https://www.youtube.com/watch?v=9H_Ms4Bf8uo

Everything you think you know about Higgs boson is wrong

Všechno, co si myslíte, že víte o Higgsově bosonu, je špatně

Emergence

11,2 tis. odběratelů

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Leonard Susskind astonishing lecture on Higgs boson Mass giving mechanism: _ • Mass Giving Mechanism and the Higgs F...

0:01
(01)- my goal tonight is going to show be to show you as so far as I can in one hour which is tough which is hard it may not work but as well as I can to explain to you the nuts and bolts of what higs physics is about first of all there's a lot of moving Parts a lot of pieces that I would have to that I would have to explain to you first uh to really do it right and I'm going to try to explain those pieces in little in little modules shall we say it's a highly quantum mechanical effect it cannot really be understood without quantum mechanics and so I would begin with a course in quantum mechanics and let's say the course in quantum mechanics consists of just one thing things are quantized the first was that quantum mechanics were going to summarize by one simple statement that things are quantized in quantum mechanics quantized means they come in discrete bits the most important example is angular momentum not the most important necessarily the most important example but the most important um example for me tonight will be angular momentum and angular momentum is to do with rotating objects and so forth angular momentum in quantum mechanics unlike classical mechanics comes in discrete units the unit is plunks constant you can't have a tenth of a unit of angular momentum you can only have angular momentum 0 1 2 3 -1 -2 minus 3 you can also have half integers but we're not going to worry about that tonight but no you can't have angular momentum Pi only discrete integers that's that's the first uh fact that I want you to remember the other fact from quantum mechanics that we'll have to remember also is the uncertainty principle but we'll come to it now the other thing we spoke about was Fields fields are things that can fill space electric field magnetic field gravitational field other kinds of fields that exist in physics they are functions of space they can vary from place to place and they affect for example the way things move an example would be an electric field affecting the way a Charged particle moves now the other thing I said was you can imagine a world in which for all practical purposes empty space is filled with a field an example would be if I went out to Alpha centu at that end and plac some capacitor plates big capacitor plate out there big one out there make an electric field in between they're so far apart that we can't see them we would say that the world is a world that exists with a magnetic field and we would say that charged particles move in Peculiar ways but that was just a fact of nature um generally speaking Fields cost

energy space without an electric field has zero energy with an electric field it has energy and if we were to plot the energy of a field a typical field could be electric could be a magnetic could be something else generally we imagine that the field energy as a function of the field horizontally imagine the value of a field vertically its energy zero field right here and we imagine exciting the field causing it to vibrate causing it to vibrate by giving it a push at some region of space and nearby the field will vibrate those vibrations are quanta of the field they are particles they are particles the quanta of vibration of a field of particles now you might have a situation where there is more than one field relevant let's call it five and F prime or whatever you want to call it doesn't matter then instead of plotting the field as onedimensional we might plot it as two-dimensional now this is not space this is the value of some collection of fields and then the energy would depend on both Fields here's an example an energy function which looks like that which simply says that no matter how you displace the field it costs energy now imagine that this upside down paraboloid here or whatever it is was nice and symmetric nice and rotationally symmetric in the field space exactly like the top of my hat here the field as a function of position would most likely if the energy is as low as possible just sit at the bottom of the potential energy of the field just to lower the energy as much as possible so we might think of the field at every point in space a little ball which can be made to oscillate back and forth and do things and those are just oscillations of the behavior of physics in a local region of space as I said they often correspond to Quantum particles those oscillations but for the moment they're just oscillations now one of the things we could do if we had a field whose values will like the position in the Hat here would be to start it out displaced from the origin let's say up to here and then start it moving in a circle just in the same way you could take this ball and if it was if the Hat was really nice and smooth and symmetric give it a push and it would go around in a in a circle that circular motion of the
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(01)- mým cílem dnes večer se ukáže, že vám ukážu tak daleko, jak jen budu moci, během jedné hodiny, což je těžké, což je těžké, nemusí to fungovat, ale stejně dobře, jak mohu, vám vysvětlit, co Higsova fyzika je především o tom, že je tu spousta pohyblivých částí, spousta kousků, které bych musel udělat, musel bych ti to nejdřív vysvětlit, uh, aby to bylo opravdu správně, a pokusím se ti ty kousky vysvětlit v malém v malých modulech řekněme, že se jedná o vysoce kvantově mechanický efekt, kterému bez kvantové mechaniky opravdu nelze porozumět, a tak bych začal kurzem kvantové mechaniky a řekněme, že kurz kvantové mechaniky se skládá pouze z jedné věci, které se kvantují, první byla že kvantová mechanika se chystala shrnout jedním jednoduchým prohlášením, že věci jsou kvantovány v kvantové mechanice kvantované znamená, že přicházejí v diskrétních bitech, nejdůležitějším příkladem je moment hybnosti, není to nejdůležitější, nutně nejdůležitější příklad, ale pro mě dnes večer nejdůležitější příklad bude moment hybnosti a moment hybnosti souvisí s rotujícími objekty a tak dále moment hybnosti v kvantové mechanice na rozdíl od klasické mechaniky přichází v diskrétních jednotkách jednotka je plunks konstantní, nemůžete mít desetinu jednotky momentu hybnosti, kterou můžete mít moment hybnosti 0 1 2 3 -1 -2 minus 3 můžete mít také poloviční celá čísla, ale tím se dnes večer zabývat nebudeme, ale ne, nemůžete mít moment hybnosti Pi pouze diskrétní celá čísla, to je první fakt, který já chci, abyste si pamatovali další skutečnost z kvantové mechaniky, kterou si budeme muset pamatovat také, je princip neurčitosti, ale k tomu se dostaneme nyní. Další věc, o které jsme mluvili, byla Pole pole jsou věci, které mohou vyplnit prostor elektrické pole magnetické pole gravitační pole jiné druhy polí, které existují ve fyzice, jsou funkcemi prostoru, mohou se lišit místo od místa a ovlivňují

