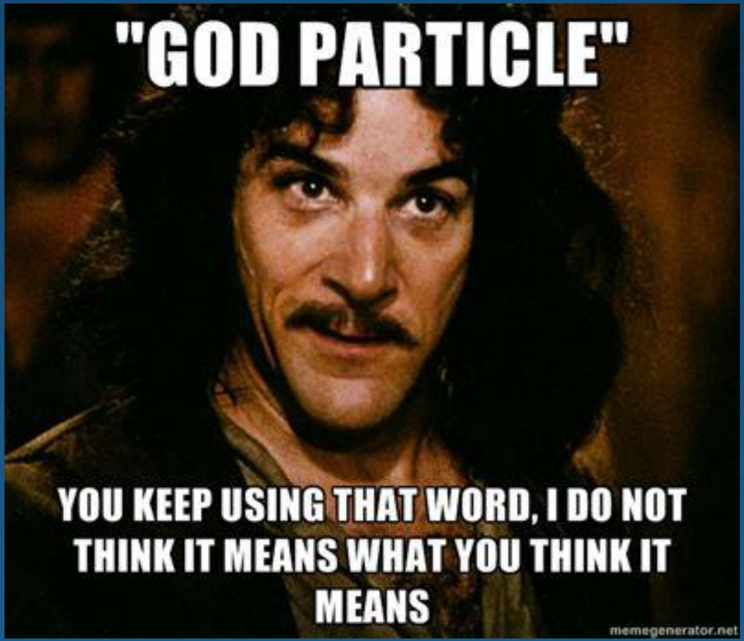
Discovery of a New Particle

Experimental High-Energy Physics Group
McGill

Homer's Physics 101

2012.September.28



http://nonsensibleshoes.com

arclight
@arclight

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My brother & sister-in-law asked me to explain the Higgs Boson. It was one of those Homer Simpson moments where he shrieks and runs away.

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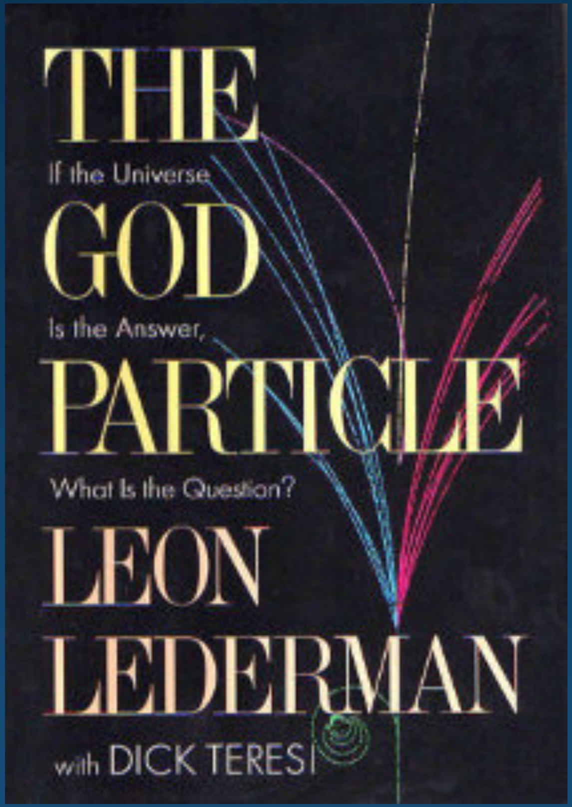


1993

Leon Lederman Quotations

"god particle" nickname: because the particle
"…is so central to the state of physics today, so crucial to our final understanding of the structure of matter, yet so elusive…"

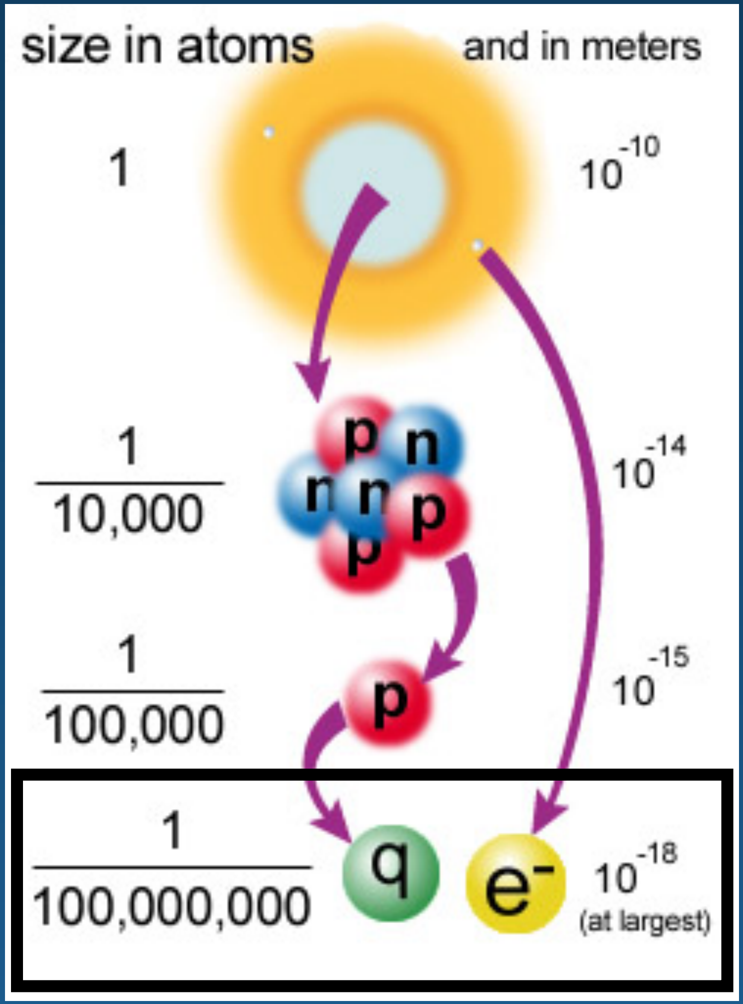
http://wikipedia.org

A second reason: because "…the publisher wouldn't let us call it the Goddamn Particle, though that might be a more appropriate title, given its villainous nature and the expense it is causing."

