Dark Matter

DM halo

Milky Way

DM

Nuclear recoil

Sven Vahsen, University of Hawaii
• Ordinary matter consists of atoms

• Atoms consist of three types of elementary particles
  – Up quark
  – Down quark
  – Electron

• In radioactive decays, also the electron neutrino is produced
  – $\nu_e$
Ordinary Matter
Three generations of particles

- “2\text{nd} and 3\text{rd} generation”
  - Discovered with cosmic rays and man-made particle accelerators
  - Heavier and unstable
  - Abundant in early universe

175 \text{GeV} (=\text{proton masses}). Discovered 1995.
What are the Force of Nature?

Even *forces* are due to elementary particles!
The Four Forces of Nature

- Four types of forces - each has its own force carrier particles
  
  - Electromagnetic interaction
    
  - Strong nuclear force
    
  - Weak Nuclear force
    
  - Gravity
Putting it all together

• Theoretically described by “Standard Model” of particle physics since early 1970s

• Standard Model predicted Higgs Boson
Questions:

*How can you see matter?*

What is happening when you see...

...the sun?
...other students?
...yourself in a mirror?
...a dark object?
Things we cannot see with photons

- Only 5% of energy in the universe due to ordinary matter

- 4.6% Ordinary Matter
- 23% Dark Matter
- 72% Dark Energy
Question: 

*Is dark matter... dark?*
What does the Dark Matter consist of?

http://home.slac.stanford.edu/pressreleases/2006/20060821.htm

- Standard Model particles cannot explain dark matter
- We think dark matter may be a new type of elementary particle!
We may need to extend the standard model

Supersymmetry predicts new particles. Including dark matter particles!
How can we test this *hypothesis*?

1. Produce dark matter with particle accelerators
2. Try to directly detect dark matter
3. Observe decays of dark matter into visible particle
The Large Hadron Collider (LHC)

- Highest Energy Accelerator to date: Two beams of 7 TeV protons $\rightarrow E=14$ TeV
- 4 large detectors where protons collide
- CMS and ATLAS: Search for the Higgs Boson & Physics beyond Standard Model
- > 10,000 scientists and engineers from over 100 countries
The ATLAS detector*

* ATLAS = A Toroidal LHC apparatus

- ATLAS surrounds one of several points where particles will collide.
- ATLAS “checks” what comes out of these collisions every 25 ns
- About 100 “snapshots” / second are written to disk for detailed analysis by the collaboration.

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~ 10^8 electronic channels
~ 3000 km of cables
Detection of charged particles takes place in 1744 identical ATLAS Pixel Modules.

1744 modules x 46080 pixels = 80 million channels!
How to transport a Muon System
How to transport a pixel detector

Completed Detector Installed June 2007

Smallest detector in ATLAS

Barrel integrated at CERN

Endcaps integrated at Berkeley Lab

On the way to CERN!
LHC Construction

• 7-TeV protons kept in orbit by superconducting magnets
• 8.33T, cooled by superfluid Helium at 1.9K

Lowering one of 1232 di-pole magnets

... after installation 100 m under ground
First Beams Circulated September 9\textsuperscript{th} 2008
2012 Higgs Discovery!

CMS Preliminary

\[ H \rightarrow \gamma\gamma \]

Higgs announcement seminar on 4 July 2012

Nobel prize in 2013
So far, we have not detected dark matter at the Large Hadron Collider...
How can we test this *hypothesis*?

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Are We Surrounded By Dark Matter?

dark matter halo?

Milky Way

Cygnus

Image: NASA/Adler/U. Chicago/Wesleyan/JPL-Caltech
We can also try to directly detect Dark Matter

• Huge detectors, Looking for 1 “blip” per year!
• Very clean, to avoid false detection from radioactivity
• Underground, to avoid false detection from cosmic rays
D³ - Directional Dark Matter Detector

I’m working on this!

Prototype detector at UH Manoa
This is how I want to detect it!
If this works, I’d like to build a dark *matter telescope* in the future, to see where the dark matter comes from!
Questions?