například způsob, jakým se věci pohybují, příkladem by bylo elektrické pole ovlivňující způsob, jakým se pohybuje nabitá částice, druhá věc, kterou jsem řekl dovedete si představit svět, ve kterém je pro všechny praktické účely prázdný prostor vyplněn polem, příkladem by bylo, kdybych na tomto konci vyšel do Alfa centu a umístil nějaké kondenzátorové desky, velká kondenzátorová deska tam velká jedna tam venku vyrobila elektrický pole mezi nimi jsou tak daleko od sebe, že je nevidíme, řekli bychom, že svět je svět, který existuje s magnetickým polem, a řekli bychom, že nabité částice se pohybují zvláštním způsobem, ale to byl prostě přirozený fakt um obecně řečeno Pole stojí energii prostor bez elektrického pole má nulovou energii s elektrickým polem má energii a pokud bychom měli zakreslit energii pole, typické pole by mohlo být elektrické, mohlo by být magnetické mohlo by být něco jiného obecně si představujeme, že energie pole jako funkce pole horizontálně si představme hodnotu pole vertikálně jeho energetické nulové pole přímo zde a představujeme si vzrušení pole, které způsobí, že bude vibrovat a způsobí, že bude vibrovat tím, že na něj zatlačíme v určité oblasti prostoru a poblíž pole bude vibrovat ty vibrace jsou kvanta pole jsou to částice jsou to částice kvanta vibrací pole částic teď můžete mít situaci, kdy je relevantních více než jedno pole, říkejme tomu pět a F prvočíslo nebo jakkoli chcete nazvat to je jedno, pak místo toho, abychom vykreslili pole jako jednorozměrné, mohli bychom to vykreslit jako dvourozměrné, teď to není prostor, toto je hodnota nějaké sbírky polí a pak by energie závisela na obou polích zde je příklad energetická funkce, která vypadá jako ta, která jednoduše říká, že bez ohledu na to, jak přemístíte pole, stojí to energii, teď si představte, že tento paraboloid vzhůru nohama nebo co to je, byl pěkný a symetrický, pěkný a rotačně symetrický v prostoru pole přesně jako můj vrchol Zde by pole jako funkce polohy s největší pravděpodobností, pokud je energie co nejnižší, sedělo na dně potenciální energie pole, jen aby se energie co nejvíce snížila, takže bychom mohli myslet na pole při každém ukažte v prostoru malou kuličku, která může oscilovat tam a zpět a dělat věci, a to jsou jen oscilace chování fyziky v místní oblasti vesmíru, jak jsem řekl, že často odpovídají kvantovým částicím těmto oscilacím, ale v tuto chvíli 're just oscilations now jedna z věcí, kterou bychom mohli udělat, kdybychom měli pole, jehož hodnoty se budou líbit pozici v Klobouku zde, by bylo začít ho posunuté od počátku, řekněme až sem, a pak ho začít pohybovat v kruhu stejným způsobem, jako byste mohli vzít tento míč, a pokud by tomu tak bylo, kdyby byl klobouk opravdu pěkný, hladký a symetrický, zatlačte na něj a on by kroužil v kruhu tím kruhovým pohybem.
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field is very very similar in a way to angular momentum it's not angular momentum in space but it's a kind of angular momentum that exists in the field space that angular momentum like all angular momenta are quantized come in integer multiples of planks constant what do they correspond to they correspond to something else that is also quantized in nature the value for example of electric charge so in modern physics the way one thinks about the electric charge in a region is that in some region of space a particle a Charged particle a Charged particle is viewed as an excitation of the field in which the field is made to spin around in the internal space of the field not in real space but in the internal space of the field that's one way in fact it's the main way that we think about charge a kind of rotation in an internal space okay now what I want you to do is Imagine taking the hat and turning it over imagine that the potential energy was not turn it over this way excuse me this way is the way that the potential energy is minimum at the crown of the hat but if the potential energy really looked like that so that it was maximum at the top of the Hat then the top of the hat would not be a position of

8:01
equilibrium it would be a position of unstable equilibrium it would look like
8:10
this turning over the Hat the crown of the Hat now this is the way you know the real
8:17
hat looks like this and it doesn't uh okay let's just let's make the
8:27
um how's that that look like a hat yeah looks like a hat what kind of hat
8:33
does it look like to you looks like a somera right looks like a Mexican hat this assists call this
8:39
kind of potential energy function a Mexican hat believe it or not it's called a Mexican
8:45
hat it turns back up the top is unstable if a PO a ball was put at the
8:54
top it would roll down and where would it go it would go to the brim of the
9:00
had if for some reason the potential energy of a field was like this then the
9:08
state of lowest energy would not be at zero field it would be out
9:15
here now that's kind of interesting it would be a vacuum a world which had a field just like having an electric field
9:22
except it's not an electric field in which the value of the field at every point in space was not zero you might
9:27
notice it how how would you notice it well you might notice it because it might affect other things and indeed it
9:34
does affect other things as we will see but there's now something
9:39
interesting you can do that you couldn't do here over here if you wanted to set
9:44
this thing into rotation you would have to displace the field a little bit because it doesn't mean anything to
9:50
rotate right at the center if you wanted to set up a rotation you displace the field and then give it a flip so making
9:58
a charged partic particle costs some energy
10:07
here you can imagine setting this thing into rotation with just a little flick
10:14
that costs no energy it costs no energy because you don't have to ride up the side of the
10:20
Hat in other words you could have a motion in which I'm

