Understanding Our Asymmetric Universe

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Symmetries vs Asymmetries

- Ancient scientists (e.g. Archimedes): Universe is made from perfectly symmetric objects like circles and spheres → wrong models of the orbits of the planets

- Now know: "perfect" symmetry gives a lifeless Universe → it is the asymmetries that give it complexity

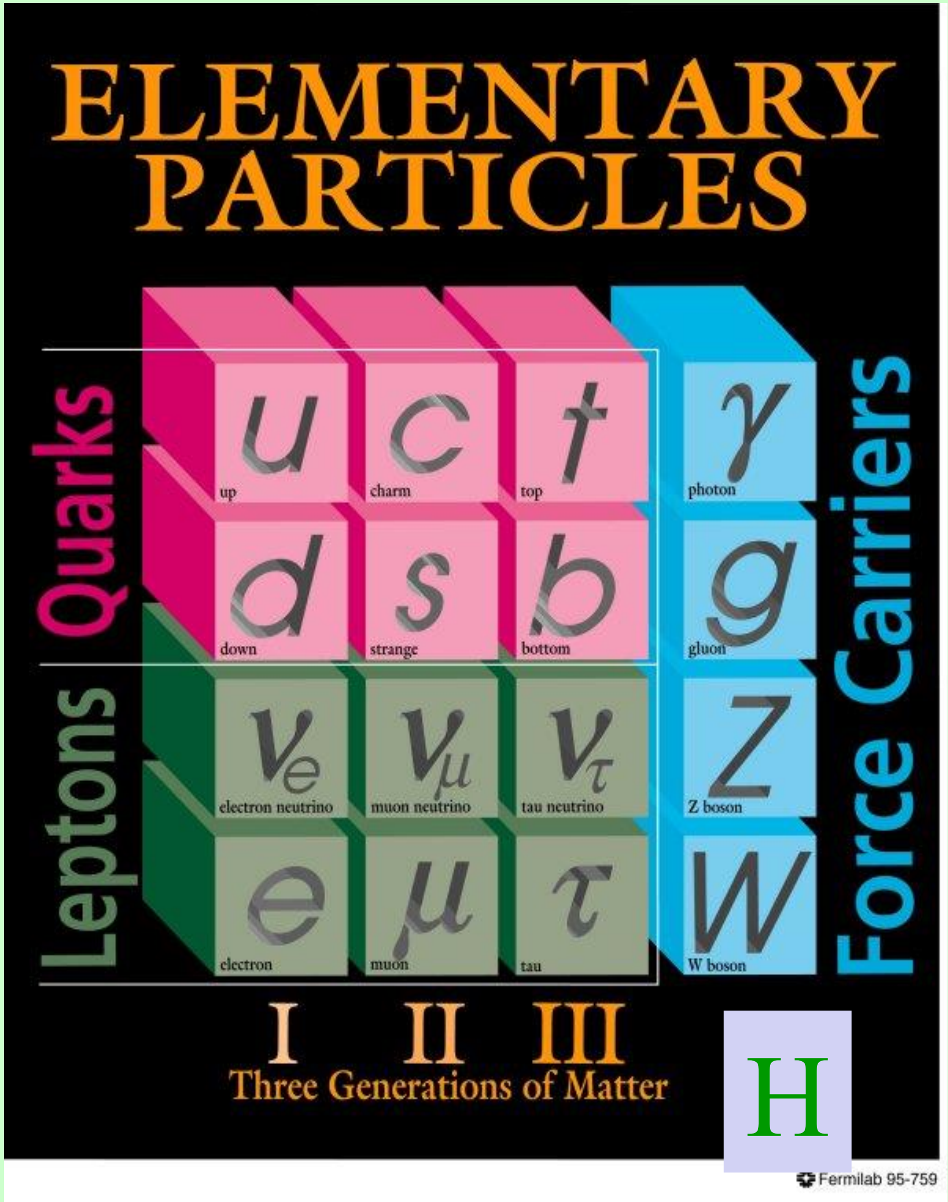
- Differences in DNA (you vs me, humans vs clams)

TODAY's TALK

- Look at 2 "everyday" asymmetries which occurred early in the history of our Universe

- If neither existed (if had "perfect" symmetry) we would not exist → particle physics doesn't really explain either (yet…we are working on it!!)

