Fermilabyrinth

Warpspeed

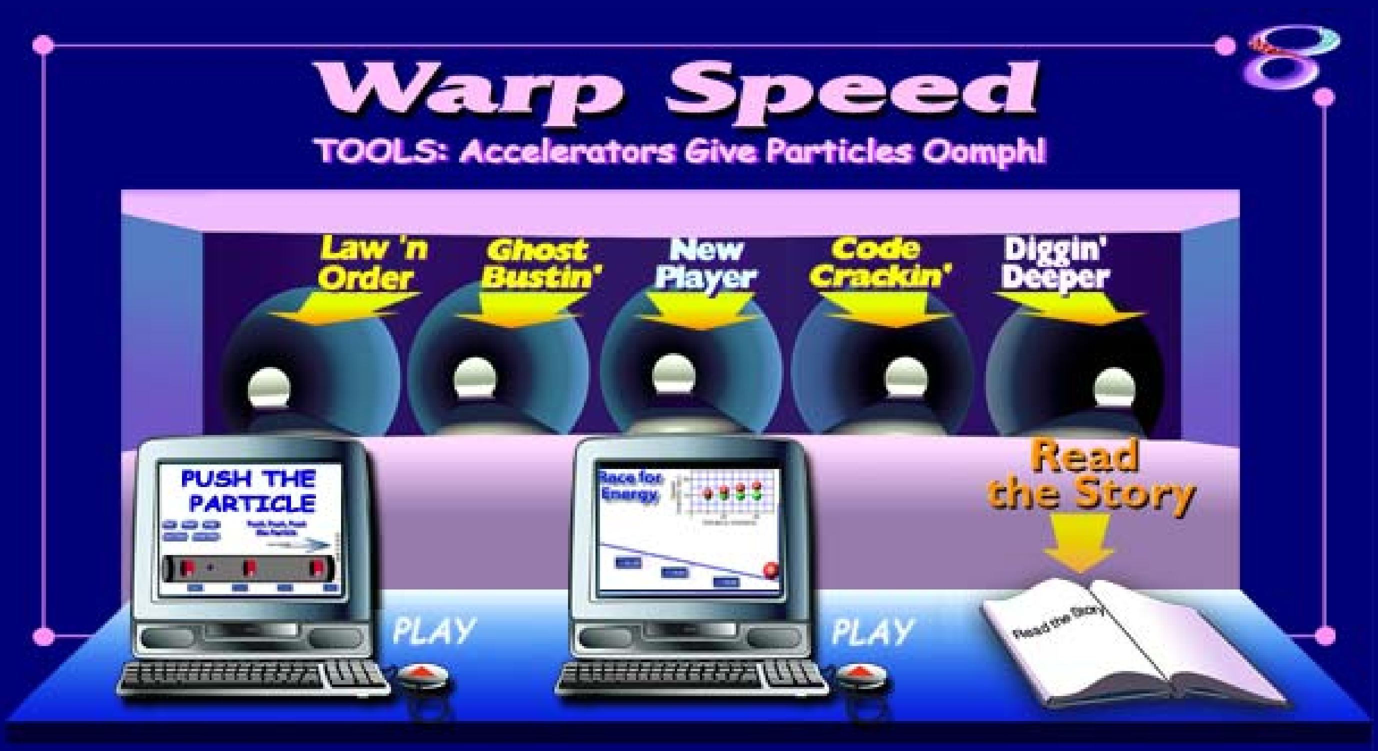
Ghostbustin'

Codecrackin'

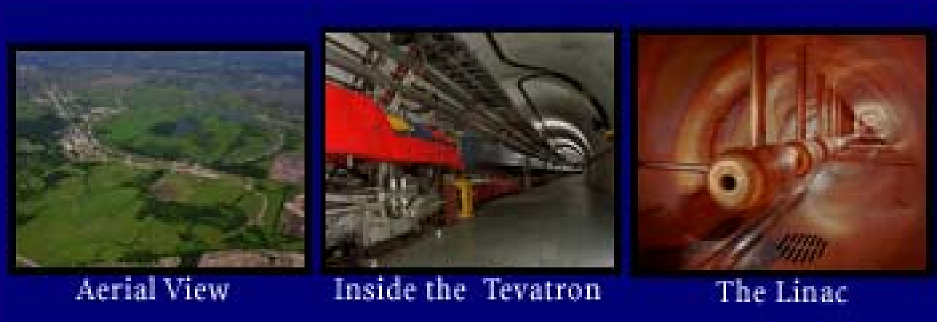
Law 'n Order

Diggin' Deeper

Students **-** ***Educators*** **-** ***Lederman Science Center***


Warp Speed
TOOLS: Accelerators Give Particles Oomph!
Law 'n Order
Ghost Bustin'
New Player
Code Crackin'
Diggin' Deeper
PUSH THE PARTICLE
PLAY
Race for Energy
PLAY
Read the Story
Read the Story

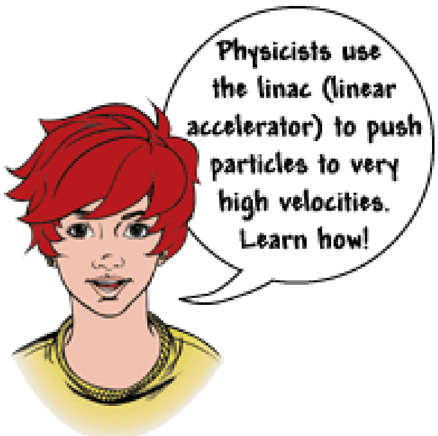
Accelerators Give Particles Oomph

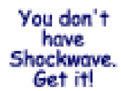


The instruments that particle physicists use for their studies include accelerators, detectors and powerful computers. Accelerators give the protons enormous energy. To study very small particles scientists need very high-energy protons and very big accelerators.

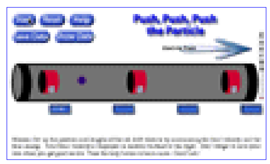
Warp Speed

Push, Push, Push the Particle

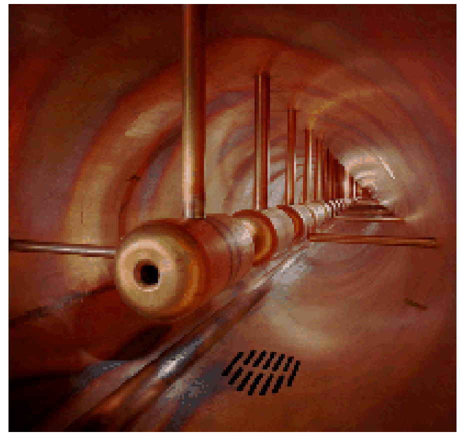




This activity needs Shockwave. If you don't see the animation above, click GET SHOCKWAVE



[Go to Game]



[Warp Speed]

Web Maintainer: ed-webmaster@fnal.gov
Shockwave Movie by Vishesh Narayen, IMSA and Liz Quigg, Fermilab
Last Update: May 11, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/warpspeed/linac/activity.html

Push, Push, Push the Particle

Skip Introduction

Watch the purple particle as the force of the electric field pushes it forward and backward.
The arrows depict the force of the electric field, so pay close attention to them.
Can you see that it always starts with the same velocity?

Next

Warp Speed

Web Maintainer: ed-webmaster@fnal.gov
Last Update: July 2, 1999 by Vishesh Nanyen: vishesh@fnal.gov
http://www-ed.fnal.gov/projects/fermilabyrinth/games/warpspeed/linac/linac.html

Push, Push, Push the Particle

Skip Introduction

By adding shielding tubes, physicists shield the particle from the force of the electric field.
Notice how the particle is affected by the force of the electric field
only when it is outside of the shielding tube.

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Web Maintainer: ed-webmaster@fnal.gov
Last Update: July 2, 1999 by Vitesh Nguyen: vitesh@fnal.gov
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Push, Push, Push the Particle

Skip Introduction

You can move and resize the shielding tube by dragging it and using the resize button.
Catch the particle in the shielding tube when the force of the electric field is pointing backwards.

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Push, Push, Push the Particle

Skip Introduction

Using this concept, physicists can accelerate particles to very high velocities and energies. To do this, they must shield the particle when the force of the electric field would slow it down, and leave it in the open when it would receive a push from the electric field. This is exactly how linear accelerators work! Click Next to run your own trials.

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Next

Warp Speed

Web Maintainer: ed-webmaster@fnal.gov
Last Update: July 2, 1999 by Vishesh Nguyen: vishesh@fnal.gov

Push, Push, Push the Particle

Skip Introduction

Using this concept, physicists can accelerate particles to very high velocities and energies. To do this, they must shield the particle when the force of the electric field would slow it down, and leave it in the open when it would receive a push from the electric field. This is exactly how linear accelerators work! Click Next to run your own trials.

Back Next

Warp Speed

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Last Update: July 2, 1999 by Vishesh Narayen: vishesh@fnal.gov
http://www-ed.fnal.gov/projects/fermilabyrinth/games/warpspeed/linac/linac.html

Trial Number	Velocity Readout Values 1	2	3	4
1	56.27	68.54	104.90	106.79
2	56.27	68.54	104.90	106.79

Push, Push, Push the Particle

More Trials

All Done!

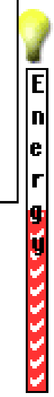
Study your data and answer the following question.

To keep accelerating the particle as it travels further down the linac, the shielding tubes should:

- ◯ get successively longer.
- ◯ all be the same size.
- ◯ get successively shorter.

Name:

Please explain your answer.



Shielding Tube Setup For: Trial

Above are the results of all the trials you have done. Click on a trial number to see its plot. In the fields above, you should enter your name if needed and write a few sentences about your understanding of this activity. Then answer the short multiple-choice question and click **All Done** to open a printable results page where you will receive the Einstein bucks that you have earned.

Warp Speed

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http://www-ed.fnal.gov/projects/fermilabyrinth/games/warpspeed/linac/linac.html

W ould you like to try to double your score?

Yes No

The Information

As you saw in the activity, physicists use many small kicks to give the particle the very high energy that they want. However, you might have asked yourself why the electric field is not set up to always give the particle a forward push. Well, to do that, the linac would have to maintain a very high voltage difference for a long period of time. The amount of energy required to do that is unreasonably large, so the physicists had to think of a different way. Instead of giving one large push, they thought, why not give many small pushes to accelerate the particle. The easiest way to give many small, forward pushes was to have an alternating electric field, but an alternating electric field gives backward pushes as well, so that is where the shielding tube came in. Physicists refer to the shielding tubes as 'drift tubes', because the particle drifts through them.

The Problem

Before the particle enters the linac, it has an energy of 750 keV, or kilo-electron Volts (kilo- is a prefix that means 1000). By the time it leaves the linac, physicists must accelerate it to an energy of 116 MeV, or mega-electron Volts (mega- is a prefix that means million). How many times greater is the energy the particle has when it leaves the linac than the amount of energy it has when it enters the linac?

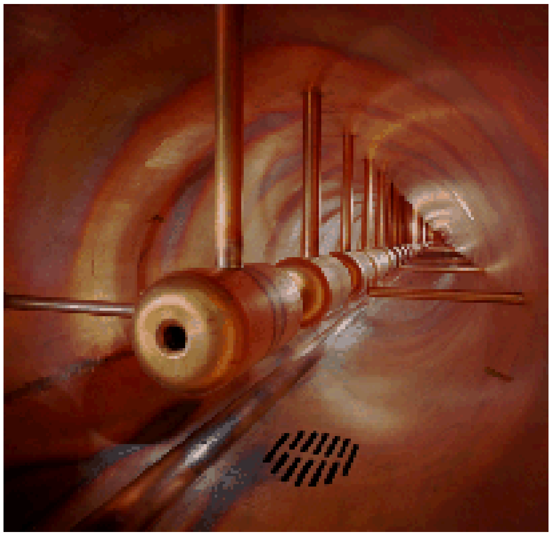
About ○ 1.5 ○ 15 ○ 150 ○ 1500 ○ 15000

All Done!

Warp Speed

Congratulations! You earned Einstein Bucks in Push, Push, Push the Particle!!

Now do you know how the Linac below works?
You can print your bucks or go back to Warpspeed.



Print Your Bucks

Go Back

Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 17, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/natures_scale/done_linac.html

Marilyn Fox's Printable Results From Push the Particle

Trial Number	Velocity 1	Velocity 2	Velocity 3	Velocity 4	Relative Energy
1	53.96	84.85	113.80	108.77	83

See The High Scores

Best Trial Configuration

Marilyn Fox's answer to the question:

To keep accelerating the particle, the drift tubes have to: get longer

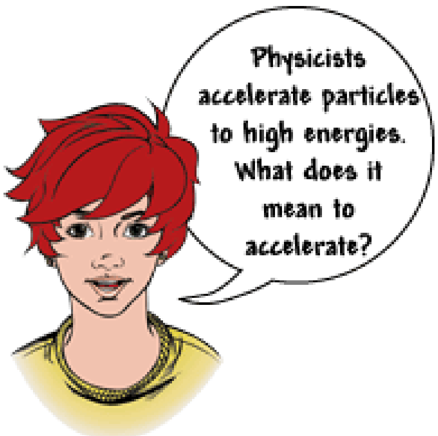
Good job! You got the answer right. As the particle speeds up, it travels a greater distance in the same amount of time. So in order to shield the particle for a given amount of time, the drift tube will have to get longer as the particle speeds up.

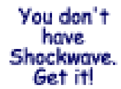
Marilyn Fox's explanation for his answer:

Going faster requires longer tubes.

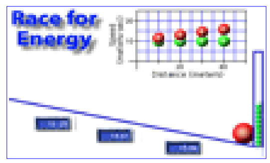
Congratulations! You succeeded in doubling your Einstein bucks!

Race for Energy





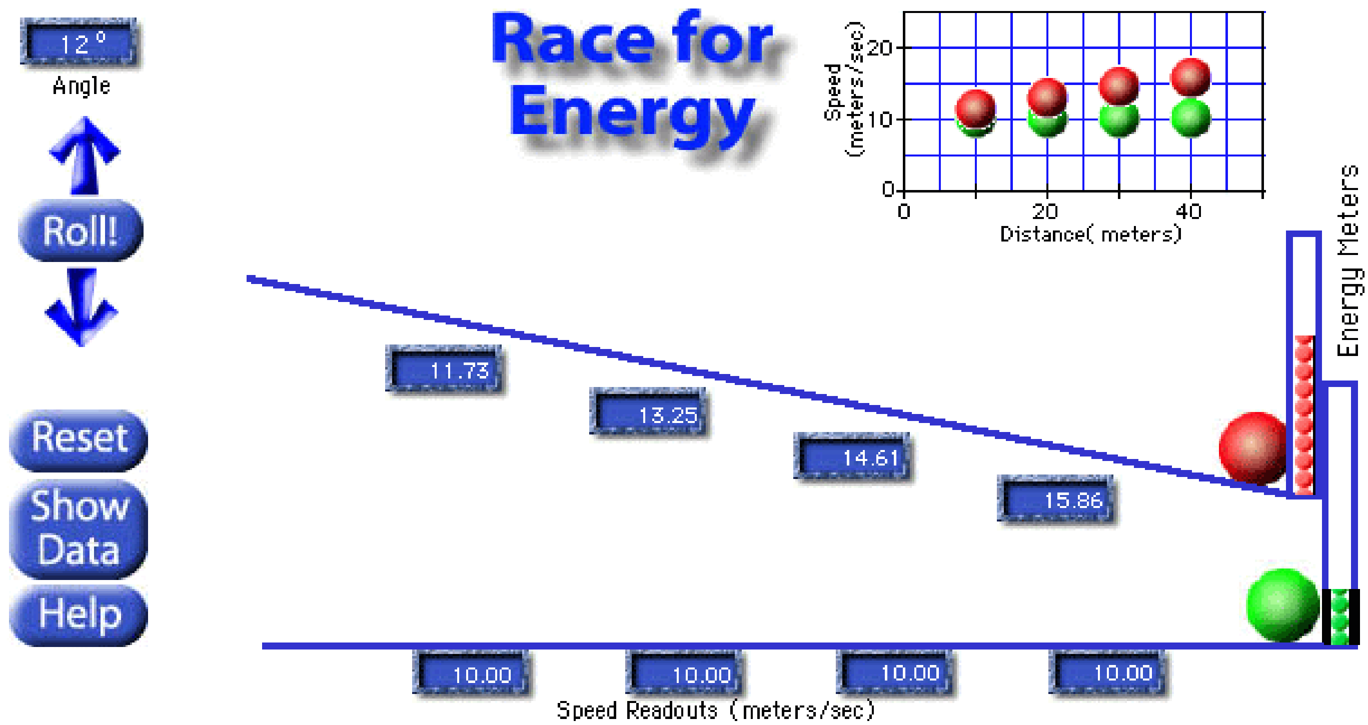
This activity needs Shockwave. If you don't see the animation above, click GET SHOCKWAVE



Go to Game

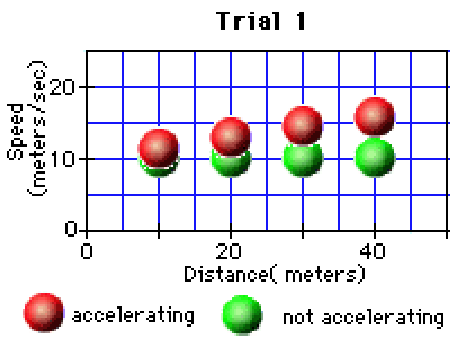
Warp Speed

Web Maintainer: ed-webmaster@fnal.gov
Last Update: Dec. 23, 1998
http://www-ed.fnal.gov/projects/fermilabyrinth/games/warpspeed/race_for_energy/activity.html

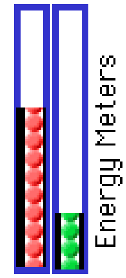


[Warp Speed]

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 24, 1999 by Vishesh Nguyen: vishesh@fnal.gov
http://www-ed.fnal.gov/projects/labyrinth/games/warpspeed/race_for_energy/race.html



Trial Number	Angle (deg.)	Speed (meters/sec) at Positions 1	2	3	4	Relative Energy
1	12	11.73	13.25	14.61	15.86	71.98
2	18	12.49	14.57	16.40	18.03	94.07



Above are the results of all the trials you have done. Click on a trial number to see its plot. In the fields below, enter your name if needed and write what you have learned about the relationship between acceleration and energy. Click **All Done** to open a printable results page.

More Trials

Name: Mary Marks

Please enter a thoughtful response below.

Study the graphs above and answer this question correctly for 100 Einstein Bucks:

Acceleration is: ◯ Enormous Speed ◯ A Change In Speed

All Done!

Warp Speed

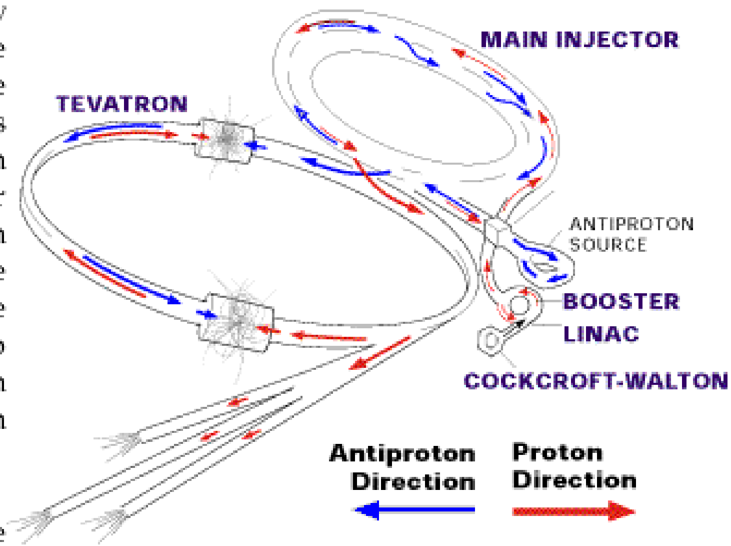
Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 24, 1999 by Vishesh Narayen: vishesh@fnal.gov
http://www-ed.fnal.gov/projects/fermilabyrinth/games/warpspeed/race_for_energy/race.html

W ould you like to try to double your score?

Yes No

The Information

In Race for Energy, the force of gravity accelerates the ball as it moves down the track. In the Fermilab accelerators, the force of an electric field accelerates charged particles (first hydrogen ions in the Cockroft Walton and the Linear Accelerator (Linac), and then protons in the Booster, Main Injector, and the Tevatron). In the last three stages of the accelerator, physicists use magnets to bend the path of the protons to keep them moving in a circle. Antiprotons travel in the direction opposite to the protons.



The Question

What force accelerates the particles in the Fermilab accelerator?

○ Electric Force ○ Gravity ○ Magnetism

Done

Warp Speed

Mary Loomis's Printable Results From Race For Energy

Trial Number	Angle	Position 1	Position 2	Position 3	Position 4	Relative Energy
1	12	11.73	13.25	14.61	15.86	71.7
2	16	12.25	14.15	15.84	17.34	87.83

See The High Scores

Mary Loomis's Thoughtful Response about the Relationship between Acceleration and Energy:

More acceleration means more energy.

Mary Loomis's Answer To The Question:

Acceleration is: a change in speed

Good job! You got the answer right. Acceleration *is* a change in the speed of something. It is even possible to calculate the acceleration once you know what forces are acting upon the ball and the angle that it is travelling at. In this case, gravity was pulling the ball down, and we knew the angle that it was travelling at, so we could calculate the speed at any moment.


Ghost Bustin'
TOOLS: Detectors Reveal Invisible Particles and Forces
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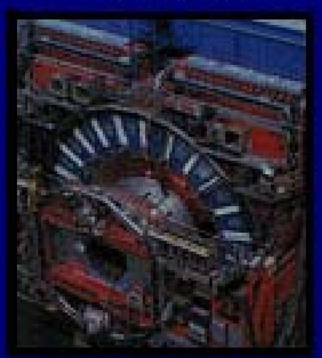
PARTICLE COUNTIN'
PARTICLE TRAPPIN'
DETECTOR DETAIL
Read the Story
PLAY
PLAY
PLAY
Read the Story

<

Detectors Reveal Invisible Particles and Forces

D0 Detector

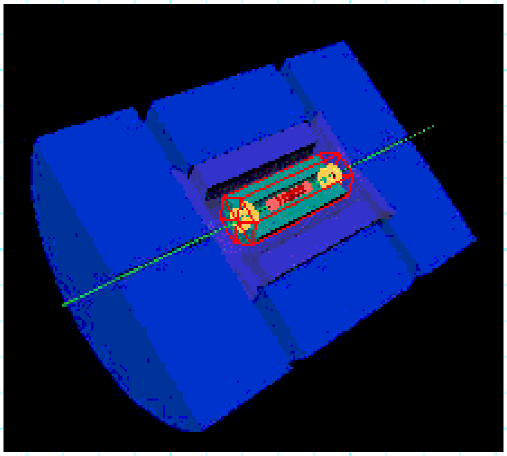


CDF Detector

The particles scientists want to study are so small that they cannot be seen by the human eye or the most powerful microscope. So physicists build huge detectors to track the particles as they move outward from a collision. Scientists need computers to collect, store and analyze the information. They need computers because the experiments create a lot of data over a very short period of time and because many of the newly created particles live for only an instant. Computers also allow scientists to use the data to reconstruct events in a collision. Subatomic particles behave like waves. Understanding the properties of waves helps scientists design their experiments and interpret the results.

Ghost Bustin'

Welcome to the Detector Design Group at Fermilab. Our job is to design a calorimeter for a new particle detector.
To get up to speed, please complete the following assignments:



- Investigate how particles look in the D0 Calorimeter.
- Identify shower shapes of three particles.
- Identify those particles in collision debris (events).
- Learn about Calorimetry.

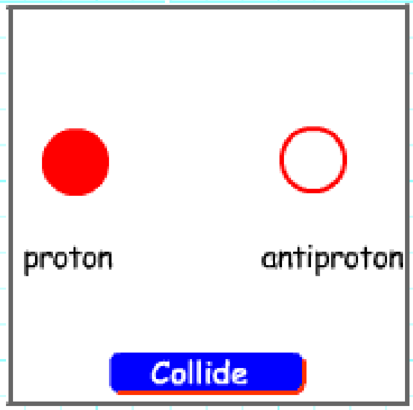
Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

Double Your Bucks and Quit Detector Detail

Intro: Calorimeter - a Detector component

Calorimeters capture the energy of particles - the debris from high-energy collisions. Click **Collide** (flash-only) to see the particle debris from a collision of a proton and antiproton. Then click the arrow to continue.



Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

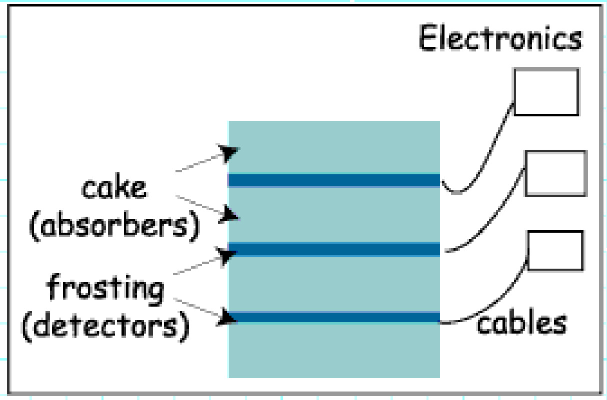
Double Your Bucks and Quit Detector Detail

Intro: Calorimeter Cake

A calorimeter - made up of layers of material, like a birthday cake.

Cake - **absorbing** material of the calorimeter

frosting - **energy detectors** with electronic readout devices



Introduction | Particles | Events | Calorimetry

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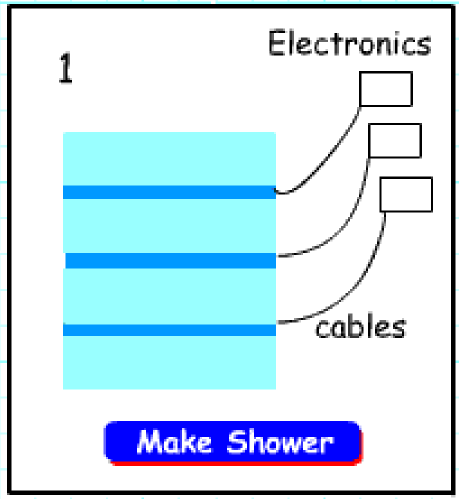
Double Your Bucks and Quit Detector Detail

Intro: Calorimeter - Recording a Shower



Click **Make Shower** to the right to see
1 - a debris particle enters the calorimeter and
2 - interacts with material creating a shower of new particles.
3- Electronics records the trail of energy deposited in each layer of material.

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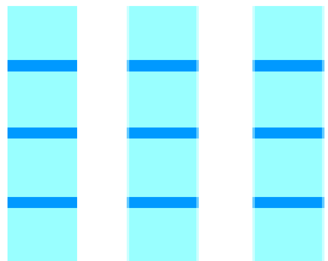
500 Einstein Bucks

Double Your Bucks and Quit Detector Detail

Intro: Calorimeter Recipe

Recipe for a Calorimeter
1 - Slice into pieces like cake
2 - Assemble the slices around the central collision point to capture all the particles.

Calorimeter Cake
Cut in Slices



Assemble Slices

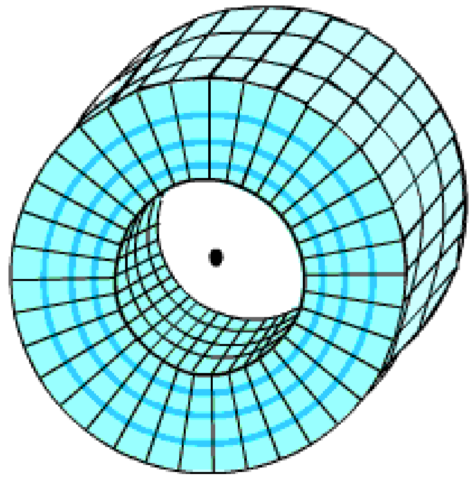
Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

Double Your Bucks and Quit Detector Detail

Intro: Calorimeter - Assembling

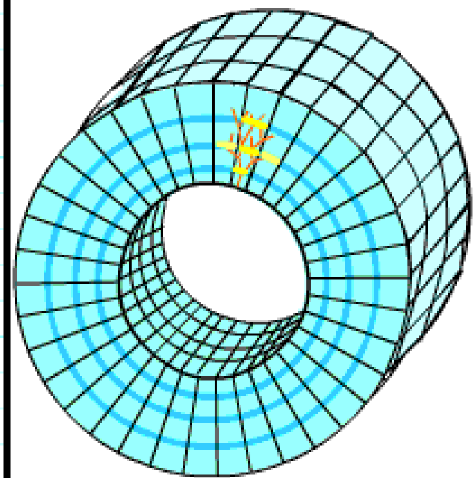
Many rings of slices surround the central collision point so the calorimeter can trap particles coming out in all directions.



500 Einstein Bucks

Intro: Making 3D plots of shower shapes

For each slice in which energy was deposited by the shower of particles, add up all the energy captured in its layers. Make a 3 D plot of all these slices using color to indicate the amount of energy. Include the central collision point. The lengths and colors of the slices in the plot tell us which particle created the shower.



Make Shower

Show Slices Hit

Shower Shape

Introduction | Particles | Events | Calorimetry

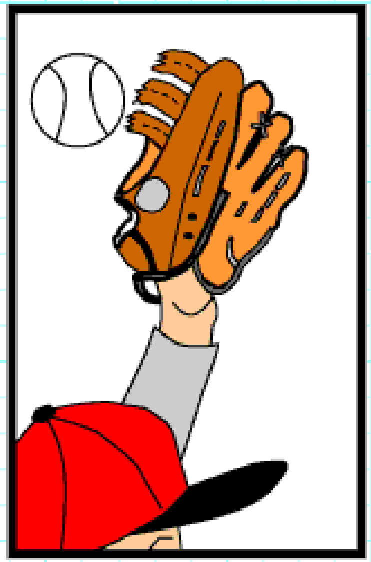
500 Einstein Bucks

Double Your Bucks and Quit Detector Detail

Intro: Choosing the Right Materials

We choose the materials and their thickness very carefully to be sure we capture as much as possible of the the energy of the particles. If we goof and don't choose the right materials, it is something like making a baseball glove out of paper. The ball would just sail through without being caught.

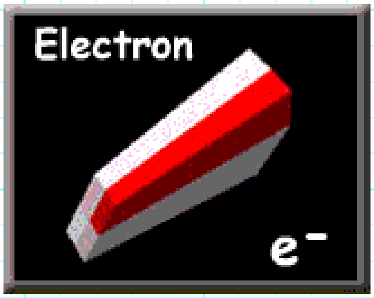
We might be able to catch a ping pong ball, but not a baseball!

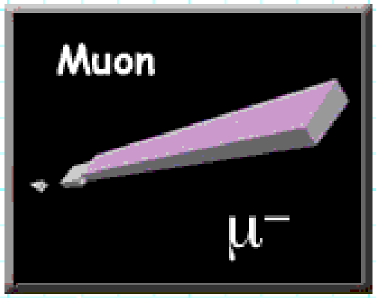


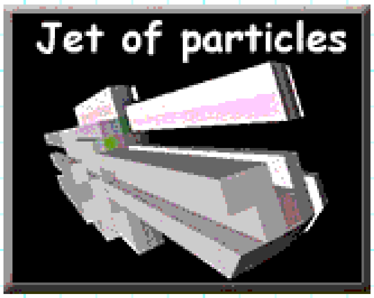
Introduction | Particles | Events | Calorimetry

500 Einstein Bucks   Double Your Bucks and Quit Detector Detail

Particles







Practice your skills!

Click on any of the particles to the left to see how they look in a calorimeter. Particles are identified by the shape and color of their shower. Color is used to indicate the amount of energy. Red is lots of energy, green is some energy and light purple is very little energy.

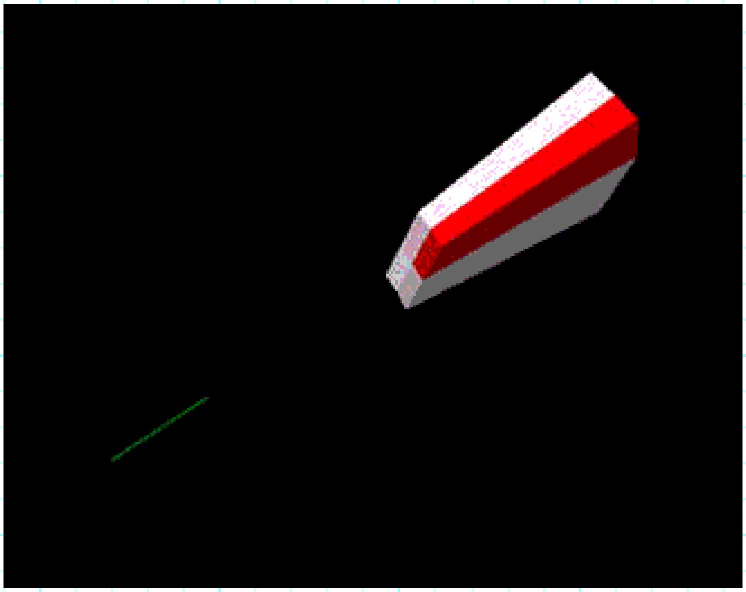
Try testing your recognition ability. You will need this knowledge to move on to the next level.

Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

Double Your Bucks and Quit Detector Detail

An Electron



As an electron moves through the calorimeter it produces photons which in turn make more electrons until the particles runout of energy. The shower occurs over a short distance and is narrow. The "shower shape" of the electron is a single tower with lots of energy surrounded by a few towers with little energy. The shower shapes vary depending on how energetic the original electron was. Watch this shower shape rotate with an Animated Gif or Quicktime Movie.

