Tour of the Subatomic Zoo

Class 6

not to be used without permission

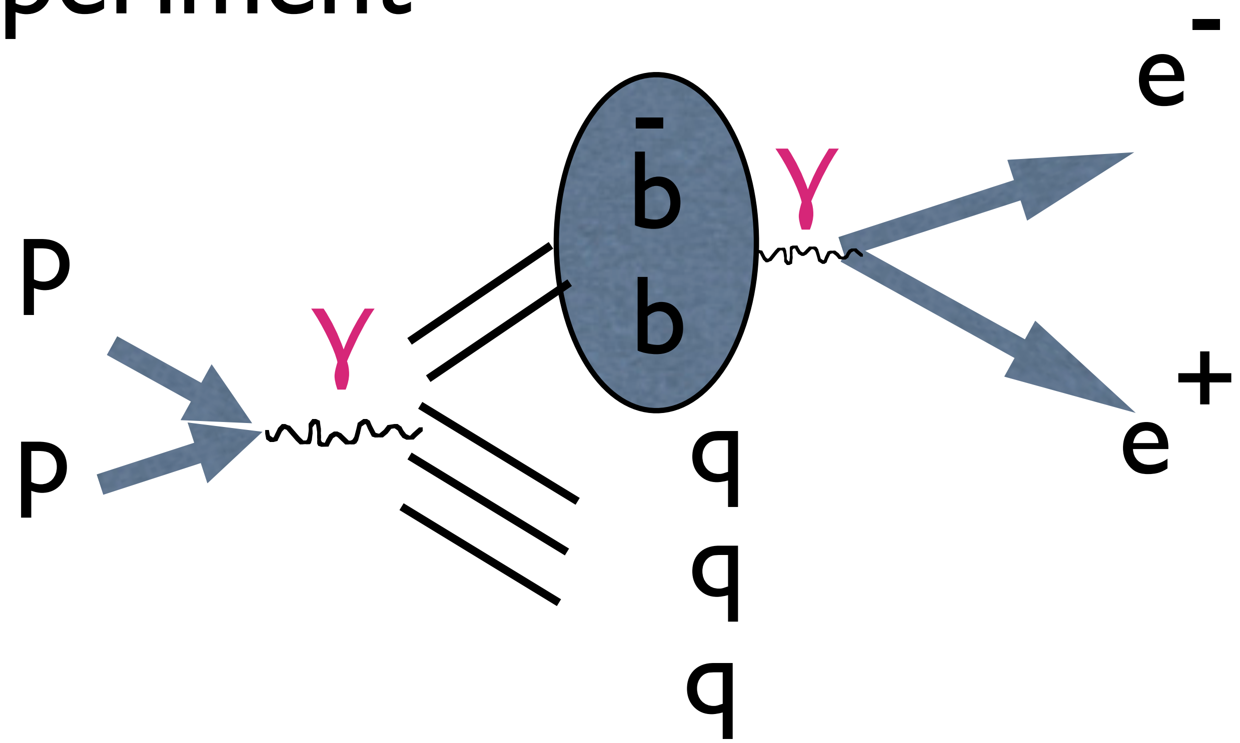
more quarks
color
debate project assignment
and planning

After 1975

Quarks (mass)	Leptons	
u (1/3) d (1/3)	e ν	first generation
c (1.5) s (.5)	μ ν	second generation
t ? (>>1.5) b ? (>1.5)	τ ν	third generation

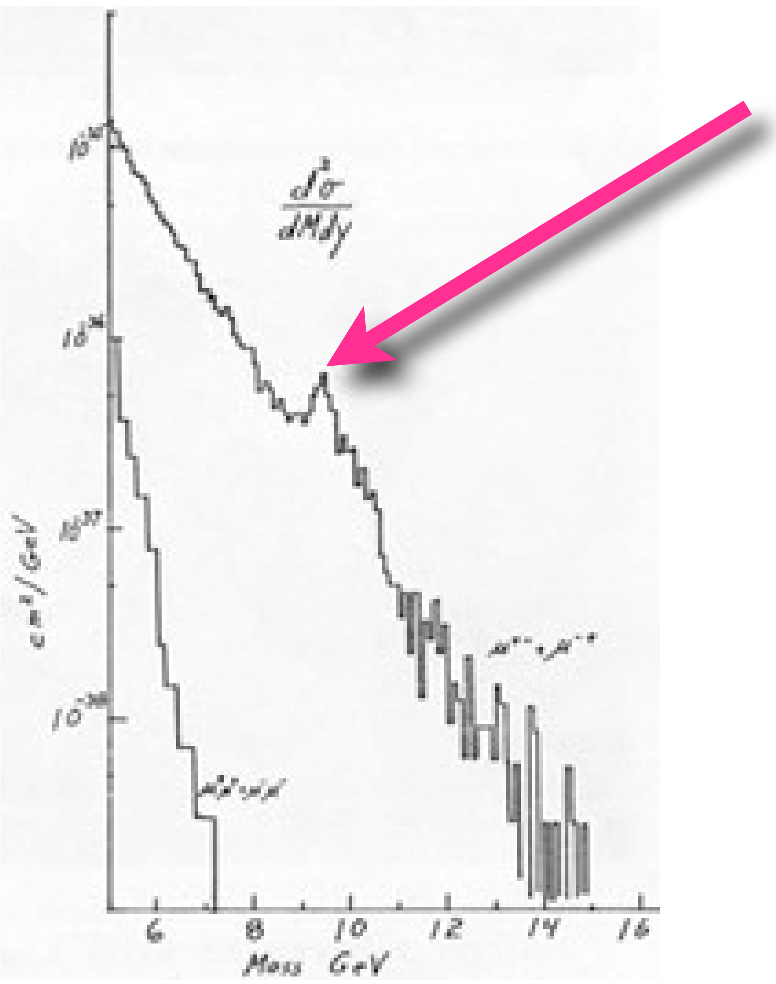
Looking for bottom (beauty) and top (truth).....

Looking for the bottom quark in a Ting type experiment



detect
electron & positron

Summer of 1977 group led by Leon Lederman at Fermilab found something in their data



Text of News Release (August 7, 1977)

77-6
For release a.m., Friday, August 5, 1977

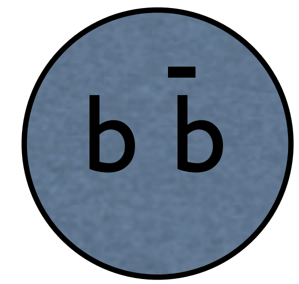
FOR TECHNICAL INFORMATION CALL:
L. Lederman, Columbia University
(914) 591-8100
C. Brown, Fermilab
(312) 840-4096

FOR GENERAL INFORMATION CALL:

M. Pearson, Fermilab
(312) 840-3351

An experimental group at the Fermi National Accelerator Laboratory announced recently that it has discovered a new particle. The new particle has a mass of 9.5 GeV. It is 10 times heavier than the proton and is the heaviest sub-nuclear particle ever seen. The new particle -- which the group has named "Upsilon" -- is interpreted by theorists to be the first hint of a whole new family of subnuclear particles.

called it the upsilon (Υ) – mass of 10 times the proton....

