F(750), We Miss You

L. Laperashvili(ITEP), H.B. Nielsen(Copenhagen), and C. D. Froggatt, C. Das

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[3] *ITEP,*
National Research Center "Kurchatov Institute", Moscow
[4] *The Niels Bohr Institute, Copenhagen*
H.B. Nielsen presents the talk.

Main ideas

- Strongly Bound State We speculate that mainly due to exchange of Higgs bosons a system of 6 top plus 6 anti top quarks bind so strongly as to make a **bound state** with appreciably lower mass than that of 12 seperate quarks and anti quarks.
- Multiple Point Principle We propose a **new law of nature(MPP)** saying, that - somewhat mysteriously may be - the **coupling constants** and other parameters, such as the Higgs mass square, **get adjusted** so as to guarantee that there are *several vacua all with very small energy density(=cosmological constant)*.


F(750),
WE MISS YOU
γ γ


650
↓
γγ
F(750),
WE MISS YOU
γ γ

Multipel Point Principle(=MPP):

Our proposal for a new law of nature - Multiple Point Principle(=MPP) - (first by Don Bennett and myself) means that **there shall exist several vacua with very small energy density.**

Three Vacua in Standard Model:

For simplicity and trustability we in this talk restrict ourselves to **pure Standard Model** and only the following **three** vacua:

- Present The vacuum, in which we live, in the sense, that, if we in practice find a place with zero density of material, then that region is in the state of the "present vacuum".
- High (Higgs) field vacuum This vacuum is a state, in which the Higgs field is at a minimum in the Higgs-effective potential $V_{eff}(\phi_H)$ having a value of the Higgs field near $\phi_H \sim 10^{18}$ GeV. It is known, that with pure Standard Model it seems, that the energy density of this vacuum is slightly negative (with 3 standard deviations from being just zero).
- Condensate vacuum This third vacuum is a very speculative possible state inside the pure Standard Model, which contains a lot of strongly bound states, each bound from 6 top + 6 anti top quarks.

Can use Multiple Point Principle together with Any Model (side-remark)

In the present talk I shall concentrate on the version "several vacua, that all have very **small energy densities**" = MPP.
But older version had it: "Several vacua all have the **same energy density** (with some accuracy, that can be discussed)" = MPP.
Also one does not need to assume just Standard Model as I shall do in the present talk. For instance with Roman Nevzorov some of us (Froggatt and me) assumed a supersymmetry only broken tinily in one vacuum, but much stronger broken in e.g. the present vacuum.

The with Roman Nevzorov works extend Standard Model with Susy etc.

(Otherwise in the present talk I only keep Standard Model.)
Assuming some of the vacua to have only tinily broken susy, a tiny **cosmological constant** in the almost susy unbroken vacuum could be **transfered - by means of MPP** - to the present vacuum, and a rather successfull fitting/derivation of the astronomically determined cosmological constant could be achieved!
Also the original idea that we - Don Bennett and I - should invent the "multiple point principle" was based on a model called AntiGUT, which extends the Standard Model, although first having new physics rather close to the Planck scale, actually by letting each family of fermions have its own system of gauge groups. The gauge bosons also in families!

Finetuning of Parameters, Couplings

Our "multiple point principle" is really just an assumption about the coupling constants - in the Standard Model, if we as in this talk take the model to be pure Standard Model - being **finetuned** so as to make the three vacua proposed have just zero energy density $V_{present}, V_{condensate}, V_{high\ field}=0$ (with say the accuracy of the order of the astronomically found energy density in the "present vacuum" $\sim$ 75 % of the total energy density in the present universe.)

I.e. MPP provides 3 restrictions between the parameters of the model in question, here the Standard Model, from which the $\sim$ zero energy densities in all three vacua follows.