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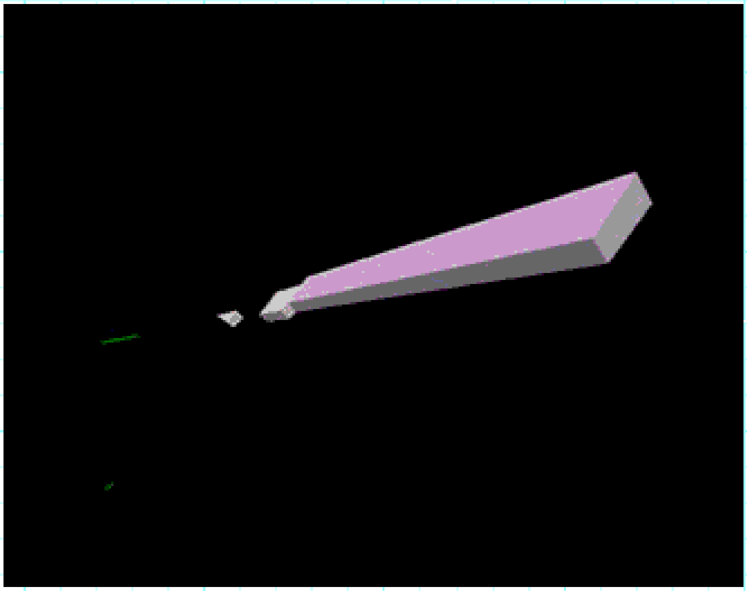
Double Your Bucks and Quit Detector Detail



A Muon

Muons are detected by charged particle detectors that are outside the calorimeter. They interact only a little with the material in a calorimeter leaving a small amount of energy all along the path they take. Their "shower shape" is one tower wide and light in color. Watch this show shape rotate with an Animated Gif or Quicktime Movie.

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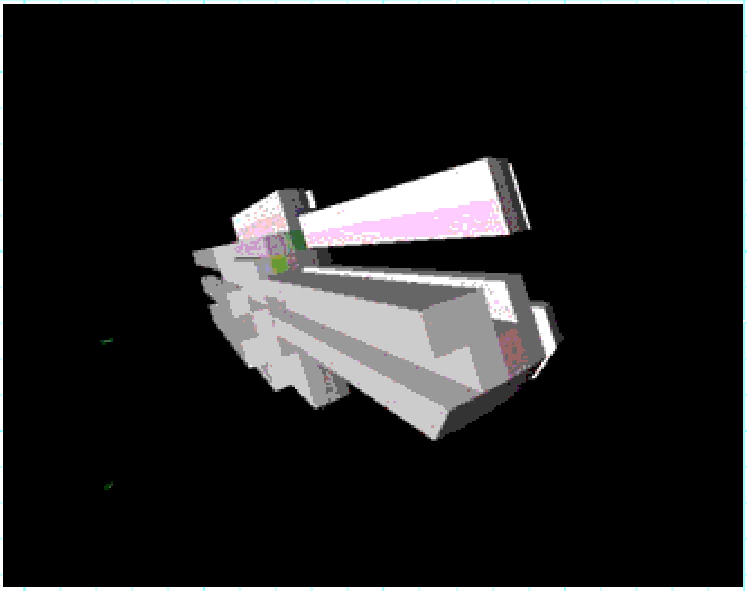
Double Your Bucks and Quit Detector Detail



Jet of Particles

Jets are composed of a spray of particles. Because lots of particles start the shower, the"shower shape" is typically very broad and has many towers with different energies displayed as different colors. The shower extends deep into the calorimeter, and so the towers are much longer. Watch this shower shape rotate with an **Animated Gif** or **Quicktime Movie**.

Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

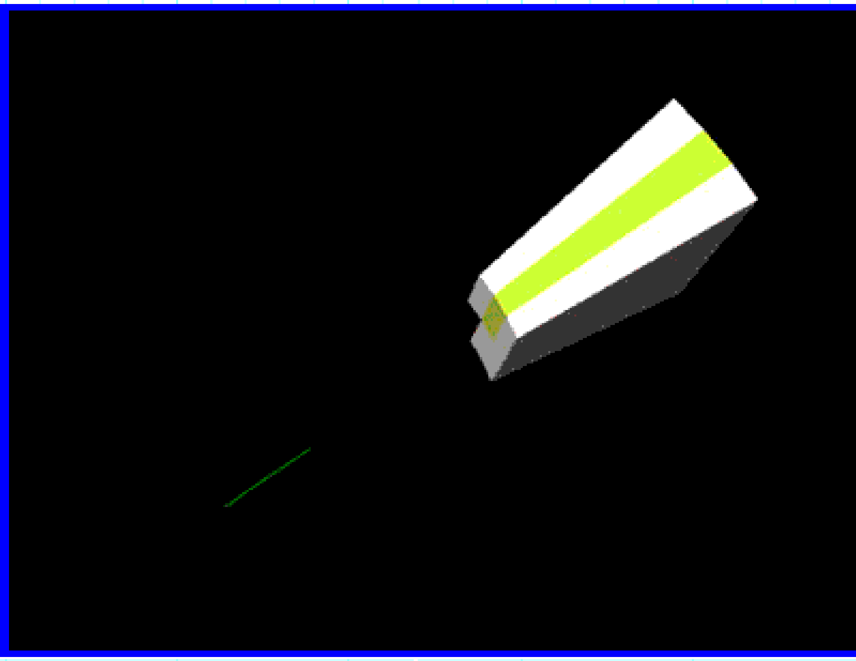
Double Your Bucks and Quit Detector Detail

See how many of the 16 shower shapes on the right you can recognize.

Electron | Jet | Muon

New Shower Shape.
Click Electron, Muon, or Jet.

Right: 2 Wrong: 2

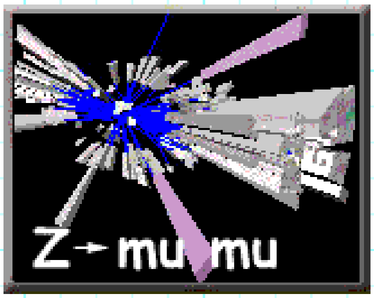


Introduction | Particles | Events | Calorimetry

750 Einstein Bucks

Double Your Bucks and Quit Detector Detail

Events



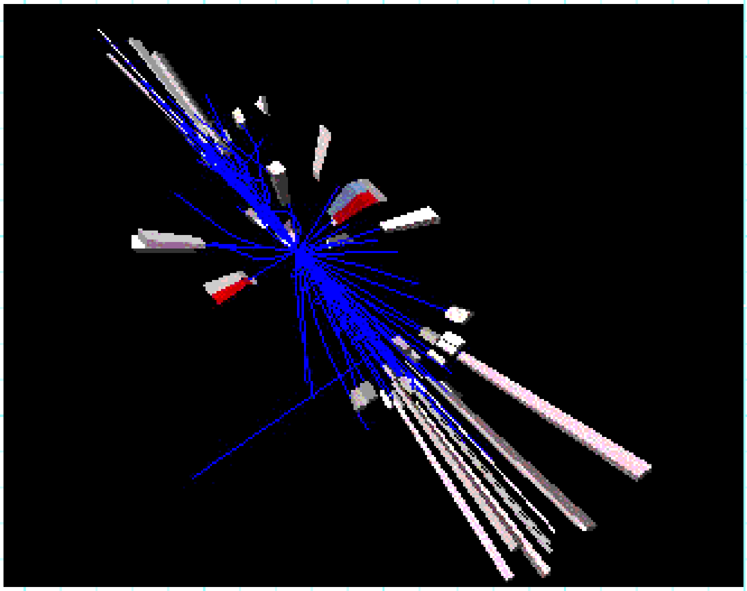
Practice your skills!

An event is a record of what happens in a collision. The 3D plot shows the towers of the D0 calorimeter in which particles deposited energy. This is a record of the final collision debris, the offspring of particles made immediately after the collision. By studying 3D plots, physicists try to discover what happened in the event. The plots you will see show the offspring from the decay of a Z particle. You may find the shower shapes of a pair of electrons, a pair of muons, or two jets.

Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

Double Your Bucks and Quit Detector Detail



Z -> e e

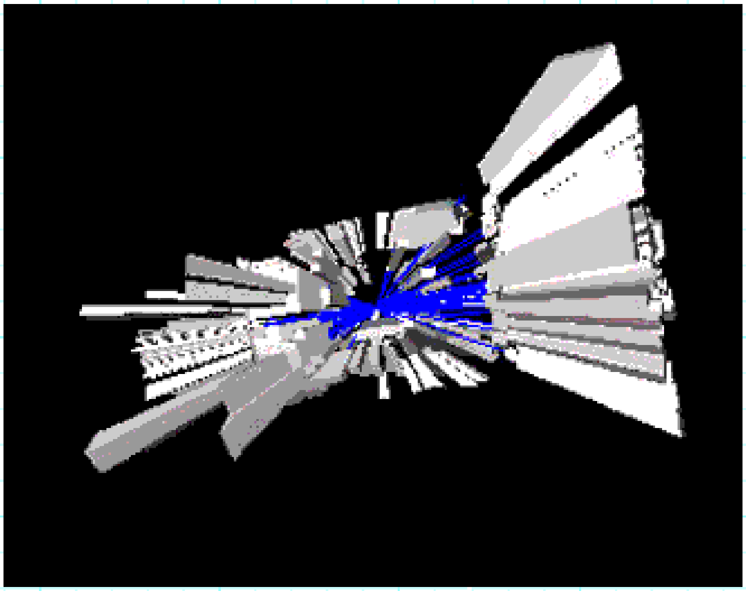
A Z particle can decay to an electron and an anti-electron (also called a positron). Positrons have the same shower shape as electrons. In this display, you can find the two electron shower shapes by rotating the event. It may not be possible to see both the electron and the positron at the same time.

Rotate the event with an **Animated Gif** or **Quicktime Movie**.

Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

Double Your Bucks and Quit Detector Detail



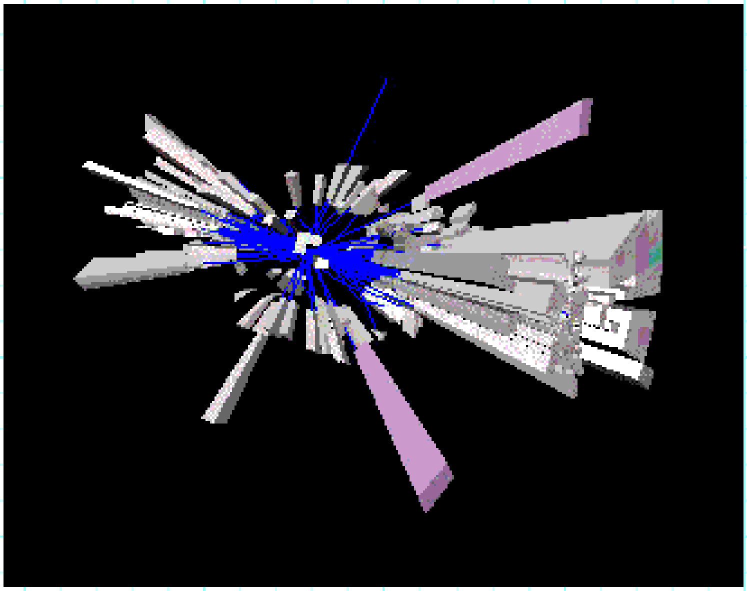
Z -> jet jet

A Z particle can decay to a quark and antiquark, and the quarks produce jets. Jets are sprays of particles and do not have as consistent a shower shape as do electrons and muons. The best way to look for jets is to look for concentrations of energy in the event. Towers with a lot of energy (the jet core) surrounded by many other towers with less energy indicates a jet while lots of towers with low energy indicates debris that is not from the Z decay. Watch this event rotate with an Animated Gif or Quicktime Movie.

Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

Double Your Bucks and Quit Detector Detail



Z -> mu mu

A Z particle can decay to a muon and an anti-muon. It is very difficult to find the muons in this display. Physicists do not rely solely on calorimeters for muon identification. Since the muons keep most of their energy as they go through the calorimeter, there are tracking chambers outside it where the muons leave a trace. Physicists match that trace with the calorimeter muon shower shape to confirm the presense of a muon. Watch this event rotate with an **Animated Gif** or **Quicktime Movie**.

Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

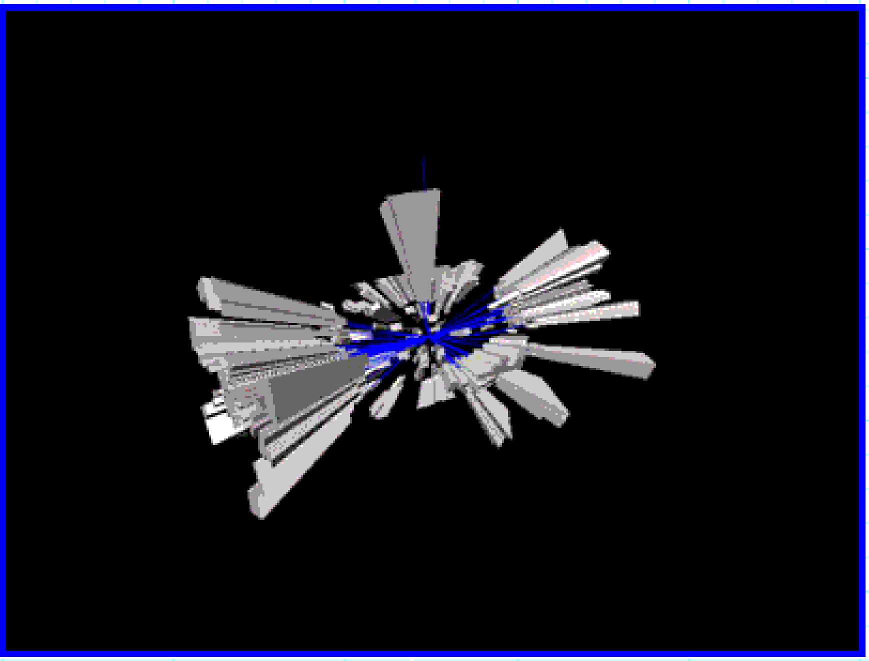
Double Your Bucks and Quit Detector Detail

See how many of 8 events on the right you can recognize.

Z → e e | Z → jet jet | Z → mu mu

New Event
Click on Z -> e e , Z -> jet jet or Z -> mu mu.

Right: 0 Wrong: 0

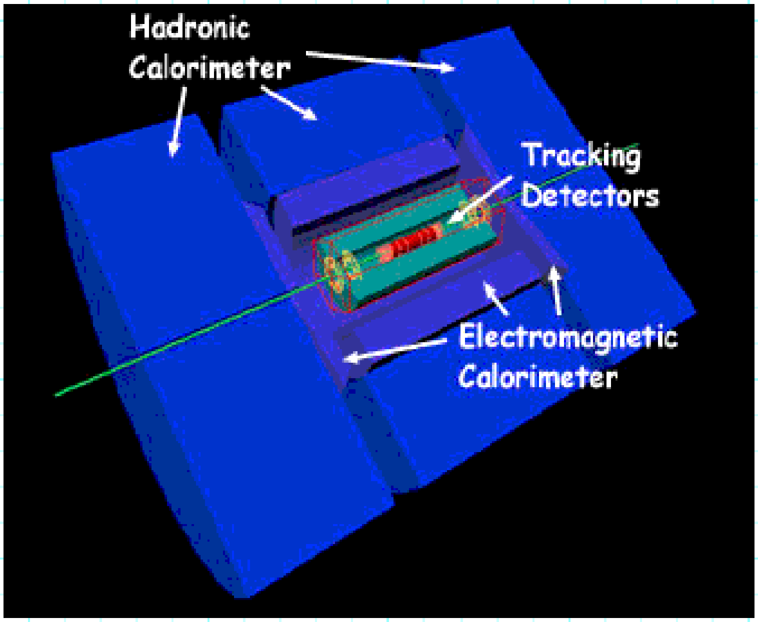


Introduction | Particles | Events | Calorimetry

500 Einstein Bucks

Double Your Bucks and Quit Detector Detail

Calorimetry



In this 3D rendering of half of the detector, the blue calorimeter surrounds the inner tracking detectors. The electrons leave energy in the inner blue section, the electromagnetic calorimeter, and particles called hadrons leave energy in the outer blue section, the hadronic calorimeter. Hadrons are particles made of quarks. Muons leave only very little energy in both parts of the calorimeter.
Zoom into the detector with an

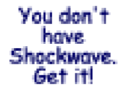
Animated Gif or **Quicktime Movie**.

Introduction **Particles** **Events** **Calorimetry**

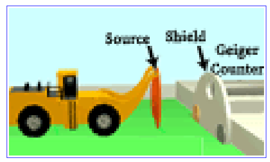
500 Einstein Bucks

Double Your Bucks and Quit Detector Detail

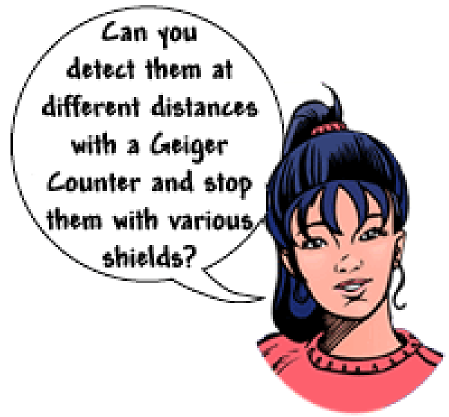
Detect Invisible Bullets with a Geiger Counter



This activity needs Shockwave. If you don't see the animation above, click GET SHOCKWAVE



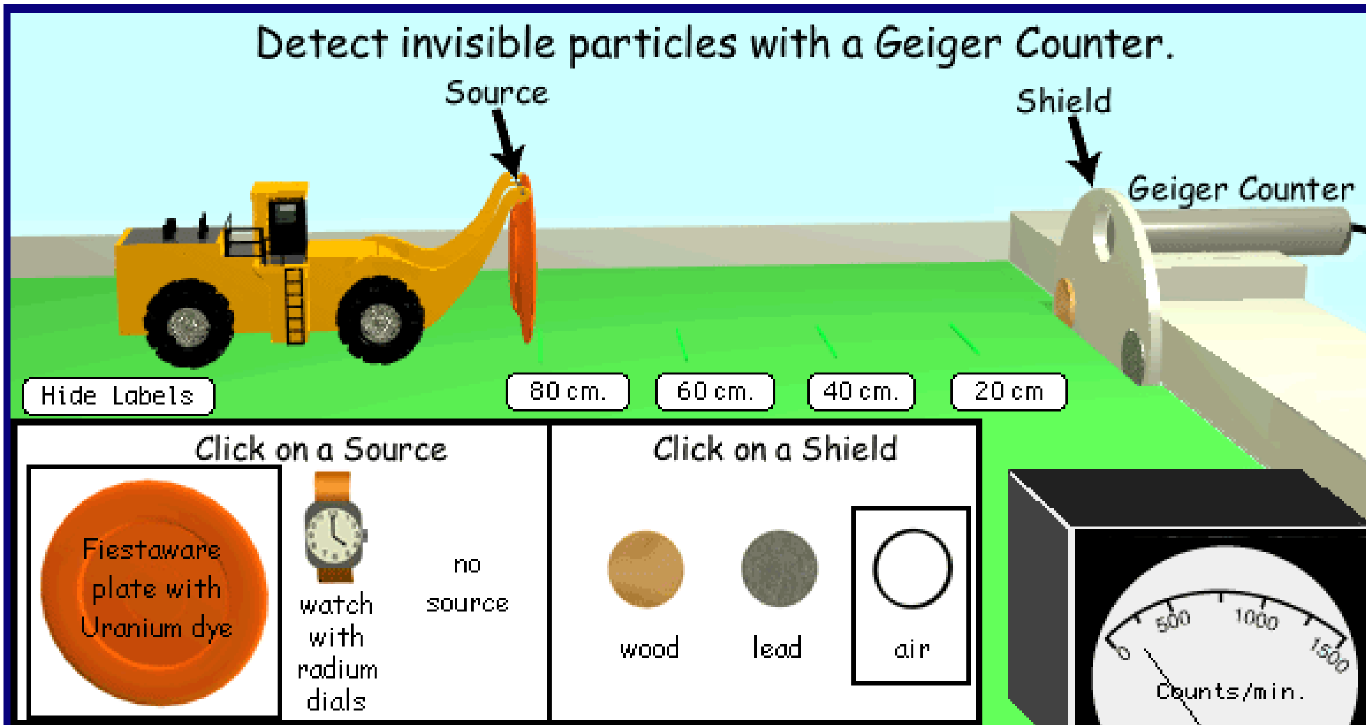
Go to Game



Be sure to turn up your sound!

Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: Mar.1,1999
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/geiger_counter/activity.html



Ghost Bustin' - Earn Einstein Bucks

Web Maintainer: *ed-webmaster@fnal.gov*
Last Update: Feb. 19, 1999
http://www-ed.fnal.gov/projects/labyrinth/games/ghostbustin/geiger_counter/geiger.html

Particle Countin' - Test What You Learned

Earn Einstein Bucks by answering the questions below. Remember you can always go back to the Particle Countin' Game. After you are done, click on the "Click to Print Bucks" Button at the bottom of the page. You'll get more Einstein bucks if you fill in the explanations.

Both the fiesta ware and the watch are radioactive; this means that very small particles, too small to see, shoot out of them. The Geiger Counter counts how many particles come from each object. The shields may stop some of the particles.

- Question 1: Which object seems to have the most particles coming out?

  ○ Fiestaware Plate ○ Watch

- Question 2: Does the Geiger counter count more particles when objects are close by or when they are far away? Explain your answer in the box below.

  ○ Close by ○ Far away

- Question 3: Which shield does the best job stopping the particles?

  ○ Wood ○ Lead ○ No Shield

- Question 4: Why do you think the Geiger counter can still count particles even though you put a shield in the way?

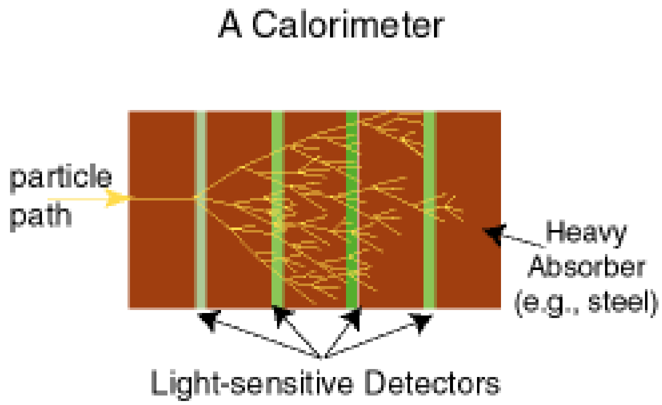
- Question 5: Why do you still hear some clicks on the Geiger Counter when you have no source?

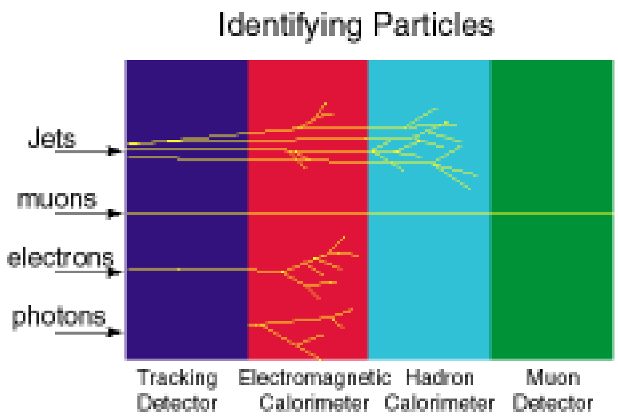
- Question 6: Physicists at Fermilab build their detectors with layers of different materials to trap the particles. These type of detectors are called **Calorimeters**. If you were going to trap all these particles with a layer of material, which would you use?

  ○ Wood ○ Lead

Double Your Bucks by reading about detectors and answering the question correctly:

Calorimetric ("energy-measuring") detectors absorb the energy of a particle and convert it into light which can be observed by light-sensitive detectors. The amount of light observed measures the energy of the particle. Absorbing high-energy particles requires a lot of material, typically many feet of steel or lead. The calorimeter surrounds the point of interaction in a collider detector.





In calorimeters different particles travel different distances before being absorbed. Photons and electrons lose energy very quickly and stop in the first layers of a calorimeter. Muons, by contrast, can pass through many feet of steel before losing their energy. Jets from quarks have an intermediate range. Physicists use the distance a particle travels in a calorimeter to identify the particle.

- Question 7: In which layer would photons be trapped?

○ Tracking ○ Electromagnetic ○ Hadron ○ Muon

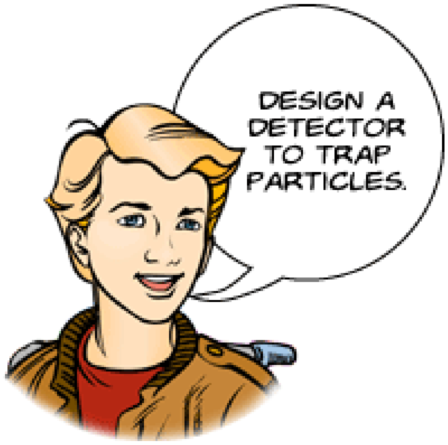
Web Maintainer: ed-webmaster@fnal.gov
Last Update: Mar.1,1999
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/geiger_counter/test.html

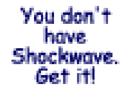
Feedback on Karin Fuchs's Answers to Particle Countin'

- Question 1: Sorry, the FiestaWare Plate is the best source.
- Question 2: No, the closer the source, the higher the count.
  You missed earning 200 Einstein bucks by not explaining why.
- Question 3: No, the best shield is made from lead.
- Question 4: You missed earning 200 Einstein bucks by not answering.
- Question 5: You missed earning 200 Einstein bucks by not answering.
- Question 6: No, the best material of the two to trap particles is lead.
- Question 7 to Double Your Bucks: Sorry, you did not double your bucks; the photons are stopped in the Electromagnetic Calorimeter.

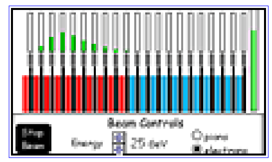
Click to Print Bucks

Particle Trappin'





This activity needs Shockwave. If you don't see the animation above, click



Go to Game

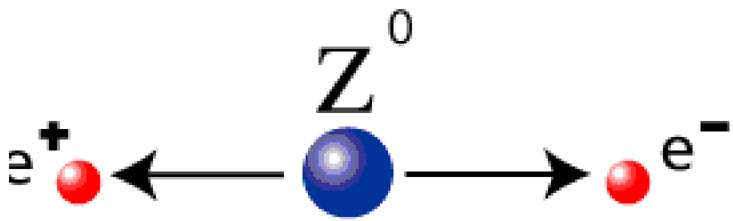
Be sure to turn up your sound!

Ghost Bustin'

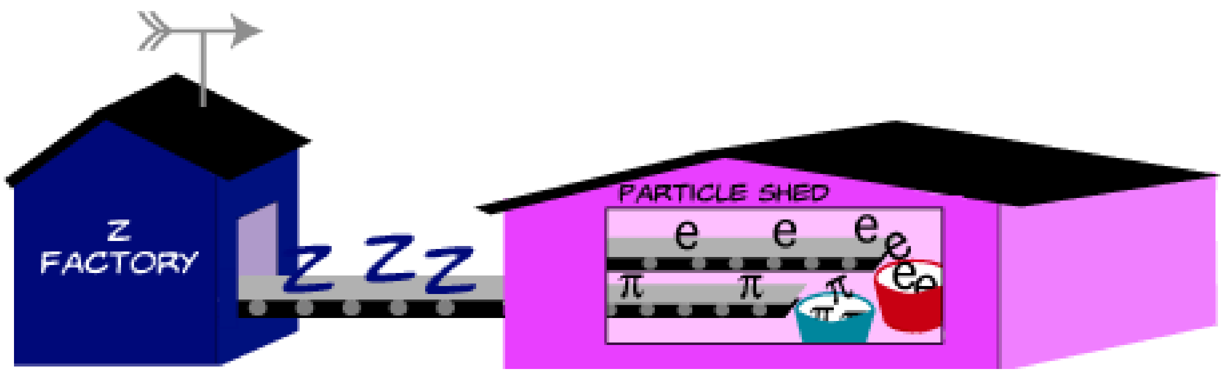
Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 12, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/activity.html

Particle Trappin' - Join the Team

Welcome to our experimental team. We want to measure the mass of the Z particle. Zs don't live long so we can't trap them, but we can trap the particles they decay into. If we measure the energies of the particle children of the Z, we can calculate its mass. Check out the animation of **some, but not all** of the ways the Z decays into its particle children.



Did you notice two particle children are the electron (**e**) and the pion (π)? Your job is to help build the "Particle Shed" below to trap electrons and pions and to measure their energy. We will be getting the Zs from a Z factory.
[How can you trap particles?]

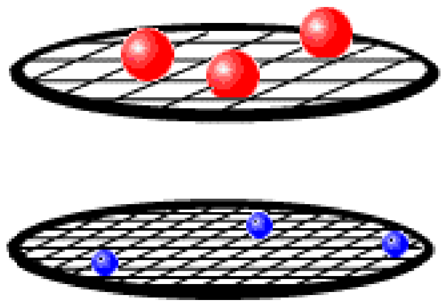


Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 26, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/intro1.html

Particle Trappin' - A Sieve

First, you need to build a device to distinguish between pions and electrons, a sort of sieve that traps each in a different section.



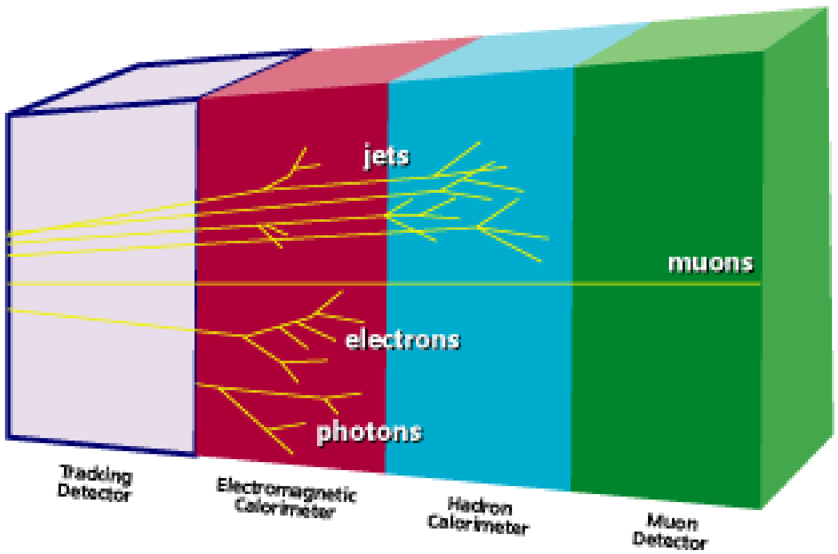
What do physicists use?

Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 26, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/intro2.html

Particle Sieve - Identifying Particles

First, you need to build a device to distinguish between pions and electrons. Physicists line up different metals (shown in red, light blue and green). Each metal traps different types of particles and allows other types to pass through. You will be building the red and light blue sections, labeled calorimeters. Show me more about calorimeters.

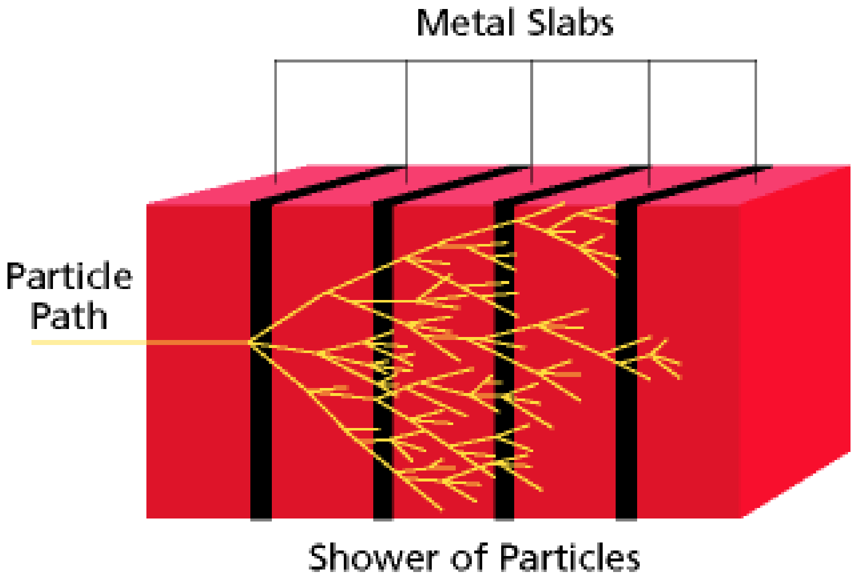


Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 26, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/intro3.html

What's a Calorimeter?

Calorimeters measure the trapped energy of the incoming particle. A calorimeter is a layer cake of metal slabs and detectors. When a particle enters the metal, it causes a shower of particles, somewhat like lightning moving through the atmosphere. The shower of particles loses energy as it goes through the metal. How do physicists measure the energy lost in the slabs?

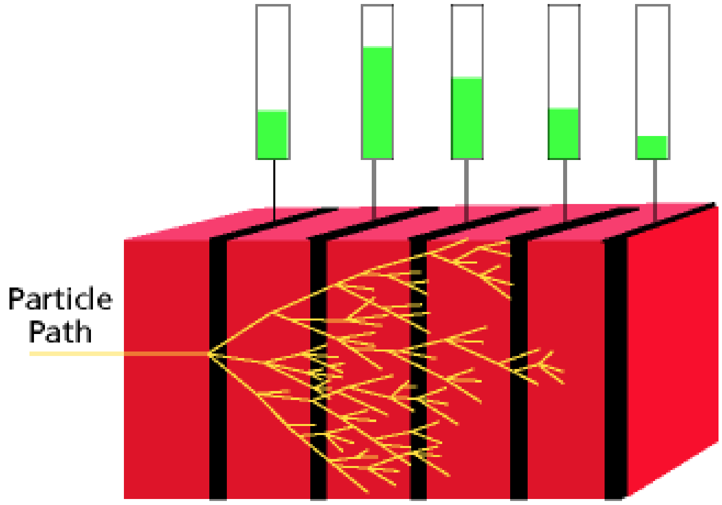


Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 26, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/intro4.html

Measuring Energy Lost in Each Slab

By placing detectors between each metal slab, physicists measure the energy lost in each slab. The green bars indicate how much energy was lost in each slab. The energy is spread out over a number of layers depending how deep the shower goes. The green bars start out small, get quite tall, and then drop off. **WARNING: If you do not have enough layers, you may miss some of the energy.** How do they get the total energy?