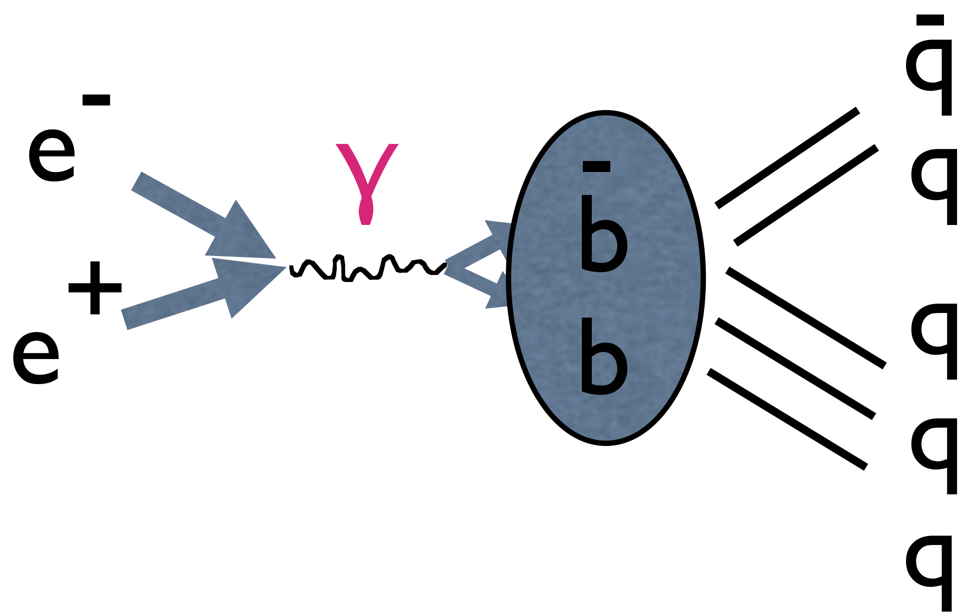


then the b quark mass was about 5 times the proton mass.......

