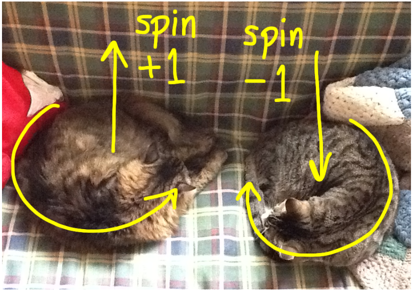
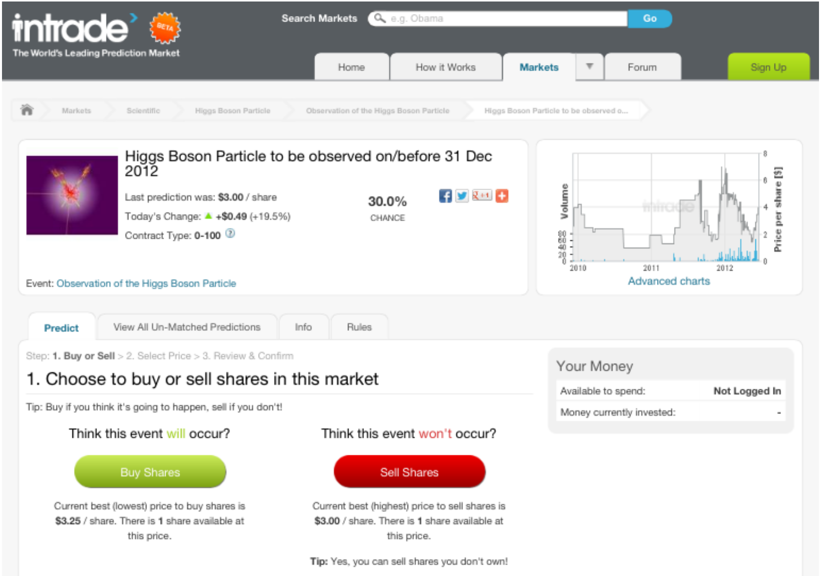
Spin!



Jim Pivarski

17 November, 2012

Betting on the Higgs discovery (June 17)



Betting on the Higgs discovery (June 17)

The rules were careful about some issues (peer reviewed journal, independent confirmation, five sigma statistical significance)...

Predict | View All Un-Matched Predictions | Info | **Rules**

Before entering any orders to trade this contract please ensure you read have and understood this DISCLAIMER.

This market will settle $10.00 if the Higgs Boson particle is observed before the specified time and date.

This market will settle $0.00 if the Higgs Boson particle is NOT observed before the specified time and date.

Confirmation of the Higgs Boson particle having been observed must be published in a major scientific journal for this contract to be expired.

Clarification (Jan 5th 2009): for the Higgs Boson particle to be "observed" there must be a "five sigma discovery" of the particle.

Clarification (8th Dec 2011):

For purposes of this market, "published in a major scientific journal" means that a scientific paper must have gone though a peer review process of a major scientific journal and then either be printed in a major scientific journal or made available on the journal's website or other repository of peer reviewed papers.
Any announcement, editorial or other non peered reviewed article published in a major scientific journal mentioning a discovery will **not** be considered adequate "confirmation" of the discovery unless it is clearly announcing a peer review process has been completed as well as the other requirements (such as the discovery being a five sigma discovery).
Any changes to the result after the market has expired will not be taken into account (Rule 3).

Due to the nature of this market you are obligated to read Rule 4 (Unforeseen Circumstances) and Rule 5 (Time Protection). Intrade may invoke these rules in its absolute discretion if deemed appropriate.

Please contact the exchange by e-mailing help@intrade.com if you have any questions regarding this market or the interpretation of these market specific rules before you place an order to buy or sell shares.

But they didn't actually require the new particle to be a Higgs boson.

The market closed on Sep 11, 2012 (the publication date of the discovery), but we still don't know if a Higgs was discovered.

What is a Higgs?

