



Adrian Buzatu



Dr. Rob Snihur

Seeing Beauty in High-Energy Particle Collisions



Philippe Roy

Andreas Warburton

**Experimental High-Energy Physics
Homer's Physics 101**



Greg Williams

What is Beauty?

- ➔ Depends on whom you ask.
- ➔ Example: Taste in motorcycling (G² / Andreas).
- ➔ “The beautiful is that which pleases universally without a concept.”
– Immanuel Kant, *Critique of Judgment* (1790)
- ➔ Huh?

Beauty in High-Energy Particle Physics

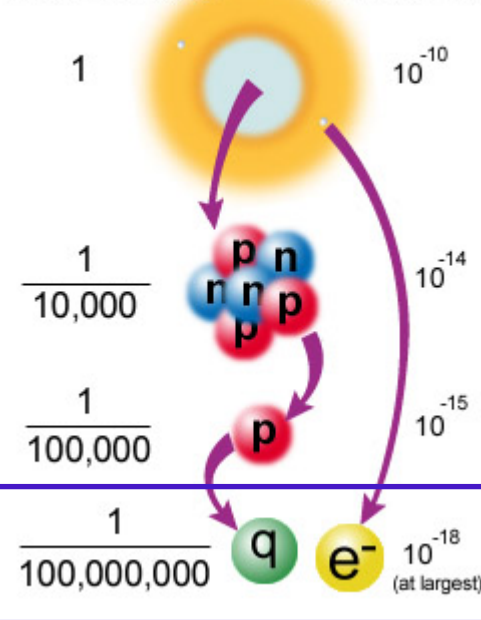
Subatomic Physics
at the **Highest Energies**



Shortest Distance Scales



size in atoms and in meters

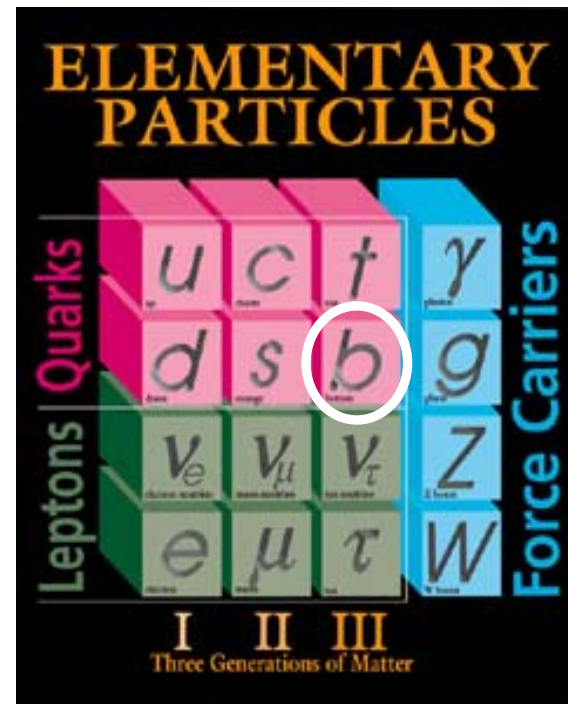


Courtesy particleadventure.org

Recall last
Homer's
talk, by
Guy

Beauty (b, bottom) Quark

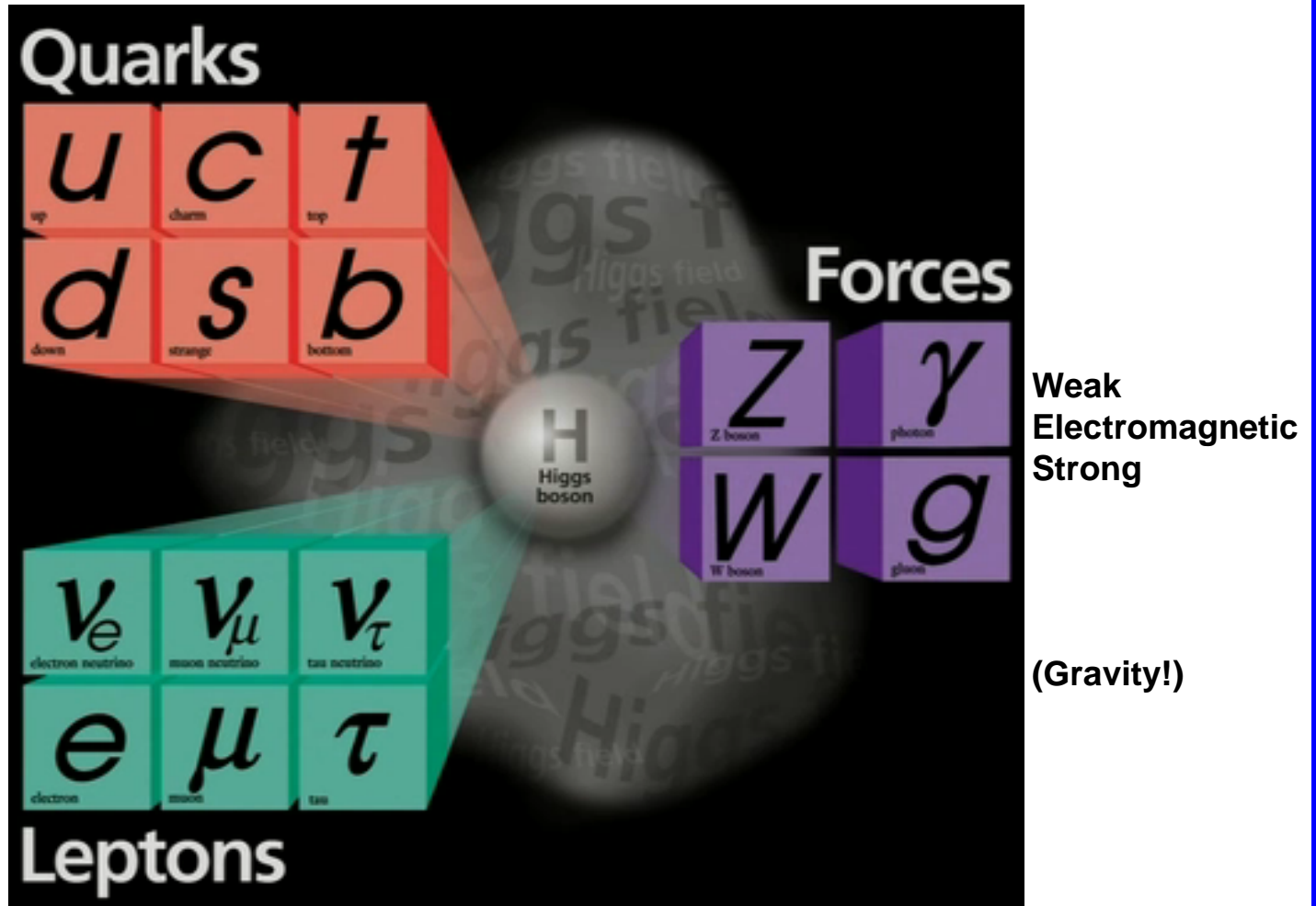
- 5x heavier than a proton!
- picosecond lifetime (long)!
- links to New Physics?!



Periodic Table of the... Particles!

Quotidian
Human
Experience

Up Quark
Down Quark
Electron
Photon
Gravity



Courtesy Fermilab

How the b Quark was Discovered

- ➔ Unlike c (charm) and t (top): It was sort of an accident.
- ➔ Experimental Proposal was effectively one page long:

A Study of Di-Lepton Production in Proton Collisions at NAL

J. A. Appel, M. H. Bourquin, D. C. Hom, L. M. Lederman,
J. P. Repellin, H. D. Snyder, J. K. Yoh (Columbia
University); B. C. Brown, P. Limon, T. Yamanouchi (NAL).