10:27
not got it you got it you got it you understand right you got to have a motion in which that field slowly wound
10:35
around the top of the potential in fact it could do it everywhere simultaneously not in real space but in this field
10:43
space that would correspond again to a charge if rotation in this internal
10:50
space corresponds to some kind of charge but now the whole world if the whole field was moving like that would have a
10:57
little bit of charge in it a charge charge density charge filling space at essentially no cost of
11:06
energy that phenomenon is called a condensate it's called spontaneous
11:12
symmetry breaking but it's also called a condensate a condensate in space of
11:19
charge now you might say okay look I want to find the lowest energy that the
11:24
vacuum can have that empty space can have my best bet is to make the field
11:30
not move with time just like a ball at the bottom of the sombrero hat here
11:36
there's also kinetic energy of motion causing the field to move around in a circle like that would cost some energy
11:43
so you would say the true lowest energy state of the world should be with a
11:49
field either here or here or here it could be anywhere as along the the rim
11:54
of the hat but it should be standing still right the problem with no angular
12:01
momentum or no charge empty space should not have charge the problem with that is
12:07
the uncertainty principle let me remind you what the uncertainty principle
12:12
says it says that if you have a object and you're interested in its
12:18
position X in ordinary space now and its momentum P velocity if you like the
12:27
uncertainty principle says that the uncertainty in its position times the uncertainty in the momentum is greater
12:35
than or equal to what plunk
12:41
constant you can't have something both standing still and having zero momentum

12:48
if it's stand sorry you can't have something standing still namely no
12:54
momentum and also localized at a point Delta P * Delta X is greater than HR
13:01
same thing here if you know where the field is on this Mexican hat if you know
13:09
with great Precision then it follows from the uncertainty principle that it must have a very large uncertainty in
13:17
how fast it's moving around here Ah that's interesting now that would say
13:22
that you can't have empty space with no charge in it can't have empty space with
13:28
no charge it because if you lay the field down at this point you know where it is on the rim of the hat and if you
13:35
know where it is there's a necessary uncertainty in the charge the charge
13:42
being like the angular momentum all right so where are we then if this were
13:47
the case for electric charge for ordinary electric charge we would say that the vacuum empty space Not only is
13:56
filled with charge in a certain sense but a to totally uncertain amount of charge totally uncertain and this is a
14:03
Quantum effect a totally uncertain amount of charge there would be equal probability
14:10
let's take a little volume of space there would be equal probability that the charge was
14:17
zero or that the charge was one or minus one or two or minus 2 3 -3 now this is
14:27
truly odd this is not something you should try to visualize because you can't visualize an uncertain amount of
14:33
charge but nevertheless that is what a region of space would look like if you
14:38
measured its charge it could be anything from minus infinity to plus infinity okay now I want you to imagine
14:46
that you have an extra charged particle an extra charged particle and
14:52
you throw it in you don't know initially what the charge is but what does that do
14:58
it displaces the charge by one unit let's suppose it was a positive charge you've displac the charge by one unit

15:06
and so if it was zero to begin with it's now one if it was one to begin with it's now two if it was two to begin with it's
15:13
three if it was minus one it's 0 1 - one -2 and so forth but that's exactly the
15:19
same as what we started with we started with something which had an uncertain amount of
15:26
charge equally likely for any value of charge and what did we end up with after we threw the charge in exactly the same
15:34
thing what if we pluck the charge out of this thing same thing so a condensate is a
15:41
funny configuration of space where with respect to whatever
15:46
kind of charge we're talking about it's so uncertain that you wouldn't even realize it if you put an extra one in or
15:53
pulled one out now the real world is not like that with respect to Electric charge we know
16:00
if we have a charge in space so it's not like that with respect to electric charge however there are materials that
16:07
behave like this superconductors superconductors are exactly like
16:13
this so it's not unheard of it's not a totally new thing to have a condensate
16:19
of charge where in a region the charge is completely
16:26
uncertain okay that was module number one if you like condensates or what is sometimes
16:33
called the spontaneous breaking of symmetry module number two the standard
16:38
model now we come to particle physics and I'll give you a short course
16:44
in particle physics first of all particles have mass and the mass can be
16:51
anywhere from zero we're talking about small particles now we're not talking about railroad
16:58
engines or uh or Stars we're talking about small particles we call them Elementary
17:04
particles but there's also a maximum Mass they can have if they were bigger than that they would form a black hole
17:11
if they were more massive than that if a point particle was more massive than something it would form a black hole and
17:17

it would be something different so up to some Maximum and that maximum is called
17:23
the plunk Mass it is not a very large mass it's neither a very large Mass or a
17:28
very small Mass it happens to be about 100,000th of a gram a small dust mod but
17:36
that is the heaviest that a Char that a um that an elementary particle can be without turning into a black hole and if
17:43
you ask now where on this chart from zero this is called mlan up to the maximum where are the
17:52
ordinary particles the electrons the photons the um quarks they are way way
17:59
down here the largest mass of a known
18:06
elementary particle is about
18:11
10-7 of the plunk Mass why are the particles so light well one answer is in
18:18
order to detect massive particles you have to have a lot of energy in order to
18:23
have a lot of energy you need a big accelerator we've only made accelerators up to some uh sign
18:29
and so for all we know the rest of this is filled with particles and that's probably true that's probably true but
18:36
what is special about these particles well first of all let me name them and then I'll tell you what's special about
18:42
them that makes them Clump up at zero Mass let's name them the particles of the standard model
18:50
they come in two varieties it is not important that you know the difference well I'll give you a rough idea of what
18:55
the difference is they come in two varieties called fir on and
19:04
bosons the Fons are all the particles that make up matter in the usual sense
19:10
the electron which I'll just call E well the neutrino goes along with the electron that's a new the electron the
19:17
neutrino quarks there's a variety of different quarks incidentally there are several
19:23

different kinds of electrons we call them electron muon TOA it doesn't matter but are very electronik and several
19:30
kinds of neutrinos the electrons have the electric charge the neutrinos don't and
19:36
then there are quarks a variety of different kinds of quarks up quirks down quirks this kind of Quark that kind of
19:42
quark and those Quark several different kinds of quarks you know what the role of them are they make up the
19:49
proton and uh that's about it for for um for Fons but bosons on the other hand is
19:57
first of all the photon gamma gamma for a gamma ray Photon there's an object
20:04
called the gluon G it's very much like a photon it's very much like a photon but
20:12
it doesn't have anything to do with atoms it has to do with nuclei and protons and neutrons it plays the same
20:18
role in holding the nucleus or better yet the proton together as the photon
20:23
plays in creating electrical Fields inside an atom so there's the
20:29
gluon and then there are two others called W bosons and
20:36
zons for the most part we won't be interested in any of them except a
20:41
photon here and there but mostly we'll be interested in the Zebo
20:47
on that's it that's the standard model that's all there is to it with one exception I've left something out it's
20:52
the thing you came to find out about tonight okay so we'll come to it if
20:59
there was no Expos on then this would be it now what is special about this set of
21:06
particles what's special about them is for reasons that I'm going to come to reasons that I will come to all of these
21:13
particles in the standard model as I've laid it out here with nothing else in it
21:18
would all have mass equal to zero they would be
21:25
massless and I'll explain why that is in a little while
21:31
we often hear that it's the role of the higs boson to create mass for particles