- neutron mass is larger then proton mass
- matter is slightly different than antimatter



•Have antiparticles for quarks and leptons

electron vs positron

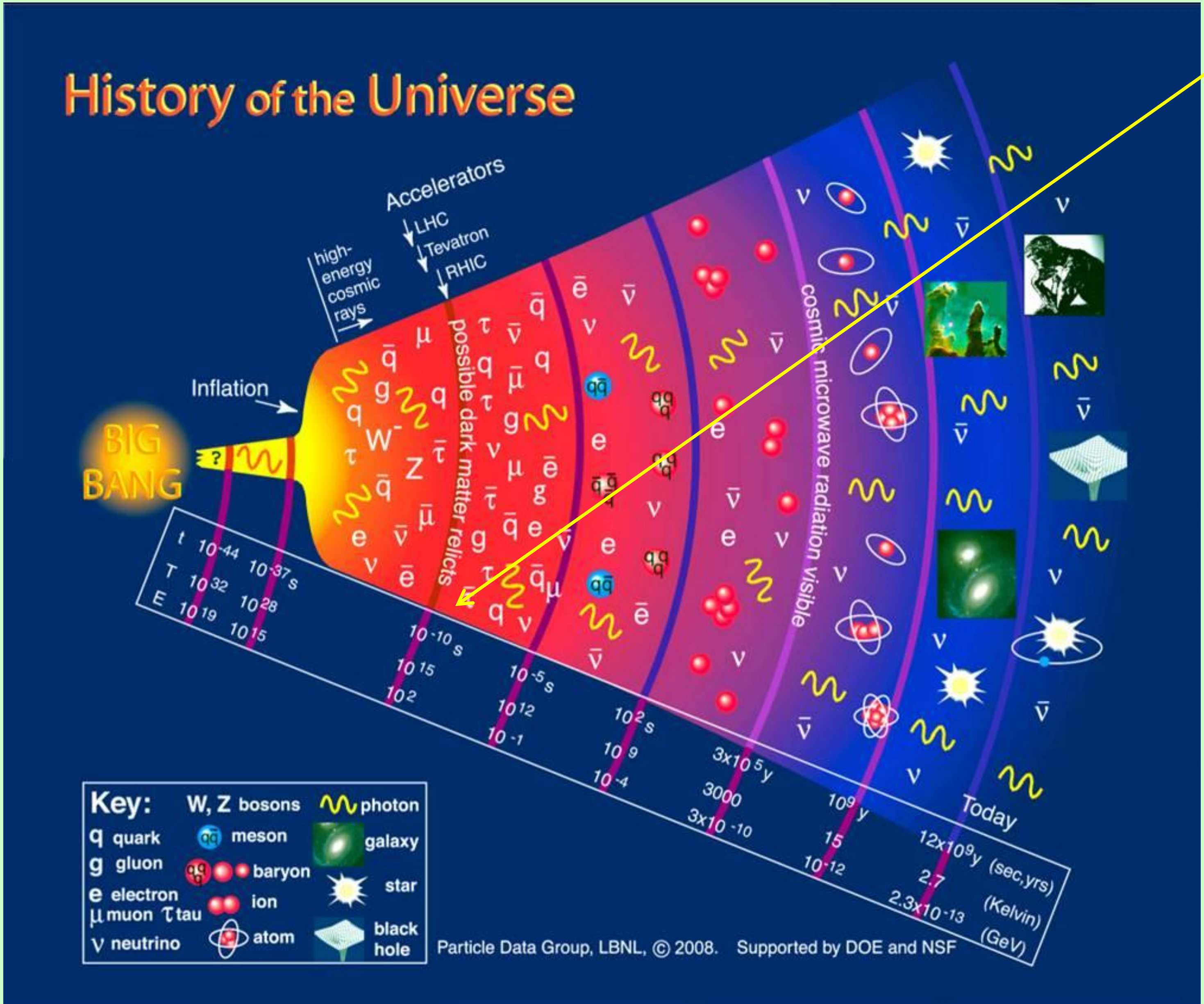
proton (uud) vs antiproton

neutron (udd) vs antineutron

matter and antimatter are different (need 3 generations)