Reductionism Epitomised

Condensed-Matter
&
Atomic Physics

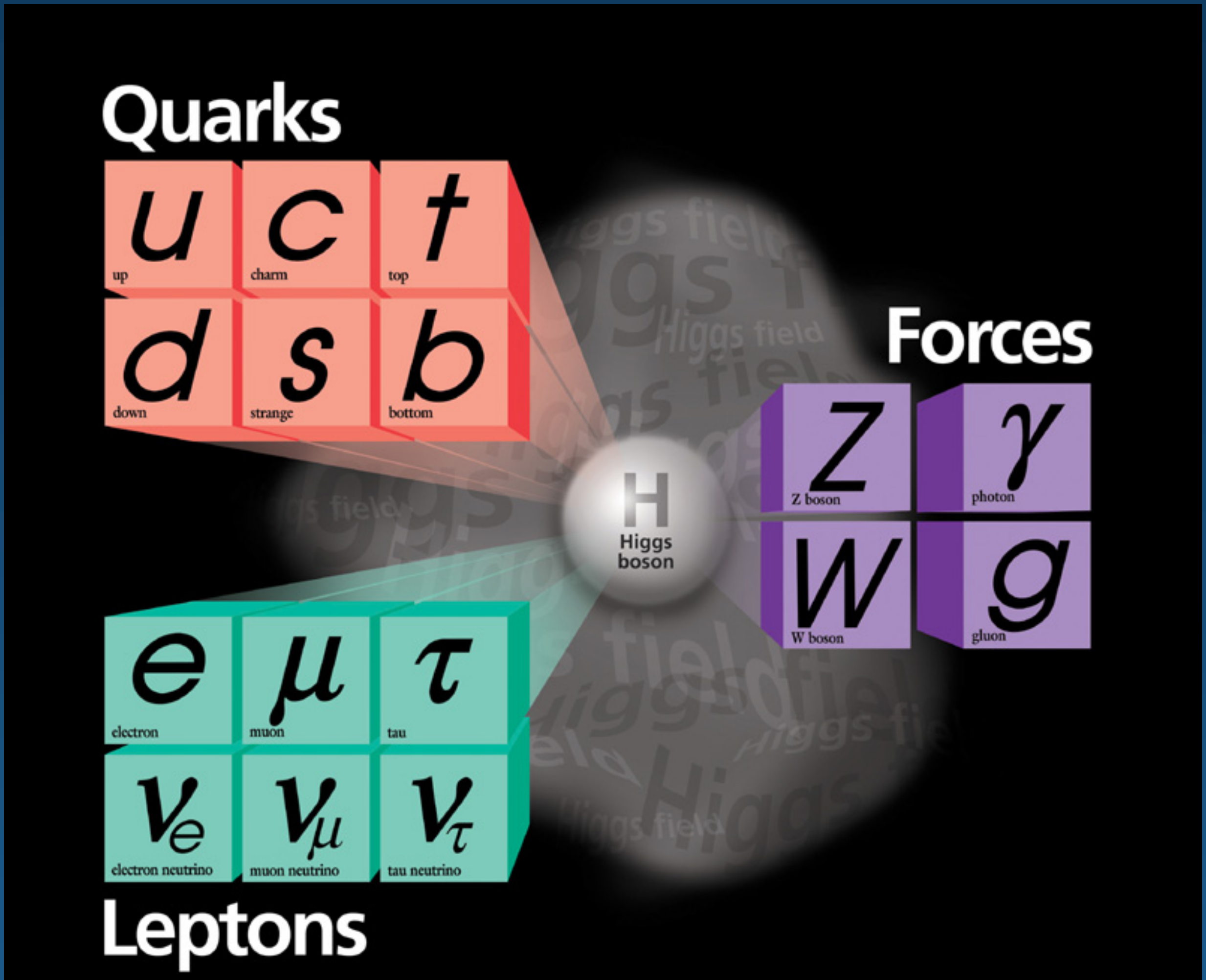
Nuclear
Physics



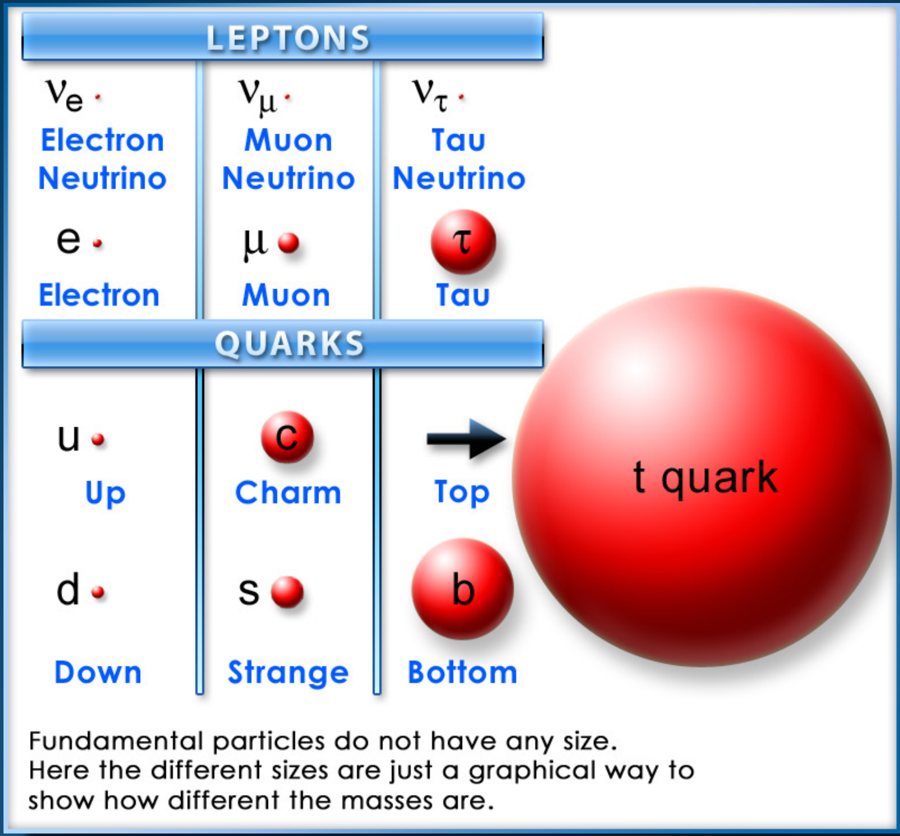
Low Energies

High-Energy
Particle Physics

The (known) Fundamental Particles & Forces



Note: gravity is (temporarily) omitted



What gives masses to fundamental particles such as quarks and electrons, and why are they so different?

Important Distinction:

We already know how composite matter (*e.g.*, atoms, fish, pizza, planets, people) gets most of its mass:

binding $E = mc^2$

So why should you care about the fundamental stuff?

Q: If your fundamental particles had no mass, what would they be doing?

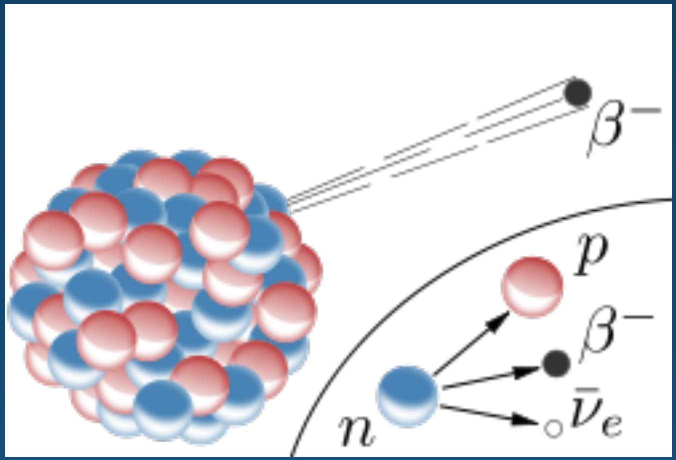
A: They'd all be zipping around at the **speed of light**.

- no fish
- no pizza
- no planets

No us…

But the issue of masses of fundamental particles really takes its origins from the time of Rutherford

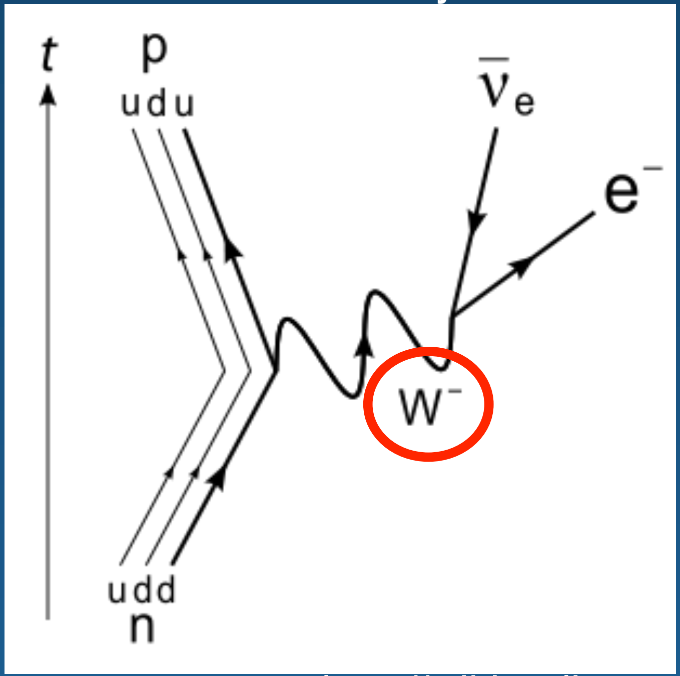
Nuclear Physics



Radioactivity:
atoms transmute

Lord Rutherford

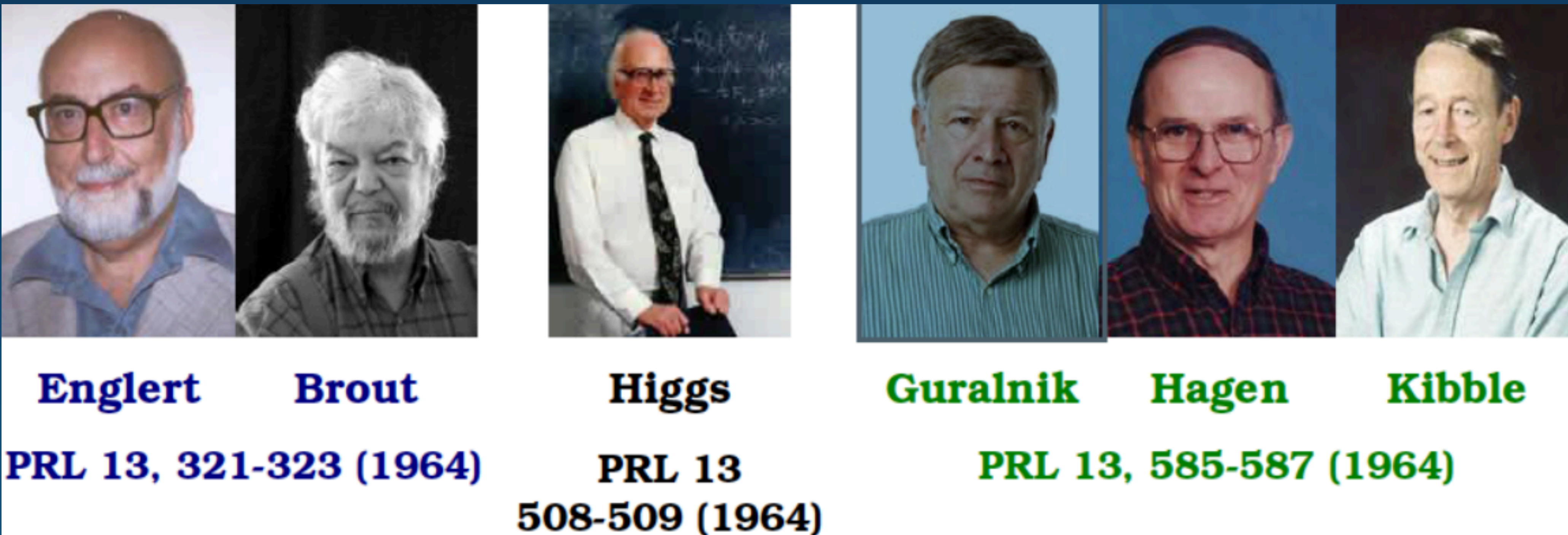
Particle Physics



Force is weak because W particle is <u>massive</u>!