(Formerly #70 Phase III)

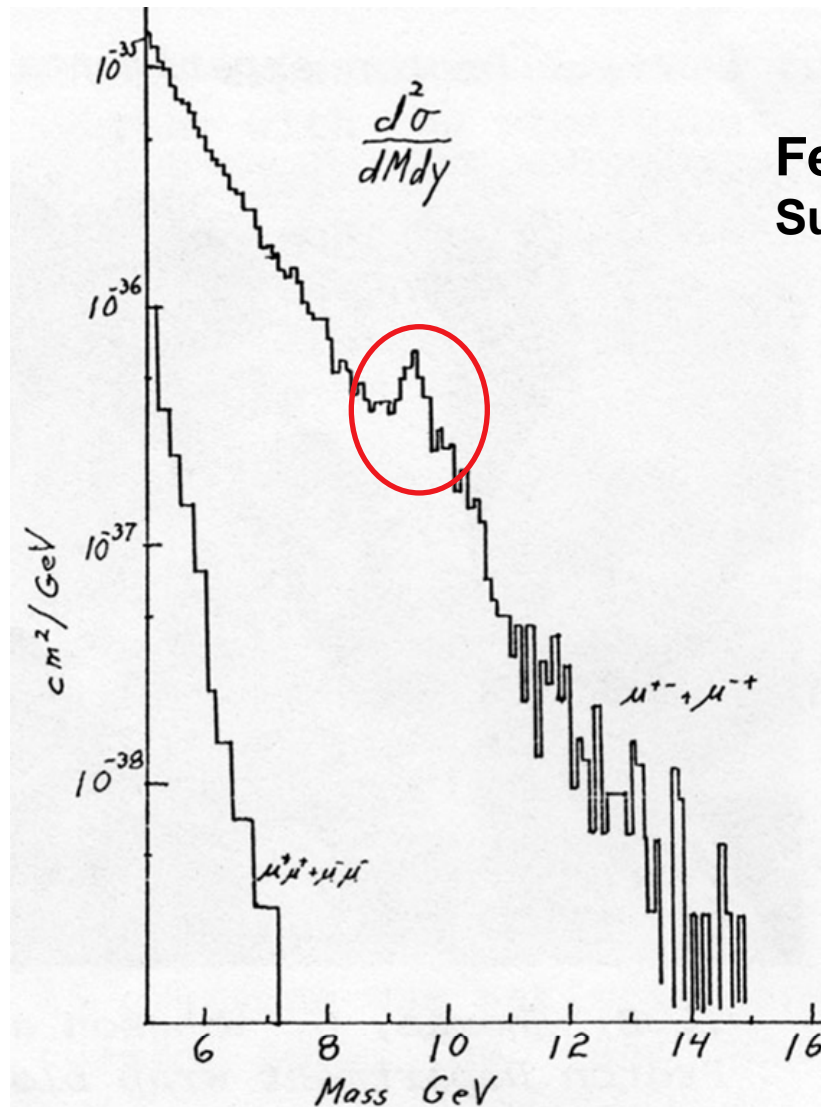
February 1974

1. Observe and measure the spectrum of virtual photons emitted in p -nucleon collisions via the mass distribution of e^+e^- pairs: $p + p \rightarrow e^+ e^- + \text{anything}$. (1)
Study characteristics, e.g. parity violation, p_{\perp} behavior.
2. Search for structures in the above spectrum, publish these and become famous, e.g. W^0 , B^0 .
- ⋮

- ➔ No mention of any search for a new quark!

First Observation of the b Quark

➔ Here's how it looked:



Fermilab
Summer, 1977

Flashback 1977: Year of the b Quark Discovery

➔ Elvis died, maybe.

➔ *Star Wars* opens May 25th.

➔ Tandy TRS-80



➔ Commodore PET



➔ Apple II



➔ Leon Lederman *et al.* discover b quarks at Fermilab.

➔ Rutherford Physics Building opens!

➔ Metrication of Canadian road signs takes place.

➔ Too old for the 2008 McGill Physics calendar:



Observing and Measuring, circa 1977

- ➔ **Laboratory: Switzerland**
(sandals with socks...)
- ➔ **Instrumentation: Tape measure.**
- ➔ **The Experiment: ???**

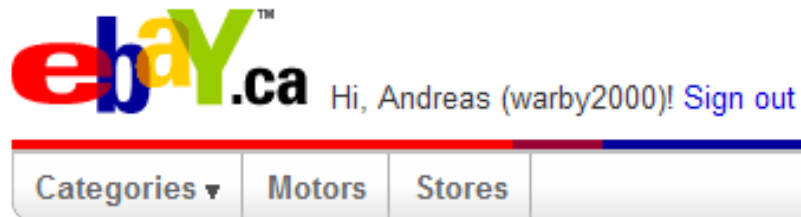


Unusual Sibling Phenomenon




How to see *b* Quarks in 2007?

- ➔ “Everything has beauty but not everyone sees it.” – Confucius
- ➔ A search on eBay for “b quark” resulted in one hit:



1 item found for **b quark** ([Save this search](#))

List View | [Picture Gallery](#) Sort by: [Customize Display](#)

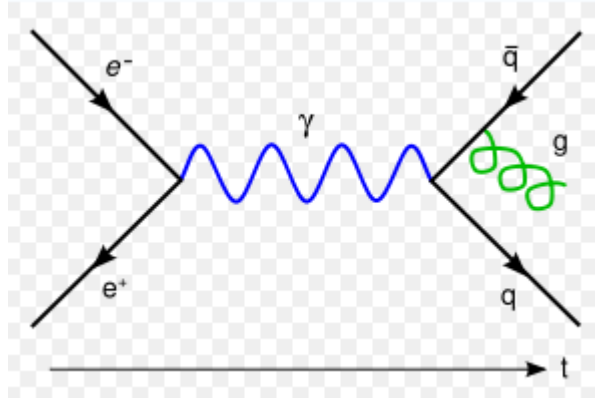
<input type="checkbox"/>	Compare	Item Title	Price*	Bids	Country/Region	Time Left ▲
<input type="checkbox"/>	Compare	 Peugeot 404 504 Elixir Quark B Leather Shift Knob Blk	C \$13.13	-	Brazil	1d 03h 10m

[Compare](#) To compare items side-by-side, select the check boxes and click the [Compare](#) button.

- ➔ In order to study *b* quarks, we first must make them in accelerators.

Beauty Salons: Where b Quarks get Made

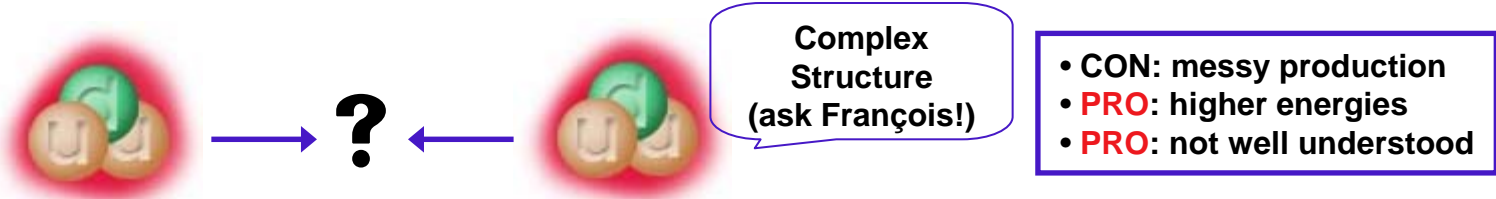
➔ The **clean** way: use electricity and light!



