1
00:00:00,600 --> 00:00:08,420
Hello everyone. Good afternoon and thank you very much for... thank you very much for joining

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00:00:08,420 --> 00:00:15,720
us today for this exciting... exciting evening. Um, I... I welcome you all to the special

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00:00:15,720 --> 00:00:20,980
physics colloquium. My name is uh, Amit Sharma. I'm an assistant professor in the Physics

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00:00:20,980 --> 00:00:28,060
Department. Um, and again, thank you very
much for coming today. We (inaudible) Dr.

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00:00:28,060 --> 00:00:34,560
Yi Li, Dean of the College of Science and
Mathematics, his... his support for this event

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00:00:34,560 --> 00:00:41,161
um, and also in helping us invite uh, high
school students to this seminar. Uh, so, just

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00:00:41,280 --> 00:00:48,980
by show of... show of hands if you're from
high school getting (inaudible). You guys

8
00:00:48,980 --> 00:00:52,220
can keep your hands up. I've got... I just
want to pass something out to all of you,

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00:00:52,220 --> 00:00:57,520
and then you can pass it back to me as he's
continuing. Thank you.

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00:00:57,720 --> 00:01:04,700
So today's event is sponsored by the Department of the College of Science and Mathematics, and I would like

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00:01:04,700 --> 00:01:11,360

to thank Professor Petkie for taking the initiative and organizing this event. He worked with

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00:01:11,360 --> 00:01:16,720
the College of Science and Mathematics, the Dayton STEM School, and the U.S. Air Force

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00:01:16,800 --> 00:01:25,440
Museum in... in discovering this exciting
two-day event. Um, and now it's my great pleasure

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00:01:25,440 --> 00:01:31,200
to introduce today's speaker, Professor James Brau. James Brau is the Knight Professor

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00:01:31,240 --> 00:01:37,800
of Natural Sciences at the University of Oregon in Eugene. He is also the director of the

16
00:01:37,800 --> 00:01:43,720
Center for High Energy Physics. Uh, Professor Brau leads a team of more than eleven faculty

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00:01:43,720 --> 00:01:51,680
members, seven research staff members, and more than ten students and post-docs. Professor

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00:01:51,700 --> 00:01:57,280
Brau is a high energy physicist and he's been a part of the ATLAS Detector, which lead to

19
00:01:57,340 --> 00:02:03,300
the discovery of Higgs Boson. Uh, just a brief... brief background of Professor James Brau.

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00:02:03,360 --> 00:02:11,380
He earned his bachelor's degree in... in physics and mathematics from the U.S. Air Force Academy,

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00:02:11,400 --> 00:02:16,060
then went on to do his master's from MIT.
And following his master's, he worked for

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00:02:16,060 --> 00:02:21,520
the Air Force, and then went back to MIT and got his PhD. For the most
part of his academic

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00:02:21,520 --> 00:02:27,900
res... career he has been at the University
of Oregon, and he holds a stellar publication

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00:02:27,900 --> 00:02:34,720
record - uh, uh, journal publications, conference publications.
Including everything, it's more

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00:02:34,720 --> 00:02:41,160
than 1000 publications for uh, Dr. Brau. And
now... now coming onto the topic today, The

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00:02:41,160 --> 00:02:47,260
Higgs Boson: A Window on the Big Bang. What's... what's really
exciting for us is that it's

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00:02:47,260 --> 00:02:54,680
rare to see such genuine excitement for a
physics discovery. Um, and I'm quoting a British...

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00:02:54,680 --> 00:03:00,801
uh, a British newspaper reporter who was at CERN. He said he had never
seen such cheering,

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00:03:00,801 --> 00:03:07,541
hugging, and crying other than like a football game or something. So
the... the world was

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00:03:07,541 --> 00:03:13,561
watching this discovery and then more and
more people got curious. And this is... it's

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00:03:13,561 --> 00:03:18,101
a pleasure for us to have Dr. Brau with us
because he has been part of this monumental

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00:03:18,101 --> 00:03:25,921
discovery and he'll be taking us um, through the discovery of Higgs
Boson. Uh, he'll be

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00:03:25,921 --> 00:03:31,921
talking about what is Higgs Boson, what is
its role in the universe today, what is dark

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00:03:31,921 --> 00:03:37,781
matter, which is the matter hanging... hanging around the galaxies,
what is dark energy,

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00:03:37,781 --> 00:03:44,141
and so on. So, I invite Professor James Brau to lead us on this
journey exploring the particle

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00:03:44,160 --> 00:03:50,559
physics world. Uh, with that, without further
ado, Professor James Brau. Okay, thank you. (applause)

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00:03:56,440 --> 00:04:05,400
Thank you Amit. Okay, let's see if we can
get this on again. Yeah, that's... Well I

38
00:04:05,400 --> 00:04:17,320
think it...(laugh) This... this is actually...
oops (inaudible) I'm going to just put it

39
00:04:17,320 --> 00:04:26,880
on the outside. Alright, so, can you hear
me okay? (laugh) No, so we need some sound

40
00:04:26,900 --> 00:04:34,760
I guess. Um, it's not... just maybe move it...
is that one (blowing into the microphone)

41
00:04:34,760 --> 00:04:39,220
Yeah that seems like... I'll just... I'll
just move it closer to you. Now maybe you

42
00:04:39,220 --> 00:04:43,740
can hear me. Maybe I... I can always speak

up too. I don't usually use a microphone when

43
00:04:43,740 --> 00:04:52,249
I'm speaking to my 200 student lecture classes.
Anyway, um, welcome to this uh, this symposium

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00:04:52,249 --> 00:04:57,849
in which I'm going to tell you about our discovery
of the Higgs Boson and what its meaning is.

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00:04:57,849 --> 00:05:07,569
Um, and t... and... and in understanding the
universe. So, to introduce this um, I remind

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00:05:07,569 --> 00:05:12,270
you of Science Magazine, which many of you
are familiar with. It's a magazine - a...

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00:05:12,270 --> 00:05:18,279
a scientific journal weekly published that
covers all areas of science. And these are

48
00:05:18,279 --> 00:05:24,360
just a selection of some of the cover pages
of the Science Magazine over a course of several

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00:05:24,360 --> 00:05:32,439
months. And um, in 2012, at the end of the
year, as it always does, uh, Science Magazine

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00:05:32,439 --> 00:05:37,809
declares what is the Breakthrough of the Year.
Uh, 2012, the Breakthrough of the Year was

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00:05:37,809 --> 00:05:42,499
the Higgs Boson. It got a lot of attention
and it was uh, highlighted in all of science

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00:05:42,499 --> 00:05:50,189
as... as that big... big breakthrough. Now, not to be left out, Time
Magazine um, of course always

53
00:05:50,189 --> 00:05:56,869
declares a Person of the Year. And um, in
2012, given all of the excitement about the

54
00:05:56,869 --> 00:06:01,449
Higgs Boson, the Higgs Boson was actually
among the nominees for Person of the Year

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00:06:01,449 --> 00:06:08,499
at Time Magazine. Here's the entry that you
can find on the Web for that. Um, they ask

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00:06:08,499 --> 00:06:13,659
uh, people whether the Higgs Boson should
be the uh, Person of the Year. Well, 80% of

57
00:06:13,659 --> 00:06:20,729
the respondents said, "no way!" But there
was a pretty large uh, uh, constituency which

58
00:06:20,729 --> 00:06:25,270
thought the Higgs Boson should be Person of
the Year. Here's a summary that shows the

59
00:06:25,270 --> 00:06:32,469
breakdown of all the various people. Um, and
you see Jon Stewart and Stephen Colbert. Uh,

60
00:06:32,469 --> 00:06:38,199
Hillary Clinton far outranks her husband,
Bill, which is down, down here. But lo and

61
00:06:38,199 --> 00:06:44,409
behold, the Higgs Boson even outranks Bill
Clinton on this list. Well, of course, Time

62
00:06:44,409 --> 00:06:49,939
did not declare the Higgs Boson as the Person
of the Year, but for the first time in my...

63
00:06:49,939 --> 00:06:55,979

as far as I know, it actually made a selection
of Particle of the Year, and made the Higgs

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00:06:55,979 --> 00:07:03,819
Boson the Particle of the Year. This last
year, the Nobel Prize was awarded to the two

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00:07:03,819 --> 00:07:08,629
principal theorists who uh, had the biggest
role in developing the theory of the Higgs

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00:07:08,629 --> 00:07:14,770
Boson. Uh, these two gentlemen, of course
one of them is Peter Higgs. So today we're

67
00:07:14,770 --> 00:07:19,569
going to talk about what is the Higgs Boson,
why it's important, and... and... and one

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00:07:19,569 --> 00:07:24,860
of the issues that I am quite interested in,
and I hope you are too, is what is its role

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00:07:24,860 --> 00:07:31,240
in the early universe and the Big Bang. Now,
bu... just to kind of set the stage for all

70
00:07:31,240 --> 00:07:38,879
of this, we recall that in 1929 uh, Edwin
Hubble discovered that the universe is expanding.

71
00:07:38,879 --> 00:07:46,489
Uh, working in Southern California he looked
out at the galaxies and he made a plot of

72
00:07:46,489 --> 00:07:51,699
all of these red spots are galaxies as a function
of the distance to the galaxy. He measured

73
00:07:51,699 --> 00:07:59,119
how fast that galaxy was moving away from
us, and he discovered this relationship that

74
00:07:59,119 --> 00:08:03,879
says the farther out you look, the faster
these galaxies are moving away from us or

75
00:08:03,879 --> 00:08:10,330
appear to be moving away from us. We now understand
what's really happening here is space is expanding;

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00:08:10,330 --> 00:08:16,509
the... literally the space between the galaxies
is expanding. But he made this discovery looking

77
00:08:16,509 --> 00:08:21,639
at these galaxies. And of course then, if
you think about that and you say, "well what

78
00:08:21,639 --> 00:08:28,939
if we run the movie backwards?" um, you immediately
come to the conclusion that, early on in the

79
00:08:28,939 --> 00:08:33,659
history of the universe, all of this matter
that is currently, apparently moving apart,

80
00:08:33,659 --> 00:08:39,759
was closer and closer together, and you go
back in time. Uh, in this, you would say,

81
00:08:39,759 --> 00:08:43,990
"well there must have been a moment at which
all this matter that's currently spreading

82
00:08:43,990 --> 00:08:51,110
out was concentrated," and that's what we
refer to as the Big Bang. We've now measured,

83
00:08:51,110 --> 00:08:59,089
quite precisely, the amount of time that this
represents uh, and that's 13.8 billion years.

84

00:08:59,089 --> 00:09:07,399
Now, we know this is a fact because, not only
the indirect uh, uh, reasoning that comes

85
00:09:07,399 --> 00:09:13,790
from Hubble's Law and Hubble's discovery,
but if you look out at the sky, here's a photograph

86
00:09:13,790 --> 00:09:18,920
- an image - of the Milky Way Galaxy in the
sky. This is what we see when we look in the

87
00:09:18,920 --> 00:09:26,490
sky in visible light - uh, it's photograph,
visible light. Um, but in fact, if you were

88
00:09:26,490 --> 00:09:31,720
to look at the sky in microwaves, if you could
do that - and we can do that with instruments

89
00:09:31,720 --> 00:09:39,899
- what we discover is, aside from uh, interference
that comes along the... the Milky Way Galaxy

90
00:09:39,899 --> 00:09:47,959
itself, where there's a huge amount of radiation,
we have a very uniform fireball of microwaves

91
00:09:47,959 --> 00:09:53,230
that have been passing through the universe
for 13.8 billion years and are just now arriving

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00:09:53,230 --> 00:09:58,740
on that instrument that you're looking at.
Um, this is the fireball of the Big Bang.

93
00:09:58,740 --> 00:10:07,350
So this was discovered in 1965. It confirmed
the notion that was um, was uh, realized based

94
00:10:07,350 --> 00:10:12,079
on Hubble's discovery of the expanding universe.

It confirmed the fact that there was an early

95
00:10:12,079 --> 00:10:18,980
universe. And, since 1965, over the course
of the last half century, this fireball has

96
00:10:18,980 --> 00:10:24,310
been studied in great detail, and a lot of
what we know about uh, the universe and its

97
00:10:24,310 --> 00:10:31,040
early histories, comes from detailed studies
of that fireball. It's very uniform, but there

98
00:10:31,040 --> 00:10:36,089
is structure on it - very small structures
- and astronomers have been measuring those

99
00:10:36,089 --> 00:10:42,160
structures and learning a lot about the early
universe based on the nature of those structures.

