

better done than said

Chip
Ray and Brock
Department of Physics and Astronomy

How the discovery of a Higgs-like Boson changes everything

it's a living.

BIG

small

COSMOLOGY

particle physicist

I'm an elementary particle physicist

our questions are about the **BIGGEST...**

COSMOLOGY

particle physicist

we know a lot!

"In baseball, you don't know nothing"

things like:

- What is the Nature of Space...are there more than 3 dimensions?
- What is the Nature of Time?
- Did the Universe have a beginning and will it end?
- What is Nothing?
- What is something Higgs?
- What was the Nature of the Early Universe?
- What is the Nature of Gravity?
- How many Fundamental Forces are there?
- How many Fundamental Particles are there?
- What is Dark Matter?
- Where is all of the Antimatter?
- Can the Proton Decay?

our paradigms

nature is clumpy

big questions

Our paradigm

Big tools

Big Discovery

Large future

theoretical commitments 3

energy particular bundles

"quanta" particles

I'm an elementary particle physicist

GOT PARTS!

the rest of matter is also clumpy

"Elementary"? no parts

I'm an elementary particle physicist

NO PARTS

100's of elementary particles

what's so "elementary" about that?

a few tiny bits quarks

all of normal matter: 2 quarks & electrons

NO PARTS

this works. normal matter is quarks

a proton is a bag 'o quarks

"quarks"

GOT PARTS!

elementary:

"It's like deja vu all over again."

up charm top
down strange bottom

12 elementary particles
"families"

electric charges:
 $Q = 0e$ (neutrinos)
 $Q = -1e$ (leptons)
 $Q = 2/3e$ (up quarks)
 $Q = -1/3e$ (down quarks)

this works.
all matter is quarks
or is it?

nature is not clumpy

lots of everyday forces

Gravitational

lots of everyday forces

Magnetic
Electric

lots of everyday forces

Magnetic
Electric
electromagnetic

If there's a force

there's a field:
gravitational field
electric field
magnetic field

Fields convey forces

Quantum Mechanics says

if there's a field: there's a particle

Feynman Diagrams

pictorial story of a reaction
complicated mathematical algorithm

Feynman Diagram for a hydrogen atom

messenger particles: the Photon

an atom: electric fields

electric fields

"messenger" particles: the Photon

are actually, particles

hydrogen atom for a hydrogen atom

4 forces

3* sets of messenger particles

* For gravity? We've not got a clue.

"strong force" very strong

messenger particle: "gluon"

"weak force" very weak...

nature is clumpy
and
nature is not clumpy

an aside on our schizophrenia about theories

1. just tools
2. a real description of the world

up quarks are forever
down quarks: notso much

neutron beta decay

4 forces messenger particles

"strong" "gluon" g
electromagnetic "photon" γ
"weak" "weak bosons" W and Z
gravitational "graviton" ?

only tools view:

...just instructions on how to predict outcomes

realism view:

the prescription is Relativistic Quantum Field Theory

what's a particle? a jiggling of one of those Ur fields

realism view?

electron field
photon field
quark field
whatever field

let's take the second path
treat our theories as real
what does our mathematics tell us?

the Vacuum contains the primordial electron field

"Ur"-electron field

Vacuum is complicated!

"Ur"-electron field

The mathematics says: electrons are created and annihilated

an actual void? ...a state of no particles?

no excitations

so how're you liking realism so far?

~~seriously, does this make sense?~~
does this work.

electron magnetism

from evaluating diagrams

a tiny correction ~ 0.001

"Quantum Electrodynamics"

4th order is complete

(1.0 - Full Theory):
 0.0011596521278 ± 772

Experiment:
 0.0011596521085 ± 74

the players

in our universe, circa June, 2012

	quarks	leptons	bosons	fermions	matter
up	u	e	g	q	✓
down	d	μ	g	q	✓
charm	c	τ	g	q	✓
strange	s	ν_e	g	q	✓
top	t	ν_μ	g	q	✓
bottom	b	ν_τ	g	q	✓
photon			γ		✓
gluon			g		✓
W boson			W		✓
Z boson			Z		✓
Higgs boson			H		✓

the most precise theory in the history of science

theoretical industry

For the "third order"

- so far:
1. matter = elementary particles, 6 quarks and 6 "electrons"
 2. quantum fields propagate forces
 3. fields are everywhere and everytime - source of particles
 4. the vacuum is full of fields which have no value by themselves
 5. QFT works! ...but weird.

mass is energy

we're confused about mass.