- **PRO**: clean production
- **CON**: lower energies
- **PRO**: well understood

Annihilate electron and positron particle beams
e.g., BaBar (ask Steve or Popat) and Belle (in Japan)

➔ The **dirty** way: smash (anti-)protons together, like 2 bags of marbles:



- **CON**: messy production
- **PRO**: higher energies
- **PRO**: not well understood

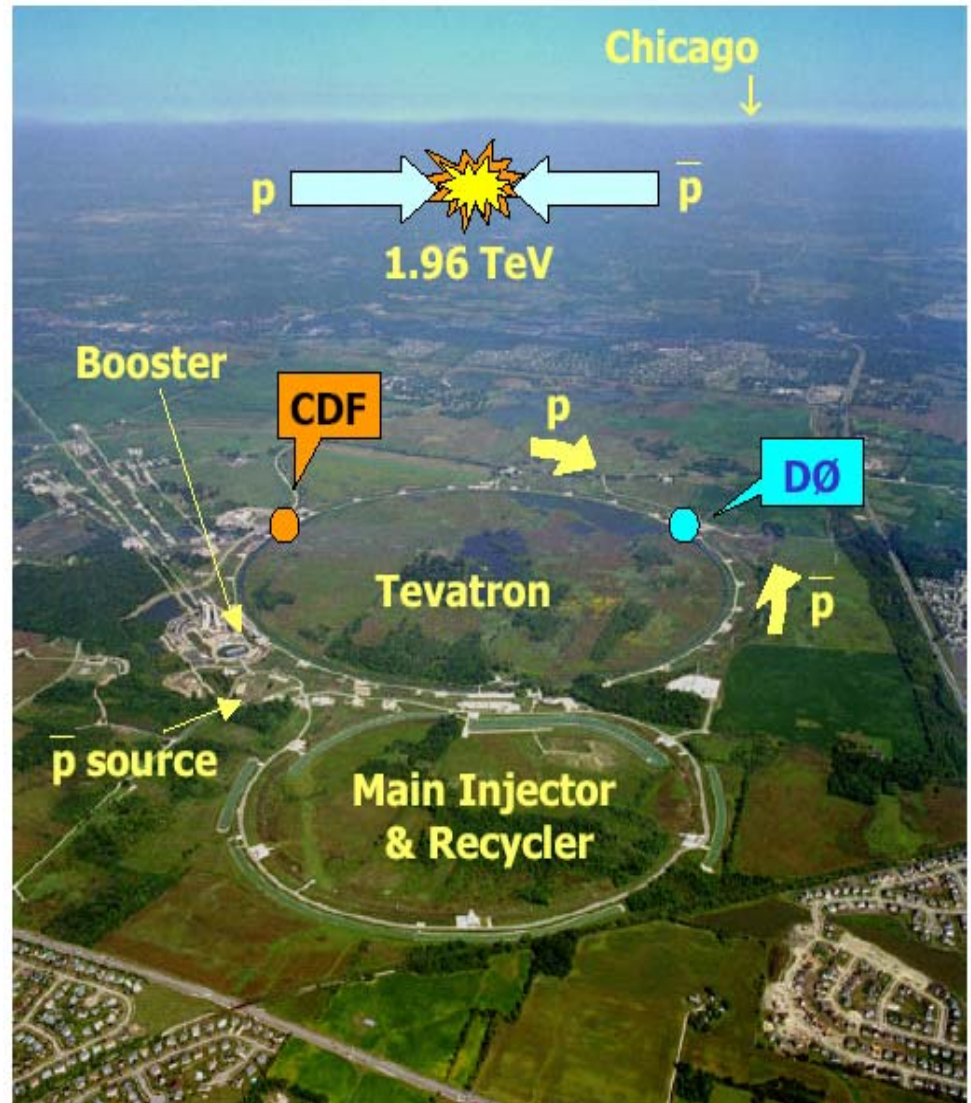
e.g., Fermilab (Tevatron) and CERN (LHC – Large Hadron Collider)

The Tevatron Accelerator: Fermilab Tevatron Matter-Antimatter Collider

**World's highest-energy
operating particle collider**

Circumference ~6.28 km

**1.96 TeV collision energy
= mass of 2100 protons
= 3×10^{-24} kg**

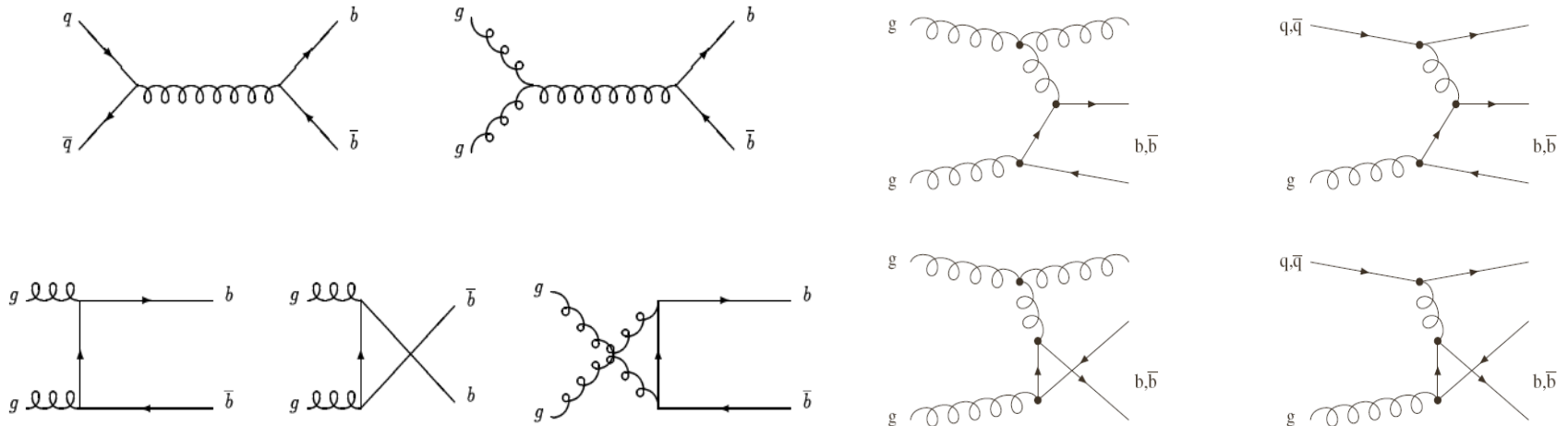


How are b Quarks made from protons?

