

Innovation in Physics: The Tangled String Theory

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Columbia University

Collin College, March 24 2010

Outline

1 The Standard Model

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- 2 Beyond the Standard Model

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- 3 The Tangled Tale of String Theory

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- 4 Theoretical Innovations: Symmetries and the Higgs Mechanism
- 5 Experimental Innovation: The Large Hadron Collider
- 6 Current Situation and Future Prospects

Four Fundamental Forces

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- Gravity: Classical theory: Einstein's General Relativity 1916. No accepted complete quantum theory to this day. Not part of the Standard Model.

Fundamental Particles

Particles come in three generations, each with this pattern, but different masses.

Only this first generation is stable, contains all particles needed to make atoms.

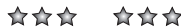
Leptons


 e_R
 $Y=-2$

 $\nu_L \quad e_L$
 $Y=-1$

 ν_R
 $Y=0$

Quarks


 d_R
 $Y=-2/3$

 u_L
 d_L
 $Y=1/3$

 u_R
 $Y=4/3$

The Standard Model and Geometry

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Gauge Fields = Connections

In the Standard Model, forces are described by what physicists call “gauge fields”, introduced by Yang-Mills (1954).

Modern formalism for geometry uses what mathematicians call “connections”, theory developed during late 1940s.

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Spinors and the Dirac Equation

In the Standard Model, matter is described by “spinor fields”, introduced by Dirac in 1928, satisfying an equation now called the “Dirac equation”.

In mathematics, spinors first introduced by Cartan in 1913.

From 1960s on, increasing use by mathematicians of spinor fields and the Dirac equation. Currently an active topic of research.

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1967: Weinberg and Salam introduce a new field, the Higgs field. Can give particles mass, but introduces lots of extra parameters.

Glashow likes to refer to Higgs field as "Weinberg's toilet": something you have to have in your home, but is not the part of your house you are most proud of and show off to the neighbors. No obvious geometrical significance, ruins your ability to predict many things you'd like to be able to predict.

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- What explains the relative strengths of these forces?
- Why the pattern of matter particles shown earlier? Why three generations?
- Why the Higgs? Can we somehow understand particle masses?

Some Speculative Ideas

Favorite speculative ideas for going beyond the Standard Model

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- Extra dimensions: explain Standard Model patterns using more than 3 space dimensions, somehow hidden.

None of these ideas has really worked. No convincing answers questions of last page.

Biggest problem: No hints from experiment, all data agrees precisely with Standard Model. Theoretical physicists are victims of their own success.

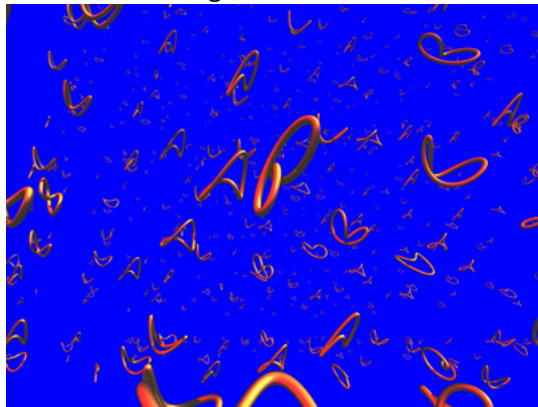
String Theory: Basic Idea

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New idea: take as elementary objects things that have one-dimensional extension: “strings”.



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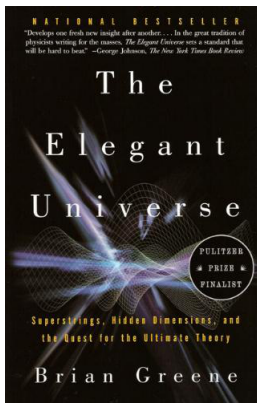
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- 1973: QCD makes string theory unnecessary.
- 1974: String theory proposed as quantum gravity theory.
- 1984: Explosion of interest in string theory as a unified theory of gravity and Standard Model. Uses strings in nine dimensions of space. Various proposals for how to deal with extra six dimensions.

The Case for String Theory Unification



Published in 2000.

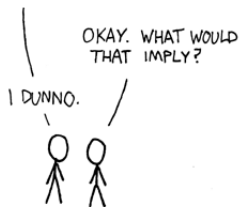
Three-part NOVA special in 2003.