needed confirmation in a Richter type experiment..
electron-positron collisions

No electron positron collider had enough energy to do this until summer of 1978

In Hamburg Germany they verified the upsilon

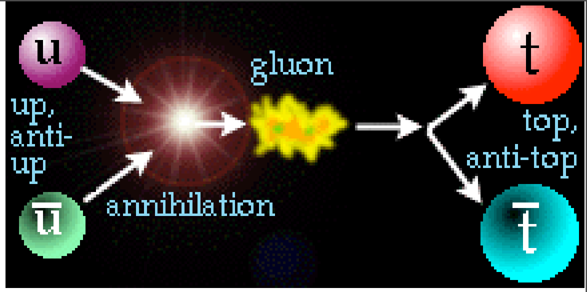


detect hadrons

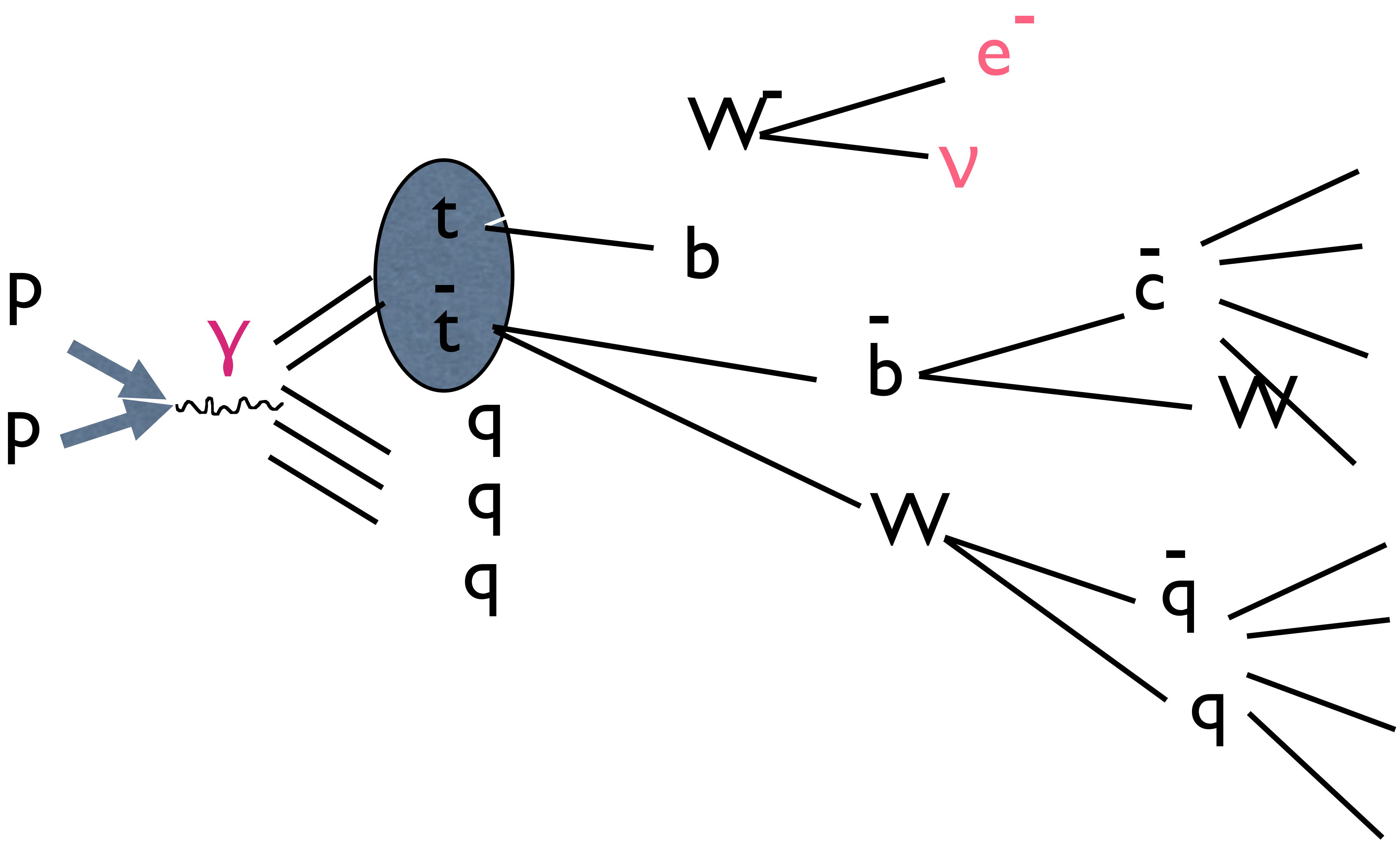
Richter type experiment

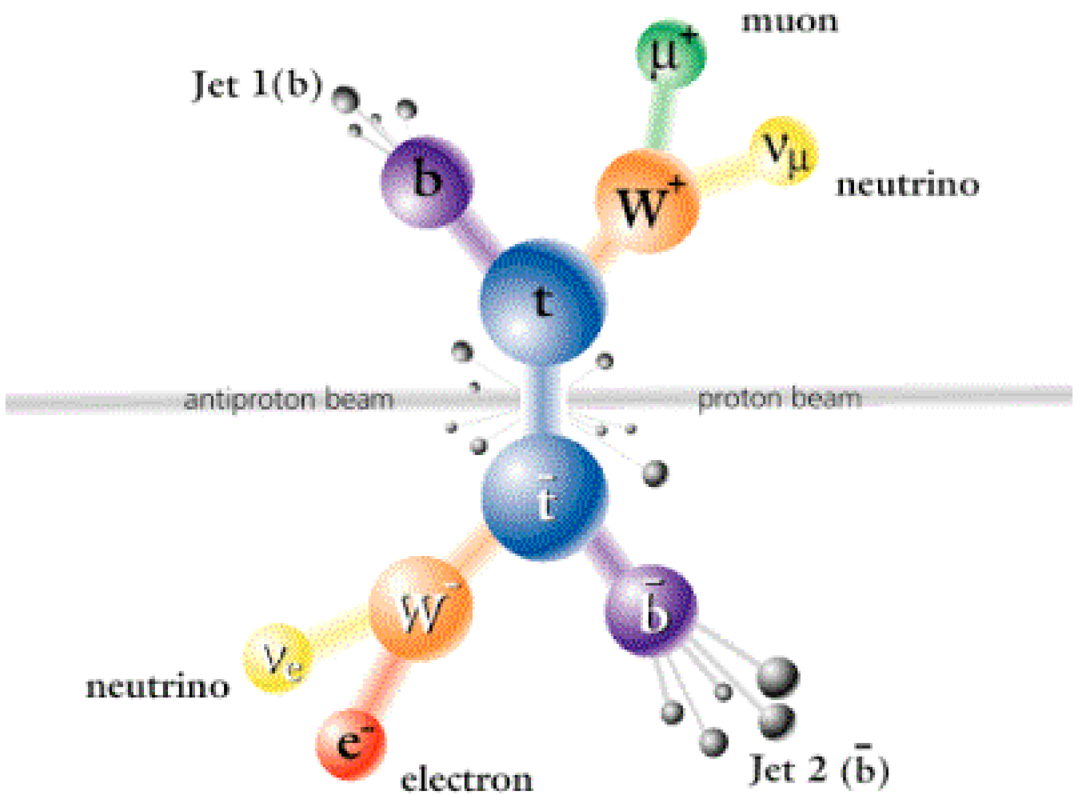
At CERN in 1980-81 other mesons were found.... for example the B^- ($b\bar{u}$) and the hunt was on for the top quark.....

And it was a long long hunt



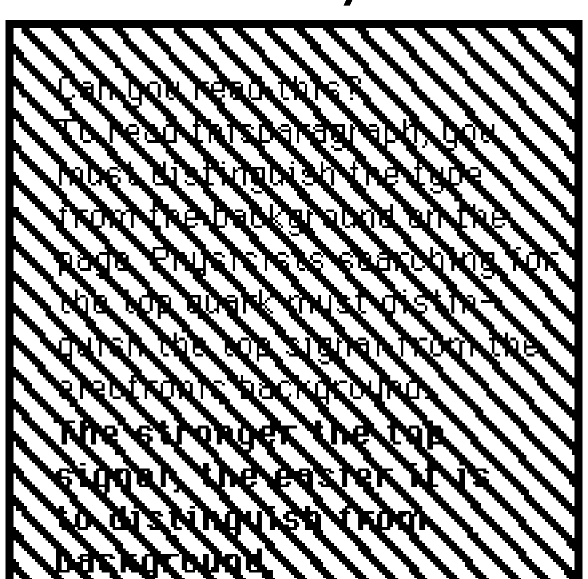
Finally in March 1995, two groups at Fermilab announced the discovery of the top quark with a mass of almost 200 times the mass of the proton

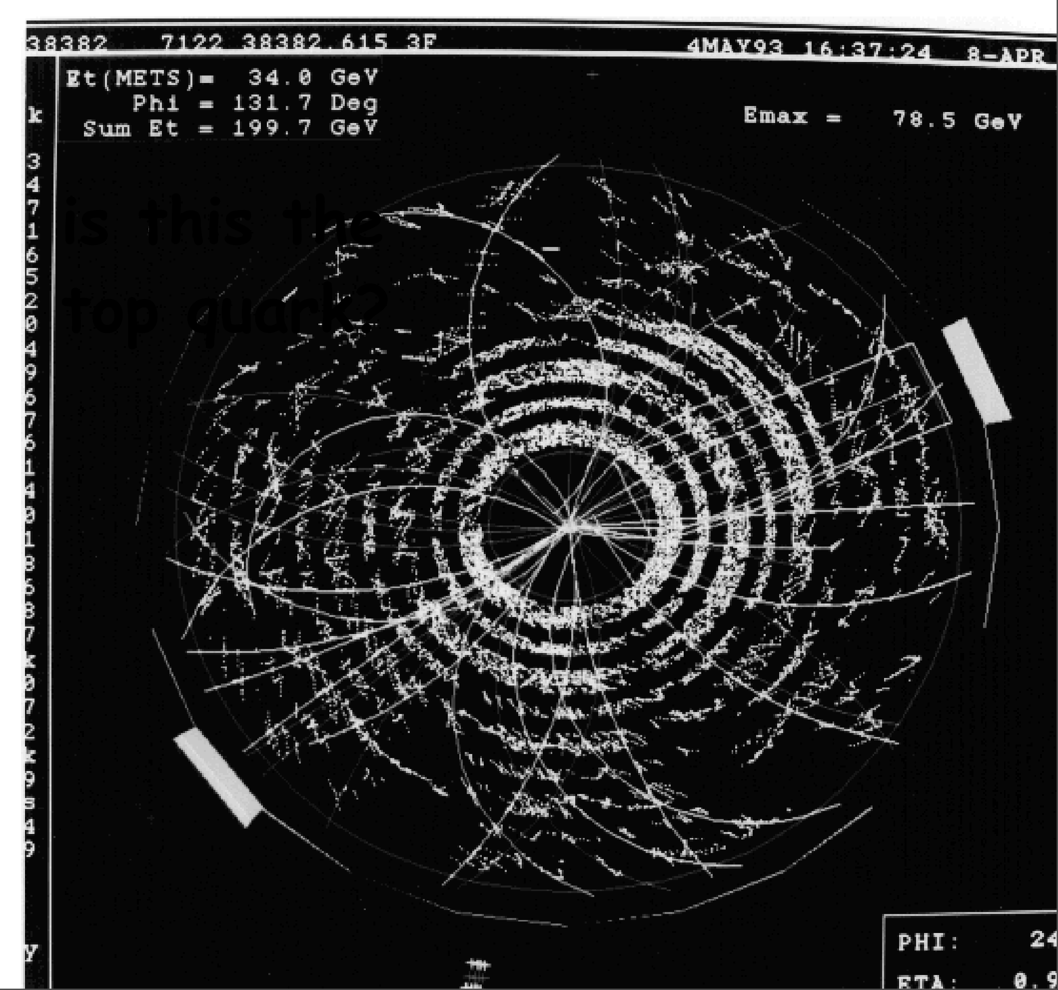




The discovery of the top quark was not a "Eureka" event--not the sudden sighting of the long-sought particle. "We discovered the top quark not in one lightning stroke, but over a long period of time, event by event," says physicist Nick Hadley, a DZero collaborator. "No single piece of evidence, no matter how strong, was enough to let us claim a discovery. We couldn't be sure we had found the top quark until we had seen so many events with the right characteristics that there was almost no chance the statistics were fooling us into making a false claim."