Multiple Point Principle means Relations between the couplings and other parameters:

$$V_{present}(\Lambda_{CC}, g_t, m_H^2, \Lambda_{QCD}, ...) = 0 \quad (1)$$
$$V_{condensate}(\Lambda_{CC}, g_t, m_H^2, \Lambda_{QCD}, ...) = 0 \quad (2)$$
$$V_{high\ field}(\Lambda_{CC}, g_t, m_H^2, \Lambda_{QCD}, ...) = 0 \quad (3)$$

Here we wrote explictely the following parameters of the Standard Model:

$$\Lambda_{CC} : \text{The cosmoligal constant} \quad (4)$$
$$g_t : \text{The top Yukawa coupling} \quad (5)$$
$$m_H^2 : \text{Higgs mass squared} \quad (6)$$
$$\Lambda_{QCD} : \text{The scale parameter of QCD} \quad (7)$$

Whether these parameters are renormalized or bare does not matter so much here.
$V_{present}$, $V_{cindensate}$, $V_{high\ field}$ are the vacuum energy densities for the three speculated vacua.

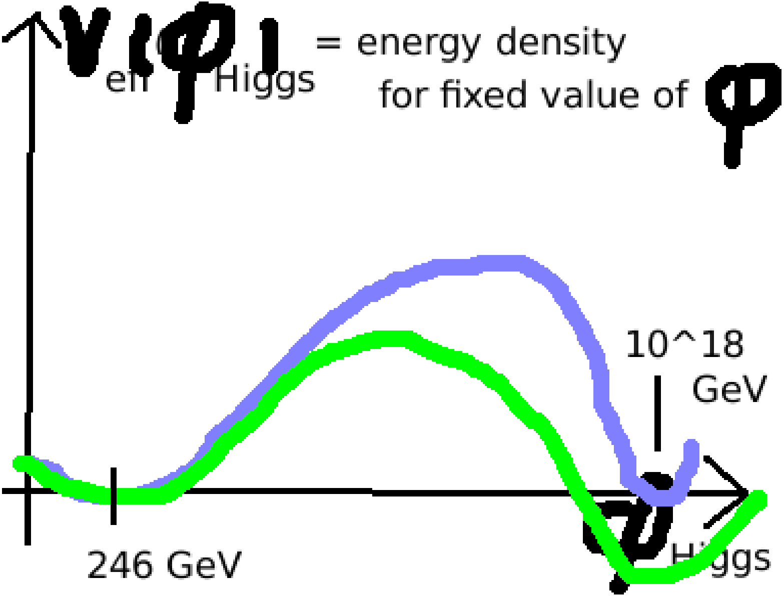
Use of Multiple Point Principle:

Taking the experimental values for all the Standard Model parameters except for say Λ_{CC}, m_H^2, and g_t we could look at it, that e.g. $V_{present} = 0$ fixes the cosmological costant Λ_{CC} to essentailly zero. (It is very small indeed). Then $V_{high\ field} = 0$ (meaning the energy density of the vacuum having the very high Higgs field $\phi_H \approx 10^{18} GeV$) could be taken to predict the Higgs mass, and the $V_{condensate} = 0$ to predict, say, the g_t Yukawa coupling. In fact Colin Froggatt and I (H.B.N.) PREdicted the Higgs mass many years ago to 135 GeV $\pm$ 10 GeV from such an MPP-assumption.

kunstmaler lars andersen http://www.23.dk/skak.htm

Lars Andersen

Historiemaler Portrætmaler Provokunstner Om Lars Andersen CV/omtale Kontakt


V(φ)
eff Higgs
= energy density
for fixed value of φ
10^18
GeV
246 GeV
φ
Higgs

A Remarkable Side-Point:

The second minimum in the Higgs effective potential corresponding to what, we call the "High field" vacuum, has an expectation value for the Higgs field ϕ_H, which is **remarkably close** (order of magnitudewise) **to the Plankc energy scale**! This should not be an accident, but rather explained: Planck energy scale is the "fundamental physics scale" for both energy and Higgs fields;they have the same dimension.

Two of the vacua, which we discuss to day, have for some reason exceptoinaly small, say, Higgs field, while the "high field" vacuum has the "normal" order of unity in Plack units value for *its* Higgs expectation value. So rather ask the question:

Why do the two vacua, "present vacuum" and "condensate vacuum", not have Planck scale, say, Higgs fields? (Let me for the moment postpone, that indeed we have an explanation from "multiple point principle", that these two vacua have exceptionally small Higgs expectation values scale.)

But Why should we believe in the postulate of Multiple Point Principle ?