- An interesting consistent extension of usual theories.
- Gives a quantum theory of gravity likely to be consistent.
- Unifies gravity and the Standard Model. Enough structure to fit the patterns seen in the standard model.

The Case Against String Theory Unification

STRING THEORY SUMMARIZED:

I JUST HAD AN AWESOME IDEA.
SUPPOSE ALL MATTER AND ENERGY
IS MADE OF TINY, VIBRATING "STRINGS."



Basic problem: Despite 25 years of effort, no predictions

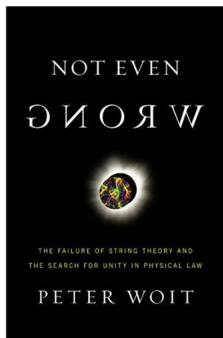
Reason: You can get just about anything, depending what you do with the extra six dimensions.

The Anthropic String Theory Landscape and the Multiverse

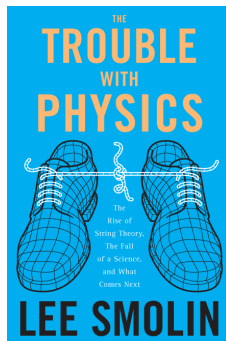


If you can't say something nice...

The String Wars: Books



US Publication date:
September 4, 2006



US Publication date:
September 19, 2006

The String Wars: Blogs



High Energy Beams at the LHC

March 19th, 2010

At 5:23 am in Geneva this morning, for the first time the two LHC beams were ramped up to high energy, the 3.5 TeV/beam that they plan to run at for the next two years. These are the highest energy (per particle) beams ever created by human beings, significantly surpassing the value at which the Tevatron operates (.98 TeV/beam) as well as the record achieved last fall (1.18 TeV/beam) during the early stages of beam commissioning.

From now on, work will continue on preparing the machine to operate at higher intensity (for now they are using low-intensity pilot beams). For the next week or two, one of the challenges will be to carefully avoid any interesting collisions between particles in the two beams, since a major [media event](#) is being organized around the first collisions, and the event is tentatively scheduled for March 30.

Update: CERN press release is [here](#).

Posted in [Experimental HEP News](#) | 8 Comments »

Millennium Prize to Perelman

March 18th, 2010

The Clay Mathematics Institute [announced](#) today the award of the

Not Even Wrong: The Book



[Reviews](#)

[Errata](#)

Categories

- [Book Reviews](#) (6)
- [BRST](#) (12)
- [Experimental HEP News](#) (59)
- [Langlands](#) (2)
- [Multiverse Mania](#) (39)
- [Not Even Wrong: The Book](#) (24)
- [This Week's Hype](#) (28)
- [Uncategorized](#) (768)

Latest Comments

- [High Energy Beams at the LHC](#) 5
- [Peter Woit, SteveB, Bill K., Dr. E., and more](#)

Started March 2004, still operating, devoted to topics in mathematics and physics

The String Wars: Blogs

String Theory Blogs

- Musings (Jacques Distler, UT Austin)
- Asymptotia (Clifford Johnson, USC)
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An Example, October 2006

"We've been thinking how to stop this whole new industry of parasites who have very significant profits from writing sensational patent lies about science and the scientists. I estimate that one of their prototypes - the black crackpot - has just done far too much damage to science and the civilization for his otherwise worthless life to be a sufficient price to repay his crimes."

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Ideas about symmetry are crucial to our understanding of physics. Basic observables and conservation laws of physics are consequences of symmetries.

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More tomorrow...

Importance of Symmetries in Mathematics

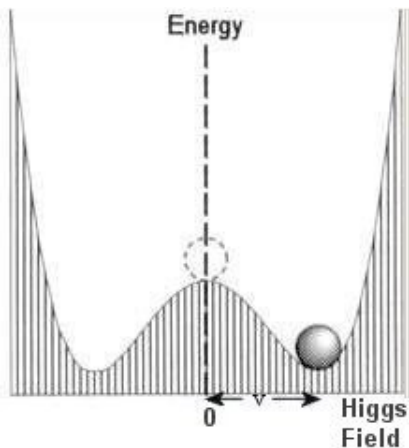
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Can define what “geometry” means in terms of symmetries, also crucial in modern number theory.

