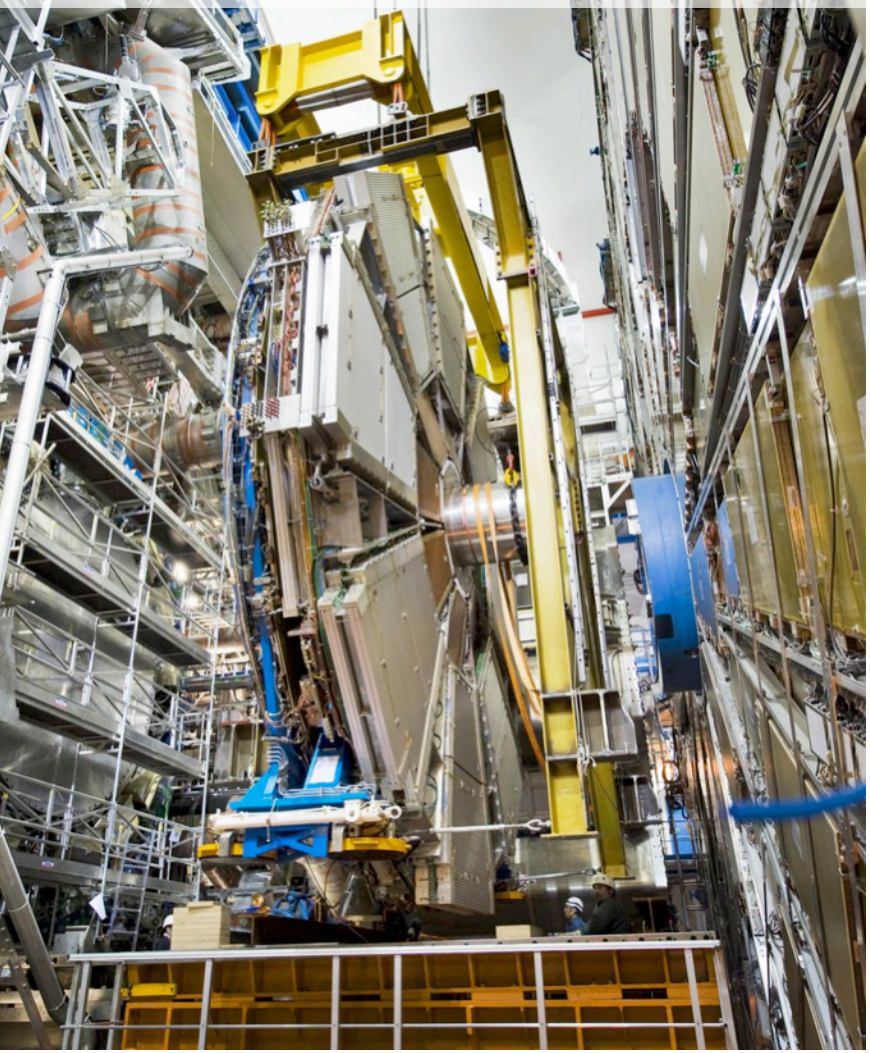
Moving Calorimeters in Place

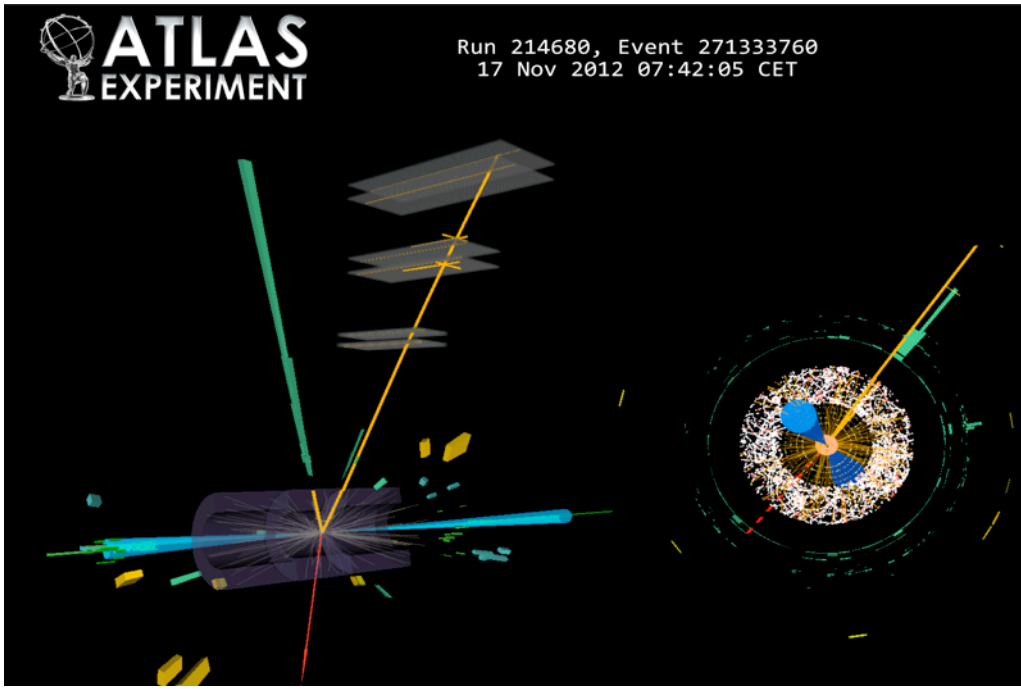


Closing the LHC Beamline

ATLAS Operation and Upgrade

