

# Big search for something very small

One of the biggest challenges to modern physics is unifying Einstein's general theory of relativity with quantum theory

Einstein's theory does a great job explaining how gravity works on a large scale, describing the movements of planets and predicting the existence of things like black holes.



But in the very small world of particle physics, gravity can't be explained—especially in realms like black holes where we don't know how gravity works or at distances as small as the size of particles.



Scientists have theorized the existence of a new particle: **the graviton**.

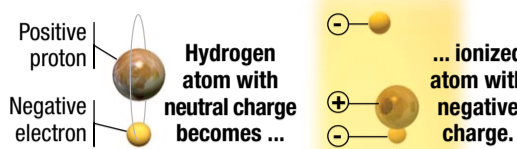
Using this particle, scientists have devised ways to unify relativity with quantum theory, possibly resulting in a "Theory of Everything."

One type of graviton in a recent predicted model also calls for the existence of extra dimensions. Evidence for that graviton is being sought at Fermilab. Here's how:

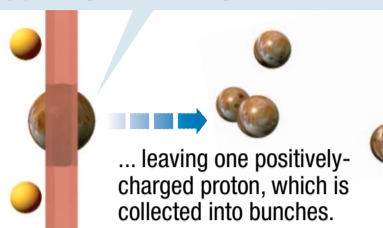
## Gathering the materials

Experimenters work with small particles called protons and antiprotons

**To get protons**, hydrogen gas is ionized, adding a negative electron. This gives the hydrogen atoms an overall negative charge, and once an atom has a charge it can be propelled by an accelerator.

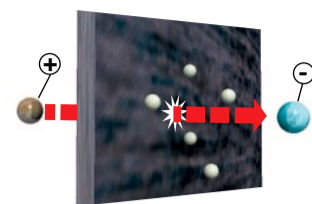


Later in the process, both electrons are removed by passing the ion through a carbon foil...



### Antiprotons

• **Protons** are accelerated into a target made of nickel, producing a number of particles including antiprotons. The antiprotons are also collected into bunches until they're ready to be used.

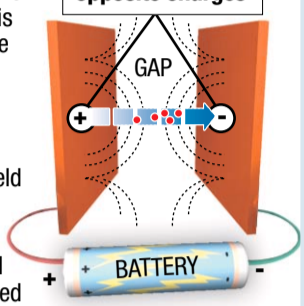


## How particles are accelerated

To get particles moving faster, scientists need to increase their energy

• **The simplest way** to increase a proton's energy, or speed, is to pass the particle between two electrified metal plates of opposite charges. An electromagnetic field is created in the gap.

**Metal plates with opposite charges**



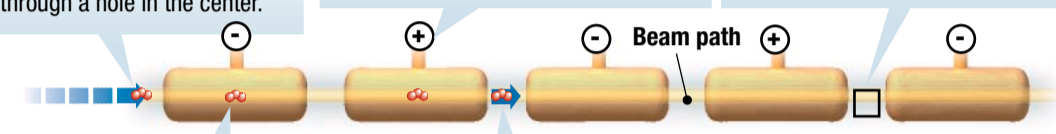
Positively-charged particles are repelled from the positively-charged plate and are attracted by the negatively-charged plate.

Advanced accelerators utilize a tube-shaped cavity with alternating charges, called a **radio-frequency cavity**.

### How a series of radio-frequency cavities works

1) As positive-charged bunches of protons approach a negative-charged RF cavity, they're drawn through a hole in the center.

3) The polarity of the RF cavity is reversed, so when the bunches emerge into the gap between two cavities ...



2) Inside, the bunches are unaffected and simply continue along the beam path.

4) ... they're repelled by the positive energy field behind them and attracted by the negative field in front.

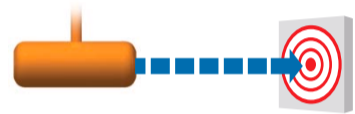
**It's in the gap** between two RF cavities that protons and antiprotons gain energy, and therefore speed. This progression is sometimes characterized as "riding" an electromagnetic wave, a wave that can reach speeds of about 300 mph. less than the speed of light, which is 186,000 miles per second.

## Different paths

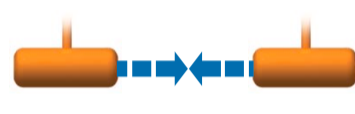
There are two ways for the particle "streams" to flow

### A straight line

• **Linear accelerators** use RF cavities to accelerate particles in a straight line, where they smash into a fixed target ...