finding it in a sea of events that could fool you



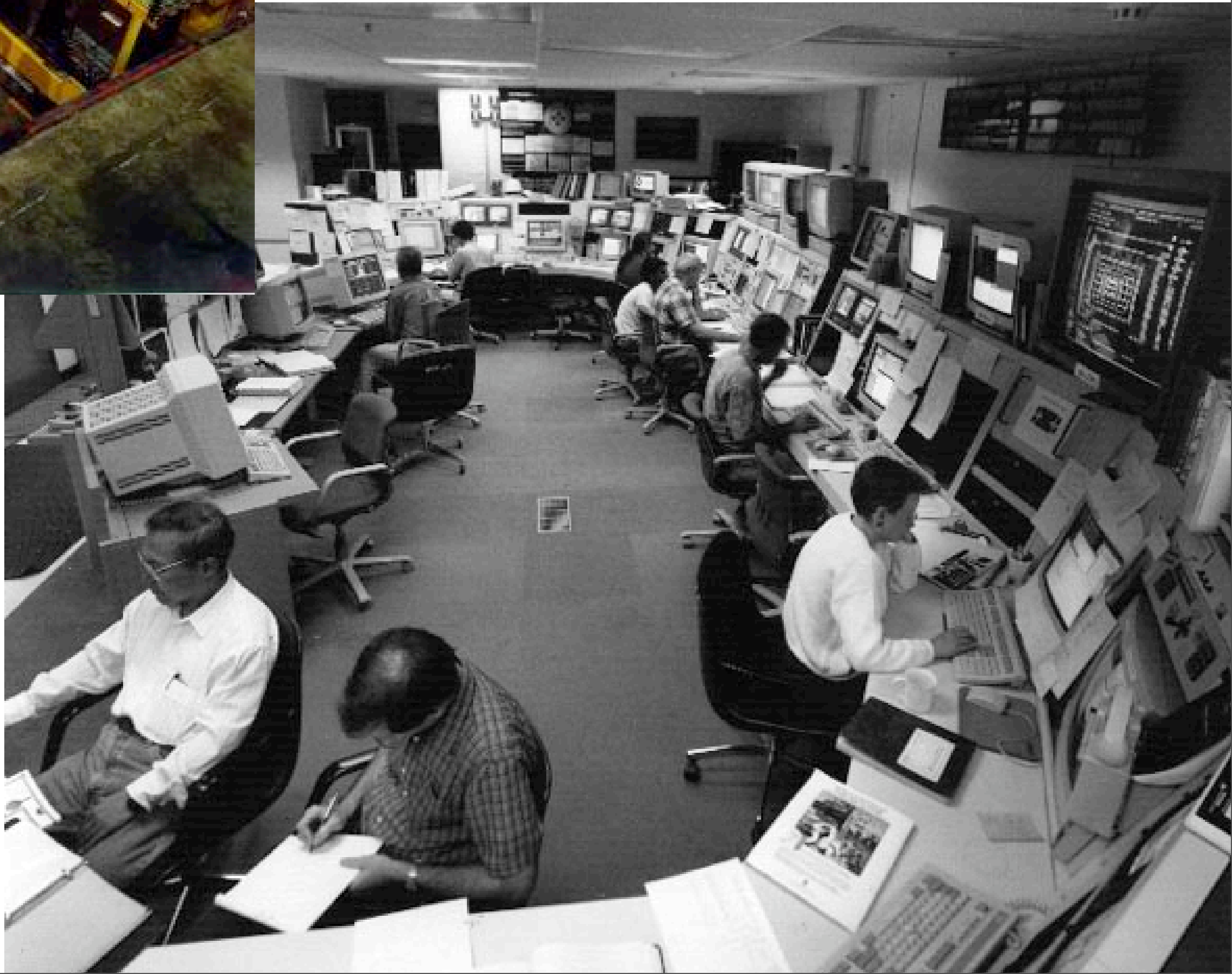


CDF collaboration

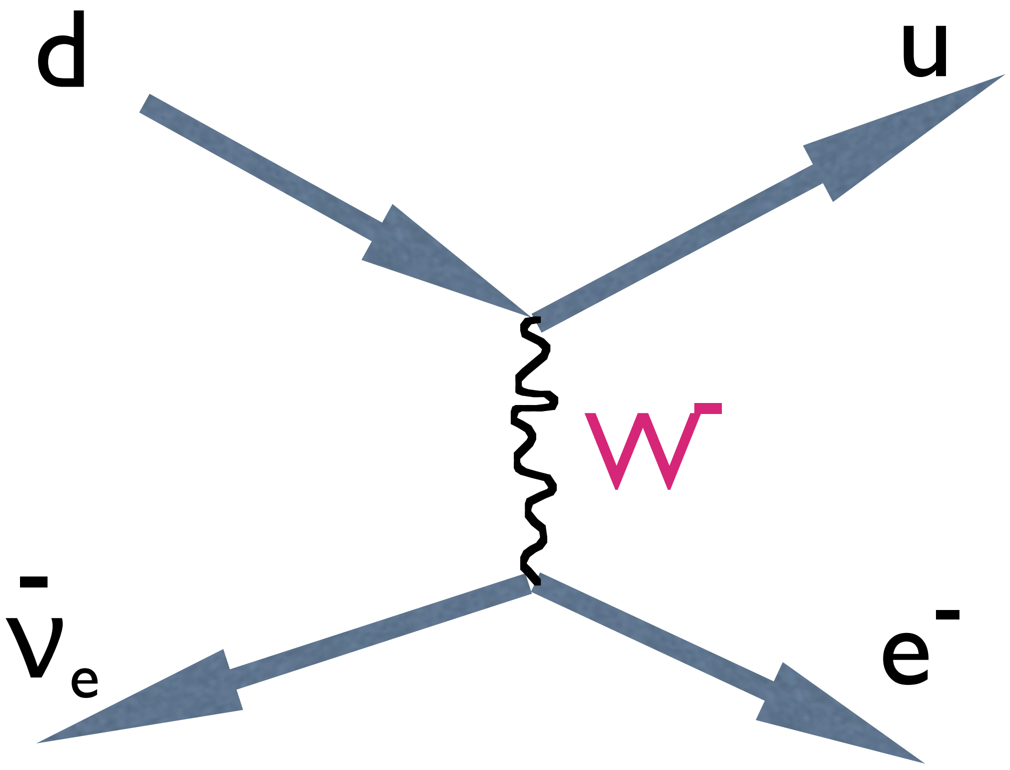
438 collaborators from 36 universities and laboratories

