Innovation in Physics: The Tangled String Theory

Peter Woit

Columbia University

Collin College, March 24 2010
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Outline

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5. Experimental Innovation: The Large Hadron Collider
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4. Theoretical Innovations: Symmetries and the Higgs Mechanism
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Four Fundamental Forces

Standard Model 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.
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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.
The Standard Model and Geometry

Einstein's theory of gravity (1916) = Riemannian geometry (late 1800s).

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.

Early 1970s: Mathematicians and physicists realize these are the same thing.

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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The Higgs Mechanism (AKA Weinberg’s Toilet)

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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.
Beyond the Standard Model

What the Standard Model Doesn’t Explain

Why the specific pattern of gauge fields that give the strong (SU(3)), weak (SU(2)) and electromagnetic (U(1)) forces?

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?
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Some Speculative Ideas

Favorite speculative ideas for going beyond the Standard Model

- Grand Unification: fit all 3 forces into one.
- Supersymmetry: extend ideas about geometry, requires un-observed doubling of particles.
- 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.
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String Theory: Basic Idea

In conventional physics, elementary objects are particles with no extension, at each moment in time, they exist at a point. New idea: take as elementary objects things that have one-dimensional extension: “strings”.
String Theory: Some History

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The Case for String Theory Unification

- 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

Basic problem: Despite 25 years of effort, no predictions

Reason: You can get just about anything, depending on 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 18th, 2010

At 5:23 am in Geneva this morning, for the first time the two LHC beams were ramped up to high energy, the 9.1 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 (0.9 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 test 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

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

- Musings (Jacques Distler, UT Austin)
- Asymptotia (Clifford Johnson, USC)
- The Reference Frame (Lubos Motl, Harvard)
The Tangled Tale of String Theory

The String Wars: Blogs

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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."

Peter Woit (Columbia University)
Importance of Symmetries in Physics

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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**Examples**

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- Symmetry under phase changes of quantum wave-function: Charge
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More tomorrow...
Study of symmetries is fundamental unifying topic throughout mathematics, goes under name “Representation Theory”
Importance of Symmetries in Mathematics

Study of symmetries is fundamental unifying topic throughout mathematics, goes under name “Representation Theory”

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.
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.
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 large detectors surrounding points where the LHC beams collide.
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.
A graph made using simulated data to show what one particular Higgs signal would look like.
Current Situation and Future Prospects

Quantum Gravity

Current Situation

Lots of proposals for ways to get a quantum theory of gravity.

No way to test any of them.

Hopes for the future

Someone will have an unexpected idea about how to indirectly measure quantum gravity effects.

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

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Innovation in Physics: The Tangled String

March 2010 27 / 31
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The Search for the Higgs

What do we know about the Higgs?

- The Higgs mass is at least 114 GeV (from LEP, previous accelerator in LHC tunnel).
- At 95% confidence level, the Higgs mass is not between 163 GeV and 166 GeV (latest Tevatron data).
- At 95% confidence level, the Higgs mass is less than 185 GeV (from searches for indirect effects of the Higgs).

What will we learn about the Higgs soon?
- 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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NOT!
What We’re Hoping For

Discovery of the Higgs particle with predicted properties.

NOT!

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.
Current Situation and Future Prospects

What’s happening at the LHC right now?

BEAM SETUP: INJECTION PROBE BEAM

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

**BCT T12:** 0.00e+00  **BCT T18:** 0.00e+00  **B1:** 3.38e+09  **B2:** 3.82e+09

**TED T12 position:** BEAM  TDI P2 gaps/mm  up: 9.06  down: 9.03

**TED T18 position:** BEAM  TDI P8 gaps/mm  up: 8.32  down: 8.35

**FBCT Intensity**

*Updated: 00:33:57*

**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**

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**LHC Operation in CCC :** 77600, 70480

PM Status B1 | ENABLED  PM Status B2 | ENABLED
Current Situation and Future Prospects

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Performance over the last 12 Hrs

**Background 1**

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