•Higgs mechanism gives different masses for different particles

Creation of Matter



early Universe was hot enough to make particle-antiparticle pairs:

$$\gamma \rightarrow b + \bar{b}$$

$$g \rightarrow b + \bar{b}$$

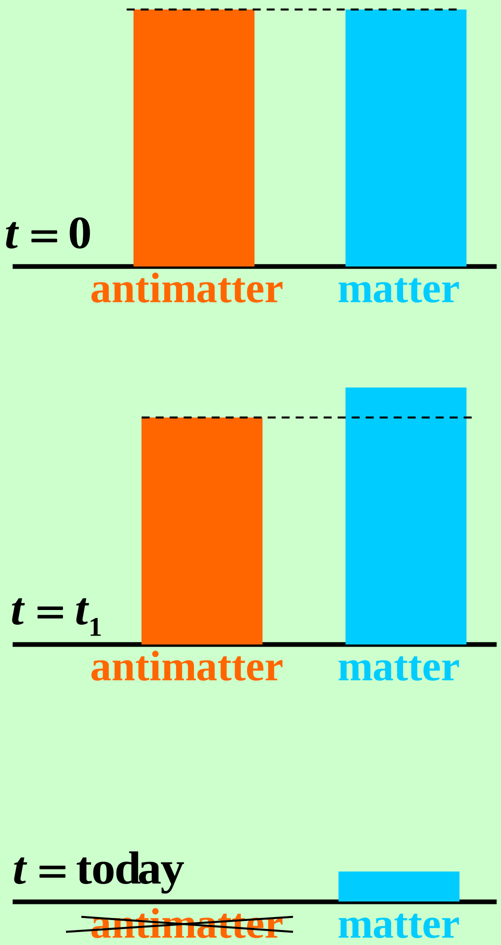
$$\gamma \rightarrow \mu^{+} + \mu^{-}$$

$$\gamma \rightarrow e^{+} + e^{-}$$

etc

Matter – Antimatter Asymmetry

- early universe: very hot, makes matter-antimatter
- For some reason matter becomes more abundant in the early stages of Universe
  1,000,000,000,000,001 protons
  1,000,000,000,000,000 antiprotons
- Antimatter completely annihilated
- Hence we're left only with matter today:
  (0.25 protons, ~10^9 photons, ~10^8 neutrinos+antineutrinos)/m^3
- One of major challenges of particle physics – explain the dominance of matter in our Universe



Observations 50 Years ago

1 Universe is mostly matter, need matter-antimatter differences in very early Universe. Andrei Sakharov

2 matter-antimatter oscillation in particles with strange quark. Leon Lederman

3 M-AM differences observed in strange quark eigenstates. Jim Cronin and Val Fitch

4 M-AM differences observed in muon charge asymmetries in strange quark decays. Mel Schwartz

Sakharov, 1975 Nobel Peace Prize

Cronin and Fitch, 1980 Nobel Prize for Physics

Schwartz and Lederman, 1988 Nobel Prize for Physics (for discovering the muon type neutrino)

Experimental Observation vs Matter in Universe

All observations of matter-antimatter differences in heavy quark decay BEFORE 2010 are much, much lower than the amount needed in the first instance of creation to explain the amount of matter in the Universe

→ Need something new

Many experiments 1968 – 2010 look for new mechanisms

A Study of Direct CP Violation in the Decay of the Neutral Kaon via a Precision Measurement of $|\eta_{oo}/\eta_{+-}|$

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University of Chicago, Enrico Fermi Institute, Chicago, Illinois
B. Cousins, J. Greenhalgh, and M. Schwartz
Stanford University, Department of Physics, ~~Stanford,~~ California
D. Hedin and G. Thomson
University of Wisconsin, Department of Physics, Madison, Wisconsin

CP violation in strange quark decay
Fermilab proposal 617 January 1979

wrong. very small effect. new physics must come from somewhere else

ABSTRACT

In this proposal, we describe an experiment to measure the ratio R of the CP violating amplitudes $|\eta_{oo}|$ and $|\eta_{+-}|$ to a precision of better than 1% thereby improving the present results by about one order of magnitude. If the CP violation is confined to the mass matrix, R = 1.0 exactly. Recent theoretical considerations which unify the CP violating interaction with the CP conserving weak and electromagnetic interactions among six quarks predict R differing from 1.0 by sizable amounts.

In 2010 the D0 experiment at Fermilab showed evidence that there is a difference between the number of observed $\mu+$ and $\mu-$ events in proton-antiproton collisions and it is larger than what is expected

Media attention: newspapers, op eds, NPR reports, other radio and TV news, politicians (Bill Clinton)...

Why all the fuss?