Symmetries and the Higgs Mechanism



Higgs field setup: choose energy potential so zero Higgs field is unstable, the field prefers to sit at a non-zero value. Vacuum state has non-trivial structure.

Standard Model has infinite-dimensional “gauge symmetries”, poorly understood in general.

Speculation: Non-trivial structure of the vacuum needed to make theory work has something to do with still mysterious behavior of these gauge symmetries.

The Tevatron



Startup in 1983 at Fermilab near Chicago.
Now colliding 1 TeV protons and 1 TeV anti-protons, was highest energy accelerator in the world until last fall.

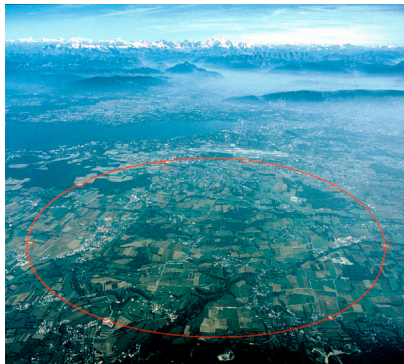
Superconducting Super Collider



Construction started around
Waxahachie, canceled in 1993.

Was to collide 20 TeV protons and
20 TeV protons.

The LHC

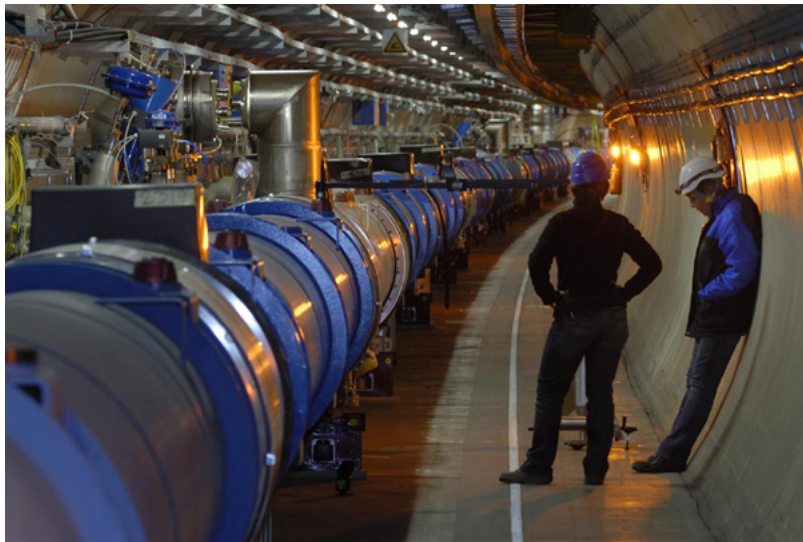


Operation as a collider beginning next week under the French-Swiss border near Geneva.

This year: 3.5 TeV protons colliding with 3.5 TeV protons

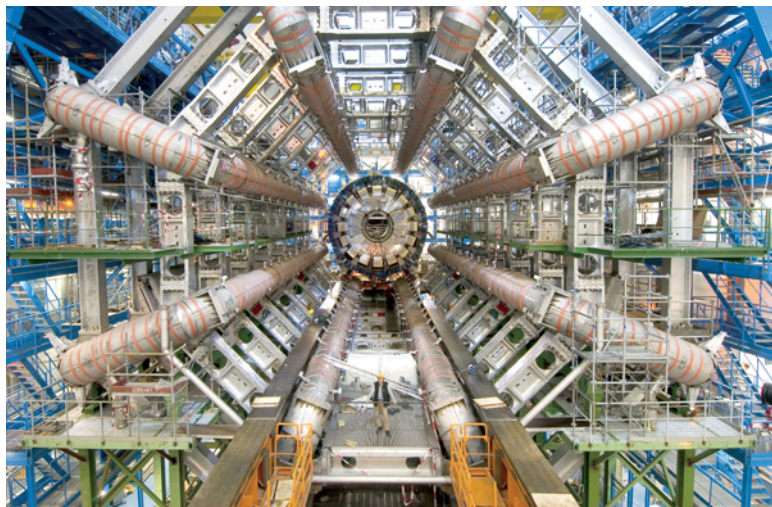
Design energy (2013?): 7 TeV protons colliding with 7 TeV protons

