What If the Particle World Were Different?

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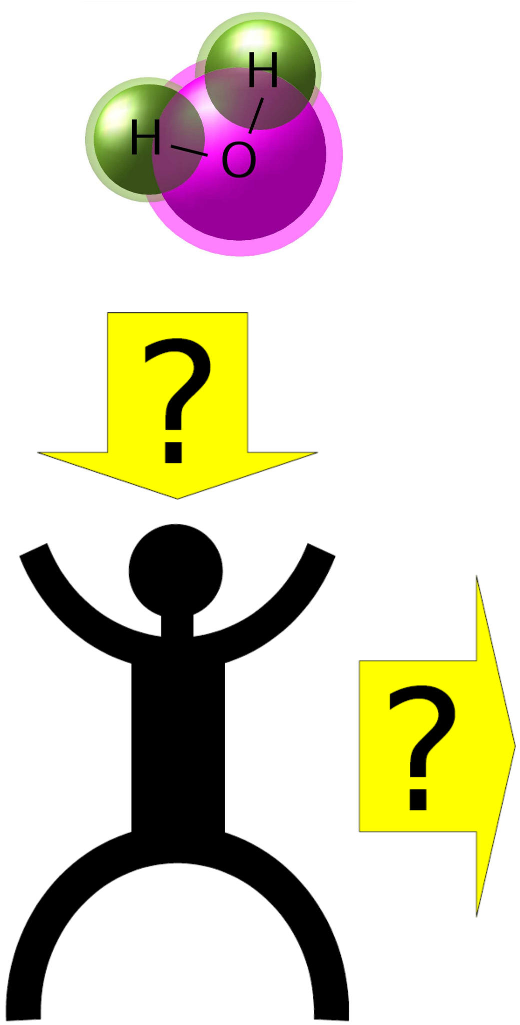
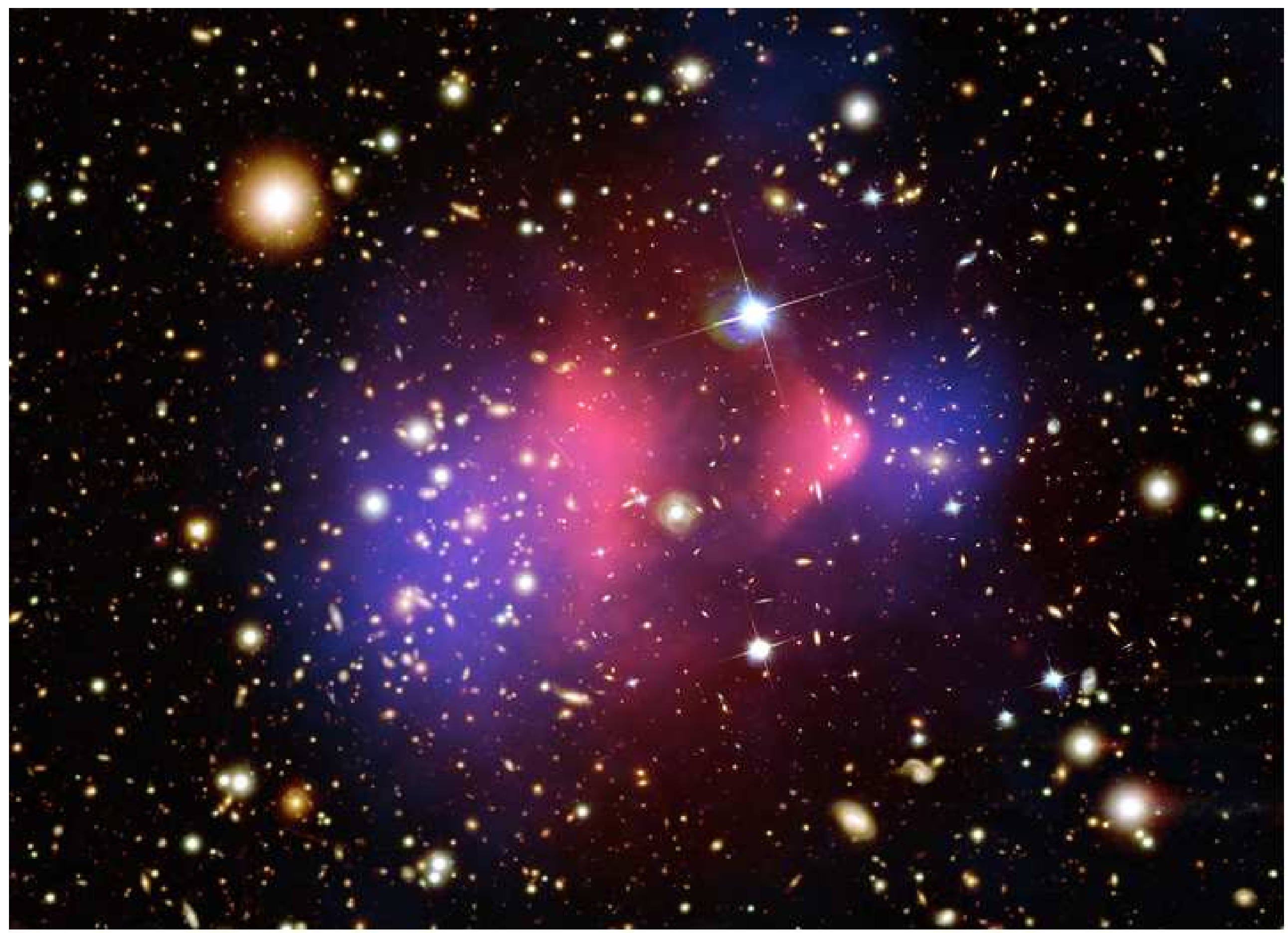
JHU Quarknet Meeting

The Particle World: the Smallest to the Largest

- On the smallest and largest scale:

  what are we made of and why

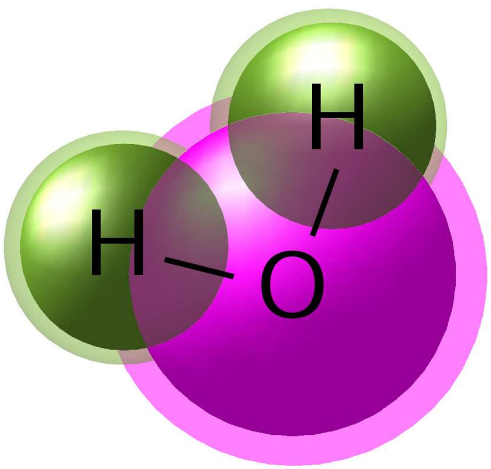




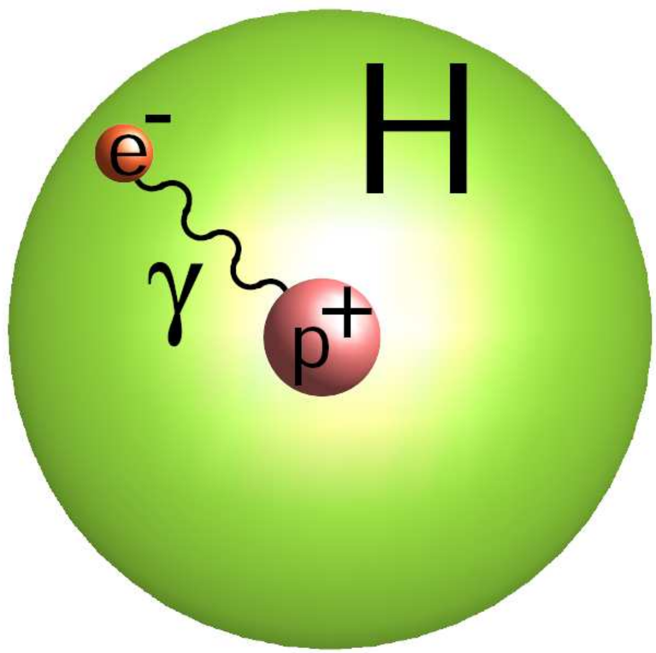
(Galaxy cluster 1E 0657-66: X-ray, Optical, Grav. Lensing)

From Molecules to Quarks

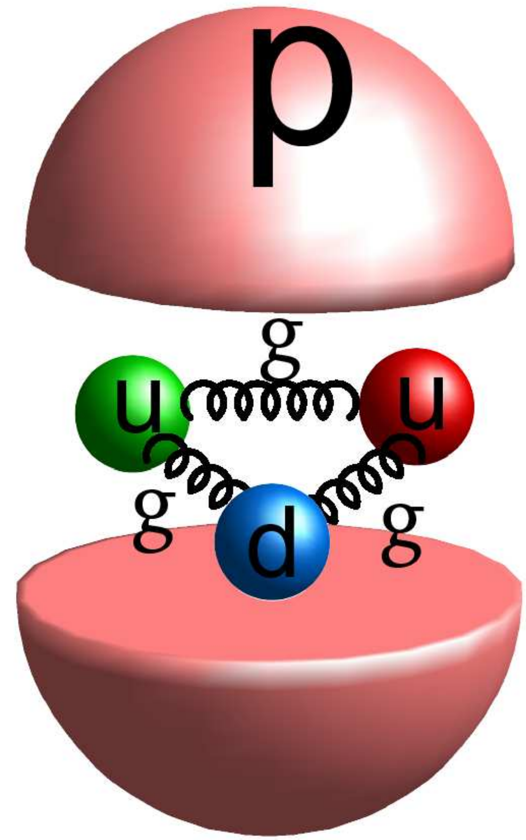
- XXth century: reaching deep into matter, Quarks



Chemistry



Atomic Physics



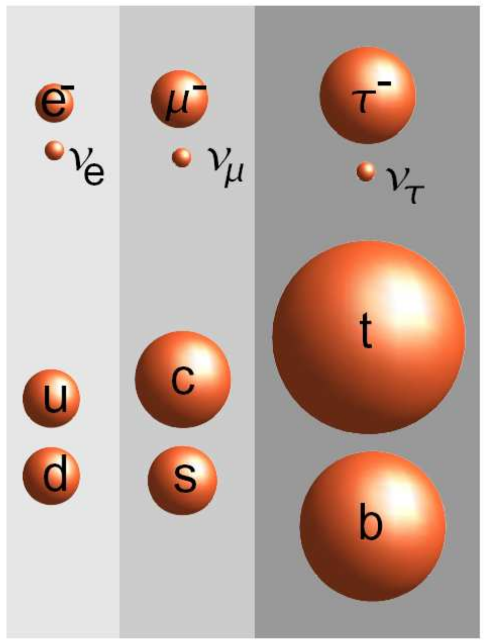
Particle Physics

Elementary Particles

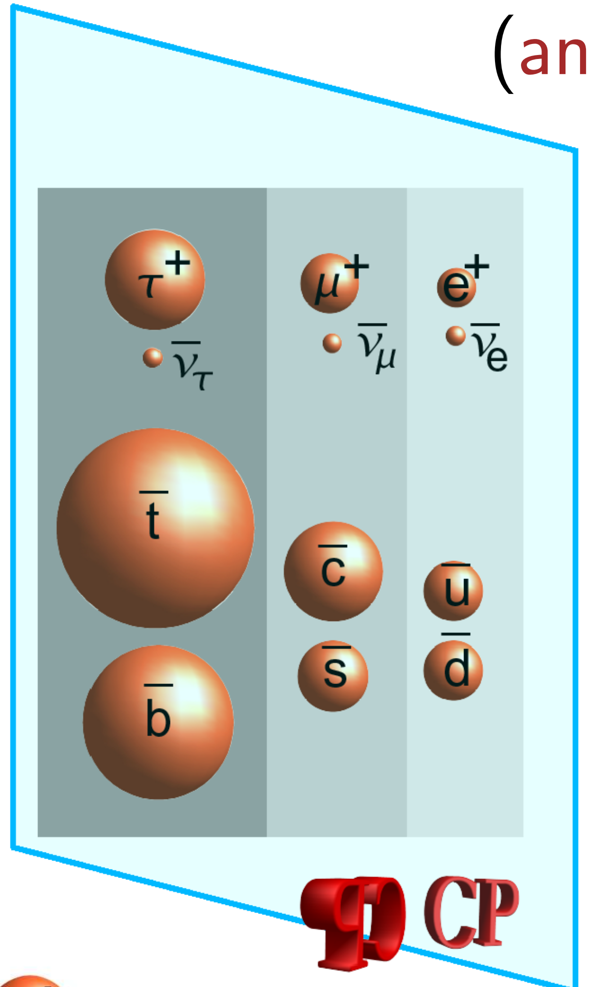
- Fermions $S = \frac{\hbar}{2}$ (matter)