- **Need Coupling Explanations** Even with great effort e.g. Graham Ross could not get the factor Δ with which the Higgs is too light further down than about $1/20$. Cosmological constant ?...
- "Derivations" In models which allow somehow influence from the future to adjust coupling constants one may make some "derivations" of MPP.
- Empirical But really it is the main point of todays talk to deliver some empirical support (our PREdiction of Higgs mass, two derivations of same bound state mass)

1. Reason:" Plural of Cosmological Constant"

- 1 We have to assume that the energy density in the "present vacuum" is very small compared say to Planck energy density, because it has been well known long before the measurements with supernovae A1 setlled it to be non-zero.
- 2 This assumption does not become essentially less bautiful or more complicated by "putting it in plural": **Several vacua have very small energy density/ cosmological constant** compared to say the Planck energy density or the Higgs energy density or most high energy physics contributions.

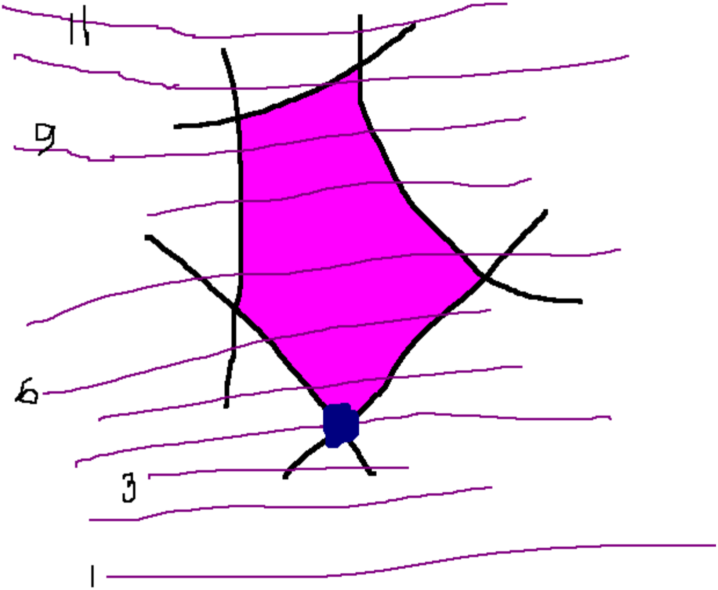
(Private conversation with L. Susskind.)
But each time you fix the energy of one more vacuum energy density you get one more relation between the parameters couplings of the theory.
It may even be more beautiful to talk about several/all vacua than

2. Reason: Extremizing Something, Positive Energy

- A. Assume that energy-density should be positive or zero. i.e. bottom in hamiltonian density is at least zero. This will restrict the coupling constants and other parameters - e.g. Higgs mass - to some polyhedron-like figre with curved sides, where the sides correspond to one possible vacuum or the other having just zero energy density.
- B. Assume that the couplings and parameters inside the positivity restriction are selected by **minimizing something / some function of these couplngs and parameters**(a generic or "random" function).

  Using antropic principle the function could suggestively be the number of human beings in the universe resulting with the couplings etc. in the point in parameter-space considered.

On the figure I have drawn the cote curves -really cote surfaces-.


11
9
6
3
1

Very offen Minimum of Function occurs in Corners

The crucial point is, that - especially in a high dimensional coupling-constant and parameter space - will very offen the minmimum fall in a **corner** (where several sides cross) of the polyhedron-like region with curved sides (violet).
But the "sides" correspond to different vacua having zero energy density. So a corner corresponds to several vacua all having zero energy density → "Multiple Point Principle"!