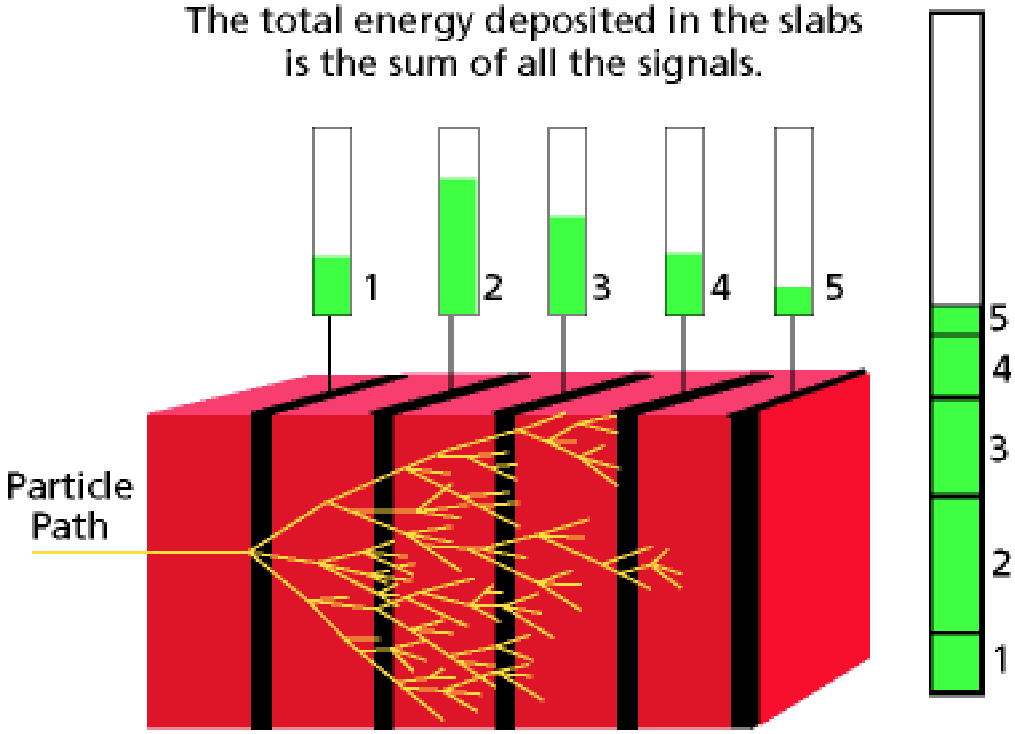


Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 26, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/intro5.html

Measuring the Total Energy Deposited in the Calorimeter

Physicists add up the energy in all the detectors to get the total energy deposited in the calorimeter by the particle.



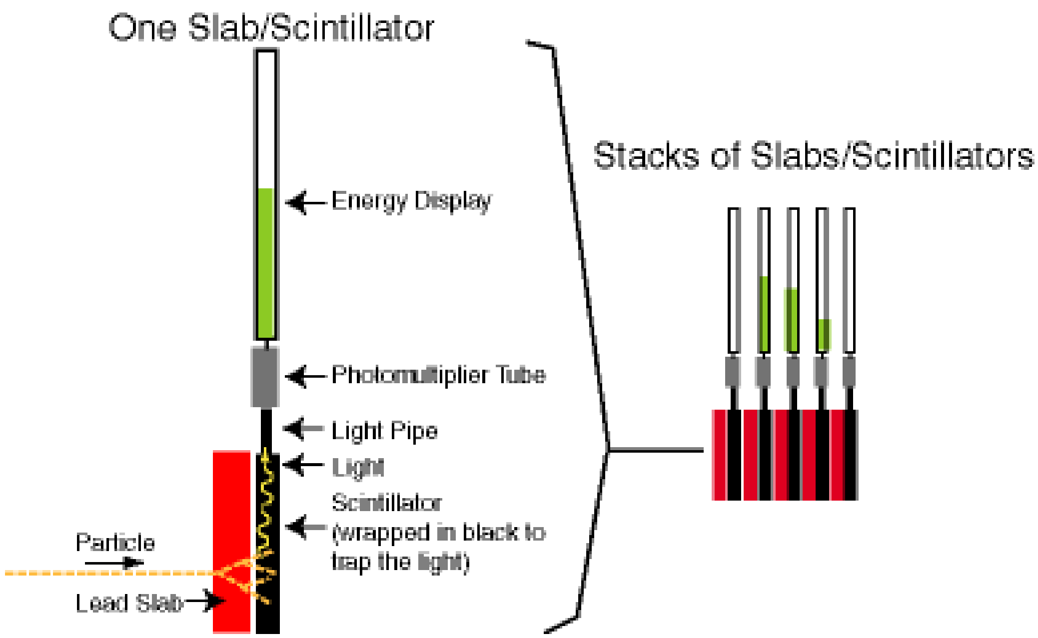
Now you know how to identify your particles and measure their energy. Find out your assignment or if you are really curious, more about the detectors.

Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 26, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/intro6.html

Optional: How the Detector Works

Physicists install light-sensitive detectors called scintillators in between the slabs of metal. The amount of light collected in the scintillator tells the amount of energy lost. The light travels through the light pipe into the photomultiplier tube which enhances the green LED signal in the Energy Display.



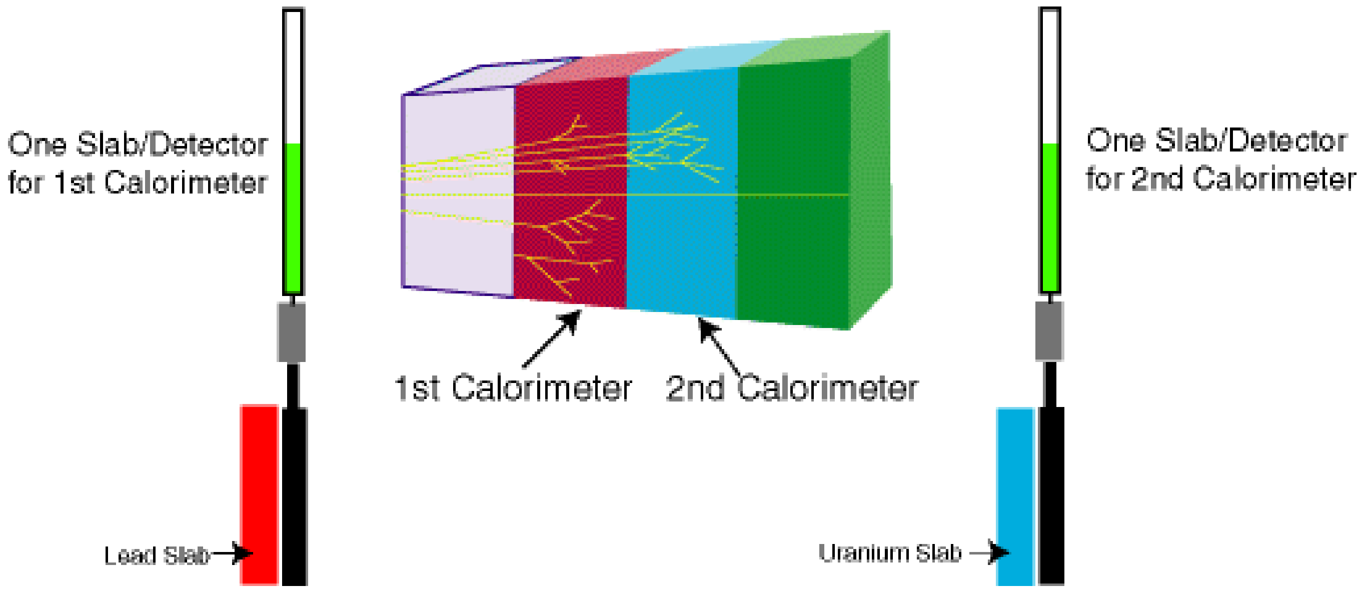
What's your assignment?

Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 26, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/intor7.html

Your Assignment

Your job is to build two calorimeters back to back. One will detect pions and the other electrons. The metals you will use are lead and uranium. Here are the basic components of each of your calorimeters.



You have to experiment with your calorimeters in a test beam to see that they

- trap pions in one calorimeter and electrons in the other for all possible beam energies.
- each have enough slabs to capture all the energy for particles in the test beam.
- do not have more slabs than you need because we cannot go over budget. These slabs and detectors are expensive!

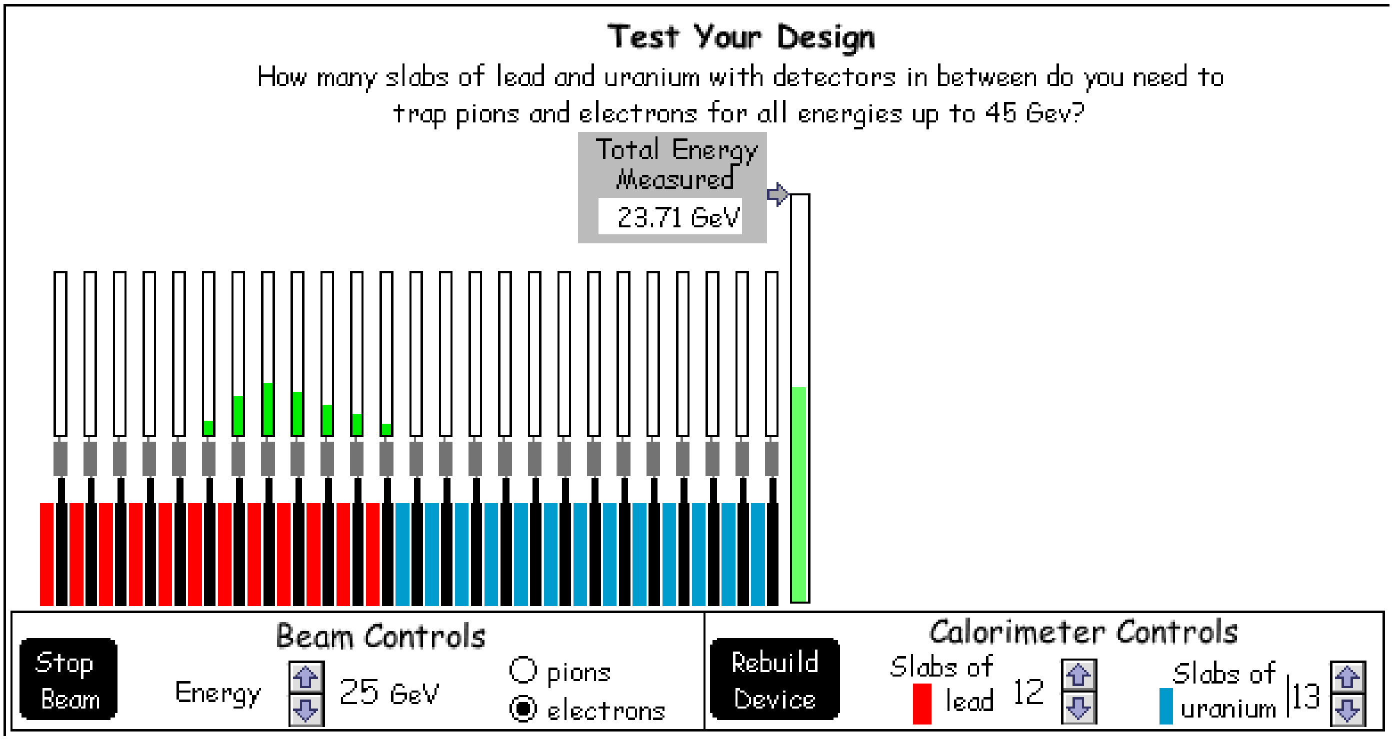
When you are done, answer these questions for your report and you can earn Einstein bucks!

Go to the Lab with the Test Beam.

Ghost Bustin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: July 2, 2000

http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/assignment.html


Test Your Design
How many slabs of lead and uranium with detectors in between do you need to trap pions and electrons for all energies up to 45 Gev?
Total Energy Measured
23.71 GeV
Beam Controls
Stop Beam
Energy
25 GeV
pions
electrons
Calorimeter Controls
Rebuild Device
Slabs of lead
12
Slabs of uranium
13

Particle Trappin'

Earn Einstein Bucks. Fill in the form below. You can always go back to the window with the calorimeter to check how it works.

Particles trapped in lead: ○ pions ○ electrons

Particles trapped in uranium: ○ pions ○ electrons

Least number of slabs of lead needed to measure 45 Gev particles:

Least number of slabs of uranium needed to measure 45 Gev particles:

To double your bucks, answer the following:

Each Z can decay into two pions **or** two electrons.
Each pion or electron has an energy of about 45 GeV.

About how much do you think the mass of the Z is? ○ 45 ○ 90 ○ 180

Web Maintainer: ed-webmaster@fnal.gov
Last Update: July 2, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/ghostbustin/calorimeter/test.html

Feedback on Marilyn Fox's Answers to Particle Trappin'

- Question 1: Yes, the lead traps electrons.
- Question 2: Yes, the uranium traps the pions.
- Question 3: You used too few slabs of lead; You'll miss some electrons!
- Question 4: You used too few slabs of uranium; you'll miss some pions!
- Doubling Your Bucks:
- Doubling Your Bucks: Sorry, you didn't double your bucks; all the mass of the Z is converted into the energy of two pions or electrons when it decays. If the energy of each pion or electron is 45 GeV, then the mass is 90.

Click to Print Bucks

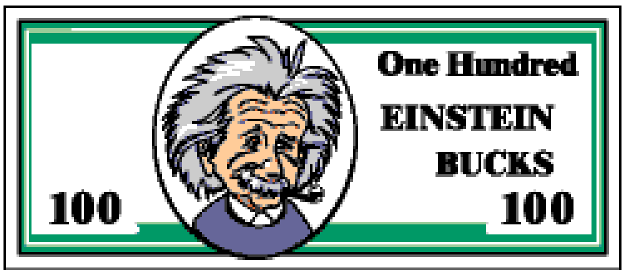
Fermilabyrinth
Batavia,IL 60510

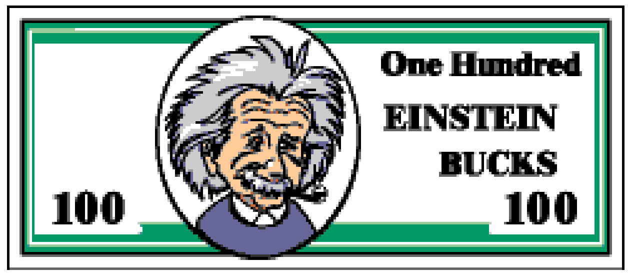
10/4/101

Pay to the order of: Marilyn Fox

200 Einstein Bucks

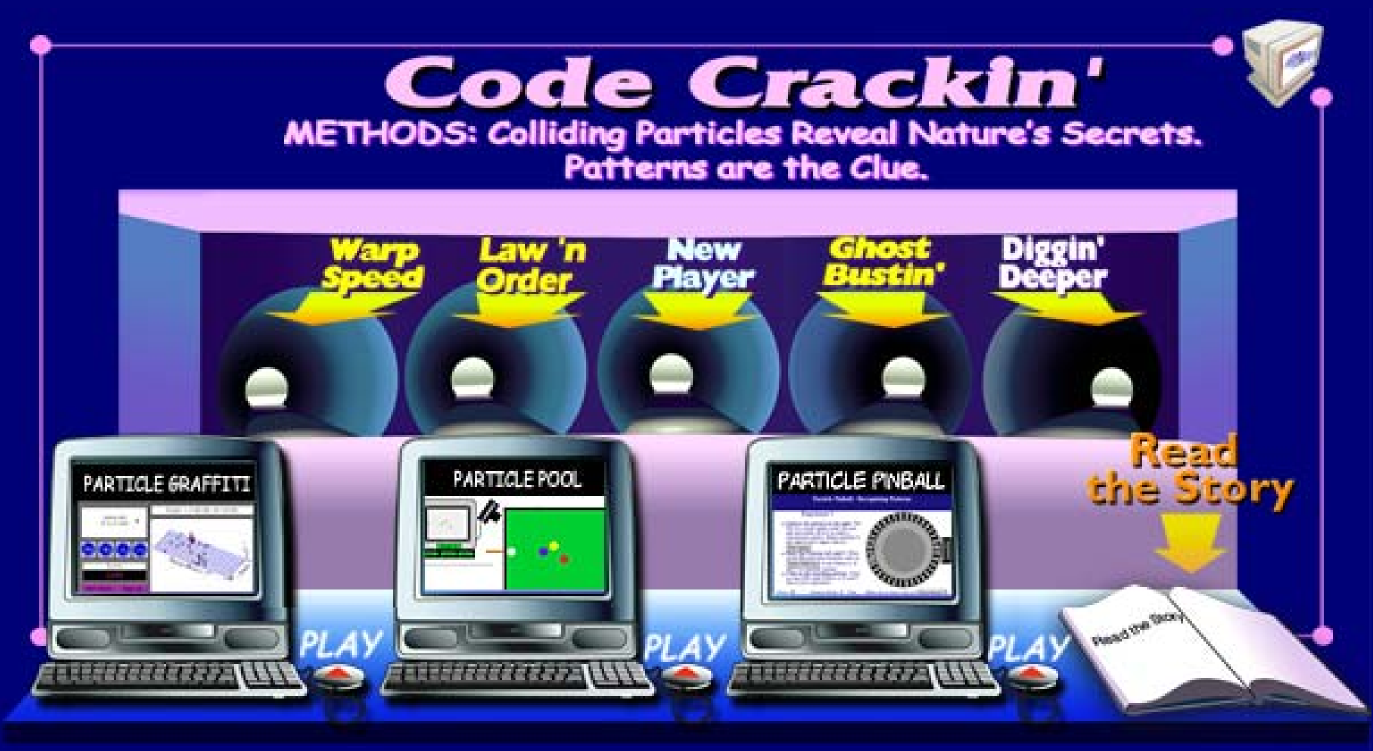
For: Particle Trappin



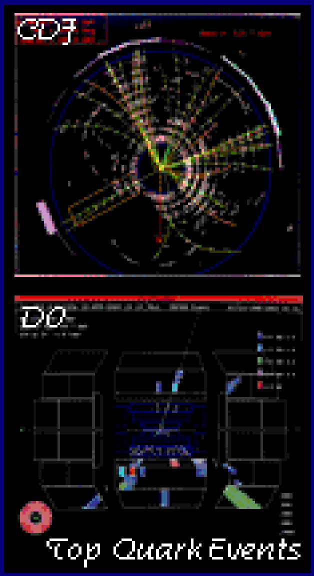


See The High Scores

If you do not see your name on the check, try resizing the window. Close this window when you have printed out your Einstein bucks or have looked at the high scores.


Code Crackin'
METHODS: Colliding Particles Reveal Nature's Secrets.
Patterns are the Clue.
Warp Speed
Law 'n Order
New Player
Ghost Bustin'
Diggin' Deeper
PARTICLE GRAFFITI
PARTICLE POOL
PARTICLE PINBALL
PLAY
PLAY
PLAY
Read the Story
Read the Story

Methods: Scattering and Collisions Patterns are the Clue.



Scientists work by posing important new questions about the natural world. They develop theories, and invent tools and techniques to answer their questions and test their theories. Particle physicists are scientists who develop and test theories about the smallest particles of matter. Fermilab physicists create particles by accelerating protons and making them collide with particle targets. Sometimes the protons collide with fixed particle targets (hydrogen ions, iron, tungsten, for example); sometimes the protons collide head on with moving anti-protons. These collisions (also called events) create new particles. Scientists record and study how the newly created particles move away (or scatter) from the collision. By observing this behavior, scientists can learn about the particles and the forces that control their interactions, and sometimes discover particles not seen before.

Code Crackin'

Read Particle Graffiti!


Control Room at the Collider Detector at Fermilab (CDF)

Today you're the physicist sitting in the control room at the CDF detector watching events as they appear on the computer screen. You are looking at the signatures of particles - "particle graffiti".

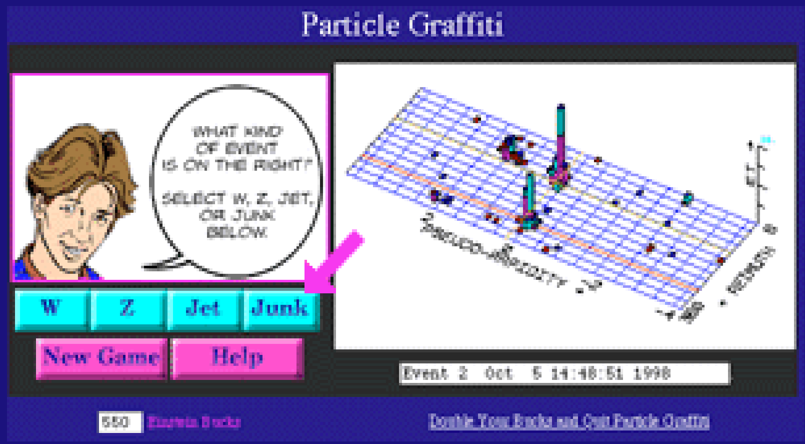
Click to Continue

....

0 Einstein Bucks

Double Your Bucks and Quit Particle Graffiti

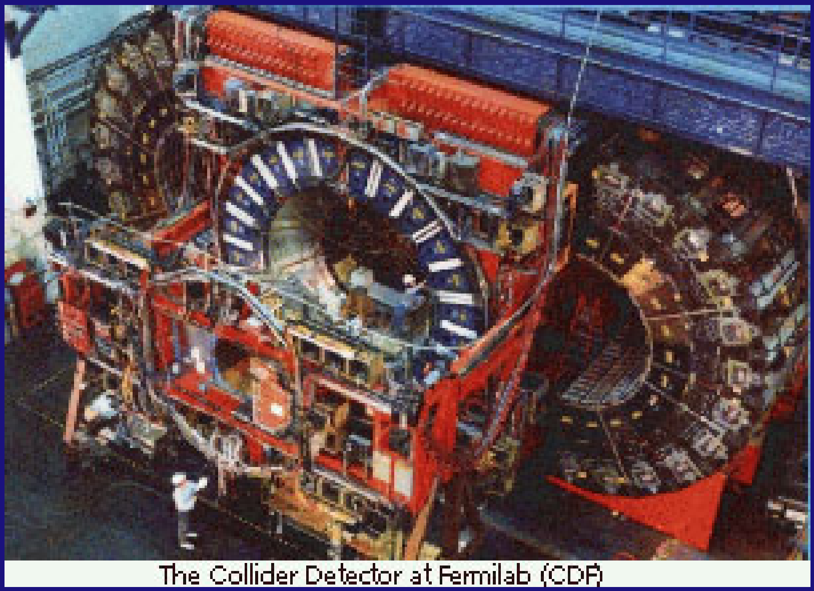
Your job is to identify W, Z, Jet and background or junk events by clicking on one of the four buttons whenever a new event appears. You will get Einstein bucks for correctly identifying particles and lose them if you misidentify them.



Remember if you get stuck, you can always click "Help".

Click to Continue

....

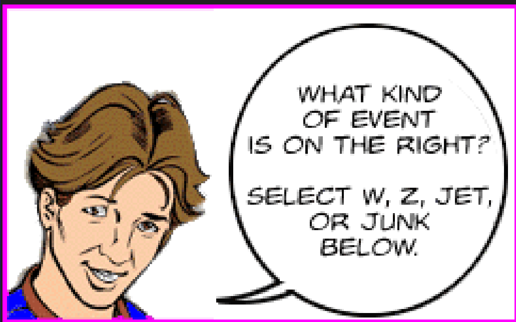


Physicists have made precise measurements of the masses of the W and Z particles. Using the CDF detector and the D0 detector, scientists discovered the top quark, the last quark to be observed.

Let's see how a good a physicist you are.

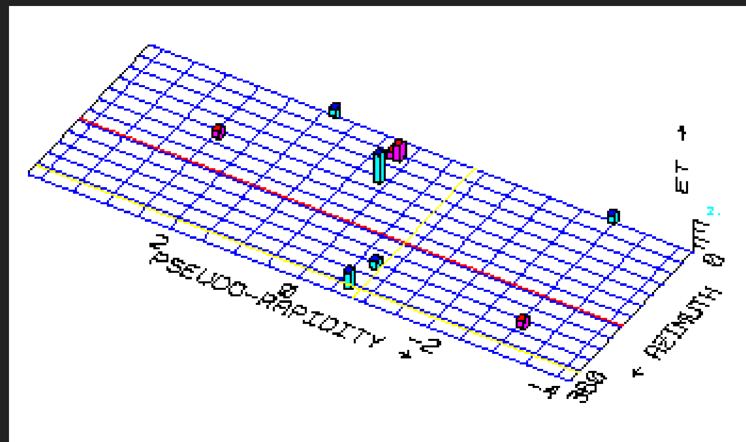
Play particle graffiti.

Particle Graffiti



W | Z | Jet | Junk

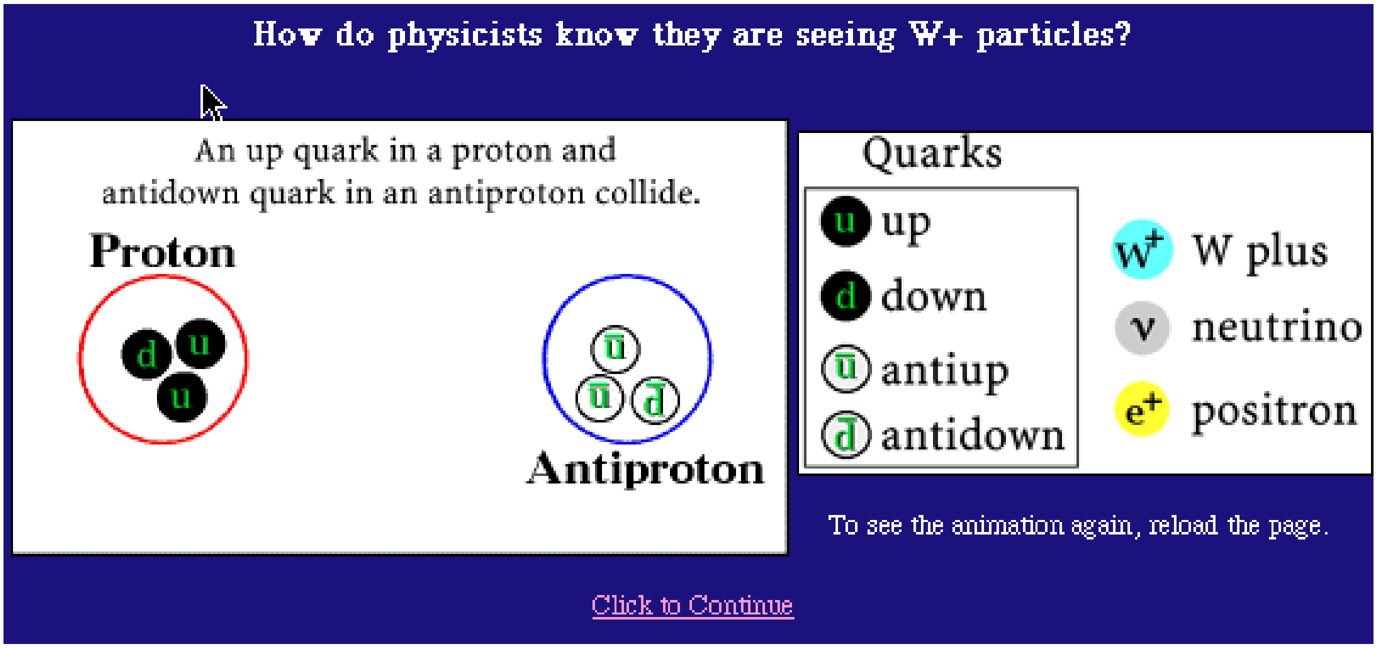
New Game | Help



Event 1 Jul 5 15:36:24 2000

500 Einstein Bucks

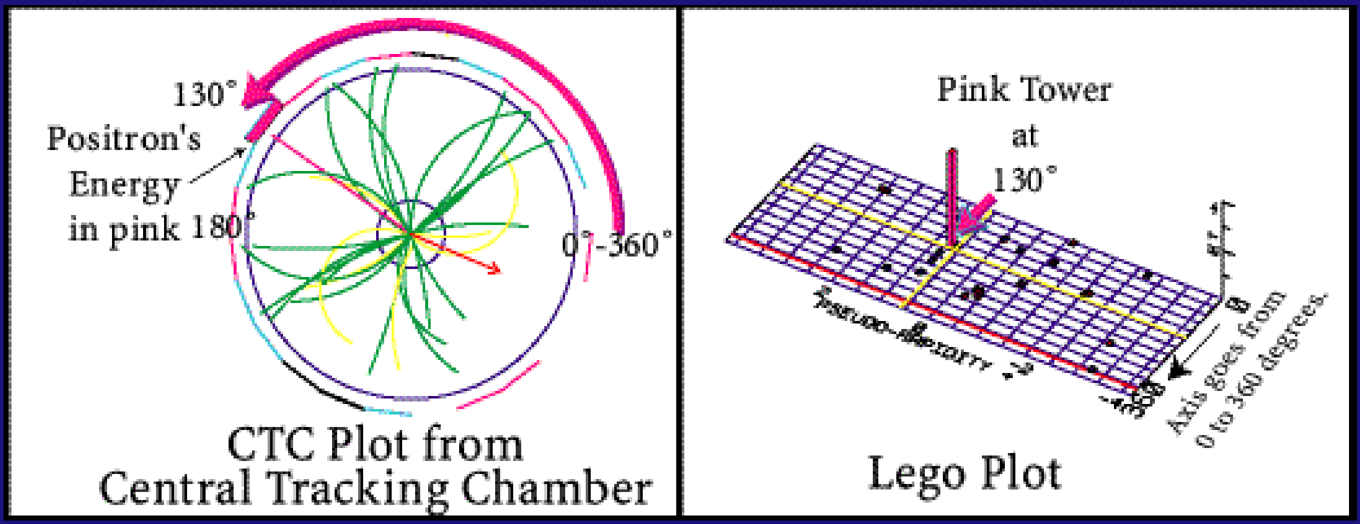
Double Your Bucks and Quit Particle Graffiti



Text in animated gif-
Making a W+ particle

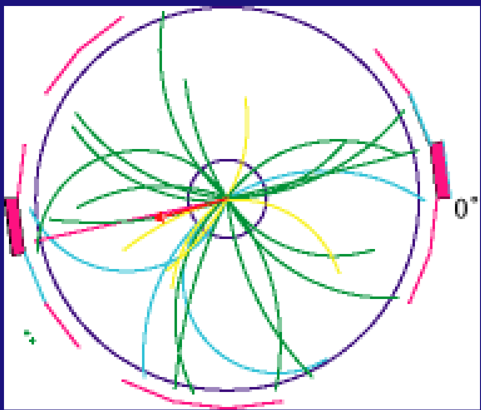
The up quark in a proton and the antidown quark in an antiproton collide.
The collision produces a W plus Particle
The W+ decays into a positron and neutrino.
The positron deposits energy in the lead calorimeter.
The positron's energy appears in pink in the plot.

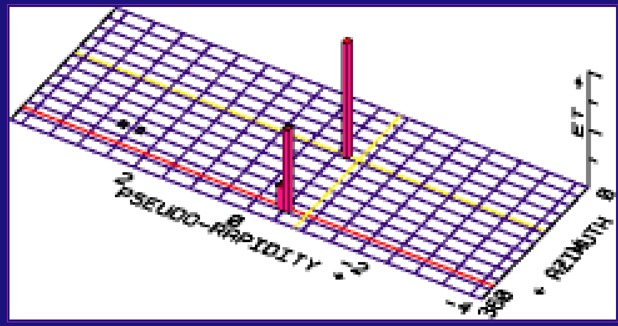
How does the positron appear in a lego plot?

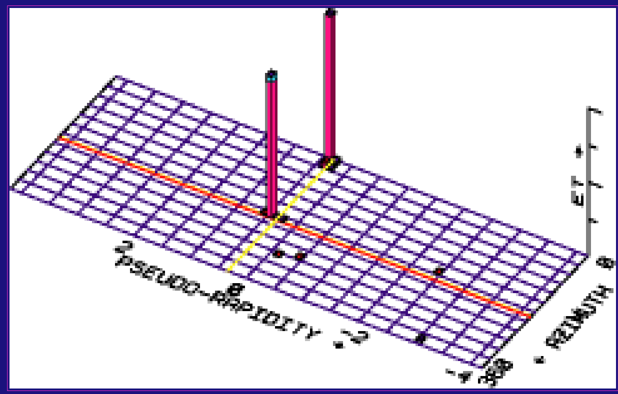


Click to see if you understand where (in degrees) the positron energy appears on each plot.

Here's a CTC plot of a Z event. We have a positron and electron depositing energy in opposite sides of the detector. To double your Einstein bucks, click on the lego plot on the right that corresponds to this CTC plot. Look at the previous plots for help.



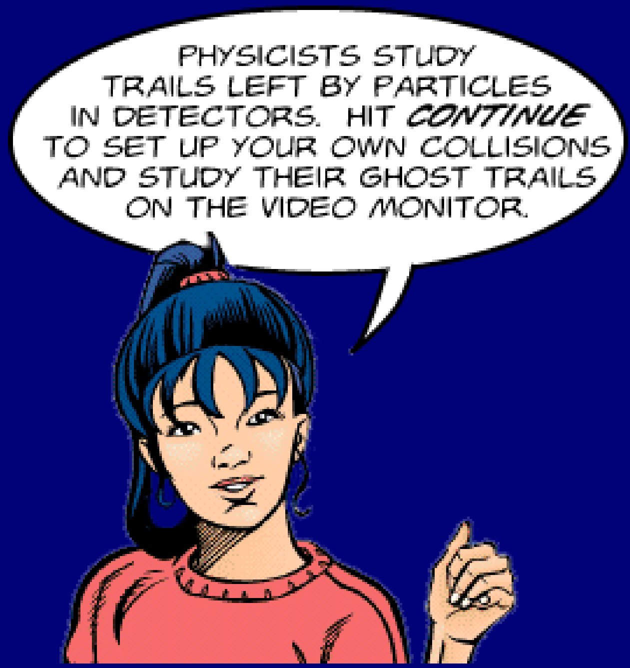


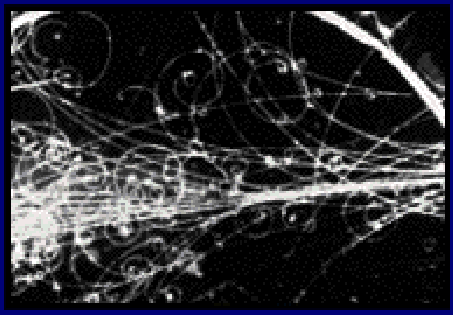


To Print Your Einstein Bucks

- Click on the Window with your bucks. If you cannot see it, click on Show Bucks.
- Select **Print** under the Browser **File** Menu.
- To check if you made the high score list, click High Score.
- When you are done, click on Quit Game.