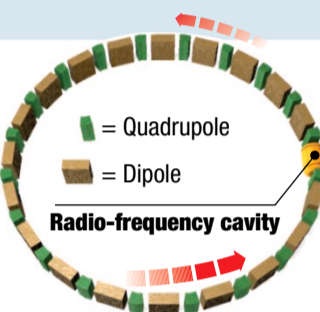


... or, two opposing RF cavities allow a fixed-target strike or for two bunches of particles to collide.



### 'Round and 'round

• **Ring accelerators** return the particle stream to the same RF cavity again and again where the particle bunches gain speed and energy.



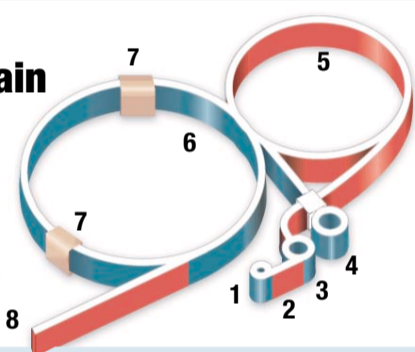
### Managing the stream

The Tevatron ring at Fermilab has the particle streams pass through 774 dipole magnets to gently bend the streams around the ring, and 216 quadrupole magnets that condense the stream.

## Fermilab's accelerator chain

Both linear and ring accelerators are used at Fermilab.

**The Tevatron has a circumference of 4 miles**



1) **Cockcroft-Walton Pre-Accelerator** and 2) **Linear Accelerator**, where protons are formed and gathered.

3) **Booster**, a circular accelerator that increases the speed of protons before they're released to the main injector.

4) **Antiproton source**, creates, collects and injects antiprotons into the main injector.

5) **Main Injector** accelerates proton and antiproton streams to 150 billion electron volts

(GeV), before injecting protons and antiprotons into the Tevatron.

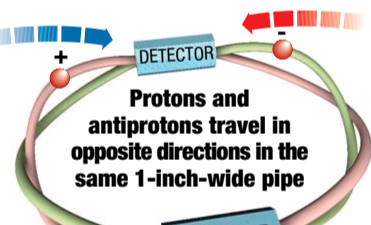
6) **Tevatron**, where protons and antiprotons are accelerated in opposite directions to 1,000 GeV or within 200 mph of the speed of light.

7) **Detectors**, where collisions (known as events) between protons and antiprotons are studied.

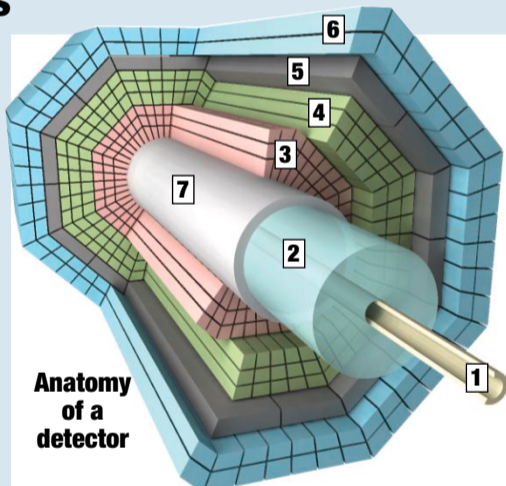
8) **Fixed-target beamline**, where beam is routed for other experiments.

## Watching the detectors

The Tevatron is set up so that collision events are more likely to occur inside Fermilab's two detectors



Electrodes keep the two streams separate, so they travel along different paths.

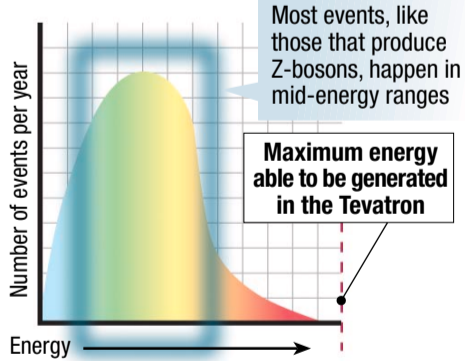


1) <b>Beam pipe</b>	Where proton and antiproton streams travel
2) <b>Tracking chamber</b>	Very accurately detects the paths of particle trajectories
3) <b>Electro-magnetic calorimeter</b>	Detects photons and electrons; paths of muons and protons
4) <b>Hadron calorimeter</b>	Detects protons and neutrons; path of muons
5) <b>Magnetized iron and</b>	Iron bends the paths of elementary particles called muons, allowing their energy to be measured.
6) <b>Muon chambers</b>	
7) <b>Solenoid magnet</b>	Creates a magnetic field inside the tracking chamber that causes the paths of particles to bend. Scientists examine the amount of curvature to measure a particle's energy, and which way the path curves reveals a particle's charge.