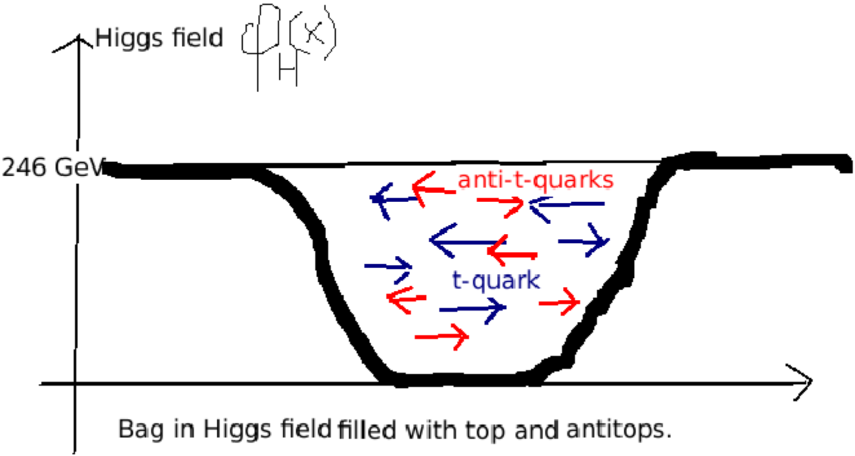
3. Reason; Our Bennett's and Mine Original Explanation

One assume that some **extensive quantities / commodities** i.e. some integrals over space time of say fields raised to some powers etc. - say Higgs field squared - are **fixed** by "God"/ some law, rather than as I think we would usually think, it is the couplings themselves that are selected y "God".


VAPOR
ICE
WATER
EXTENSIVE Q's : E, V, N

The Difficulty of the Bound State

When we - as we now want - want check if the “multiple point principle” is true/valid law of nature, we have the difficulty, that an important role is played by a bound state, with which the vacuum, which we call “condensate vacuum”, is filed.
Fundamentally one cannot calculate completely perturbatively, when one calculates on a bound state!


Higgs field
246 GeV
anti-t-quarks
t-quark
Bag in Higgs field filled with top and antitops.

Lucky Overdetermined Situation

Luckily we are with "multiple point principle"(to be tested) in the very good situation calculationally, that in addition to know already from experiment all the parameters of the Standard Model to day, we have the ca. three extra equations, if MPP assumed, and so we can use this information to help us through the caculational problems with the bound state.

Checking MPP by Calculating Mass of the Bound State in Several Ways

Since it is non-perturbative and thus either difficult or very crude only that we can compute say the mass of the bound state, it is suggestive to take it as parameter. Then we may formulate testing the "multiple point principle" as evaluating by *different* assumptions inside MPP the mass of the bound state.

Really Check Bound State Mass Obtained from Degeneracy of Vacuum Pairs

Our technique - to day - is to estimate/calculate the value of the mass of the bound state of 6 top and 6 anti top quarks speculated to exist in our picture/model. (Since we have two relative energy density predictions - ignoring the absolute smallness of cosmological constant - we get two such bound state mass fits.) In addition we can seek to obtain the bound state mass by building a bag-model-like ansatz for the bound state and estimates its mass. Thus we get using our mutiple point principle two a priori different mass predictions for the

Our Three Bound State Mass Fits:

- high field fit We fit to get a tiny correction to the Higgs mass relative to the running selfcoupling so as to ensure the MPP-requirement that the "present vacuum" be degenerate with the "high field vacuum": Fitting mass $m_{from\ high\ field\ fit} \approx 700 GeV$ to $800 GeV$.
- condensate vacuum fit We fit the mass to the binding between the bound states in a region filled with such particles to lowest energy density just gets zero/same energy density as the present vacuum. With a simple but accidentally almost true assumption we fit the mass to $m_{from\ condensate\ fit} \approx 4m_t = 692 GeV \pm 100 GeV$, say.
- Ansatz calculation We make a bag-model-like crude ansatz for the bound state of the 6 top + 6 anti top and seek the minimum energy/mass by varying bag radius R. With very crude inclusion of various corrections we reach the mass estimate $m_{bag-model} \approx 5m_t = 865 GeV \pm 200 GeV$, say.