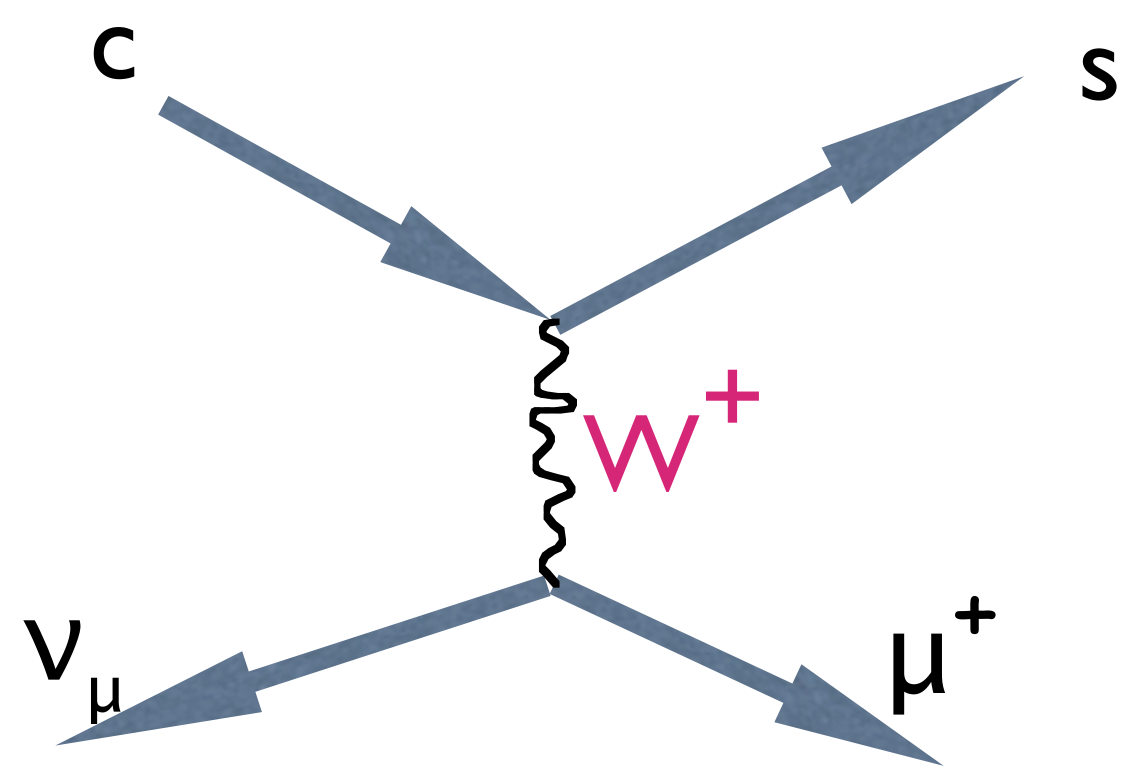
Argonne National Laboratory
Istituto Nazionale di Fisica Nucleare, Universita di Bologna, Bologna, Italy
Brandeis University
University of California at Los Angeles
University of Chicago
Duke University
Fermi National Accelerator Laboratory
Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, Frascati, Italy
Harvard University
Hiroshima University, Higashi-Hiroshima, Japan
University of Illinois at Urbana-Champaign
Institute of Particle Physics, McGill University, Montreal, and University of Toronto, Toronto, Canada
Institute of Physics Academia Sinica Nankang, Taipei Taiwan, R.O.C.
The Johns Hopkins University
National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki, Japan
Lawrence Berkeley Laboratory
Massachusetts Institute of Technology
University of Michigan
Michigan State University
University of New Mexico
Osaka City University, Osaka, Japan
Universita di Padova, Instituto Nazionale di Fisica Nucleare, Sezione di Padova, Padova, Italy
University of Pennsylvania
University of Pittsburgh
Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, Pisa, Italy
Purdue University
University of Rochester
Rockefeller University
Rutgers University
Superconducting Super Collider Laboratory
Texas A &M University
University of Tsukuba, Tsukuba, Ibaraki, Japan
Tufts University
University of Wisconsin

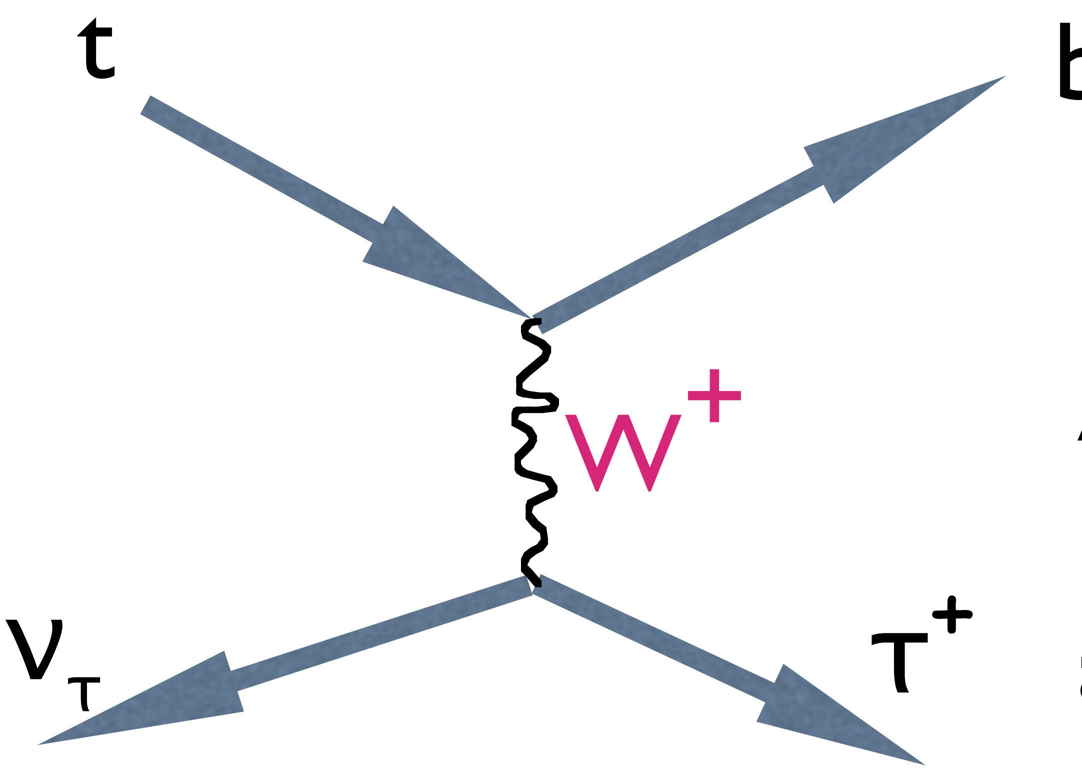
DZero



Three complete generations







And we have symmetry...
but masses not understood...
and why three generations?

2007

Quarks (mass)	Leptons (mass)	Mediators
u (1/3) d (1/3)	e (1/1800) ν	photon
c (1.5) s (.5)	μ (1/9) ν	gluons (8)
t (200) b (10)	τ (2) ν	W^+, W^-, Z
6+6 anti's	6+ 6 anti's	12

But there are more......