http://wikipedia.org

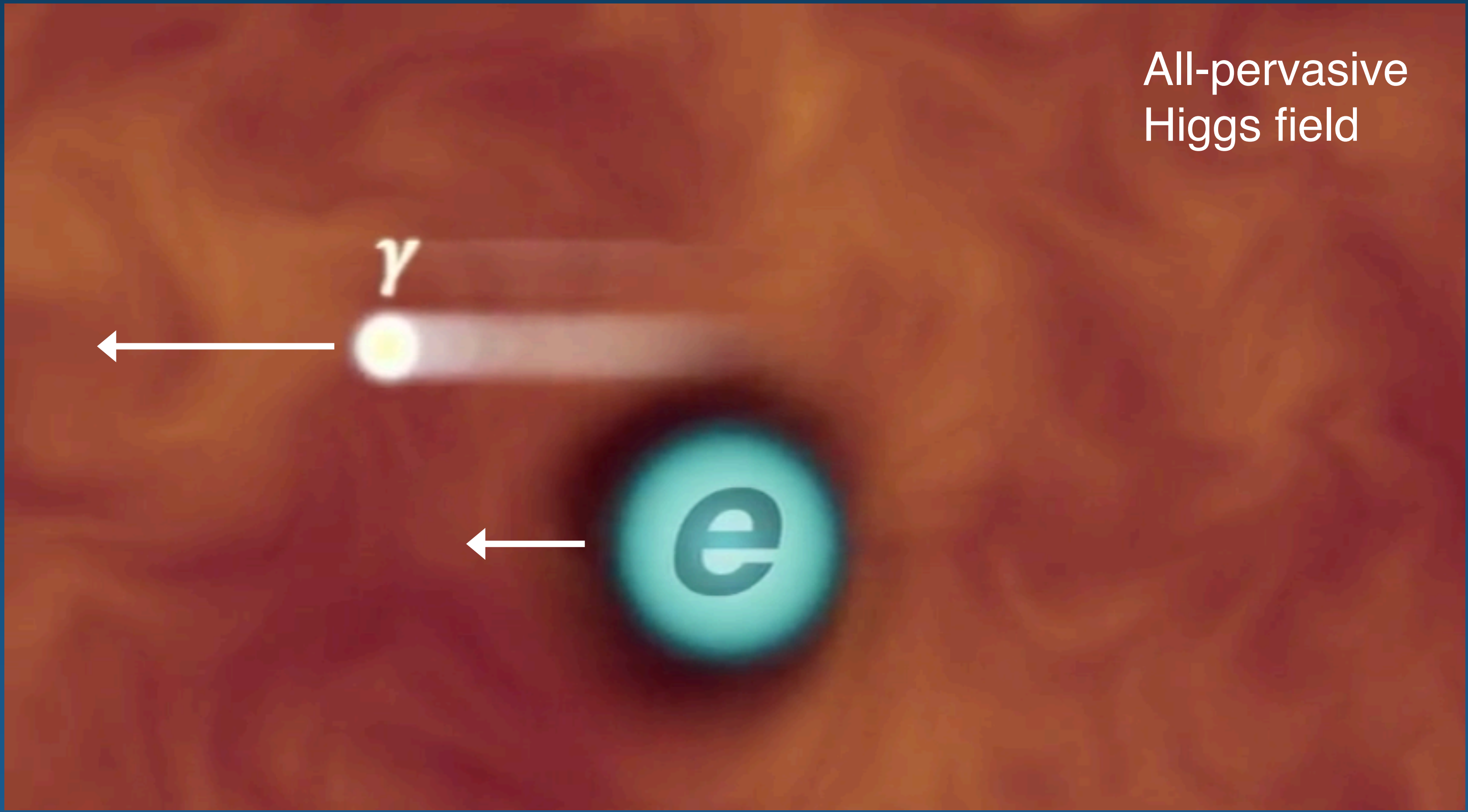
Theory devised in 1964 to explain how W (also Z) particle gets its mass



"Simplest" idea: add a new "Higgs field" to the theory (*i.e.*, to the Universe…)

Changes the symmetry of the equations, spontaneously allowing certain types of particles to have nonzero mass

Different fundamental particles experience different amounts of resistance when interacting with the Higgs field



Perimeter Institute, 2012

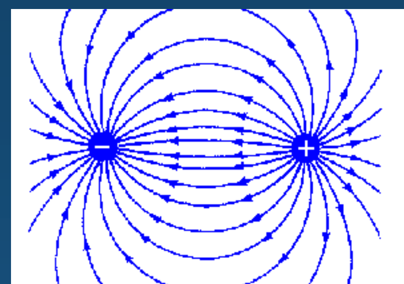
Higgs Field → Higgs Particle

http://www.spreadshirt.co.uk

Think: <u>Electric and Magnetic Fields</u>

Look at them closely and you see little “chunks”:

- Quantum chunks
- photon particles
- γ



http://labman.phys.utk.edu

Same idea for a <u>Higgs Field</u>:

- Different Quantum chunks
- Higgs particles!
- Discover particle to discover a new field!
- (Contrast: top quark discovery)

Think of fields like fabrics:

- Waves & ripples
- Look closely, see threads
- Chunky particles…

So, where do you look for Higgs particles?

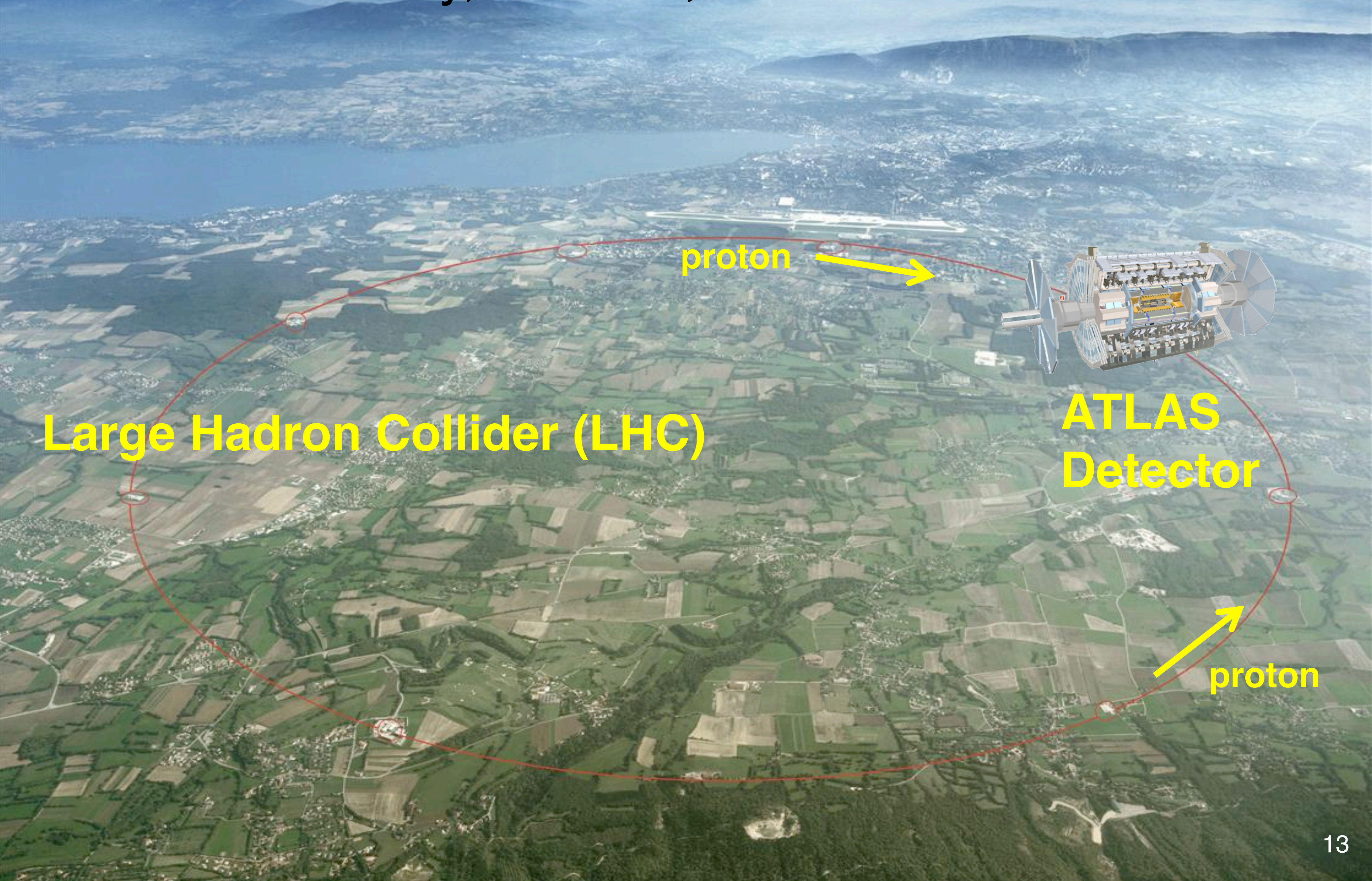
1. Make them in particle colliders

2. Study them using particle detectors (“experiments”)

Challenges:

- Need a lot of energy to make them
- They’re pretty rare but look a lot like common stuff
- They only exist for 0.00000000000000000000016 seconds