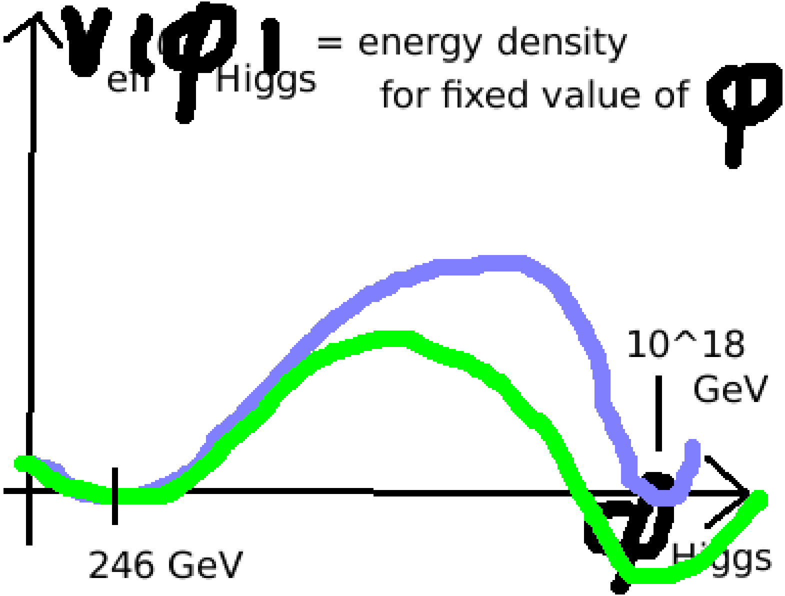
Plan of talk:

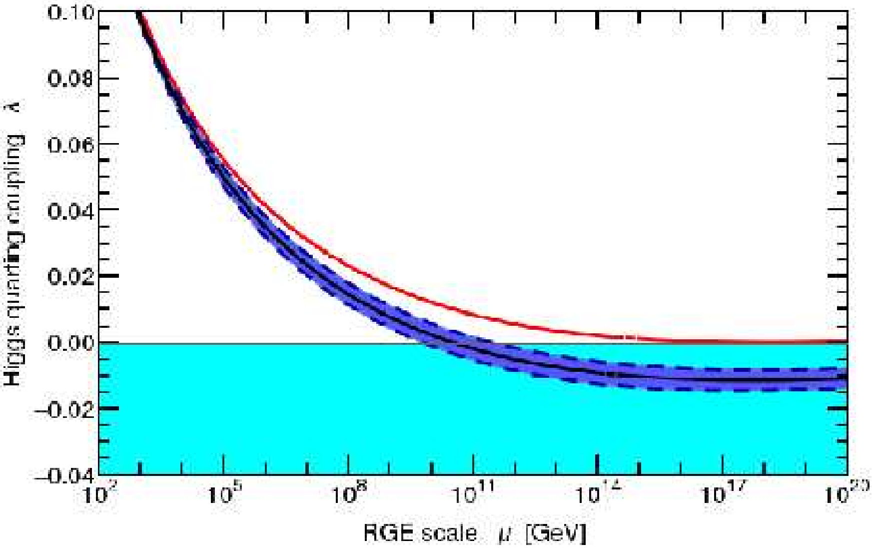
- headingF(750), We miss you!
- introduction New Natural Law of Nature, and Bound State
- MPP The New law, "Multiple Point (Criticallity) Principle".
- Bound Bound state of 6 top and 6 anti top.
- Plan Plan of the talk.
- Reasons Attempts to explain why MPP.
- High The mass of the bound state that could arrange the stability of our vacuum to be just boarderline stable w.r.t. the Higgs field.
- Condensate The mass of the bound state making the "condensate vacuum" degenerate in energy density to the "presnet vacuum"
- Bag Bag model estimation of the mass of the bound state.
- Conclusion Telling that you should now believe our MPP law of nature!

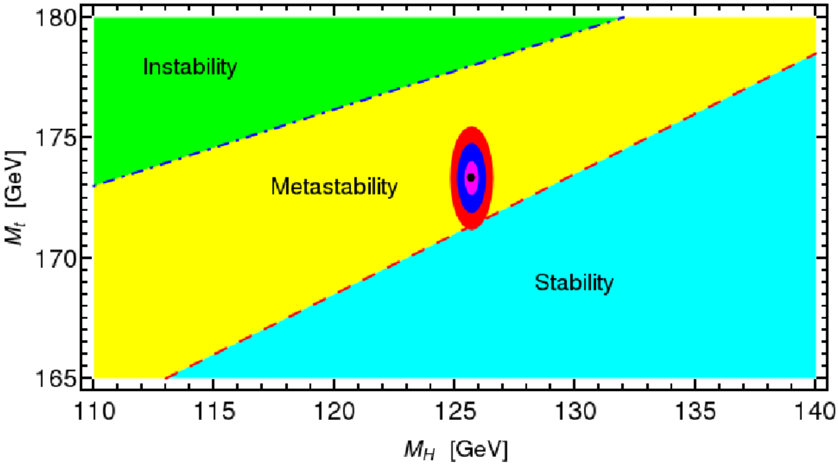
Small Correction by Laperashvili, Das, and me to "High field Vacuum" Energy Density