100
00:10:42,160 --> 00:10:50,810
So... so we now have this picture of the history
of the universe. And, here we are today with

101
00:10:50,810 --> 00:10:58,009
all of the developments of mankind. Um, and
as we go back in time - here we actually have

102
00:10:58,009 --> 00:11:05,290
a chart going back in time - we come to that
point of 300,000 years after the Big Bang.

103
00:11:05,290 --> 00:11:12,810
So, it's almost 13.8 billion years - only
300,000 years after the Big Bang - is where

104
00:11:12,810 --> 00:11:19,240
that cosmic microwave uh, fireball appears
in the sky. Before this moment - before this

105
00:11:19,240 --> 00:11:25,670
time - the density is so great that light
cannot escape from that fireball; the light

106
00:11:25,670 --> 00:11:33,100
is trapped in the fireball. And as the universe
expands, uh, it eventually becomes um, transparent

107
00:11:33,100 --> 00:11:38,459
to the... to the photons - the light that's
being generated by the fireball. And that

108
00:11:38,459 --> 00:11:44,470
light is released and then travels through
space uh, and we eventually see the photons

109
00:11:44,470 --> 00:11:51,189
that are released to this point in time. But
what we're doing with our experiments at accelerators,

110
00:11:51,189 --> 00:11:58,839
in particular, the Large Hadron Collider,
is recond... recreating conditions that occurred

111
00:11:58,839 --> 00:12:06,389
deep within that fireball earlier in time.
In fact, you see here we have 10^-10 seconds.

112
00:12:06,389 --> 00:12:13,660
So, less than one-billionth of a second after
the Big Bang. That's what we're doing, on

113
00:12:13,660 --> 00:12:21,209
a very small scale, in our experiment at the
LHC. And what you see in... in... in this

114
00:12:21,209 --> 00:12:26,839
uh, region are lots of very elementary particles
- fundamental particles. Uh, the temperature

115
00:12:26,839 --> 00:12:33,149

here is very, very high. You see it's 10^5
- I don't even know what that number is; it's

116
00:12:33,149 --> 00:12:40,459
huge - in Kelvin - degrees Kelvin - very high
temperature. Um, and what we're learning about

117
00:12:40,459 --> 00:12:44,889
are the fundamental particles. So, for those
of you that are very familiar with the fundamental

118
00:12:44,889 --> 00:12:51,240
particles, excuse me for a... a short uh,
introduction to these, but I just think I

119
00:12:51,240 --> 00:12:57,749
need to do this. Um, the fundamental particles,
basically, come in two forms. There's the

120
00:12:57,749 --> 00:13:04,170
matter particles that we're all made out of
and everything um, is made out of. And then

121
00:13:04,170 --> 00:13:09,509
there are the force particles that actually
mediate forces between the matter particles.

122
00:13:09,509 --> 00:13:17,430
Now, we have these various particles. We have
the electron, the up and the down quarks,

123
00:13:17,430 --> 00:13:21,589
and the electron neutrino. And these are really
the fundamental particles that we have in

124
00:13:21,589 --> 00:13:29,949
our everyday experience. Um, all of the protons
and neutrons that we are built from are made

125
00:13:29,949 --> 00:13:36,050
out of these up and down quarks. Uh, they're
held together by a particle that's over here

126
00:13:36,050 --> 00:13:42,709
on the far-side called the gluon, which glues
these quarks together into the uh, proton

127
00:13:42,709 --> 00:13:51,439
and the neutron. And, another force particle
is the photon. Now the photon is active in

128
00:13:51,439 --> 00:13:57,559
constructing an atom because um, in the case
of the atom, we have this electron orbiting

129
00:13:57,559 --> 00:14:03,610
around a proton. This is a hydrogen atom - it's...
pretty poor example, but I... kind of get

130
00:14:03,610 --> 00:14:09,420
the idea. The electron is orbiting around
a proton in a hydrogen atom and that... that

131
00:14:09,420 --> 00:14:15,019
orbit is being controlled by the exchange
of these uh, these force particles called

132
00:14:15,019 --> 00:14:23,149
the photon. Of course the photon is also been...
comes out in many ways. Uh, we see it all

133
00:14:23,149 --> 00:14:31,209
the time in visible light, in radio transmission,
and so forth. Now, two other force particles

134
00:14:31,209 --> 00:14:36,800
that we have discovered in these kind of experiments
are the z and the w. And these are particles

135
00:14:36,800 --> 00:14:41,809
that are responsible for what we call the
weak nuclear force. The weak nuclear force

136

00:14:41,809 --> 00:14:51,550
is the kind of force that causes radioactive
decay. And that's illustrated here. Um, and

137
00:14:51,550 --> 00:15:01,910
then finally, we find that uh, we have in
fact a duplication of all of these fundamental

138
00:15:01,910 --> 00:15:07,589
particles in our experiments and in cosmic
rays initially, but further in experiments

139
00:15:07,589 --> 00:15:13,389
in accelerators. We found that there are...
for each one of these particles that normal

140
00:15:13,389 --> 00:15:19,910
atoms are made out of, there's a duplication.
So, for the electron, there's another particle

141
00:15:19,910 --> 00:15:24,399
which we call the muon. And these muons are
seen in cosmic rays a lot. If you're in a

142
00:15:24,399 --> 00:15:31,990
physics lab you'll be detecting um, in...
in many situations the muons that are... that

143
00:15:31,990 --> 00:15:37,699
are everywhere - they're coming from cosmic
rays. We have uh, another set of quarks and

144
00:15:37,699 --> 00:15:44,809
another kind of neutrino, but it doesn't stop
there. We also discovered a third uh, repetition

145
00:15:44,809 --> 00:15:52,149
of these quarks and... leptons - we call these
leptons, which have various names. And it's

146
00:15:52,149 --> 00:15:57,019
quite fascinating that we have these three

- we don't understand why; we hope to understand

147
00:15:57,019 --> 00:16:02,509
why someday - and it appears as though that's
all there is. For some reason - for some magical

148
00:16:02,509 --> 00:16:09,220
reason - nature has chosen to make three uh,
copies of each of these types of particles.

149
00:16:09,220 --> 00:16:15,050
Now, the Higgs Boson plays a role in understanding
the properties of these particles, and in

150
00:16:15,050 --> 00:16:22,459
particular, as you go from one of these uh,
sequences to the next, the particles get heavier

151
00:16:22,459 --> 00:16:30,610
and heavier. The heaviest of all is this top
quark. Um, and that's the reason why all or

152
00:16:30,610 --> 00:16:37,110
our everyday matter is made out of these because
uh, nature tries to reduce the energy levels

153
00:16:37,110 --> 00:16:42,629
of things. And so things cascade down to the
lightest objects that they can and this is

154
00:16:42,629 --> 00:16:48,499
the bottom of the ladder. And so, in the early
universe, when the mass didn't matter and

155
00:16:48,499 --> 00:16:53,339
it was very, very hot, all of these things
would be equally populating the early universe.

156
00:16:53,339 --> 00:17:00,629
Uh, but, as time went on and the universe
cooled off, then uh, the more heavy and energetic

157
00:17:00,629 --> 00:17:05,529
particles would disappear. We have to recreate
them with accelerators or you can actually

158
00:17:05,529 --> 00:17:10,179
look for them in cosmic rays, for example,
because we have high energy particles bombarding

159
00:17:10,179 --> 00:17:16,189
the Earth naturally in the form of cosmic
rays. And the Higgs Boson is going to... we're

160
00:17:16,189 --> 00:17:22,799
going to talk about how it plays a role in
uh, creating this... the masses of these particles.

161
00:17:22,799 --> 00:17:28,569
Well here's the... here's the actual quantitative
data on what these masses are. Um, and what

162
00:17:28,569 --> 00:17:33,279
you see here are... is the first... what we
call the first generation. Uh, and we call

163
00:17:33,279 --> 00:17:39,549
these matter particles fermions. Uh, that's
the technical term for them. The field particles

164
00:17:39,549 --> 00:17:46,270
are part... are uh, force particles are called
bosons. And you see the masses um, of the

165
00:17:46,270 --> 00:17:52,270
down and up quark and electron, and the neutrinos
are really light, you see? So here's a scale.

166
00:17:52,270 --> 00:17:59,929
Um, you can think of this scale as... here's
the electron, which is um, in the scale of

167
00:17:59,929 --> 00:18:05,850

10^-3, and every one of these lines refers
to a power of ten going up. And you can see

168
00:18:05,850 --> 00:18:10,039
we go way down here to get to the neutrinos
from the electrons. So these neutrinos are

169
00:18:10,039 --> 00:18:14,450
very light. Um, and then we have the... these
getting heavier and heavier and you see the

170
00:18:14,450 --> 00:18:19,929
top quark here. And the Higgs is almost as
heavy as the top quark, but not quite. These

171
00:18:19,929 --> 00:18:25,820
w's and z's are pretty heavy. Uh, field particles
for the weak force, and in fact it turns out,

172
00:18:25,820 --> 00:18:30,830
for technical reasons, the reason the weak
interaction that we talk about for radioactive

173
00:18:30,830 --> 00:18:34,500
decay is called weak is because it turns out
it's related to the fact that these are very

174
00:18:34,500 --> 00:18:40,130
heavy. And then the photon, the gluon - the
gluon holds the quarks together in the nucleus

175
00:18:40,130 --> 00:18:46,529
- are actually massless. It's kind of interesting.
So, in order to kind of think, in concrete

176
00:18:46,529 --> 00:18:53,110
terms, about the scale here, if we put uh,
an elephant mass up here we can ask, you know,

177
00:18:53,110 --> 00:18:57,970
what scale are we talking about as we go down here? We have our... our
friendly companion,

178
00:18:57,970 --> 00:19:05,309
the dog and the cat, here, a mouse, a hummingbird,
a flea is down here, and then finally, the

179
00:19:05,309 --> 00:19:09,020
lightest insect of all, as far as I know - maybe
someone can correct me - is the fairy fly

180
00:19:09,020 --> 00:19:13,740
uh, and that's where... way down here where
we have the neutrinos. So you can get a sc...

181
00:19:13,740 --> 00:19:20,380
an idea of the scale uh, of range of masses that
we're dealing with here. And the Higgs Boson

182
00:19:20,380 --> 00:19:26,559
is responsible, to a very large extent, for
this difference. Why are the masses of...

183
00:19:26,559 --> 00:19:31,200
of each of these fundamental particles so
different? In... in some sense, they're...

184
00:19:31,200 --> 00:19:38,779
they're copies of the same particle, but they
have these different masses. And uh, so we

185
00:19:38,779 --> 00:19:44,419
want to understand why they do. Now, another
way of introducing what we're going to talk

186
00:19:44,419 --> 00:19:51,120
about today is to think about the evolution
or advances of physics as we've understood

187
00:19:51,120 --> 00:20:00,899
the forces at work between the fundamental
particles. If we go back to 19... to 1850,

188

00:20:00,899 --> 00:20:10,409
uh, the forces that people were aware of were
gravity, electricity, and magnetism. And that's...

189
00:20:10,409 --> 00:20:18,600
those are the forces um, that scientists were
working on, and they were being applied uh,

190
00:20:18,600 --> 00:20:27,610
to everyday uh, uh, things. And the question
is... physicists are looking for ways to relate

191
00:20:27,610 --> 00:20:31,309
things. And so the question is: are these
forces somehow related? Is gravity related

192
00:20:31,309 --> 00:20:37,480
to electricity? Blah, blah, blah. Well um,
what was found is in fact that electricity

193
00:20:37,480 --> 00:20:44,690
and magnetism are related. And a gentleman
named Maxwell wrote down a theory - a unified

194
00:20:44,690 --> 00:20:51,549
theory - which was then verified. And now
it's an established, solid theory of electromagnetism.

195
00:20:51,549 --> 00:20:59,360
And out of that came an understanding of light.
It just came out from that theory. So figuring

196
00:20:59,360 --> 00:21:06,760
out how to relate two... what appear to be
two separate forces - electricity from...

197
00:21:06,760 --> 00:21:15,700
and magnetism - uh, an understanding of light
emerged. Um, so now we reduced our list from

198
00:21:15,700 --> 00:21:25,519
two... from these three forces down to two.