Collide beams of **protons** and **antiprotons** at the highest energies

Produce **b quarks** in reactions of beam constituents: light quarks (**q**) and gluons (**g**)

time \longrightarrow



These are all interactions of the **Strong force**

Studying Jets of b quarks

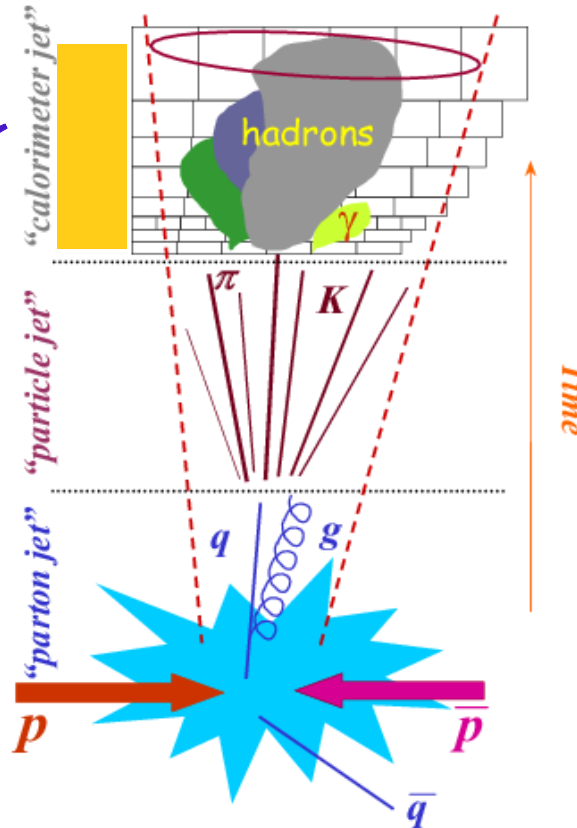


Greg Williams

Find beauty here



To figure out what's going on with beauty here!



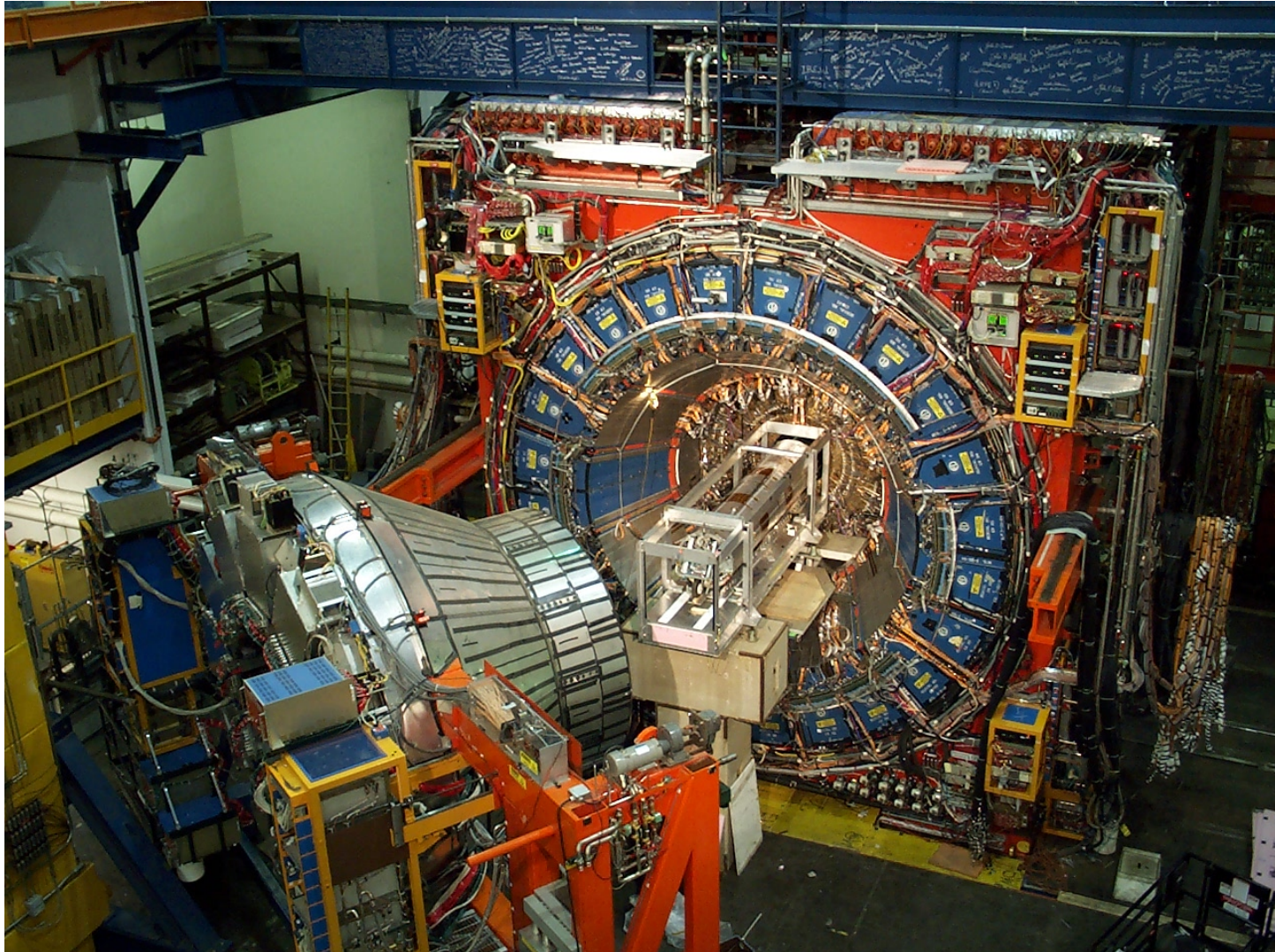
Dr. Rob Snihur

Questions:

Which reactions occur? How many b quarks get produced with what energies?

Are theoretical predictions correct? Are there new exotic physics processes?

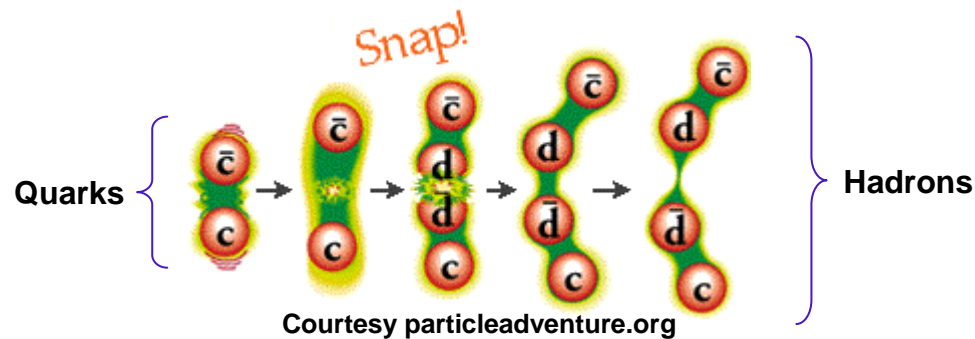
The Experiment: Collider Detector at Fermilab (CDF)



Mère Nature: Strong Force keeps (most) Quarks Modest

- ➔ No bare bottoms allowed!
- ➔ More correctly: all the quark types can stay bare for only 0.000000000000000000000001 seconds (that's 10^{-23} s)
- ➔ **Q:** Why is quark nudity so short lived?
A: Because the strong force is so strong.
- ➔ **Q:** How much force is required to separate two quarks by 10^{-15} m?
A: 14 tons.