D0 Experiment: Charge Asymmetry

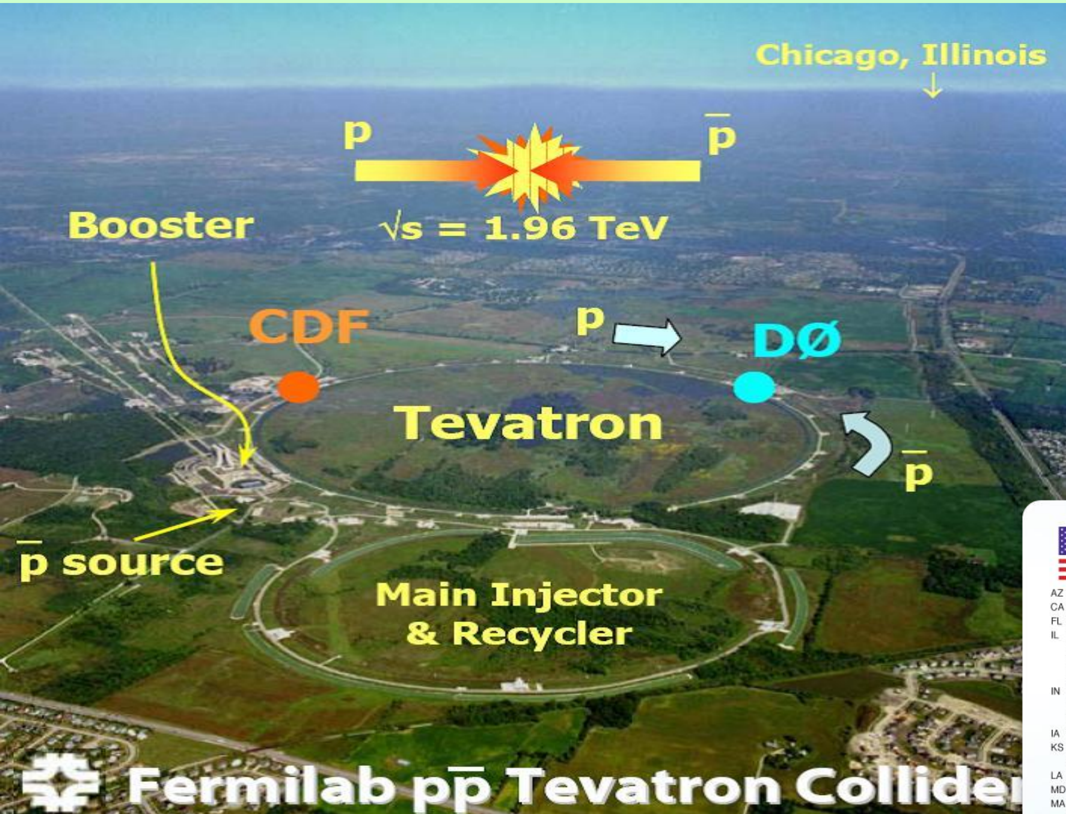
Initial state: proton and antiproton collide
→ equal amounts of matter and antimatter

Final state: either one or two negative charge muons (both matter particles) or one or two positive charge muons (both antimatter particles)