Some essential properties (to solve the problem for which it was intended):

- Non-zero vacuum expectation value
- Couples to particles in proportion to their masses
- Spin-0

Some non-essential properties (variants of the basic theory):

- Fermiophobic (only explains boson masses, not fermion masses)
- Supersymmetric (fits into a larger context that explains the Higg's own mass)
- Two-doublet (multiple Higgses, each bearing a part of the load)
- Metastable (the evacuum expectation value might change)

Some essential properties (to solve the problem for which it was intended):

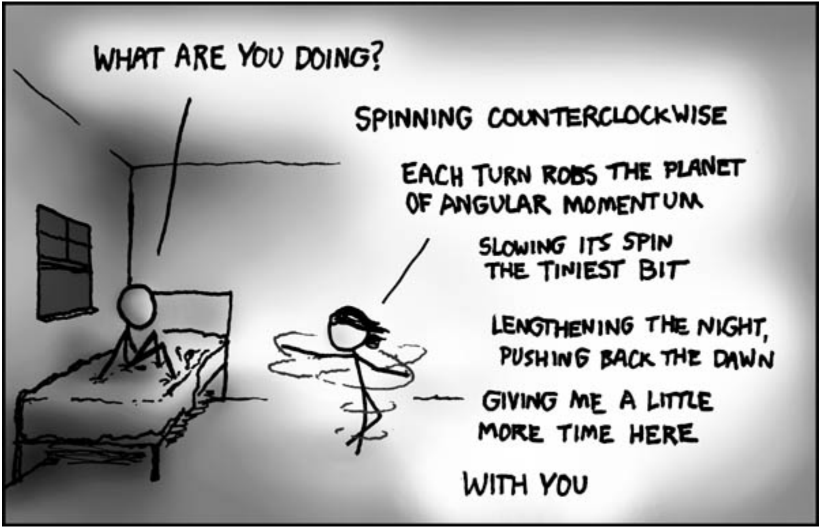
- Non-zero vacuum expectation value
- Couples to particles in proportion to their masses
- Spin-0

Some non-essential properties (variants of the basic theory):

- Fermiophobic (only explains boson masses, not fermion masses)
- Supersymmetric (fits into a larger context that explains the Higg's own mass)
- Two-doublet (multiple Higgses, each bearing a part of the load)
- Metastable (the evacuum expectation value might change)

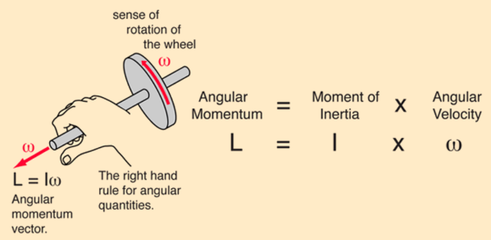
This talk is about spin

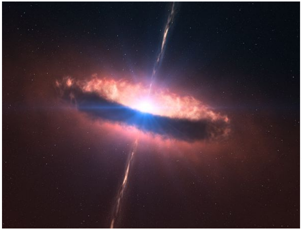
- Classical angular momentum
- Spin: angular momentum in quantum mechanics
- Examples of quantized spin, some visible to the naked eye
- Measuring the new particle's spin

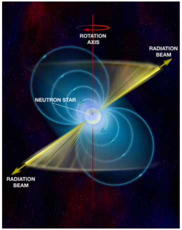


http://xkcd.com/

Angular momentum





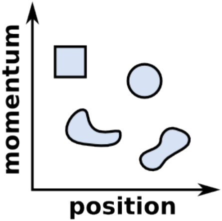


Quantized angular momentum

Angular momentum $\vec{L} = \vec{r} \times \vec{p} =$ position times momentum.

Position times momentum is quantized in units of

$$\hbar/2 = 5.27 \times 10^{-35} \text{ meter} \cdot \text{Newton-seconds.}$$



Phase space (momentum vs. position) is granular at an extremely small scale.

Related to $\Delta x \Delta p \geq \hbar/2$.