leptons

quarks

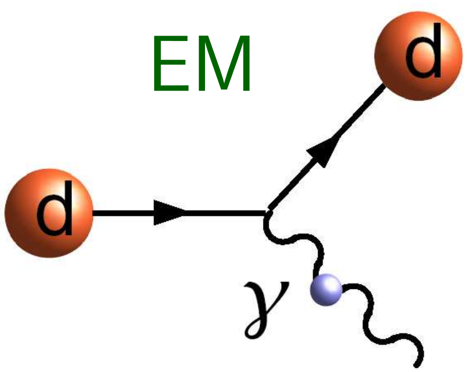


(anti-matter)

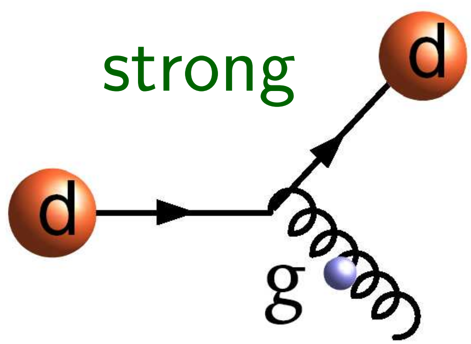


- Bosons $S = \hbar$ (force carries):

EM



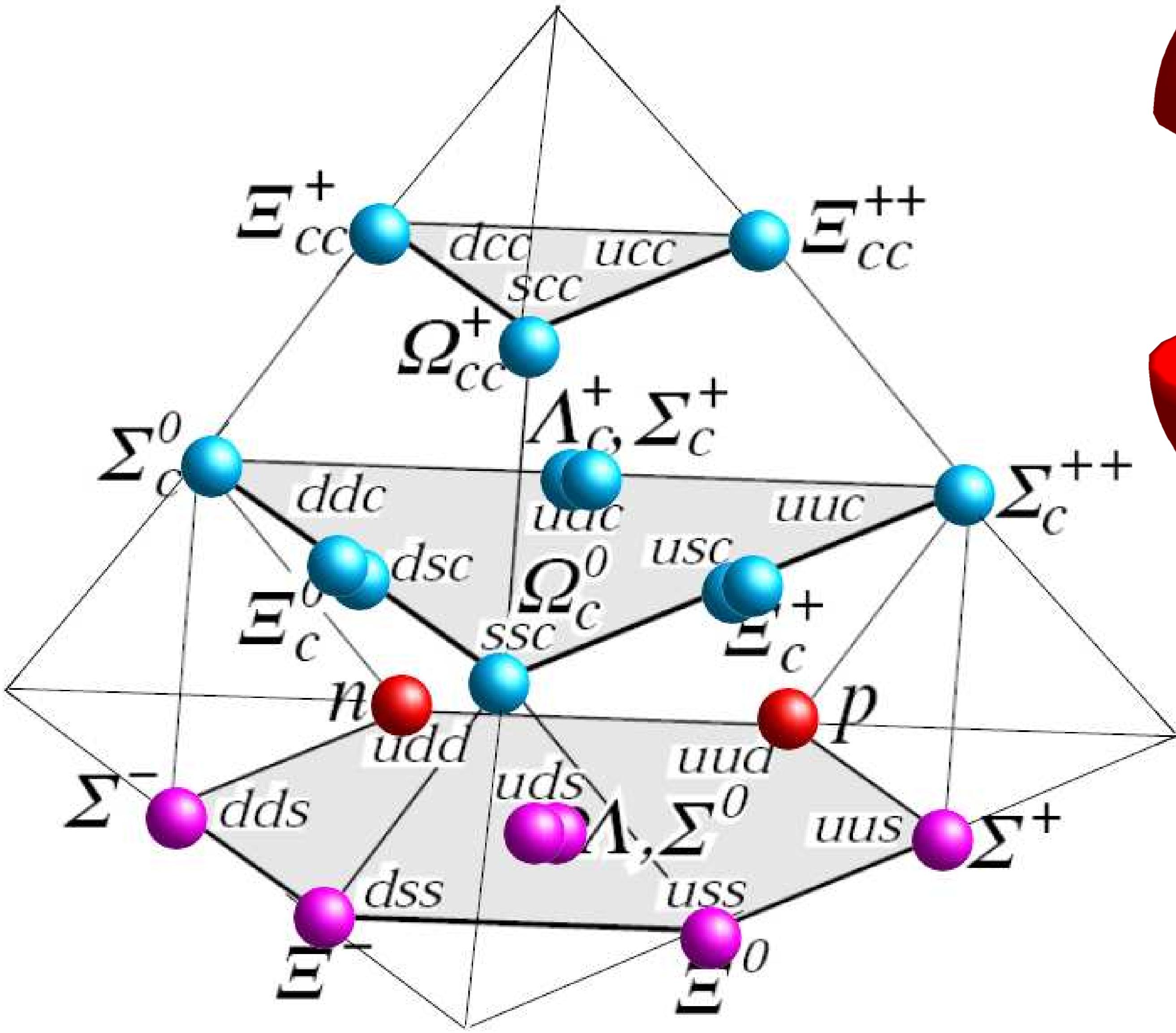
strong

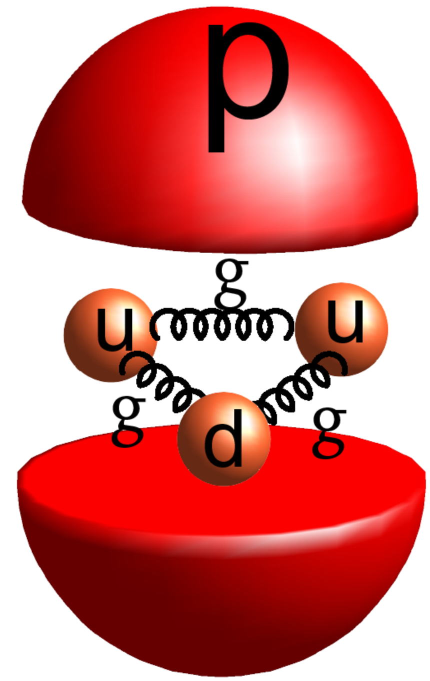


(weak force later)

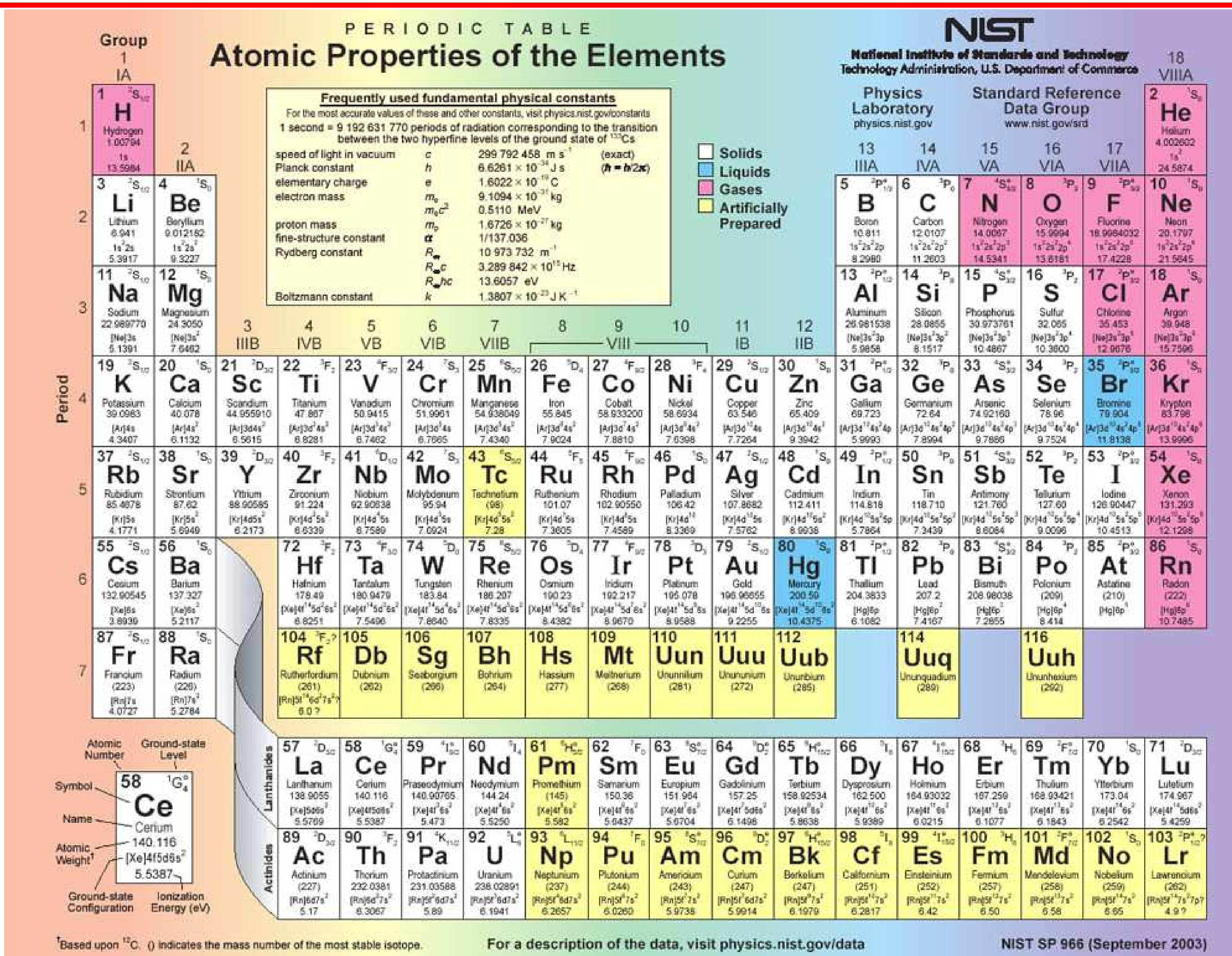
"Periodic Table" of Baryons: Proton, Neutron,...