## Inside an event

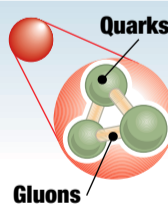
Scientists looking for the graviton are examining events that create an unstable elementary particle called the Z-boson

A particle's speed is measured by the amount of energy it has – Fermilab's Synchrotron can accelerate particles within 300 m.p.h. of the speed of light, or a quadrillion electron volts (quadrillion = a 1 with 15 zeros after it). That's about the voltage that one could get connecting 100 billion 9-volt batteries.



Most events, like those that produce Z-bosons, happen in mid-energy ranges

**Maximum energy able to be generated in the Tevatron**

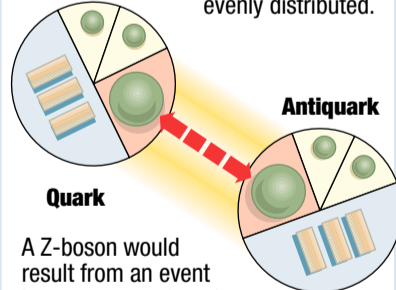


Protons are made up of smaller particles called quarks that are held together by gluons. Antiprotons have antiquarks, etc.

As protons are accelerated, they gain energy. That energy is roughly divided between the gluons and the quarks.

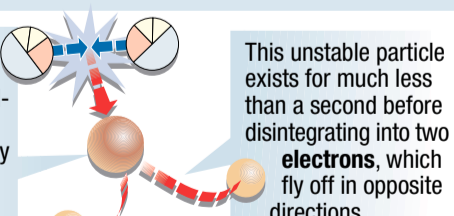
**Approximate distribution of energy in a proton**

But the energy among the quarks in those particles is not necessarily evenly distributed.



A Z-boson would result from an event between a quark and antiquark with energies in the mid-range of the Tevatron's capabilities.

When a mid-energy quark collides with a mid-energy antiquark, the released energy results in a Z-boson particle.



**Z-boson event detected by electromagnetic calorimeter**

The calorimeter is able to measure a particle's energy and position. In addition, scientists are able to identify the kind of particle because they are fully absorbed into specific layers of the calorimeter.

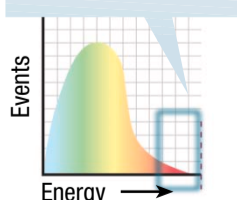
This unstable particle exists for much less than a second before disintegrating into two electrons, which fly off in opposite directions.

**Collision in beam pipe**

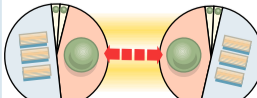
**Detected energy in mid-range**

**Particle trails in tracking chamber**

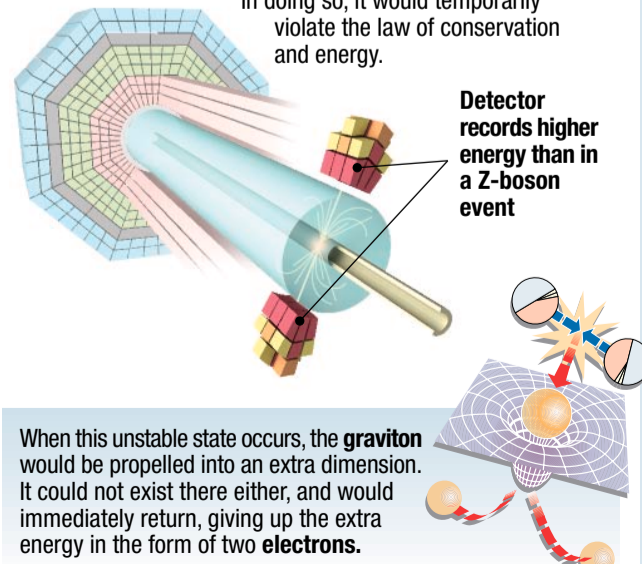
A graviton event is theorized to look similar to the Z-boson event, except it happens at the maximum energy levels of the Tevatron.



That means the event would involve a quark and antiquark with energy in the highest range of the Tevatron's capabilities.



In this event, scientists theorize that a graviton would temporarily absorb the energy from two high-energy, disintegrating quarks. In doing so, it would temporarily violate the law of conservation and energy.



**Detector records higher energy than in a Z-boson event**

When this unstable state occurs, the **graviton** would be propelled into an extra dimension. It could not exist there either, and would immediately return, giving up the extra energy in the form of two **electrons**.