CERN Laboratory, Geneva, Switzerland

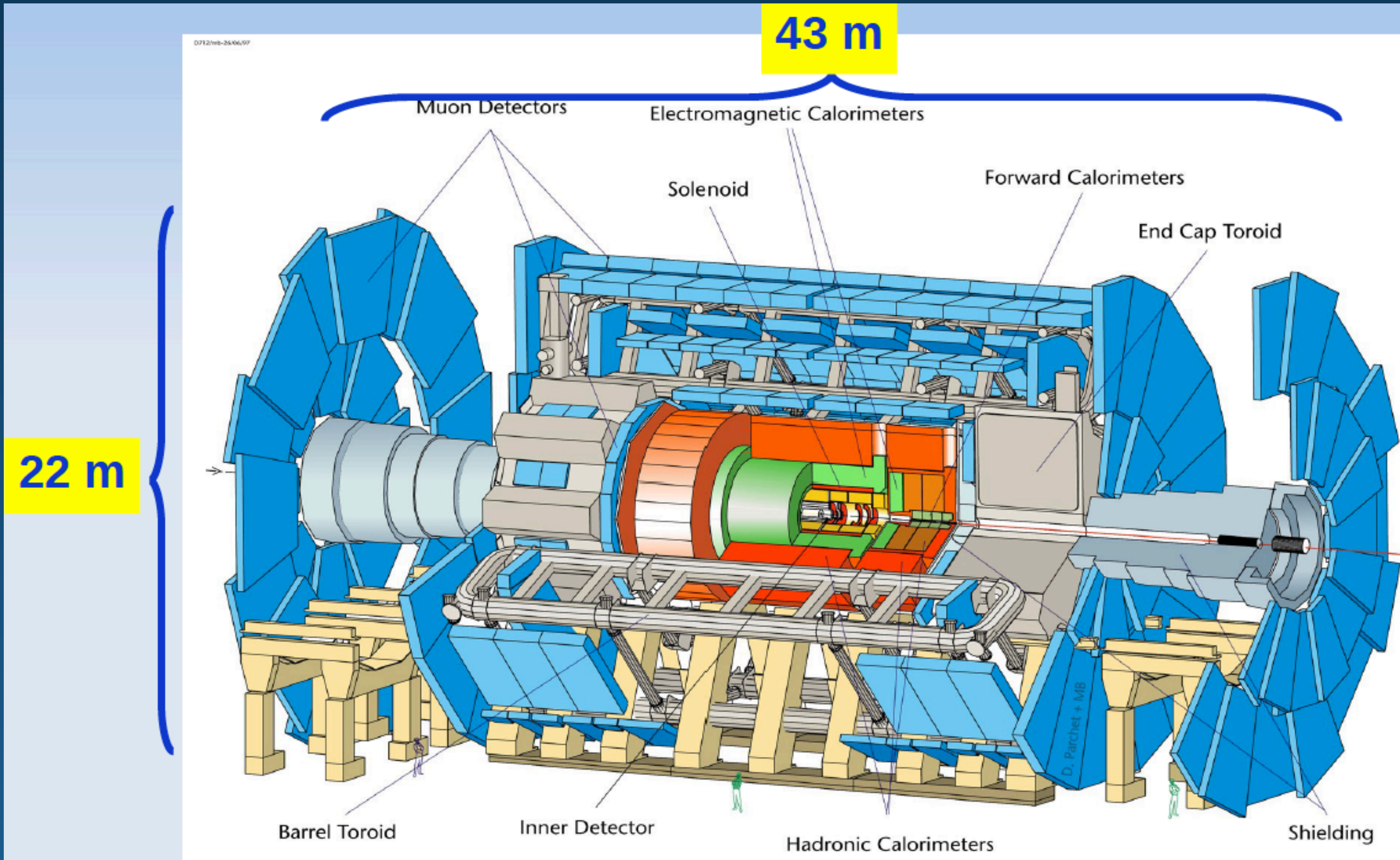


The Large Hadron Collider (LHC)

proton → **E** ← proton

E = $M_{\boxed{?}}c^2$

ATLAS (A Toroidal LHC ApparatuS)



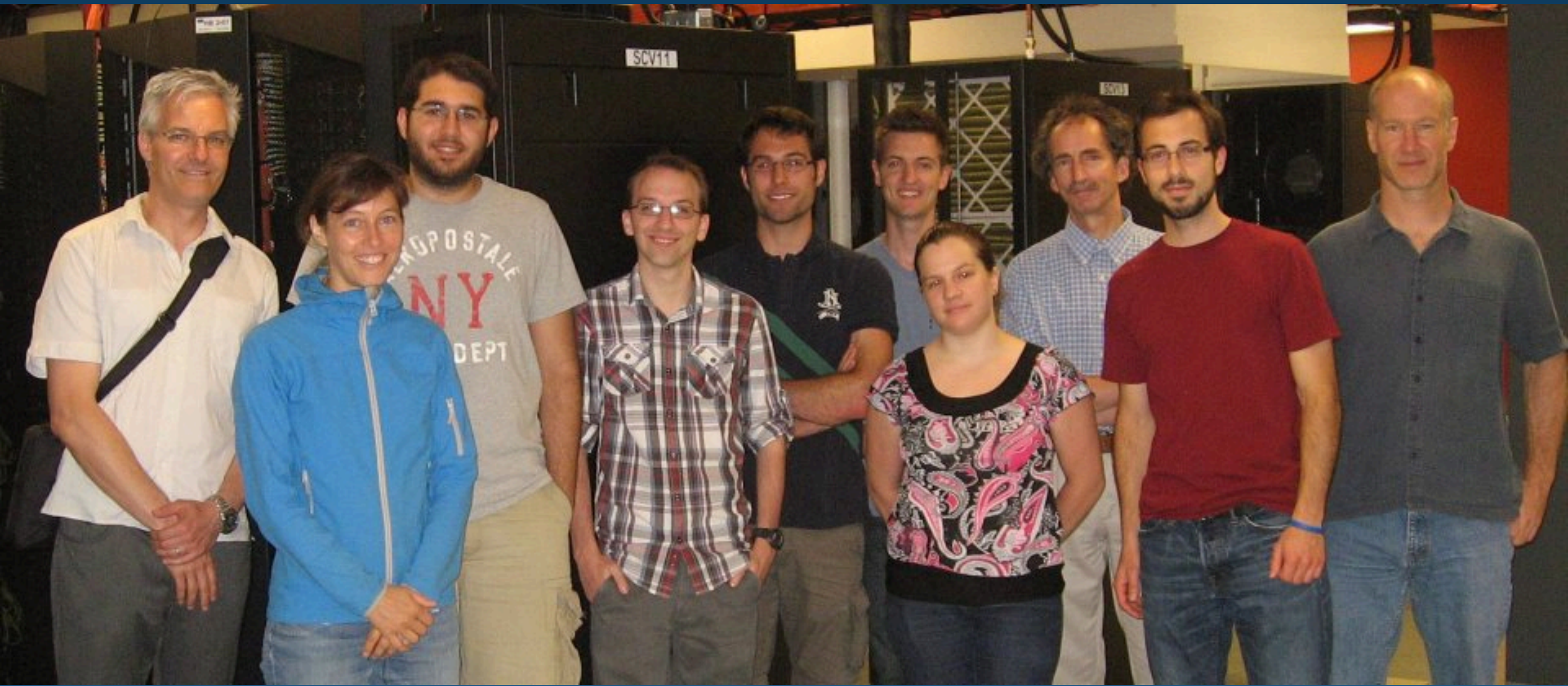
ATLAS, Under Construction

Prof. Brigitte Vachon

Prof. Peter Higgs April, 2008

“Higgs seen by ATLAS already in 2008...”

(part of) The McGill ATLAS Group



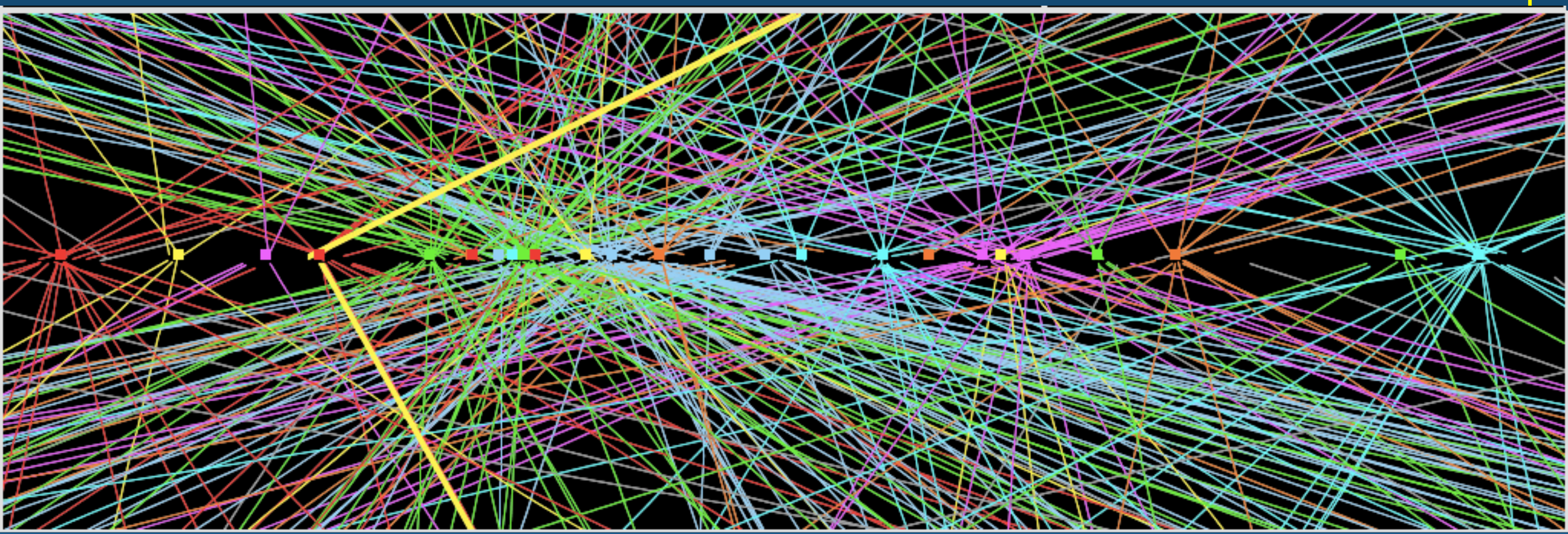
2012.June.27 CLUMEQ Site Visit, ETS, Montréal

The LHC assaults ATLAS with about 600 million collisions every second

McGill group has contributed to development of the ATLAS trigger:

- Designed to select interesting collisions, reject boring ones
- Keep recording rate well under 1000 collisions per second
- Without throwing away any Higgs (or other interesting) candidates…

Pile-Up



July 2010: Canadian High-Level Trigger Computers Delivered to ATLAS Experiment

A. Warburton (McGill)
M. Galloway (McGill)
S. Picard (UdM)

Surface building, above ATLAS cavern

Many thanks to CLUMEQ-McGill
High Performance Computing Centre

- Host site for ATLAS data files

- Computing power
  - Data analysis
  - Simulated LHC collisions

- Special thanks:
  - Steven Robertson
  - Bryan Caron, Simon Nderitu
  - Nik P., Sangyong J., Brigitte V.