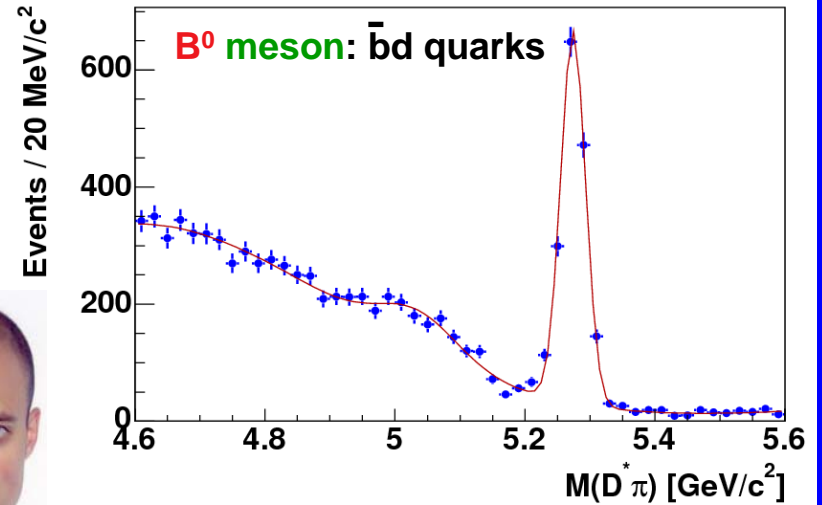
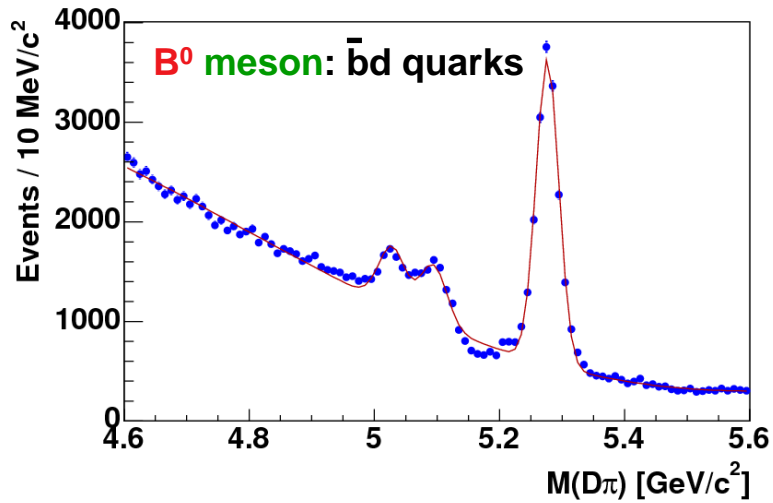
Imagine replacing
c (charm)
with
b (beauty)



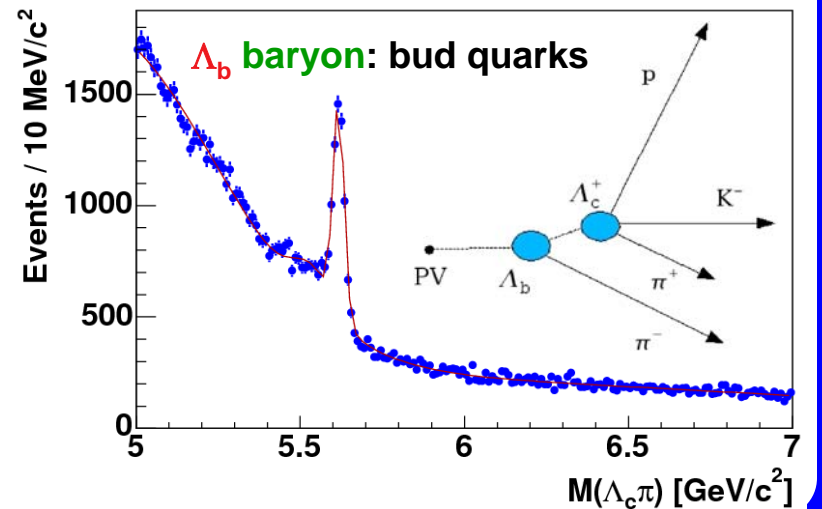
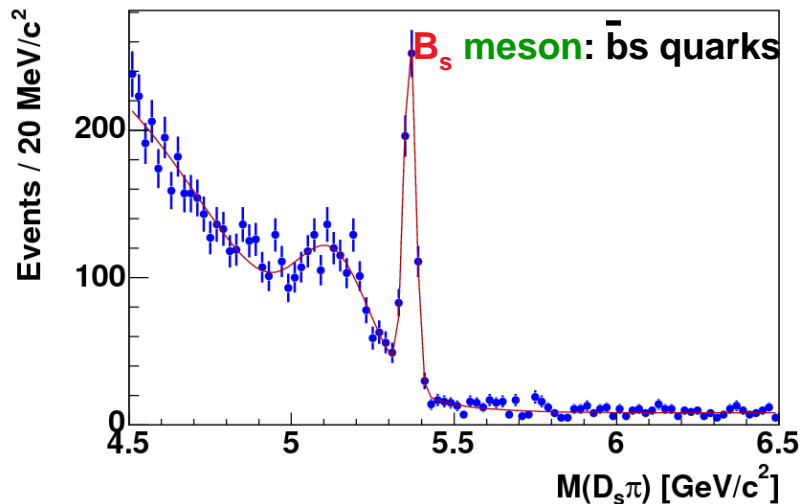
A Mystery of Bottom Hadrons

- ➔ Do b quarks dress themselves differently in Chicago, Geneva, and San Francisco?
- ➔ More precisely: does the collision environment affect how b quarks combine with other quarks to form hadrons?
- ➔ Flashback McGill, 1993, Leacock 132:
5th International Symposium on Heavy Flavour Physics
- ➔ A likely discrepancy exists between earlier CERN (electricity) and modern Fermilab (bags of marbles) measurements.
- ➔ We have now, finally, reached the precision to resolve this question.