But of course um, as time goes on uh, the

199
00:21:25,519 --> 00:21:31,580
physicists continued to try to think, "how
can we reduce the two to one?" And in particular,

200
00:21:31,580 --> 00:21:38,200
Einstein was very uh, active in trying to
figure out how he could u... unite gravity

201
00:21:38,200 --> 00:21:41,919
and electromagnetism. He worked on this...
this is one of the main... his main research

202
00:21:41,919 --> 00:21:49,730
interests for a long time um, and he was never...
never successful, but he had some gut feeling

203
00:21:49,730 --> 00:21:53,860
that somehow he ought to be able to do it.
So while he was working on trying to unify

204
00:21:53,860 --> 00:22:01,510
these forces, other physicists were discovering
new forces and adding to the list, which makes

205
00:22:01,510 --> 00:22:06,690
life more complicated because now we have
more work to do. Um, and those two forces

206
00:22:06,690 --> 00:22:10,899
were the nuclear forces, what we've just already
referred to - the weak nuclear force and the

207
00:22:10,899 --> 00:22:20,559
strong nuclear force. And by 1950 um, the
list had grown to this... to this list. Well,

208
00:22:20,559 --> 00:22:28,620
over the course of the last half of the 20th
century uh, we were successful in unifying,

209
00:22:28,620 --> 00:22:34,809
believe it or not, electromagnetism with the
weak nuclear force. And we call this the electroweak

210
00:22:34,809 --> 00:22:43,070
force. And this unification anticipated the
discovery of Higgs Bosons. So when... just

211
00:22:43,070 --> 00:22:51,980
like when we made electromagnetism - we had
photons that had to be there - the uh, unification

212
00:22:51,980 --> 00:22:59,760
of electromagnetism with the weak force suggested
- didn't prove, but suggested - that there

213
00:22:59,760 --> 00:23:05,070
might be Higgs Bosons around and we ought
to look for them. And... and... and... and

214
00:23:05,070 --> 00:23:10,429
so that's what we did. Now, we're not going
to get to this, but, looking ahead, we should

215
00:23:10,429 --> 00:23:17,029
still consider the possibility in the future
of understanding how all of these forces are

216
00:23:17,029 --> 00:23:21,500
related. And there's certainly very active
work going on to try to see if that can be

217
00:23:21,500 --> 00:23:28,100
done. But that's not... that's a topic for
another day. So here's a graphic picture showing

218
00:23:28,100 --> 00:23:34,470
um, again what we're dealing with in terms
of fundamental particles. We have those quarks

219
00:23:34,470 --> 00:23:40,130

- the up and the down are the ones that make up the nucleus - protons and neutrons - are

220
00:23:40,130 --> 00:23:45,289
the electron and the neutrino, and then there's
the uh, repetition here. Here are the force

221
00:23:45,289 --> 00:23:51,149
particles, and then the Higgs Boson plays
a central role. Um, and there's an important

222
00:23:51,149 --> 00:23:54,529
point being made on this plot, which we're
not going to really talk about too much, but

223
00:23:54,529 --> 00:23:59,299
let me just point it out for those that are
interested. All of these particles carry a

224
00:23:59,299 --> 00:24:05,919
little internal spin which we call 1/2. It's...
the units are Planck's constant, if you're

225
00:24:05,919 --> 00:24:10,980
familiar with that is. And all of these particles
carry a half a unit of that in... sort of

226
00:24:10,980 --> 00:24:17,519
like little spinning tops. These particles
always carry a full unit of Planck's constant,

227
00:24:17,519 --> 00:24:24,600
internal spin. And the Higgs Boson, which
springs from the vacuum of the universe um,

228
00:24:24,600 --> 00:24:30,000
has no internal spin. So there's a fundamental
difference between these particles. And in

229
00:24:30,000 --> 00:24:34,950
partic... and we're thinking now that maybe
the Higgs Boson is the first of a whole new

230
00:24:34,950 --> 00:24:39,500
type of particle that carries no angular
momentum. And there's other... other connections

231
00:24:39,500 --> 00:24:44,070
to other ideas that people are working on.
But it's the first one we've found of a fundamental

232
00:24:44,070 --> 00:24:50,889
particle that carries no internal angular
momentum. Okay. So what is the Higgs Boson?

233
00:24:50,889 --> 00:24:58,440
Well, it's named after Peter Higgs and this
gentleman uh, Indian physicist, Bose, who

234
00:24:58,440 --> 00:25:03,899
worked on the statistics of particles like
the Higgs Boson, but like lot's of particles

235
00:25:03,899 --> 00:25:09,210
- all the field particles, all of the force
particles. He worked on a lot of things. So

236
00:25:09,210 --> 00:25:14,179
it's just a Boson but it's interesting that
his name is associated there. Now the theory

237
00:25:14,179 --> 00:25:23,600
was postulated in 1964. That's when Peter
Higgs uh, wrote a paper thinking about this

238
00:25:23,600 --> 00:25:28,230
electroweak unification and what is might
mean and how you might get to it. He wrote

239
00:25:28,230 --> 00:25:36,429
a paper that a few people understood. Um,
and uh, other people wrote papers as well.

240

00:25:36,429 --> 00:25:41,789
So there's a long list of people who wrote
papers right at that time, describing a field

241
00:25:41,789 --> 00:25:47,549
a uni... fiel... in the only universe uh,
that we now understand is the Higgs Field.

242
00:25:47,549 --> 00:25:54,299
That was historical era. Remember uh, Beatles
arrived in the USA at Kennedy Airport in 1964.

243
00:25:54,299 --> 00:25:58,889
It's been... actually that's been uh, that's
fifty years ago... just fifty years ago and

244
00:25:58,889 --> 00:26:06,519
there's been... February in fact. Um, what
else? Oh yes, President Johnson signed the

245
00:26:06,519 --> 00:26:12,210
Civil Rights Act in July of 1964 and the Voting
Rights Act in 1965. Many things were happening

246
00:26:12,210 --> 00:26:19,850
at that time. And many of us had been reliving
that era uh, in Mad Men on AMC. You may be

247
00:26:19,850 --> 00:26:24,519
a... if you're a fan - I'm a fan of Mad Men.
I... so... so that's a... that's a special

248
00:26:24,519 --> 00:26:31,510
era. And that's when this was postulated and
that was fifty years ago. Imagine, fifty years.

249
00:26:31,510 --> 00:26:38,590
So, what is the Higgs Field? Well, it's...
it's like other fields. Now the Earth has

250
00:26:38,590 --> 00:26:44,260
a gravitational field. So the mass of the

Earth creates a field around that pulls things

251
00:26:44,260 --> 00:26:53,000
to it. It's a field. Uh, the elec... the magnet
creates a magnetic field - a magnetism uh,

252
00:26:53,000 --> 00:27:01,850
field. And each of these fields is essentially
made to act by a particle - in the case of

253
00:27:01,850 --> 00:27:07,080
gravity we call it the graviton. Um, we haven't
actually discovered the graviton, but it...

254
00:27:07,080 --> 00:27:12,250
it's embedded in our theories of the gravity.
And in the case of electromagnetism it's the

255
00:27:12,250 --> 00:27:18,399
photon; we've already mentioned that. And
so, the Higgs Field at... it... the Higgs

256
00:27:18,399 --> 00:27:24,940
is both a field and a particle. It's a field
that is fundamental to the universe, and I

257
00:27:24,940 --> 00:27:30,130
like to think of it as being sourced by the
universe. You see, these other fields are

258
00:27:30,130 --> 00:27:38,789
sourced by the Earth or a magnet creates the
source of the field. The Higgs Field is embedded

259
00:27:38,789 --> 00:27:44,940
in the universe. And it's the universe itself
in some sense that gives rise to it. And then

260
00:27:44,940 --> 00:27:49,299
there's a particle also associated that comes
out of that field just like we have particles

261
00:27:49,299 --> 00:27:56,139
that... that are... that make these fields
act. So it fills the universe - the Higgs

262
00:27:56,139 --> 00:28:02,630
Field does. Um, it interacts with the fundamental
particles and it actually gives them their

263
00:28:02,630 --> 00:28:09,419
mass. The reason they have the mass they have
is through their interaction with this field

264
00:28:09,419 --> 00:28:17,440
that fills the universe. Uh, now you... this
is a little bit of a circular argument because

265
00:28:17,440 --> 00:28:21,340
they have the mass they have because of their
interaction and they have the interaction

266
00:28:21,340 --> 00:28:27,029
that's associated with their mass. But if
it's true, it's uh, it's ve... and we... and

267
00:28:27,029 --> 00:28:32,620
our theories are being backed up by data that
show that this is uh, this is true. But it

268
00:28:32,620 --> 00:28:39,759
has another role and that is uh, which is
what was the clue that led these gentlemen,

269
00:28:39,759 --> 00:28:46,139
including Peter Higgs, to en... envision that
this existed, and that is to essentially break

270
00:28:46,139 --> 00:28:53,240
apart electricity, electromagnetism, and the
weak nuclear force from the unified electroweak

271
00:28:53,240 --> 00:29:00,500

uh, force, and break them apart and make them
look very different. Uh, so in our theories

272
00:29:00,500 --> 00:29:06,929
we have, we start out with a... with a equation
where they are basically symmetric and...

273
00:29:06,929 --> 00:29:12,389
and not distinguished uh, to a large degree.
And then through the interaction of the Higgs

274
00:29:12,389 --> 00:29:19,059
Field, again related to mass generation, the
photon remains massless and the other particles

275
00:29:19,059 --> 00:29:26,330
acquire mass, and this leads to a big difference
in the way they behave. The weak nuclear force,

276
00:29:26,330 --> 00:29:31,389
which uh, was responsible for radioactive
decay, and the electromagnetic force behaved

277
00:29:31,389 --> 00:29:36,200
very differently as a result of this. So here's
an illustration showing you particles moving

278
00:29:36,200 --> 00:29:41,019
through space and they're interacting with
this Higgs Field - uh, it's just a cartoon

279
00:29:41,019 --> 00:29:47,750
- to illustrate how, when they interact with
the Higgs Field, it... they acquire mass and

280
00:29:47,750 --> 00:29:52,820
the more heavy an object is, at a given energy
it goes more slowly; its velocity slows down,

281
00:29:52,820 --> 00:29:56,950
and that's what's kind of illustrated here.
So you see photons, these white things, passing

282
00:29:56,950 --> 00:30:01,570
through. Uh, they don't... they don't directly
interact with the Higgs Field so they just

283
00:30:01,570 --> 00:30:06,730
move through it the maximum velocity of the
universe, which is the speed of light. And

284
00:30:06,730 --> 00:30:15,519
heavier particles um, are being... interacting,
slowing down, acquiring mass, uh, makes them

285
00:30:15,519 --> 00:30:22,769
essentially more sluggish. So... so this is
sort of building up to the Higgs Boson and

286
00:30:22,769 --> 00:30:30,590
what we have done now is a massive global
effort uh, at CERN in Geneva, Switzerland,

287
00:30:30,590 --> 00:30:38,960
has uh, put together uh, a collider that has
allowed scientists to discover uh, the Higgs

288
00:30:38,960 --> 00:30:46,200
Boson. Uh, this is um, a aerial view of the
region around the collider. Here's the Geneva

289
00:30:46,200 --> 00:30:52,669
Airport. Here's the lake. The city is over
this way. And just outside of Geneva, you

290
00:30:52,669 --> 00:30:59,379
have underground, under this white line that's
drawn here, the actual Large Hadron Collider.

291
00:30:59,379 --> 00:31:06,860
Uh, there are a number of accelerators that
bring the beams up through stages to the energy

292

00:31:06,860 --> 00:31:14,769
that's required for the collisions. Uh, here's
a cartoon uh, animation s... uh, zooming in

293
00:31:14,769 --> 00:31:19,679
on Geneva. Uh, soon we'll see the Collider.
There you see the protons going around in

294
00:31:19,679 --> 00:31:27,830
both directions. We'll go underground to see
our ATLAS experiment um, in a moment. Here

295
00:31:27,830 --> 00:31:36,389
you see the ring in our experiment. Uh, all
seven tons of it is embedded underground uh,

296
00:31:36,389 --> 00:31:42,820
and pretty soon one of our colleagues, a physicist,
will walk in to give you a scale - a perception

297
00:31:42,820 --> 00:31:48,970
- of the size of this massive apparatus. So
what's happening is we're circulating protons

298
00:31:48,970 --> 00:31:55,480
in both directions at very high energy and
smashing them together at the center of this

299
00:31:55,480 --> 00:32:03,330
apparatus. And then the apparatus measures
what happens. And a sm... small fraction of

300
00:32:03,330 --> 00:32:09,330
the time what happens is a Higgs Boson. And
I'll show you why we know that uh, in some

301
00:32:09,330 --> 00:32:17,220
of the coming slides. So here's the tunnel.
Uh, a gentleman on a bicycle there. It's a

302
00:32:17,220 --> 00:32:23,080
seventeen mile circumference, 300 feet underground.