McGill Physics

Paul Mercure
Juan Gallego

July 4, 2012

- First day of ICHEP 2012 (International Conference on High Energy Physics), Melbourne, Australia
- Specially timed CERN Seminars by ATLAS and CMS Experiments
- Both experiments announced discovery of a new particle

CERN, Geneva, Switzerland

Melbourne, Australia

Much media attention…

One of the harder questions…

Attempting to explain the discovery to my 8-year-old niece

Sandra Sousa Julia says she wants to know what the particle looks like

4 July at 16:46 via mobile · Like

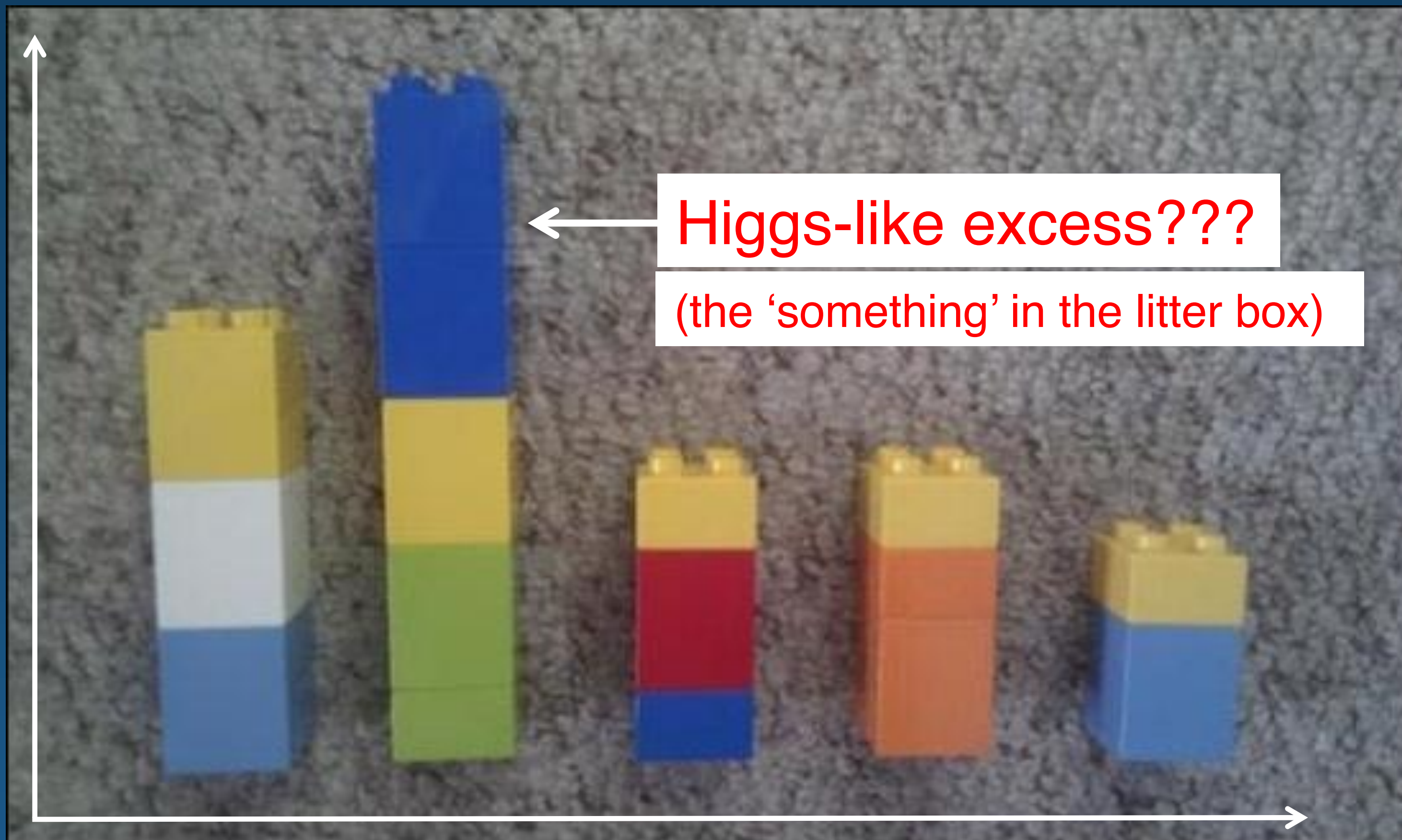
Andreas Warburton Julia, it's too small to see with your own eyes, so we built a big machine to try to take a picture of it (like a giant microscope with a camera attached to it). The machine actually makes the particle, but then the particle falls apart almost right away, breaking into smaller particles. The machine takes pictures of these smaller particles, so that's how we know the new particle existed. It's like when you find something in Kookie's/Smoukkie's litter box. It tells you that the cats are somewhere in the house, even if you don't see them. :)

4 July at 17:04 · Like · 6


Julia
Smoukki

How do we find the signal? Look for a bump!

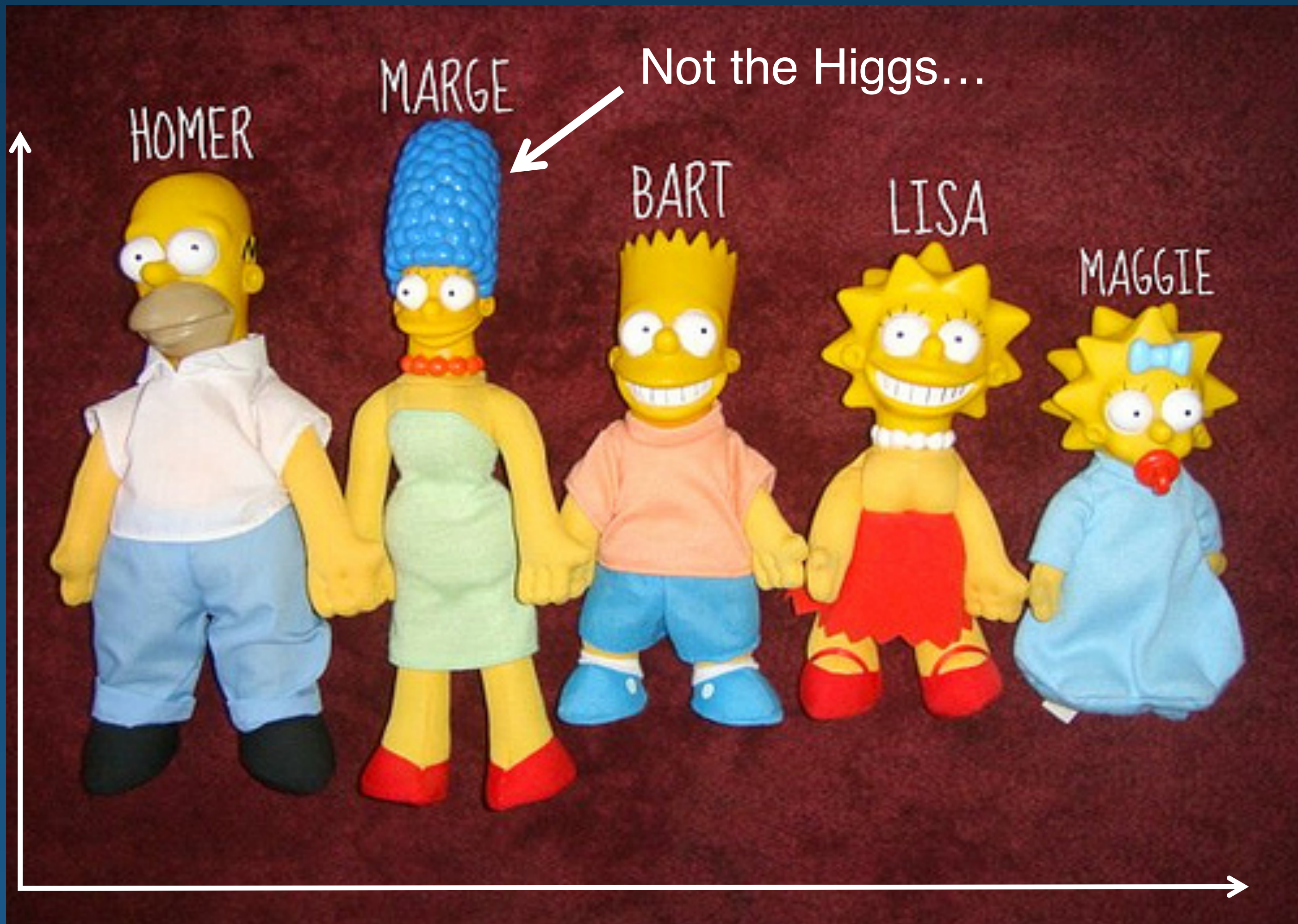
Amount
of
Data



Higgs Mass

Discovery Mass?!