"stuff"

"I always thought that record would stand until it was broken."

~~2~~



TODAY ONLY!

$$E = mc^2$$

$$E = \cancel{m}c^2$$

mass is just trapped energy

money is money: $\$ = \text{€} \times 1.31$
a number

energy is mass: $E = mc^2$
 $E = m \times 9 \times 10^{16}$
a number



Field Energy

especially vexing

Energy

lots of pent-up energy in a 100g apple

Motion energy = 1 Joule

$E = mc^2 = (0.1)(3 \times 10^8)^2$
Mass energy = 9,000,000,000,000,000 Joules!!



gluon field energy

accounts for the inertia of a proton

$m = \frac{E}{c^2}$

why?

173 proton mass

quarks, leptons, Bosons

a tally

mass scale in units of protons

a tally

everything is the same size

a tally

this is how it should be

two models

a tally

this randomness is insulting!

a completely symmetric mass arrangement makes most sense

stay tuned

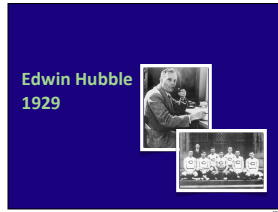
let's talk about the

BIG

Big Bang invented: 1929 confirmed: 1965 evolved: this decade?



the universe is expanding



Georges Lemaître 1931

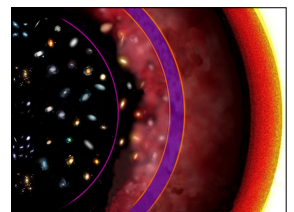
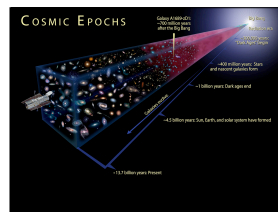


“ We can compare space-time to an open, conic cup. The bottom of the cup is the origin of atomic disintegration; it is the first instant at the bottom of space-time, the now which has no yesterday because, yesterday, there was no space. ”

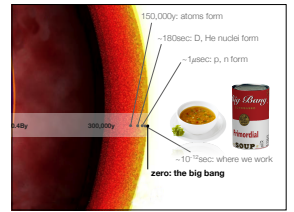
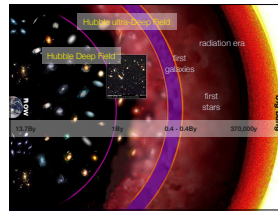
George Lemaître, The Primeval Atom

“ Big Bang cosmology is a form of religious Fundamentalism Big Bang cosmology refers to an epoch that cannot be reached from any form of astronomy... ”

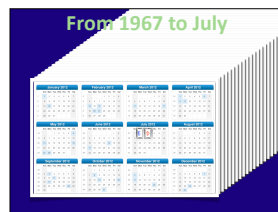
Fred Hoyle Home is Where the Wind Blows 1994.



“Standard Model” of cosmology incredibly precise

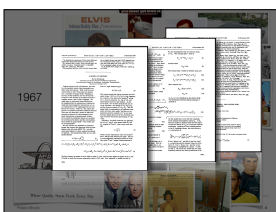
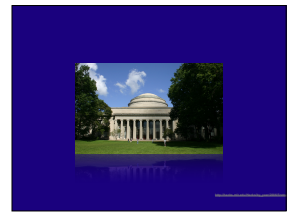


let's talk about the small

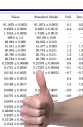


Standard Model of particle physics invented: 1967 confirmed: 4 months ago evolved: this or next decade