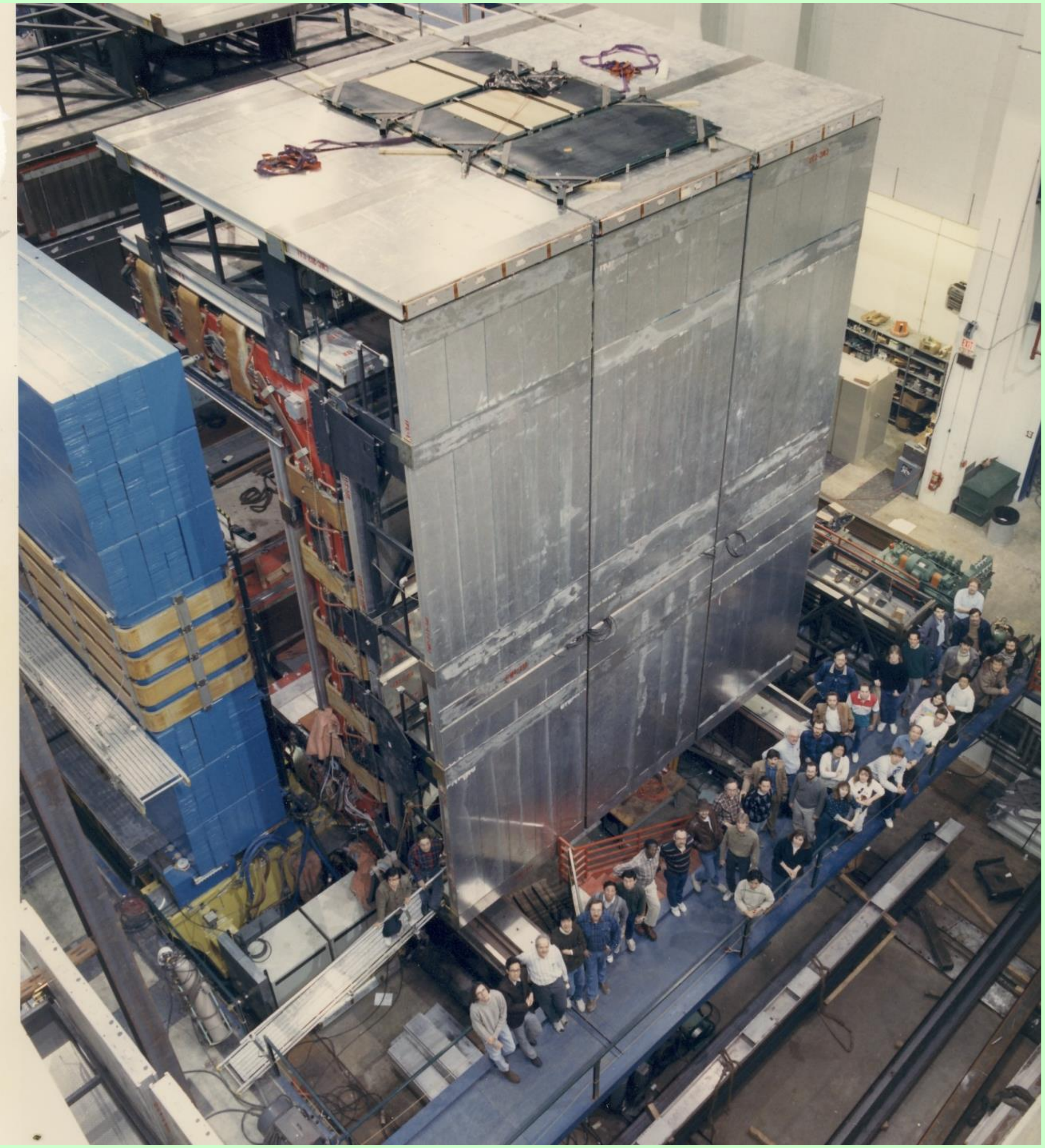
→ A difference between the observed number of $\mu+$ and $\mu-$ events indicates a matter-antimatter difference in weak decays of heavy quarks

- easy in principle but need a $200,000,000 detector (!), the Fermilab Tevatron Collider (!!!), and 10 years of data (!!)
- **Still not sure if something new has been discovered**