But Nature can sometimes be so cruel…



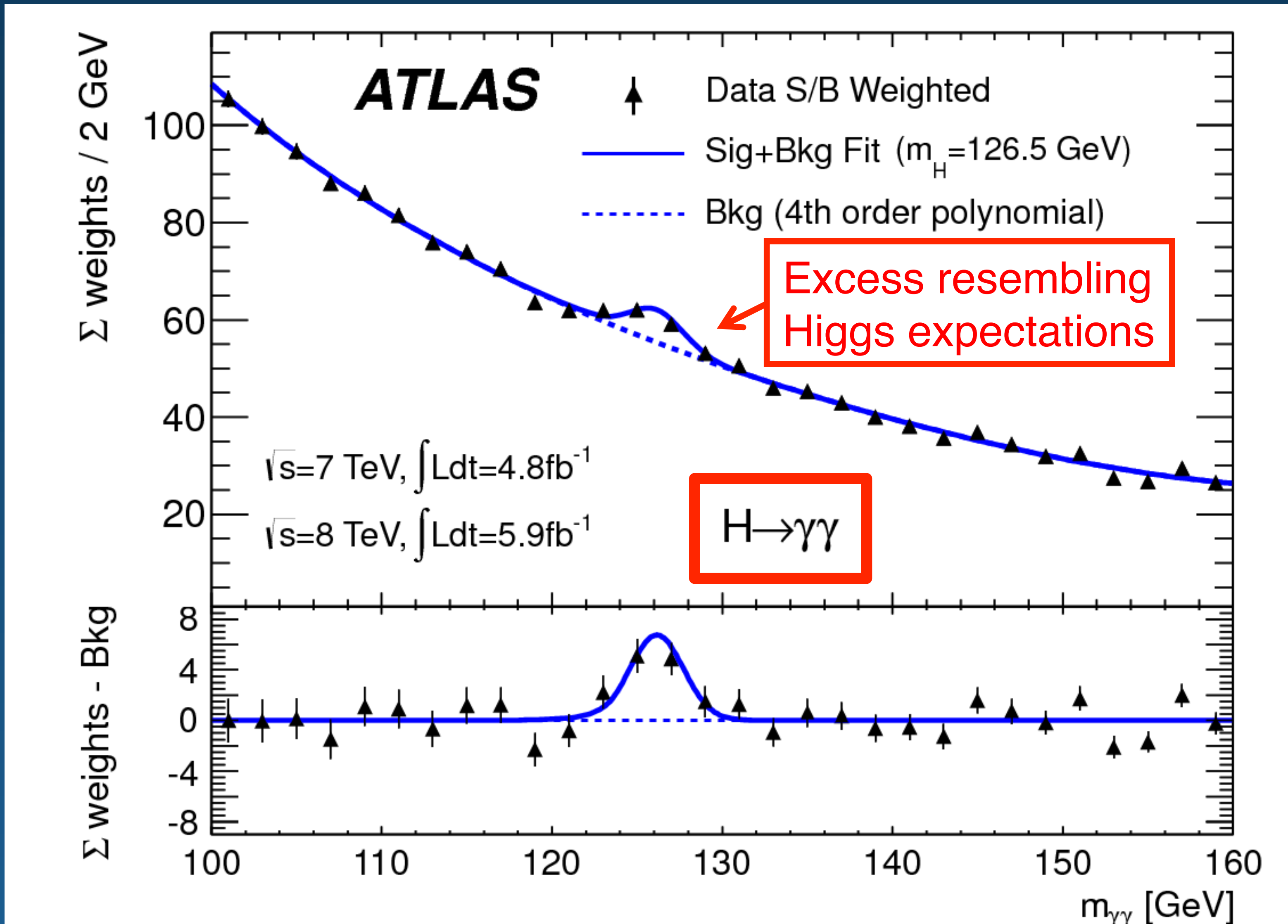
Simpson stature

Raw intelligence

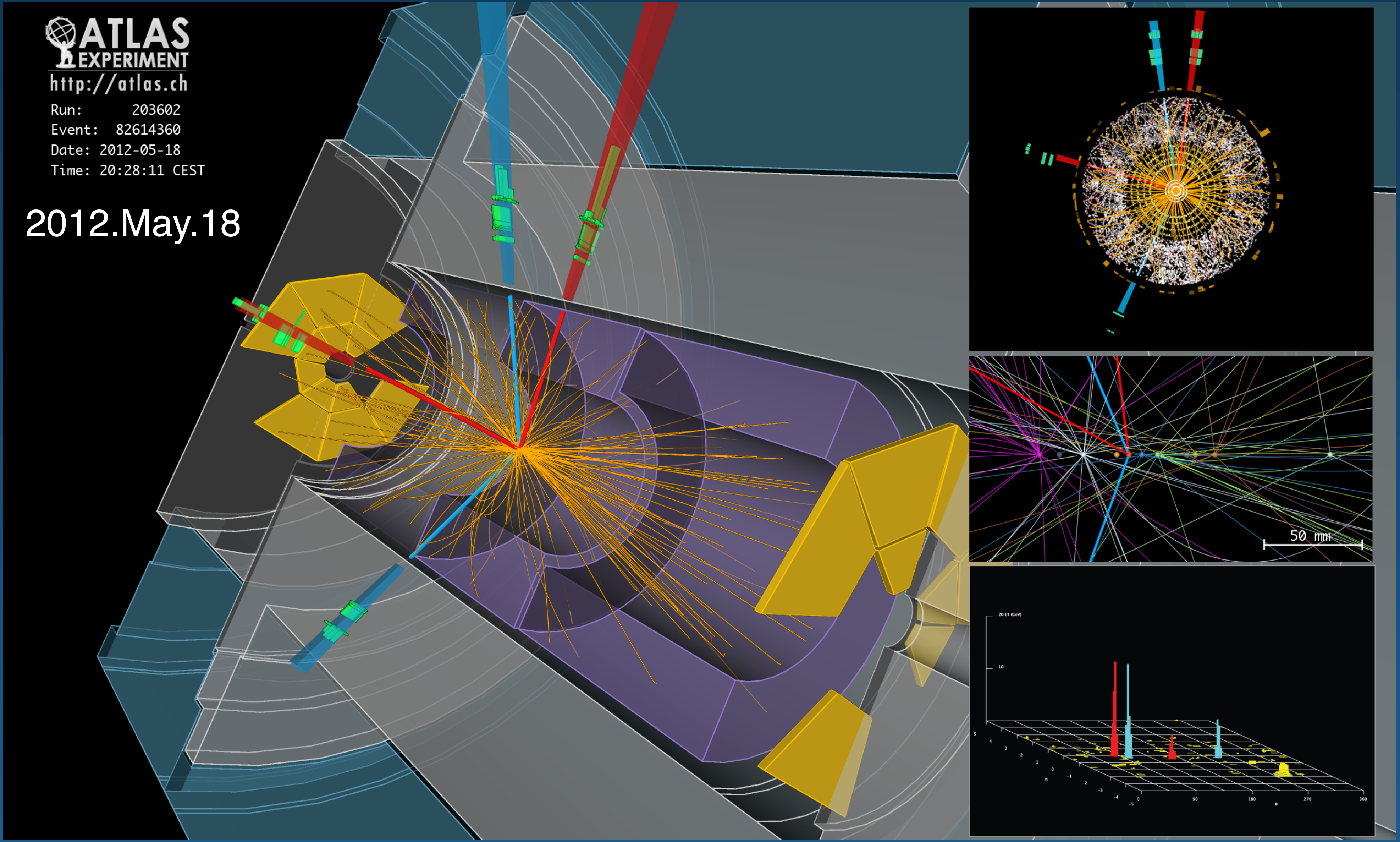
http://flickrhivemind.net/User/TRUE%20NECROMANCE/Recent

Real ATLAS Data: Clear Excess (Bump) Visible by Eye

G. Aad *et al.*, Phys. Lett. B **716**, 1 (2012)

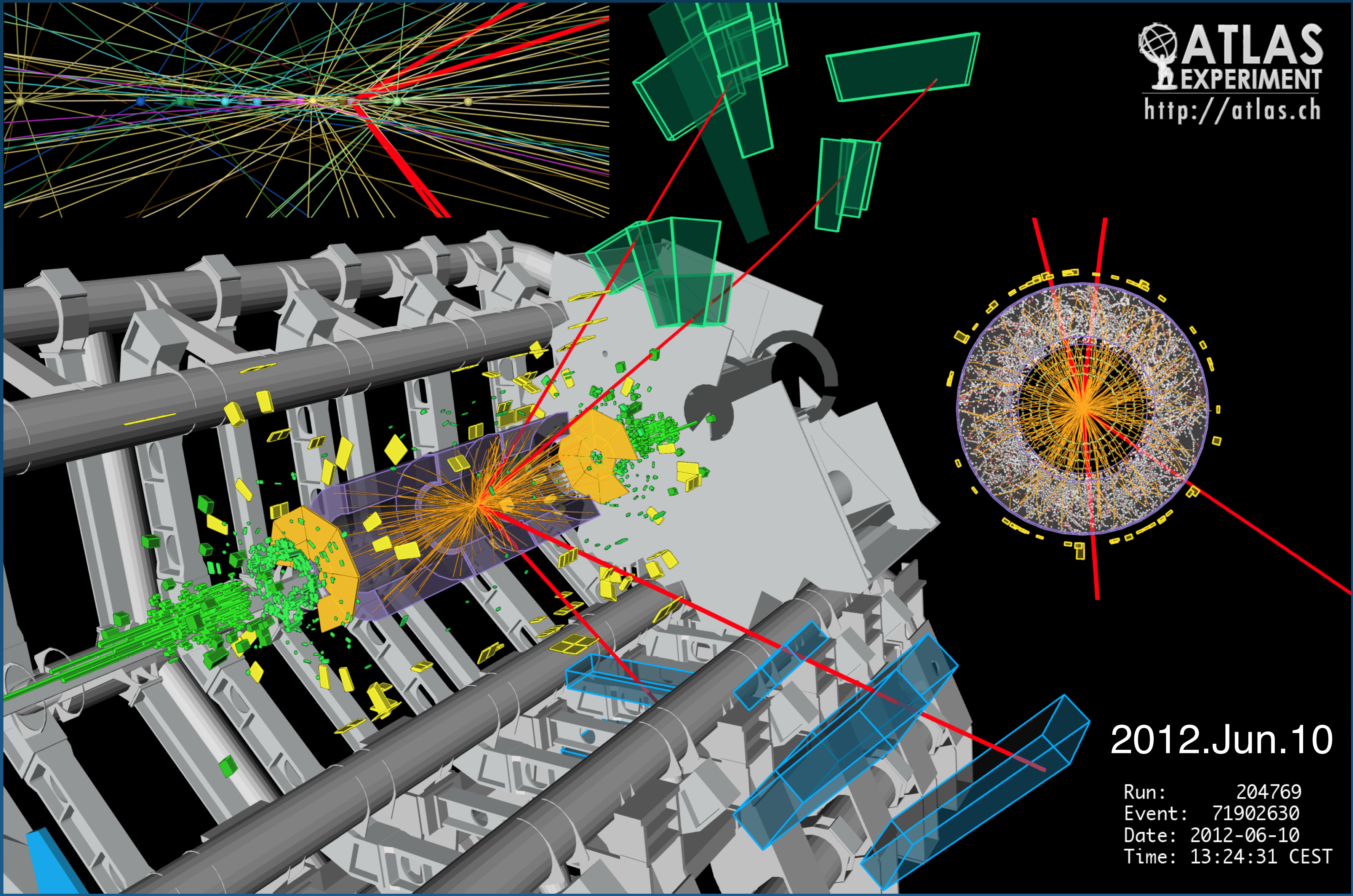


One Candidate Higgs Decay to 4 Electrons



I happened to be doing a remote Trigger Monitoring Shift from Montréal on this day.