Standard Model standard [ˈstændərd] noun 1. a level of quality or attainment model [ˈmɒdl] noun 2. a simplified description, esp. a mathematical one, of a system or process, to assist calculations and predictions



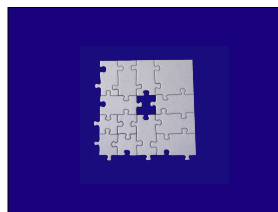
The most precise theory in the history of physics



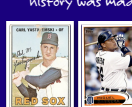
1967 - 2012 history was made



“ Ninety percent of this game is half mental. ”



1967 - 2012 history was made



a special idea about mass replacing old ideas

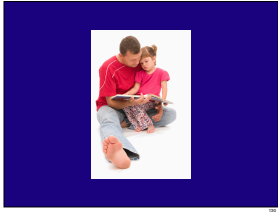


like!
The Higgs Boson
is what the fuss is
all about

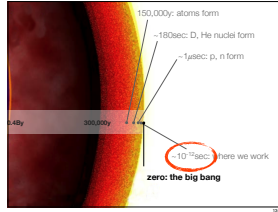


the plot
takes place in the
vacuum

picosec after the big bang
universe condensed.



about nothing



this created a
new force

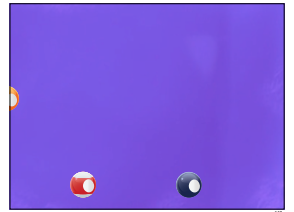
remember:
if there's
a force
there's a field

Higgs Field
is non-zero

this Ur-field has a "charge"
that's
everywhere

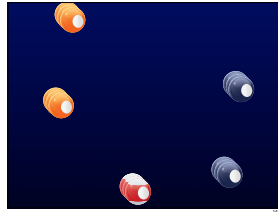
treat it like a mist
of paint

the more it's painted, the
slower it goes



vacuum had empty fields
now it's full of
Higgs Fields

treat it like a mist
of paint



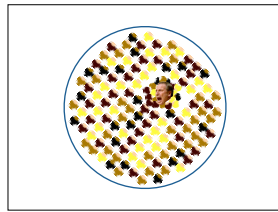
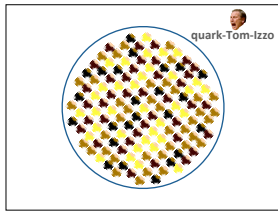
masses of everything
depend on the particle

a light particle...

a heavy particle...

a Higgs
metaphor

the crowd: Higgs Field



quark-Tom-Izzo has mass.

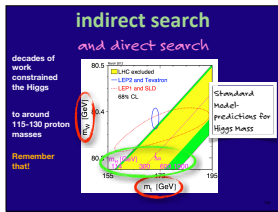
loud

popular

quark-Tom-Izzo has gained inertia

mass was born
in the Higgs Field

Higgs Boson



“ You can observe a lot
just by watching.”

how?
 $E = mc^2$

find the Higgs
particle confirmation of
the process

Big tools
Big accelerators,
Big Collaborations, and
Big detectors

particle
colliders to create energy
ready to clump

High Energy

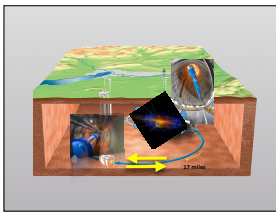
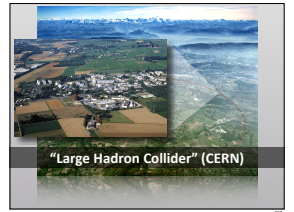
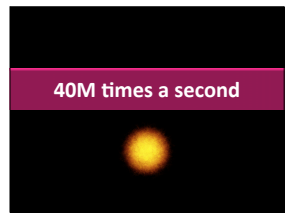
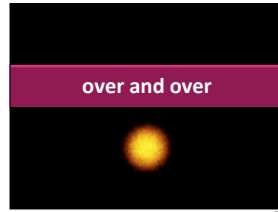
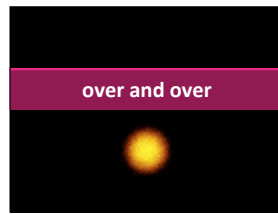
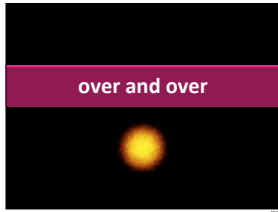
the Large Hadron Collider - a proton collider

