Rencontres de Moriond 2014

Theory Summary Talk

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ENS PARIS


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BEING INTELLIGENT

Theory Summary

HEP-EX is on the move
The triumph of the SM
Naturalness challenged
Where is BSM physics?

EW Moriond 2013
Theory Summary

HEP-EX is on the move
The triumph of the SM
Naturalness challenged
Where is BSM physics?

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Contents:

- **I. What we have learned:**
    - *Heavy flavours*
    - *Neutrinos*
    - *Astro - Cosmo*
    - *Standard Model Physics*
    - *The Brout-Englert-Higgs scalar*
    - *Beyond the Standard Model*
- **II. General Outlook**

General Outlook

- With the discovery of the BEH scalar the Standard Model is complete
- It is no more the **Standard Model**
- but the **Standard Theory**

The Standard Theory has been enormously successful

$SU(3) \times SU(2) \times U(1) \rightarrow SU(3) \times U(1)_{em}$

The ST has four fundamental coupling constants (+ the Yukawa cc)

Can we reduce the system?

For ex. A relation of the form $\lambda = f(g)$ *(see M. Schmaltz)*

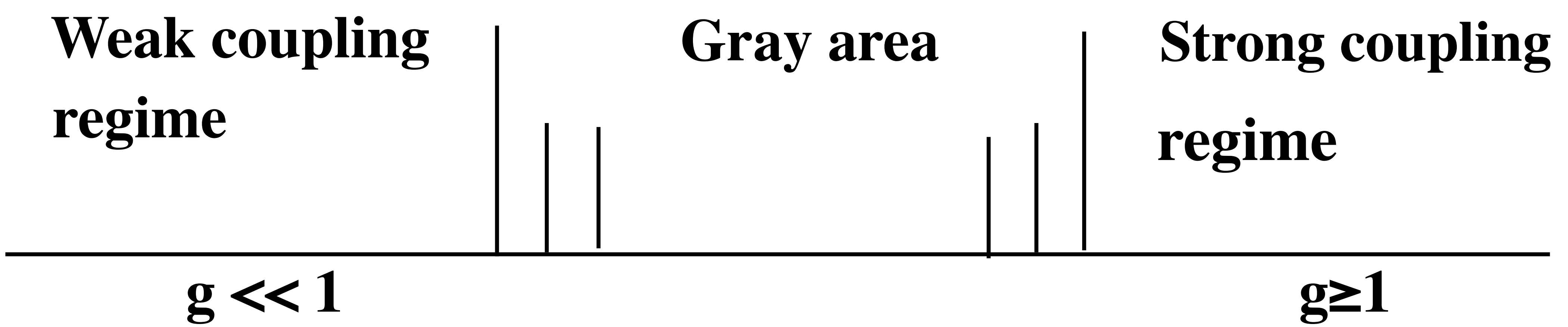
Answer: No!

It will not be respected by renormalisation

The ST is the absolute totalitarian system:

Whatever is not forbidden is compulsory!

The ST is a renormalisable Quantum Field Theory



Perturbation expansions

???

Strong coupling expansions

In a large part of present energies QCD is in the gray area !

Perturbation theory has been remarkably reliable outside the region of strong interactions

- Do we understand why?

- Dyson's argument:

$A_n \sim \alpha^n (2n - 1)!!$

Perturbation theory breaks down when $A_n \sim A_{n+1}$

$2n + 1 \sim \alpha^{-1}$

For QED $n >> 1$; For QCD ???

The validity of (improved) perturbation theory seems to extend deep inside the gray area

- Why ??
- How??
- Stay in Moriond next week

In the strong coupling regime we use a lattice approximation

- It is a direct numerical computation of the functional integral.
- The formulation is interesting in its own right.

Think of a field theory formulated on a space-time lattice:

$\Psi(x) \Rightarrow \Psi_i\, ;\, \partial\Psi(x) \Rightarrow (\Psi_i - \Psi_{i+1})$

$\Psi(x) \rightarrow e^{i\theta}\Psi(x) \Rightarrow \Psi_i \rightarrow e^{i\theta}\Psi_i$

For global transformations, i.e. constant θ:

$\bar{\Psi}_i\Psi_i$ as well as $\bar{\Psi}_i\Psi_{i+1}$ remain invariant

For gauge transformations, i.e. $\theta(x) \Rightarrow \theta_i$, the term:

$\bar{\Psi}_i\Psi_{i+1}$ transforms into $e^{-i\theta_i}\, \bar{\Psi}_i\Psi_{i+1}e^{i\theta_{i+1}}$

We need a field to connect the points i and i + 1.

$U_{i,i+1}$ which transforms as $U_{i,i+1} \rightarrow e^{i\theta_i} U_{i,i+1} e^{-i\theta_{i+1}}$

The term $\bar{\Psi}_i U_{i,i+1} \Psi_{i+1}$ is now invariant.

In the continuum limit the field U becomes the gauge potential A

The matter fields live on the lattice points.
The gauge potentials live on the oriented lattice links

The functional integral becomes a multiple ordinary integral

- Problem with fermions: Chiral Symmetry (K. Wilson, Nielsen-Ninomiya)

- Problem with fermions: Computation of a determinant

- Large computational problem

- Heavy quarks (talk by F. SanFilippo)

- Need to match weak and strong coupling regimes

NEW PHYSICS must be around the corner…

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- ….but we see no corner!