- Three quarks make up a Baryon:



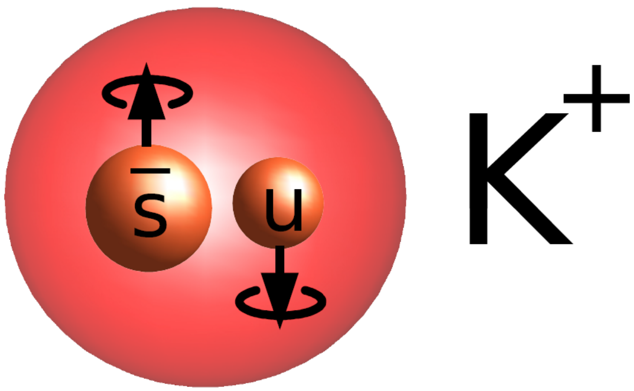


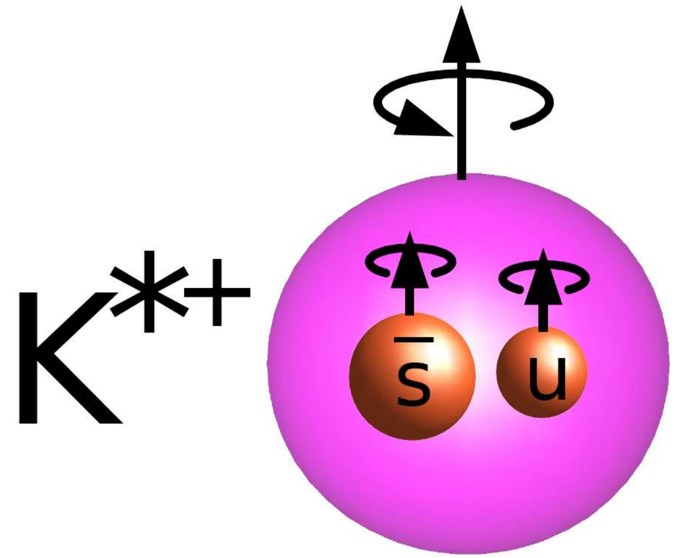
Like Periodic Table of Atoms



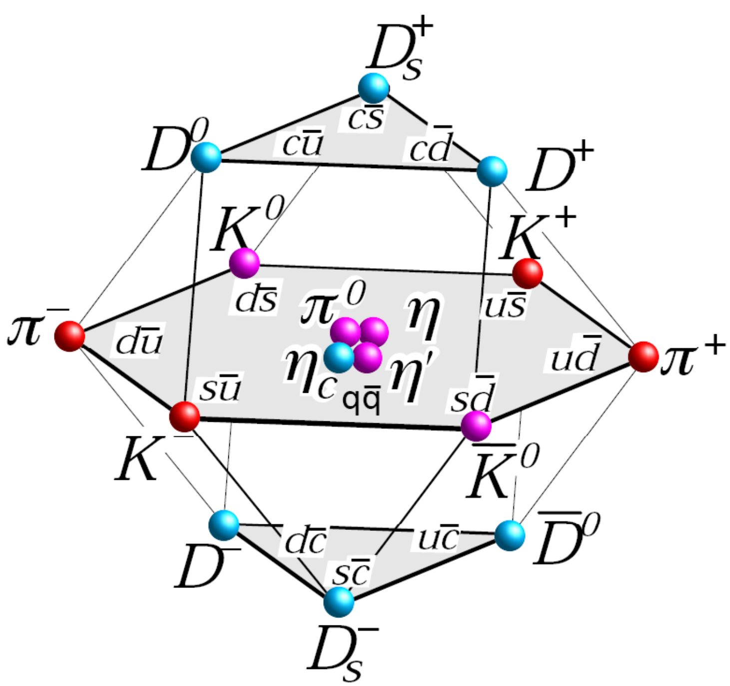
"Periodic Table" of Mesons

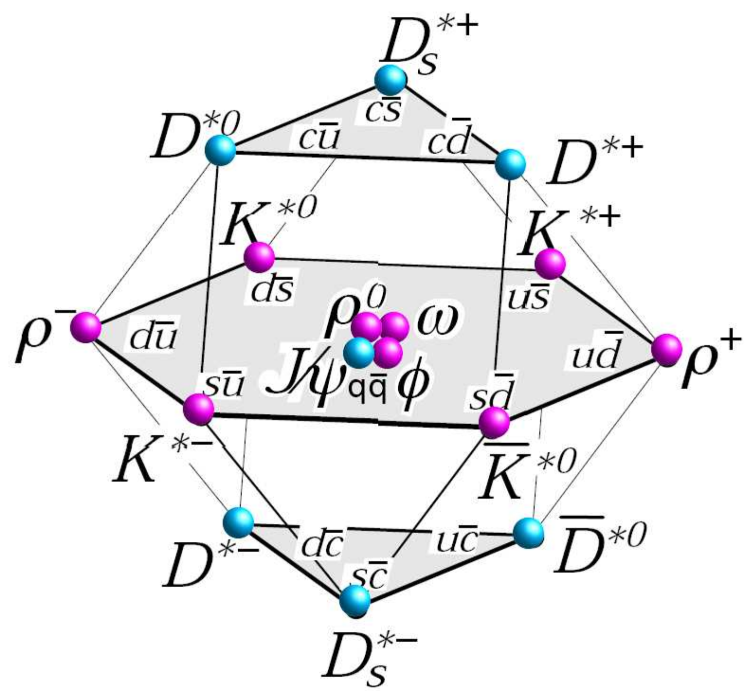
- Quark-antiquark make up a Meson:





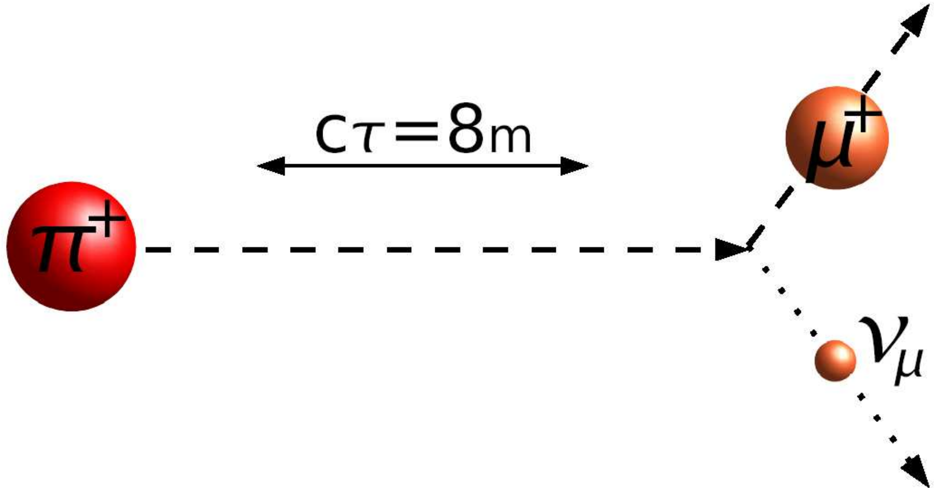
ground state (L=S=0) Vector meson S=$1\hbar$



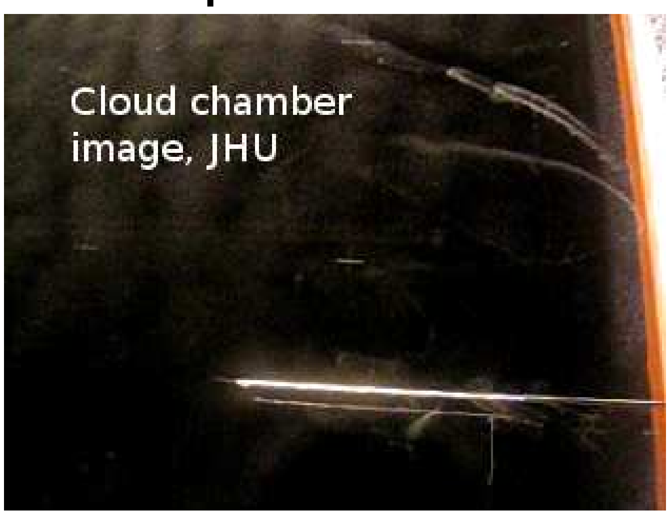


How do We "See" Particles

- We "see" semi-stable particles by "tracks" in matter:

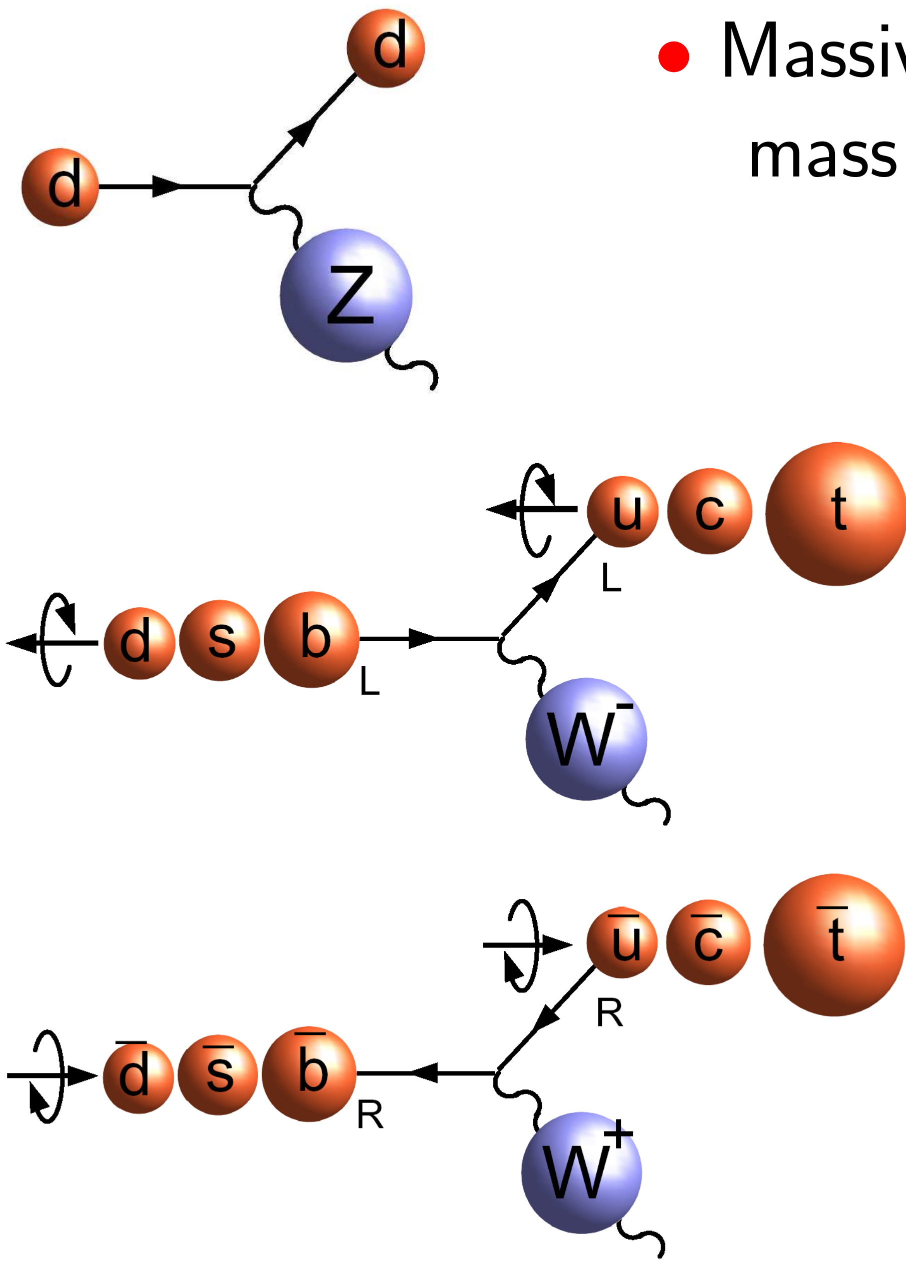


- Table-top illustrations



- Complex multi-ton detectors

Weak Interactions



- Massive carries $\Rightarrow$ weak (short-range) mass $\sim$ 80-90 GeV

- Special interactions:

  change type of quark

  change families

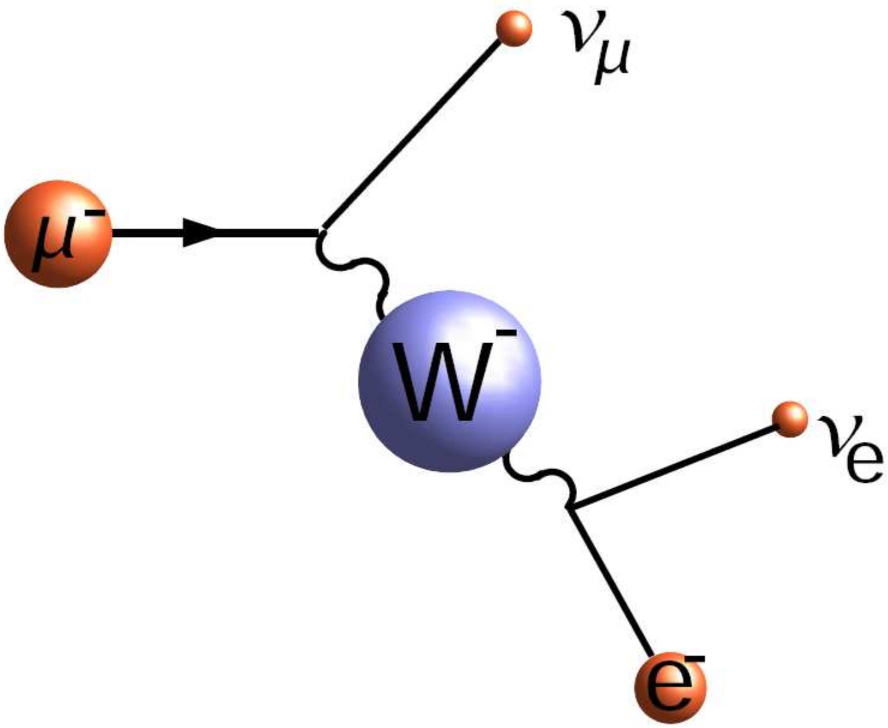
  left-handed fermions

  violate Parity and C

  violate CP symmetry

(1) Scenario: Muonic World

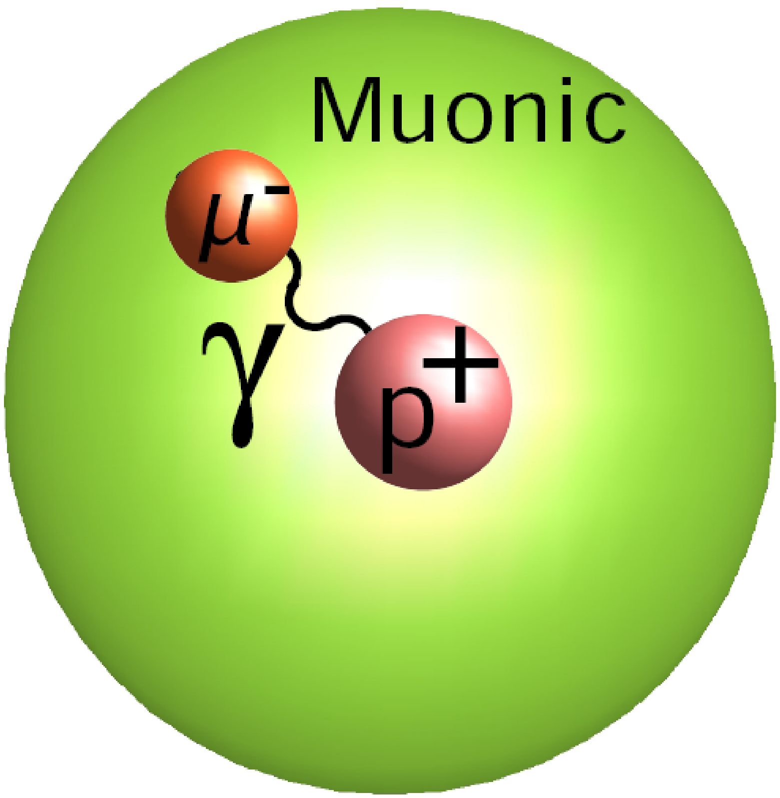
- What if muon were the lightest fermion (no electron)
- Normally muon decays:



- Now muon is stable

(1) Scenario: Muonic World

- We would get a muonic atom:



- Size changes:

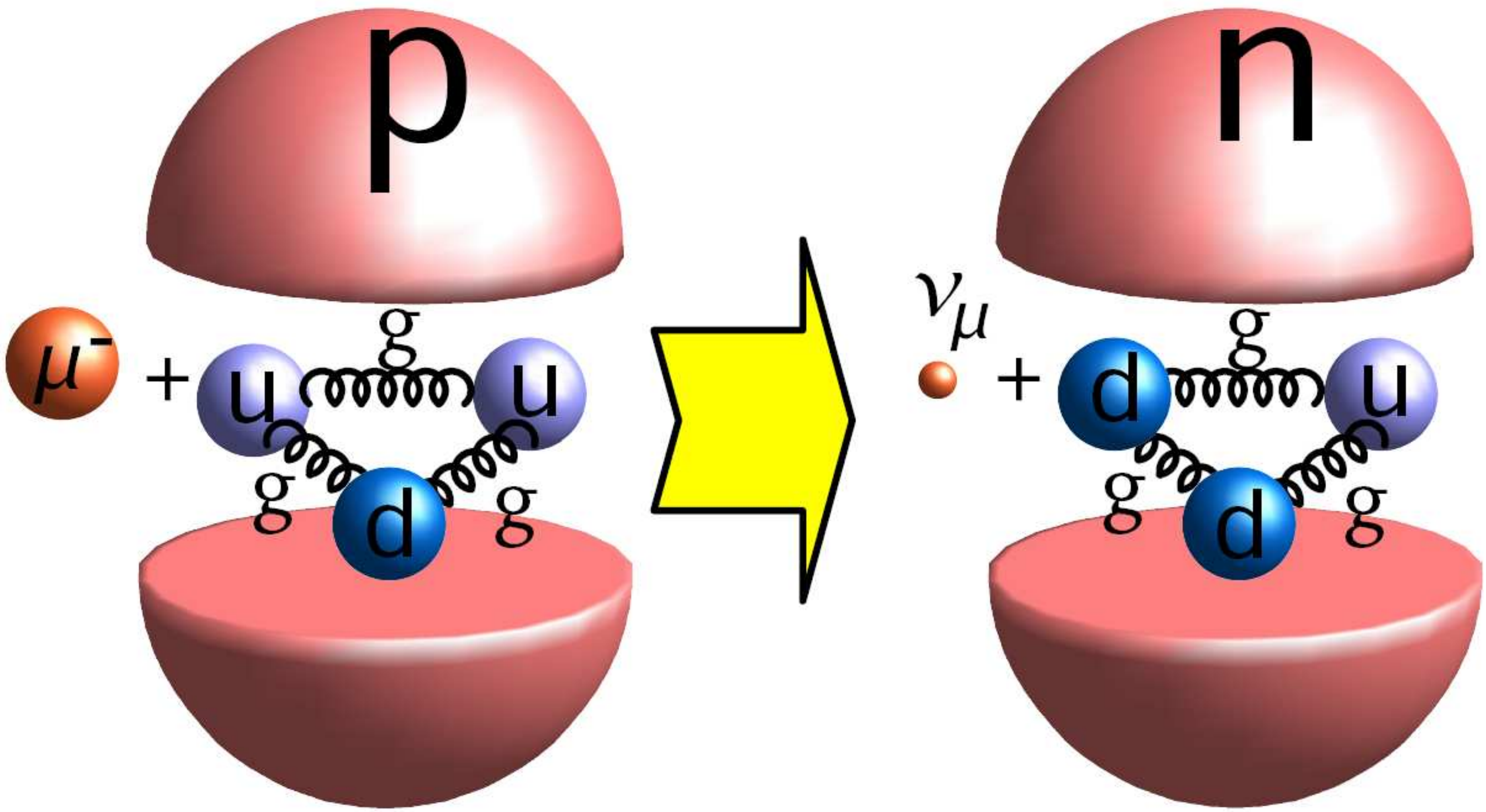
radius $r = \frac{4\pi\epsilon_0\hbar^2}{m_\mu e^2}$, 200 smaller !