D0 Collaboration



82 institutions
19 countries
~500 physicists



D0 Detector

muon system under construction
January 1990

11 from NIU in photo
80 undergrads and 44 grad students from NIU on D0

Neutrons and Protons

- the mass of a neutrons is just a little bit more than a proton's mass

- → neutrons radioactively decay with a lifetime of 15 minutes

$$m_p = 938.3\,MeV/c^2$$
$$m_n = 939.6\,MeV/c^2$$
$$m_e = 0.5\,MeV/c^2$$

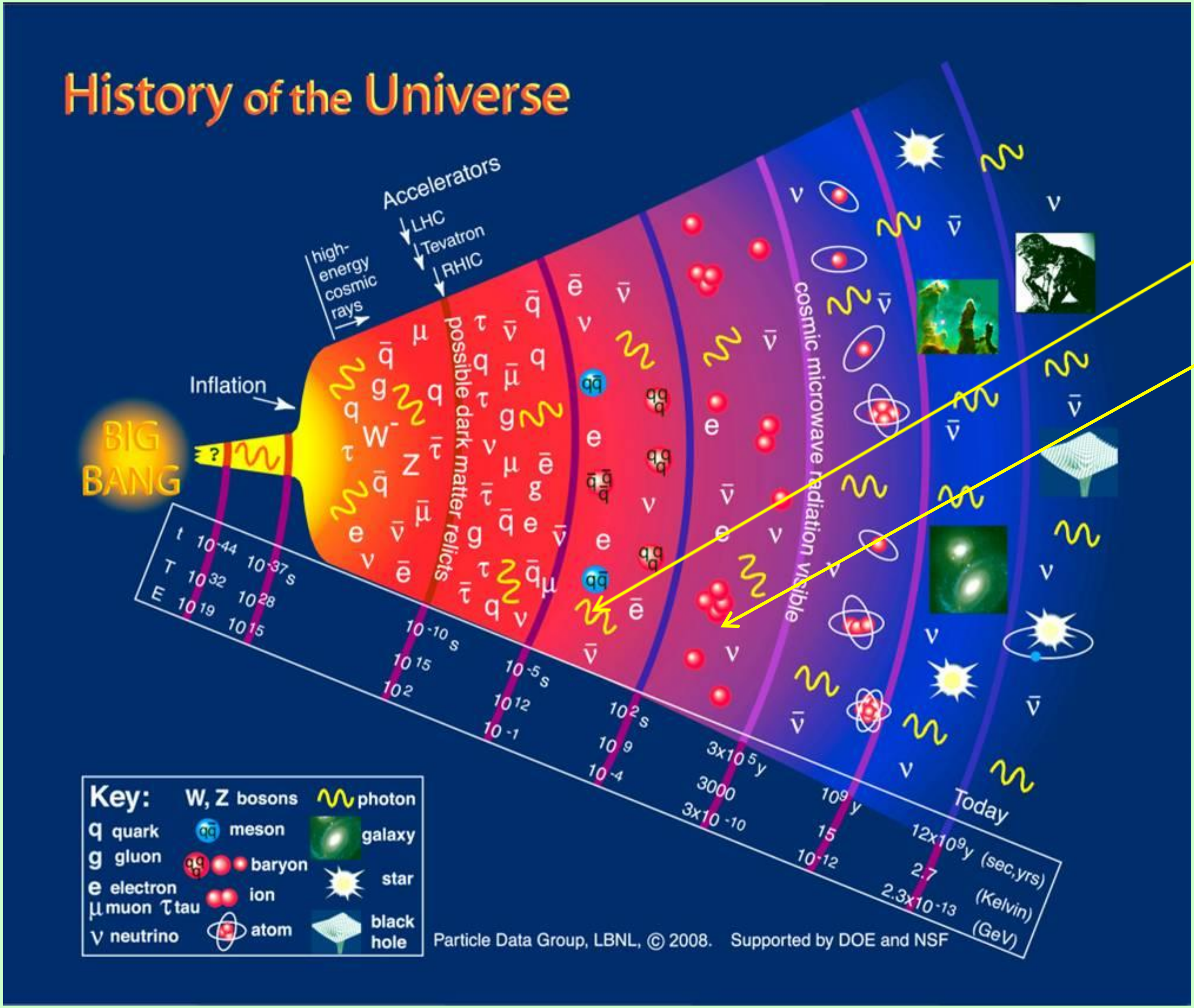
$$n \rightarrow p + e^- + \bar{\nu}_e$$

Neutrons and Protons

- all the protons and neutron were formed in the first minute after the Big Bang.
- Neutrons decayed to protons or combined with protons to make Helium.
- Our Universe is 90% H + 9% He+1% heavy
- 7/1 p/n ratio