Proton beams are going in both directions.

303
00:32:23,080 --> 00:32:28,559
Um, there's 1,600 superconducting magnets
in there. They're held at a temperature of

304
00:32:28,559 --> 00:32:36,179
two degrees above absolute zero, um, with
8.3 Tesla fields. And that's the design value.

305
00:32:36,179 --> 00:32:43,210
Uh, they haven't actually operated at that
full field yet. Um, and there's 10,000 megajoules...

306
00:32:43,210 --> 00:32:50,840
10,000 megajoules of stored energy at full
operating uh, once the thing gets fully operating.

307
00:32:50,840 --> 00:32:54,720
So there's currents running through these
magnets with that amount of energy. The full

308
00:32:54,720 --> 00:33:02,240
design is 600 million collisions per second.
Um, so little big bangs happening 600 million

309
00:33:02,240 --> 00:33:09,340
times a second. And the center of mass collision
energy is fourteen trillion electron volts.

310
00:33:09,340 --> 00:33:13,600
Everybody has a feel for what an... a volt
is. So you have batteries that are on the

311
00:33:13,600 --> 00:33:19,950
scale of a volt or a volt and a half or whatever.
That's a lot of batteries. Now so far it's

312
00:33:19,950 --> 00:33:25,870
only operating at eight and seven uh, trillion
electron volts. And all of our data is based

313
00:33:25,870 --> 00:33:31,529
on that energy. Uh, it's been upgraded now
to go up to the fourteen, and beginning next

314
00:33:31,529 --> 00:33:36,940
year, we're expecting to run at the fourteen
trillion electron volts. Now the proton beam

315
00:33:36,940 --> 00:33:45,740
itself only stores 700 megajoules, but that's
equivalent to 747 energy on takeoff, all stored

316
00:33:45,740 --> 00:33:51,299
in that beam circulating around the ring.
And if you calculate it out, it's enough energy

317
00:33:51,299 --> 00:33:57,250
to melt a half a ton of copper. So when that
beam is circulating, it's very important that

318
00:33:57,250 --> 00:34:05,100
you keep it in the vacuum uh, and don't let
it uh, let it run into the walls or something.

319
00:34:05,100 --> 00:34:10,920
Well here's a little cartoon that um, shows
some of... how we look... by the way, the

320
00:34:10,920 --> 00:34:18,470
ATLAS collaboration that discovered the Higgs
Boson consists of 3,000 physicists um, including

321
00:34:18,470 --> 00:34:24,910
our group, and 176 other university and laboratory
groups, and 38 countries. It's a very large,

322
00:34:24,910 --> 00:34:31,380
almost a United Nations type of operation.
And it operated simultaneously with another

323
00:34:31,380 --> 00:34:38,060

detector called CMS, which also discovered
simultaneously uh, the Higgs Boson. So here's

324
00:34:38,060 --> 00:34:44,040
a little image of a Higgs Boson. Of course
we can't photograph the Higgs Boson, but just

325
00:34:44,040 --> 00:34:50,920
for the moment, consider that to be a Higgs
Boson. And it's very heavy. Uh, it's equivalent

326
00:34:50,920 --> 00:34:58,790
to about 133 hydrogen atoms or one cesium
atom. So this is a fundamental particle um,

327
00:34:58,790 --> 00:35:05,570
uh, you see and it's... but it's hugely massive.
That's why it's been so long to find; it took

328
00:35:05,570 --> 00:35:09,540
us so long to discover it. And many other
experiments have looked for it in the past

329
00:35:09,540 --> 00:35:17,740
- didn't have the capability to go to such
a heavy mass. Um, and, let's see. Here's the

330
00:35:17,740 --> 00:35:23,510
way we do it. Well we bring a couple protons
in. So here's our protons uh, with two up

331
00:35:23,510 --> 00:35:30,820
quarks and a down quark, coming together - smashing
together. And, when they do, they can convert

332
00:35:30,820 --> 00:35:38,990
the energy of the collision into a mass of
a Higgs Boson. So uh, energy equals mass.

333
00:35:38,990 --> 00:35:43,040
Here's a picture. Now you see the Higgs is
produced and then it decays into a couple

334
00:35:43,040 --> 00:35:48,820
of photons. So we don't see the Higgs Boson
in our experiment. What we see are these two

335
00:35:48,820 --> 00:35:55,960
photons, or gamma rays, that have come out
of the Higgs Decay, and they'll go out into

336
00:35:55,960 --> 00:36:06,510
the apparatus and we will detect them and
then try to make sense out of what we found.

337
00:36:06,510 --> 00:36:20,920
Okay, should be enough. It's a lot of times
per second huh? Okay, let's see. Okay. So

338
00:36:20,920 --> 00:36:27,860
on July fourth 2012, about a year and a half
ago, uh, the ATLAS collaboration and, as I

339
00:36:27,860 --> 00:36:34,400
mentioned, the CMS collaboration both announced
the discovery uh, of the Higgs Boson. And

340
00:36:34,400 --> 00:36:41,500
what I want... so I'm going to play a video
clip from the announcement that was being

341
00:36:41,500 --> 00:36:48,920
made by our spokesperson, Fabiola Gianotti.
Uh, she was speaking in Geneva, but a large

342
00:36:48,920 --> 00:36:55,590
fraction of our collaboration and of the world's
physicists were gathered in Melbourne. Uh,

343
00:36:55,590 --> 00:37:03,090
and so this was being simultaneously uh, viewed
in Melbourne by a very large audience of physicists.

344

00:37:03,090 --> 00:37:07,600
And of course all over the world people were
watching this on the Internet as well. So

345
00:37:07,600 --> 00:37:17,560
let's just listen to Fabiola's uh, presentation.
...extremely clean except one big spike here

346
00:37:17,600 --> 00:38:00,700
- in this region here. So, zooming in this
region. (applause) So um, I'm going to explain

347
00:38:00,700 --> 00:38:05,180
to you why everybody got so excited when she
flashed up that slide - when she changed slides.

348
00:38:05,180 --> 00:38:10,310
Uh, but first um, the gentleman who was wiping
the tears from his eyes was Peter Higgs. He

349
00:38:10,310 --> 00:38:17,710
had waited fifty years for, you know, some
paper he wrote become such an important contribution

350
00:38:17,710 --> 00:38:22,450
to the advances of physics. And I think he
say... has been quoted saying that it was

351
00:38:22,450 --> 00:38:27,130
remarkable that he was actually alive to see
this discovery. And here's the slide that

352
00:38:27,130 --> 00:38:33,290
created all the excitement among the physics
community. What was exciting about this was

353
00:38:33,290 --> 00:38:40,940
the five sigma significance. So here's uh,
a plot of the possible masses of the Higgs

354
00:38:40,940 --> 00:38:47,590
Boson. And what the data is telling us about

the possible masses - and we have statistical

355
00:38:47,590 --> 00:38:55,090
fluctuations around any particular value.
But right here at 126 we have a five sigma

356
00:38:55,090 --> 00:39:01,920
significance. And we consider five sigma in
our field to be the required amount to make

357
00:39:01,920 --> 00:39:08,020
a discovery. So until she made that announcement,
it was not known broadly within... even within

358
00:39:08,020 --> 00:39:13,700
the collaboration, that that was the level
of significance of the data. So here's a bell

359
00:39:13,700 --> 00:39:18,750
curve to kind of illustrate this. Uh, five
sigma... uh, so this is what you would get

360
00:39:18,750 --> 00:39:24,840
if you just took random measurements of something.
Uh, you'd normally get um, the amount... so

361
00:39:24,840 --> 00:39:29,610
I'm saying suppose there was no Higgs Boson
and you just randomly measured something.

362
00:39:29,610 --> 00:39:37,300
Uh, you'd get a distribution like this. And
the chances to go out five sigma away from

363
00:39:37,300 --> 00:39:45,960
just random uh, data is very very small. In
fact um, that randomness can be produced only

364
00:39:45,960 --> 00:39:52,440
once in three and a half million times. So
suppose you flip a coin ten times and it turns

365
00:39:52,440 --> 00:39:59,770
up heads every time. Well you'd be tempted
to say there's something fishy about this

366
00:39:59,770 --> 00:40:06,910
coin. That's one in a thousand probability
that you could get that many heads. But uh,

367
00:40:06,910 --> 00:40:13,360
we don't go... we don't stop there. Um, suppose
you flip it twenty time. That's one in a million.

368
00:40:13,360 --> 00:40:18,640
We don't stop there. What we require is basically
to declare that there's something about that

369
00:40:18,640 --> 00:40:23,890
coin or, in this case, to declare that there's
a particle we declare the five sigma effect,

370
00:40:23,890 --> 00:40:28,160
which means they're really confident that
it's very unlikely that this comes from anything

371
00:40:28,160 --> 00:40:35,530
else. Now the evidence uh, comes from about
one in every trillion collisions where you

372
00:40:35,530 --> 00:40:42,240
get two photons produced from the Higgs Boson.
So remember we're colliding the protons together

373
00:40:42,240 --> 00:40:51,370
a lot and mostly we don't produce Higgs Bosons;
we produce other things of interest. And uh,

374
00:40:51,370 --> 00:40:56,690
what we now know is about one in a trillion
times we get a Higgs Boson that spits out

375
00:40:56,690 --> 00:41:03,850

a couple of photons. Um, and that's illustrated
here. And the problem in finding this is even

376
00:41:03,850 --> 00:41:10,220
though we could find one in a trillion if
it was just there uh, there are many more

377
00:41:10,220 --> 00:41:17,590
pairs of photons produced by random, unrelated
processes in the experiment. So what you have

378
00:41:17,590 --> 00:41:28,140
to do is collect the data and somehow figure
out how to get rid or to overcome the very

379
00:41:28,140 --> 00:41:34,650
large number of random uh, unrelated events.
And this is a uh, an image that was put together

380
00:41:34,650 --> 00:41:40,810
by the collaboration to show you the development
of the data over time which shown here is

381
00:41:40,810 --> 00:41:46,880
the data. And we'll run this video and it'll...
it'll accumulate data uh, for two photons

382
00:41:46,880 --> 00:41:53,600
coming from a particular value of mass. So
you see two photons and you say, "if those

383
00:41:53,600 --> 00:41:58,150
two came from a particle, what would the mass
have been?" And most of the time it's some

384
00:41:58,150 --> 00:42:03,630
random combination that has nothing to do
with the Higgs Boson. That's illustrated here.

385
00:42:03,630 --> 00:42:12,890
You see as the data accumulated, you'd basically
just get a smooth curve, fluctuations, and

386
00:42:12,890 --> 00:42:17,700
we now know that the Higgs Boson is in this
region. Here's the uh, difference. It's starting

387
00:42:17,700 --> 00:42:22,630
to appear, but of course you can't see anything
from the amount of data that was taken by

388
00:42:22,630 --> 00:42:31,220
October 31st 2011. But as you continue to
acquire data, now one has a statistically

389
00:42:31,220 --> 00:42:35,420
significant excess appearing in this region,
and you can sort of see how that's building

390
00:42:35,420 --> 00:42:41,910
up above that smooth curve where there's fluctuations
around. But when you get into this region

391
00:42:41,910 --> 00:42:49,190
you have a systematic um, accumulation. And
as you go on to the end of the experiment,

392
00:42:49,190 --> 00:42:55,650
the uh, data just continues to build up, and
now you have a very significant uh, excess

393
00:42:55,650 --> 00:43:03,290
building up in this region. And this is one
of the uh, one of the measurements that uh,

394
00:43:03,290 --> 00:43:08,380
from the ATLAS experiment that shows us where
the Higgs Boson is. There's also a very similar

395
00:43:08,380 --> 00:43:14,900
measurement uh, from CMS for pho... two photons,
and then there's some other decay modes that

396

00:43:14,900 --> 00:43:20,530
also show uh, the Higgs Boson because the
Higgs decays to the two gammas very small

397
00:43:20,530 --> 00:43:26,130
fraction of the time and it's decaying to
other things as well. Uh, this is just a curve

398
00:43:26,130 --> 00:43:32,810
showing you the best uh, best understanding
of what's going on there. Again, a statistical

399
00:43:32,810 --> 00:43:36,810
analysis - I think I'll go through this very
quickly - but this shows you uh, what the

400
00:43:36,810 --> 00:43:41,760
probability to get any one of thes... uh,
to get it what you see at a given mass - the

401
00:43:41,760 --> 00:43:47,910
probability to get it just by random occurrences.
And you can see it's very very unlikely. So

402
00:43:47,910 --> 00:43:53,990
a paper was published by the collaboration,
announcing this after the uh, uh, public uh,

403
00:43:53,990 --> 00:43:59,980
presentation. Uh, it was... appeared on the
front page. You see ATLAS and CMS both prominently

404
00:43:59,980 --> 00:44:07,740
displayed here. And of course the young people
in the collaboration celebrated by uh, making

405
00:44:07,740 --> 00:44:14,820
t-shirts that they wore around everywhere,
and uh, I think the front says, "all I got

406
00:44:14,820 --> 00:44:20,590
was this t-shirt - I found a particle, but

all I got was this t-shirt." Okay, so, why

407
00:44:20,590 --> 00:44:24,740
is the Higgs Boson important? We've already
pretty much said this. It gives mass to the

408
00:44:24,740 --> 00:44:31,080
fundamental particles - the quarks, the leptons,
fundamental Bosons - and it produces a difference

409
00:44:31,080 --> 00:44:37,010
in the fundamental forces that we've already
discussed. That's the particle physics view.