From De Grassi et al.'s calculation of the effective Higgs field potential $V_{eff}(\phi_H)$ there is a minimum in this potential, but it goes **slightly** under 0 so that the present vacuum is **unstable** for the experimental Higgsmass 125.09 ± 0.24, while the value that would have made the second minimum just degenerate with the present vacuum energy density would be rather
$m_H|_{from\ MPP\ De\ Grassi...} = 129.4$ GeV.

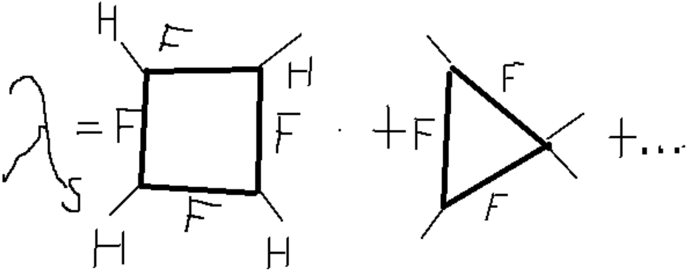
We claimed that with a bound state e.g. with the mass 750 GeV we would get corrected the De Grassi et al. calcuation so as to be consistent with exact MPP.
Basically we claim: The leading diagrams treating the bound state as an "elementary particle"(i.e. with formal Feynmann rules) though modified by including estimated formfactors, we can fit the mass of the bound state so that the diagrams just cancel the instability and make the energy density of the high Higgs field minimum exactly zero, $V_{eff}(\phi_H \sim 10^{18} GeV) = 0$. That comes for a mass $\sim$ 700 to 800 GeV.


eff
Higgs
= energy density
for fixed value of
10^18
GeV
246 GeV
Higgs


0.10
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
Higgs quartic coupling λ
10^2 10^5 10^8 10^{11} 10^{14} 10^{17} 10^{20}
RGE scale μ [GeV]



Instability
Metastability
Stability
180
175
170
165
M_t [GeV]
110
115
120
125
130
135
140
M_H [GeV]



Correction to Higgs-self coupling

The Small Instabily Negative Self-coupling at the High field Minimum:

Extrapolated using DeGrassi et al. without our correction one gets the following value of the running self coupling $\lambda_{run}(10^{18}GeV)$:

$$\lambda(\phi_{\text{“high field”}}) = -0.01 \pm 0.002. \tag{8}$$

at the high field scale $\phi_{\text{“high field”}}$. However, a value very accurately zero is requied by Multiple Point Principle(=MPP).
Since bound state F is an extended object we must include a formfactor, when using it in Feynman diagrams.
Defining a quantity b denoting the radius of the bound state measured with top quark Compton wave length $1/m_t$ as unit by:

$$< \vec{r}^2 > \; = \; 3r_0^2, \tag{9}$$

$$r_0 \; = \; \frac{b}{m_t}, \tag{10}$$

Approximating the Bound State as were it an Elementary Particle, since so Strongly Bound

The dominant diagram/correction - the first and quadratic of the diagrams on the figure just above - is

$$\lambda_S \approx \frac{1}{\pi^2}\left(\frac{6g_t}{b}\frac{m_t}{m_S}\right)^4$$

where we have the estimated or measured values

$$g_t = 0.935;\ m_t = 173 GeV;\ b \approx 2.34 or 2.43$$

Using the after all rather small deviation from perfect MPP

$$\lambda_{\text{high field}} = -0.01 \pm 0.002$$

and requiring it to be cancelled by the correction from the bound state we get the requirement

$$\lambda_S = \frac{1}{\pi^2}\left(\frac{6g_t}{b} * \frac{m_t}{m_F}\right)^4 * (\sim 2) \approx 0.01 \pm 0.002, \qquad (12)$$

where $g_t = .935$, $m_t = 173GeV$, $b \approx 2.43$ and the factor "(~ 2)" were taken in to approximate some neglected diagrams.