The angular momentum of an individual particle is only one or two units, called spin.

spin-0	spin-$\frac{1}{2}$ ($\hbar/2$)	spin-1 ($\hbar$)	spin-2 ($2\hbar$)
Higgs bosons	Quarks, electrons, muons, taus, neutrinos	Photons, W, Z bosons, gluons	Gravitons

Angular momentum of composite particles, such as protons (3 quarks), is the sum of these “intrinsic” spins and physical rotation.

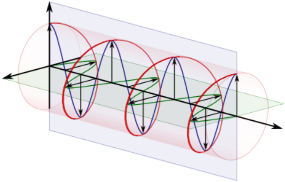
Spin of fundamental particles

spin-0	spin-$\frac{1}{2}$ ($\hbar/2$)	spin-1 ($\hbar$)	spin-2 ($2\hbar$)
Higgs bosons	Quarks, electrons, muons, taus, neutrinos	Photons, W, Z bosons, gluons	Gravitons

Angular momentum of composite particles, such as protons (3 quarks), is the sum of these "intrinsic" spins and physical rotation.

Photon spin is circular polarization

All photons have total spin 1; some in the direction of travel ($+1$), some opposite to the direction of travel (-1). Used to project 3-D movies.

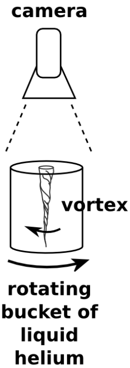


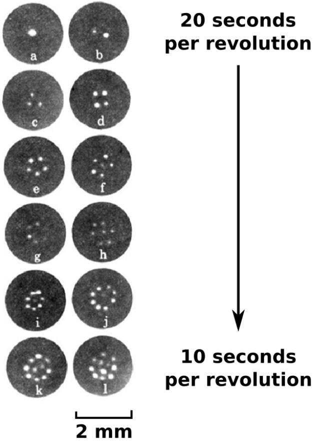
Quantized angular momentum, big enough to see

I have a problem with the idea that something related to rotation is quantized. Why not just put it on a record player and turn it slowly?

This experiment was performed with liquid helium, a quantum system big enough to see.

The result: quantized vortices emerged to cancel the angular momentum.





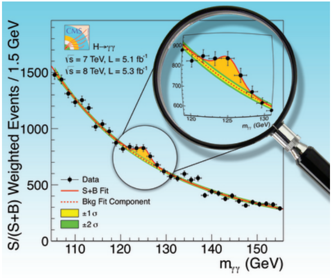
Why the Higgs must have no spin

A little more background about the Higgs mechanism:

- All particles are excitations of fields: the quark field, the electron field, the photon field ($\vec{E}$ and $\vec{B}$), etc.
- The vacuum is the minimum energy state. For most fields, this means the field value is zero (e.g. $\vec{E} = 0$, $\vec{B} = 0$ means no photons).
- The Higgs field has a minimum energy state that is not zero; everywhere in the universe, the Higgs field is present, to interact with particles and give them the illusion of having mass.
- A Higgs particle is an excitation around that non-zero minimum.

The vacuum does not have a preferred direction in space: it is rotationally symmetric. Fields with spin are asymmetric when they are non-zero because angular momentum is a vector.

The Higgs field must be non-zero everywhere and *not* rotationally asymmetric. Hence it must have no spin.



(Only showing CMS results: adding results from other experiments increases confidence.)

Something with mass = 126 GeV decays to

- two photons (99.9937% confidence)
- two Z bosons (99.9989% confidence)

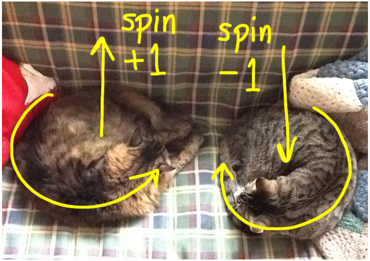
Something with a mass in the 120–130 GeV ballpark decays to

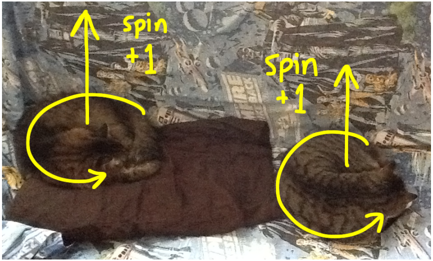
- two W bosons (99.73% confidence)
- two b quarks (92.8% “hint”)
- two taus (92.8% “hint”)

Only spin-0 and spin-2 particles can decay into two photons (the most restrictive decay mode).