Play Particle Pool



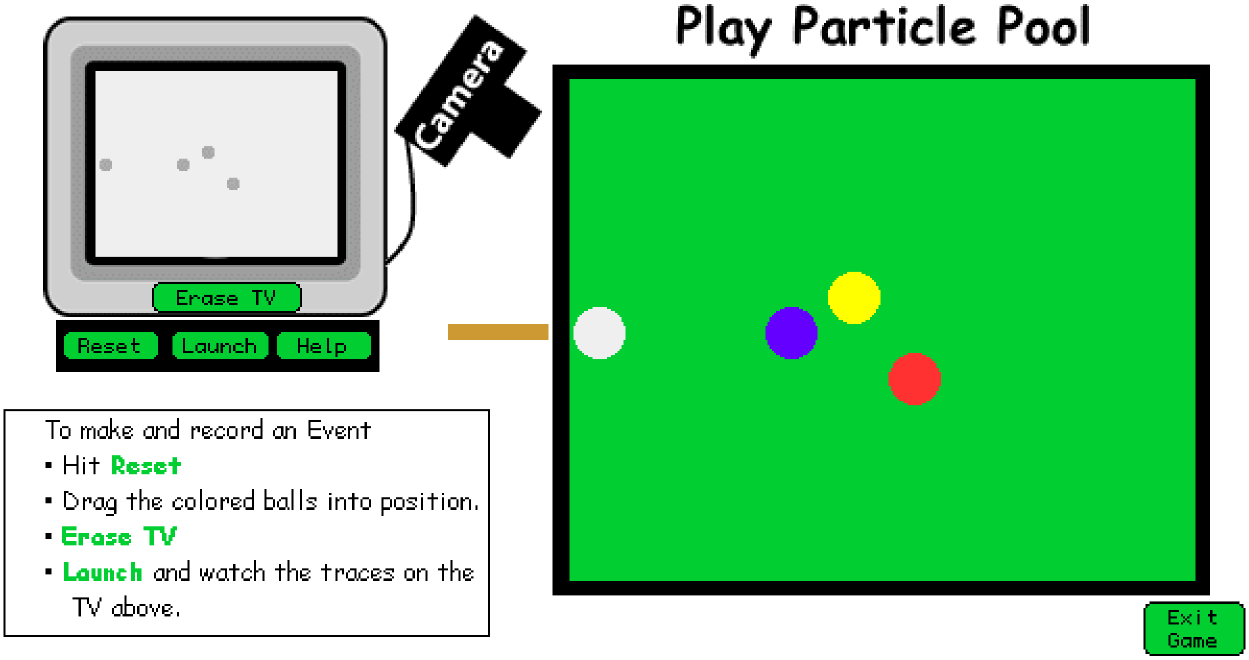

Tracks of Particles in a Bubble Chamber

Continue

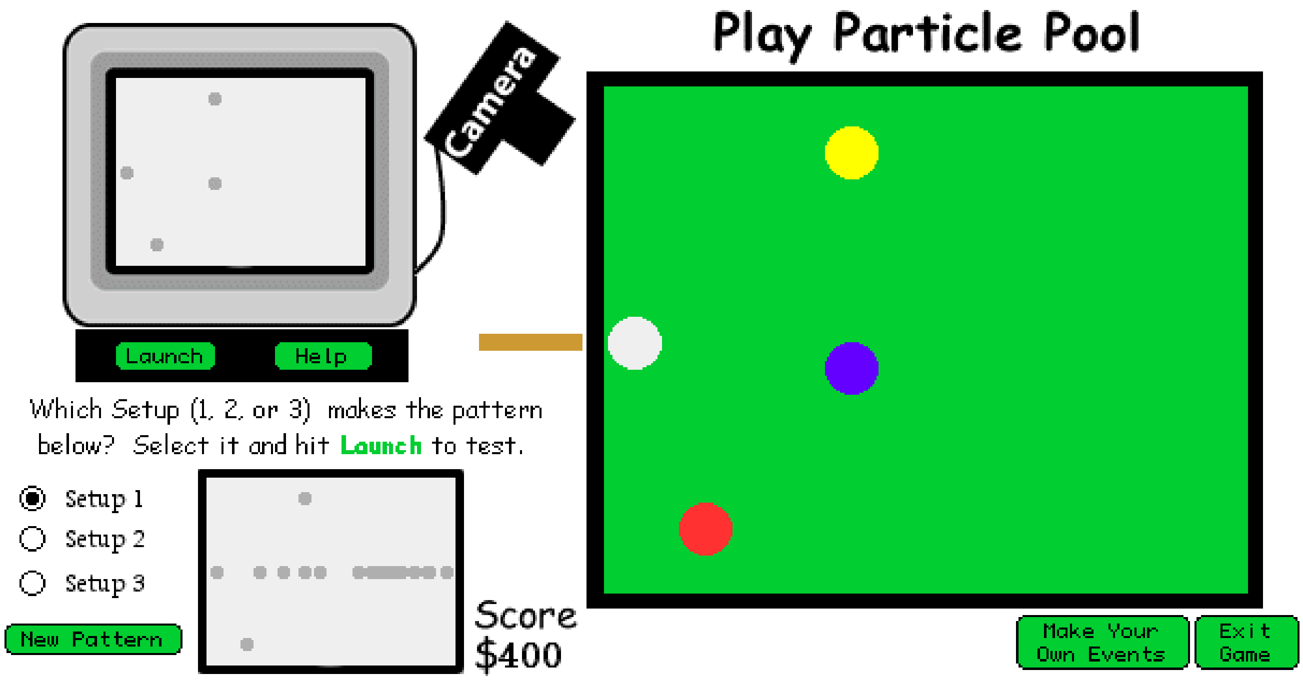
You don't have Shockwave. Get it!

This activity needs Shockwave. If you can't see the animation, click

GET SHOCKWAVE

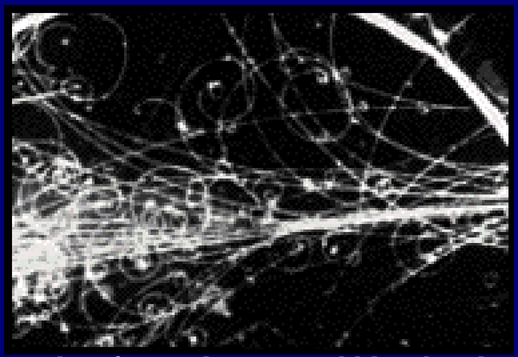


Code Crackin



Code Crackin

Adding a Magnet


Tracks of Particles in a Bubble Chamber

Look how some of the tracks in the bubble chamber picture are curved. Particle physicists discovered that they could make the trails of the particles more distinctive if they put a magnet in their apparatus. The paths of charged particles would bend. The direction a particle bent depended on whether the particle had a positive or negative charge. In Particle Pool, we had nothing comparable to a magnet so our tracks were straight.

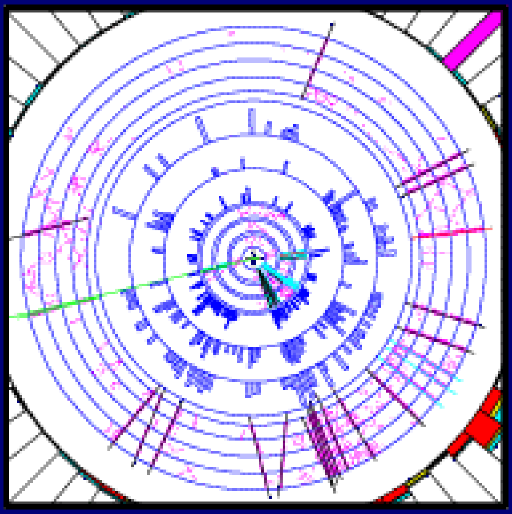
Double Your Einstein Bucks.

Code Crackin'

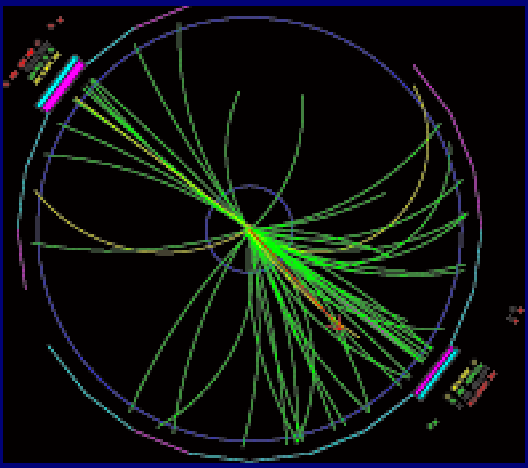
Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 9, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pool/pp_moreinfo.html

Particle Pool - Double Your Einstein Bucks!!

Look at the tracks in events from the two collider experiments at Fermilab, D0 and CDF. Can you tell which one or ones used a magnet as part of the detector? Select the correct answer on the right and double your bucks!



D0 Event



CDF Event

Only D0

Only CDF

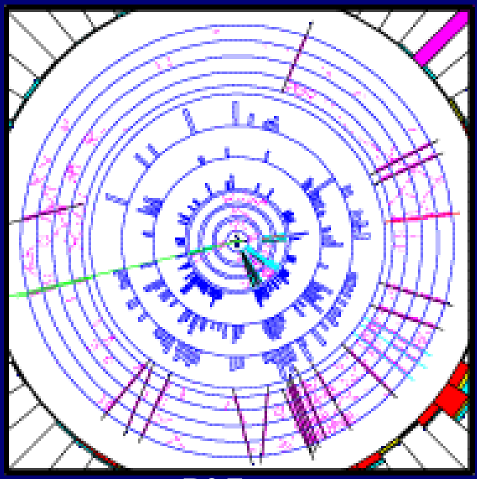
Both D0 and CDF

Code Crackin'

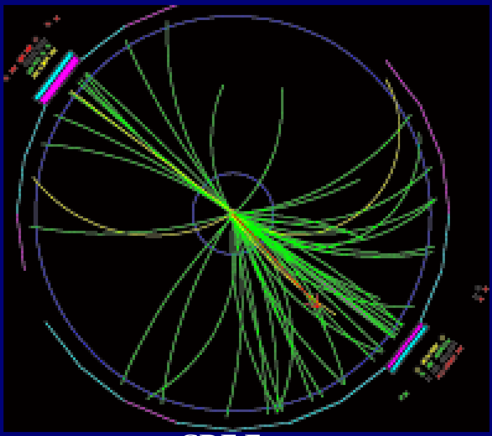
Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 9, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pool/double_bucks.html

Great! You now have Einstein Bucks!!

Only the CDF detector had a magnet when experimenters at CDF and D0 discovered the top quark. Many of the tracks in the CDF event are curved, but those in the D0 event are not. The next upgrade of the D0 detector has a magnet.



D0 Event



CDF Event

Print Your Bucks

Go Back

Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 10, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pool/correct.html

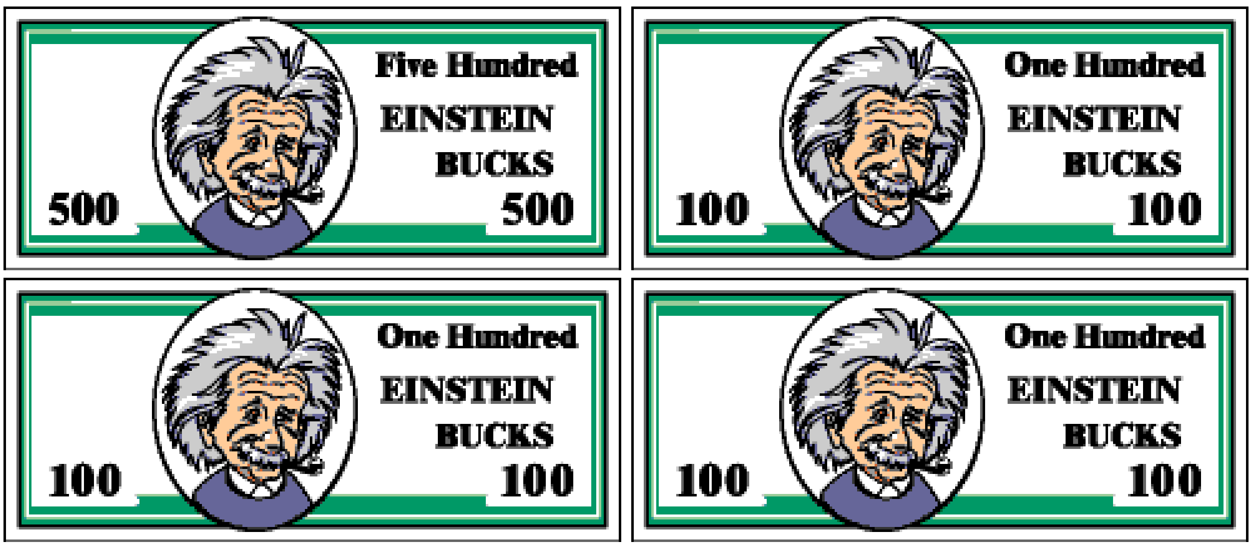
Fermilabyrinth
Batavia,IL 60510

10/4/2001

Pay to the order of: Marilyn Fox

800 Einstein Bucks

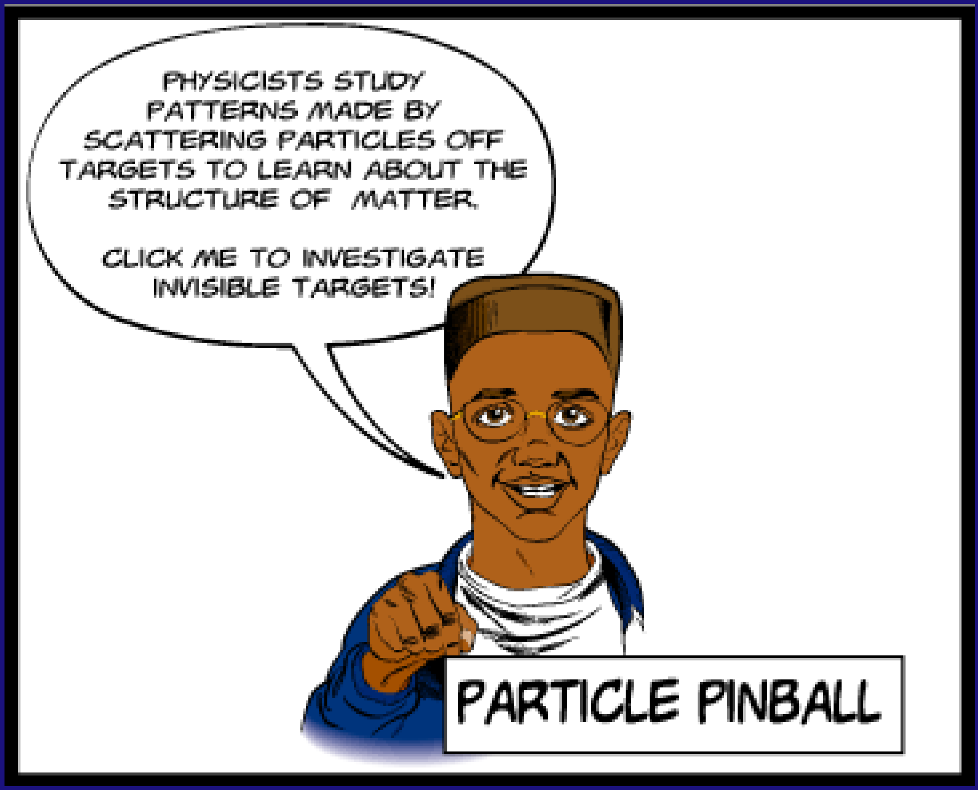
For: Particle Pool



See The High Scores

If you do not see your name on the check, try resizing the window. Close this window when you have printed out your Einstein bucks or have looked at the high scores.

Particle Pinball - Recognizing Patterns

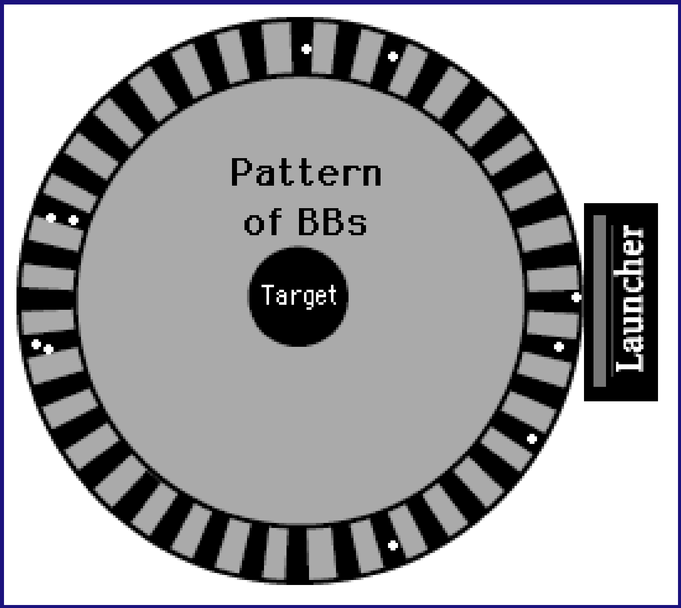


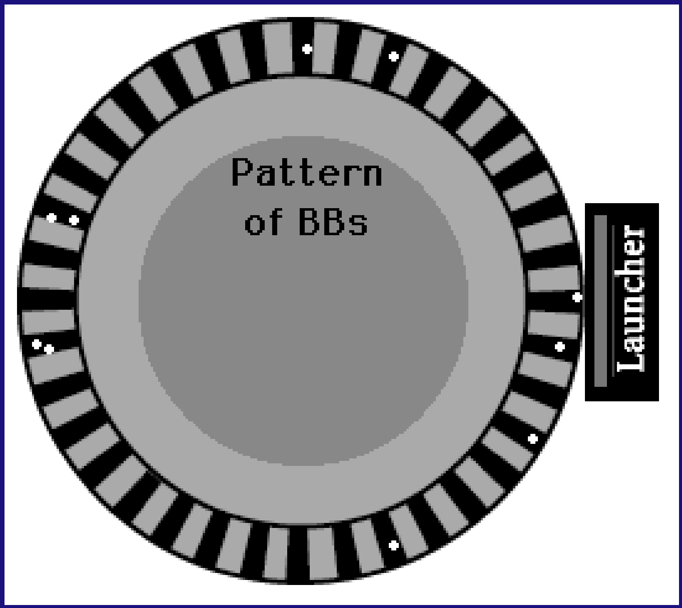
Code Crackin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 25, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/index.html

Particle Pinball - Recognizing Patterns

Look at the pattern made by BBs hitting a circular target. They produce a characteristic pattern as they pass by or careen off the target and land in the black bins around the outside. Can you recognize the patterns made by different hidden targets? To try, click on





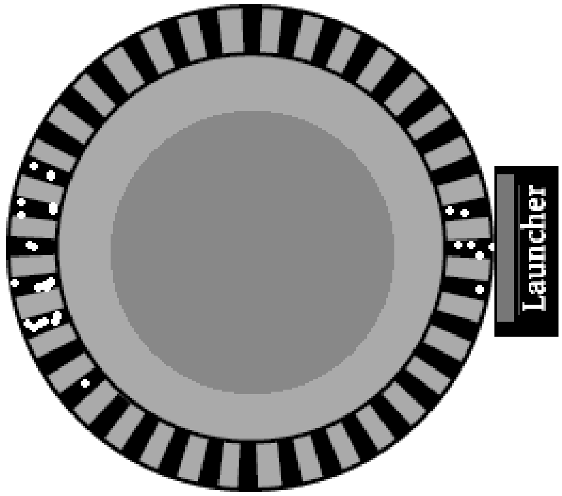
Code Crackin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 20, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/activity.html

Particle Pinball - Recognizing Patterns

Experiment 1

- **Observe the pattern on the right:** The BBs hit a target hidden under the gray disk and scatter off of it to make a characteristic pattern. Watch carefully! If you need to see it again, click on [Play Again]
- **Match the pattern the BBs made with Patterns A,B, or C:** Click on [Show Patterns A,B,&C].
- **Click on the matching pattern (Pattern A, B or C):**

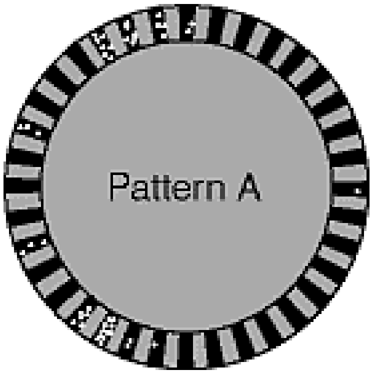


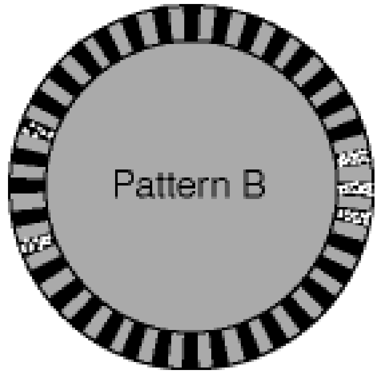
Score: $ 0 Einstein Bucks 0 Tries

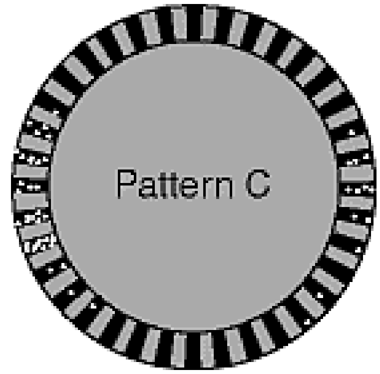
When you're done, click on [Experiment 2]

Code Crackin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 22, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/experiment1.html





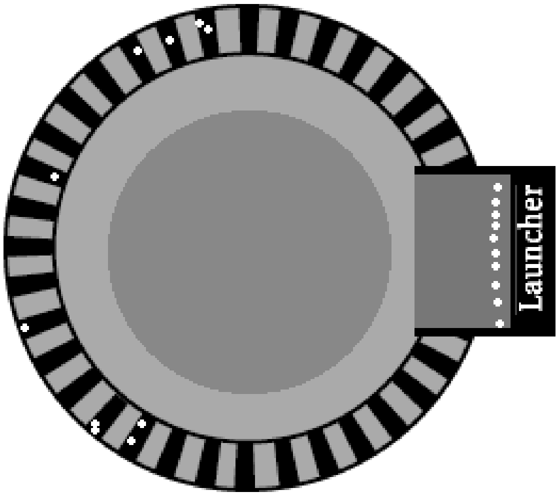


Click on the pattern above that matches your results in the experiment. Twice as many BBs made Patterns A, B, and C than in your experiment.

Particle Pinball - Recognizing Patterns

Experiment 2

- **Observe the pattern on the right**: The BBs hit a target hidden under the gray disk and scatter off of it to make a characteristic pattern. Watch carefully! If you need to see it again, click on [Play Again]
- **Match the pattern the BBs made with Patterns A,B, or C**: Click on [Show Patterns A,B ,&C].
- **Click on the matching pattern (Pattern A, B or C)**:



Score: $ 0 Einstein Bucks 0 Tries

When you're done, click on [Experiment 3]

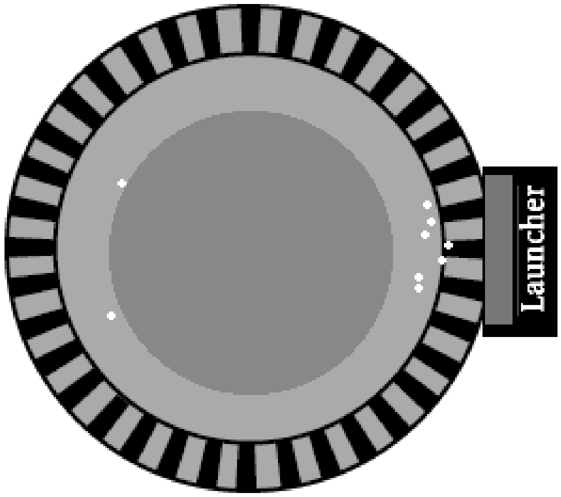
Code Crackin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 22, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/experiment2.html

Particle Pinball - Recognizing Patterns

Experiment 3

- **Observe the pattern on the right**: The BBs hit a target hidden under the gray disk and scatter off of it to make a characteristic pattern. Watch carefully! If you need to see it again, click on [Play Again]
- **Match the pattern the BBs made with Patterns A,B, or C**: Click on [Show Patterns A,B ,&C].
- **Click on the matching pattern (Pattern A, B or C)**:



Score: $ [0] Einstein Bucks [0] Tries

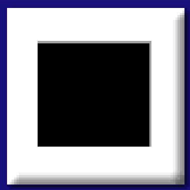
When you're done, click on [Double Your Bucks]

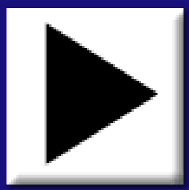
Code Crackin'

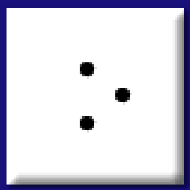
Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 22, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/experiment3.html

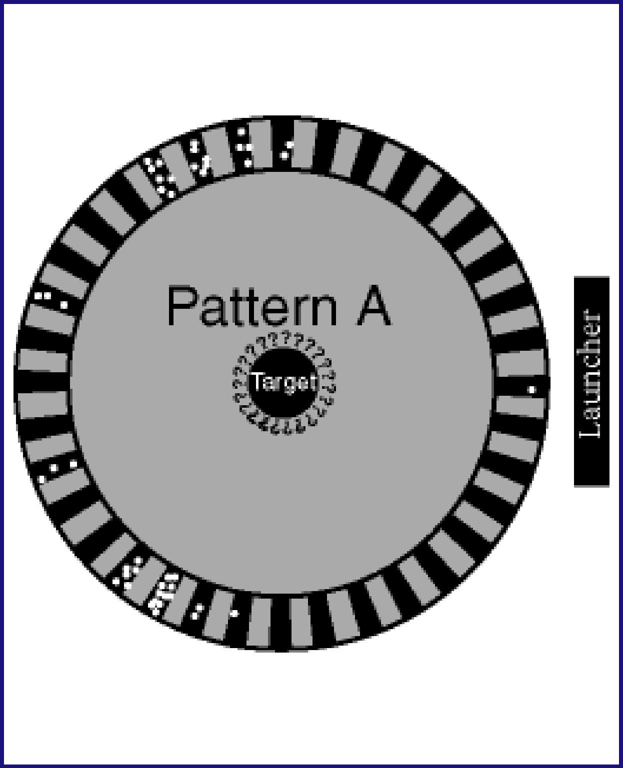
Particle Pinball - Double Your Einstein Bucks!!

In Experiment 2, you made a pattern like Pattern A. When the gray disk was taken off to reveal the hidden target, what shape do you think it had? Was it a square, triangle, or three pegs? Click on the correct shape below.







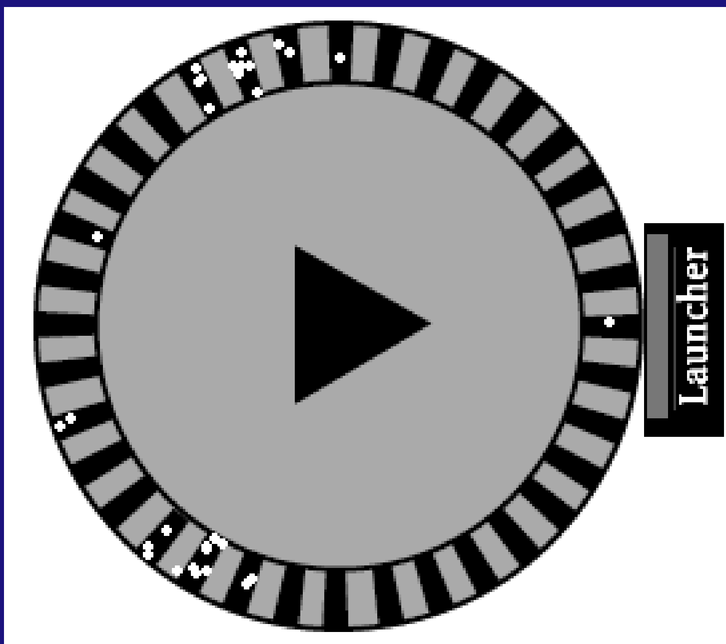


Code Crackin'

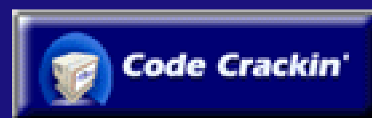
Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 20, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/pinball_bucks1.html

Sorry! You still have Einstein Bucks!!

Pattern A is made by the BBs hitting a triangle.



Print Your Bucks

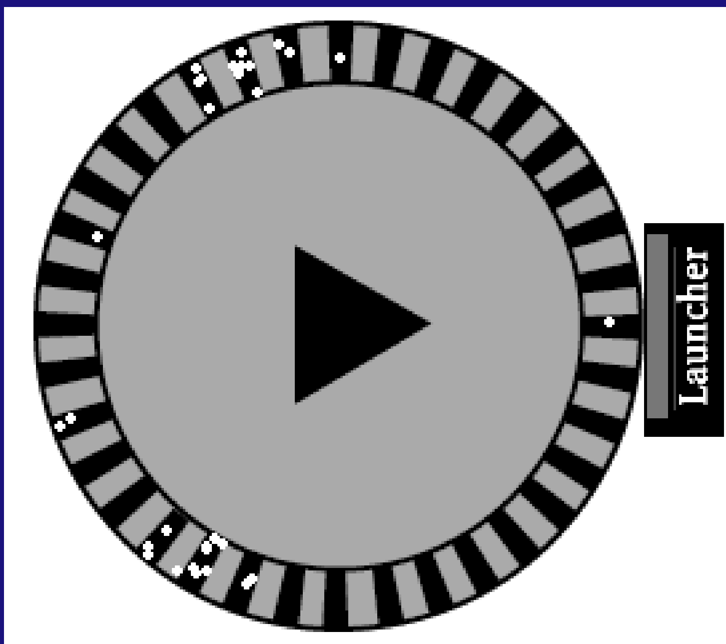


Go Back

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 24, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/wrong1.html

Great! You now have Einstein Bucks!!

Pattern A is made by the BBs hitting a triangle.

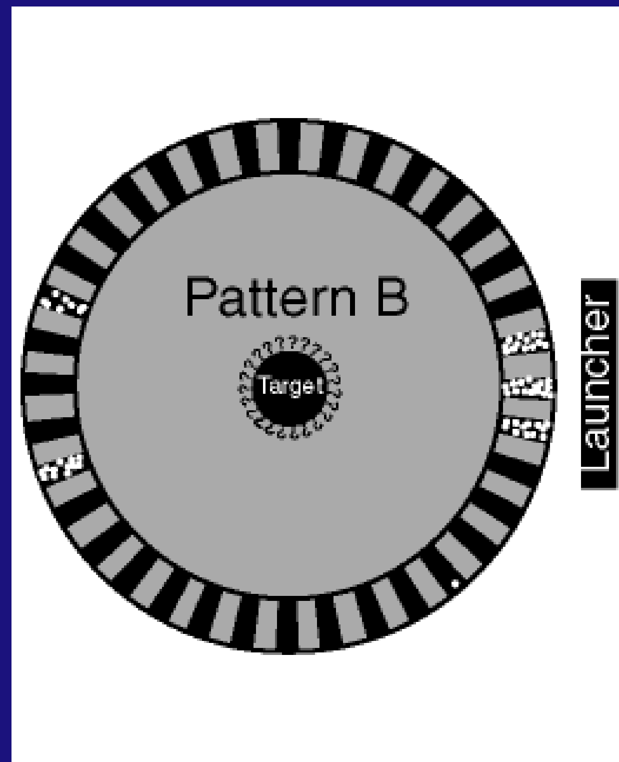


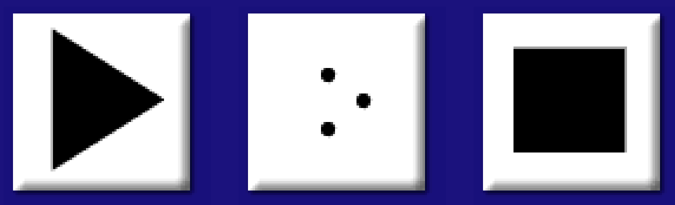
Print Your Bucks

Go Back

Particle Pinball - Double Your Einstein Bucks!!

In Experiment 3, you made a pattern like Pattern B. When the gray disk was taken off to reveal the hidden target, what shape do you think it had? Was it a square, triangle, or three pegs? Click on the correct shape below.



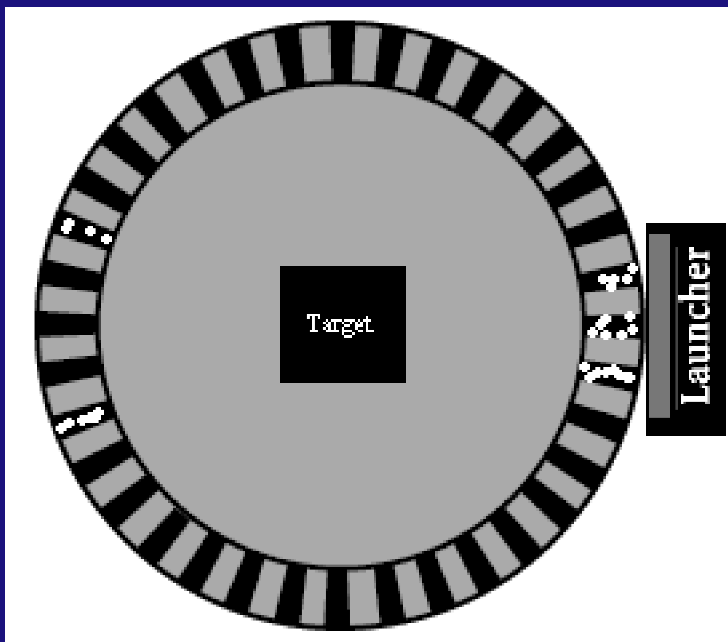


Code Crackin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 24, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/pinball_bucks2.html

Sorry! You still have Einstein Bucks!!

Pattern B is made by the BBs hitting a square.