One Candidate Higgs Decay to 4 Muons



I happened to be *en route* to Calgary for the CAP Congress at this time.

Significance of the Findings

Current Standards in Particle Physics

"Evidence":
- 3σ (three sigma) or greater
- Less than 1 chance in ~400 that it's a fluke

"Observation" or "Discovery":
- 5σ (five sigma) or greater
- Less than 1 chance in ~3.5 Million that it's a fluke

This Summer's Results:

2012.July.04 (ICHEP): CMS 4.9σ; ATLAS 5.0σ

2012.July.31 (papers): CMS 5.0σ; ATLAS 5.9σ

Less than 1 in ~588 Million

An alternative indicator of significance?

Prevalence of fake David Letterman Top 10 lists…

Homer Simpson on the Higgs Boson – Top 10

July 6, 2012

Like 2 Tweet 1 +1 2 Share 1

A list of top 10 things that Homer Simpson might have to say on the recent discovery Higgs Boson in à la David Letterman mode.

10 Higgs Boson? Wait a minute.. I thought it was Hog the Bison.

9 Since the universe has been explained, do we now get to play with lasers? Please, please, please..

8 I found an elementary particle once.. I named it Simps-on. Hee hee..

7 Now that Higgs Boson is found.. can we use the LHC for NASCAR?

6 If I were a particle physicist, my mass would be 86 terra yotta electron volts.

5 ..and the antiparticle is Higgs Bos-off?

4 Hey! I too have no charge, no spin and a hell load of mass.

3 God particle eh? Has Flanders been visiting the CERN?

2 Being the Nuclear Safety Inspector, I demand my Nobel Prize.

1 And all this while I had been thinking that the missing link was some kind of a monkey! Stupid formal education.

http://chotudochai.info/2012/07/06/homer-simpson-on-the-higgs-boson-top-10/

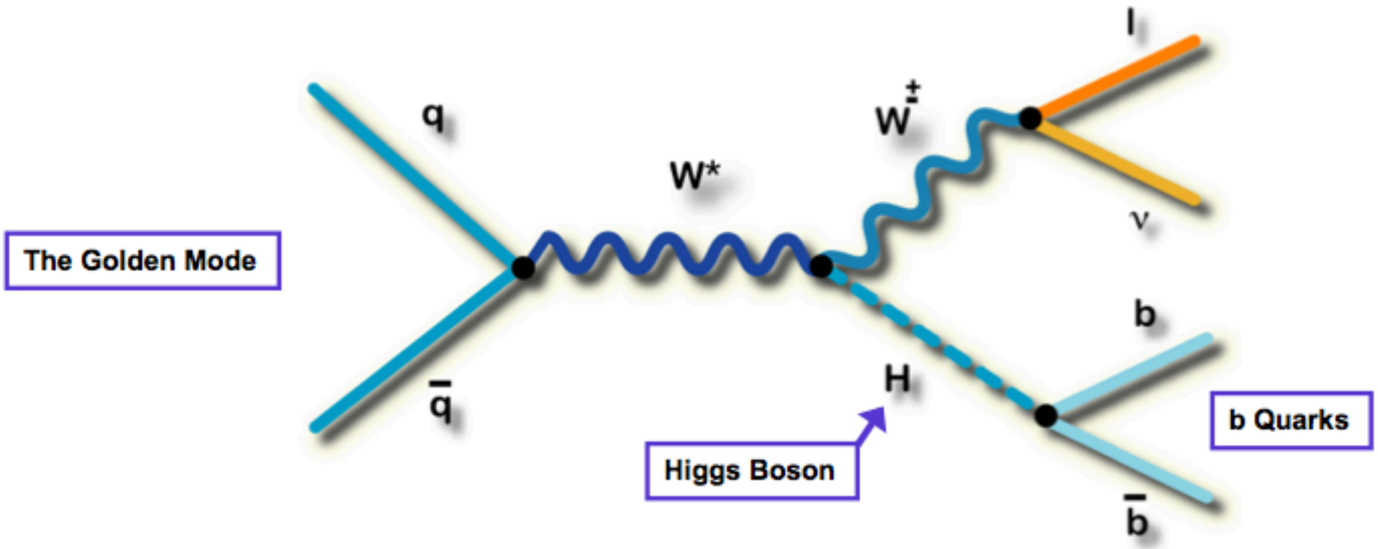
Wait, what about Fermilab?

Homer’s Physics Flashback: Nov. 2007

Hunting down the Higgs Boson

- The “Holy Grail”, a missing link in Particle Physics.
- Theory: Higgs gives particles their masses.
- Can we find it at Fermilab before CERN/LHC/ATLAS does? Maybe.
- Our best bet right now: use *b* quarks!

Adrian Buzatu



Fermilab claims first (peer-reviewed) Higgs-like evidence, *b*-quark couplings

Selected for a Viewpoint in *Physics*
PRL **109,** 071804 (2012) PHYSICAL REVIEW LETTERS week ending 17 AUGUST 2012

Evidence for a Particle Produced in Association with Weak Bosons and Decaying to a Bottom-Antibottom Quark Pair in Higgs Boson Searches at the Tevatron

(*CDF Collaboration)
(†D0 Collaboration)

(Received 26 July 2012; published 14 August 2012)

We combine searches by the CDF and D0 Collaborations for the associated production of a Higgs boson with a W or Z boson and subsequent decay of the Higgs boson to a bottom-antibottom quark pair. The data, originating from Fermilab Tevatron $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, correspond to integrated luminosities of up to 9.7 fb^{-1}. The searches are conducted for a Higgs boson with mass in the range 100–150 GeV$/c^2$. We observe an excess of events in the data compared with the background predictions, which is most significant in the mass range between 120 and 135 GeV$/c^2$. The largest local significance is 3.3 standard deviations, corresponding to a global significance of 3.1 standard deviations. We interpret this as evidence for the presence of a new particle consistent with the standard model Higgs boson, which is produced in association with a weak vector boson and decays to a bottom-antibottom quark pair.

DOI: 10.1103/PhysRevLett.109.071804 PACS numbers: 13.85.Rm, 14.80.Bn

Dr. Adrian Buzatu explains his McGill PhD thesis research to Professor Peter Higgs

Adrian's work contributed to first evidence of Higgs particles coupling to beauty (bottom) quarks

St. Andrews, Scotland (2012.August.23)