FRANCE SWITZERLAND

200 bunches of protons
100,000,000,000 protons per bunch

$$E = mc^2$$

the cosmos performed the first particle experiment once



Large Hadron Collider

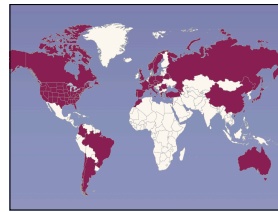
who: 3000 of my closest friends ATLAS collaboration 15 years

2 experiments each of comparable size

MSU's LHC experiment

ATLAS: 2007 production, 170 universities and labs, 74 countries, 3000 Ph.D. physicists, 40 universities

CMS: 2007 production, 170 universities, 40 countries, 3000 students, 40 universities



Higgs discovery author list

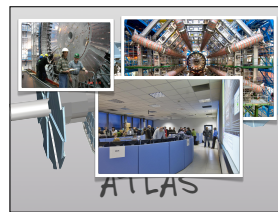
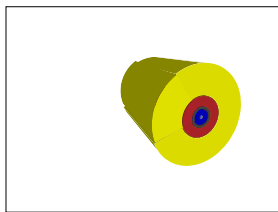
The Higgs discovery paper author list

MSU particle physics

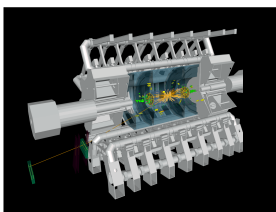
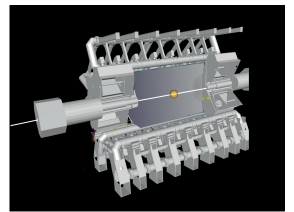
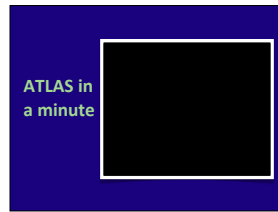
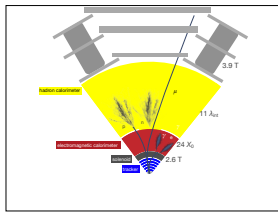
MSU's LHC personnel

Faculty	Research Associates	Grad Students	UG Students
James Ball	Matthew Bevilacqua	Andrew Brundage	Shahabuddin
Chris Bunker	Chris Bunker	Michael DeGroot	Michael DeGroot
...
Technical			Engineers
...

©2009-2010 MSU
* associated, ** associated at CERN, *** resident at Fermilab



particle detector ATLAS

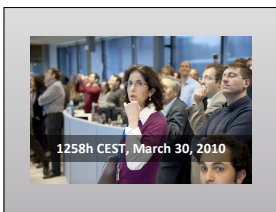
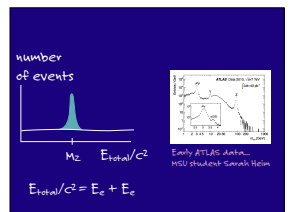


Big Discovery July 4, 2012

no...it lives only 10^{-22} seconds

create the particles in collisions

Have to look for the Higgs by putting together its decay products with the tee shirt equation



how to find the Higgs? look for him!

mass and energy let's call it the Z

start out with: M_Z so $E_Z = M_Z c^2$

end up with: E_e two of them

add them up and calculate E_{total}/c^2

Higgs is related to mass

it's birthright is mass

it couples to matter in proportion to mass

the heaviest particles we knew how.