410
00:44:37,010 --> 00:44:44,310
From the Big Bang view uh, the Big Bang actually,
as we understand it, produced massless particles

411
00:44:44,310 --> 00:44:51,360
uh, 13.8 billion years ago. This Higgs Field
appeared everywhere. As the universe expanded

412
00:44:51,360 --> 00:44:59,260
and cooled, the interaction of the fundamental
particles with this Higgs Field uh, gave them

413
00:44:59,260 --> 00:45:05,920
the difference in masses that we've seen.
And if... if the particles didn't have their

414
00:45:05,920 --> 00:45:12,120
masses, we would never have been able to have
atoms formed, so in that sense it's also uh,

415
00:45:12,120 --> 00:45:17,360
the reason why we have atoms because, if the
electron didn't have a mass, it wouldn't be

416
00:45:17,360 --> 00:45:29,440
able to be uh, to be formed into an atom.
So, there's where we're looking. Um, one big

417
00:45:29,440 --> 00:45:35,270
problem we have... so we've discovered the
Higgs. Uh, that's... is that the end of the

418
00:45:35,270 --> 00:45:39,020
story? No, that's not the end of the story.
We've just started, you know? Imagine when

419
00:45:39,020 --> 00:45:43,180
you've discovered the photon, for example,
or discovered any other particle. An enormous

420
00:45:43,180 --> 00:45:50,050
amount uh, of knowledge comes beyond that,
and where it leaves you is certainly very

421
00:45:50,050 --> 00:45:57,760
uncertain. Uh, but um, one of the issues we're
thinking about now is what we call technically

422
00:45:57,760 --> 00:46:03,060
the hierarchy problem, which is theories suggest
the Higgs Boson should be much much heavier

423
00:46:03,060 --> 00:46:08,060
than it actually is. So now that we have the
mass, we try to understand - can we understand

424
00:46:08,060 --> 00:46:16,590
that mass; is everything happy with that mass?
And the answer is no because the mass in physics

425
00:46:16,590 --> 00:46:20,670
- in quantum physics for those of you who
have a little bit of knowledge of that - there

426
00:46:20,670 --> 00:46:26,550
are things called radiative corrections that
change the properties of things. And in particular

427
00:46:26,550 --> 00:46:32,850

the Higgs Boson uh, if you look at the Higgs
Boson, some of the time it spontaneously makes

428
00:46:32,850 --> 00:46:38,640
pairs of particles and then returns to itself.
These are called radiative corrections. It's

429
00:46:38,640 --> 00:46:45,570
in... deeply embedded in quantum mechanics.
Um, and this is a very large effect. And what...

430
00:46:45,570 --> 00:46:50,980
when we do the calculation, what it does is
it pushes the mass of the Higgs, corrects

431
00:46:50,980 --> 00:46:56,980
it to a very very high value, way beyond
something that uh, we can possibly understand.

432
00:46:56,980 --> 00:47:04,020
Well one way to fix this is to uh, add new
particles - new physics - that we have not

433
00:47:04,020 --> 00:47:09,350
yet discovered - some kind of new particle.
And so when we do the theory and put this

434
00:47:09,350 --> 00:47:14,710
uh, process in, where the Higgs makes these
particles, we have to also consider the Higgs

435
00:47:14,710 --> 00:47:19,440
making some other type of new particle. And
it turns out if you... if you think about

436
00:47:19,440 --> 00:47:26,650
the right kind of new physics, these cancel
out and retain the Higgs mass at a lower value.

437
00:47:26,650 --> 00:47:36,500
Um, this is somewhat akin to the theoretical
ex... uh, d... um, notion of... of um, antiparticles

438
00:47:36,500 --> 00:47:44,060
that Dirac uh, theoretically discovered when
he was trying to understand the electron itself.

439
00:47:44,060 --> 00:47:49,390
And in order to develop a theory of the electron,
he had to invent a whole new type of particle:

440
00:47:49,390 --> 00:47:53,900
the antiparticles. They weren't discovered
yet. But he put them in his theory; his theory

441
00:47:53,900 --> 00:48:00,000
worked out, and within a few years uh, these
anti-electrons we call positrons were discovered

442
00:48:00,000 --> 00:48:06,840
in cosmic rays. So maybe we're now uh, on
the threshold of these... finding some of

443
00:48:06,840 --> 00:48:12,420
these particles that we need in order to solve
this hierarchy problem and... and understand

444
00:48:12,420 --> 00:48:18,900
why the Higgs mass is what it is. But there
are other um, solutions. Um, these new particles

445
00:48:18,900 --> 00:48:25,590
that we are talking about are called supersymmetric
particles. Just like antimatter duplicates

446
00:48:25,590 --> 00:48:31,520
all of matter, supersymmetric particle duplicates
all that. Uh, maybe that's the way nature

447
00:48:31,520 --> 00:48:39,080
is. Or maybe there are extra dimensions that
we have to fold into our theory. Uh, so instead

448

00:48:39,080 --> 00:48:44,250
of being three spacial dimensions, there's
other dimensions that alter these uh, calculations

449
00:48:44,250 --> 00:48:52,620
uh, uh, and we have to discover them to understand
what's going on. Or there are other ideas

450
00:48:52,620 --> 00:48:58,370
uh, so-called composite Higgs. There's new
physics needed to solve this problem, and

451
00:48:58,370 --> 00:49:06,940
so this is one of the avenues of future research
that we're involved in. Now what is matter?

452
00:49:06,940 --> 00:49:17,600
Um, so everything we see is made out of ordinary
matter. Cosmic rays, wild animals uh, stars

453
00:49:17,600 --> 00:49:25,590
and planets, trees and meteorites - this is
all atomic matter made of quarks and leptons.

454
00:49:25,590 --> 00:49:32,680
But I ask the question: could the universe
contain another form of matter? And the answer

455
00:49:32,680 --> 00:49:40,150
is probably yes. And that other form of matter
is dark matter. Uh, and this dark matter could

456
00:49:40,150 --> 00:49:46,400
be linked to these new particles that we need
to understand the hierarchy problem. So let's

457
00:49:46,400 --> 00:49:52,230
talk a little bit about um, this dark matter.
Now we know that galaxies are surrounded

458
00:49:52,230 --> 00:49:59,230
by dark halos of a mit... mysterious, unidentified

stuff. That's what we call dark matter. So

459
00:49:59,230 --> 00:50:07,180
here's a uh, an animation showing the motion of stars in a galaxy that one would extect...

460
00:50:07,180 --> 00:50:14,530
expect based on the mass we observe in the
galaxy. We know how to apply the gravitational

461
00:50:14,530 --> 00:50:20,820
laws of Newton; we know how much mass we see
in a galaxy. So we can calculate what the

462
00:50:20,820 --> 00:50:27,230
stars' motion should be as they go around
in the galaxy. But what's observed is something

463
00:50:27,230 --> 00:50:32,890
quite different. What's observed - and this
is work that was largely done by Vera Rubin

464
00:50:32,890 --> 00:50:38,220
back in the 50's - is that the stars in the
galaxies are actually moving to... much more

465
00:50:38,220 --> 00:50:42,230
rapidly than they should be. In other words,
they would spin apart. The galaxies should

466
00:50:42,230 --> 00:50:48,830
be spinning apart unless there's some other
matter in the galaxy that's gravitationally

467
00:50:48,830 --> 00:50:57,700
pulling them together, and holding everything
into orbit. Um, well how much of the dark

468
00:50:57,700 --> 00:51:04,160
matter is there? We know the universe has
a certain amount of matter and energy. And

469
00:51:04,160 --> 00:51:09,020
the matter and energy of the universe - we
know this from various measurements - is equivalent

470
00:51:09,020 --> 00:51:16,930
to about five hydrogen atoms per cubic meter.
Um, and the amount of ordinary matter - the

471
00:51:16,930 --> 00:51:23,160
atoms that we see - and these measurements
are... come about in a number of ways. The

472
00:51:23,160 --> 00:51:28,230
most precise comes from measuring that cosmic
microwave background - that early universe

473
00:51:28,230 --> 00:51:34,400
fireball in the sky - measuring the fluctuations
on that fireball. It turns out we can deduce

474
00:51:34,400 --> 00:51:38,930
how much ordinary matter there is, but there
are other... other ways of also getting this

475
00:51:38,930 --> 00:51:44,440
and we get a consistent picture. About five
percent of the total matter and energy of

476
00:51:44,440 --> 00:51:51,730
the universe is in the form of atoms, and
about a lot... much larger fraction has to

477
00:51:51,730 --> 00:51:58,640
be in form of dark matter. So this dark matter
that we see through the gravitational effects

478
00:51:58,640 --> 00:52:04,280
that cause the motions of stars and galaxies,
alter - and there's a lot of different measurements

479
00:52:04,280 --> 00:52:10,070

that are consistent with this - um, dominates
the ordinary matter. So yes, the universe

480
00:52:10,070 --> 00:52:15,060
is probably made much more of some mysterious
dark matter that we haven't discovered yet

481
00:52:15,060 --> 00:52:22,680
than it is of the ordinary atoms. It's quite
interesting. But notice there's a lot of black

482
00:52:22,680 --> 00:52:28,470
space here. This is not enough to make up
the known matter and energy of the universe.

483
00:52:28,470 --> 00:52:35,580
And what we have found is that there's an...
probably another uh, form of matter called

484
00:52:35,580 --> 00:52:41,830
dark en... or form of energy called dark energy.
We have no idea what it is, but we can deduce

485
00:52:41,830 --> 00:52:47,730
its existence from measurements of the expansion
of the universe. And the universe is known

486
00:52:47,730 --> 00:52:54,820
now to be accelerating in its expansion - not
just expanding, but expanding at a uh, accelerated

487
00:52:54,820 --> 00:53:01,300
rate. The amount of dark energy that's needed
to account for the kind of acceleration that

488
00:53:01,300 --> 00:53:09,530
we observe is, remarkably enough, just the
fraction that's needed to fill in this budget.

489
00:53:09,530 --> 00:53:15,160
So we have a kind of a picture of all the
matter and energy of the universe um, dominated

490
00:53:15,160 --> 00:53:23,800
by dark energy. But in the case of matter,
there's much more uh, dark matter than atoms.