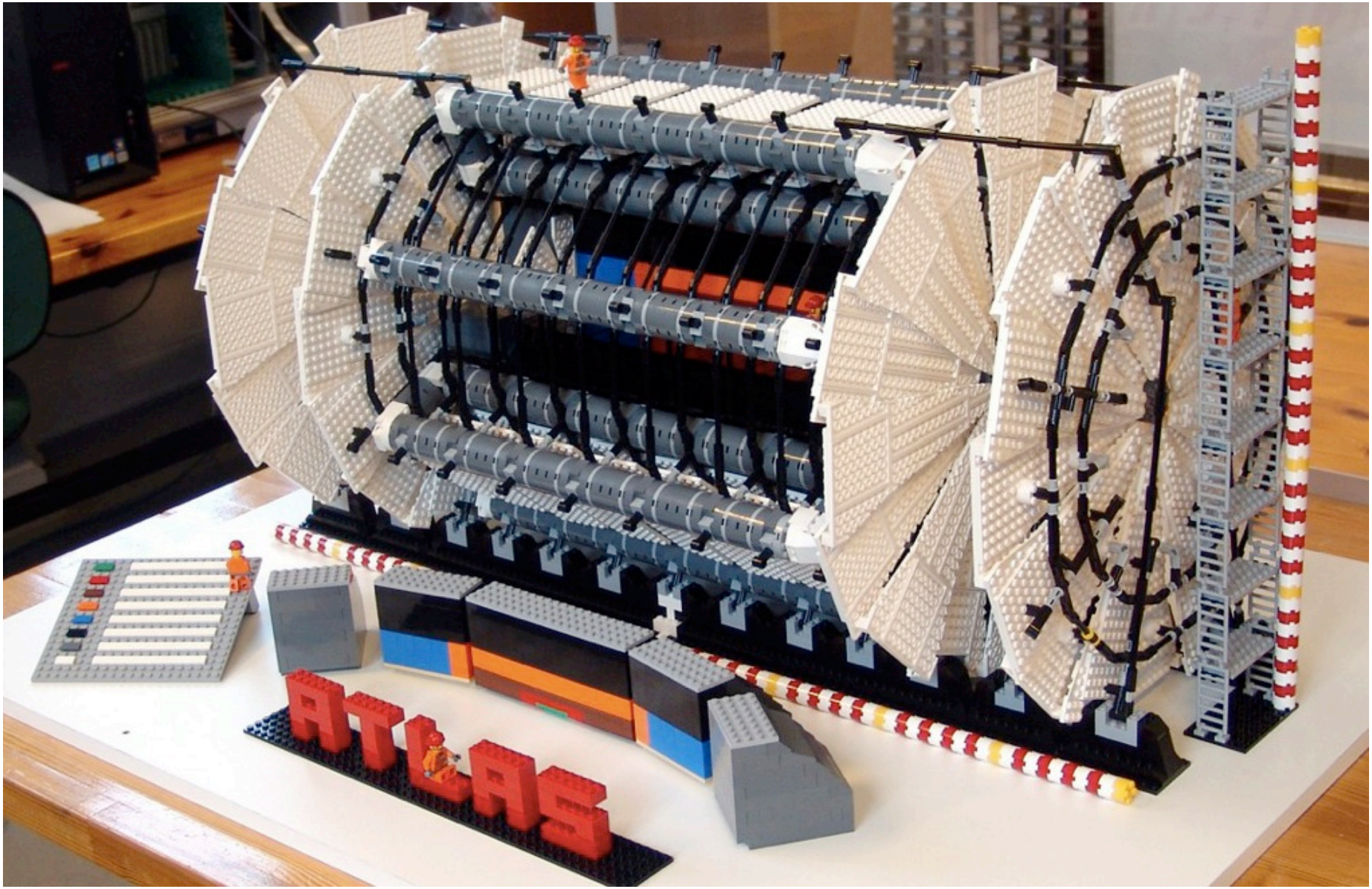
Canada will build 40% of the upgraded ATLAS NSW sTGC muon detectors (to cope with high intensity LHC beam)