21:37
or to give the particles their Mass that's the expression that I've heard over and over the higs gives particles
21:43
why do why do the particles have to be given Mass why can't they have mass of their
21:49
own why do they have to be given Mass well as a turns out for reasons we explain this set of particles is exactly
21:56
the set of particles which would have no Mass if this was all there was now in
22:02
part that explains in part it explains why the particles why these particles
22:09
are so very light it's because they're massless they have no Mass well not
22:14
quite we can't live with that because we know that particles really do have mass next question I'm going to draw
22:21
some figures over here what do these particles do what kind of processes that
22:27
they are they involved in all right the basic process of the standard
22:32
model this is an oversimplification but it's qualitatively right is that the firion
22:39
there's a firon moving along and I will describe a firon by a solid line solid
22:45
because it's what makes up stuff solid line that's moving from one point in
22:51
space time to another point of space time what the standard model does is it
22:57
causes the emission of bons a electron moving along can emit a
23:05
photon electron moving along can emit a photon and that's connected with the
23:11
electric charge any electrically charged particle can emit a
23:18
photon a photon that's the first thing that the standard model does now this of
23:23
course is just Quantum electrodynamics it does not have to be the electron it could be any
23:28
electrically charged particle next the
23:34
Quark let's see do we have room here yeah we'll just do it the
23:40
Quark Quark let's just call it Q the Quark can emit a
23:45
gluon precisely the same pattern The Quirk emits a gluon now the Quark can

23:52
also emit a photon if it happens to be electrically charged and quarks are electrically charged but but electrons
23:58
cannot emit gluons gluons are the things that bind quirks together to hold them together into protons and
24:05
neutrons and then there's one more important process for me tonight there are two more processes but I'll just
24:11
write down one here and it is either an electron oh incidentally a
24:18
neutrino cannot emit a photon it has no electric charge it cannot emit a gluon it's not a
24:26
quark okay both electrons and neutrinos and quirks for that matter can
24:34
emit the zebon where's the zebon here's the zebon right here and when they do
24:40
so the zebon being electrically neutral the electric charge of whatever is here
24:47
doesn't change so this is another process that the standard model
24:52
describes now first of all why are the bans Mass
24:59
well the photon is massless we know that it travels with a speed of light now
25:06
could we make a theory in which the photon had some Mass yes we could but
25:11
the more important thing is that we can make a theory in which the photon doesn't have a mass why because the
25:18
photon doesn't have a mass using the same kind of
25:26
theory the ZB Boon would not have a mass and the gluon would not have a mass
25:33
everything would be massless these would be the processes that could happen these would be the
25:39
particles they would all be massless okay now how do Fields how do
25:46
Fields give particles mass or better yet more simply a simple example I'm going
25:53
to show you a simple example now the simple example is how a field can affect
25:59
the mass of a particle we'll come back in a moment to how it can give something which didn't have mass mass but let's
26:06

take a more modest question how may Fields affect the mass or better yet how
26:13
might they make different masses for different particles so I'm going to show
26:18
you an example this example is a little bit contrived but it's a real
26:24
example a water molecule water molecules have the basic
26:29
property that they're little dumbbells they have a plus end and a minus end electrically charged plus end and minus
26:36
end uh they're actually not they're more like y's you know y with three ends but
26:41
we can think of them as having a plus end dumbbells and a minus
26:47
end now the mass of a water molecule water molecules have mass the mass of a
26:54
water molecule doesn't depend on its orientation if we turned it over and
26:59
made a water molecule with its minus end here and the plus end here it would have
27:05
exactly the same mass why it's the symmetry of space space is the same in
27:11
every direction and so by symmetry we would say that the water
27:17
molecule standing up straight has exactly the same mass as the water molecule standing on its head let's not
27:23
worry for tonight about whether it's lying on its side quantum mechanic tells us we don't have to worry about anything
27:30
but standing up straight and lying on its head all right so that's uh that's true about water molecules their mass is
27:37
the same if they're standing up straight and think of water molecules now as particles think of them just as
27:42
particles we don't know what they are they're just little Elementary particles we can't see them and so we have two
27:47
kinds of particles the upstanding and the standing on his head particle with exactly the same mass let's create a
27:55
region in which there's an electric field we're going to make a field it could be between two capacitor plates
28:02

the capacitor plates could be far apart it doesn't matter but let's put them the capacitor plates here and here and
28:07
inside that region let's create an electric
28:12
field the electric field in this case pointing up that means it pushes plus
28:18
charges up and minus charges down if I have my signs right and let's take one of these water
28:25
molecules and insert it in here right once I insert the water molecule
28:31
in here the energy of the upstanding water molecule and the upside down water
28:39
molecule are different which one has less energy the
28:44
one with the plus up has less energy and the one turned
28:50
over has larger energy the water molecule itself is electrically neutral
28:56
it has no electric charge charge but it's a little dipole it has a pair of charges and which one has more energy
29:05
depends on the sign of the electric field okay so there we are we have two
29:11
water molecules two types of water molecules two different particles we could give them different names we could
29:18
call it water and um uh scotch and water molecule has one one
29:25
energy the scotch molecule has another uh energy and there they are well by eal
29:35
mc^2 this also tells us that the two molecules have different mass now in
29:41
practice this would be a tiny different Mass between them but they would have different Mass so the same effect of
29:49
this field which exerts itself on charged particles does something to neutral water molecules incidentally
29:56
notice that it doesn't exert any net force on the water molecule the water molecule moves smoothly through it with
30:02
no Force no net force acting on it but there was a difference in the up uh in
30:08
the uh two configurations of the water molecule and so it's as if we had particles of two different Mass so this
30:15