491
00:53:23,800 --> 00:53:33,250
And this uh, this points out that the dark
side controls the universe. Um, actually the

492
00:53:33,250 --> 00:53:37,850
dark matter is holding the universe together
because it... all the matter pulls on all

493
00:53:37,850 --> 00:53:43,140
the other matter. And so you've got gravitational
pulls between all of this matter. The dark

494
00:53:43,140 --> 00:53:50,270
energy is actually pushing the universe apart,
and it's driving this accelerated force. We

495
00:53:50,270 --> 00:53:54,340
don't know what the dark matter is; we don't
know what the dark energy is. We know what

496
00:53:54,340 --> 00:54:01,500
their names are. The... these names are accepted.
But other than that, we don't know. Uh, and

497
00:54:01,500 --> 00:54:06,480
so maybe uh, we'll... what we're hoping is
to discover this dark matter uh, at the Large

498
00:54:06,480 --> 00:54:11,730
Hadron Collider it... when it turns on at
a higher energy. Well I just wanted to take

499
00:54:11,730 --> 00:54:17,930
a couple moments to talk about another future
project that might uh, complement the Large

500

00:54:17,930 --> 00:54:23,520
Hadron Collider in the future. This is known
as the International Linear Collider. And

501
00:54:23,520 --> 00:54:30,520
the idea here is to collide electrons and
positrons, as opposed to protons. And it turns

502
00:54:30,520 --> 00:54:35,340
out with electron and positron collider uh,
if we can build this thing, we could make

503
00:54:35,340 --> 00:54:42,430
more precise measurements of the Higgs Boson,
uh, then can be done from the Large Hadron

504
00:54:42,430 --> 00:54:48,360
Collider uh, to really narrow its properties
down and understand how it connects maybe

505
00:54:48,360 --> 00:54:52,700
to some of these dark matter and hierarchy
problem and so forth. So there's a very strong

506
00:54:52,700 --> 00:54:59,820
theoretical scientific motivation for this.
Um, there's been a very intense worldwide

507
00:54:59,820 --> 00:55:05,840
collaboration for the last decade - little
more than decade - very heavy R&D developing

508
00:55:05,840 --> 00:55:12,310
the technology that's needed for this machine.
Um, and as of now - as of this year - we're

509
00:55:12,310 --> 00:55:17,470
basically ready for construction, and there
are governmental discussions underway. There's

510
00:55:17,470 --> 00:55:24,630
particularly a very strong interest in Japan

uh, in hosting uh, this global project. And

511
00:55:24,630 --> 00:55:31,000
so um, we're hoping that we'll have another
uh, avenue to explore uh, the Higgs Boson

512
00:55:31,000 --> 00:55:37,150
just as astronomers have many different wavelengths
and ways to look at space. Um, this would

513
00:55:37,150 --> 00:55:42,290
be a complementary way to study the Higgs
Boson. Just to give you an idea... illustration

514
00:55:42,290 --> 00:55:47,070
of this... and when we collide protons in
the Large Hadron Collider we have a lot of

515
00:55:47,070 --> 00:55:53,840
different objects colliding. But when we collide
electrons and positrons um, we have just the

516
00:55:53,840 --> 00:56:00,430
electron - the positron - themself, and so
this gives us a more precise measurement.

517
00:56:00,430 --> 00:56:06,900
So I'm nearing the end of my presentation.
Let me ask the question, or uh, respond to the

518
00:56:06,900 --> 00:56:12,890
question - uh, are there any practical applications?
Because that's the question a lot of people

519
00:56:12,890 --> 00:56:20,240
often ask. And uh, I'm not going to give you
an answer to that, but what I want to do is

520
00:56:20,240 --> 00:56:28,780
remind you of what happened with J. J. Thomson.
J. J. Thomson uh, discovered the electron.

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00:56:28,780 --> 00:56:36,340
Um, and that was in 1897. He was awarded the
Nobel Prize for this great discovery. And

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00:56:36,340 --> 00:56:46,760
in 18... in 1934, 37 years later after he
discovered the electron, tremendous advances

523
00:56:46,760 --> 00:56:52,030
were made as a result of that discovery. We
don't know what is going to come in the future

524
00:56:52,030 --> 00:56:55,980
based on the work we've been doing with the
Higgs Boson. It may not be the Higgs Boson;

525
00:56:55,980 --> 00:57:01,150
it may be some of the technologies that are...
that were required to create the Higgs Boson.

526
00:57:01,150 --> 00:57:06,170
Who knows? We don't know the future. But it's
interesting to see this kind of example. This

527
00:57:06,170 --> 00:57:11,330
is one of many examples one can come up with
as to how a discovery that appears to have

528
00:57:11,330 --> 00:57:16,540
no practical applications uh, eventually does.
So I have a recording here that was made.

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00:57:16,540 --> 00:57:21,310
It's uh, on the American Institute of Physics
webpage. Um, and let's just listen to what

530
00:57:21,310 --> 00:57:32,030
he said. Could anything at first sight seem
more impractical than a body which is so small

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00:57:32,080 --> 00:57:39,880

that its mass is an insignificant fraction
of the mass of an atom of hydrogen, which

532
00:57:39,900 --> 00:57:51,400
itself is so small that a crowd of these atoms
equal in number to the population of the whole

533
00:57:51,480 --> 00:58:03,280
world would be too small to have been detected
by any means then known to science? Okay so,

534
00:58:03,290 --> 00:58:08,150
this is the summary of my talk. Uh, the Higgs
Boson discovery helps explain the mysteries

535
00:58:08,150 --> 00:58:14,270
of physics and the early universe. Um, it
was discovered in 2012 by large, international

536
00:58:14,270 --> 00:58:19,890
collaborations - uh, these two collaborations
at the LHC in Switzerland. Uh, actually I

537
00:58:19,890 --> 00:58:25,160
should say Switzerland-France border. Detailed
properties of this Boson will be measured

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00:58:25,160 --> 00:58:30,450
in more detail. The LHC will be turning on
again uh, early next year, and it will have

539
00:58:30,450 --> 00:58:35,740
uh, nearly twice the energy that it's operated
at so far - go to the full design energy or

540
00:58:35,740 --> 00:58:42,090
close to it - as close to fourteen uh, teraelectronvolts
as possible and much higher event rates. We'll

541
00:58:42,090 --> 00:58:47,530
get much better measurements of all of the
properties of the Higgs Boson. Uh, and other

542
00:58:47,530 --> 00:58:53,340
new physics will be searched for. There are
targets at physics that relates to the dark

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00:58:53,340 --> 00:58:58,050
matter question - very directly related to
that that people are involved in. Lots of

544
00:58:58,050 --> 00:59:05,080
different physics. And um, hopefully in the
future uh, it'll be joined by uh, the International

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00:59:05,080 --> 00:59:11,850
Linear Collider. Um, so let me just finish
by a couple of quotes from Einstein, which

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00:59:11,850 --> 00:59:18,600
I find particularly uh, enlightening or...
or... or inspiring. "One thing I have learned

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00:59:18,600 --> 00:59:22,730
in a long life: that all our science measured
against reality, is primitive and childlike

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00:59:22,730 --> 00:59:27,620
- and yet it is the most precious thing we
have." And he also said, "The most beautiful

549
00:59:27,620 --> 00:59:32,650
experience we can have is the mysterious.
It is the fundamental emotion which stands

550
00:59:32,650 --> 00:59:51,680
at the cradle of true art and true science."
Thank you very much. (applause) So, any questions

551
00:59:51,680 --> 01:00:02,500
for Jim? We have one here. Uh, so you mentioned
that uh, theory predicts it like a mass (inaudible)

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01:00:02,540 --> 01:00:07,480
Why isn't one of the outcomes or one of the
possibilities then that what you found isn't

553
01:00:07,500 --> 01:00:13,060
the Higgs Boson? So the question was - why
is one of the possible outcomes is that it

554
01:00:13,060 --> 01:00:19,660
is not the Higgs Boson? Um, so, really what
I... so, first of all, the properties of the

555
01:00:19,660 --> 01:00:26,090
Higgs Boson are well defined in terms of how
often it should decay into various objects.

556
01:00:26,090 --> 01:00:31,090
And so far those measurements have con...
have been consistent with what's expected

557
01:00:31,090 --> 01:00:36,260
by the theory. So for example, how often should
we see two photons? Another channel we're

558
01:00:36,260 --> 01:00:41,940
looking at are two z Bosons coming out of
the Higgs, and we see that. And the frequency

559
01:00:41,940 --> 01:00:48,070
with which we see those are very different,
but very consistent with what the theory says

560
01:00:48,070 --> 01:00:53,320
the Higgs Boson should do. So that's why it's
the Higgs Boson. Uh, nothing else would produce

561
01:00:53,320 --> 01:00:59,310
that. And also the production rates um, are
consistent with what we anticipate from the

562
01:00:59,310 --> 01:01:04,430
Higgs Boson. All of these predictions were

made as a function of the mass before it was

563
01:01:04,430 --> 01:01:08,490
discovered, so you'd say, "if its mass is
certain value, this is what we should see.

564
01:01:08,490 --> 01:01:12,050
If its mass is a different value, this is
what we see," and so forth. And so the searches

565
01:01:12,050 --> 01:01:17,010
then were done through a variety of different
areas and what... and uh, in all of these

566
01:01:17,010 --> 01:01:23,710
different possible masses, and it sh... showed
up at 126 GeV. Now, just to clarify this question

567
01:01:23,710 --> 01:01:29,640
of the mass um, there's a radiative correction
going on. We don't have a theory of the Higgs

568
01:01:29,640 --> 01:01:35,160
mass at all, really. It's just that when you
try to think about how it should be altered

569
01:01:35,160 --> 01:01:40,200
by these radiative corrections, you get a
really big number. It should really be altered

570
01:01:40,200 --> 01:01:46,960
a lot. And that's the... that's the puzzle,
is why it's not... uh, why that doesn't happen.

571
01:01:46,960 --> 01:01:53,780
So, there's a question here. Yeah. (inaudible)
I was wondering, how close to... how fast

572
01:01:53,820 --> 01:02:01,060
does the Higgs Boson (inaudible) Yeah, so
the Higgs Boson... the question was how fast

573
01:02:01,070 --> 01:02:08,590
does it decay. Yes. And it decays uh, you
know, in a very very short period of time,

574
01:02:08,590 --> 01:02:14,710
something on the order of 10^-25 seconds,
if you know what that means, or actually less

575
01:02:14,710 --> 01:02:19,830
than that. It's... it's less than that. So
it's... it's... it's not there very long at

576
01:02:19,840 --> 01:02:29,040
all. There's a question at (inaudible) As...
as I understand it uh, from your explanation

577
01:02:29,040 --> 01:02:33,700
that Higgs Boson and the Higgs Field are two
different aspects of what's essentially the

578
01:02:33,740 --> 01:02:39,980
same object. Uh, and my question is, why are
we hearing so much about the Higgs Boson and

579
01:02:39,980 --> 01:02:45,380
so little about the Higgs Field uh, in comparison
with electromagnetism when they're both very

580
01:02:45,420 --> 01:02:51,480
important? So the question is, if we have
both the Higgs Field and the Higgs Boson,

581
01:02:51,480 --> 01:02:57,470
why do we pay so much attention to the Higgs
Boson and not more to the Higgs Field. And

582
01:02:57,470 --> 01:03:02,130
the point is that the... the way we know there's
a Higgs Field, is because we've discovered

583
01:03:02,130 --> 01:03:08,300

the Higgs Boson. If we didn't... if we didn't
find the Higgs Boson, it would be pure speculation.

584
01:03:08,300 --> 01:03:13,910
But the f... the... and so the only way we
can actually um, detect that field is by creating

585
01:03:13,910 --> 01:03:19,960
this Higgs Boson and seeing it. And then we
deduce from that uh, because it has the properties

586
01:03:19,960 --> 01:03:25,660
we referred to earlier that are all consistent
with what we predicted in terms of the couplings.

587
01:03:25,660 --> 01:03:31,540
You see, the fact that it has a certain number
of decays into one final state and another...

588
01:03:31,540 --> 01:03:36,830
into another final state is directly related
to this in... interaction that it produces

589
01:03:36,830 --> 01:03:44,560
mass. It wants to decay to the heaviest objects
more prominently uh, because it couples to

590
01:03:44,560 --> 01:03:50,950
them - it interacts with them - th... as a
function of their mass. Um, so it's really...

591
01:03:50,950 --> 01:03:55,560
we're focusing on the Higgs because that's
the way we can see the Higgs Field. There's

592
01:03:55,560 --> 01:04:02,340
no other real way we see it directly. We can
only infer that it exists because of the masses

593
01:04:02,340 --> 01:04:08,900
of all the particles. But that's very indirect.
Does that seem to make some sense now? There's

594
01:04:08,920 --> 01:04:15,560
a question in the back. I had a question.
Is it clear that the mass of the Higgs Boson

595
01:04:15,640 --> 01:04:31,440
was the same as the time in the fireball?
(inaudible) Um, well I would think it would

596
01:04:31,460 --> 01:04:35,850
be. I think so, but I'm... you know, that's
uh, that's something that we could talk about.

597
01:04:35,850 --> 01:04:40,580
I'm not sure what you're... so the question
was, is it clear that the mass of the Higgs

598
01:04:40,580 --> 01:04:44,130
was the same at the time... I mean certainly
at the time of the fireball it would have

599
01:04:44,130 --> 01:04:50,570
been the same because that's actually very
late in the development of uh, the early universe.

600
01:04:50,570 --> 01:04:55,190
You know, that's hundreds of thousands of
years. I understand. So the... so during...

601
01:04:55,190 --> 01:04:59,370
at the time of the fireball, it would definitely
be the right mass. Now as you go back to you

602
01:04:59,370 --> 01:05:04,220
know, less than a second uh, certainly at
the time that we're doing these experiments

603
01:05:04,220 --> 01:05:10,640
it's there, but you know, you can go to 10^-
whatever seconds and... and I don't... I don't know.