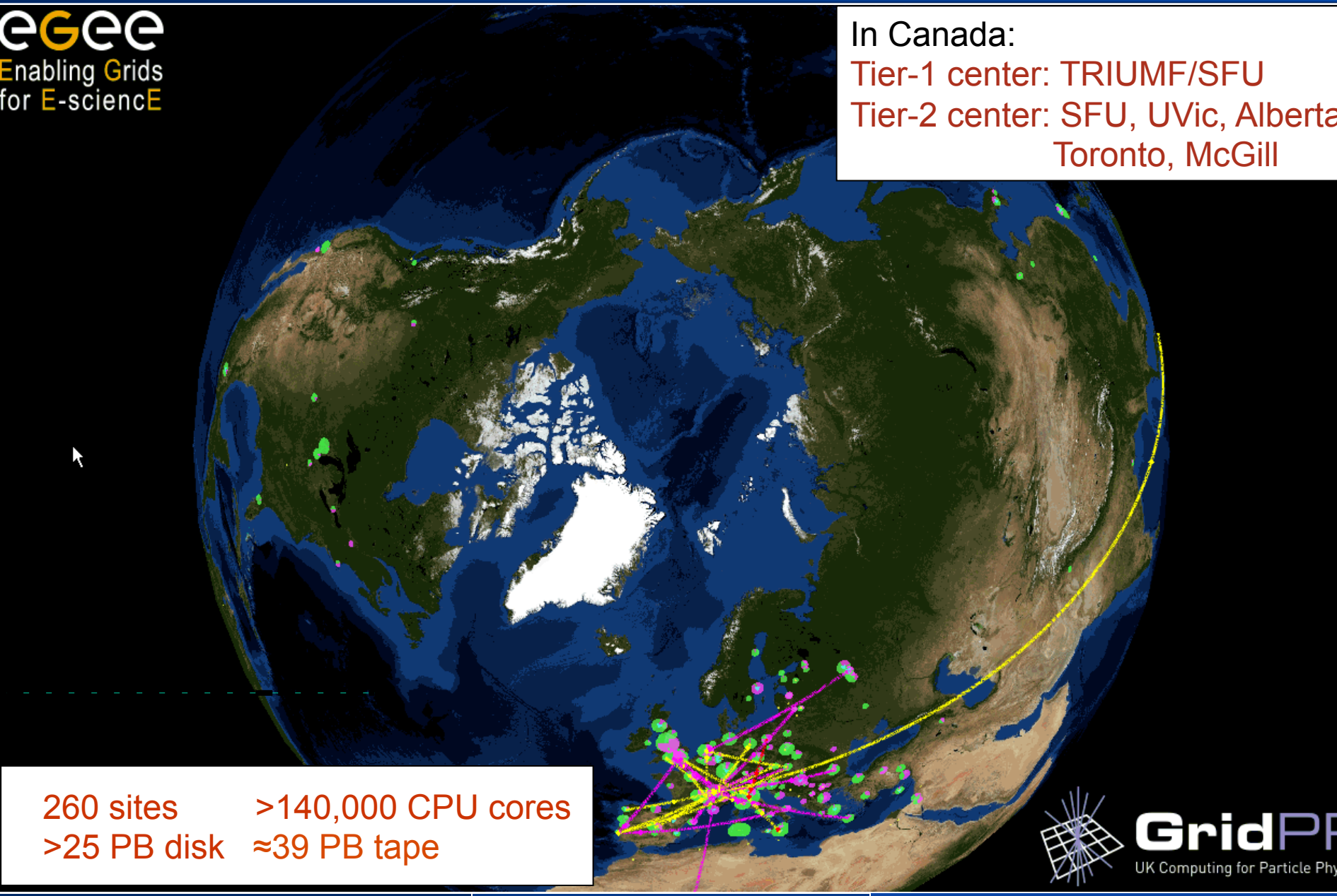


ATLAS Control Room

Build your own ATLAS Detector



Grid Computing



In Canada:
Tier-1 center: TRIUMF/SFU
Tier-2 center: SFU, UVic, Alberta
Toronto, McGill

260 sites >140,000 CPU cores
>25 PB disk ≈39 PB tape

Computing Challenge – Fun Facts

> 140 000 CPUs, interconnected
to a *supercomputer* around the World

Other Questions the LHC could answer!

1. What is the Origin of mass?
   Find Higgs boson(s).