Hydrogen radius

$$r = \frac{4\pi\epsilon_0\hbar^2}{m_e e^2} = 5 \times 10^{-11} \text{ m}$$

(1) Scenario: Muonic World

- However muonic hydrogen would decay:

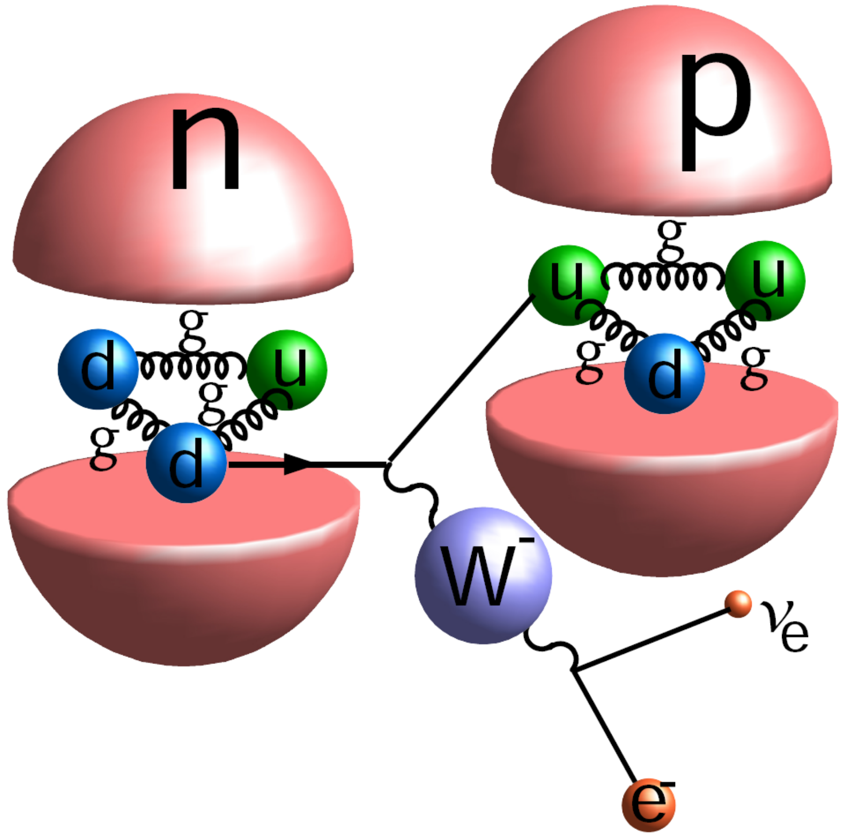


- Not very interesting universe
  – filled with neutral “balls” of neutrons and neutrinos

(1) Scenario: Muonic World

- Normally neutron is not stable (life $\tau \sim 886$ seconds)

  $$\mathrm{m}(n) > \mathrm{m}(p) + \mathrm{m}(e) + \mathrm{m}(\nu_e)$$



- But stable in the muonic world:

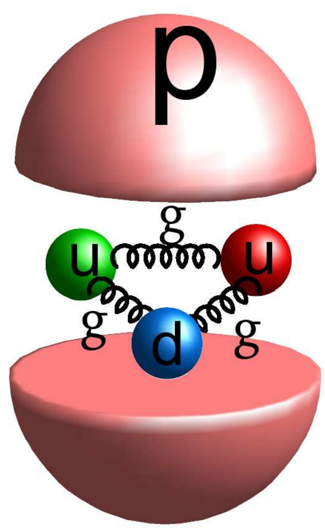
  $$\mathrm{m}(n) < \mathrm{m}(p) + \mathrm{m}(\mu) + \mathrm{m}(\nu_\mu)$$

(2) Scenario: Another Neutron World

- Again, normally proton is stable and neutron decays:

  $$\mathrm{m}(n) > \mathrm{m}(p) + \mathrm{m}(e) + \mathrm{m}(\nu_e)$$

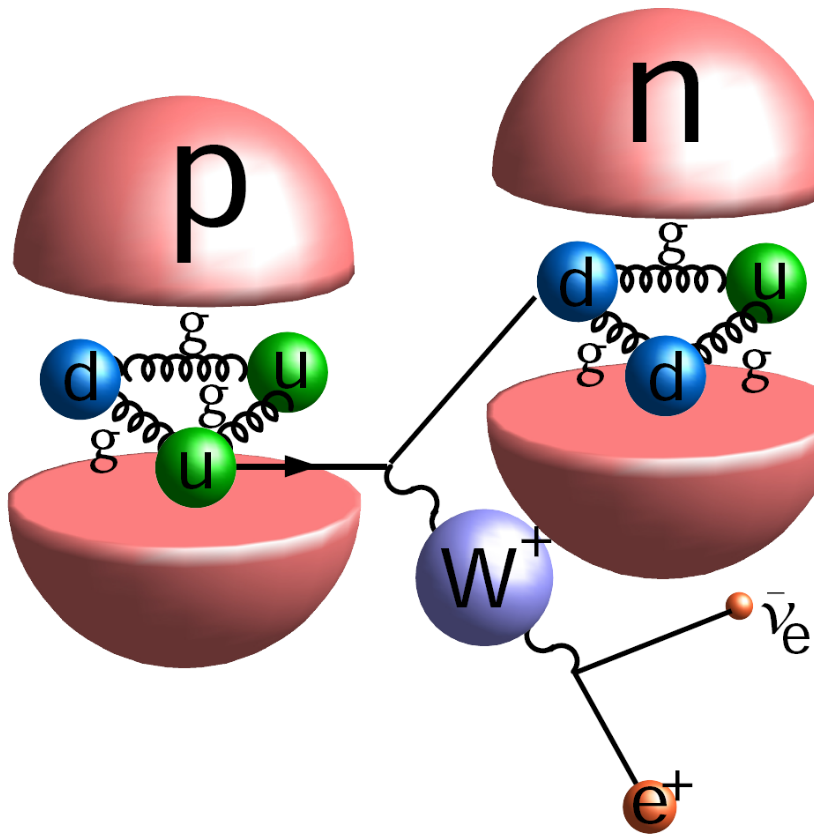
- Why is $\mathrm{m}(n) > \mathrm{m}(p)$
  - $\mathrm{m}(p) = 938$ MeV, $\mathrm{m}(n) - \mathrm{m}(p) = 1.3$ MeV
  - tiny difference makes a big difference!
  - naively expect $\mathrm{m}(p) > \mathrm{m}(n)$ if u and d were the same
  - but $\mathrm{m}(d) > \mathrm{m}(u)$



- New scenario:
  - what if $\mathrm{m}(d) < \mathrm{m}(u)$

(2) Scenario: Another Neutron World

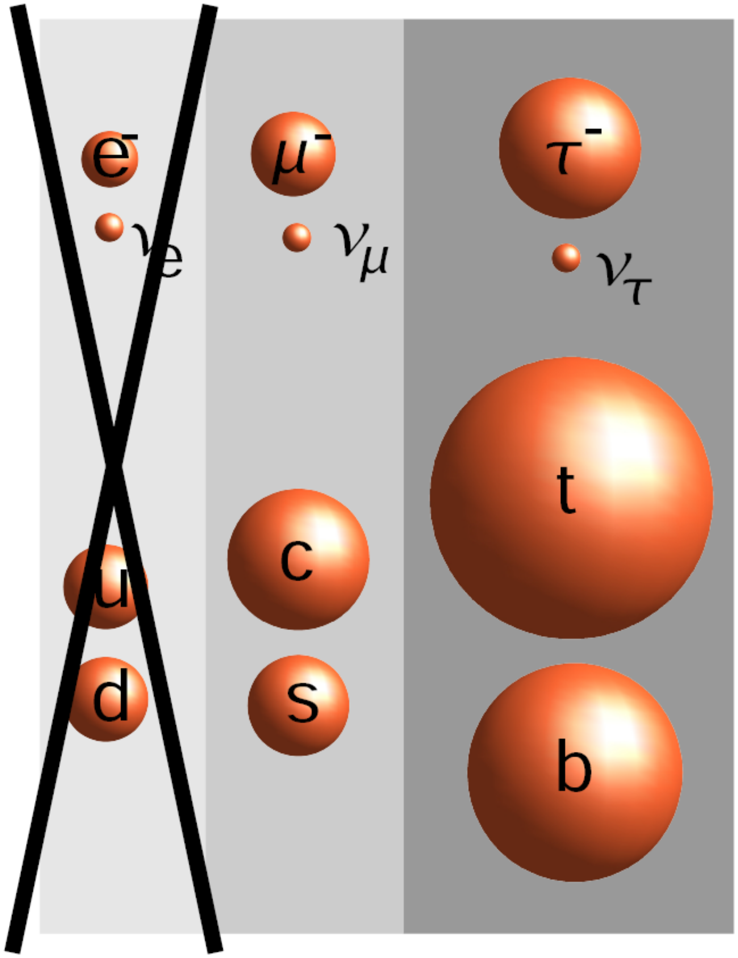
- If m(d) $<$ m(u), proton decays:



- Consequence: no Hydrogen, no $H_2 0$
  - still have He^4, rapid nn fusion, instead of slower pp

(3) Scenario: No First Family

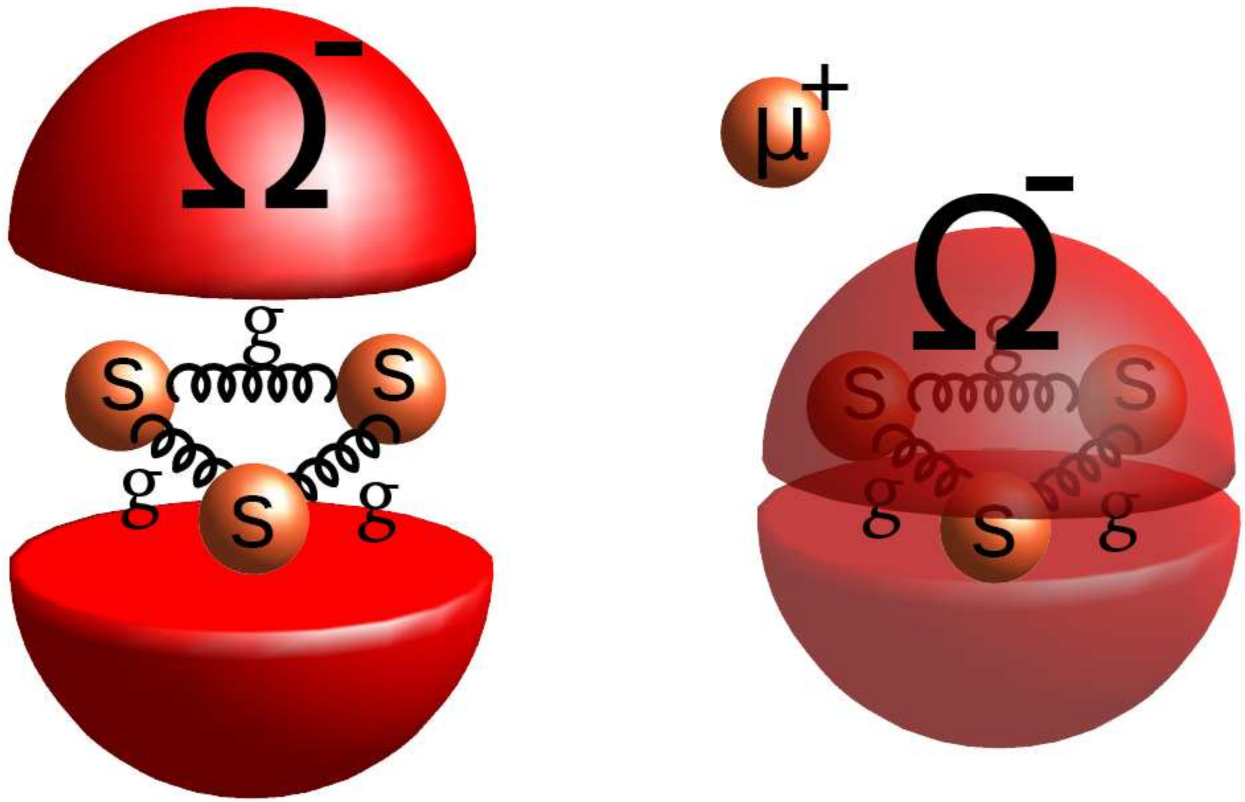
- What if the second family of fermions were the first?



- Would we get muonic atoms?