Signals to 'Visualize' Different b Particles



Philippe Roy

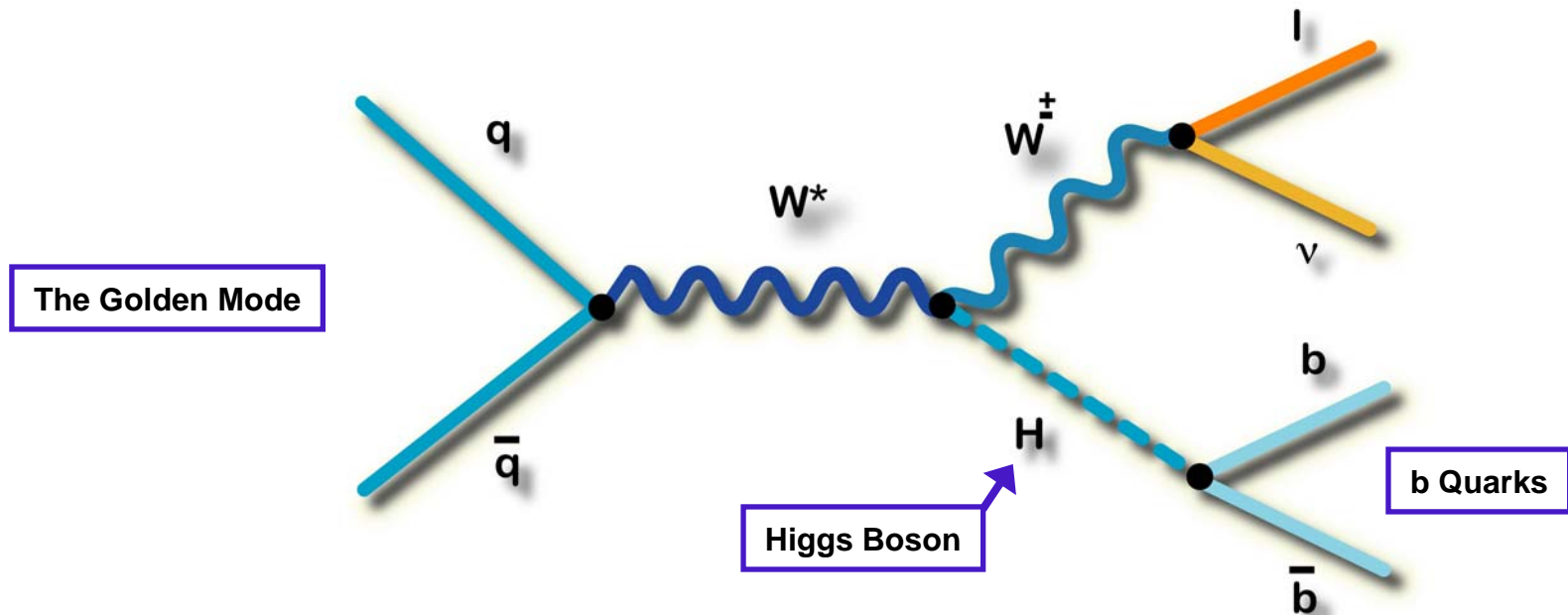


Hunting down the Higgs Boson

- ➔ 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!**



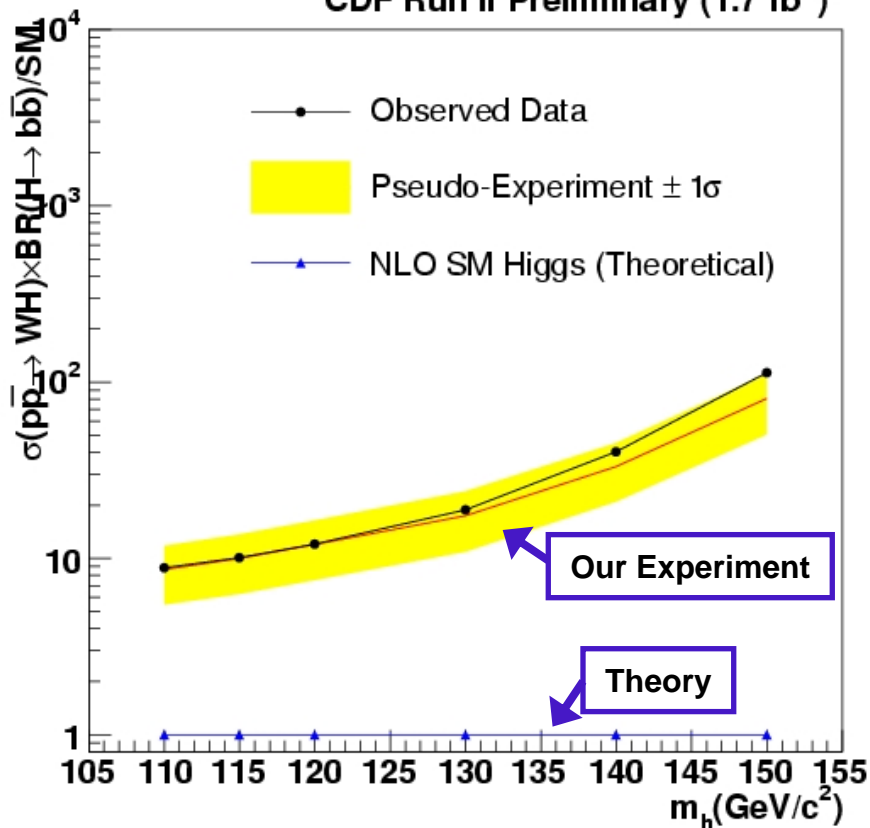
Adrian Buzatu



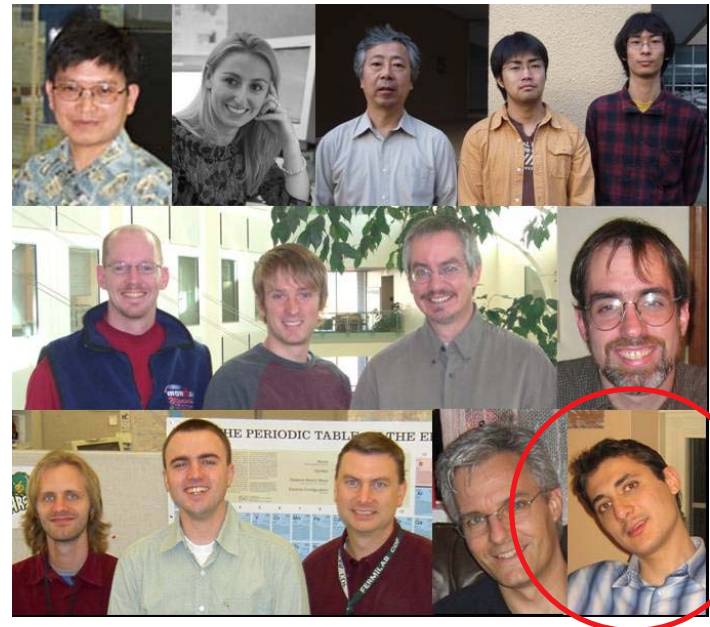
Fermilab Result of the Week

Article link: http://www.fnal.gov/pub/today/archive_2007/today07-11-08.html

CDF Run II Preliminary (1.7 fb⁻¹)

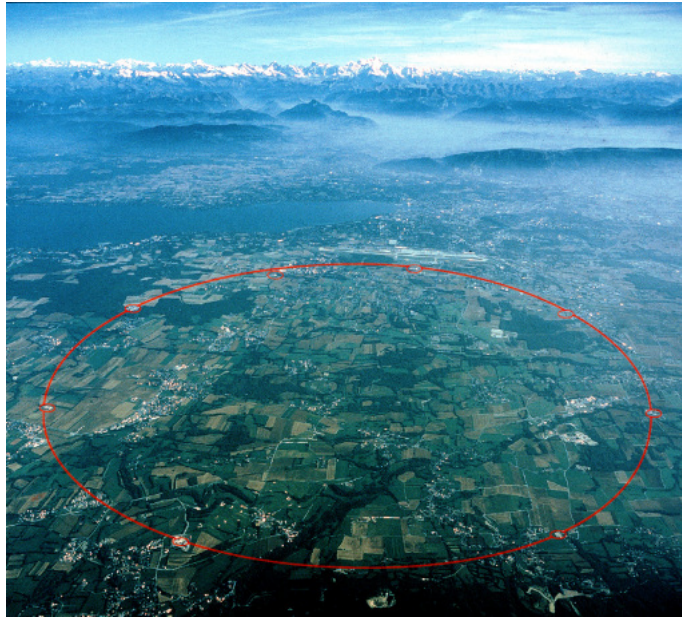


Closing in on the Higgs



Adrian Buzatu
McGill

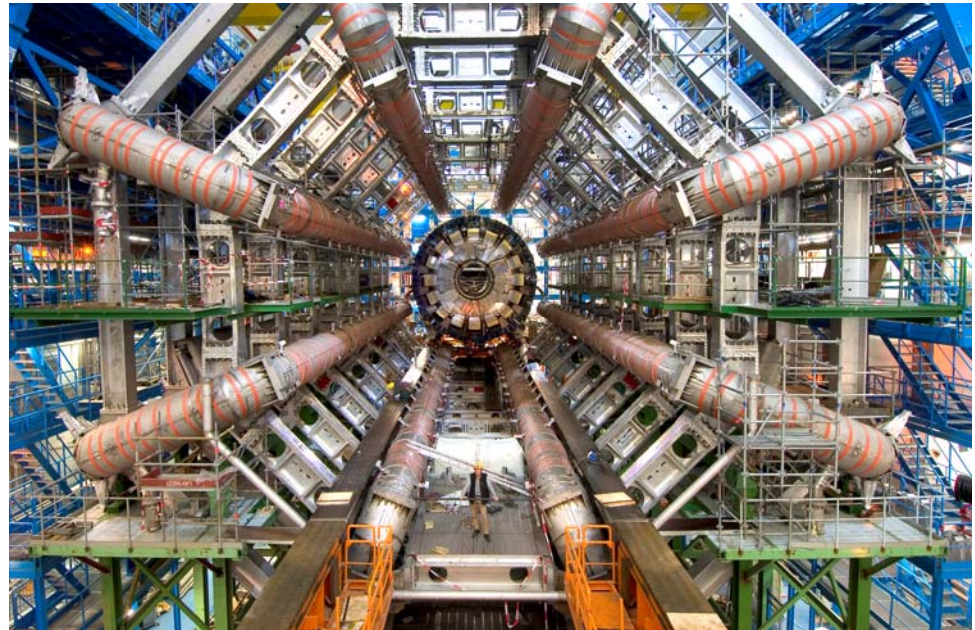
The Next Frontier: ATLAS at the LHC



27 km **Large Hadron Collider (LHC)**

CERN Laboratory, Geneva, Switzerland

14 TeV proton-proton collision energies!
= 15,000 protons in mass (2×10^{-23} kg)



ATLAS Experiment

First collisions in 2008,
we hope!

