What is stuff made of?
Greg Kestin

Search for the Higgs Boson
Laura Jeanty

Dark matter
Brian Clark
• What is stuff made of?
• How do we see small things?
• What do we know about?
• What don’t we know?

» Brian and Laura
Outline

• What is stuff made of?
• How do we see small things?
• What do we know about?
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» Brian and Laura
What is Stuff Made of??
What is Stuff Made of??

A

B

C

D

Earth, Wind, Water, Fire
But, what are atoms made of?

- Electrons
- Protons
- Neutrons
But, what are electrons made of?
And protons...?
What is stuff made of?

quarks

+2/3

-1/3

electrons

Is there more?
Outline

• What is stuff made of?
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» Brian and Laura
Can we use a microscope?

- The best microscope:
  - Can see an atom
  - Can’t see inside an atom
What are Golf Balls Made of?
Seeing what golf balls are made of...
Seeing what protons are made of...

What flies into detectors?

A lot of Particles!

But most of the other particles are made of quarks!

Are there particles they can’t see?
Yes! Imagine short lived particles.
• What is stuff made of?
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What is stuff made of?

Is there more?

YES!

quarks

+2/3

-1/3

electrons

-
Actual plots and physics of blowing up cross-sections

Standard Model

Quarks
- u (up) charge +2/3, spin 1/2
- c (charm) charge +2/3, spin 1/2
- t (top) charge +2/3, spin 1/2
- d (down) charge -1/3, spin 1/2
- s (strange) charge -1/3, spin 1/2
- b (bottom) charge -1/3, spin 1/2

Gluons
- mass 2.4 MeV/c², charge +2/3, spin 1/2
- mass 1.27 GeV/c², charge +2/3, spin 1/2
- mass 171.2 GeV/c², charge +2/3, spin 1/2

Leptons
- electron (e⁻) mass 0.511 MeV/c², charge -1, spin 1/2
- muon (μ⁻) mass 105.7 MeV/c², charge -1, spin 1/2
- tau (τ⁻) mass 1.777 GeV/c², charge -1, spin 1/2

Neutrinos
- electron neutrino (νₑ) mass <0.17 MeV/c²
- muon neutrino (ν_μ) mass <15.5 MeV/c²
- tau neutrino (ν_τ) mass <15.5 MeV/c²

Heavy Bosons
- Z boson mass 91.2 GeV/c²
- W boson mass 80.4 GeV/c²

Gauge Bosons
- photon mass 0 ± 0

These particles and the way they interact describe almost all experiments!
What does SM explain?

Almost Everything!
How does the sun burn?

One of the reactions in the fusion chain is

\[ + \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = + \frac{2}{3} - \frac{1}{3} + \frac{2}{3} \]
Outline

• What is stuff made of?
• How do we see small things?
• What do we know about?
• What don’t we know?

» Brian and Laura
Are there problems with SM?

• There are problems with predictions

• What to do: Update App
What does the Higgs Boson do?

- Fixes broken predictions
- Gives particles their mass
- How does the Higgs field give particles their mass?

The Higgs field is all around us!

David Miller and CERN
The Higgs Boson

Higgs Boson = clustering in Higgs field Has a mass itself!

The Higgs Boson (if it exists) is very heavy compared to other particles.

The Higgs field is all around us (or so we think) but, Higgs Bosons are rare.
Where else Doesn’t SM work?

Dark Matter
THANK YOU!
How to discover the Higgs Boson*
Laura Jeanty

* If it exists
First, make a Higgs Boson
E = mc^2
$E = mc^2$

Energy = mass $\times$ (speed of light)$^2$
How to make energetic particles?
How to control moving particles?
The first particle accelerator 1931
1931

1% speed of light
The Large Hadron Collider
99.9999991% speed of light
Questions?
What happens when two particles collide?
What happens when two particles collide?
What happens when two particles collide?
What happens when two particles collide?
What happens when two particles collide?

Thank you, Quantum Mechanics!
What happens when two particles collide?

Thank you, Quantum Mechanics!
What happens when two particles collide?
What happens when two protons collide one trillion times?

around 999,999,900,000 times

10 – 100,000 times

one time
40 million collisions every second
Questions?
Second, observe the Higgs that you made
What happens after we’ve produced a Higgs Boson?
What happens after we’ve produced a Higgs Boson?

(Almost) instantaneous decay into other particles
What happens after we’ve produced a Higgs Boson?
How do we see the particles?

We build a detector

Panasonic FZ-100:
• 10 – 60 pictures a second
• 1 type of particle
• Only sees “low energy” light

ATLAS detector:
• 40 million pictures a second
• (almost) all particles
• Detects particles 1 billion times more energetic
The ATLAS detector
The ATLAS detector
Mass of two photon events

Number of events

ATLAS Preliminary

Data 2011

Background model

Higgs? 99% probability

Interpreting many ATLAS pictures
What else will we see in the next few years?

The more unusual, the better!
Just when we thought we knew it all...
Energy Budget of Universe

- Dark Energy: 70%
- Dark Matter: 25%
- 0.01% Other Components:
- 0.03%
- 0.47%
- 0.50%
- 4%
Outline for the Talk

• Making a case for dark matter
• What is dark matter
• Searching for dark matter
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How massive is a galaxy?
“Weighing” a galaxy
“Weighing” a galaxy

How Bright?

How Heavy?
“Weighing” a galaxy

That’s as bright as a million flashlights, so it must weigh…

Far, far away…
We’re not seeing something...

Measure Brightness → 7 Billion Suns
Galactic Rotation Curves

$v (\text{km/s})$

$R (\text{kpc})$

observed

expected from luminous disk
We’re not seeing something…

Measure Brightness → 7 Billion Suns

Measure Speed of Stars → 46 Billion Suns!
Dark Matter Halo
Questions?
Outline for the Talk

• Making a case for dark matter
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What is dark matter?

- Interacts gravity
- "Dark"
- Stable
- Massive particles
What is dark matter?
Outline for the Talk

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Collisions, collisions, collisions!
Dark matter all around us...

... but how do we “see” it?
Nature Provides the Collisions
Dark Matter Collisions in the Lab

Detect freed electrons, phonons, ...
Dark Matter Collisions are Very Rare

Many targets

Go underground
A Look at the Data

1 event / kg / day

1 event / kg / 100 days

1 event / kg / 10000 days

http://cedar.berkeley.edu/plotter/
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