$$n \rightarrow p + e^{-} + \bar{\nu}_e$$

$$2n + 2p \rightarrow He$$



Neutrons and protons are formed

Neutrons either decay or used to make Helium

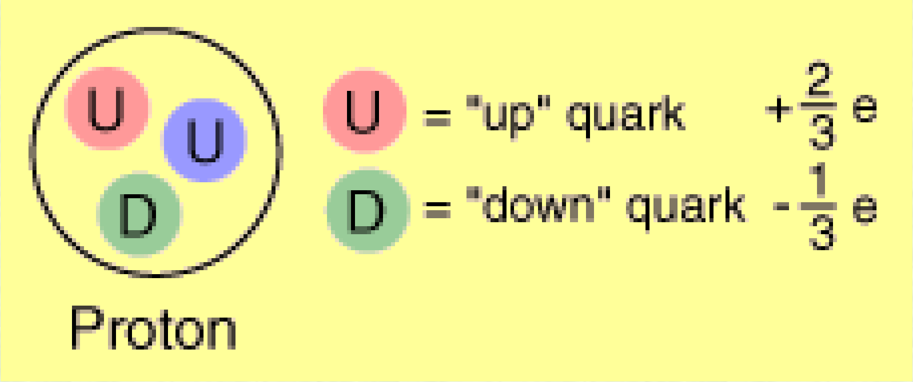
Masses of Neutrons and Protons

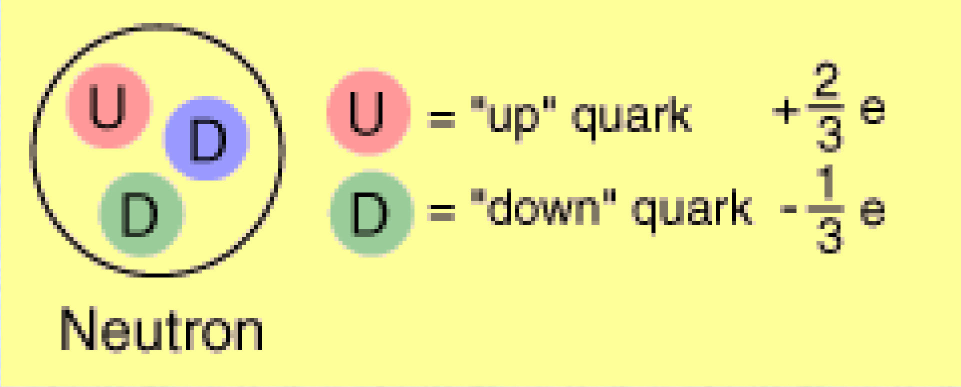
Why is the neutron heavier than the proton?

How would universe look if masses were different?

Masses of Neutrons and Protons

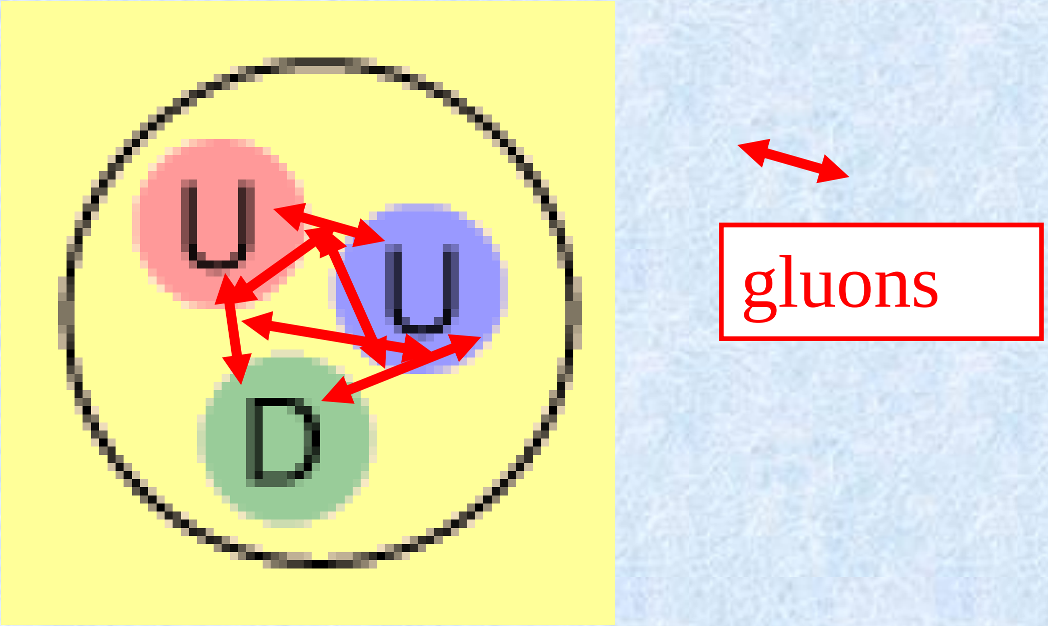
- In the 1960s it was realized the p,n are made from up and down quarks
- bound together by gluons





Neutron and Proton Masses

- gluons bind together quarks. 3 quark combinations are stable
- gluons have energy → ~99% of proton mass due to this energy
- about 1% due to "bare" masses of 3 quarks



Quark Masses – in MeV/c^2

charge 1/3	d	s	b
	6	125	4,200
charge 2/3	u	c	t
	4	1,200	175,000

- first generation lightest
- in second/third charge 2/3 heavier but in first charge 1/3 is heavier ????????
- No one understands this

proton and neutron masses vs Quark Masses

- as the neutron is made from up-down-down and the proton from up-up-down quarks

- and the down quark is slightly heavier than the up quark

→ neutron slightly heavier than the proton

What if??

many different universes exist

→ each forms its own space
→ each has own starting conditions and possibly different physics