(3) Scenario: No First Family

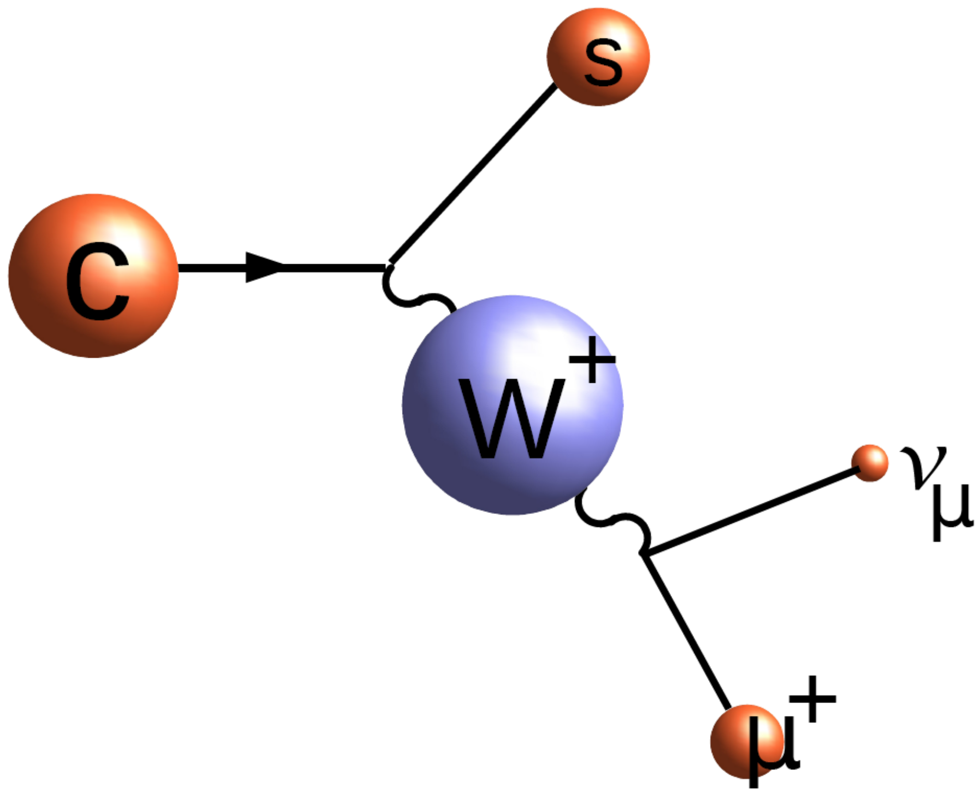
- Would we get muonic atoms?
  - probably yes, but only one of them...



- No atoms, molecules, or anything bigger...

(3) Scenario: No First Family

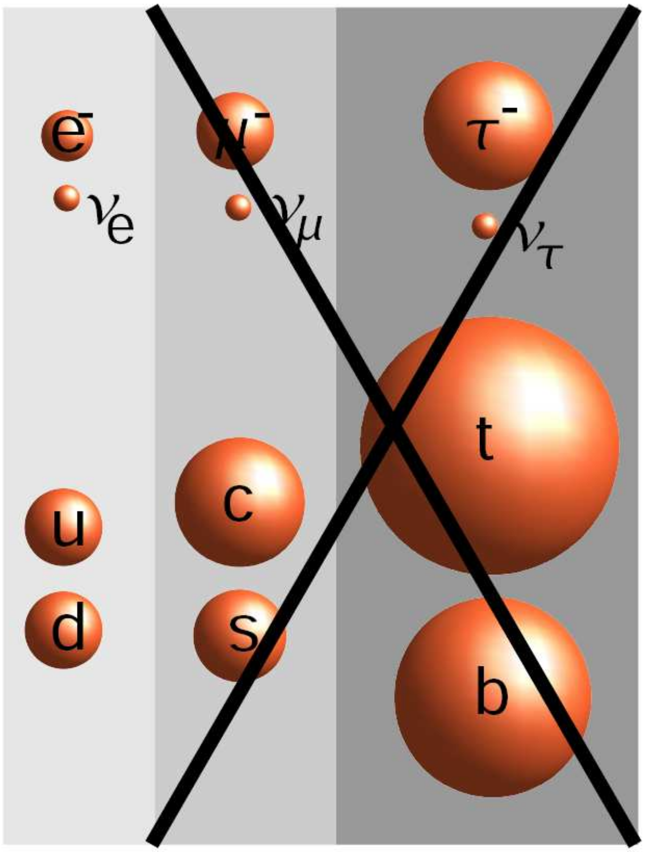
- Only one baryon with an s quark
  - because c is much heavier (unlike u and d)



- No stable baryons with c quarks

(4) Scenario: Only First Family

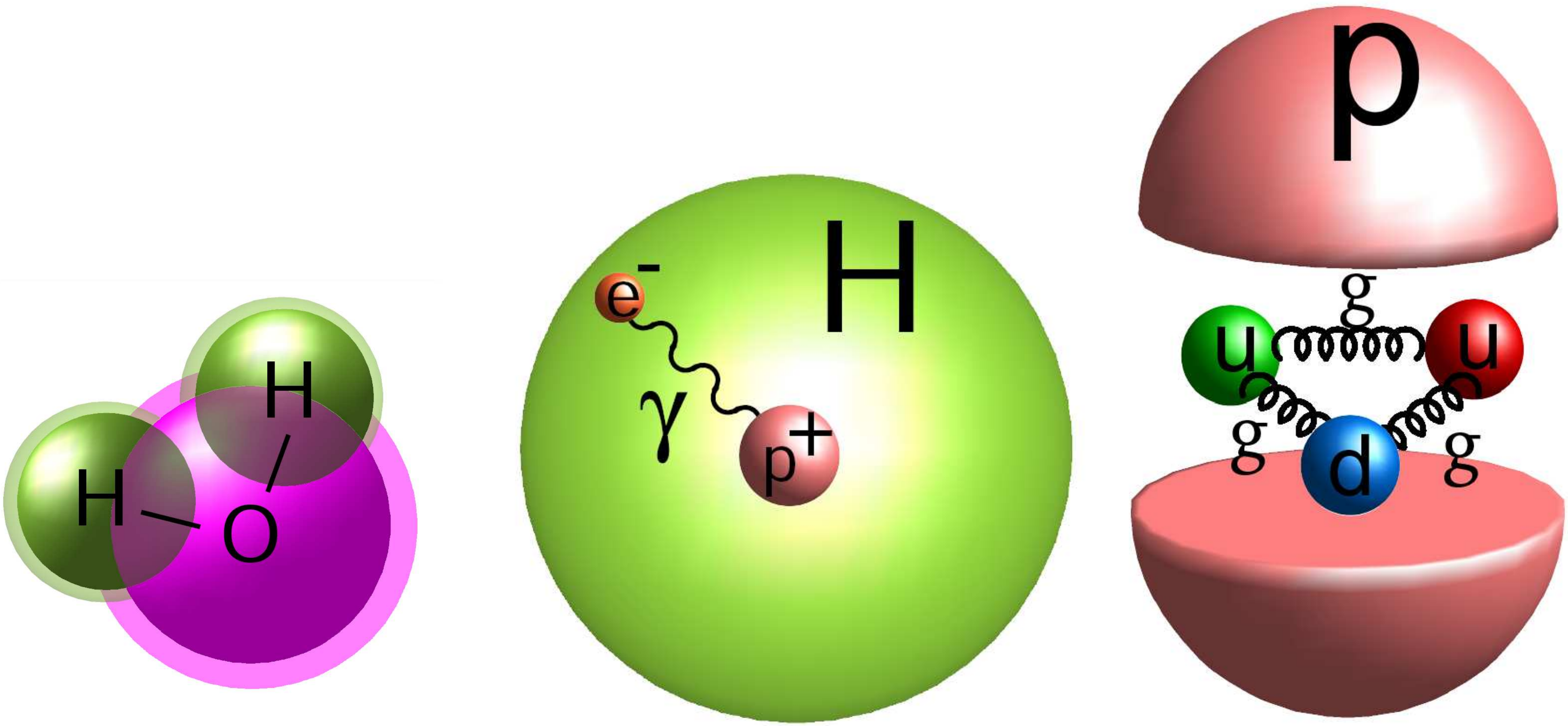
- What if we had only first family of fermions?



- Would the world around us be the same?

(4) Scenario: Only First Family

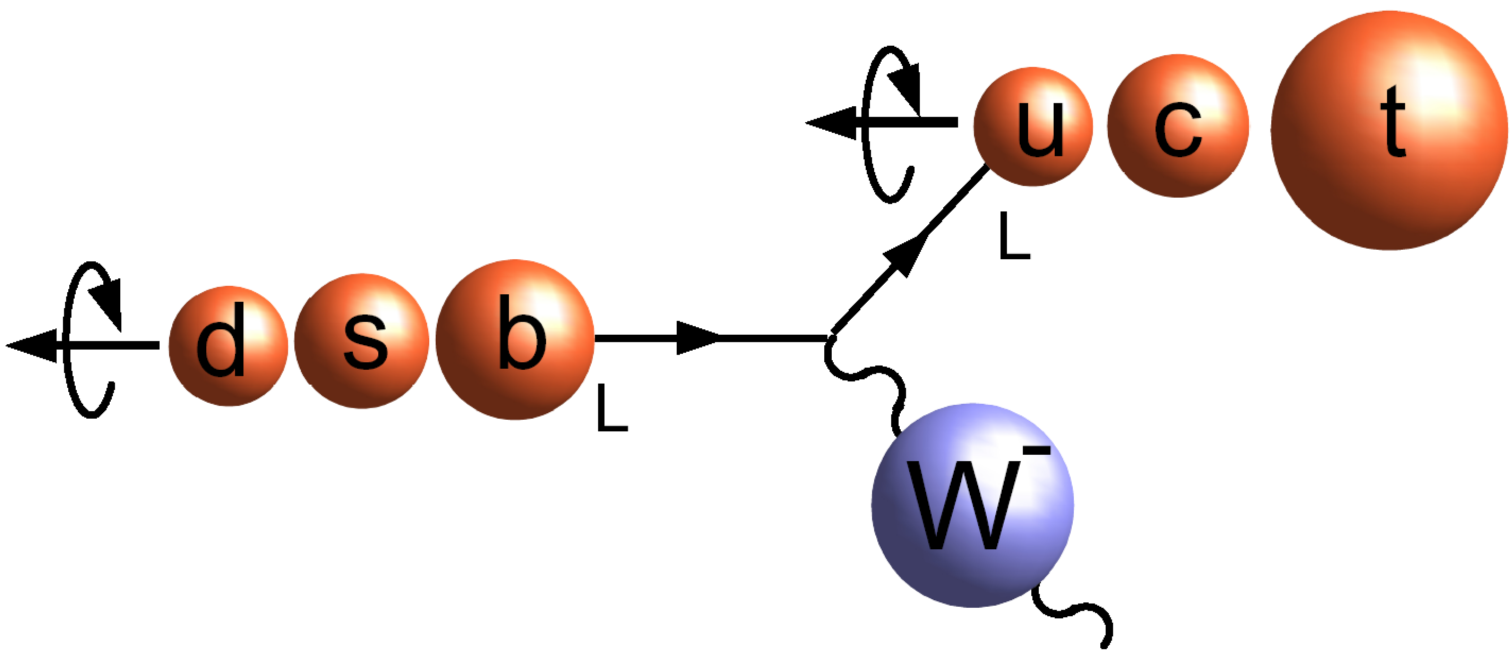
- Would the world around us be the same?