Quantum Chromodynamics - A Theory for Quarks

Commonality	Atom parts	Quarks
Patterns seen	2 periodic table	1 eightfold way
Structure discovered	3 alpha particle scattering	2 electron-proton scattering
Attractive forces identified	1 electric charges repel or attract	4 quark colors attract and repel
Pauli Exclusion Principle	4 electron energy levels	3 quarks have color

The Pauli Exclusion Principle leads to color

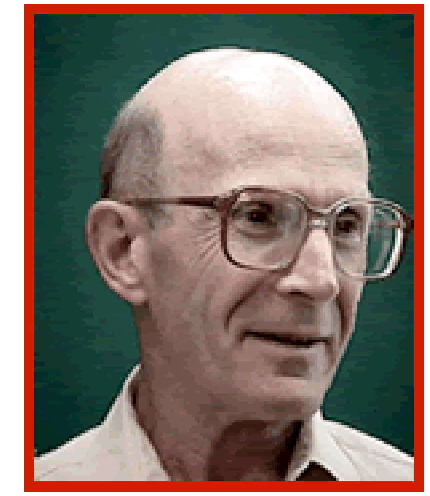
The Pauli Exclusion Principle states that no two IDENTICAL spin 1/2 objects can be in exactly the same state (energy and spin direction)

Applied to electrons this explains atomic structure- for example only two electrons can occupy the lowest energy state in an atom - one with spin up and one with spin down	Applied to quarks it leads to a problem - the omega minus particle (sss) shouldn't exist...but it does. Three identical spin 1/2 objects in the same state...so

S ↑ S ↑ S ↑

Forbidden

The quarks must be different - they are “colored”