is just an example of how a field creates mass in this case it increases
30:21
one mass and decreases the other Mass incidentally if you read some of
30:28
the literature and they'll tell you about how the um Hicks field gives a mass I've read any number of places that
30:36
it's something like space being filled with molasses it is not like space being
30:41
filled with molasses the vacuum is not sticky and one of the things that
30:47
molasses would do well the idea is that
30:52
massive particles move slower than massless particles so the the idea is
30:58
that molasses slows them down but Fields don't slow particles down if you give
31:05
the particle a push in this direction it will just continue to move because there's no net force on it it'll just
31:12
slide right through this thing frictionlessly no uh no impedance no uh
31:20
no friction no masses there's not the other the other analogy I once heard is
31:25
um that it was like trying to push a snow plow through a heavy snow in the
31:31
Arctic uh it's got nothing to do with it whatever that's a that's a that's a lazy
31:36
way to explain it and it's a wrong way to explain it okay so there we are but now let's
31:43
think of this in a slightly different way the electric field in here can also
31:50
be pictured in terms of photons a field is another way of
31:56
talking about a collection a condensate of photons an electric field we can
32:02
replace the electric field
32:08
by a condensate the same kind of condensate the same kind of condensate
32:13
of photons Let's uh draw photons by just a little squiggly lines fill this up
32:20
with photons how does it know which way the electric field is pointing well photons have a polarization they be up
32:27
or they could be down so just imagine this thing being filled with photons but not filled in the usual way but filled

32:34
in a condensate what does a condensate mean a condensate means that if I pull one out it doesn't make any difference
32:41
if I put an extra one in it doesn't make any difference that's the meaning of the condensate so it's an indefinite number
32:47
of photons that's what a field is indefinite and if you pull one out
32:52
nothing happens and now let's reintroduce the um
32:58
the water molecule let's just draw the water molecule moving through here now I'm going to make the water molecule
33:03
right I've already blown my uh my color coding here's a water molecule moving through here and what is it going to do
33:11
it has charged particles inside it the charged particles can Emit and absorb
33:17
photons they Emit and absorb photons we've made the photons green now so it
33:22
emits photons but when it emits a photon putting it extra Photon in doesn't
33:28
matter and so we usually draw that by just putting a cross at the end a cross
33:34
simply means that throwing an extra Photon in doesn't affect
33:40
anything photon is emitted and just is absorbed or is
33:46
just um disappears into the condensate as this object the dumbbell
33:54
moves through the electric field it's constantly emitting and absorbing these photons which get lost
34:03
in the condensate that is another way of talking about how the field affects the
34:11
particle and depending on whether the photons are polarized up or down this
34:17
effect of constantly being absorbing and emitting photons will have the effect of
34:22
Shifting the energy of the two configurations of the uh of the
34:27
dumbbell that's simply an example of how a field can affect the mass of a particle
34:35
and how it can be thought of in terms of particles and
34:40
condensates that's what I want you to keep in mind that

34:47
picture okay now let's come to Elementary particles not dumbbells not
34:52
molecules first question is there any reason why a particle or an object just can't
34:59
have a mass does it need an excuse to have a mass uh does it need anything
35:05
called the higs phenomena to have a mass well there are lots of things in nature that have mass and have nothing whatever
35:11
to do with the higs phenomena let me give you an example imagine you had a box and let's
35:17
make that box out of extremely light stuff the lightest stuff you can think
35:23
of but it's a box with good reflecting walls and fill it with lots of high
35:29
energy radiation bouncing off the walls but never getting
35:34
out it's made out of massless stuff the photons are massless they have no Mass
35:40
the Box we're imagining is made out of stuff which is exceedingly light doesn't have much
35:45
mass but there's plenty of energy in there lots and lots of energy well eal
35:54
mc^2 and so this box will behave exactly as if it had a mass we didn't need
36:01
anything to give Mass Just Energy that's all it took are there any particles
36:06
which are like this which get Mass having nothing to do with uh higs or anything else yes the
36:13
proton the proton is a particle which is made out of quirks quirks three quirks
36:20
and a bunch of gluons G's a bunch of gluons a large number of
36:26
gluons quarks and gluons in the standard model are
36:32
massless does that mean that the proton would be massless if the quarks and gluons were massless not at all if the
36:41
quarks and gluons were massless the effect on the proton would be about a 1%
36:48
or even less change in its mass not much at all where does its mass come from it
36:55
comes from the kinetic energy of these massless particles rattling around in a
37:01
box the Box being created by the proton so Mass doesn't have to come from black
37:09

holes are another example black holes have mass it doesn't come from the higs phenomenon doesn't have anything to do
37:14
with higs so what is it about the models of
37:20
the St the particles of the standard model which require us to introduce a new ingredient so I'm going to
37:26
concentrate on the electron let's concentrate on the electron we don't need all of
37:34
this what I need to tell you about is a direct theory of
37:42
electrons but really we don't have to know very much about the direct Theory all we have to know is that electrons
37:48
have Spin and furthermore if an electron was moving very fast down the axis here
37:56
let's say with close to the speed of light you really accelerate that electron then there's two possibilities
38:02
the spin of the electron can be right-handed like that think of my thumb as the direction of motion of the
38:08
electron it can be going that way like my right hand or could be going that way
38:13
like my left hand oh I didn't realize I could do that now two kinds of electrons
38:21
right-handed and left-handed now do right-handed
38:27
electrons always stay right-handed can they flip and become left-handed can the
38:34
right-handed become a left-handed left-handed become a right-handed yeah that's exactly what the direct Theory
38:40
says but if it was moving with a speed of light it couldn't why not because if
38:46
a thing is moving with a speed of light time is infinitely slowed down and
38:52
nothing can happen to the object it just moves along but nothing can happen happen internally to the object so if
38:58
its mass was Zero it couldn't flip but in the direct Theory this
39:04
flipping back and forth between I I tend to do it this way but that's not right this way this way this way this way that
39:10
is intimately associated with the mass of a particle and in fact the mass of a