604

01:05:10,640 --> 01:05:17,800
You might find some mysterious things
going on. Yep. Um, I was just curious about

605
01:05:17,800 --> 01:05:23,420
what drew you to particle physics to begin
with? Pardon me? Um, what drew you to this

606
01:05:23,420 --> 01:05:29,240
branch of physics as opposed to other branches?
What drew me? Yeah. Oh, what drew me to this

607
01:05:29,260 --> 01:05:34,130
branch of physics. Well I was... I was interested
in understanding the universe and to me the

608
01:05:34,130 --> 01:05:39,220
most uh, direct way to learn about that is
through the most fundamental objects of the

609
01:05:39,220 --> 01:05:43,070
universe. And those are the fundamental particles.
And that's... and that's what particles physics

610
01:05:43,070 --> 01:05:49,970
is all about. Thank you for the question.
Yeah? Will the linear collider make obsolete

611
01:05:49,970 --> 01:05:54,120
the hadron collider? No the linear collider
will not mak... so the question was, will

612
01:05:54,120 --> 01:05:58,970
the linear collider make the hadron collider
obsolete. And absolutely not. They're complementary.

613
01:05:58,970 --> 01:06:03,930
Uh, the linear collider does not reach the
same center of mass energy that the hadron

614
01:06:03,930 --> 01:06:10,050
collider reaches, for one thing. So it...

it reaches a much higher energy - that is,

615
01:06:10,050 --> 01:06:14,240
the Large Hadron Collider - than the linear
collider can reach. The advantage of the linear

616
01:06:14,240 --> 01:06:20,360
collider is in its precision. And you know,
we... we suspect there's mo... there's a

617
01:06:20,360 --> 01:06:26,080
new physics beyond just this Higgs. In
fact, one popular model is that there's five

618
01:06:26,080 --> 01:06:33,420
Higgs Bosons. And we've only found the first
one. Um, and in that model uh, (inaudible)

619
01:06:33,420 --> 01:06:38,370
goes partway towards explaining this hierarchy
problem. So we're driven by trying to figure

620
01:06:38,370 --> 01:06:43,470
out the mysteries that we haven't yet solved
and come up with solutions for that. Uh, and

621
01:06:43,470 --> 01:06:48,740
that's through supersymmetry that I referred
to earlier. If the... if there's supersymmetry

622
01:06:48,740 --> 01:06:55,180
where there's a bunch of new particles, then
there would be five Higgs Bosons. And the

623
01:06:55,180 --> 01:07:01,280
properties of the Higgs would be slightly
altered uh, in this model - slightly altered.

624
01:07:01,280 --> 01:07:05,720
So you want to make very precise measurements
of the properties of the Higgs um, even if

625
01:07:05,720 --> 01:07:10,010
you don't discover the other Bosons right
away - and you may not discover them for fifty

626
01:07:10,010 --> 01:07:15,340
years. If you can measure the properties of
the Higgs we have, you can tell whether it's

627
01:07:15,340 --> 01:07:22,960
consistent with there being just one or it's
got some slight anomaly um, that suggests,

628
01:07:22,960 --> 01:07:28,410
for example, where those other Higgs Bosons
are that could guide our future research.

629
01:07:28,410 --> 01:07:33,680
So that's part of the motivation for the International
Linear Collider. Um, there are other technical

630
01:07:33,680 --> 01:07:38,630
details, but it certainly is complementary.
It does not surpass the energy reach of the

631
01:07:38,630 --> 01:07:44,230
Large Hadron Collider. Yeah? Does Higgs Boson
have to do with the inertia, because I saw

632
01:07:44,230 --> 01:07:48,470
in your animation that you know, it's... some
of them are the like... the light particles

633
01:07:48,470 --> 01:07:52,580
just went through and the other particles
slowed down? Yeah so what that's kind of...

634
01:07:52,590 --> 01:07:57,790
that's a cartoon; that's not the real world.
So the question had to do with, on this cartoon

635
01:07:57,790 --> 01:08:03,400

where the particles slow down. What that's
illustrating is when... if at a particular

636
01:08:03,400 --> 01:08:10,890
energy the velocity of a particle depends
on its mass. If it has no mass, it will travel

637
01:08:10,890 --> 01:08:17,369
at the speed of light. As it has more and
more mass, it travels at a lower speed at

638
01:08:17,369 --> 01:08:24,769
a given energy. And so, if it interacts with
this Higgs Field and acquires mass at a given

639
01:08:24,769 --> 01:08:31,829
energy, it will have a lower velocity. That's
what that's illustrating. (inaudible) question.

640
01:08:31,829 --> 01:08:38,700
So if you have a 10^-25 second lifetime - or
less, or less really - or less, would... wouldn't

641
01:08:38,710 --> 01:08:42,969
Heisenberg say there's a certain uncertainty
then in the energy - yes - corresponding to

642
01:08:42,969 --> 01:08:48,489
that - yes - and is that a small part or a
large part of this 126 GeV. So the... what

643
01:08:48,489 --> 01:08:54,109
we... we... we li... so the question was having
to do with the uncertainty in the mass of

644
01:08:54,109 --> 01:09:02,679
the particle. And uh, we... we've... we anticipate
the uncertainty to be about four MeV - four

645
01:09:02,679 --> 01:09:09,549
million electron volts - compared to 126 billion
electron volts. So it's... it's... and um,

646
01:09:09,549 --> 01:09:15,599
we're... we're... we're going to have to measure
that at some point, but it's not easy to measure.

647
01:09:15,599 --> 01:09:25,619
(inaudible) there's a question. So you're
talking about the... the time after the Big

648
01:09:25,620 --> 01:09:32,020
Bang and if I understood you correctly you said that all particles
initially uh, were massless and

649
01:09:32,020 --> 01:09:36,860
then they eventually uh, as the universe cooled,
came to interact with the Higgs Boson and

650
01:09:36,860 --> 01:09:43,859
gained mass, is that part correct? That's
right. That's what... that's what uh, generally

651
01:09:43,859 --> 01:09:47,539
people think in terms of... you know, nobody
was there so. Okay, well... well if you...

652
01:09:47,540 --> 01:09:51,760
if you accept that and continue that train
of thought and you take the absolute zero,

653
01:09:51,760 --> 01:10:01,360
does that imply then that uh, particles become
super massive as it cools. Is there a measurable

654
01:10:01,360 --> 01:10:07,800
change in mass (inaudible) temperature? I
don't uh... so I don't quite understand your

655
01:10:07,809 --> 01:10:10,940
question, maybe we should talk about that
afterwards... I. Alright. Yeah, I don't...

656

01:10:10,940 --> 01:10:17,660
I don't... I don't see the thrust of it,
I'm sorry. Sure, that's fine. Yeah. Do...

657
01:10:17,660 --> 01:10:26,760
do we have more questions? Yeah, here. Is
there a reason why photons don't react (inaudible)

658
01:10:26,760 --> 01:10:31,730
So this is a very interesting point. Um, the
question had to do with the interaction of

659
01:10:31,730 --> 01:10:40,260
the photons with the Higgs Boson. And um,
remember particles acquire mass by their interaction

660
01:10:40,260 --> 01:10:47,070
with the Higgs Boson. And in the... in the
um, in the theory, you write down the equations

661
01:10:47,070 --> 01:10:52,460
for the Higgs Field - the Higgs Potential
- and miraculously the mass term for the photon

662
01:10:52,460 --> 01:10:58,769
disappears - it goes away. So that means the
mass is zero in the theory. So then you should

663
01:10:58,769 --> 01:11:04,119
ask, "well if that's the case, how come the
Higgs decays to photons? Because it doesn't

664
01:11:04,119 --> 01:11:11,030
interact with the photons so why does it decay
to photons?" You want to ask that? (laugh)

665
01:11:11,030 --> 01:11:16,429
And... and the answer is, it's through a loop
diagram where the Higgs couples to two top

666
01:11:16,429 --> 01:11:19,619
quarks. Now the Higgs cannot decay to two

top quarks because the top quarks are too

667
01:11:19,619 --> 01:11:25,579
heavy, but it can make, through this Heisenberg
uncertainty principle, it can make two - a

668
01:11:25,579 --> 01:11:32,320
top-anti-top pair - which then both emit...
then emits two photons and then reannihilates

669
01:11:32,320 --> 01:11:36,880
the t... the top-anti-top pair can reannihilate.
So you... you have a Higgs going along. It

670
01:11:36,880 --> 01:11:42,530
makes a top-anti-top pair. They emit two photons,
and then these tops go away. That's... Heisenberg

671
01:11:42,530 --> 01:11:47,090
says you can do that for a short period of
time. You can have those tops in there. The

672
01:11:47,090 --> 01:11:52,619
tops are charged, so they... they emit photons.
So it's a... it's a what we call a higher

673
01:11:52,619 --> 01:11:58,940
order uh, process. It's not a direct coupling
of the Higgs to the photon, but it's indirect.

674
01:11:58,940 --> 01:12:05,019
And that's why we see very few Higgs decaying
to two photons because it has to go through

675
01:12:05,019 --> 01:12:16,720
this stage where these uh, top quarks are
there. Does that make sense? Do you have more

676
01:12:16,720 --> 01:12:24,640
questions? Oh yeah. I was wondering do you
have an idea where the location of this um,

677
01:12:24,640 --> 01:12:30,599
(inaudible) The International Linear Collider...
so the question had to do with the location

678
01:12:30,599 --> 01:12:38,110
of the International Linear Collider. And
um, the current best prospect for this is

679
01:12:38,110 --> 01:12:45,699
uh, north... northern part of Japan. The
Japanese uh, have been uh, studying various

680
01:12:45,699 --> 01:12:52,409
possible locations. There uh, there's a lot
of support in Japan to host a global project

681
01:12:52,409 --> 01:13:00,389
like this. And they have chosen a sight uh,
in a hilly area that's - I've visited there

682
01:13:00,389 --> 01:13:07,440
actually - in the northern part of Japan to
be the... to be their preferred site. So it's

683
01:13:07,440 --> 01:13:12,420
uh, early yet in the discussions about whether
this can be realized, but that's the best

684
01:13:12,420 --> 01:13:19,880
chance right... right now. Uh, and - (inaudible)
- well this is... so this is embedded in solid

685
01:13:19,880 --> 01:13:27,139
uh, rock basically, underground, and there's
seismic effects that um, have been measured

686
01:13:27,139 --> 01:13:34,559
and studied and uh, they are... have to be
dealt with, but it's not... it's not a showstopper;

687
01:13:34,559 --> 01:13:40,489

they're acceptable. So that's all been studied
very carefully. Um, but you ask about the

688
01:13:40,489 --> 01:13:44,400
time frame for it as well, and uh, that's
very hard to predict. I mean, the biggest

689
01:13:44,400 --> 01:13:49,400
question is, how long does it actually take
to get it approved? That's at least a few

690
01:13:49,400 --> 01:13:57,000
years. And then to construct is uh, a good
fraction of a decade to actually get it constructed.

691
01:13:57,000 --> 01:14:02,340
So it's going to be at least a decade before
you could have collisions uh, in this... in

692
01:14:02,340 --> 01:14:08,180
this... and that's optimistic; it'd be a little
bit more than that, optimistically. Yep. So

693
01:14:08,180 --> 01:14:13,300
we talked about fields uh, which is the gravity,
there's the electromagnetic fields. Those

694
01:14:13,300 --> 01:14:18,940
come from particles. If the Higgs Boson decays
so quickly, then where does the Higgs Boson

695
01:14:18,960 --> 01:14:27,269
Field come from? Well the... the... so the
Hi... as I s... so in the case of the Higgs

696
01:14:27,269 --> 01:14:32,300
Field, the way I think of it is it's... the
source of the Higgs Field is the universe

697
01:14:32,300 --> 01:14:38,630
itself. Um, and that's where the... the Higgs
Field is just there. It's part of the vacuum

698
01:14:38,630 --> 01:14:44,239
of the universe. And the Higgs particles that
are produced are popping out of this field,

699
01:14:44,239 --> 01:14:49,989
but it... the field stays there all the time.
It's embedded in the universe. And it doesn't

700
01:14:49,989 --> 01:14:54,449
require you have - like in when you have gravity,
you require to have some mass that creates

701
01:14:54,449 --> 01:14:59,820
this field around the mass. It doesn't require
that; it requires the universe to have...

702
01:14:59,820 --> 01:15:15,159
to have a field. Okay. Yep, back there. So
essentially (inaudible) Well I... actually

703
01:15:15,159 --> 01:15:20,150
you know what? I think it's a little longer
than that, but it's in that range, okay. The...