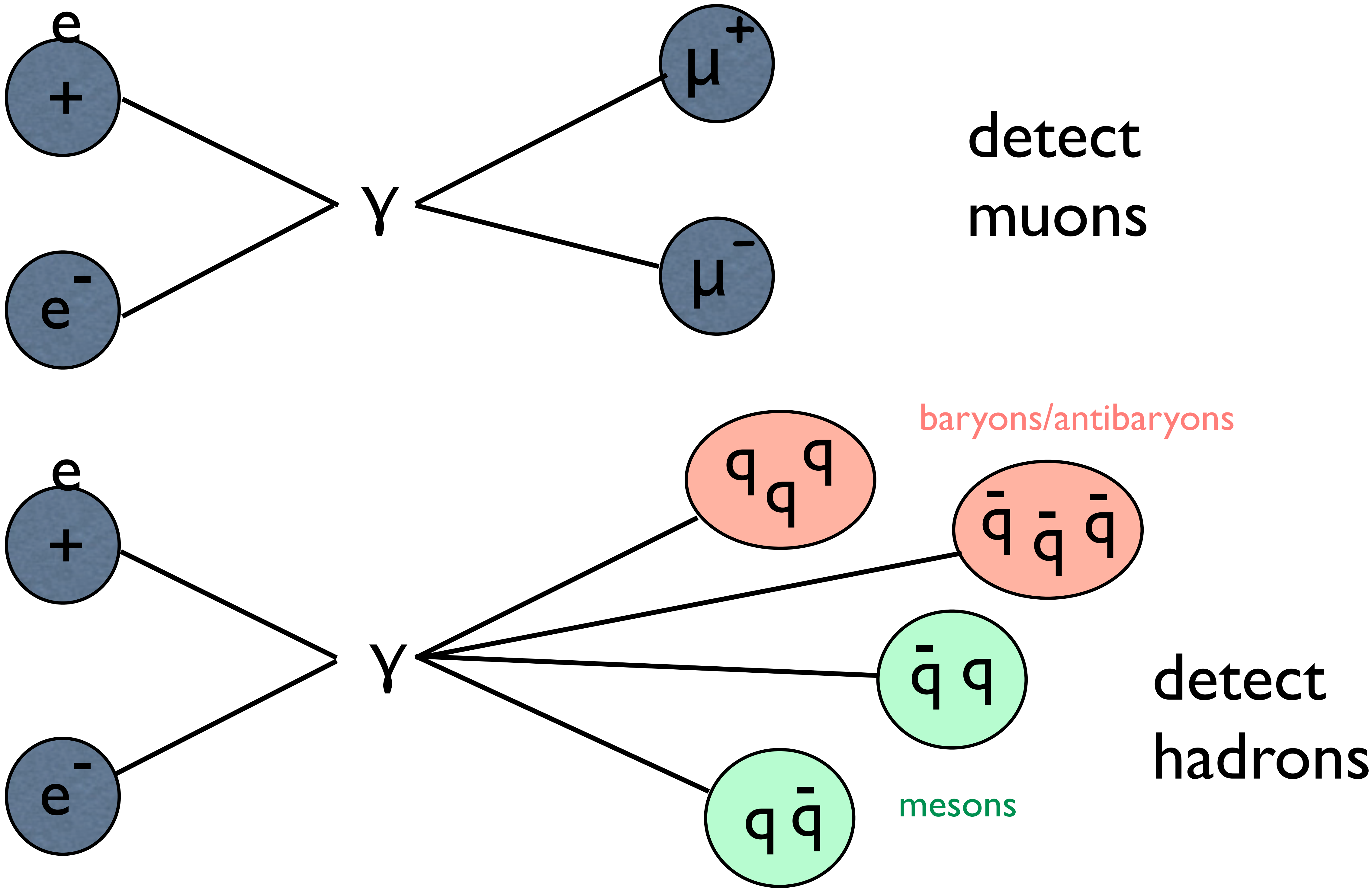


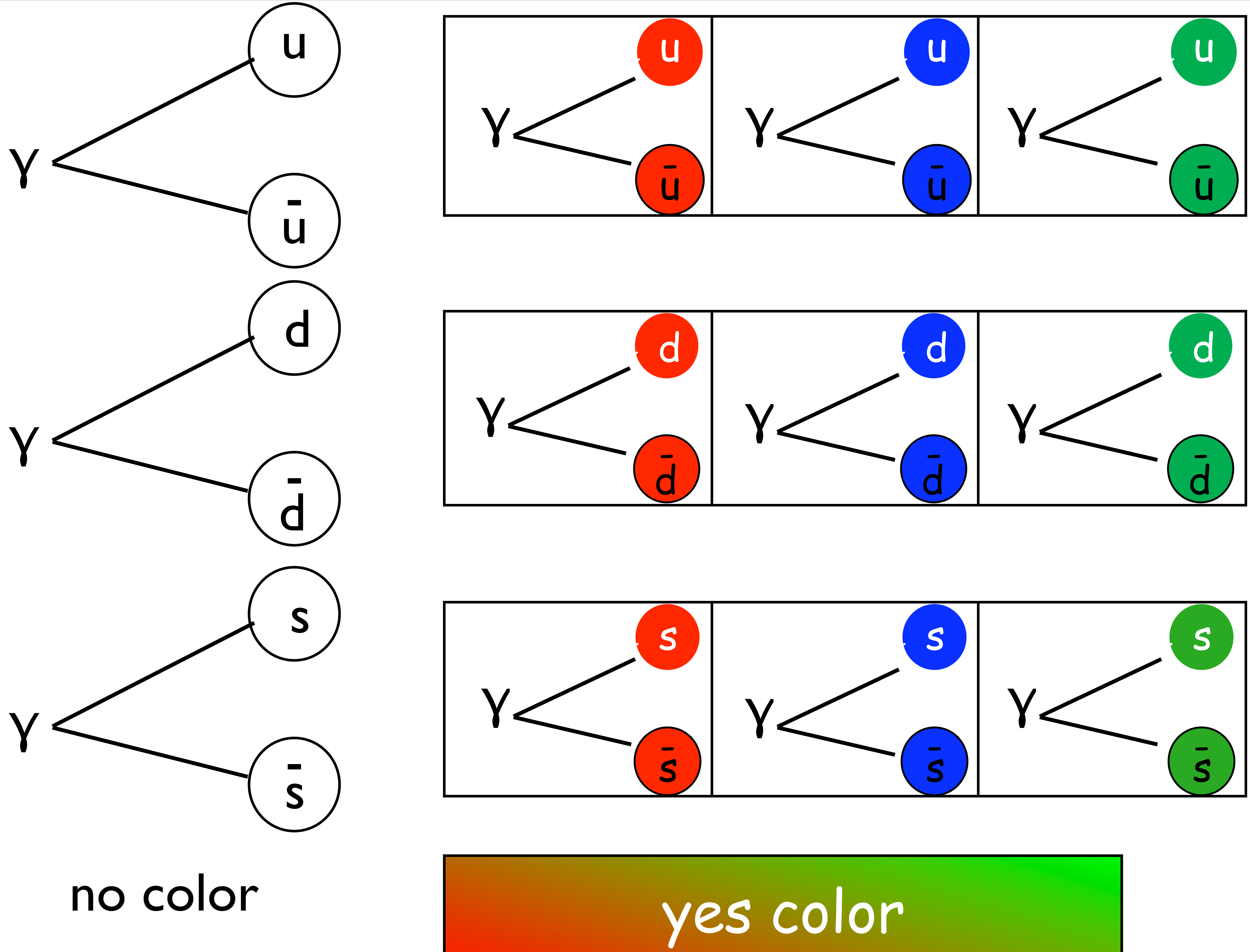
S ↑ S ↑ S ↑

Proposed by Oscar Greenberg in 1964...not well accepted...no evidence then even for quarks...let alone a property called “color”

Experimental evidence for color (1970-1972)

Electron positron collisions





γ
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no color
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d̄
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γ
s
s̄
yes color

What do you measure?

Ratio = $\frac{\text{how many hadrons}}{\text{how many muon pairs}}$

the ratio depends on the number of quark types

no color	2/3
yes color	3x(2/3)=2

first experiments in Frascati, near Rome, gave values of 1.6 -2.4

later at SLAC measurements gave 2 within 10%

So quarks have color.....

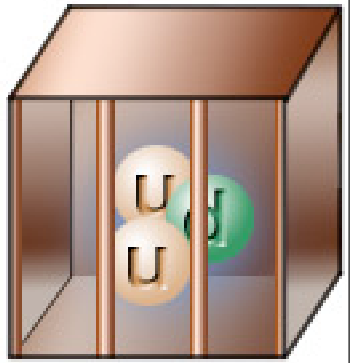
Color or color charge is the source of the strong force between quarks

With electric charge there is only ONE kind - positive and its opposite

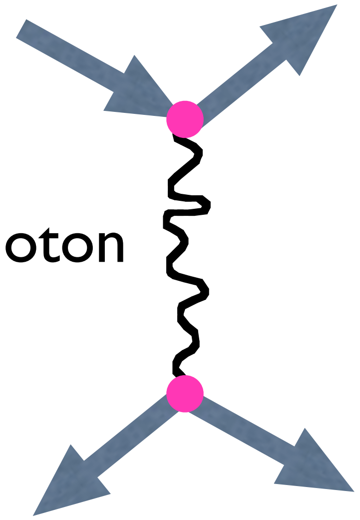
With color charge there are THREE kinds - red, green and blue and their opposites - which we call antired, antigreen and antiblue

This difference is one of the reasons we believe the strong force behaves so differently than the electrostatic force....leading to apparent quark confinement

Quark Confinement

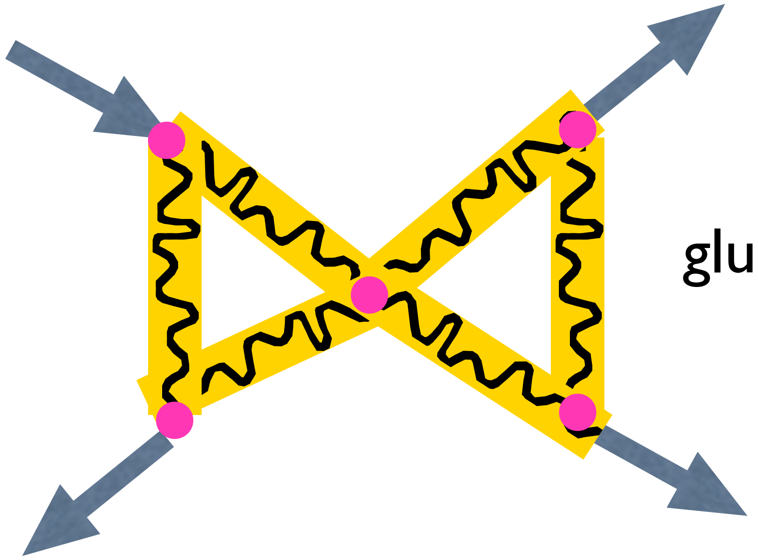


photons can't "self-interact"

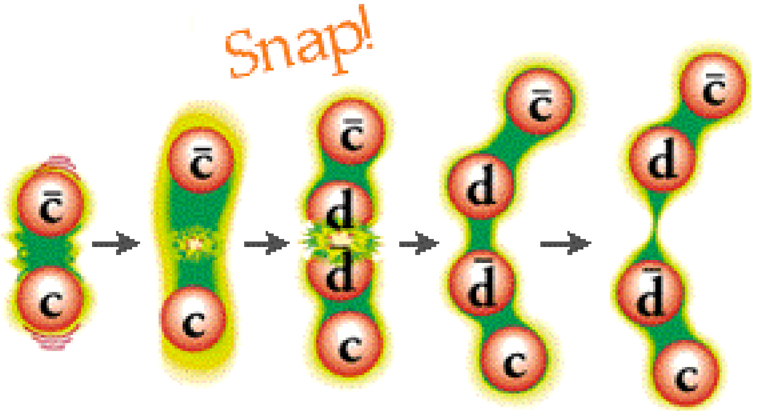


because they don't have electric charge

gluons can "self-interact"

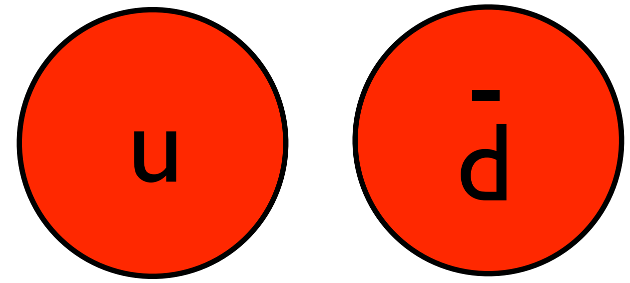


because they have color charge



Do color charges attract or repel?