This chart shows the masses of various particles. The Higgs boson is highlighted with a red circle and the text "Higgs boson mass is known!".

basically 2 ways for Higgs to show itself

About 400 Higgs Bosons per hour

where q should be top quarks or bottom quarks

many events every 50 ns electronically sift through chaff

number of all events per second: 1,000,000,000
number of Higgs Boson events per second: 0.1

same event in a cartoon detector view

4 ways to produce Higgs Bosons

"gluon fusion"

basically 2 ways to see the Higgs - low background

add up all of the energies and get a bump at the Higgs particle mass...if it exists

1 event every hour
1 event every half-day

putting it together in Feynman language: "gluon fusion to ZZ to ee mu mu"

same event but a real-life this time

candidate event

low background

ZZ few events so far but seen in both experiments



the problem is backgrounds

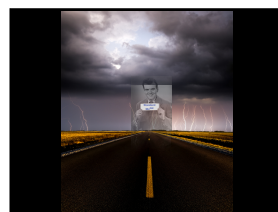
"You've got to be very careful if you don't know where you are going because you might not get there."

two photons but seen in both experiments



the current results using a "five standard deviation" requirement for discovery

with slightly improved results



huge hint using Feynman's rules

there has to be more beyond the Standard Model

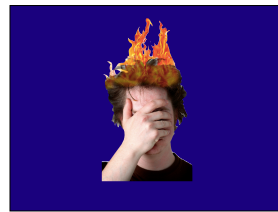
the Higgs mass should be 10¹⁴ proton masses yet the Higgs mass is 126 proton masses

We've known this for decades!

Physicists did not use the phrase: Discovery of THE Higgs Boson. The DG did.

You'll know us carefully talk about the "Discovery of the Higgs-like boson"

Large Future 2020 and beyond



"Beyond the Standard Model"

30 year Theoretical Physics Industry

"I never said most of the things I said."

where's the anti-matter?

natural antimatter? anywhere...?

O, nada, zilch, none

Beyond Standard Model

there are well know "issues"

particles

why? Dunno.

galaxies should not hang together
luminous matter insufficient
DARK MATTER

but, nature is clumpy

dark ma

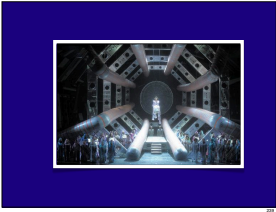
why? Dunno.

gotta be new particles

what's next?
we go down in March
back in 2015 - double the energy
run for 2 years
then down for higher intensity beams
significant upgrades

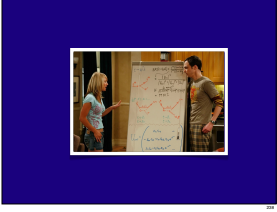
pretty:

astonishingly
The world followed the Higgs
Boson saga
that's a big responsibility



We now expect deviations from the naive Standard Model

study the Higgs hard
search for additional particles



I know



DARK MATTER

nature is clumpy

we're tired of it too

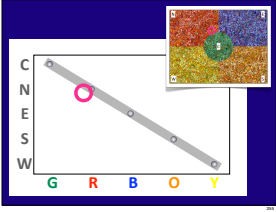
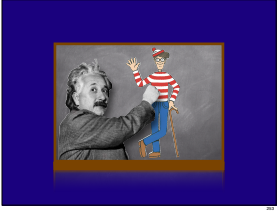


nature is clumpy

the further away
the younger a snapshot appears

loops
the rules say:

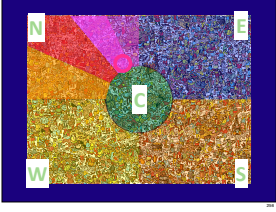
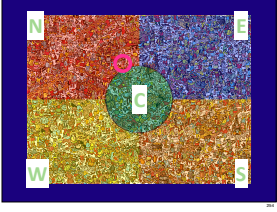
make a prediction for γ and look for its effects as deviations



why? to test the theory in an extreme limit
the loops can contain surprises

LANDFEND

FREE SHIPPING with 100 particles. On this page, you can see the results of the experiment.



event rates are staggering