The ST is a renormalisable Quantum Field Theory

- Perfectly well-defined answers for every correlation function at any order in perturbation theory.

- Parameters such as masses and coupling constants are not calculable. They are taken by experiment.

- From the mathematical point of view any number is as good as any other.

Problems

- I. Hierarchy: Why all dimensionless numbers are not of order one. In particular, why there seem to be widely separated mass scales. The problem is physical, not mathematical.

- II. Naturalness, or Fine tuning: Why some choice of parameters may require fine tuning in perturbation.

- The problems are esthetic. If you are happy with very small, or very large, numbers, you do not have to worry about.

The ST and scale invariance

- We had a good discussion on this subject (see talks by M. Raidal, K. Kannike, M. Schmaltz)
- The ST is not scale invariant. This result does not depend on the regularisation scheme one uses to perform the renormalisation.
- The only 4-dim, non-trivial, scale invariant, q.f.t. is the N=4 supersymmetric theory with an SU(k) gauge symmetry. The beta-function vanishes and the coupling constant does not run (go to Nordita August 4-12, 2014)

Wilson's effective theory

- Consider any 4-dim renormalisable theory.
- Integrate over all modes of the fields with energy above a given scale M.
- M does not have to correspond to a physical scale.
- You obtain an effective theory in terms of the « light » modes.
- The general form of this theory will be an infinite sum of terms:

Wilson’s effective theory

$$\Sigma \; C_i(g,M) O_i$$

Remarks:

(i) This expansion is valid irrespectively of whether the initial theory was « fundamental » or « effective »

(ii) The operators O are all monomials in the fields and their derivatives compatible with the symmetries of the original q.f.t.

(iii) If the original theory was renormalisable, the c-number functions C can be computed order by order in perturbation.

(iv) Their dependence on M can be deduced by dimensional analysis

If d_i is the dimension of the operator O_i, the corresponding coefficient is proportional to M to the power $(4-d_i)$.

Wilson’s effective theory

- « Irrelevant » operators: di > 4
- « Marginal » operators: di=4
- « Dominant » operators: di < 4
- **In the ST the only dominant operator is the scalar boson mass**
- Can we make the corresponding coefficient equal to zero?
- **Yes, but we must introduce New Physics**

Beyond the Standard Theory

- I. « Model independent » analysis using higher dimensional operators of the effective theory.

- *see talks by A. Pomarol (NP in the scalar sector), S. Najjari, (on LFV), S. Fukasawa (on higher terms in the Lagrangian), D. Marzocca (scaling properties)*

- II. EDM's High precision measurements may give hints for NP. But, shall we be able to interpret them?

- *see talks by J. Hisano, F. Sala, M. Jung*

Beyond the Standard Theory

- III. Possible new particles but no New Physics
- Example: **Axions**
- Axions are part of QCD with massive quarks, but their detailed properties are model-dependent.
- *See review by A. Ringwald*

Beyond the Standard Theory

- IV. Flavour Physics
- Rabi's question.
- We do not understand the structure (Naturalness)
- Since we do not understand it, we hope it will help us to discover NP!!
- Source of CPV

Beyond the Standard Theory

- IV. Flavour Physics

- *Many contributions by S. Descotes-Genon, W. Altmannshofer, M. Gorbahn, Ch. Bobeth, A. Tayduganov*

Beyond the Standard Theory

- V. SUSY
- By now you have heard more than you ever wanted to know
- I was pleased to see that both theorists and experimentalists are escaping the unjustified tyranny of MSSM
- If SUSY is there, we do not know neither where, nor how, it is broken.
- If the breaking is spontaneous, it may have to do with super-gravity in order to get rid of the Goldstino

Beyond the Standard Theory

- V. SUSY
- *Many contributions on SUSY, or SUSY-inspired subjects by D. Buttazzo, Ch. Petersson, M. Badziak, C. Biggio, J. Quevillon, O. Eberhardt, M. Buchkremmer*

Beyond the Standard Theory

- VI. Neutrinos
- A data driven subject in which the theorists did not play the major role.
- Very few new ideas.
- An independent indication for the possible existence of a GUT-like scale
- From G. Altarelli's review: So far no real illumination came from leptons to be combined with the quark sector for a more complete theory of flavour

Beyond the Standard Theory

- VI Neutrinos
- *We had many reviews and contributions: G. Altarelli (General review), M. Maltoni (on sterile neutrinos), P. Coloma, R. Alonso, F. Capozzi, Y. Wong, F. Lyonnet, A. Kartavtsev*

Great New Results in Astrophysics and Cosmology

- I. Planck: Beautiful measurements of CMB anisotropies in temperature and polarisation
- II. Ice Cube: We enter the era of High Energy Neutrino Astronomy
- BICEP2: First evidence for the B-mode in polarisation. The trace of GW?

CONCLUSIONS

- The field is active showing a good collaboration between theorists and experimentalists
- More than 40 theoretical presentations, many coming from young researchers.
- We have the clear feeling of excitement, both from the long awaited confirmation of the Standard Theory, as well as from the expectation of New Physics.

To end, a story:

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- What is past, is prologue.

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- What is past, is prologue.
- It means, you aien’t heard nothing yet!