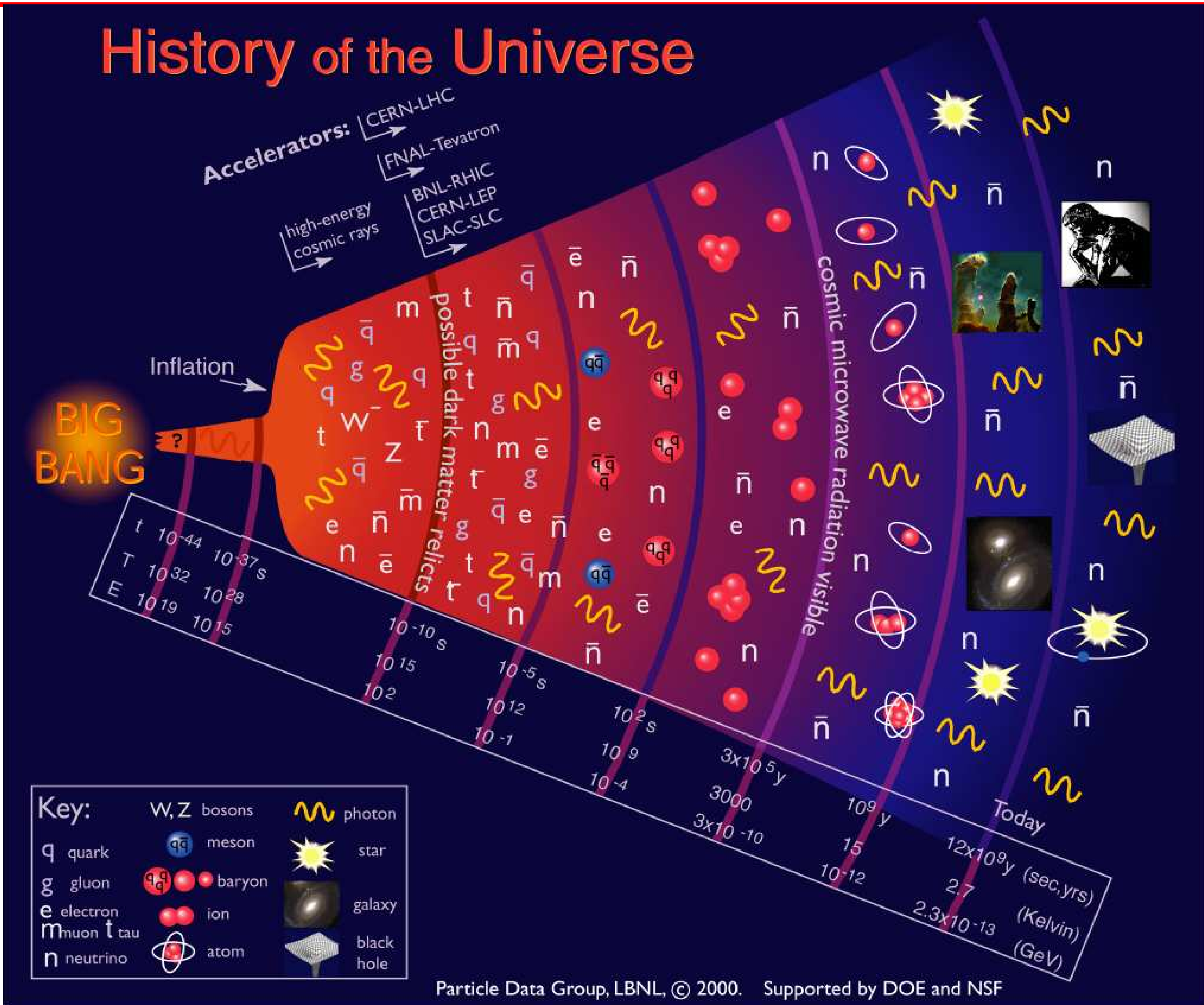


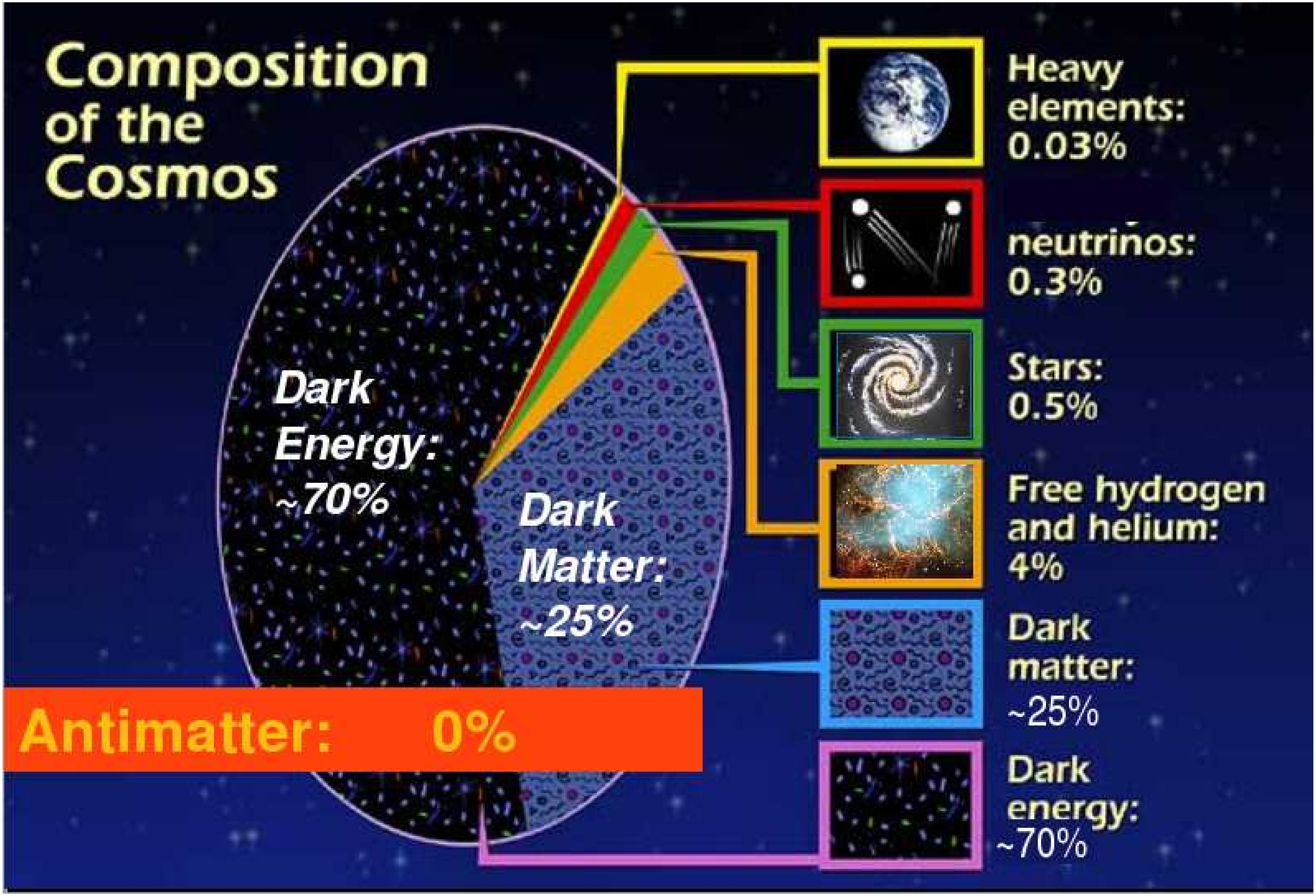
- Yes, if it already existed, almost no difference.

(4) Scenario: Only First Family

- However:
  - laws of physics different in Universe evolution
  - in early moments all families equal
  - $\Rightarrow$ matter-antimatter asymmetry




History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37s
T 1032 1028
E 1019 1015
10-10 s
1015
102
10-5s
1012
10-1
102s
109
10-4
3x105y
3000
3x10-10
109y
15
10-12
Today
12x109y (sec,yrs)
2.7 (Kelvin)
2.3x10-13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W,Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF



Composition of the Cosmos
Heavy elements: 0.03%
neutrinos: 0.3%
Stars: 0.5%
Free hydrogen and helium: 4%
Dark matter: ~25%
Dark energy: ~70%
Dark Energy: ~70%
Dark Matter: ~25%
Antimatter: 0%

(4) Scenario: Only First Family

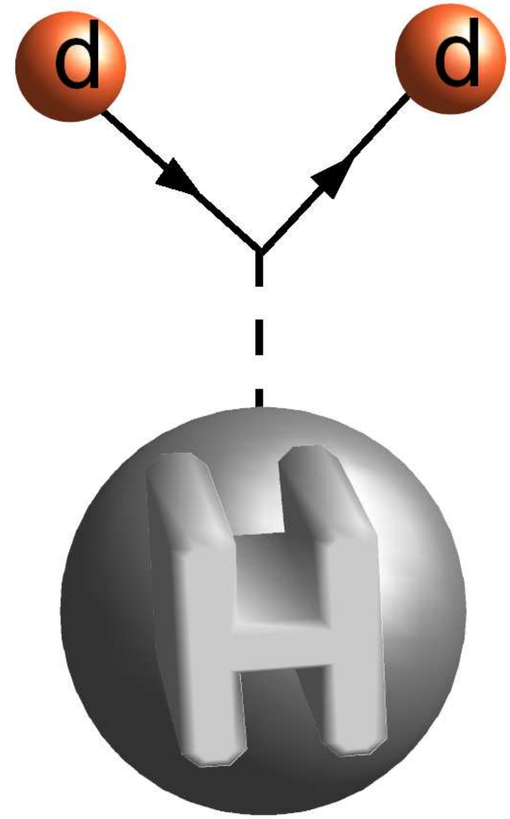
- With only first family we will not have much
  - everything annihilate to photons...

What Have We Learned?

- Parameters of elementary particles are essential
- Small change in mass leads to dramatic change in universe
  - electron mass
  - proton and neutron (u and d quark) mass
  - fermion families
- Do we understand these parameters?
  - unfortunately not yet
  - but believe secrets of the universe are behind them
  - and believe we are about to uncover them...