→ Quark masses are different

→ Matter-antimatter asymmetry smaller

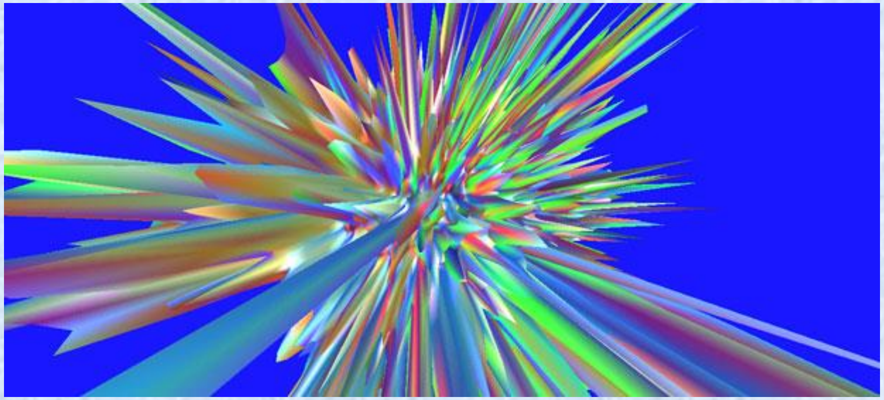
MULTIVERSE

Snowflakes

- each snowflake is unique due to the slight variations in the conditions when they formed

What if Multiverse

- many (infinite??) universes in a multiverse
- not really "next" to each other. "nothingness" separates
- no communication between universes



two artist conceptions – mostly meaningless

Basis of His Dark Materials/The Golden Compass trilogy by Philip Pullman

What if in different universe

- up quark mass greater than down quark mass

→ proton heavier than neutron

- Two possibilities

if $|m_{proton} - m_{neutron}| < m_{electron}$ → both protons and neutrons are stable

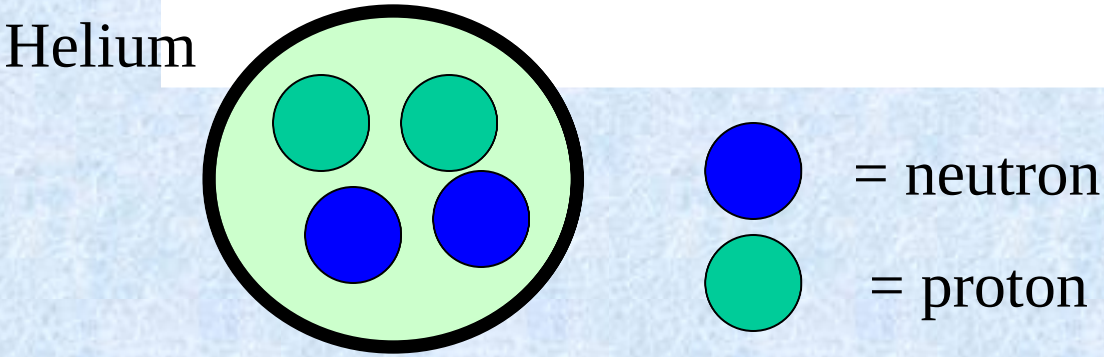
if $m_p - m_n > m_e$ → proton is unstable and decays into neutrons

what if in a different universe

- proton and neutron are both stable

- most p and n combine into Helium (2p+2n)

→ have Hydrogen but it is rare.
DH guess fraction H/He ~ 1%



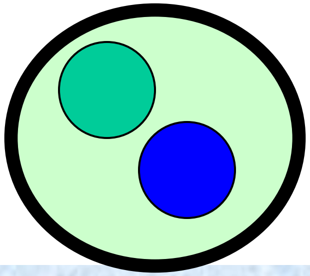
What if in different universe

- proton is unstable and decays to neutrons

- still have stable heavy Hydrogen (Deuterium pn nucleus) but is very rare. DH guess D/He~.0005

- in early universe, He forms and then extra neutrons easily attach to He and then decay making Li, Be, B, C

- some free neutrons remain



Deuterium

What if in different universe

- in either case with stable neutron

- very small amount of Hydrogen

→ different type of Stars and planets but with little water and Hydrogen : needed for biochemistry (proton bonds, DNA, etc)

→ no life

Anthropic Principle and Multiverse

- intelligent life in our universe depends on having the physics "just right". Why?

→ anthropic principle holds that with an infinite number of universes, there is a non-zero probability that one is "just right"

→ That's ours where the masses of the up quark, down quark and the electron, and the matter-antimatter difference are "just right"

Goldilocks and the Three Bears

This universe has the matter-antimatter variation too small

This universe has the proton mass too large

This universe has the strong nuclear force too strong

This universe has the electron mass too small

This universe has the W/Z mass too small

Our Universe is just right

Conclusion

- We live in a matter-dominated world (plus dark matter and dark energy but that's another talk)
- Protons are stable while neutrons radioactively decay
- Both are due to asymmetries
- Asymmetries allow us to exist, and ponder what causes the asymmetries

(last slide) STEMfest

Saturday October 19   10 am to 5 pm

Convocation Center – free event