What If the Particle World Were Different?

Andrei Gritsan
Johns Hopkins University

August, 2008

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
    - $e^-$
    - $\nu_e$
    - $\mu^-$
    - $\nu_\mu$
    - $\tau^-$
    - $\nu_\tau$
  - Quarks
    - $u$
    - $c$
    - $d$
    - $s$
    - $b$

- Bosons $S = \hbar$ (force carries):
  - EM
  - strong
  - (weak force later)

Andrei Gritsan, JHU
August, 2008
“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:

  \[ K^+ \]  
  \[ K^{**+} \]

  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 $P$arity and $C$
  - violate $CP$ symmetry

Andrei Gritsan, JHU
August, 2008
• 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:

\[ r = \frac{4\pi\epsilon_0 \hbar^2}{m_{\mu}e^2}, \text{ 200 smaller!} \]

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)
  \[ m(n) > m(p) + m(e) + m(\nu_e) \]

- But stable in the muonic world:
  \[ m(n) < m(p) + m(\mu) + m(\nu_\mu) \]
(2) Scenario: Another Neutron World

- Again, normally proton is stable and neutron decays:
  \[ m(n) > m(p) + m(e) + m(\nu_e) \]

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

- New scenario:
  - what if \( m(d) < m(u) \)
(2) Scenario: Another Neutron World

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

- Consequence: no Hydrogen, no $H_2O$
  - 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
  - ⇒ matter-antimatter asymmetry
History of the Universe

Accelarators: CERN-LHC, FNAL-Tevatron

High-energy cosmic rays

BNL-RHIC, CERN-LEP, SLAC-SLC

Inflation

Possible dark matter relics

Cosmic microwave radiation, visible

Particle Data Group, LBNL, © 2000. Supported by DOE and NSF
Composition of the Cosmos

- Dark Energy: ~70%
- Dark Matter: ~25%
- Antimatter: 0%

Heavy elements: 0.03%
Neutrinos: 0.3%
Stars: 0.5%
Free hydrogen and helium: 4%
Dark matter: ~25%
Dark energy: ~70%
(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:
  \[ \mathcal{Q}|\text{fermion}\rangle = |\text{boson}\rangle \]
  \[ \mathcal{Q}|\text{boson}\rangle = |\text{fermion}\rangle \]

- Solve:
  
  1. natural light
     \( H^0 \)
  2. dark matter
     lightest \( \tilde{\chi}_1^0 \)
  3. large matter/antimatter
     \( g \) \( \gamma \)

- Just around the corner in mass...
Reaching Highest Energy

- $mc^2 = E$
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_