Print Your Bucks

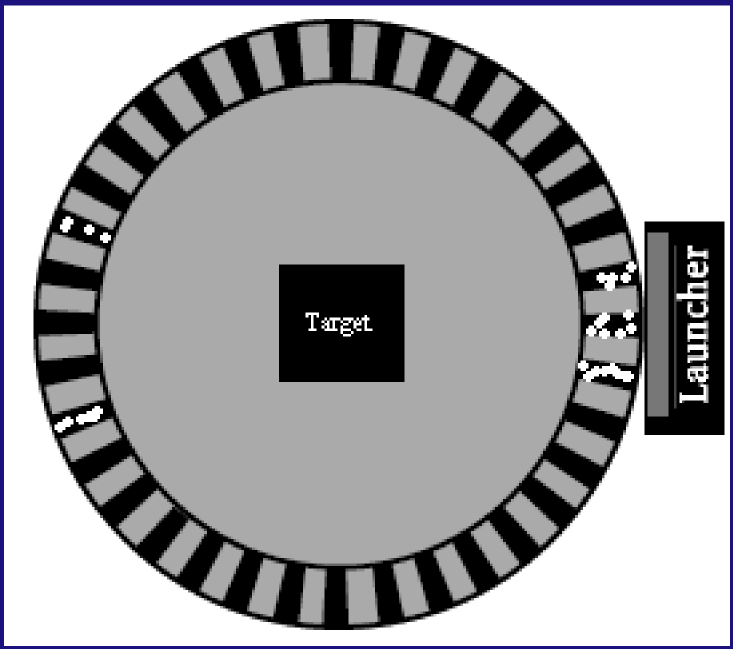
Code Crackin'

Go Back

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 20, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/wrong2.html

Great! You now have Einstein Bucks!!

Pattern B is made by the BBs hitting a square.



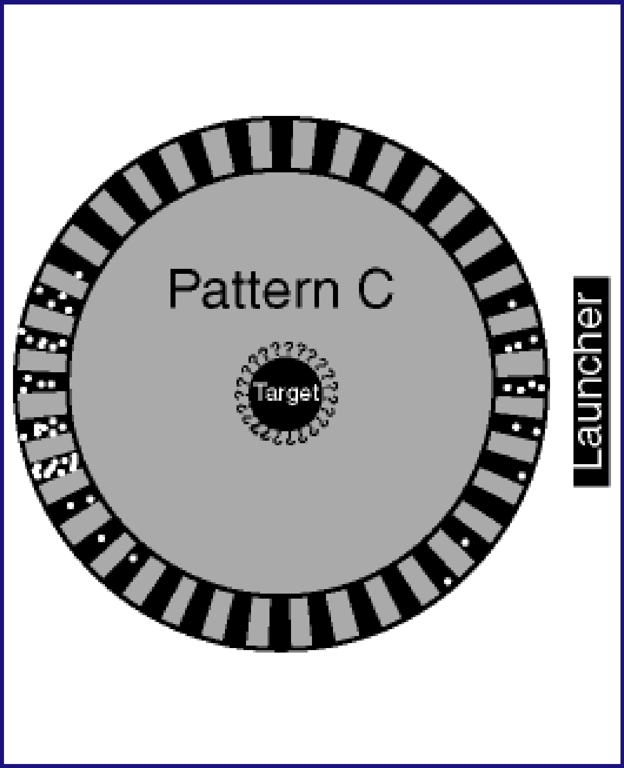
Print Your Bucks

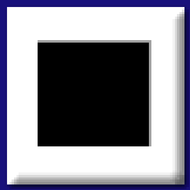
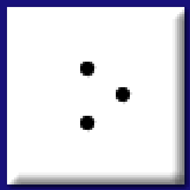
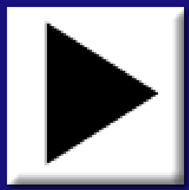
Go Back

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 20, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/correct2.html

Particle Pinball - Double Your Einstein Bucks!!

In Experiment 1, you you made a pattern like Pattern C. When the gray disk was taken off to reveal the hidden target, what shape do you think it had? Was it a square, triangle, or three pegs? Click on the correct shape below.



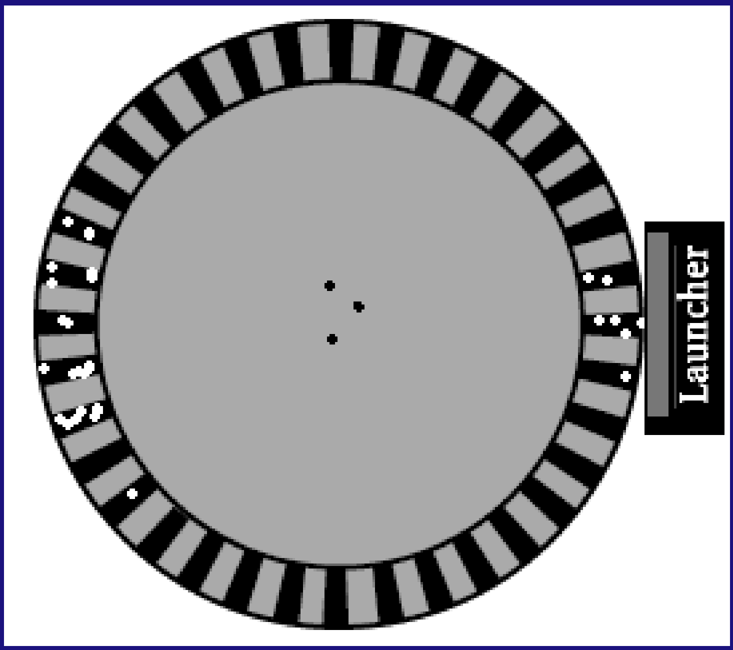




Code Crackin'

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 20, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/pinball_bucks3.html

Sorry! You still have Einstein Bucks!!

Pattern C is made by the BBs hitting three pegs.



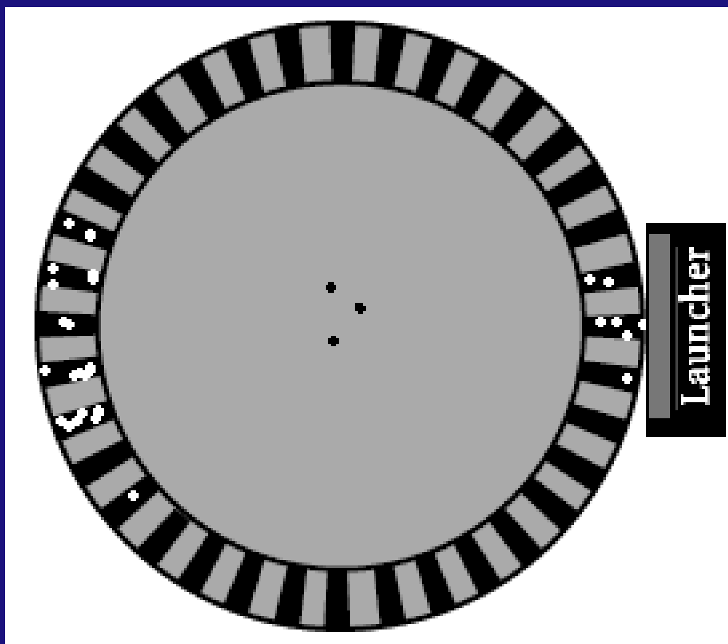
Print Your Bucks

Go Back

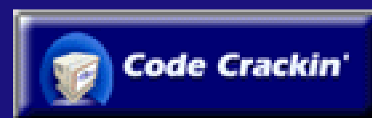
Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 24, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/wrong3.html

Great! You now have Einstein Bucks!!

Pattern C is made by the BBs hitting three pegs.



Print Your Bucks



Go Back

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 24, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/codecrackin/particle_pinball/correct3.html

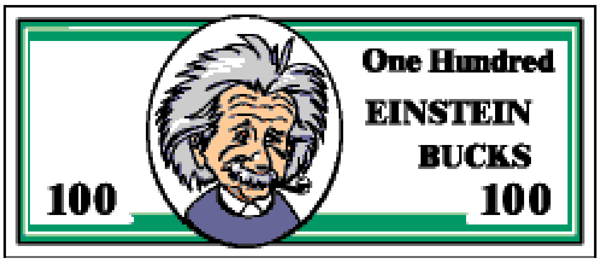
Fermilabyrinth
Batavia,IL 60510

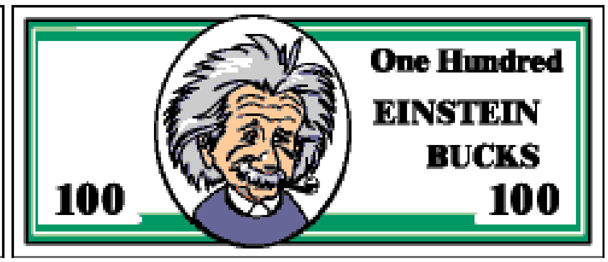
10/5/101

Pay to the order of: Marilyn Fox

200 Einstein Bucks

For: Particle Pinball





See The High Scores

If you do not see your name on the check, try resizing the window. Close this window when you have printed out your Einstein bucks or have looked at the high scores.


E=mc²
Law 'n Order
IDEAS: Scientists Discover Nature's Laws
Warp Speed
Ghost Bustin'
New Player
Code Crackin'
Diggin' Deeper
Baryon Bonanza
PARTICLE FAMILIES
NATURE'S SCALE
FOUR FORCES
Read the Story
Read the Story

Ideas: Discovering Nature's Laws

There is an amazing beauty and symmetry in nature. Think of snowflake, a daisy or a honeycomb. The shapes of these and all other natural objects depend on an underlying structure of matter. For centuries scientists have wondered what this structure might be. Their studies have led to a search for particles that are the smallest, simplest building blocks of matter, and for the forces that control their behavior. The particles are quarks and leptons; the forces are gravity, electromagnetism, the weak force and the strong force. Fermilab scientists are leading this international search to learn how the universe works.

When scientists study the subatomic particles and forces that bind them together, they also learn about the early history of the universe and how it began with the "Big Bang." When the universe was very young, atoms didn't exist, because it was too hot for them to form. The only form of matter was a sort of "primordial soup," consisting of the most basic particles, such as quarks and electrons. At Fermilab, scientists use the Tevatron to make the ingredients of primordial soup by smashing together protons and antiprotons at very high energies. The earlier we look in time, the fewer and more basic the particles become, and the fewer forces are needed to control their behavior. The laws of physics are valid in the whole universe and throughout the whole of time.

Law 'n Order

Can You Make Particles with Nature's Building Blocks?

Physicists developed the Standard Model in the late 1960s and early '70s to explain the particles in the Particle Zoo.

Physicists proposed that the Particle Zoo contained basic particles called Leptons, force carriers called Bosons and compound particles made of basic particles called Quarks.

Do quarks have structure?

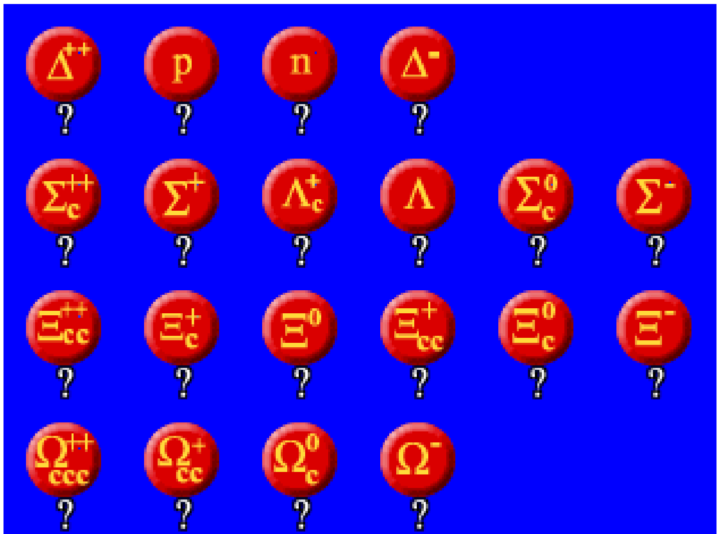
Someday, maybe you will find the answer!

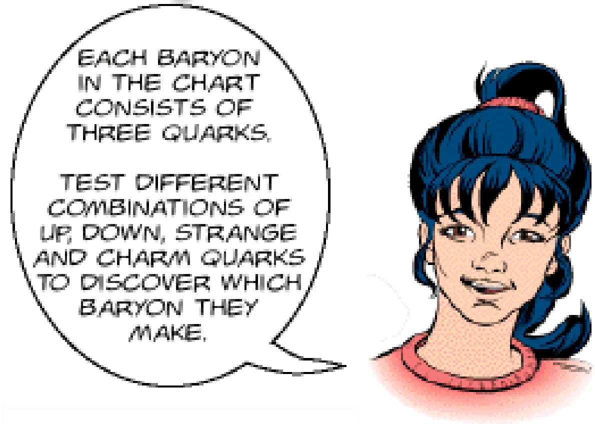
Baryon Bonanza

Law 'n Order

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 28, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/standard_model/activity.html

Baryon Bonanza





Baryon Name:

u d c

up | down | charm | TEST

Select three quarks and hit TEST.

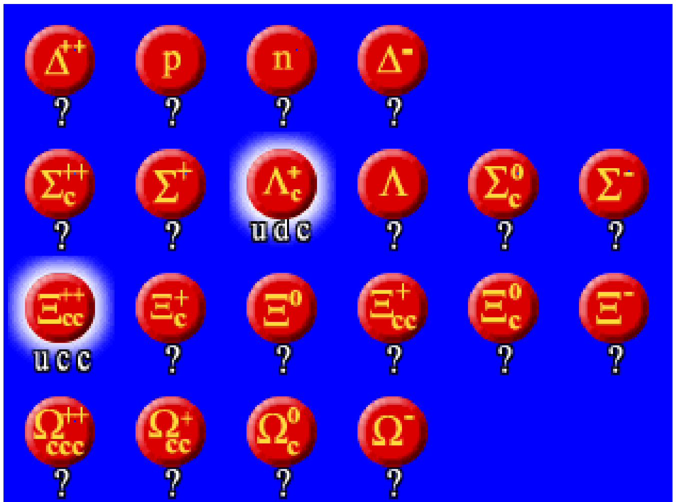
You've earned $ 0 Einstein Bucks!

When finished, click below to

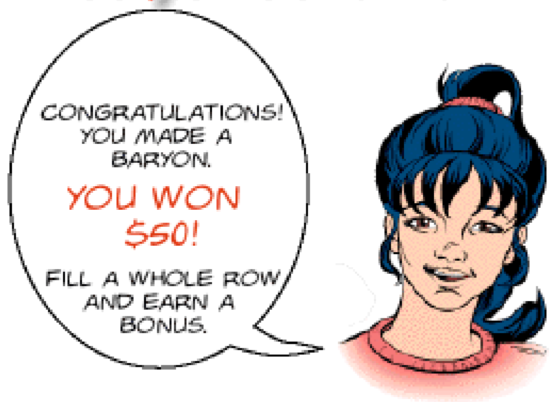
Curious? | DOUBLE YOUR BUCKS!

Law 'n Order

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 28, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/standard_model/baryon_table.html



Baryon Bonanza



Baryon Name: Xi cc ++

u c c

up | charm | charm | TEST

Select three quarks and hit TEST.

You've earned $ 100 Einstein Bucks!

When finished, click below to

Curious? | DOUBLE YOUR BUCKS!

Law 'n Order

[Making Baryons] [Matter/ Antimatter] [Antibaryons] [Mesons] [Hadrons]

Making Baryons: Some quark combinations can actually make more than one baryon, but the game only shows one to make it simpler. You could make even more baryons if you combined these four quarks with the bottom quark, but not the top quark. The top quark lives for such a short time that it cannot combine with other quarks to form a baryon.

Matter/Antimatter: For every kind of particle there is a corresponding kind of antiparticle. This almost doubles the size of the Particle Zoo. When a particle and its antiparticle get together, they can annihilate into pure energy or into other particles. This happens at Fermilab when protons and antiprotons collide in the Tevatron. The Tevatron Collider is the only place in the world where physicists can make all the observed particles.

Proton/Antiproton Collision

Antibaryons - Even More Baryons: For every quark combination that makes a baryon, you can make an antiquark combination. For example, if you combine an antidown, antiup and antiup quark, you get an antiproton! But Nature does not combine quarks and antiquarks in baryons.

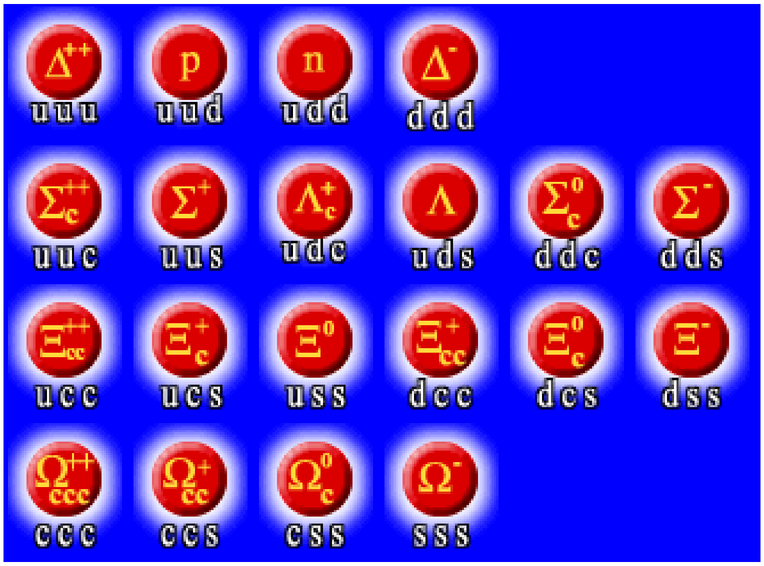
Mesons: Quarks and antiquarks combine to make a whole new set of particles called mesons. For example, up and antidown make a pion; an strange and antiup make a kaon. These quark pairs add many more particles to the Particle Zoo.

Hadrons: are particles made from quarks. Mesons and baryons are hadrons.

[Making Baryons] [Matter/ Antimatter] [Antibaryons] [Mesons] [Hadrons]

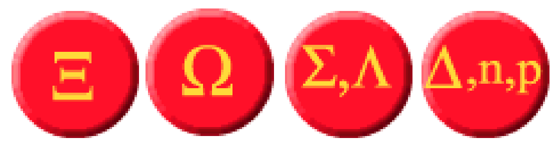
Close this window when you are done.

Welcome to Double Delight where you can go home with double the bucks you came in with by answering a question.



Physicists named baryons with Greek letters like you see on the buttons below. What letter(s) did they give **baryons made of two up or down quarks and one charm and strange quarks**?

Study the chart to see which Greek letters they used and then click below on the matching letter(s).



Xis

Omegas

Sigmas and Lambdas

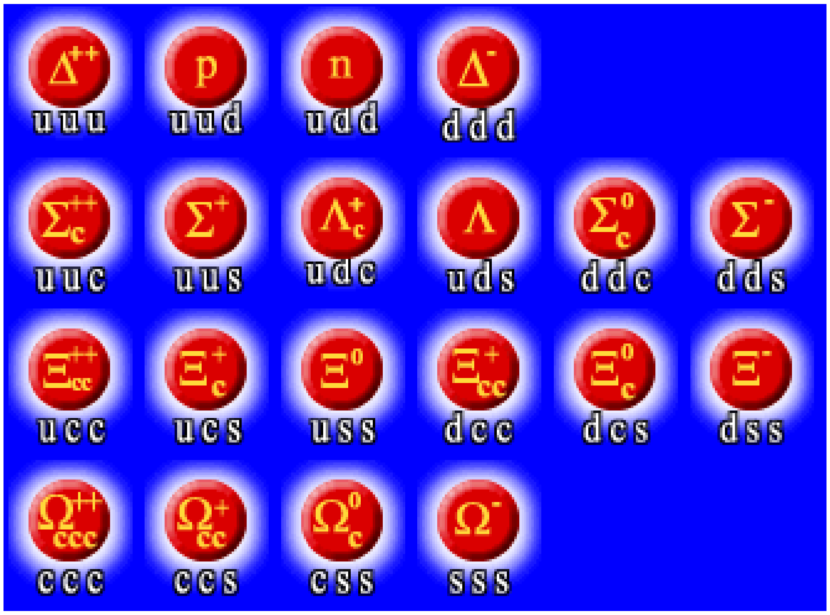
Deltas, neutron and proton

Law 'n Order

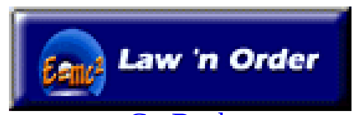
Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 28, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/standard_model/baryon_bucks4.html

Great! You Made The Correct Choice!
You doubled your Einstein Bucks!!

The sigmas and lambas are made up of two up or down and one strange or charm quarks.



Print Your Bucks



Go Back

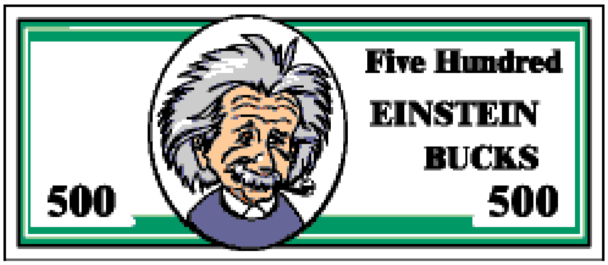
Fermilabyrinth
Batavia,IL 60510

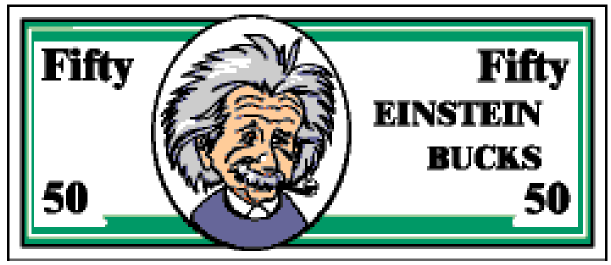
10/5/101

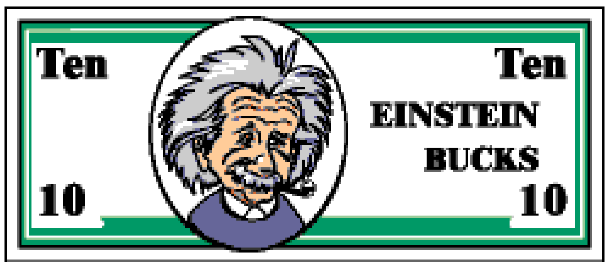
Pay to the order of: Marilyn Fox

560 Einstein Bucks

For: Baryon Bonanza





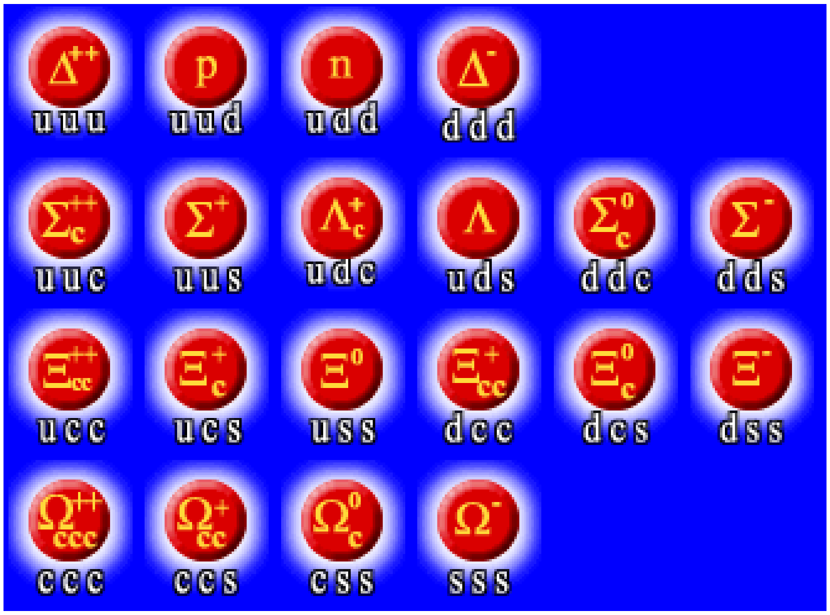


See The High Scores

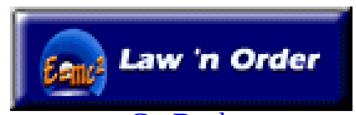
If you do not see your name on the check, try resizing the window. Close this window when you have printed out your Einstein bucks or have looked at the high scores.

Sorry! You made the wrong choice! The correct answer is sigmas and lambdas

The sigmas and lambas are made up of two up or down and one strange or charm quarks.

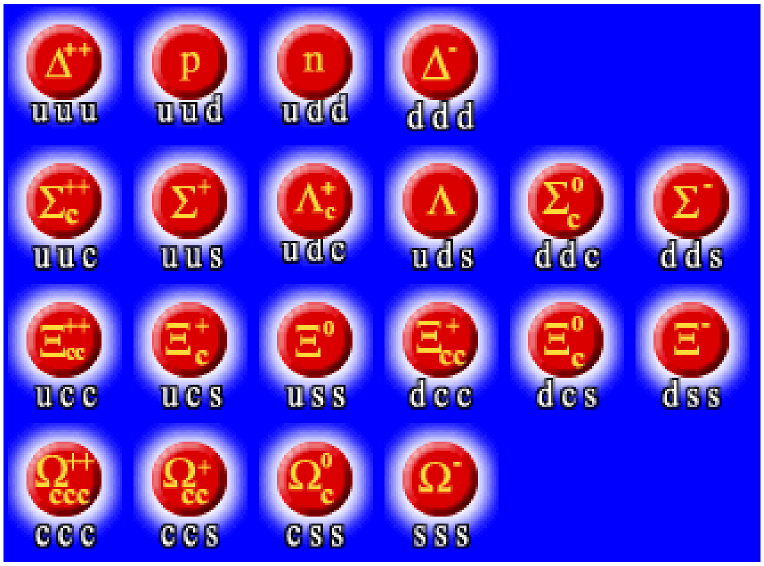


Print Your Bucks



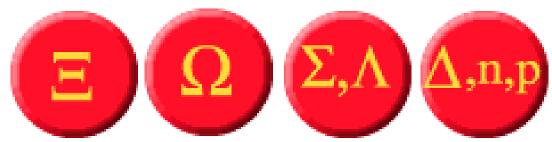
Go Back

Welcome to Double Delight where you can go home with double the bucks you came in with by answering a question.



Physicists named baryons with Greek letters like you see on the buttons below. What Greek letter(s) did they give **baryons made of only up and down quarks**?

Study the chart to find baryons with the right quarks, look at what Greek letters they have and then click on the matching letter(s) below.



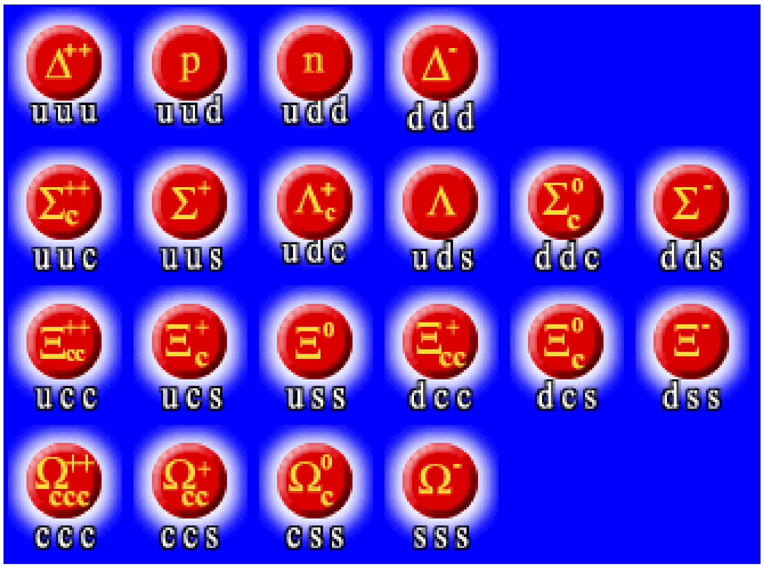
Xis | Omegas | Sigmas and Lambdas | Deltas, neutron and proton

---

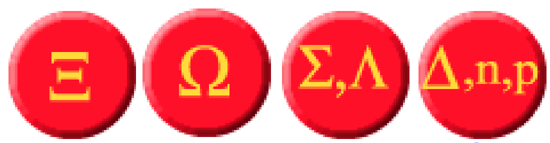
Law 'n Order

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 28, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/standard_model/baryon_bucks1.html

Welcome to Double Delight where you can go home with double the bucks you came in with by answering a question.



- Find the row of baryons made of **only charm and strange quarks** in the chart on the left.
- See the strange letters physicists used to label them? They're mainly letters in the Greek alphabet.
- Click on the matching letter(s) below.



Xis | Omegas | Sigmas and Lambdas | Deltas, neutron and proton

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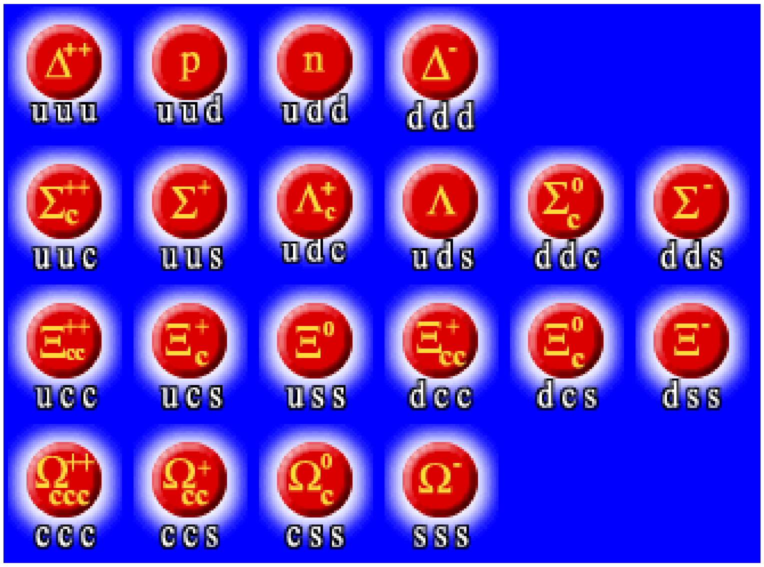
Law 'n Order

Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 28, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/standard_model/baryon_bucks2.html

Welcome to Double Delight where you can go home with double the bucks you came in with by answering a question.



Physicists named baryons with Greek letters like you see on the buttons below. What letter(s) did they give **baryons made of one up or down and two strange or charm quarks**?

Study the chart to see which Greek letters they used and then click below on the matching letter(s).

Xis

Omegas

Sigmas and Lambdas

Deltas, neutron and proton

Law 'n Order

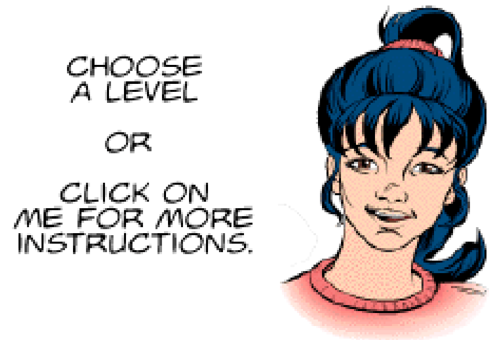
Web Maintainer: ed-webmaster@fnal.gov
Last Update: April 28, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/standard_model/baryon_bucks3.html

Particle Families

Imaginary Families		
Level 1	Introduction	200 Points per Game
Level 2	Geometry 1	400 Points per Game
Level 3	Geometry 2	800 Points per Game

Real Families

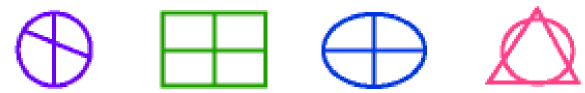
Level 4	Physics	1600 Points per Game



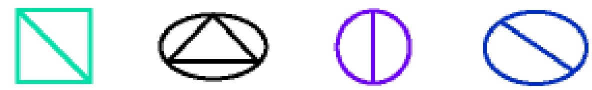
Quit Particle Families | Einstein Bucks: 0 | Next Family | New Level Intro - Geom1 - Geom2 - Physics | Double Your Bucks

Level 2 Game - 100 Einstein Bucks Per Game

All of these are Guinons.

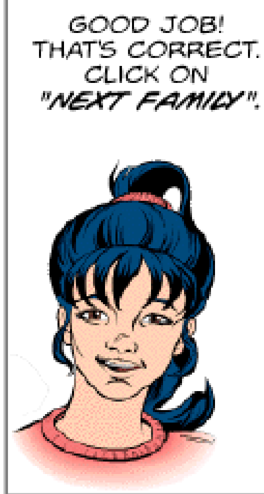


None of these are Guinons.



Which of these are Guinons?

Guinon A	Guinon B	Guinon C	Guinon D
☐	☑	☑	☐



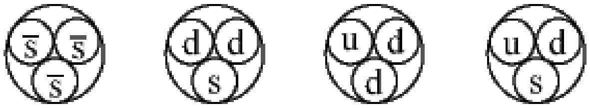
Number of tries: 4

Check Your Answers | Get Answer

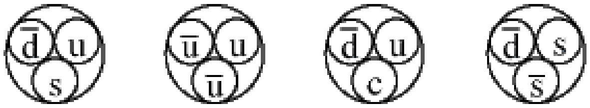
Quit Particle Families | Einstein Bucks: 70 | Next Family | New Level: Intro - Geom1 - Geom2 - Physics | Double Your Bucks

Level 4 Game - 400 Einstein Bucks Per Game

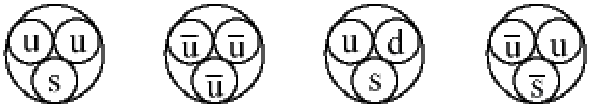
All of these are Baryons.



None of these are Baryons.



Which of these are Baryons?



Baryon A ☐ Baryon B ☐ Baryon C ☐ Baryon D ☐

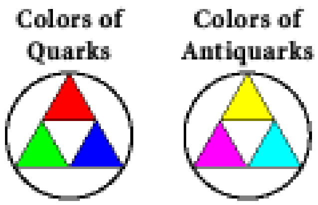
Number of tries: 0

Check Your Answers | Get Answer

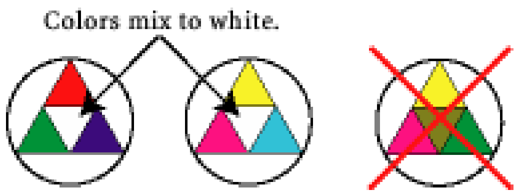
Quit Particle Families | Einstein Bucks: 270 | Next Family | New Level: Intro - Geom1 - Geom2 - Physics | Double Your Bucks

Explanation of the Color of Quarks in Baryons

In this representation, each baryon consists of three quarks or antiquarks shown as triangles within the larger circle.