Inside the LHC Tunnel



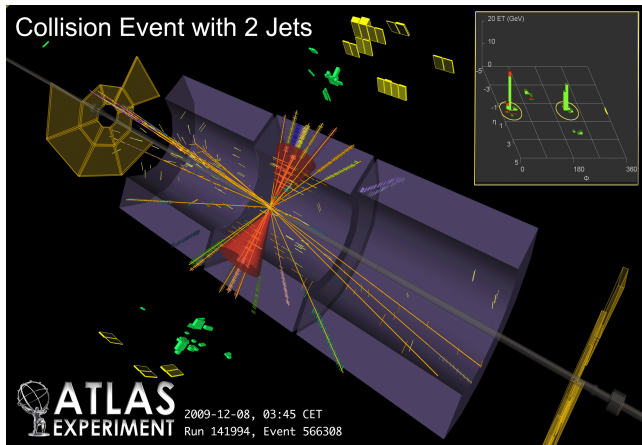
Inside the 53 mile long LHC tunnel.

ATLAS: One of the LHC Detectors



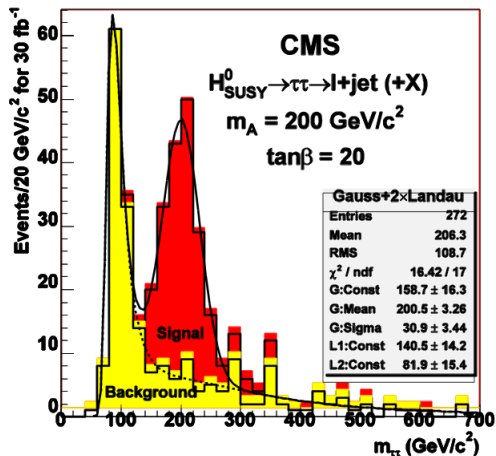
ATLAS, one of the large detectors surrounding points where the LHC beams collide.

An ATLAS collision event from last year



In December, lower energy beams (1.18 TeV) were circulated and collided. This is a graphical display of the data from one event at ATLAS.

What the LHC will be looking for



A graph made using simulated data to show what one particular Higgs signal would look like.

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- Deeper insight into the mathematical structures of the Standard Model and General Relativity will show how to unify them.

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- Now until Tevatron shutdown (late 2011, later?): exclusion of a wider range of masses, or tentative evidence of existence.
- Late 2011: LHC data arrives competitive with Tevatron data.
- 2014?: 7 GeV + 7 GeV LHC data, sufficient to rule out the existence of the Higgs, or confirm its existence if there.

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Discovery of the Higgs particle with predicted properties.

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Much better: some surprising data inconsistent with the Standard Model, that will give us a hint towards new theoretical ideas and a better mechanism for getting masses than the Higgs field.

We'll know in a few years. First data from new energy region should arrive next Tuesday.

What's happening at the LHC right now?

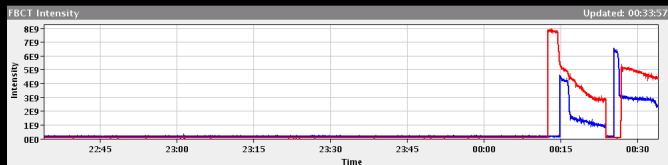
LHC Page1 Fill: 977 E: 450 GeV 23-03-2010 00:33:57

BEAM SETUP: INJECTION PROBE BEAM

BCT TI2: 0.00e+00 I(B1): 3.38e+09 BCT TI8: 0.00e+00 I(B2): 3.82e+09

TED TI2 position: **BEAM** TDI P2 gaps/mm up: 9.06 down: 9.03

TED TI8 position: **BEAM** TDI P8 gaps/mm up: 8.32 down: 8.35



Comments 23-03-2010 00:05:58 :

Injecting both beams
 Beam 1 on Bucket 1
 Beam 2 on Bucket 1
 Orbit feedback measurement

BIS status and SMP flags

	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true
Setup Beam	true	true
Beam Presence	false	true
Moveable Devices Allowed In	false	false
Stable Beams	false	false

LHC Operation In CCC : 77600, 70480

PM Status B1 **ENABLED** PM Status B2 **ENABLED**

What's happening at the LHC right now?