39:17
direct particle is simply proportional to the rate at which it flips from left
39:23
to right that's the direct theory in a nutshell mass is the rate for the electron to
39:29
flip back and forth from left to right okay of course the faster it's
39:35
going the slower it will flip but that's all right you take that into account so mass is left to right to left to right
39:43
and we could draw the motion of an electron in the following way here's the
39:49
electron moving down the axis at first it's right-handed so it's
39:56
it's going this way and then it's left-handed it's going this way and then it's right hand can you tell the difference maybe not but that's okay and
40:03
in between it jumps from one to the
40:09
other the probability or the rate at which it jumps is a measure of the mass
40:15
of the electron so it jumps back and forth and back and forth now I'm going to ask you
40:21
to believe something really crazy do you remember this zbo on where is the zbo on
40:27
the zon was Associated was emitted it could be
40:33
emitted from electrons it could be emitted from neutrinos but let's concentrate on electrons it is not the
40:40
same as the photon and the thing which emits it is not the same as the electric
40:46
charge it is another kind of charge a completely separate kind of charge it's
40:52
like charge but it emits Zebo we need we need a name for it we don't have a name
40:58
for it well we do have a name for it's a very awkward name it's called the weak hypercharge I don't like that because
41:06
it's the thing which emits the Zebo I call it zilch zilch zilch is like electric
41:14
charge but it's not electric charge when a particle which has zilch accelerates
41:19
it emits a Zebo on it may also emit a photon if it also happens to have electric
41:25
charge right now electrons both right-handed and left-handed have the
41:31

same electric charge okay but left-handed and
41:38
right-handed electrons do not have the same Z in the standard model this is part of
41:45
the mathematics of the standard model the left-handed and the right-handed
41:50
electrons have different zilch the left-handed electron has zil of plus one
41:56
and the right-handed electron has zero zilch I didn't make this up in fact my
42:03
friend Steve Weinberg didn't make it up if anybody made it up he's up there or down there I don't know where but uh and
42:11
uh it is just the way it is it is the way the mathematics of the standard model
42:16
works that the left-handed and the right-handed particles have different zots and now we have a
42:24
puzzle when the electron moves along and it flips from left to right
42:31
that means the zil goes from plus one to zero but zilch is like electric charge
42:36
it's conserved how can the zilch go from zero to one it can't it can't and that's the
42:45
reason that the electron in the standard model doesn't have a mass because the left-handed and the right-handed have
42:52
different value of a conserved quantity and so left can't go to right
42:58
period no Mass okay how do we get around this we get around this by introducing a
43:04
new ingredient and the new ingredient is called the zigs
43:09
ban it's not the higs bosan not yet we haven't gotten to the higs bosan yet
43:14
we've gotten to the zigs bosan the zigs bosan is one new
43:22
ingredient it is closely con connected with this Mexican Hat type configuration
43:30
here it's a kind of particle but it forms a
43:36
condensate you can't tell how many are there you can put one in you can take one out and so forth without changing
43:43
the vacuum so we have one more ingredient
43:48
it's a condensate that space is filled with and the nature of the condensate is

43:55
that doesn't have electric charge it has zilch and it's a condensate meaning that if you put a zilch in nothing happens if
44:03
you take one out nothing happens and let's ask now what that
44:10
means the left-handed electron coming in has a zilch of one let's call it a z of
44:19
one the right-handed has Z equals Zer back to the left hand at Z equal 1
44:28
is that possible only if you emit something at this point
44:34
which carries off that Z equals 1 a
44:39
zigs zigs B on gets emitted it carries a zal
44:47
1 but what happens to it where does it
44:53
go it goes into the condensate it gets lost in the condensate you put a
45:00
you put one in and it just gets absorbed into the condensate and so the electron goes on its merry way the condensate
45:08
absorbs the zilch and it goes from one to zero but then it can borrow a particle back from the condensate borrow
45:16
one back it doesn't even have to borrow it if you pull one out nothing changes
45:22
again and so it goes on its merry way from left-handed to right-handed from
45:28
left-handed to right-handed every time it switches it emits a particle carrying
45:33
this zilch quantum number which then just gets absorbed into the
45:40
condensate that's the mechanism by which a field and in this case it's a field
45:48
which forms a condensate by itself it doesn't require capacitor plates it just
45:53
requires the energy to be such that the field naturally gets
45:59
shifted and that's the mechanism by which electrons quirks and the various
46:05
partners of those particles the MU particle the um the too lepton all those
46:13
ordinary ordinary and extraordinary particles the Fons get their mass by
46:18

this phenomenon here phenomenon doesn't really have a name it's called a spontaneous breaking
46:24
of chyro symmetry but uh it does have a name but this is what it is okay what about the
46:32
zebon I told you before the zebon is like a photon photons are massless how does a
46:39
zebon get a mass so I'll just show you something very similar happens to the zebon let's remind ourselves what a
46:46
zebon can do it can take any particle which has a zilch and in particular this
46:52
green ziggs particle it can take the zig zigs
46:59
particle and the zigs particle can emit a
47:05
zebon it has charge not real charge but zilch and zilch emits
47:12
zebon all right so now let's ask what that means that means that a zebon
47:18
moving along can do something a little bit similar to this it can
47:30
absorb some zilch out of the condensate condensate but now it has zilch
47:40
originally it was just a Zebo on zebon don't have zilch it absorbs some zilch
47:45
and it becomes a zigs zebon becomes a zigs but then it can
47:51
emit zigs which gets lost in the condensate again
47:57
and the Zebo on just moves on its merry way constantly going back and forth from
48:03
being a Zebo on to being one of these
48:09
imaginary not imaginary uh zigs particles that's the nature
48:16
of the way that particles get Mass from Fields this phenomenon of the Zebo on
48:24
getting a mass is called called the brout angare higs phenomenon this is the
48:30
one that's called the higs phenomenon the zebon getting a mass now this could
48:36
have happened to the photon had there been a condensate of ordinary charged
48:42
particles the photon would have become massive we would all be dead if that were the case massive photons would not
48:50