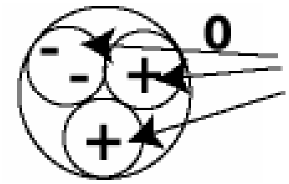


The colors of each quark represent a property physicists call color. The quarks aren't really colored, but it is a convenient way to represent the property. Quarks can be red, blue, or green while antiquarks can be yellow, cyan, or magenta.

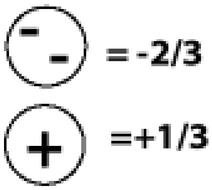


The three quarks or antiquarks in a baryon must have different colors and combine to make white. Baryons cannot be made from a mixture of quark and antiquark colors. For example, a mixture of two antiquark colors (yellow and magenta) and one quark color (green) would not mix to make white so it is illegal.

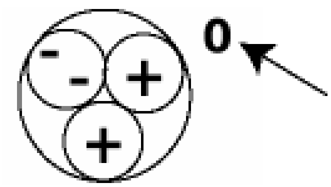
Explanation of the Charge on Baryons



Each baryon consists of three quarks represented by small circles within the larger circle.

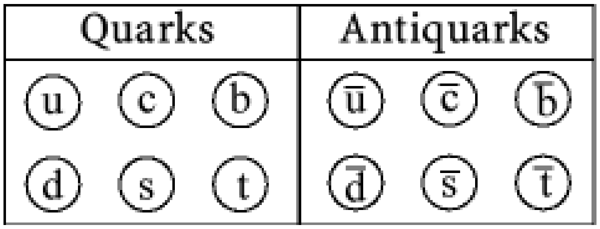


The pluses and minuses in each quark represent the charge of each quark where each plus represents 1/3 of a charge and each minus represents -1/3 of a charge.

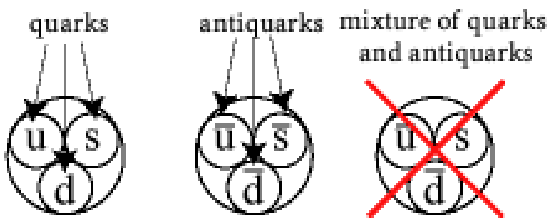


To be a baryon, the sum of all the charges has to equal an integer (e.g.,-1, 0, 1). In the example, the sum is zero shown in the upper right corner.

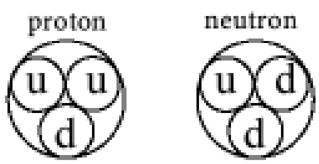
Explanation of Quarks in Baryons



Physicist believe there are six quarks - up (u), down (d), charm (c), strange (s), top (t), and bottom (b) and their antiquarks - antiup, antidown, anticharm, antistrange, antibottom, and antitop. Antiquarks are labeled with a letter with a bar over it.

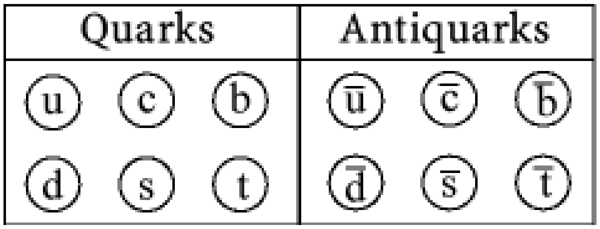


Each baryon consists of three quarks or three antiquarks represented by small circles within the larger circle. Quarks are labeled with a letter. A baryon cannot be made of a mixture of quarks and antiquarks.

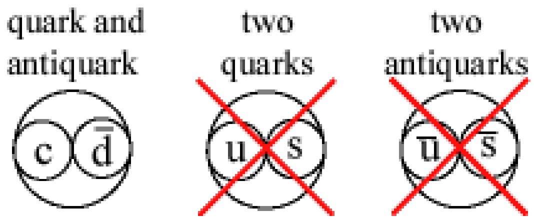


The most familiar baryons are protons and neutrons. They make up the nucleus of atoms and are made up of top and bottom quarks. In fact, everything you see in the world, for example, your computer or your body, is made of top and down quarks and electrons. They are truly the building blocks of matter.

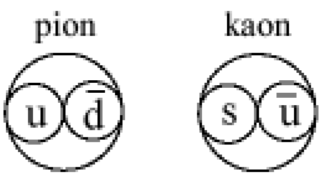
Explanation of Quarks in Mesons



Physicist believe there are six quarks - up (u), down (d), charm (c), strange (s), top (t), and bottom (b) and their antiquarks - antiup, antidown, anticharm, antistrange, antibottom, and antitop. Antiquarks are labeled with a letter with a bar over it.

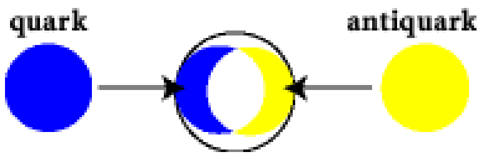


Each meson consists of one quarks and one antiquark represented by small circles within the larger circle. Quarks are labeled with a letter. A meson cannot be made of two quarks or two antiquarks.



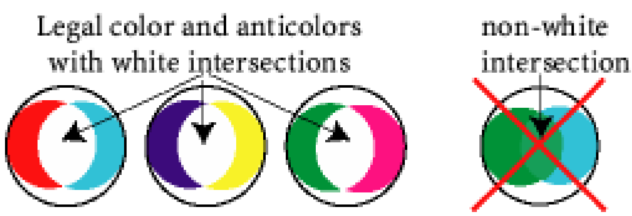
Examples of mesons are the pion and the kaon.

Explanation of the Colors of Quarks and Antiquarks in Mesons

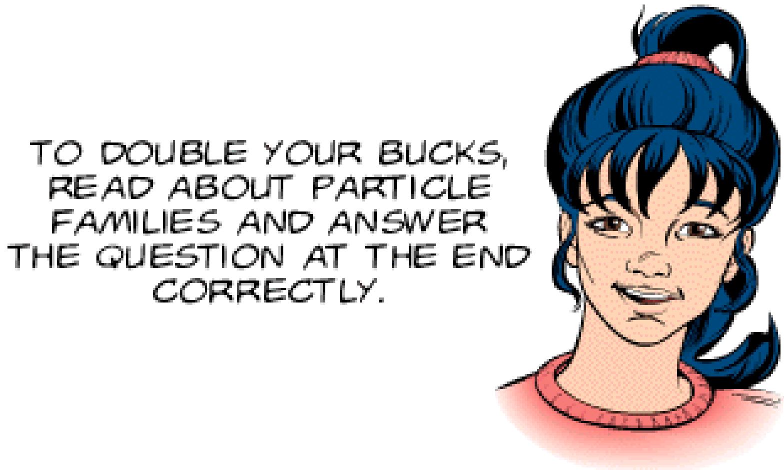


In this representation, each meson consists of one quark and one antiquark shown as intersecting circles within the larger circle.

The colors of each quark represent a property physicists call color. The quarks aren't really colored, but it is a convenient way to represent the property. Quarks can be red, blue, or green while antiquarks can be cyan, yellow, or magenta.



The one quark and one antiquark in a meson must have colors that combine to make white. Only the anticolor of a color combines to make white. Red's anticolor is cyan; blue's anticolor is is yellow; green's anticolor is magenta. The part of the two circles that overlaps represents the mixture of the colors of the two quarks.



What is a Particle FAMILY?

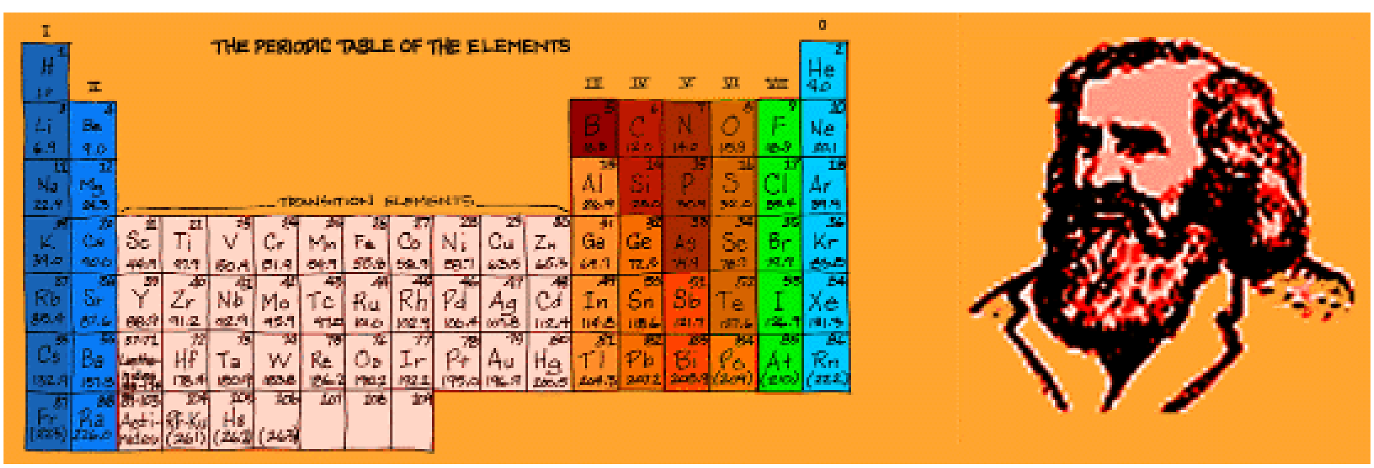
One reason scientists study particles is to find their similarities and differences.

What is a family?

Science often begins by grouping things.

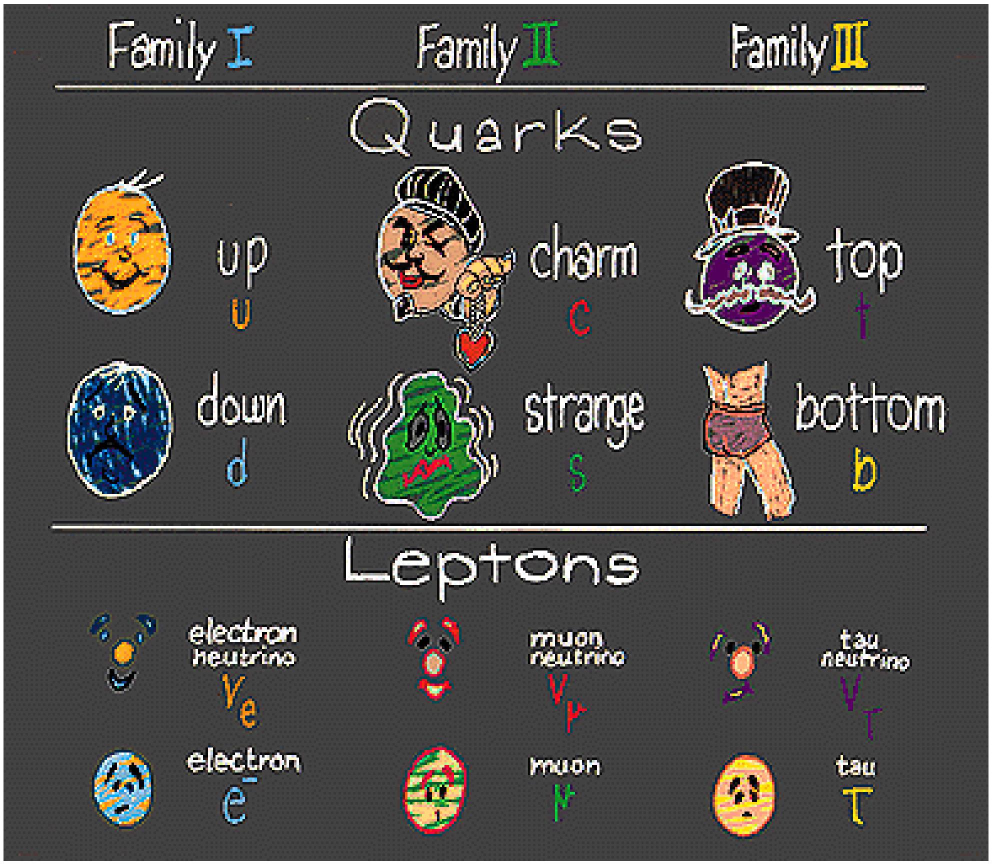
Zoologists classify animals so that tigers, cheetahs, and tabbies end up in the family of "cats" (felines).

The Russian scientist, Dmitri Mendeleev, grouped elements in the Periodic Table according to their chemical properties and atomic weights. It was many years after Mendeleev that chemists understood WHY elements belonged to certain groups.



What is a particle family?

Physicists group particles called quarks and leptons into "families."



Today, physicists are trying to understand WHY quarks and leptons belong to particular groups.

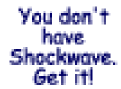
Not so long ago scientists discovered so many new particles (several hundred) they called them a Particle Zoo. The picture was simplified with the discovery of more basic particles - quarks and leptons - that physicists group into families. In the Particle Family Game, you grouped the imaginary particles by identifying common characteristics as physicists do.

QUESTION: Does the electron belong to the Family of Quarks or Leptons?

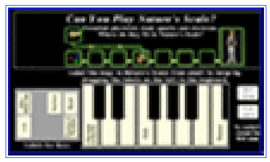
Quarks - Leptons

Original Author: Mason Kidd - mrkidd@fnal.gov
Web Maintainer: ed-webmaster@fnal.gov
Last Update: June 11, 1998

Nature's Scale



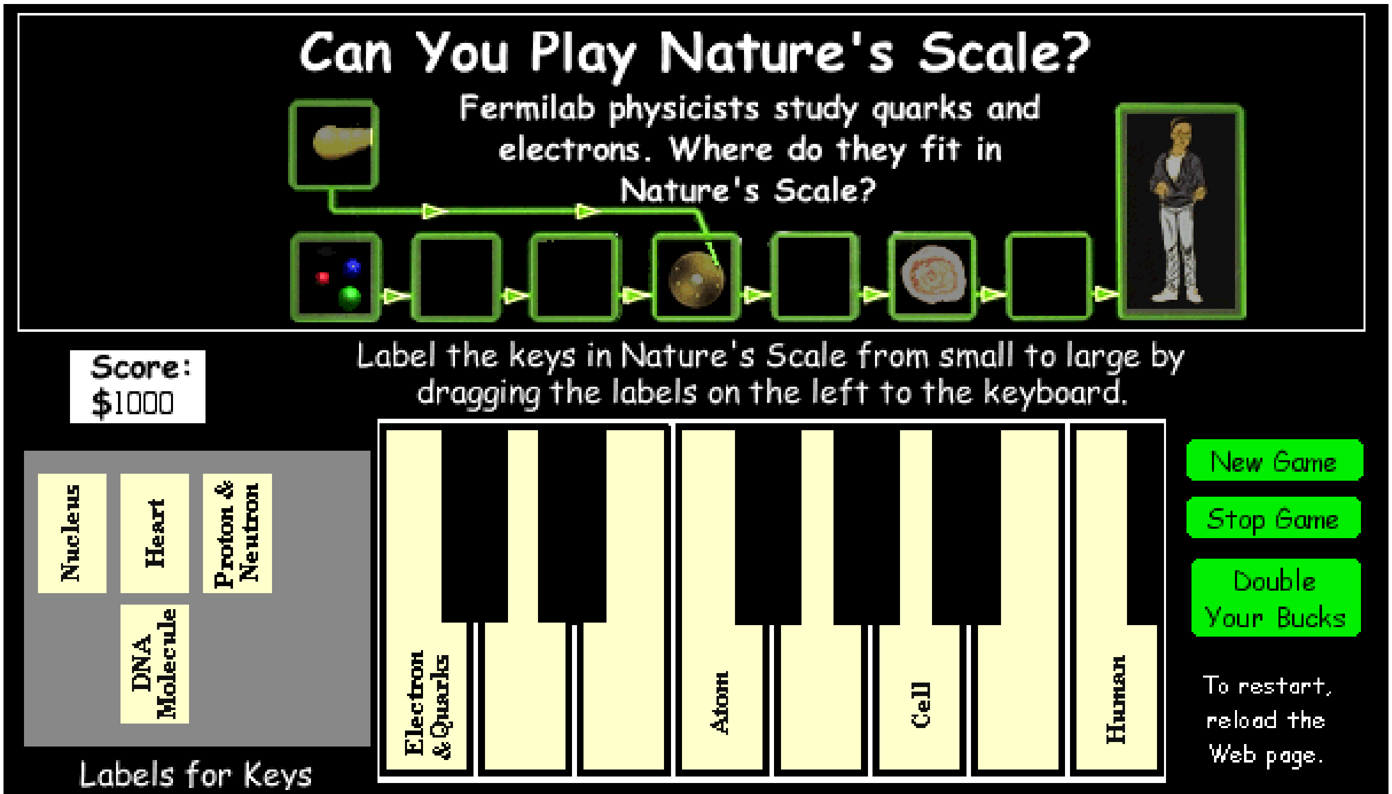
This activity needs Shockwave. If you don't see the animation above, click



[Go to Game]

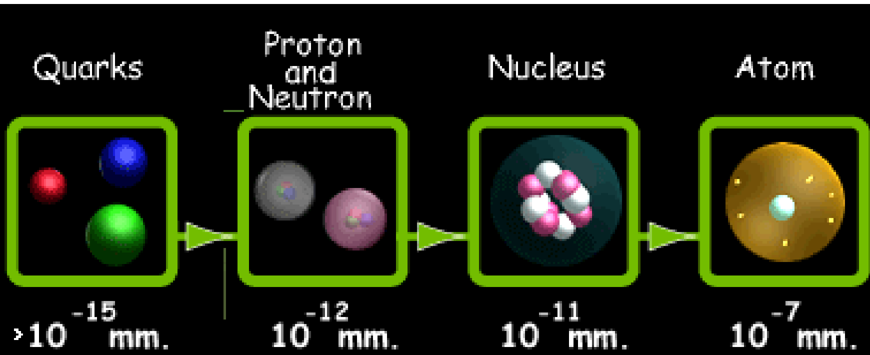
[Law 'N Order]

Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 11, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/natures_scale/activity.html



Law 'N Order

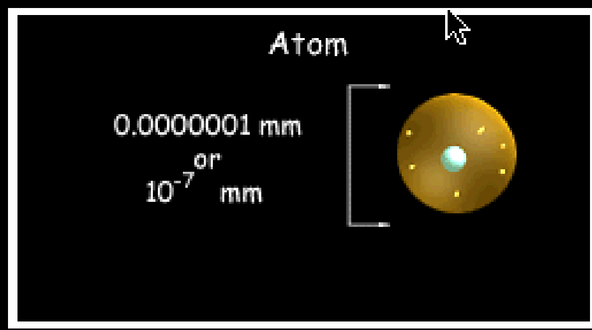
Macromedia Shockwave Movie by: Liz Quigg - liz@fnal.gov
Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 16, 2000
http://www-ed.fnal.gov/projects/labyrinth/lawnorder/natures_scale.html



Score:
$ 200

Zoom In | Zoom Out | Test | All Done

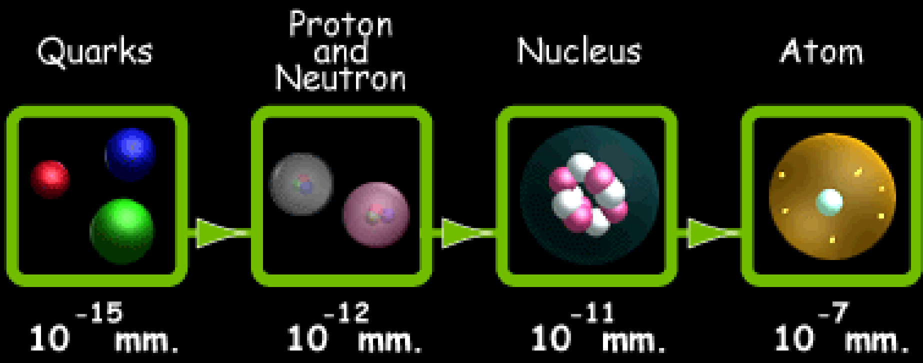
Fermilab scientists explore quarks, objects more than one hundred million times smaller than an atom! Click the **Zoom In** button to move from an atom to a quark. (Each click of the button lets you look at an object 10 times smaller than the previous object.) Once you think you've reached the quark size, click **Test**. See if you can double your bucks!



Law 'N Order

Congratulations! You earned Einstein Bucks in Nature's Scale!!

Quarks are the smallest objects physicists have discovered.
Are they made of something smaller?
Print out your bucks or go back to Law 'n Order.



Print Your Bucks

Law 'n Order

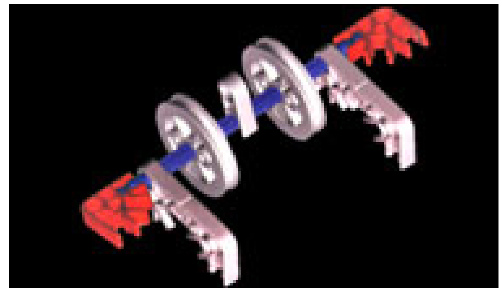
Go Back

Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 16, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/natures_scale/done.html

What are the Basic Forces Between Particles?

The Standard Model describes how the fundamental particles affect each other–how they interact, the forces they feel.

You may think of forces as pushes and pulls. Particle physicists think of forces as **interactions between particles** that produce structure–from protons to galaxies. The Standard Model would not be complete if it did not explain how particles behave together. It would be like having a set of K'nex without the rods–you couldn't build much.

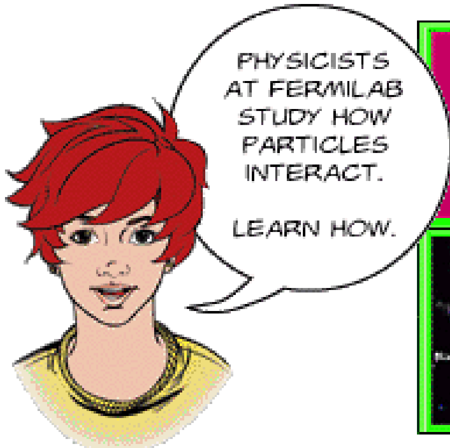


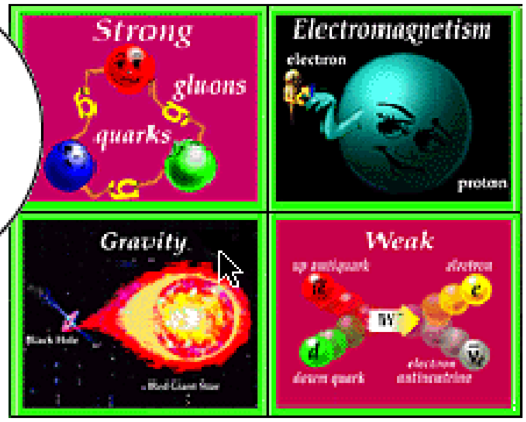
Continue

Law 'n Order

Web Maintainer: ed-webmaster@fnal.gov
Shockwave Movie by Liz Quigg: liz@fnal.gov
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/four_forces/intro.html

What are the Basic Forces between Particles?





You have Shockwave

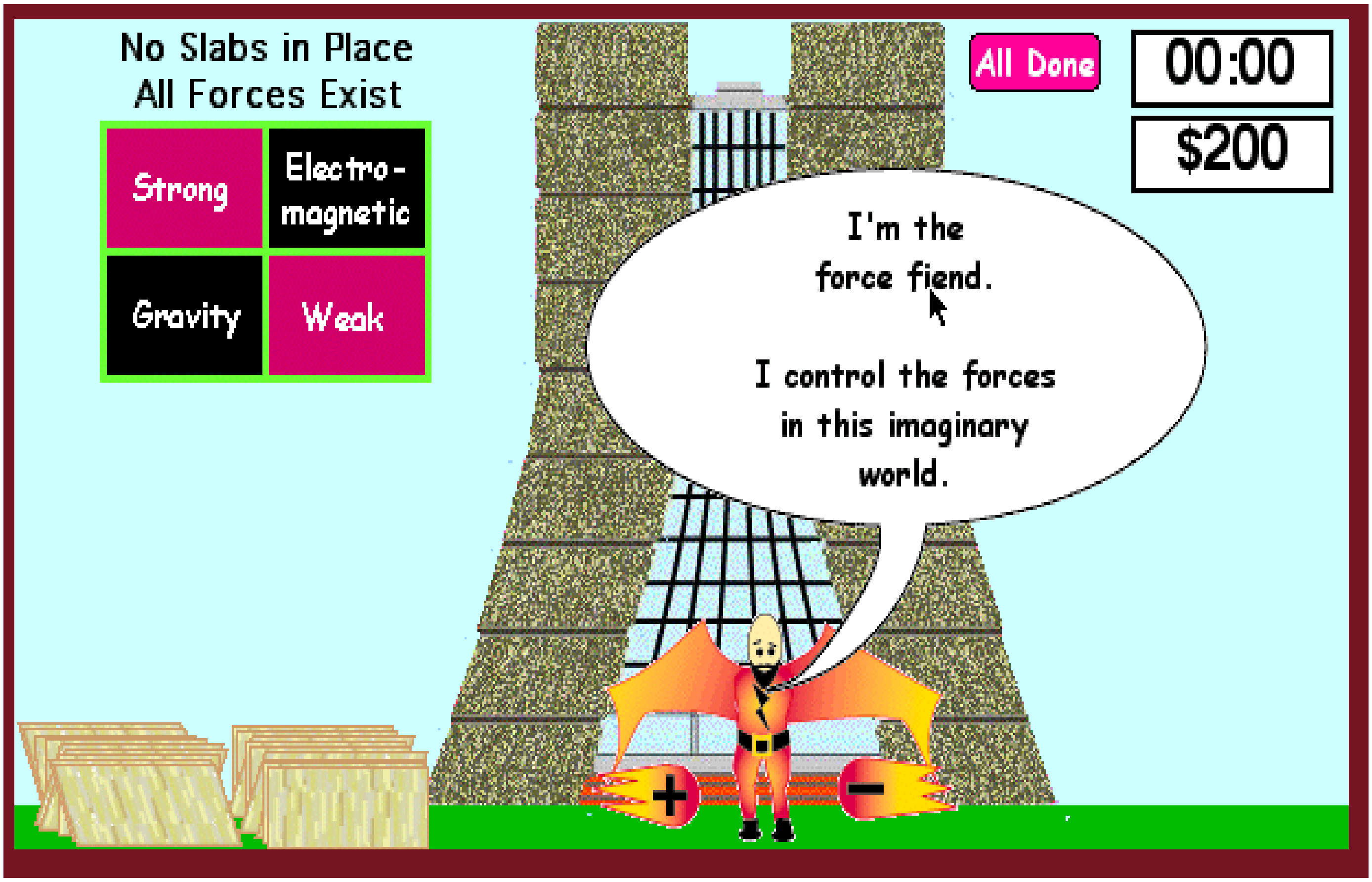
Continue

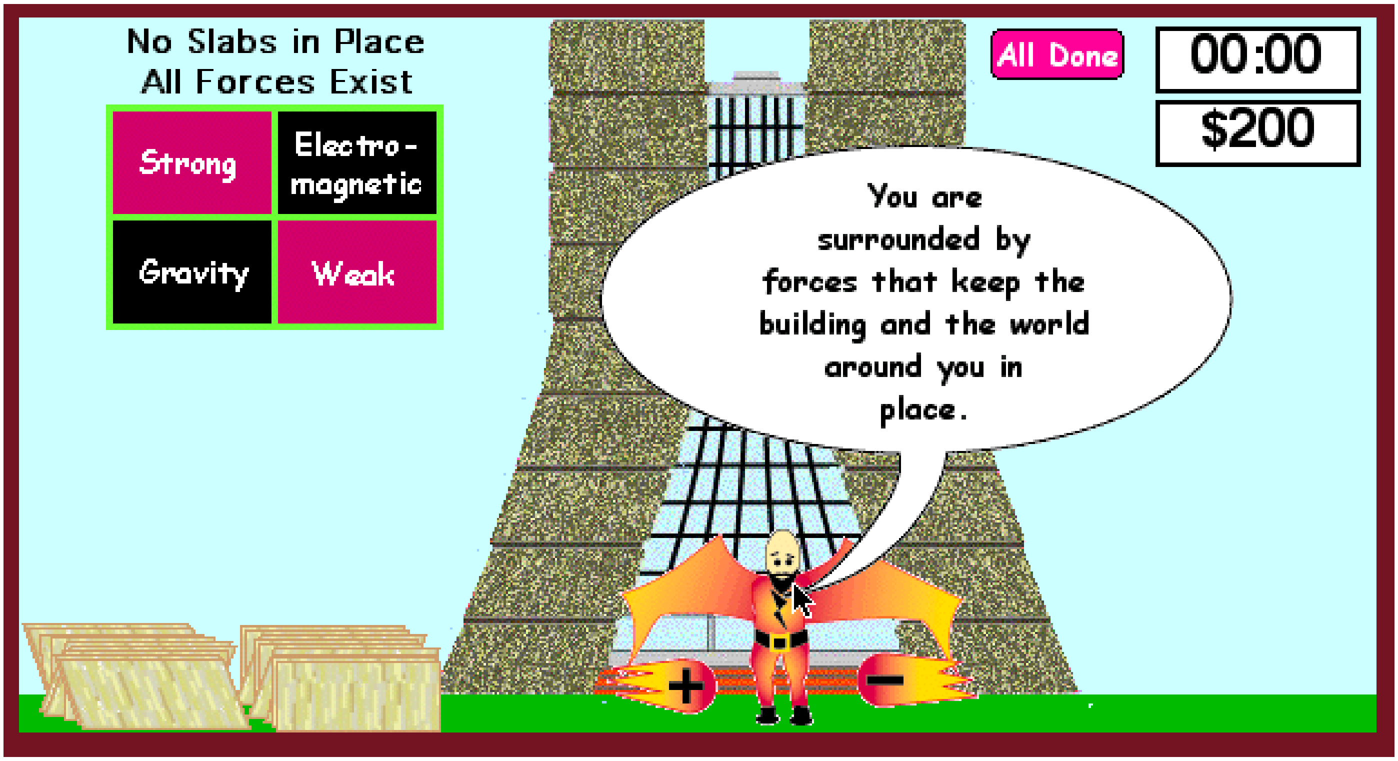
This activity needs Shockwave. If you can't see the animation, click

