素粒子論研究・電子版 Vol. 2 (2009) No. 1

Closing Remarks by a Rehabilitant

March 25, 2009

@ YKIS workshop

Taichiro Kugo, YITP

Amateur see only (too) big problems,

while experts are hooked on (too) detailed problems.

Rehabilitant may be near to Armature.

But let me summarize present problems which we are facing.

What are the problems?

The standard model is a great theory
succeeding to
Maxwell's electromagnetic theory
Einstein's general relativity.

It describes all the interactions perfectly well up to the energy scale ~100GeV.

One might say
``No problem is the biggest problem of the SM''

Real Problems (real vs. theoretical)

- ``All the interactions are gauge interactions. There are only four interactions.''

  ⟶ Not true!

- The SM contains

  Higgs interaction, which is not a gauge interaction but another new Interaction.

  It contains many and arbitrary parameters: the problem of masses. (Yamawaki, Appelquist)

- (Beyond) SM also contains neutrino (Majorana) mass terms. (Han, Kusenko)

- Quark masses 6, lepton masses 3
- CKM mixing angles 3+1

- Neutrino masses 3
- MNS mixing angles 3+1+3

- Large mixing of MNS in sharp contrast to small mixing of CKM!

- Higgs and Neutrino shows two New Interactions yet to be understood

Yet other real problems?

(Masiero)

- Dark matter 23%
- Dark energy 73%

Despite the brilliant SM, which describes only 5% matters in our Universe!

- Higgs condensates ~ 10^{62} %

QCD chiral condensates, ….

Dark energy will pose a totally different problems.

Higgs

- Composite or Supersymmetry (=elementary)?

- Composite model = Extended Technicolor
  It leads to severe (theoretical) problems:
  FCNC → walking technicolor
  (Appelquist, Yamawaki)

ETC seems to have no concrete viable models yet

- Supersymmetric model: MSSM

  This can predict as many new particles as we have ever known!

  Welcome to explain the Dark Matter

  in particular, gravitino dark matter is attractive.

  a priori raison d'etre

  (Hamaguchi, Ibarra, Strumia, Kribs), PAMELA

This also leads to many (theoretical) problems:

the origin of SUSY breaking

FCNC, μ -problem, ….

cf: combined model of SUSY and composite:

Ibe-Kitano's sweet spot model (Kitano)

Neutrino Masses

- In the SM, it is simply a higher dim intr term:

$$\frac{1}{\Lambda}(\bar{L}_i\tilde{H})\frac{m_{ij}^2}{v^2}(\bar{L}_j\tilde{H}) + \text{h.c.}$$

Too tiny masses 0.45×10^{-2} eV , 0.85×10^{-3}eV

- If m~200GeV → $\Lambda\sim10^{16}$GeV ~ GUT scale
  m~1GeV → $\Lambda\sim10^{11}$GeV

Implying the existence of New energy scale or GUT
Or SM group singlet right handed neutrinos (cf: Kusenko)

- If GUT exists, the contrast between

  Large MNS mixing and Small CKM mixing would be a great clue.

- But the problem there is:

  Although the Dirac masses of lepton and down quarks can be connected, we have no idea about the Majorana masses of the right handed neutrinos.

Theoretical Problems

- GUT:

  The existence of GUT is bound to be correct.

  Anomaly cancellation or Tr Q = 0 between quarks and leptons.

  Also supported by the tiny neutrino masses and gauge coupling unifications

But leads to a bunch of problems: (in particular, SUSY GUTs)

- proton decays (dim 5)
- doublet-triplet splitting
- FCNC
- Contrast between quarks and lepton

How to understand problems:

- Generations, or how to obtain chiral generations

  No promising ideas:
  enlarging GUT group – horizontal symmetry,
  Hodge numbers of CY manifold,
  orbifolds, ….

- Dark energy or vacuum condensates

The point is:

- Survival Hypothesis (Georgi)

  Quarks and Leptons are light (compared with Planck scale),

  because they are chiral (complex representation) with respect to the SM group $SU(3) \times SU(2) \times U(1)$

This beautifully explains why they exist, but also pose a difficulty in enlarging the GUT group such that it includes generations.

Simple Groups do not work

- SU(n), SO(4k+2), E_6 allow complex rprs.

But SU(n) with n>5, SO(4k+2) with k>2 have only real (vector-like) reprs wrt the subgroup SU(5) or SO(10).

- E_7 and E_8 have only real rprs.

- Needs:

  orbifold projection, (Ratz) or

  complex structure for extra dimensions, or

  other ideas?

How to calculate Yukawa coupling?

How to break GUT symmetry spontaneously?

F-theory approach (Watari, Blumenhagen)

Extra-dimension approach (Gherghetta)

Dark energy or vacuum condensates

- Many spontaneous symmetry breaking at various stages of the theory:
- They are accompanied by vacuum condensates which would necessarily give (an enormous amount of) vacuum energy.
- SSB's above SUSY scale are of no problem
- SSB's below SUSY scale are the problem.

  may be a problem of micro-macro relation like measurement problem in quantum mechanics

Conclusion

- We still have many big problems whose beautiful solutions we can believe to exist and can discover!
- Let us hope that we will soon get important clues from LHC and astrophysical observations.