be healthy for us and so we are very lucky that uh that this phenomenon here
48:56
did not apply to ordinary electric
49:03
charge will we ever discover the zigs particle sure we discovered it long
49:09
ago it's just part of the zebon zebon
49:16
was discovered I mean it was postulated 1967 but or even before that by many
49:22
people but it was discovered I don't even remember where 1980 I forgot when the uh when the experiment uh slack
49:30
first discovered the existence experimentally but when it was
49:35
discovered that there was a zos on that it had a mass and that when its properties were studied the properties
49:42
were not only consistent but required that it was a thing which went back and forth and back and forth and back and
49:48
forth between pure zebon and the zigs particle so they've
49:54
existed we are not in out about them and we never were at least not for many years so far I have not mentioned the
50:02
higs boson so what is the higs boson well the higs boson has to do with
50:09
this condensate that has to do with this
50:14
condensate but it's a different kind of excitation than sliding around the uh
50:21
the edge of the sombrero here does not have to move it's not something which has to do with
50:27
sliding around here it has to do I'll tell you two different ways to think about it you have a condensate and you
50:35
can imagine the condensate has a density a density of these uh fictitious
50:42
particles in the condensate imagine something which changes the density of
50:48
them kind of like a sound wave a compression wave of some kind which
50:53
squeezes them closer and further and closer apart makes it more and more less dense that kind of vibration is what a
51:00
higs higsbo on is another way to think about it is that it doesn't have to do with

51:08
sliding around the uh periphery of the sombrero it's it go to a place in space
51:15
and start the field oscillating this way in and
51:24
out this way the further away it is the stronger the condensate the closer to
51:30
the center the weaker the condensate so when it slashes back and forth It's Kind of a compressional wave in the
51:38
condensate that mode that phenomena that oscillation is
51:44
what is called a higs boson the higs boson is like the sound wave propagating
51:51
through the uh through the condensate the the reason it has been so
51:56
important is because it was the one element that had not yet been
52:02
discovered as I said the zigs was discovered long ago the Z and the W the electrons and all the others were
52:09
discovered long ago and so the next question which I'll try to answer in a couple of in five minutes is why it was
52:17
so hard to discover the higs what we discovered about it
52:22
and very very quickly what the future might or might not bring
52:29
try to do this in a couple of minutes okay
52:39
so what kind of thing does the higs BOS on itself do now we're talking about the higs BOS on not the zigs BOS on not the
52:45
zos on the higs itself the one the one that's been so elusive all these years
52:53
it's called h and what it can do with some
52:58
probability is for example create we read this from left to right a higs
53:05
boson moving along in time time is now to the left can create an
53:14
electron and a positron it can create a pair of
53:21
quirks it can also create other things a me particle or a top Quark or a bottom
53:27
Quark all of the different quarks electrons also neutrinos all the
53:33

various ferons can be created in pairs when a higs boson decays you say if it's
53:40
like a sound wave why does it decay well believe me sound waves Decay if they didn't Decay you'd continue to hear my
53:46
voice ring forever and ever wouldn't you so sound waves do Decay and it is possible to think of
53:53
sound waves as decaying by creating particles so the higs boson decays it
53:59
decays quickly if it exists if it really exists it decays quickly either into an
54:04
electron positron or a pair of quarks or maybe some other of the Fons that exist
54:10
in nature you can read this diagram in two different ways oh incidentally the
54:17
probability that the higs decays like this is proportional to the mass of the
54:22
particle that it decays into the the heavier the mass the more
54:29
strongly that particle is coupled to the higs boson so heavy particles are
54:35
favored and light particles are not favored now you can read this diagram in
54:40
either direction you can say the Hig boson decays but you can also say an
54:45
electron and a positron confuse together to make a Hig
54:50
boson well if we want to make higs bosons and see them in the laboratory we we want to read the diagram from right
54:56
to left and we want to say this is a process whereby a pair of electrons can
55:02
come together and make a hbos on we've been colliding electrons and
55:07
positrons for a long long time almost as long as I've been a physicist not quite we've been uh
55:14
colliding electrons and positrons together and nobody was ever able to discover the higs now one reason in the
55:21
early days is it turns out that the higs is a fairly heavy particle I will tell tell you what its mass is but it's a
55:27
fairly heavy particle and unless you have enough energy you don't have enough energy to make the higs B on but there's
55:33
a more important reason in fact slack in the later days of Slack's life had

55:38
plenty of energy to make the higs the problem was the weakness of the coupling
55:45
the smallness of the mass of the electron translated into a very weak
55:53
improbable cross crosssection too small in effect too
55:59
unlikely to make the higs and so when you Collide electrons together at high energy electrons are just not favorable
56:06
they're too light and because they're light they tend to not make higs with any appreciable
56:12
probability well how about quirks we can Collide quirks
56:18
together the usual quirks that make up the proton and neutron are also very
56:23
light and because they are light also unlikely to ever make a higs BOS on well
56:29
you I'm sure they were made in slack but never in appreciable numbers that it was possible to uh to detect them so that
56:38
was the main difficulty the lightness of these particles was a thing that
56:44
essentially prohibited us from making higes in abundance at slack or in other
56:50
Laboratories where collisions took place what is the most most favorable
56:57
particle most likely particle for the higs to decay in the
57:04
heaviest the heaviest of the Fons and the heaviest of the fion is called the
57:09
top Quark the top Quark is hundreds and hundreds thousands of times heavier than
57:15
the electron many thousand many many times heavier many thousands of times heavier than the
57:21
electron and the higs preferentially will Decay into top
57:28
quirks so we'll just call those the're quirks they are quirks but they're very
57:35
heavy 170 times the mass of a proton basically which is heavy top and
57:42
anti-top top quirks and anti- quk so you say well look now it's easy to make the
57:47
higs BOS on you just oh actually in fact not possible for the
57:54
higs to decay the two top quirks because the two top quirks are too heavy but if