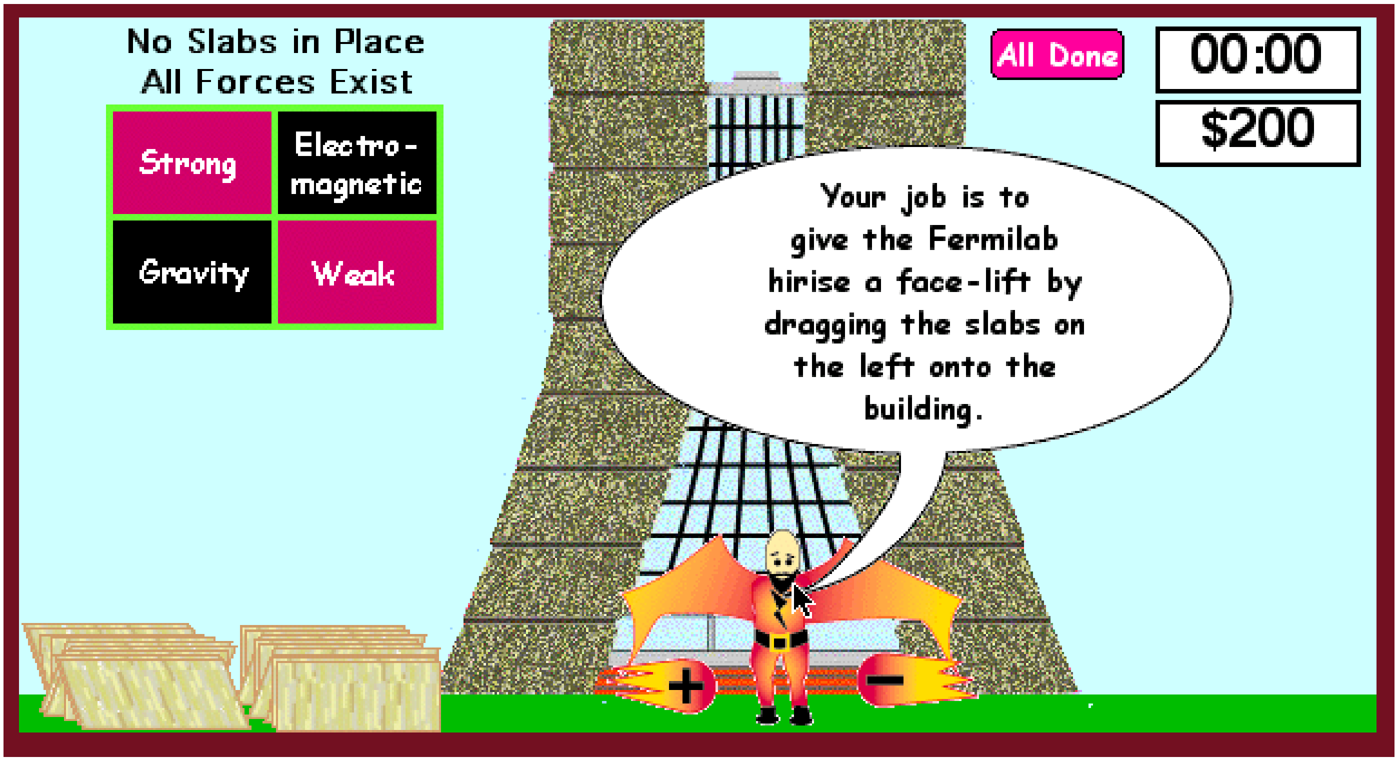
GET SHOCKWAVE

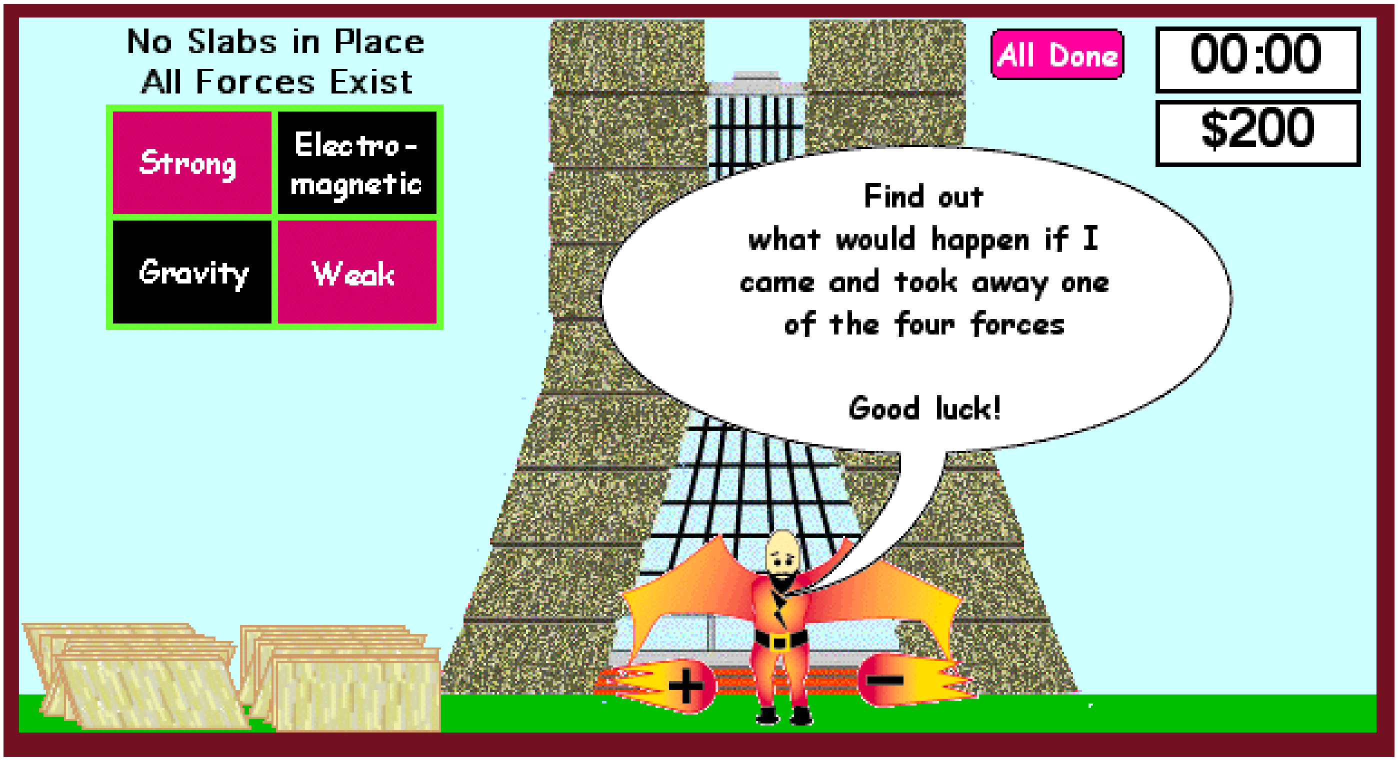
Law 'n Order

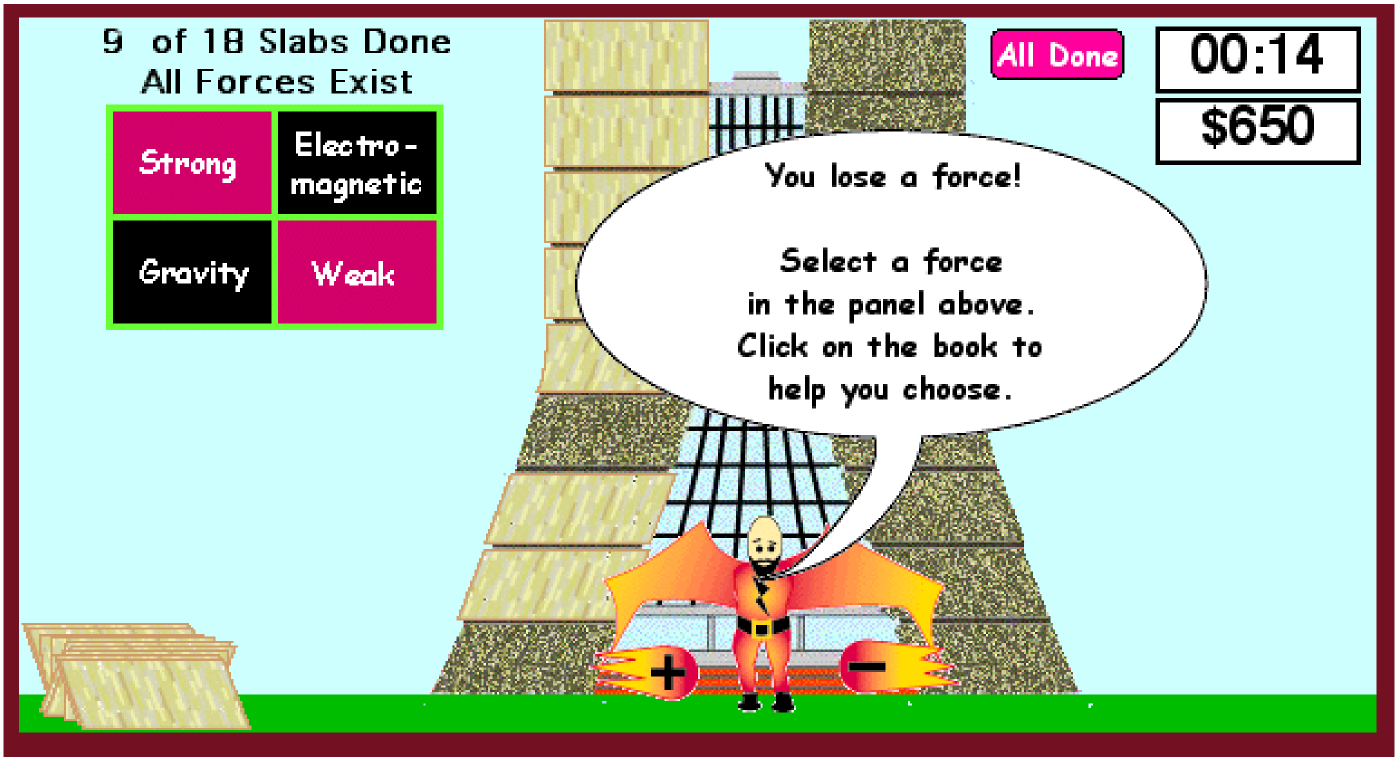
ed-webmaster@fnal.gov
e by Liz Quigg: liz@fnal.gov
al.gov/projects/fermilabyrinth/games/lawnorder/four_forces/activity.html

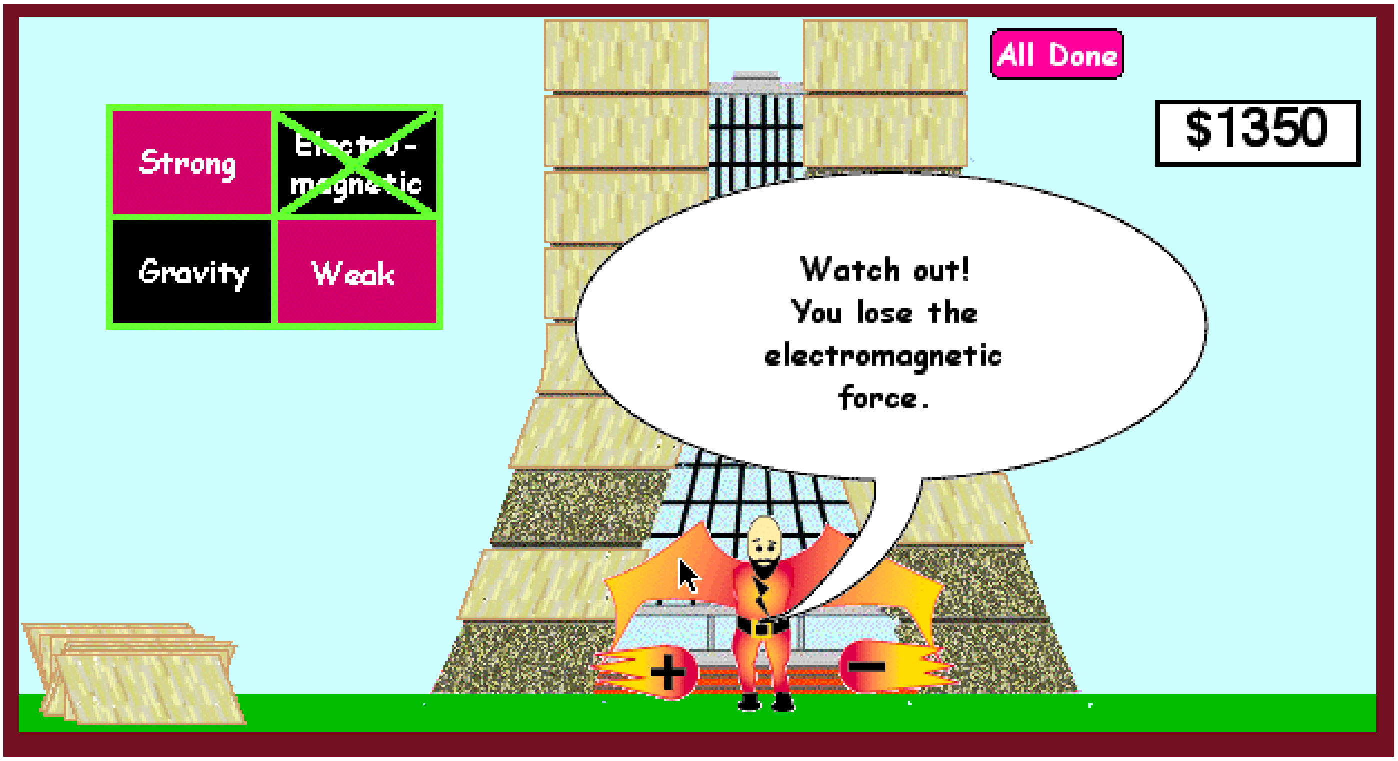

No Slabs in Place
All Forces Exist
Strong
Electro-magnetic
Gravity
Weak
All Done
00:00
$200
I'm the force fiend.
I control the forces in this imaginary world.

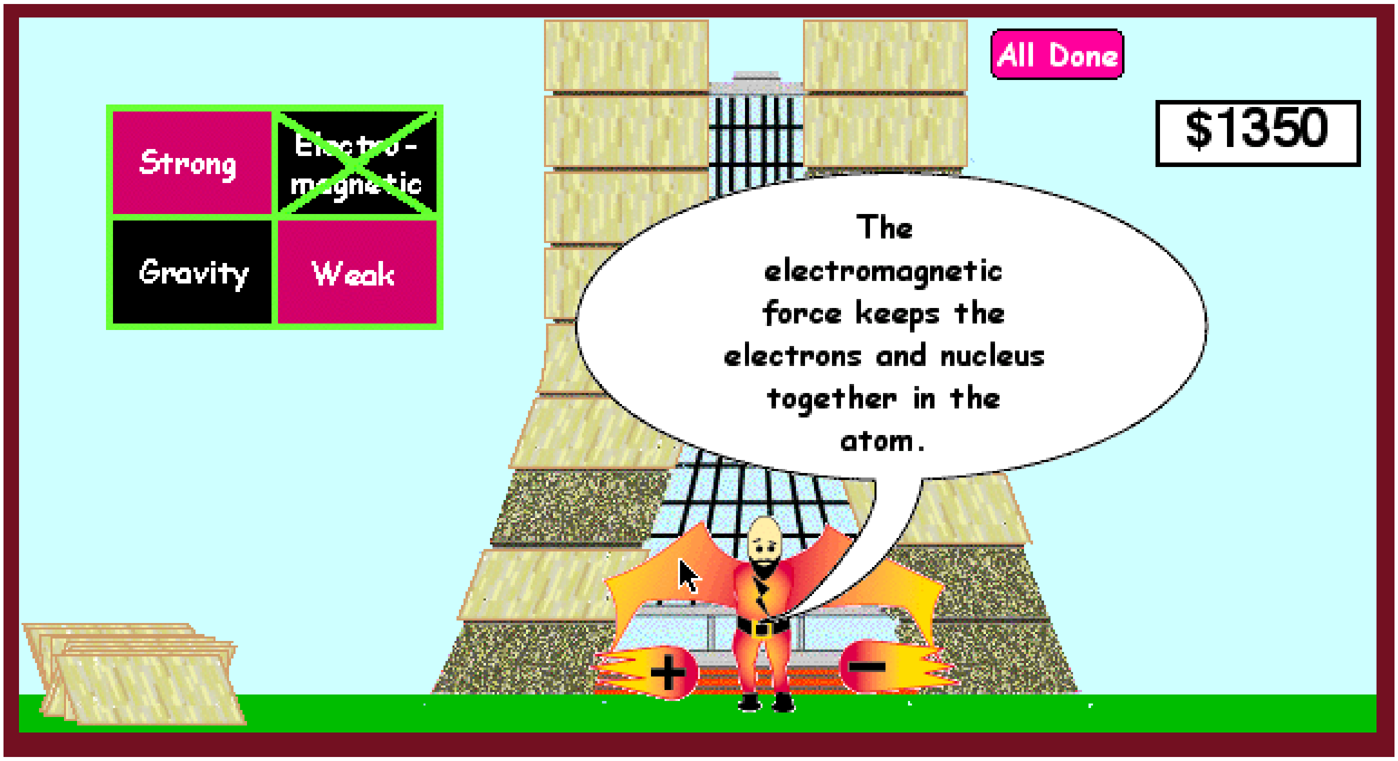

No Slabs in Place
All Forces Exist
Strong
Electro-magnetic
Gravity
Weak
All Done
00:00
$200
You are surrounded by forces that keep the building and the world around you in place.

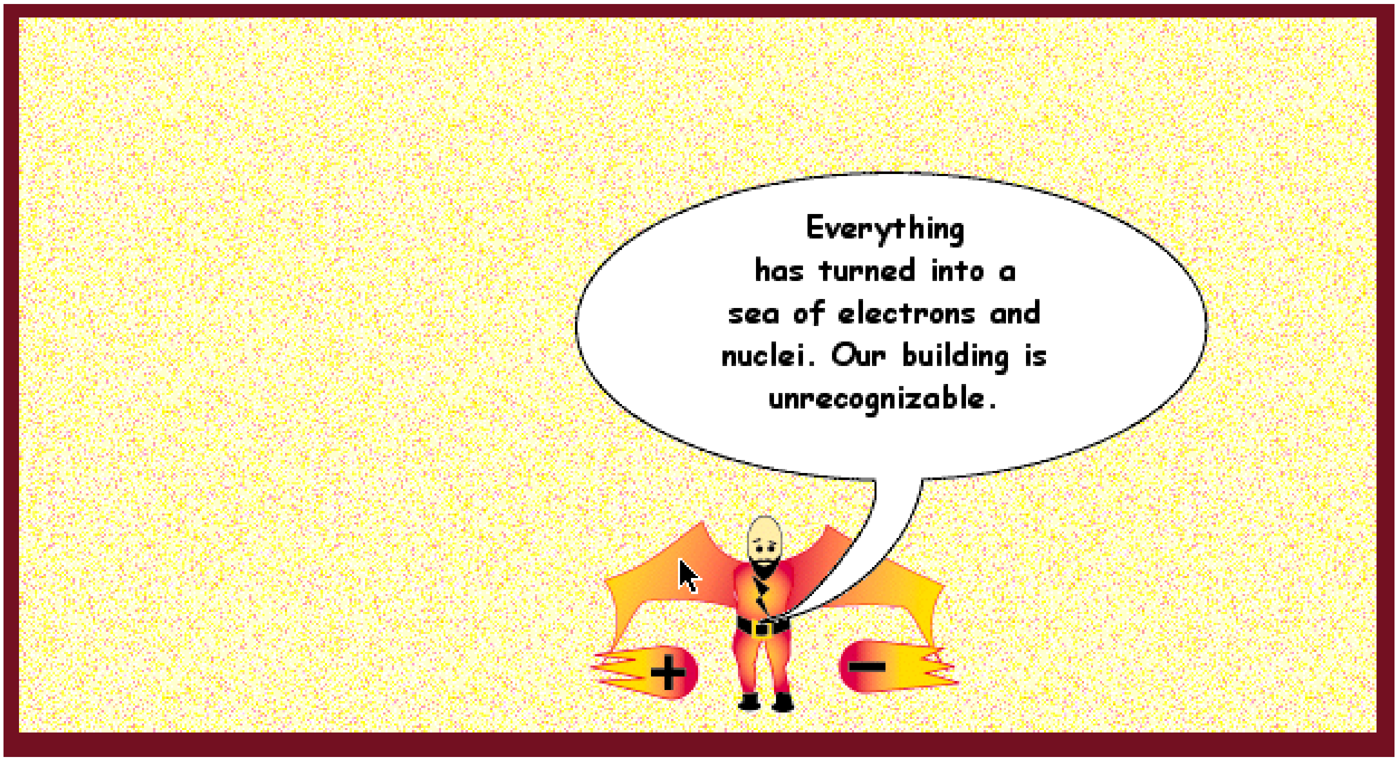

No Slabs in Place
All Forces Exist
Strong
Electro-magnetic
Gravity
Weak
All Done
00:00
$200
Your job is to give the Fermilab hirise a face-lift by dragging the slabs on the left onto the building.
+
−

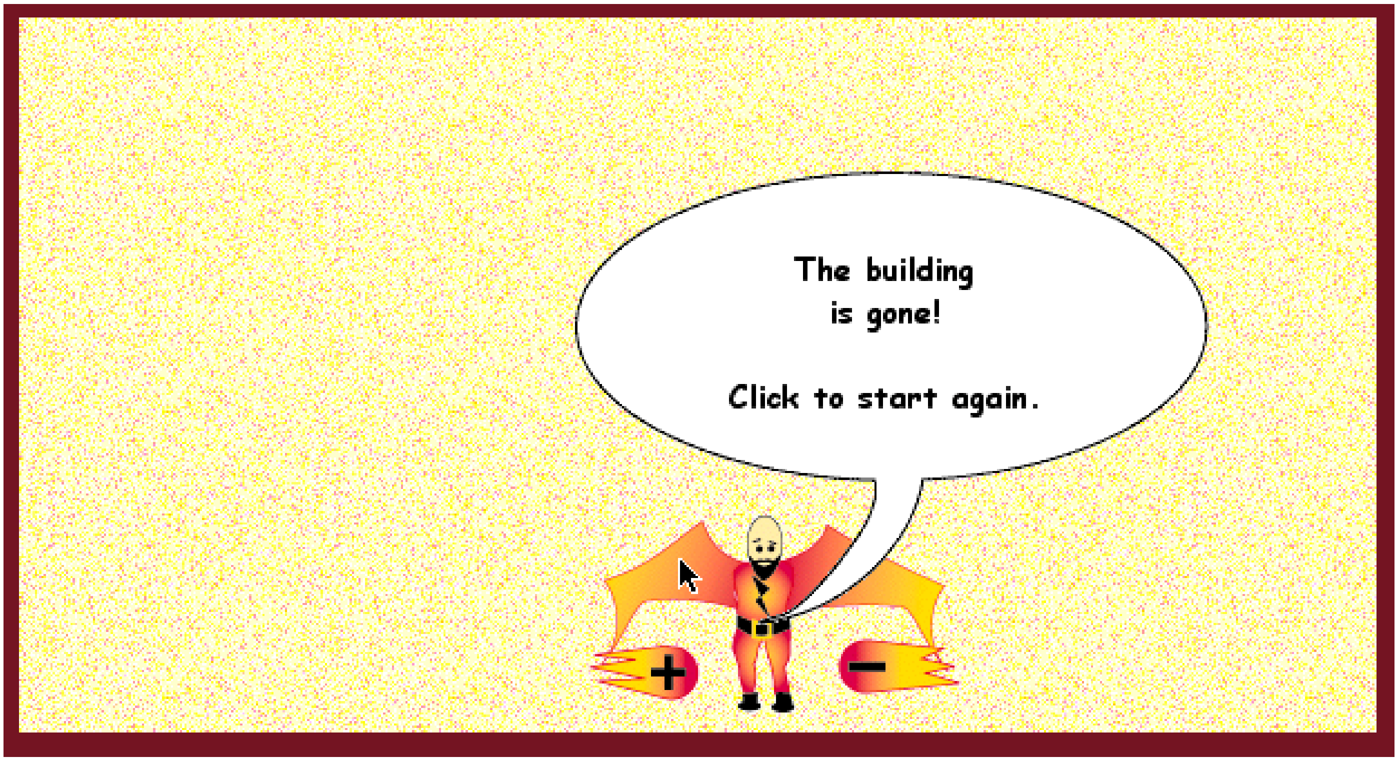

No Slabs in Place
All Forces Exist
Strong
Electro-magnetic
Gravity
Weak
All Done
00:00
$200
Find out what would happen if I came and took away one of the four forces
Good luck!
+
−


9 of 18 Slabs Done
All Forces Exist
Strong
Electro-magnetic
Gravity
Weak
All Done
00:14
$650
You lose a force!
Select a force in the panel above. Click on the book to help you choose.
+
−

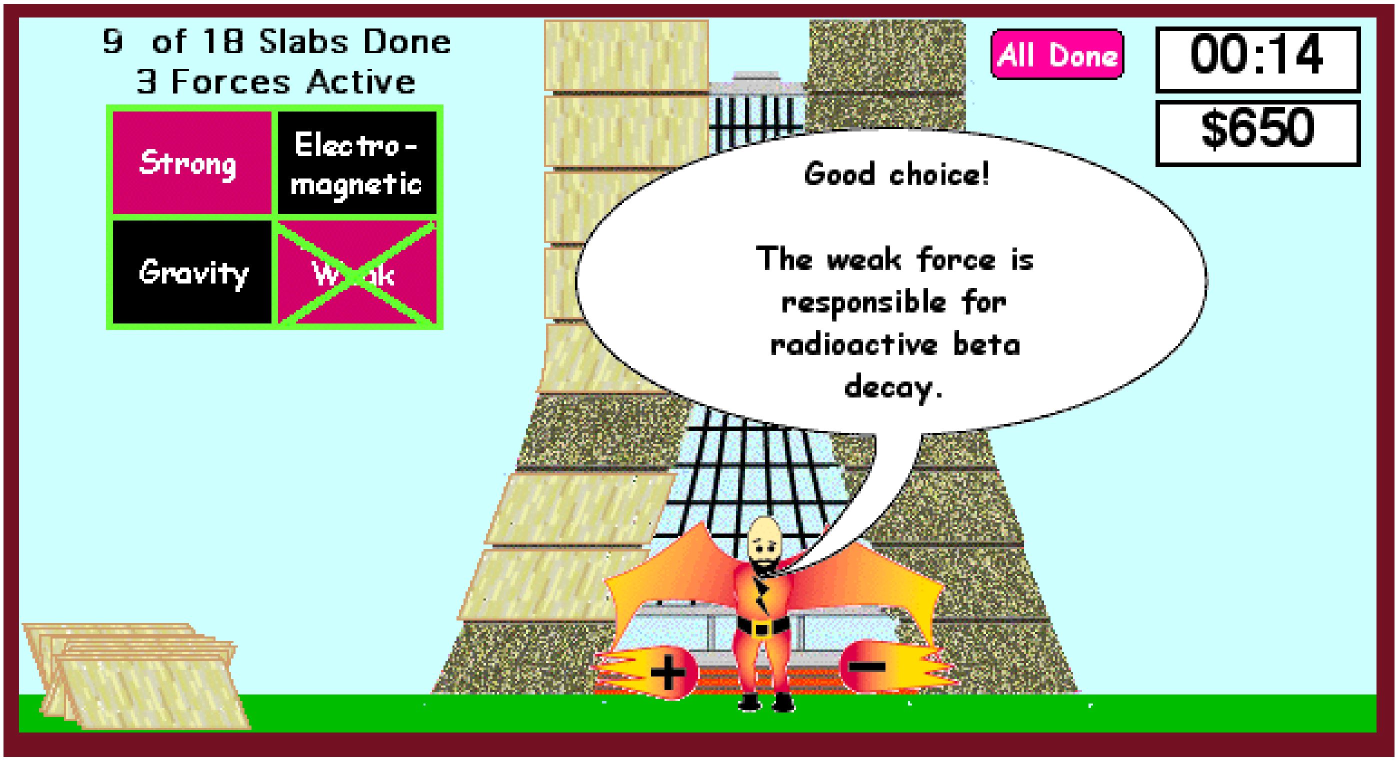

All Done
$1350
Strong
Electro-magnetic
Gravity
Weak
Watch out!
You lose the
electromagnetic
force.
+
−

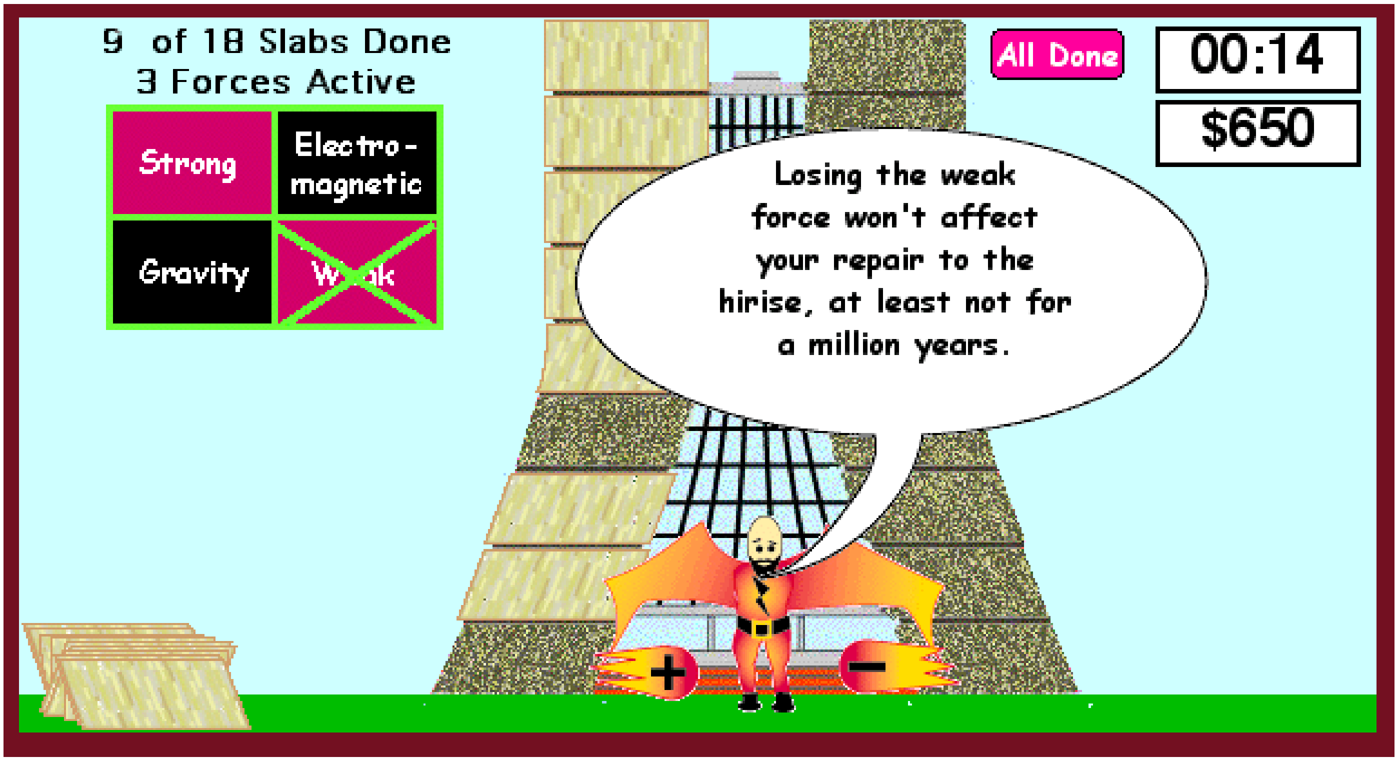

All Done
$1350
Strong
Electro-magnetic
Gravity
Weak
The electromagnetic force keeps the electrons and nucleus together in the atom.
+
−

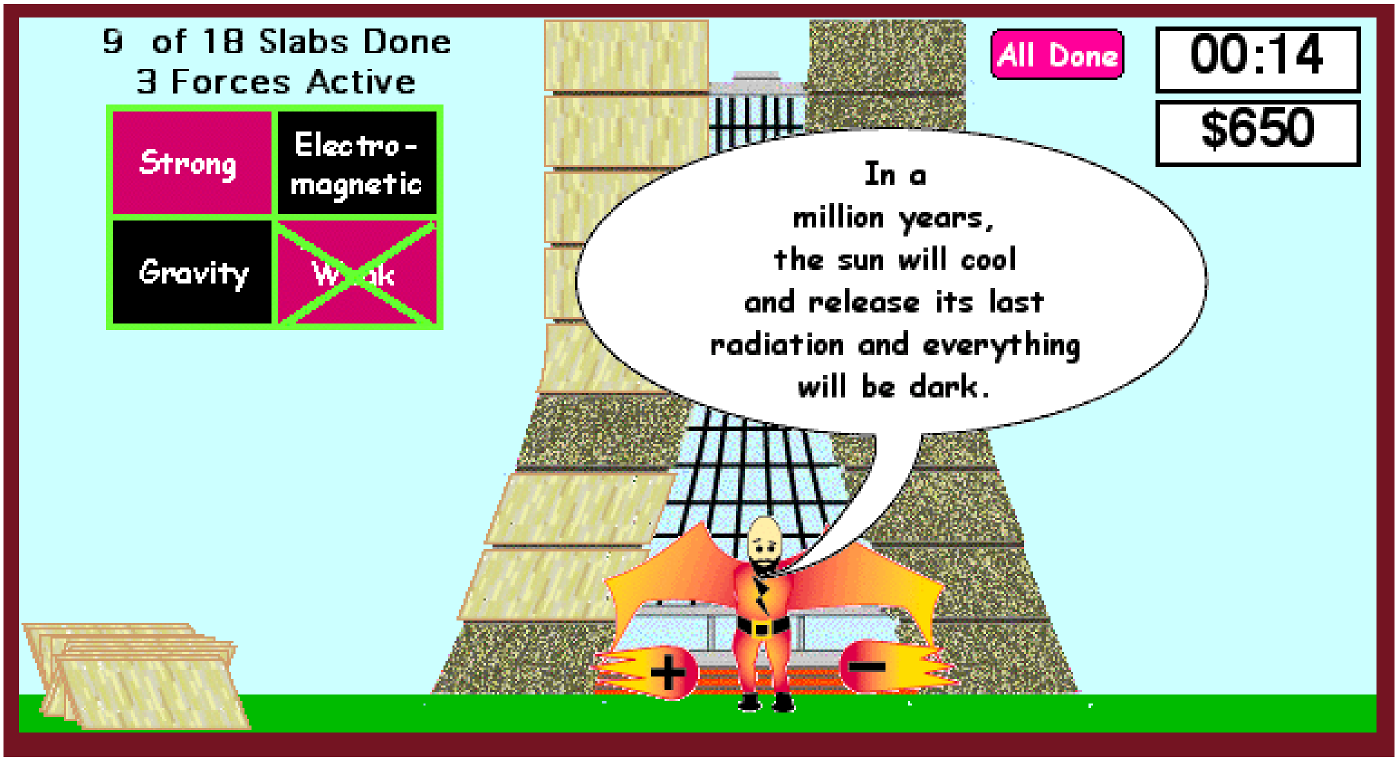

Everything
has turned into a
sea of electrons and
nuclei. Our building is
unrecognizable.

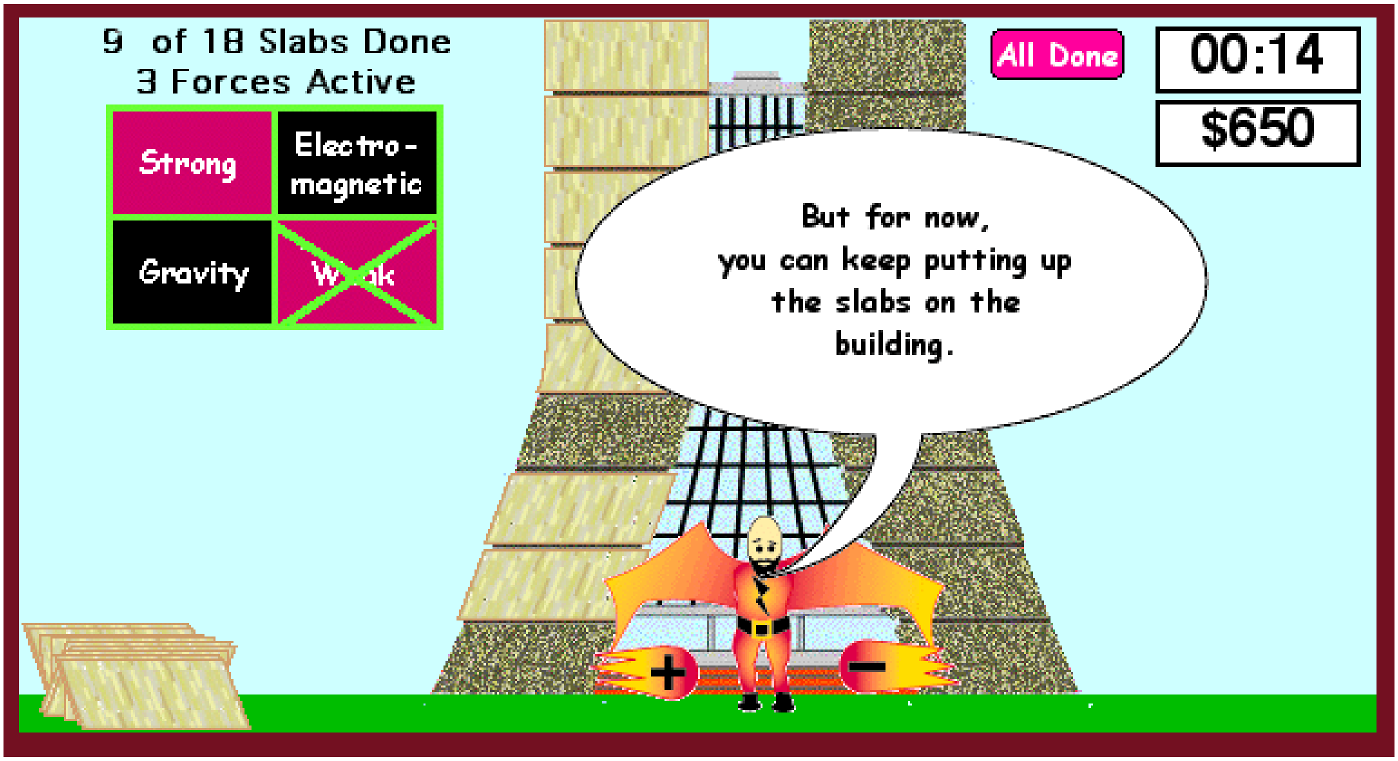

The building
is gone!