Beauty quarks will get
produced at ~5 MHz!

ATLAS Cavern: View from the Surface



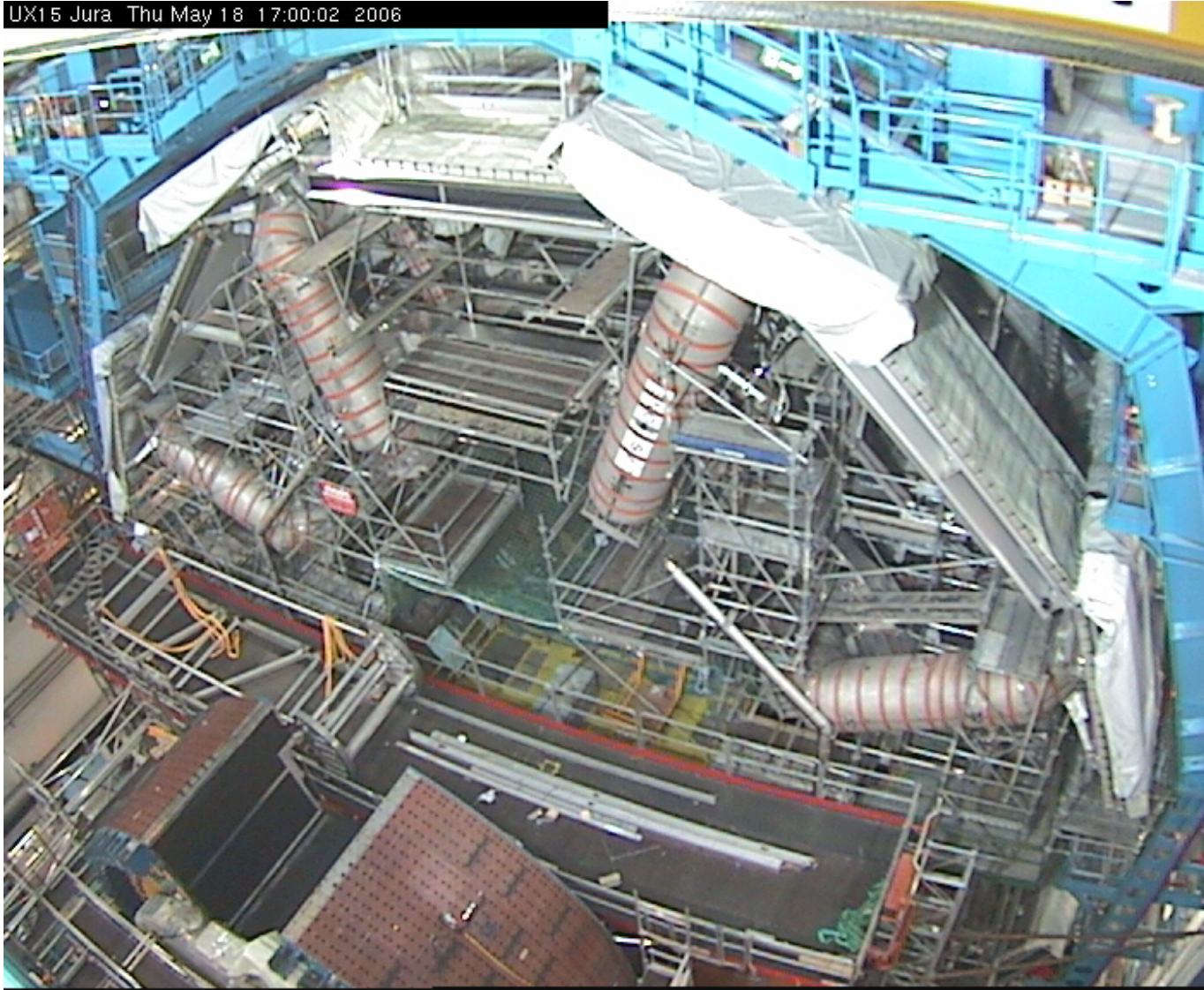
2006.05.18
~17:00
(A.W.)

Diameter:
~18m

Length:
~100m

Cavern View of the Same Components

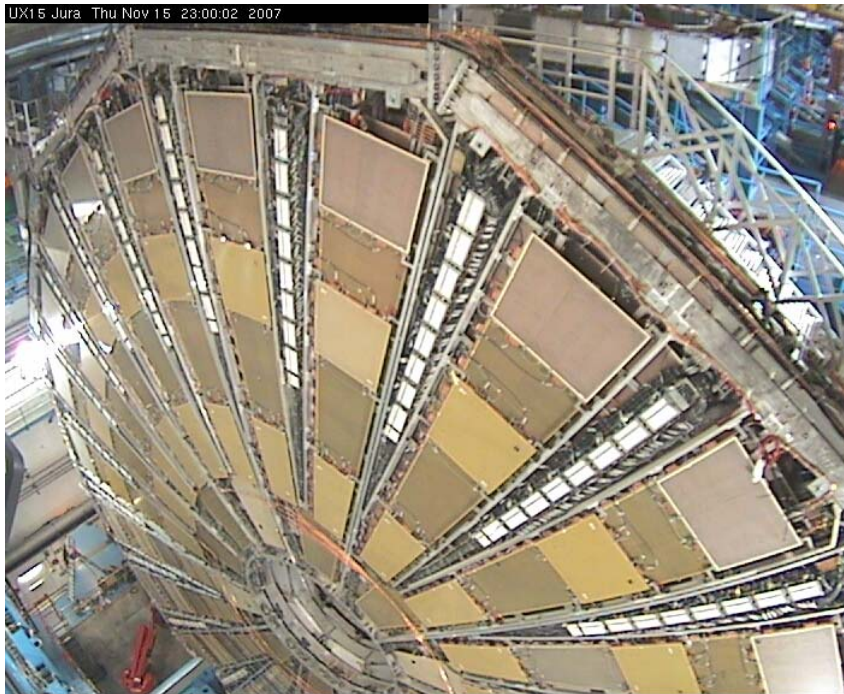
UX15 Jura Thu May 18 17:00:02 2006



2006.05.18
~17:00
(Cavern Cam)

ATLAS Detector: How it looks this week

Yesterday



This week back in 2003



Recall Brigitte's Homer's Physics talk (March)

Recent Press: Higgs Boson & the LHC

The screenshot shows the National Post website interface. At the top, the logo "NATIONAL POST" is displayed in a yellow banner. Below the logo is a search bar with the text "Search for" and a dropdown menu set to "in the National Post". A "find" button is to the right of the search bar. The date "Monday, November 12, 2007" is shown in the top right corner, circled in red. The main navigation bar includes "National Post Home" and "News >".