57:59
you read it the other way and you take a pair of top quirks and Collide them together you can make a higs so it's
58:05
easy we just go in the laboratory take a pair of top quirks Collide them together and make a higs well the problem is that
58:13
it's not so easy to find top quirks in nature why not they Decay very rapidly
58:19
to the other quirks they're not sitting around you can't put them into the accelerator accelerate them they
58:26
disappear in a tiny fraction of a second there are no top quirks sitting
58:32
around uh not even buried inside protons and so forth not even buried inside
58:39
other kinds of particles there are no top quirks around so we have to make the top Quirk somehow in the Collision how
58:46
do you make a top Quirk all right so here's a way to make a top quk a gluon can come along this is a gluon now and
58:55
remember what gluons do they couple to quirks one possibility is that the gluon
59:03
can make a top quk and an anti-top Quark well there's plenty of gluons
59:09
around as we'll see in a moment so why don't we just take a gluon and make a top quark and an anti-top
59:15
Quark out of it the reason is because gluons are very light they're almost they're almost massless they don't weigh
59:22
very much top quarks are very heavy there's simply not enough energy in the
59:27
gluon to create a pair of top quarks so what we have to do is we have to take a
59:32
pair of gluons now here's a process that you can imagine take a pair of gluons
59:37
with a lot of energy moving toward each other with a huge speed plenty of energy
59:43
let one of them make a pair of top quarks for a short period of time and
59:48
then let the other one come and be absorbed by one of the top quarks
59:55
there we have it a pair of top quarks created by a pair of gluons a pair of
1:00:00

high energy gluons smashed together and make a pair of top quarks once we've created those pair of
1:00:07
top quirks the top quirks can come together and make our higs bows
1:00:15
on this is the way we usually draw this is to just draw gluon gluon and then a
1:00:21
triangle higs these are top Works going around the loop here that's the most
1:00:27
efficient process for making um for making Hig bosons but where do you get
1:00:33
gluons from gluons aren't floating around well yes they are the proton is
1:00:40
filled with gluons the proton mass of the proton is maybe 50%
1:00:47
energy from gluons or something like that it's filled with gluons and
1:00:52
quirks you take two protons and you Collide them together and the gluons
1:00:58
inside the protons can Collide during the collision and do
1:01:03
this that was what was detected at LHC LHC is a proton proton collider
1:01:12
it collides protons together and when protons a very indirect way do protons
1:01:17
collide together a gluon from each one of them scatter coll
1:01:25
create a pair of top quirks and then the top quarks then have plenty of come together and create the higb on
1:01:33
that's the process that was discovered at the LHC and it took a long time to get there it was a hard thing to do it
1:01:40
was a very very hard thing to do but now it's done we know the mass of the higs
1:01:45
ban it's 125 gev about 127 time the mass of the
1:01:50
proton and that's I think a finished fact
1:01:55
before I quit Let's uh talk about the near
1:02:04
future what have we learned we've learned that the standard model is essentially correct we've learned the
1:02:11
standard model is essentially correct everything seems to fit together the higs BOS on fitting together remember
1:02:19

it's not the higs boson really that gives the particles their Mass it's the zigs boson but the higb is just what's
1:02:25
left over when you think of these density oscillations was the last remaining piece is now in
1:02:31
place uh it's finished but is everything fitting together exactly right
1:02:36
quantitatively right well that we don't know we don't know there's one hint one
1:02:43
hint of a discrepancy and I'll tell you what the hint of that discrepancy is Let's uh here's I drew this picture let
1:02:50
me draw it again over here it's the process
1:02:57
of creating a higs by two gluons coming together gluon
1:03:03
gluon top Quark going around the loop and
1:03:08
higs now this same process once the higs is created also allows the higs to
1:03:17
Decay but it's not so easy to see gluons in the laboratory they're difficult to
1:03:23
work with that's not the best process for looking for the higs boson after
1:03:28
you've created it the best process is to replace the gluons by photons I don't
1:03:35
have to even change the picture photons it's exactly the same process except
1:03:40
with photons out here once the higs is created by whatever it can create it it
1:03:46
can Decay into two photons it's an intricate process it
1:03:52
involves a lot of theory and a lot of calculation a Fineman diagram not easy
1:03:57
to calculate but you can calculate it and it depends on the properties of the
1:04:02
top Quirk going around here at the moment at the moment and I'm not an
1:04:09
expert at this I can only quote what I'm told at a at the moment the higs bosan
1:04:14
that was produced in the laboratory appears to Decay into two photons a little too quickly about one and a half
1:04:23
times too quickly now everybody agrees that that is not a
1:04:29
statistically really significant fact yet but what will it mean if it persists
1:04:37

it doesn't seem like a big deal one and a half times too fast but the point is the theorists have the ability to
1:04:44
calculate that rate very accurately a one and a half times too big a rate is
1:04:50
serious it means something is going on the most most likely thing that would be going on is that there's another kind of
1:04:57
particle in addition to the top quk that has not been discovered yet that can also participate in the same kind of
1:05:05
it's called a triangle diagram some other kind of particle that of course would be big news if there's something
1:05:12
there that is not described by the standard model that would be big news it could be a super symmetric particle it
1:05:18
could be anything all kinds of things if this this is something to watch for now The Buzz words are the decay of the higs
1:05:26
into a pair of photons and a excess of about one and a half I think it's a two
1:05:32
Sigma effect whatever that means means something the statisticians um it means that it's not so robust but
1:05:41
it could be right right if it turns out to be right it means that we've discovered something unexpected or it
1:05:48
might be even something that's expected but something new beyond the standard model remember the standard model is
1:05:54
over 50 years old well over 50 years old and so 1967 am I right 77 87 97
1:06:03
2007 no not K getting on 50 years old so
1:06:09
discovering the hings BOS I wasn't really discovering anything I was confirming something if this should be
1:06:14
off by a factor of one and a half one will have discovered something absolutely new so if you want to watch
1:06:19
if you know you want to be a spectator in the sport and you want to watch what happens this is the thing to watch for
1:06:25
next whether the higs decays are consistent with the standard model okay that's uh we we're finished
1:06:33

uh thank you very much