704
01:15:20,150 --> 01:15:31,310
so the... the lifetime is less than 10^-20
seconds. It's short. That's the point. (inaudible)

705
01:15:31,310 --> 01:15:44,760
Boson is supposed to be (inaudible) 10^-10 (inaudible)
The... something is 10^-10? (inaudible) Oh.

706
01:15:44,760 --> 01:15:52,119
So the... the Large Hadron Collider is recreating
collisions that were common at the epic of

707
01:15:52,119 --> 01:16:00,550
10^-10 seconds after the Big Bang. Okay? So
the energies of these collisions, which are

708

01:16:00,550 --> 01:16:07,820
a design. There's seven trillion electron
volts colliding at 10^-10 seconds after the

709
01:16:07,820 --> 01:16:12,639
Big Bang. That was kind of the typical energy
of the universe, and these collisions were

710
01:16:12,639 --> 01:16:17,530
very common and so there would have been Higgs
Bosons being produced all the time. But they

711
01:16:17,530 --> 01:16:20,679
would decay away right away, but they'd be
produced all the time in these collisions

712
01:16:20,679 --> 01:16:38,159
in the early universe. Does that... does that
answer your question? (inaudible) Well if

713
01:16:38,180 --> 01:16:43,119
you... they can appear if you make a high
enough energy collision, you can produce a

714
01:16:43,119 --> 01:16:49,969
Higgs Boson. Um, you have to convert... you'd...
you'd... basically using Einstein's E = mc^2.

715
01:16:49,969 --> 01:17:02,249
You're taking energy and you're... and you're
making uh, particles. (inaudible) Well, yeah.

716
01:17:02,260 --> 01:17:07,340
If... if you have collisions you... you can
produce uh, you know, any... any particle

717
01:17:07,340 --> 01:17:12,010
that has uh, a mass that's less than the energy
of the collision. It's a... the real challenge

718
01:17:12,010 --> 01:17:16,639
is how often do you do that? And in the case

of the Large Hadron Collider, they're not

719
01:17:16,639 --> 01:17:22,940
producing very many of these particle. They're
very hard to find. It takes a lot of collisions,

720
01:17:22,940 --> 01:17:26,150
and there's a lot of other things - and you
saw that distribution with the background

721
01:17:26,150 --> 01:17:30,360
there - a lot of things that um, look... you
know, if you don't have statistics to build

722
01:17:30,360 --> 01:17:35,389
up to see there's a... some small excess. You...
you'd never be able to pick out a single one.

723
01:17:35,389 --> 01:17:40,400
We can't tell in a given single event that
this is a Higgs Boson because there... for

724
01:17:40,400 --> 01:17:47,159
every Higgs Boson, there are far more, in
that same mass region, that are not Higgs

725
01:17:47,159 --> 01:17:55,199
Bosons. They're just random fluctuations.
Yep there's a... Did you say that the uh,

726
01:17:55,200 --> 01:18:00,360
collisions are occurring at two
degrees Kelvin? No what I said was the

727
01:18:00,360 --> 01:18:07,369
magnets that store... that store the beams...
so the beam is being circulating in this

728
01:18:07,369 --> 01:18:13,889
ring, and it's being brought around by a magnetic
field that's created by magnets. And those

729
01:18:13,889 --> 01:18:20,230
magnets are superconducting magnets. That
means there's currents in the magnets that

730
01:18:20,230 --> 01:18:26,550
create a magnetic field - electron currents
in the magnets. And those magnets are held

731
01:18:26,550 --> 01:18:31,820
at two degrees. That's how you get a superconductor
is to lower the temperature of the magnets

732
01:18:31,820 --> 01:18:38,699
down to... down to a very low temperature.
And then the resistance in the... in the coils

733
01:18:38,699 --> 01:18:43,340
in this... in these magnets uh, disappear
and you get a uh, you get a superconducting

734
01:18:43,340 --> 01:18:50,520
capability. And that's how you can achieve
a very large field. I've just got kind of

735
01:18:50,520 --> 01:18:56,760
a... it's a simple question, but it's like
whenever you do an ex... a scientific experiment

736
01:18:56,760 --> 01:19:08,420
(inaudible) you want to get consistent results all the time. Why are
we getting so - I mean so many things can happen (inaudible) where
you collide these two uh, you know, these

737
01:19:08,420 --> 01:19:15,600
two together - but, why are we getting such
variety in the results? You mean why don't

738
01:19:15,610 --> 01:19:22,550
we produce a Higgs every time? Yeah, or...
or (inaudible) Okay, so the question is,

739

01:19:22,550 --> 01:19:26,480
why is there so much variety in the results.
And this is a very fundamental principle of

740
01:19:26,480 --> 01:19:33,550
quantum mechanics. Quantum mechanics says
you can have a whole bunch of different possibilities

741
01:19:33,550 --> 01:19:39,869
and ther.... the outcomes of all those different
possibilities is totally random. Um, you...

742
01:19:39,869 --> 01:19:44,900
you can't... in any give incident you can't
predict which one of the possible outcomes

743
01:19:44,900 --> 01:19:51,199
you're going to get. It's just random. That's
a fundamental principle in quantum mechanics.

744
01:19:51,199 --> 01:19:54,519
And so if you repeat the same thing over and
over again and there's several possible outcomes

745
01:19:54,519 --> 01:19:59,230
uh, quantum mechanics says you... you... you're
probably going to get a different set of outcomes

746
01:19:59,230 --> 01:20:06,699
from... from the set. And... and we... and
what quantum mechanics says is, there's no

747
01:20:06,699 --> 01:20:11,840
variable or hidden variable inside the system
that would allow you to predict which outcome

748
01:20:11,840 --> 01:20:16,900
comes. It's just fundamental and quantum mechanics
that is completely random and the... and nothing...

749
01:20:16,900 --> 01:20:23,999
nothing can predict it. Do we... yeah? Uh,

you explained very well why the Higgs Boson

750
01:20:23,999 --> 01:20:30,269
is so important. Why is it that it's been
called the "god particle?" Could you explain...

751
01:20:30,269 --> 01:20:36,300
explain that? Well I've heard this story about how...
why it was called the "god particle." And

752
01:20:36,300 --> 01:20:43,269
the story I heard uh, has a certain obscenity
to it, so I'll try to clean it up a little

753
01:20:43,269 --> 01:20:52,969
bit. But uh, as Leon Lederman uh, wrote
a book about um, particle physics, and he

754
01:20:52,969 --> 01:20:59,210
referred to this things as the "God-darned
particle." He didn't say, "God-darned." Uh,

755
01:20:59,210 --> 01:21:04,349
because it was so hard to find and it was
costing so much money to find it - it was

756
01:21:04,349 --> 01:21:09,710
really important to find it - and
this is a "God-darned particle." Well, so

757
01:21:09,710 --> 01:21:13,659
he proposed, apparently - this is again a
story I just heard - to the publisher that

758
01:21:13,659 --> 01:21:18,219
they should title the book that way. And the
publisher didn't think that was a good idea,

759
01:21:18,219 --> 01:21:22,380
but they thought "well we can refer to it
as the God particle." And so his book is called

760
01:21:22,380 --> 01:21:28,280
The God Particle, and that... and that stuck.
It... it... it... it was not for the reason

761
01:21:28,280 --> 01:21:31,889
that a lot of people think of it is - something
having to do with religious or early universe

762
01:21:31,889 --> 01:21:35,989
or creation or anything like that. It was
basically because - the story I heard - is

763
01:21:35,989 --> 01:21:42,599
because this thing was causing so much trouble
trying to find it. That's the story I heard,

764
01:21:42,599 --> 01:21:49,439
so. Yeah? Uh, how many (inaudible)
um, Higgs Bosons were created at the Big Bang

765
01:21:49,440 --> 01:21:55,560
or close to it? Are there any more being created,
and, I... I know in Large Hadron Collider

766
01:21:55,560 --> 01:21:59,800
they are, but um, also is there any place
else in the universe where they're being created?

767
01:21:59,800 --> 01:22:04,200
Yeah. What's the density of them? Well, okay,
so the question was, are they... can they

768
01:22:04,210 --> 01:22:08,909
be created and what's the density of them.
The density is nothing, basically. I mean

769
01:22:08,909 --> 01:22:14,300
it's... but in... in natural occurring cosmic
ray interactions, you know, there are very

770
01:22:14,300 --> 01:22:20,400

high energy cosmic rays. There's a spectrum
of cosmic rays bombarding the Earth. Um, most

771
01:22:20,400 --> 01:22:25,219
of them aren't energetic enough to create
a Higgs Boson, but occasionally we... there

772
01:22:25,219 --> 01:22:30,489
is one, and it can create a Higgs Boson. It...
it's going to be very rare because even if

773
01:22:30,489 --> 01:22:34,710
you get a collision it's not very likely to
make one, but you can make them naturally.

774
01:22:34,710 --> 01:22:38,900
But they're not going to last long enough
to be of any relevance, right? They're going

775
01:22:38,900 --> 01:22:43,550
to... and... and searching for them through
that kind of a natural uh, source would be

776
01:22:43,550 --> 01:22:48,849
hopeless. Well I... I thought they were everywhere,
like a big ocean of them, and that's what...

777
01:22:48,849 --> 01:22:52,929
Well there are virtual... there are virtual
Higgs particles everywhere. So there's this

778
01:22:52,929 --> 01:23:00,179
field and as particles exist, the other particles
- the fundamental particles - they're interacting

779
01:23:00,179 --> 01:23:05,139
to... with this field through these virtual
particles. By virtual I mean that they're

780
01:23:05,139 --> 01:23:12,219
not real Higgs Bosons; they're just instantaneous
interactions to the field. And that's where

781
01:23:12,219 --> 01:23:17,860
we think the mass comes from - through these
virtual interactions. So... so they... they

782
01:23:17,860 --> 01:23:24,010
do exist in that sense. The field is the source
of... of emitting these things, the same way

783
01:23:24,010 --> 01:23:31,449
that in the atom you have the nucleus, which
is positively charged, and you have the electron,

784
01:23:31,449 --> 01:23:36,030
negatively charged, and there are virtual
photons being exchanged, which keeps the electron

785
01:23:36,030 --> 01:23:44,090
in orbit in the atom. You have virtual photons
um, that create that interaction. And so in

786
01:23:44,090 --> 01:23:50,030
the same sense you have virtual Higgs Bosons
interacting out of this field to give source

787
01:23:50,030 --> 01:23:56,079
to the mass of the particles. And... and this
field gives other matter (inaudible) inertia?

788
01:23:56,079 --> 01:24:01,840
(inaudible) Well it... it gives it its fundamental
mass, which then leads to um, to what you're

789
01:24:01,840 --> 01:24:06,679
talking about. So, you know, the mass of the
top quark is as large as it is because it

790
01:24:06,679 --> 01:24:11,899
interacts very strongly with the... with these
virtual Higgs Bosons that are coming out of

791

01:24:11,900 --> 01:24:20,500
the field. Give me one last question there.
Um, has it been (inaudible) or is it possible

792
01:24:20,500 --> 01:24:27,420
that the Higgs Boson can emit something other
than photons? So the question was, is it possible

793
01:24:27,429 --> 01:24:34,499
the Higgs Boson could decay into other things
besides photons, and the answer is yes. It

794
01:24:34,499 --> 01:24:40,809
decays very strongly into the bottom quarks
um, because the bottom quarks are the heaviest

795
01:24:40,809 --> 01:24:50,329
quarks that it can decay to. Um, it decays
very strongly into um, z particles with uh,

796
01:24:50,329 --> 01:24:57,800
vir... two z particles, one real and one virtual.
Um, it decays strongly into w particles. It

797
01:24:57,800 --> 01:25:03,489
decays into charms, talk... uh, taus. So it
decays into lots of things. And... but the

798
01:25:03,489 --> 01:25:10,980
strategy for finding it at the Large Hadron
Collider was to assess the uh, interfering

799
01:25:10,980 --> 01:25:16,289
signals from all the kind of things that can
happen. And it turns out that looking for

800
01:25:16,289 --> 01:25:20,280
them in the two photons do... despite the
fact that you're looking for a little blip

801
01:25:20,280 --> 01:25:25,789
on top of a large background, compared to

every other way of looking for them was um,

802
01:25:25,789 --> 01:25:31,639
was one of the most strongest ways to find
it. Okay. Okay, once again thank you all for

803
01:25:31,639 --> 01:25:34,349
coming. (applause) Thank... thank you all.
Thank you.