A spin-0 particle can decay into two photons with oppositely aligned spins: $0 = (+1) + (-1)$.

A spin-2 particle can decay into two photons with the same spin: $(+2) = (+1) + (+1)$ or $(-2) = (-1) + (-1)$.



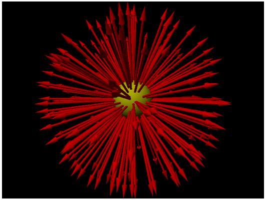


However, we can't easily measure the spin of these photons. Their energy is 30 billion times too high for photographic filters.

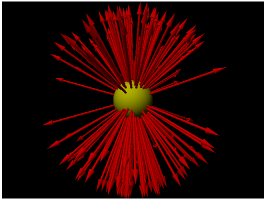
Measuring spin from decay angles

When particles decay, the angle of the decay products is random, but with a probability distribution that depends on spin.

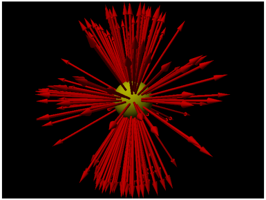
spin-0



spin-1



spin-2



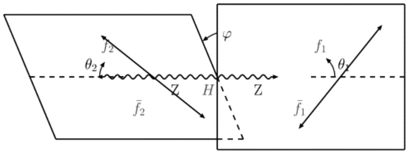
Spin-0 particles have no preferred direction in space, so a large sample of spin-0 particles decay symmetrically.

Spin-1 particles prefer to decay toward or against their angular momentum vector.

Spin-2 particles have a more complicated pattern: toward the poles or along the equator.

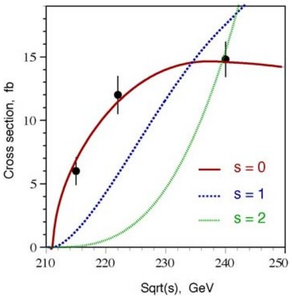
Measuring spin from decay angles

The Higgs to ZZ decay has the most experimental "handles," since Z bosons are spin-1 objects that decay into muons, which have very distinctive tracks. The analysis gets complicated, though:



Another option is to produce Higgses in electron collisions, which is like a Higgs decay to electrons in reverse.

The Higgs production rate versus electron energy depends on spin.



The bottom line

We don't have enough events to determine the spin of the new particle!

- Many events are required to measure the shape of a distribution.

In fact, there's a lot about it that we don't know: none of the "essential properties" (to determine if it is a Higgs boson or not) and none of the "variants of the basic theory" that I listed.

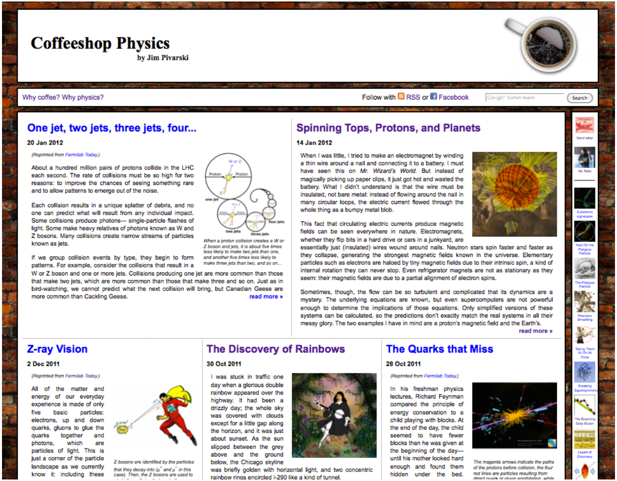
This is, of course, just the beginning.