With electric charge likes repel and opposites attract



π^+

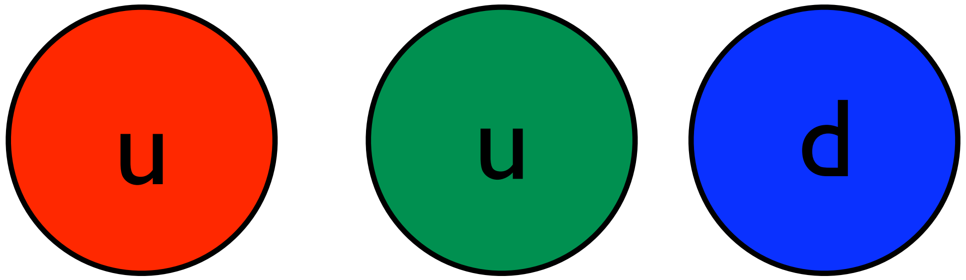
true opposites attract the most (red antired)

true likes repel (red red)

opposites attract less (blue antired)

opposites attract less (red blue)

Nature seems to only allow physical particles to have no net color... that's why we don't have $\bar{q}qqq$ or $\bar{q}qq$ combinations. But it doesn't explain everything.....and the equations are not fully developed



p

Including colored quarks

Quarks (mass)	Leptons (mass)	Mediators
u (1/3) d (1/3)	e (1/1800) ν	photon
c (1.5) s (.5)	μ (1/9) ν	gluons (8)
t (200) b (10)	τ (2) ν	W^+, W^-, Z
18+18 anti's	6+ 6 anti's	12

60 fundamental (?) objects.....

what about the Higgs boson?

How do we make these tiny particles?

next time...

Assignment - due Tuesday 5/8

<u>Fictional story or poem</u> with subatomic particles as the characters
4-5 pages for the story choice
2-3 pages for the poem choice
(you can write a sequel to one of the stories in the book)

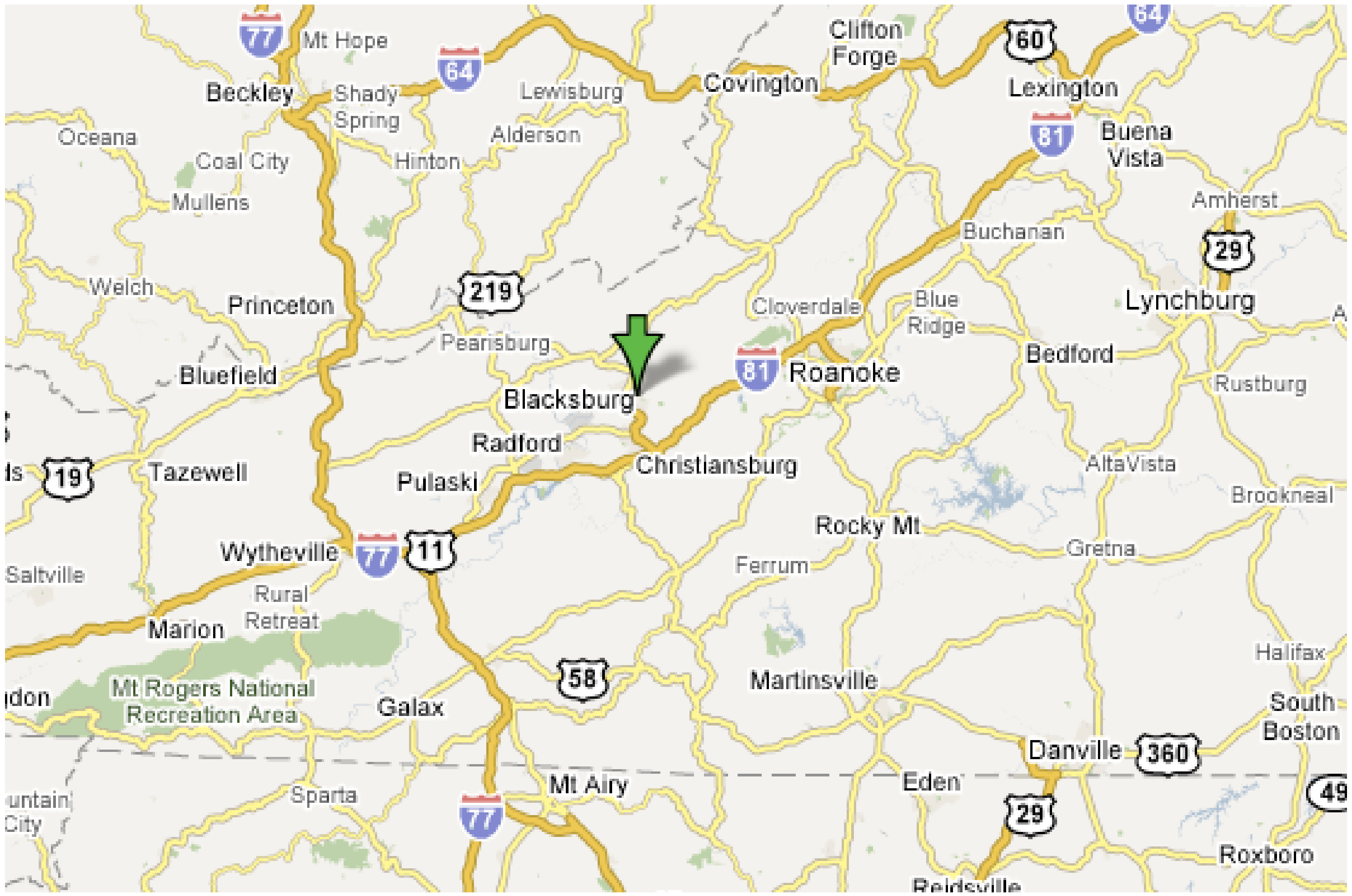
or
you can do a <u>song/performance</u> (1-3 people)

or
a <u>skit/video</u> (2-4 people)

note if you are doing the song/performance or skit/video - you must clear it with me by May 1 - including what you will do and who will be participating and how long it will be

Assignment - Group Presentations - 20 minutes

You will be presenting arguments to a committee of “senators” on the topic of building a new accelerator near Blacksburg VA outside of the town of Pulaski



We will let the physicists from the US decide the type of accelerator.....

presentation must be done in powerpoint - you can find it on many machines on campus - do it on a mac - save it as

Save a presentation as a PowerPoint Package, including all linked files

1. Open the presentation you want to save as a PowerPoint Package.
2. On the **File** menu, click **Save As**.
3. On the **Format** pop-up menu, click **PowerPoint Package**.
4. In the **Save As** box, type a name for the new folder you want to store the presentation and linked files in.
5. Click **Save**.

Tips

- To save the Package in a different location, use the column browser to locate the folder you want.
  If the column browser is hidden, click the arrow next to the **Save As** box or **Where** pop-up menu.
  To save the Package folder in a new folder, click **New Folder**.
- If you want to save to a network server, but you don't see it listed in the column browser, you may need to connect to it.

You can argue for or against the accelerator - make sure you have the facts to backup your position

group	people
Physicists from Virginia Tech	Vendela, Kyle, Katherine H., Chris
Environmental Impact Group	Eric, Sean, Katherine M, Olivia
Business Owners and Residents of Pulaski	Ben, Andrew, Corydon, Sarah
Medical Imaging Device Company - affiliated with a local hospital	Daniel, David, Austin
Taxpayers Lobbyists from Washington DC	Justin, Luke, Dwayne, Phillip