The main content area features a large article titled "Seeking the 'God particle'", where the phrase "God particle" is circled in red. The article is by Joseph Brean, published on Monday, November 12, 2007. The text describes a significant event at the Perimeter Institute for Theoretical Physics, where a large crowd gathered to see a lecture about the Higgs boson experiment. The article mentions that the event was held in a high school auditorium because the nearby Perimeter Institute clubhouse was full.

On the left side of the page, there is a sidebar with a "NATIONAL POST" logo and a section titled "Inside the National Post". This section contains a list of links: Columnists, News, Canada, Toronto, World, Letters, Editorials, Issues, Arts & Life, Sports Monday, Entrepreneur, Sports, Diversions, 30 days Archive, and Print Edition. Below this is another section titled "Inside the Financial Post" with links for Financial Post, Small Business, FP Trading Desk, FP Summary, and FP 500.

On the right side of the page, there is a large advertisement for Residence Inn by Marriott. The ad shows a well-furnished living room with a red sofa and a fireplace. The text of the ad reads "Spacious rooms MASTER THE LONG TRIP" and includes a "SEE MORE" link.

Below the advertisement is a section titled "Today's Post" with a link to "Military shrinking instead of growing". Below this link is a small list of items, including "Seeking the 'God particle'", which is highlighted with a red square.

CBC Nature of Things Magazine

- ➔ **Aired yesterday on CBC-TV at 8pm...**
- ➔ **Again next week, Thursday, Nov. 22, 10pm, CBC Newsworld.**

Brevity and the Higgs in Creative Writing

➔ A university creative writing class was asked to write a concise essay containing the following important elements:

1. Religion
2. Royalty
3. Mystery
4. Sex

➔ The prize-winning essay read:

“My God,” said the Queen, “I'm pregnant. I wonder who did it?!”

➔ A particle physics student, reluctantly taking the same class:

➔ “Can't I just use bare bottom quarks to find the God particle, unravel the mystery of mass, and have supper with the King of Sweden?!”

[Urban Legend, dated as early as 1935; promulgated on the Internet, starting in 2000]

Closing Remarks

- ➔ About 30% of all high-energy physics data analyses involve b quarks
- ➔ Three categories of measurement, each involving beauty quarks:
 1. How do b quarks **get made** by smashing matter into antimatter?
 - ➔ How does the strong force work?
 - ➔ Is the strong force enough or is there New Physics at play?
 2. How do b quarks **combine** with other quarks?
 - ➔ Partner quark(s): preference and number?
 - ➔ Dependent on collision environment?
 3. Hunt for the Higgs Boson **using** b quarks!

➔ Measurement  and discovery  are related...

➔ An interest in the beauty of nature for its own sake is always a sign of goodness. – Immanuel Kant

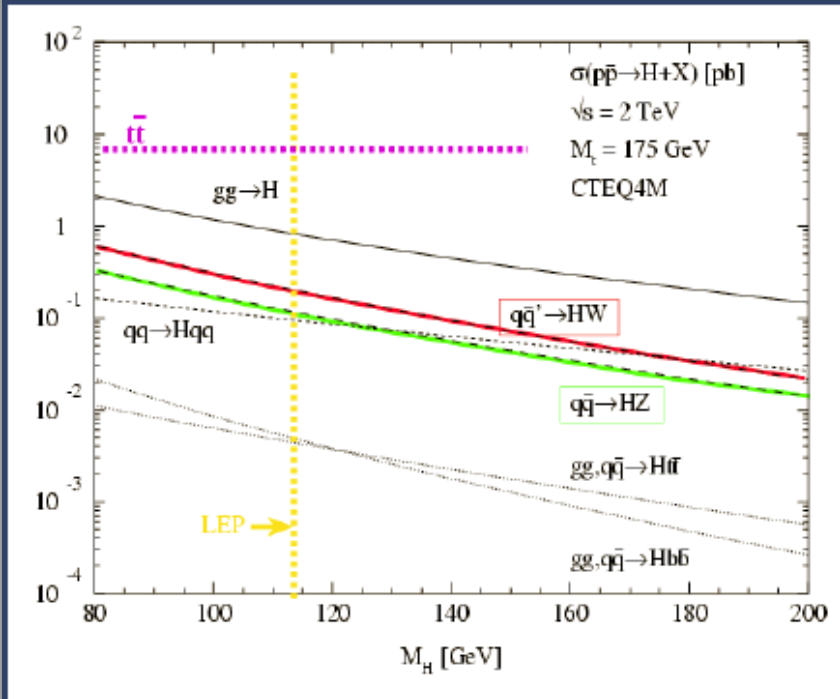
Thanks

A good many thanks to many good people.

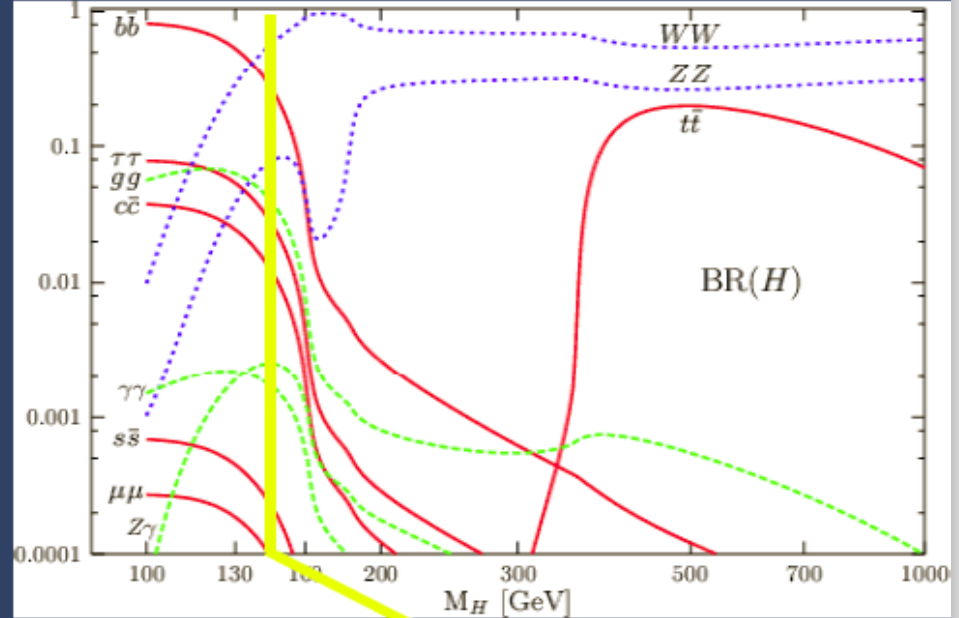
Extra Slides

One-slide SM Higgs Introduction

Production



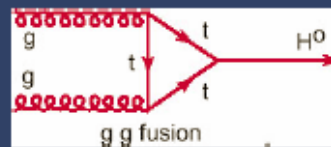
Decay



$100 < M_H < 140$

$\sim 140 < M_H < 200$

- Single Higgs production dominates
- Production in association with a vector boson order of magnitude less, but provides most sensitivity to low-mass searches



Light Higgs

- $H \rightarrow b\bar{b}$ most important
- Require VH production for sensitivity
- Searches defined by vector boson decay

Heavy Higgs

- Can exploit single Higgs production using WW^* decay

Higgs Constraints