Click to start again.


9 of 18 Slabs Done
3 Forces Active
Strong
Electro-magnetic
Gravity
Weak
All Done
00:14
$650
Good choice!
The weak force is responsible for radioactive beta decay.


9 of 18 Slabs Done
3 Forces Active
Strong
Electro-magnetic
Gravity
Weak
All Done
00:14
$650
Losing the weak force won't affect your repair to the hirise, at least not for a million years.
+
−


9 of 18 Slabs Done
3 Forces Active
Strong
Electro-
magnetic
Gravity
Weak
All Done
00:14
$650
In a
million years,
the sun will cool
and release its last
radiation and everything
will be dark.

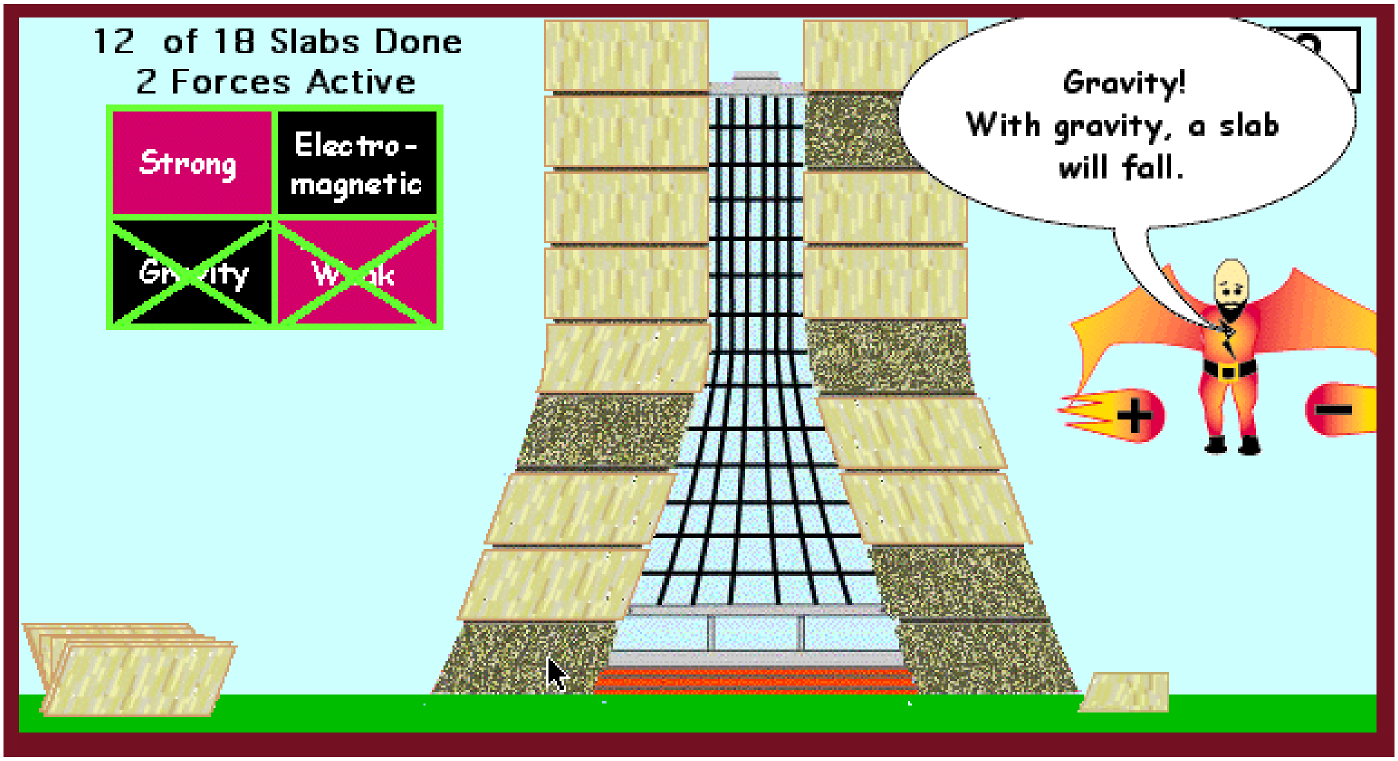

9 of 18 Slabs Done
3 Forces Active
Strong
Electro-
magnetic
Gravity
All Done
00:14
$650
But for now,
you can keep putting up
the slabs on the
building.
+
−

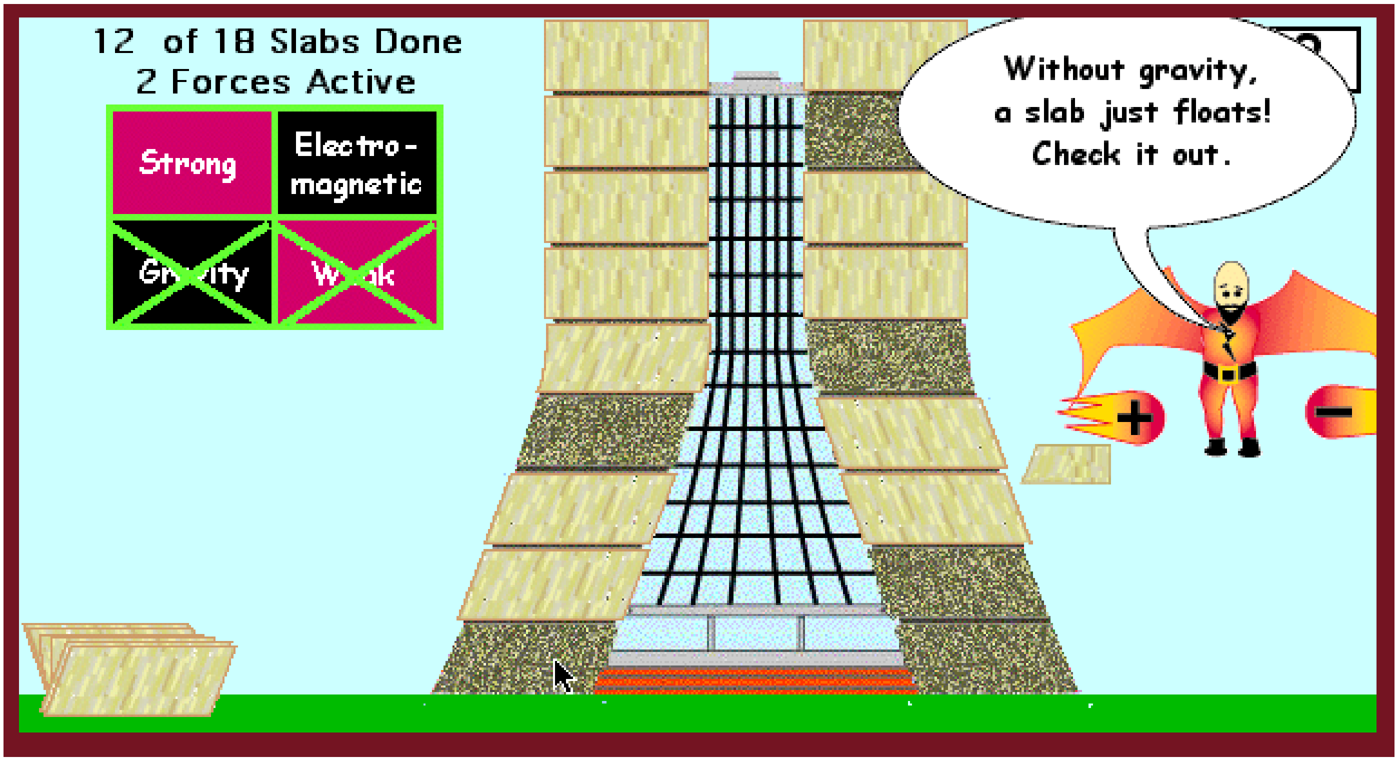

Whoa! We need the strong force! It holds the quarks together in protons and neutrons.


The quarks escape
and cause a big flash.
Everything is gone.


The building
is gone!

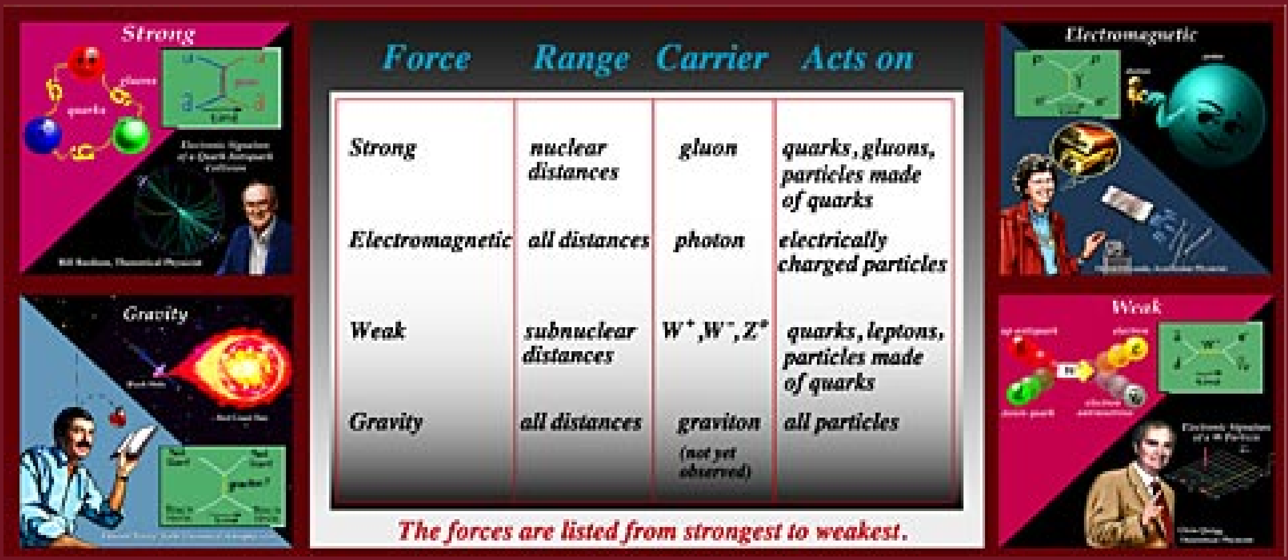
Click to start again.


12 of 18 Slabs Done
2 Forces Active
Strong
Electro-
magnetic
Gravity
Weak
Gravity!
With gravity, a slab
will fall.


12 of 18 Slabs Done
2 Forces Active
Strong
Electro-magnetic
Without gravity,
a slab just floats!
Check it out.

Learn about the four forces and the Fermilab physicists who study them.

Chart - Strong - Electromagnetic - Gravity - Weak - Return to Game



Force	Range	Carrier	Acts on
Strong	nuclear distances	gluon	quarks, gluons, particles made of quarks
Electromagnetic	all distances	photon	electrically charged particles
Weak	subnuclear distances	W^+, W^-, Z^0	quarks, leptons, particles made of quarks
Gravity	all distances	graviton (not yet observed)	all particles

The forces are listed from strongest to weakest.

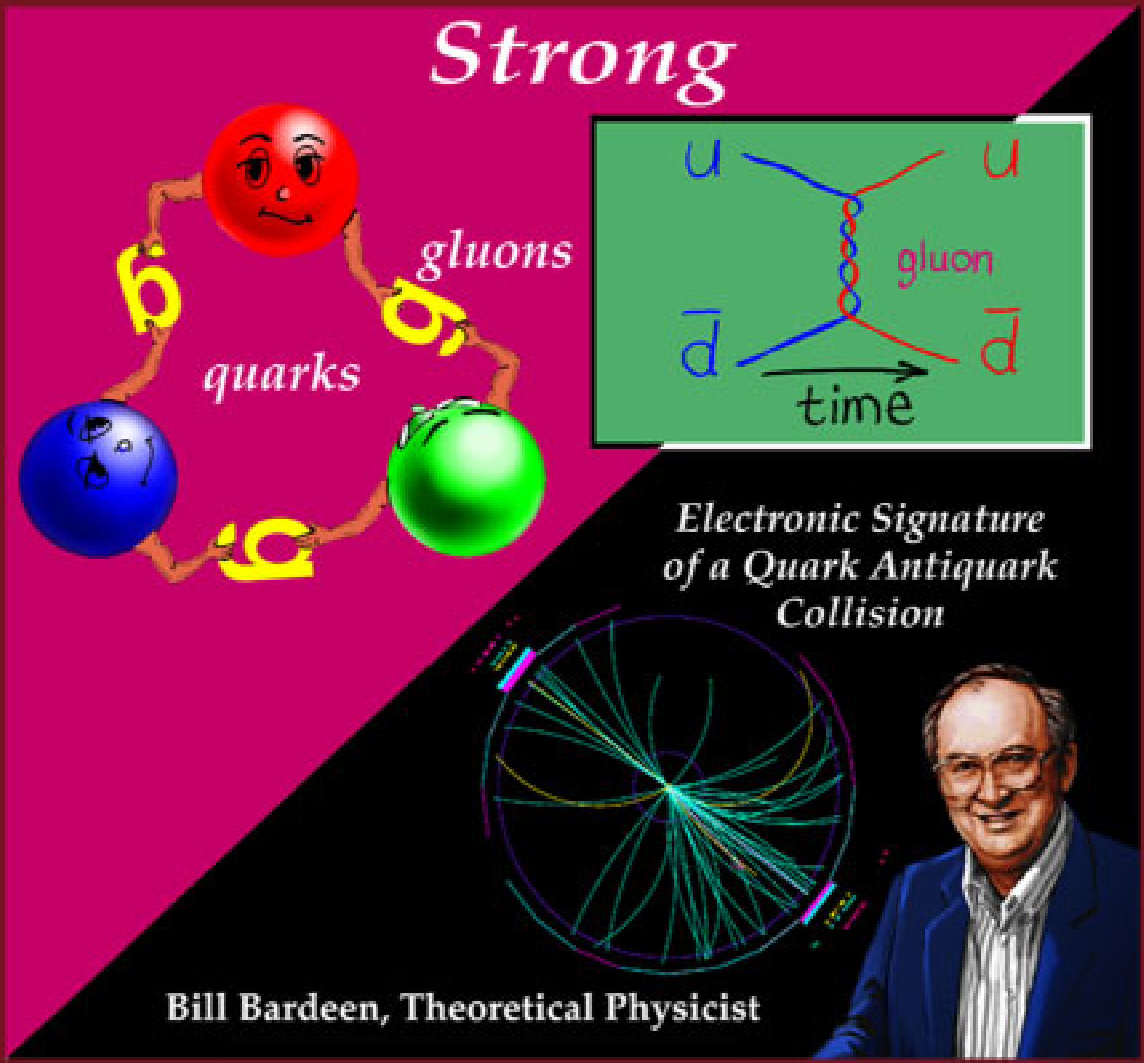
Learn about the four forces and the Fermilab physicists who study them.

All - Strong - Electromagnetic - Gravity - Weak - Return to Game

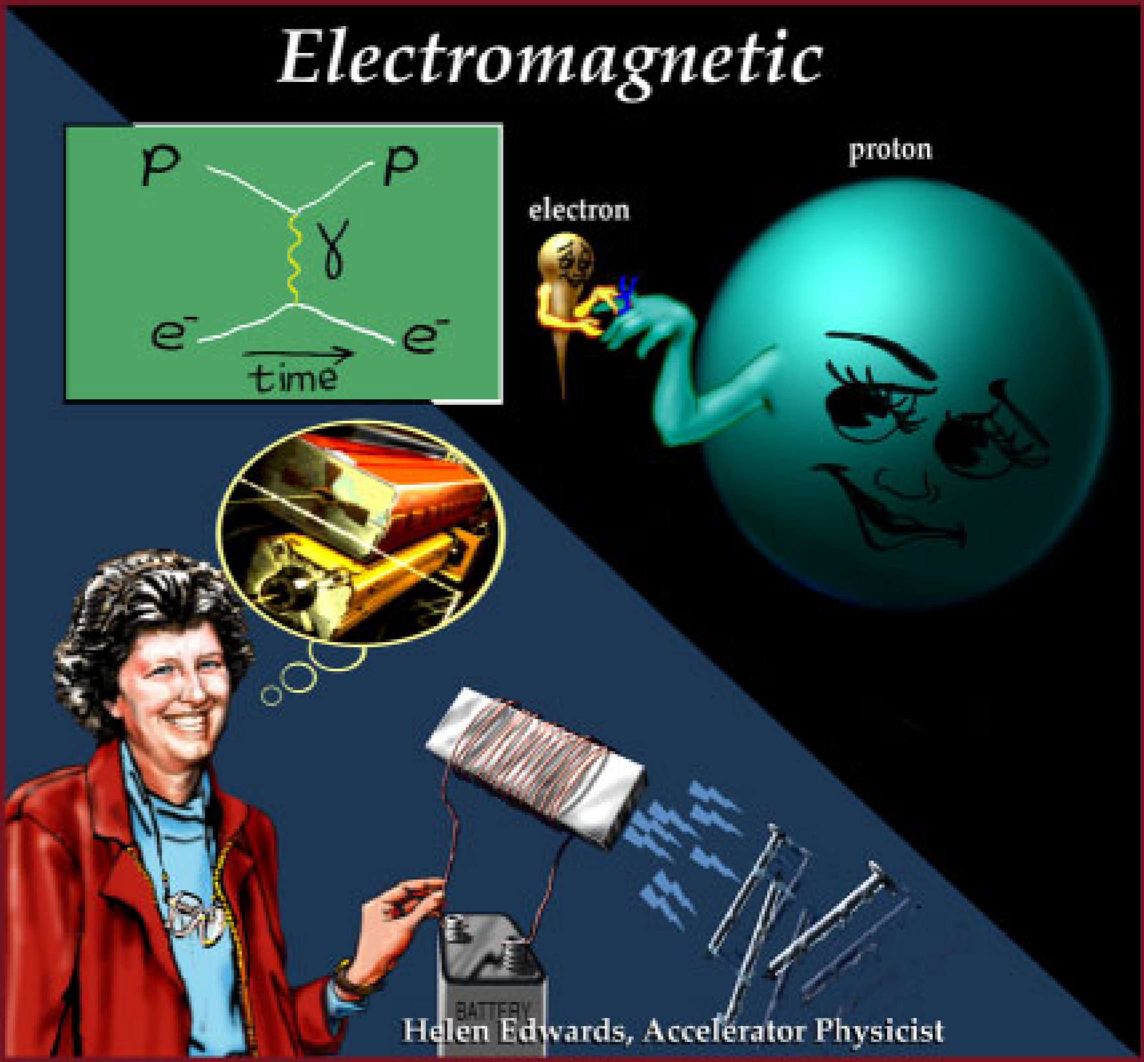
Force	Range	Carrier	Acts on
Strong	nuclear distances	gluon	quarks, gluons, particles made of quarks
Electromagnetic	all distances	photon	electrically charged particles
Weak	subnuclear distances	W^+, W^-, Z^0	quarks, leptons, particles made of quarks
Gravity	all distances	graviton (not yet observed)	all particles

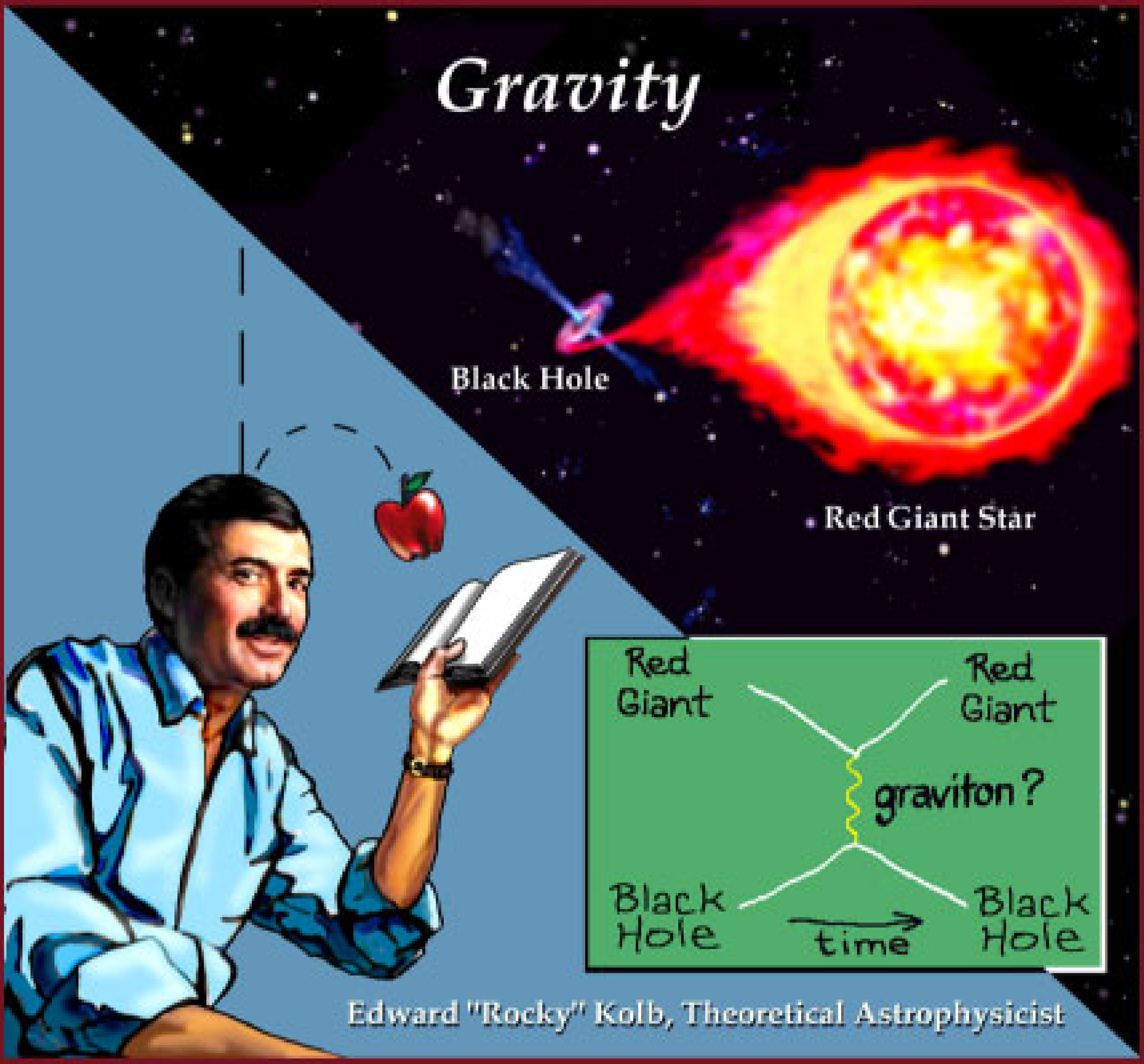
The forces are listed from strongest to weakest.

All - Chart - Strong - Electromagnetic - Gravity - Weak - Return to Game

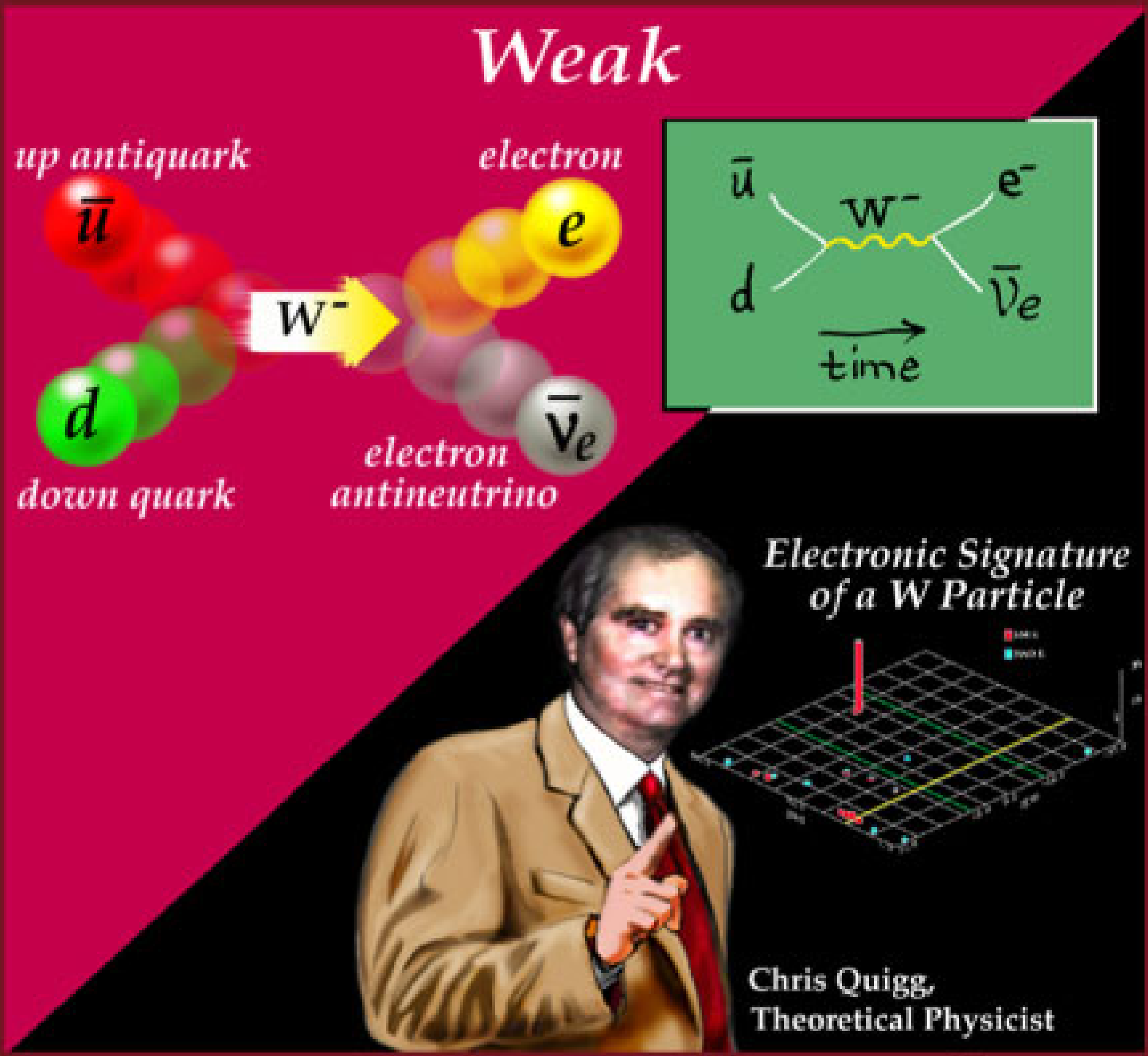


All - Chart - Strong - Electromagnetic - Gravity - Weak - Return to Game




Gravity
Black Hole
Red Giant Star
Red Giant
Red Giant
graviton?
Black Hole
time
Black Hole
Edward "Rocky" Kolb, Theoretical Astrophysicist

All - Chart - Strong - Electromagnetic - Gravity - Weak - Return to Game



Double Your Bucks

Fill out the following chart to indicate which forces affect the particles along the left. Click on the circle next to **Yes** if they feel the force and **No** if they don't. Some of the answers may surprise you, but you can double your bucks if you answer most of them correctly.

Refer to the chart in the other window or the glossary below if you need help.

	Four Forces			
Particles	**Gravity**	**Electromagnetic**	**Weak**	**Strong**
neutron	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No
neutrino	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No
quark	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No
proton	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No
photon	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No
electron	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No

Click the button to .

Glossary

electron

A negatively charged particle belonging to the family of leptons. It has mass and combines with the nucleus to make atoms.

neutrino

An elusive particle because it barely interacts with other particles. It has zero or very little mass. Scientists are trying to determine if it has mass. It has no electrical charge and belongs to the family of leptons. There are three types of neutrinos: electron neutrinos, tau neutrinos, and mu neutrinos, corresponding to their lepton partners, the electron, tau, and mu.

neutron

A particle with no charge made up of three quarks,one up and two downs. The neutron and proton make up the nucleus of an atom.

photon

A particle with no mass or electrical charge. Photons are the carriers of the electromagnetic force.

proton

A particle with positive electrical charge made up of three quarks,two ups and one down. The neutron and proton make up the nucleus of an atom.

quark

One of the basic building blocks of matter. There are six types of quarks: up, down,charm, beauty, bottom, and top. Three of them combine to make baryons, for example, the proton and neutron. Two combine to make mesons. They have mass and electrical charge.

You can learn more about different particles in Particle Families and Baryon Bonanza in Law 'n Order.

Law 'n Order

Web Maintainer: ed-webmaster@fnal.gov
Last Update: May 31, 2000
http://www-ed.fnal.gov/projects/fermilabyrinth/games/lawnorder/four_forces/four_forces_bucks.html

You did not double your Einstein Bucks. You got 6 out of 24 correct. You earned 200 Einstein Bucks in the Four Forces!!

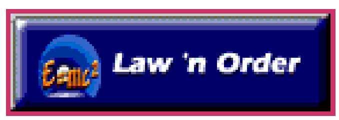
Here are the correct answers. Those with a red background, you answered incorrectly.

All the particles experience **gravity**. If a particle has energy, it feels **gravity**. The **neutrino** and **photon** do not feel the **electromagnetic force** because they have no charge. You might think that the **neutron** might not feel it, but it does because it is made up of charged particles. All the particles except the **photon** experience the **weak force**. Only **quarks** and **hadrons** feel the **strong force**, so that leaves out the **photon**, **electron** and **neutrino**. Remember to have the structure around us, we need the four forces.

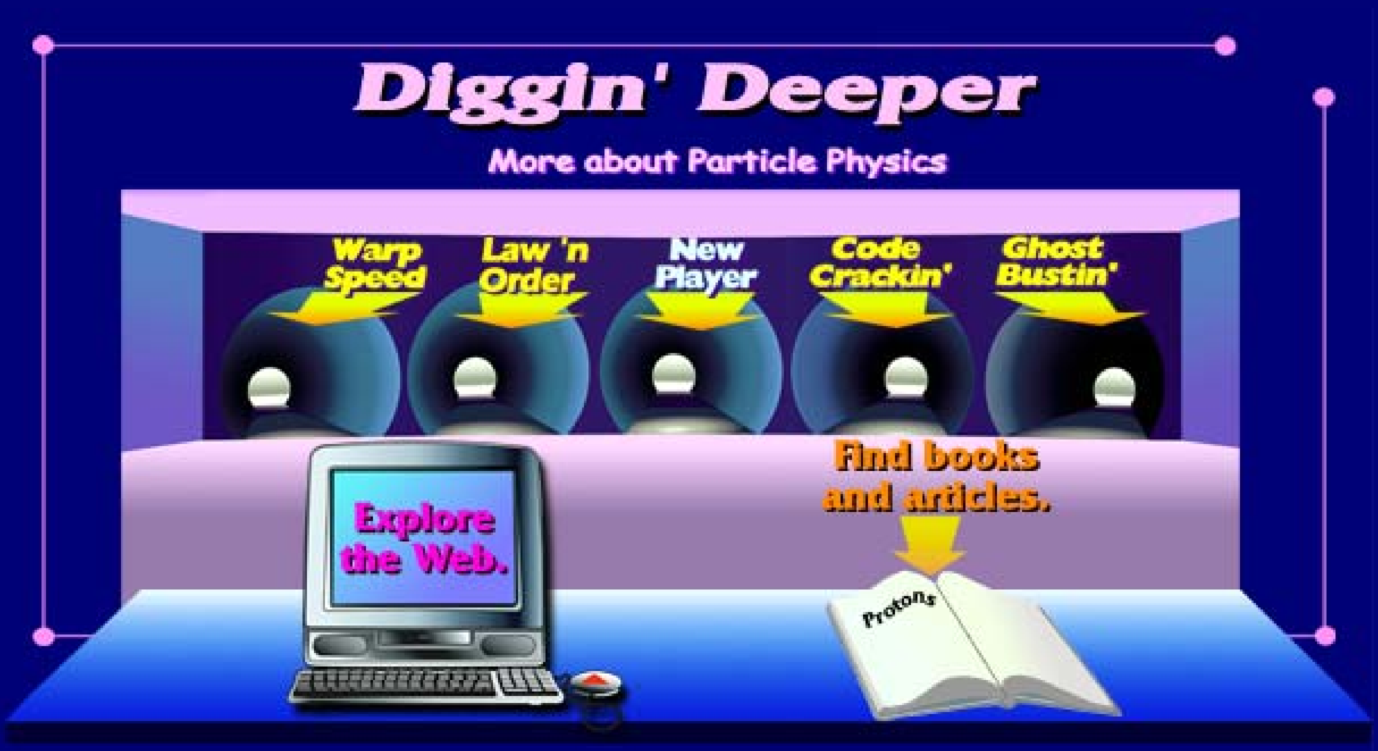
After you study the table, print out your bucks or go back to Law 'n Order.

	Four Forces			
Particles	**Gravity**	**Electromagnetic**	**Weak**	**Strong**
neutron	◉ Yes ○ No	◉ Yes ○ No	◉ Yes ○ No	◉ Yes ○ No
neutrino	◉ Yes ○ No	○ Yes ◉ No	◉ Yes ○ No	○ Yes ◉ No
quark	◉ Yes ○ No	◉ Yes ○ No	◉ Yes ○ No	◉ Yes ○ No
proton	◉ Yes ○ No	◉ Yes ○ No	◉ Yes ○ No	◉ Yes ○ No
photon	◉ Yes ○ No	○ Yes ◉ No	○ Yes ◉ No	○ Yes ◉ No
electron	◉ Yes ○ No	◉ Yes ○ No	◉ Yes ○ No	○ Yes ◉ No

Print Your Bucks



Go Back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More about Particle Physics
Warp Speed
Law 'n Order
New Player
Code Crackin'
Ghost Bustin'
Explore the Web.
Find books and articles.
Protons

Diggin' Deeper:
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Information on High Energy Physics from Fermilab

Fermilab Virtual tour and Research at Fermilab

Topics on Particle Physics from *inquiring minds*

QuarkQuest: A Fermilab Newspaper Written by Students for Students

Searching for the Building Blocks of Matter

The Discovery of the Top Quark

Top Quark (Fermilab Site)
Scientific American Article on the Top Quark

Lab and University Sites

The Particle Adventure from CPEP with a link to Physics Resources

CERN- Europe's High Energy Physics Lab

ATLAS: A Big Detector Being Built at CERN

Guide to High Energy Physics at Boston University

Powers of Ten from Florida State University

Diggin' Deeper:
Books and other Resources

Bibliography of Particle Physics Educational Materials