This talk is based on my *Fermilab Today* article:

http://www.fnal.gov/pub/today/archive_2012/today12-11-02_NutshellReadMore.html

and many others like it can be found on my website:

http://www.coffeeshopphysics.com



Coffeeshop Physics

by Jim Pivarski

Why coffee? Why physics? Follow with RSS or Facebook Search

One jet, two jets, three jets, four...

20 Jan 2012

(Reprinted from Fermilab Today.)

About a hundred million pairs of protons collide in the LHC each second. The rate of collisions must be so high for two reasons: to improve the chances of seeing something rare and to allow patterns to emerge out of the noise.

Each collision results in a unique splatter of debris, and no one can predict what will result from any individual impact. Some collisions produce photons— single-particle flashes of light. Some make heavy relatives of photons known as W and Z bosons. Many collisions create narrow streams of particles known as jets.

If we group collision events by type, they begin to form patterns. For example, consider the collisions that result in a W or Z boson and one or more jets. Collisions producing one jet are more common than those that make two jets, which are more common than those that make three and so on. Just as in bird-watching, we cannot predict what the next collision will bring, but Canadian Geese are more common than Cackling Geese.

When a proton collision creates a W or Z boson and jets, it is about five times less likely to make two jets than one, and another five times less likely to make three jets than two, and so on...

read more »

Spinning Tops, Protons, and Planets

14 Jan 2012

When I was little, I tried to make an electromagnet by winding a thin wire around a nail and connecting it to a battery. I must have seen this on *Mr. Wizard's World*. But instead of magically picking up paper clips, it just got hot and wasted the battery. What I didn't understand is that the wire must be insulated, not bare metal: instead of flowing around the nail in many circular loops, the electric current flowed through the whole thing as a bumpy metal blob.

This fact that circulating electric currents produce magnetic fields can be seen everywhere in nature. Electromagnets, whether they flip bits in a hard drive or cars in a junkyard, are essentially just (insulated) wires wound around nails. Neutron stars spin faster and faster as they collapse, generating the strongest magnetic fields known in the universe. Elementary particles such as electrons are haloed by tiny magnetic fields due to their intrinsic spin, a kind of internal rotation they can never stop. Even refrigerator magnets are not as stationary as they seem: their magnetic fields are due to a partial alignment of electron spins.

Sometimes, though, the flow can be so turbulent and complicated that its dynamics are a mystery. The underlying equations are known, but even supercomputers are not powerful enough to determine the implications of those equations. Only simplified versions of these systems can be calculated, so the predictions don't exactly match the real systems in all their messy glory. The two examples I have in mind are a proton's magnetic field and the Earth's.

read more »

Z-ray Vision

2 Dec 2011

(Reprinted from Fermilab Today.)

All of the matter and energy of our everyday experience is made of only five basic particles: electrons, up and down quarks, gluons to glue the quarks together and photons, which are particles of light. This is just a corner of the particle landscape as we currently know it: including these

Z bosons are identified by the particles that they decay into (μ^+ and μ^- in this case). Then, the Z bosons are used to

The Discovery of Rainbows

30 Oct 2011

I was stuck in traffic one day when a glorious double rainbow appeared over the highway. It had been a drizzly day; the whole sky was covered with clouds except for a little gap along the horizon, and it was just about sunset. As the sun slipped between the grey above and the ground below, the Chicago skyline was briefly golden with horizontal light, and two concentric rainbow rings encircled I-290 like a kind of tunnel.

The Quarks that Miss

28 Oct 2011

(Reprinted from Fermilab Today.)

In his freshman physics lectures, Richard Feynman compared the principle of energy conservation to a child playing with blocks. At the end of the day, the child seemed to have fewer blocks than he was given at the beginning of the day— until his mother looked hard enough and found them hidden under the bed.

The magenta arrows indicate the paths of the protons before collision, the four red lines are particles resulting from