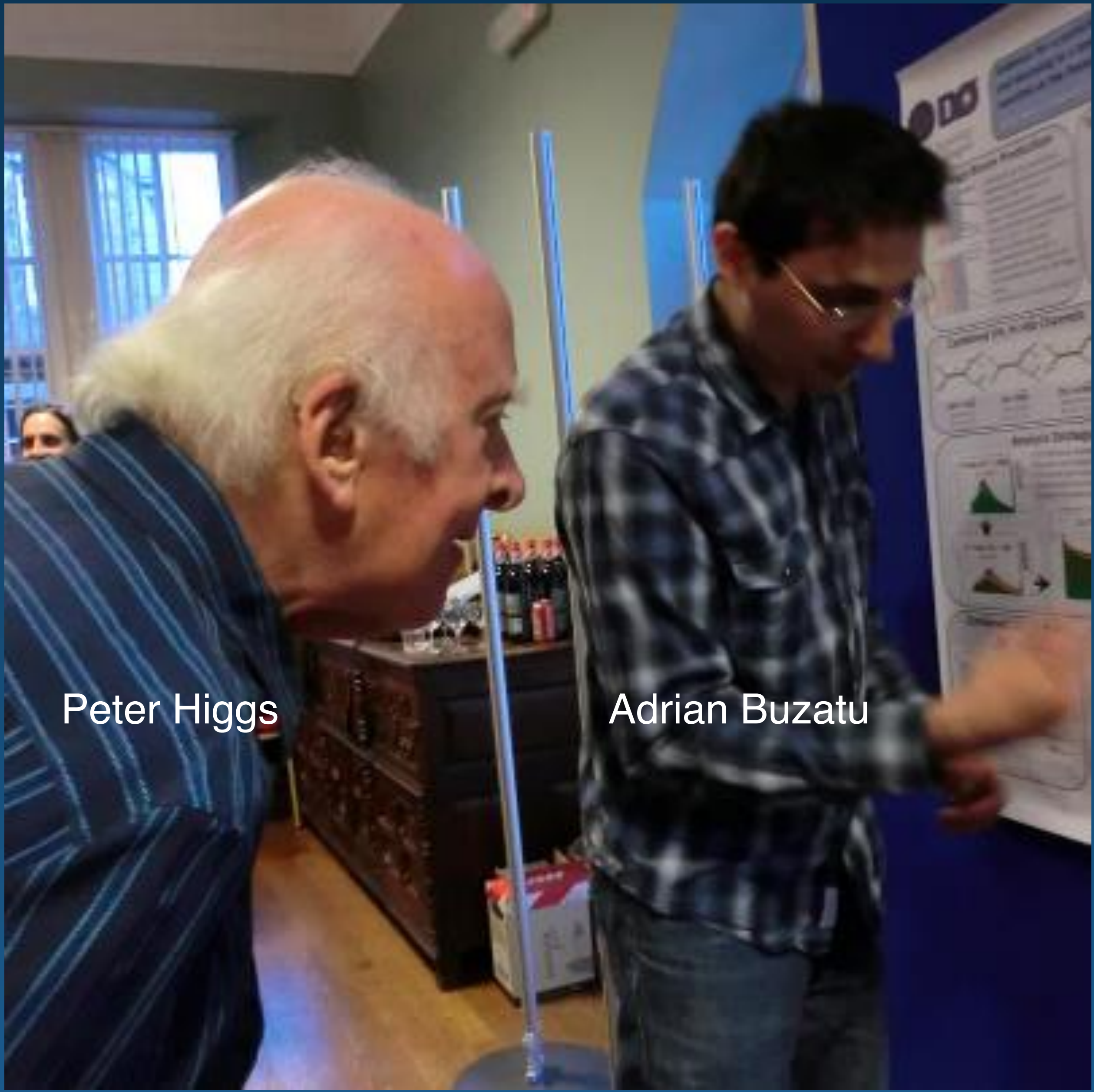
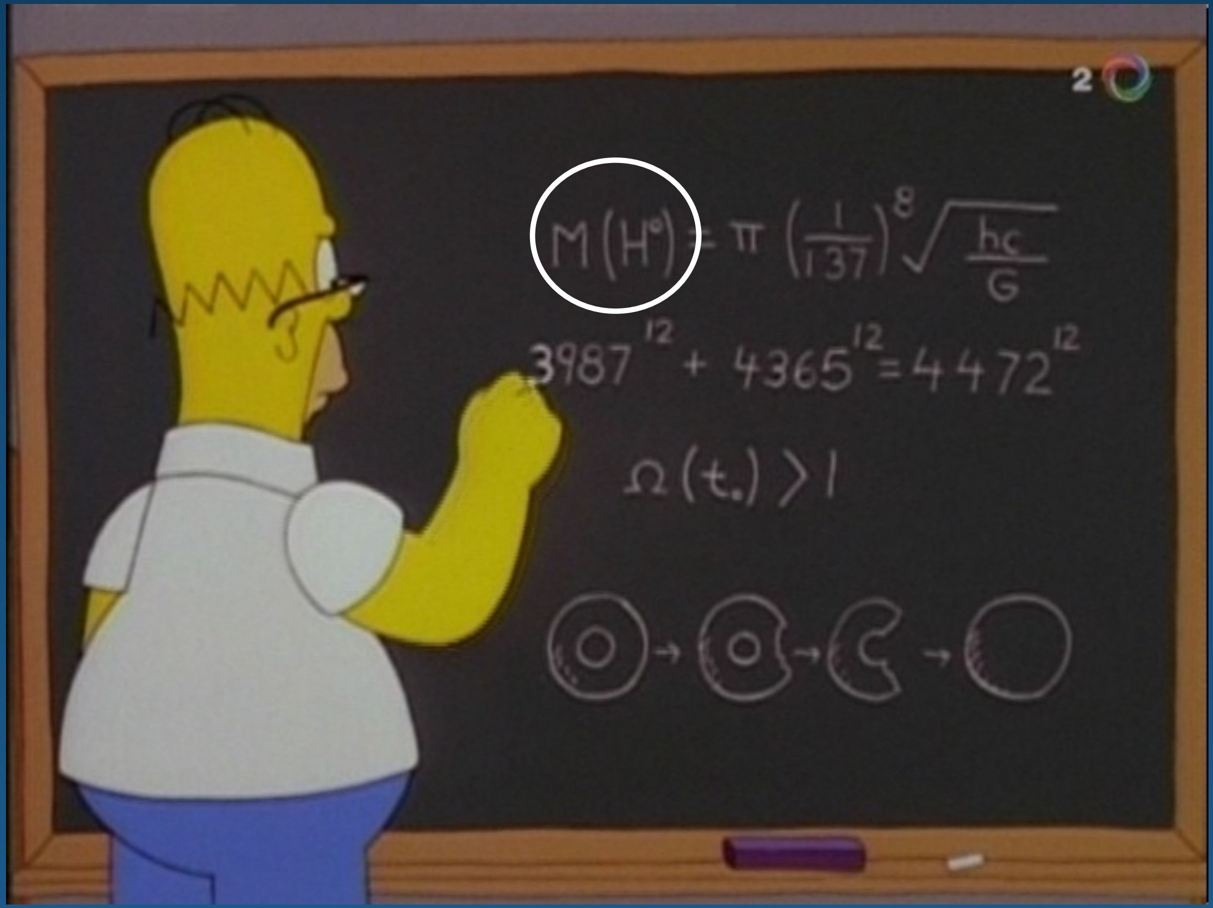


Photo: Huong Nguyen


Evidence for a particle produced in association with weak bosons
and decaying to a bottom-antibottom quark pair in Higgs boson
searches at the Tevatron
Tevatron Accelerator, CDF & D0 Detectors
Divide, Conquer, Combine
Validate in VZ, Z->bb
Adrian Buzatu
Peter Higgs
Huong Nguyen

What about this new particle's properties?



http://spinor.info/weblog/?p=1591

Higgs mass
or
Homer's mass?

Properties: What we know so far…

- Neutral electric charge
- Boson (integral spin, but not spin 1)
- CMS Measured mass: 125.3 ± 0.4 (stat.) ± 0.5 (syst.) GeV
- ATLAS Measured mass: 126.0 ± 0.4 (stat.) ± 0.4 (syst.) GeV
- ATLAS / CMS: <u>Observed</u> couplings to spin-1 bosons (photon, Z)
- CDF / D0 (Fermilab): <u>Evidence</u> of couplings to fermions (*b* quarks)

Recommended Reading

GQ (Gentleman's Quarterly)
Bruno Maddox
2012.September.11

Newsmakers

The Higgs Boson: Steaming Particle of Bull$#!%

Bruno Maddox visited the Large Hadron Collider, and all he got was one lousy God Particle, a whole bunch of Swiss coffee, and infinite questions about the universe

BY BRUNO MADDOX

September 11, 2012

http://www.gq.com/news-politics/newsmakers/201209/higgs-boson-rolf-dieter-heuer

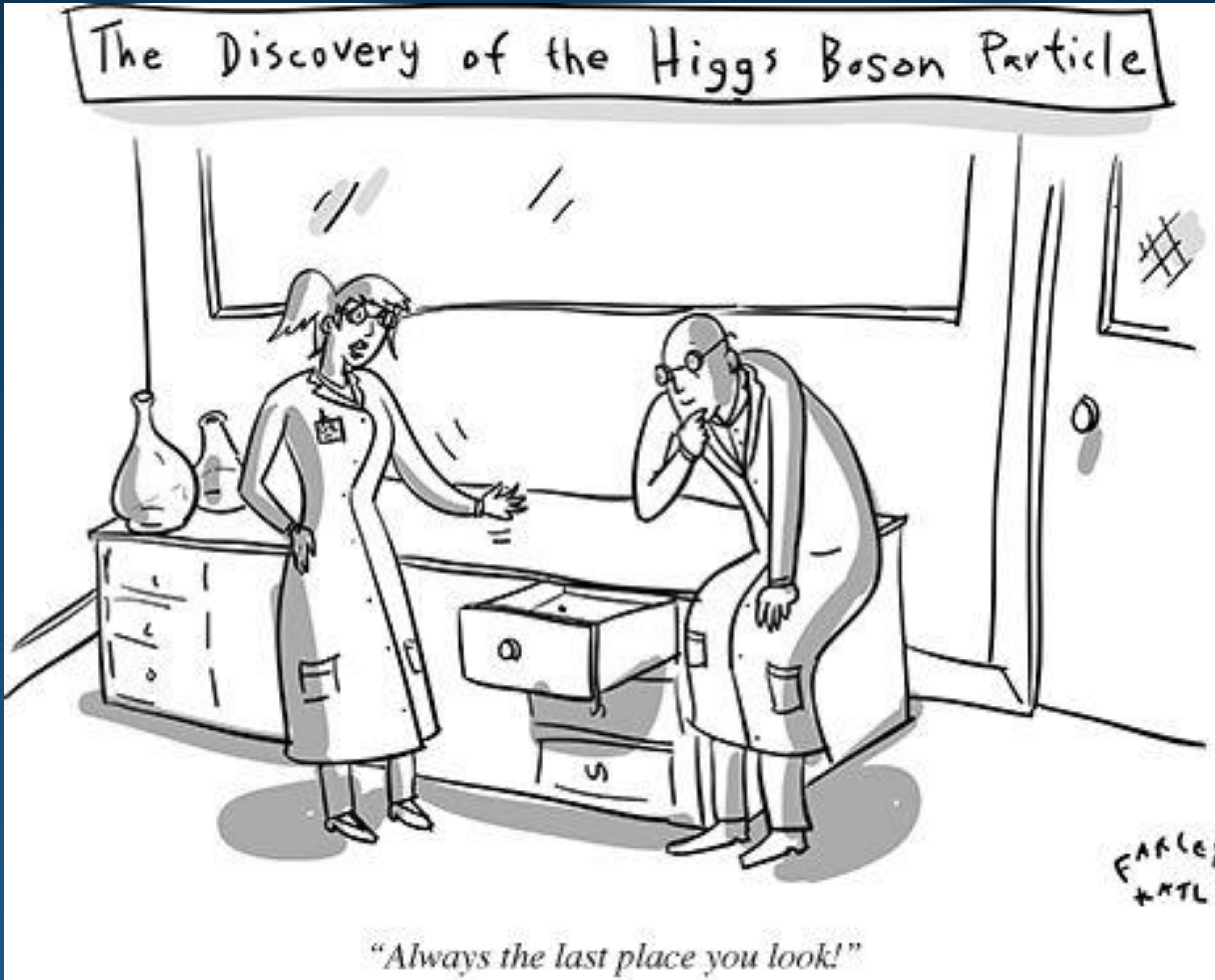
Closing Remarks

- We (Humanity) have discovered a new particle
- The discovery was made while searching for the Standard Model Higgs Boson
- A Higgs boson has been predicted to exist if a Higgs field were to exist (but it may be in a "system" of multiple Higgs-related particles)
- Now we must extract this particle's properties:
  - More LHC data
  - Upgrades to detectors (McGill: ATLAS muon detectors)
  - Another collider (International Linear Collider)
- Note: LHC was not built just to find this particle
- Other big questions need answering; surprises may lie ahead!

A good many thanks to many good people.

This discovery has been made possible by, literally, thousands of individuals and organizations worldwide:

- Scientific authors
- Technical personnel (many of you!)
- Institutional support staff (many of you!)
- Funding agencies (NSERC, FRQNT, CFI)



The New Yorker

Courtesy Prof. John Crawford