Look Beyond the Standard Model

- Mysterious Higgs field
  - gives mass to particles



- Need something beyond the SM
  - large matter-dominance
  - dark matter
  - light Higgs

Possible Extension: Super-Symmetry

- New (super)symmetry:

Q|fermion⟩=|boson⟩

Q|boson⟩=|fermion⟩

- Solve:

(1) natural light

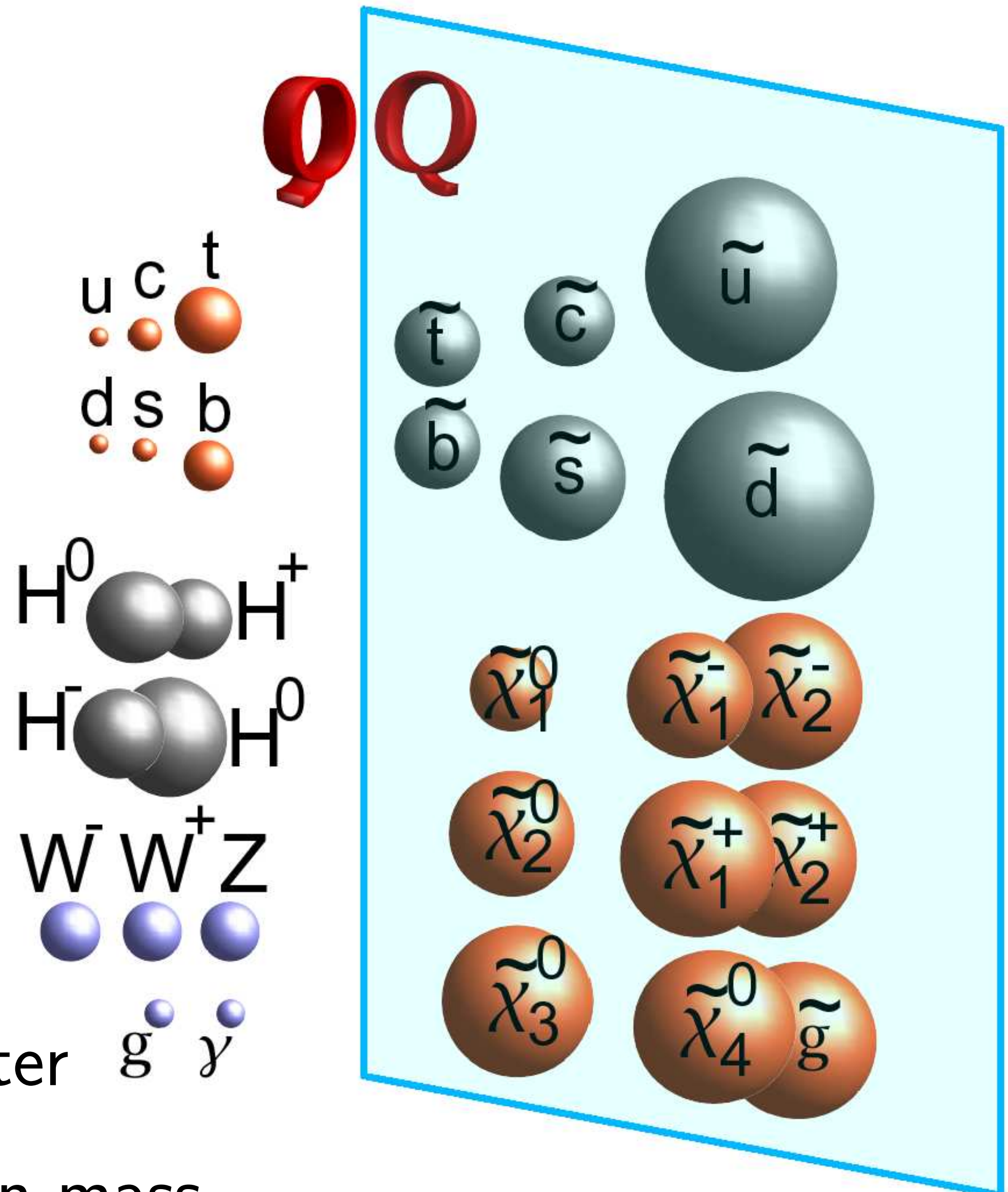
Higgs

(2) dark matter

lightest $\tilde{\chi}_1^0$

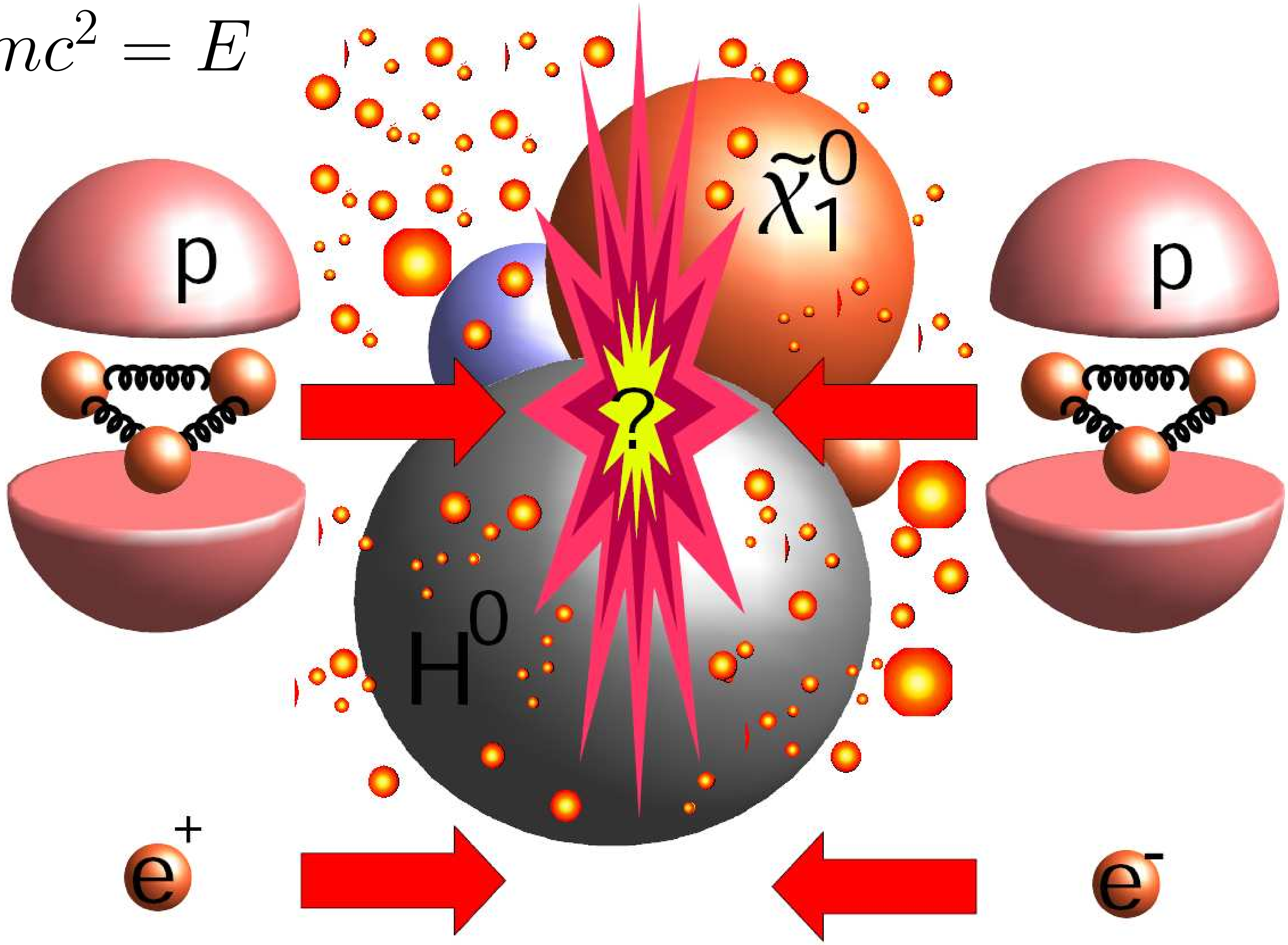
(3) large matter/antimatter

- Just around the corner in mass...

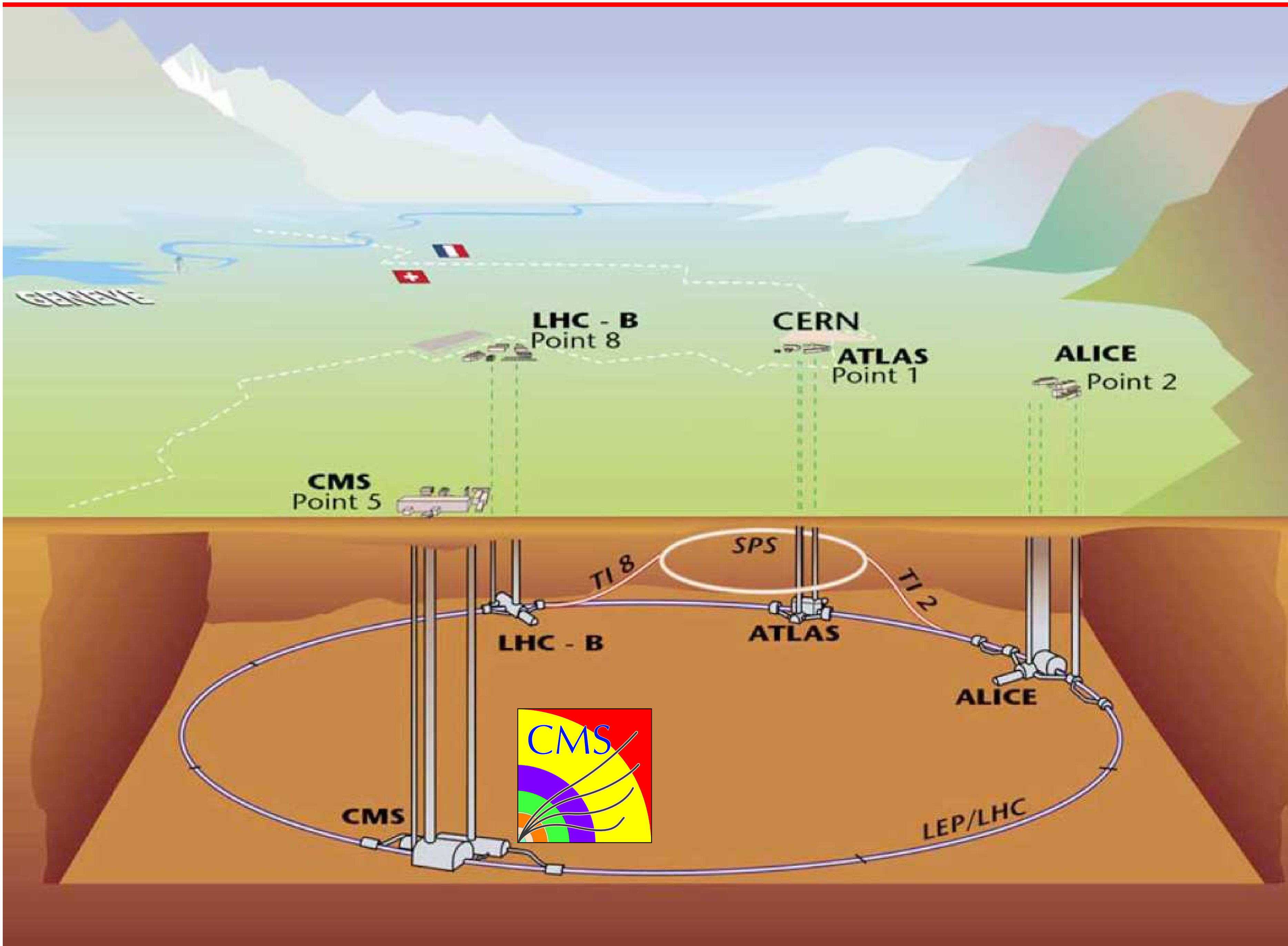


Reaching Highest Energy

- $mc^2 = E$



Large Hadron Collider: Fall 2008



Thanks

Thanks to my mentor at LBNL: Robert N. Cahn

for inspiring ideas

about standard model parameters in everyday life, see

Reviews of Modern Physics, Vol. 68, No. 3, July 1996