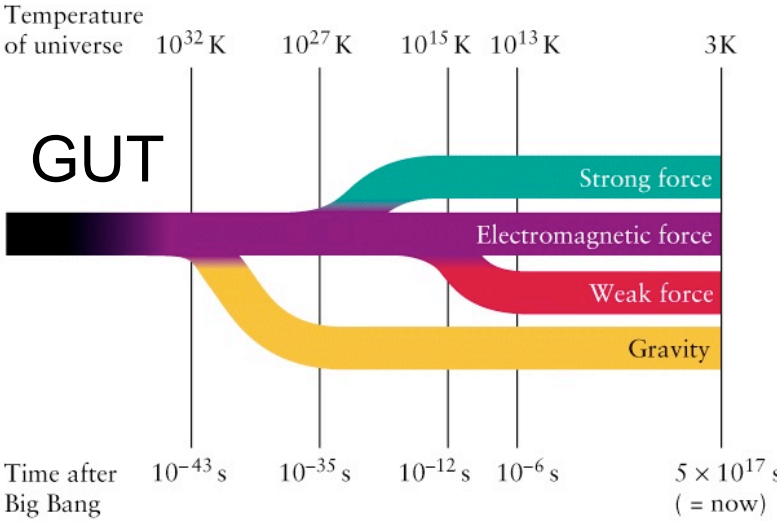
2. What is Dark Matter?
   LHC should be able to produce it!

3. Where did the anti-matter go?
   We only know part of the story

4. Grand Unified Theory (GUT):
   Unify all forces to a super force

5. Are there additional space-time dimensions?

6. Explore the unknown
   Surprises can happen at any time



Physics Beyond the Standard Model

The Team

SFU ATLAS Group

http://higgs.phys.sfu.ca/