If a nearer study should show that the next diagrams add up to roughly as much as the first one should include the factor ~ 2 to take into account the neglected Feynman diagrams correcting the Higgs self coupling.
The solution w.r.t. the mass of the bound state $m_{F(750)}$ gives

$$\begin{aligned} m_F &\approx \frac{6 g_t m_t}{b}\left(\frac{\sim 2}{\pi^2 * 0.01 \pm 0.002}\right)^{1/4} \\ \approx 2.31 * 173 GeV * 2.1 &= 4.9 * 173 GeV = 850 GeV \pm 20\% \\ \text{or without the } \sim 2: & \qquad (13) \\ m_F = 2.31 * 173 GeV * 1.8 &= 4.1 * 173 GeV = 710 GeV \pm 20\% \end{aligned}$$

Three Agreeing Fits of the Bound State Mass:

In this way we got even two calculations for the bound state mass - using in addition crude estimation -

$$m_F(\text{from “high field vacuum”}) \approx 850\,GeV \pm 30\%\text{with} \sim 2 \quad (14)$$
$$m_F(\text{from “high field vacuum”}) \approx 710\,GeV \pm 30\%\text{without} \sim 2 \quad (15)$$
$$m_F(\text{“condensate vac.”}) \approx 692\,GeV \pm 40\% \quad (16)$$
$$m_F(\text{“bag estimate”}) \approx 5m_t = 865\,GeV(very uncertain) \quad (17)$$

The agreement of the value “692 GeV” with the estimate(s) from the completly different vacuum with the high Higgs field “850GeV” or “710 GeV” and with the mass by estimating how strong the top and anti tops can bind $m_F(\text{“}bagestimate\text{''}) \approx 865 GeV$ is encourraging and a support of our “Multiple Point Principle”!

Fitting Bound State Mass to the "Condensate Vacuum" having Same Energy Density as the "Present" one.

For calculational purpose we approximate the "condensate vacuum" with a chrystal (but it should at least be a fluid, but that may not matter much for our crude energy density estimate) made from the bound states sitting each with 4 neighbors, the top and anti tops of which are in approximate main quantum numbers n=2 seen from the bound state considered.

The MPP-requirement may be written

$$
\begin{aligned}
0 &= m_F - \text{“binding per F”} && (18)\\
&= m_F - \frac{\#\text{neighbors}}{2} * \text{“binding to neighbor F”} && (19)\\
&\approx m_S - \frac{4}{2} * \text{“binding of F in n=2 arround another F”} && (20)\\
&\approx m_F - \frac{4}{2} * \text{“binding of F”} * \frac{1/2^2}{1/1^2} && (21)\\
&= m_F - \frac{1}{2} * \text{“binding of F”} && (22)\\
&= m_F - \frac{1}{2} * (12m_t - m_F) && (23)\\
&= \frac{3}{2} m_F - 6m_t && (24)
\end{aligned}
$$

We shall indeed follow an appendix of our earlier work[?] and assume, that the structure of the condensate can be approximated

We made then the approximation, that we can effectively consider it, that the neighboring top quarks and anti topquarks contained in an F neighboring to another one are *in effect in the n=2 orbit* of the latter. Thus we can take the binding energy of a neighboring F to a given one "binding to neighbor F(750)" to be as, if the top and anti tops were in an n=2 orbit or some superposition thereof. Thus the binding of the neighbors occur with binding energy "binding of F in n=2 around another F".
As long as we can take the effective Higgs mass for the two lowest orbits n = 1 and 2 to be zero, we can count, that the binding energy, for top say, in the orbit n=2 is just one quarter of that in the n=1 orbit, provided we can use the same potential of the form $\propto 1/r$. But now that were, what our above discussion "accidental cancellation" in section **??** should ensure, and so even for an F-particle, which consists of tops and anti tops the ratio of the binding energies should be $1/2^2 = 1/4$.

From the last step in (24) we easily derive of course

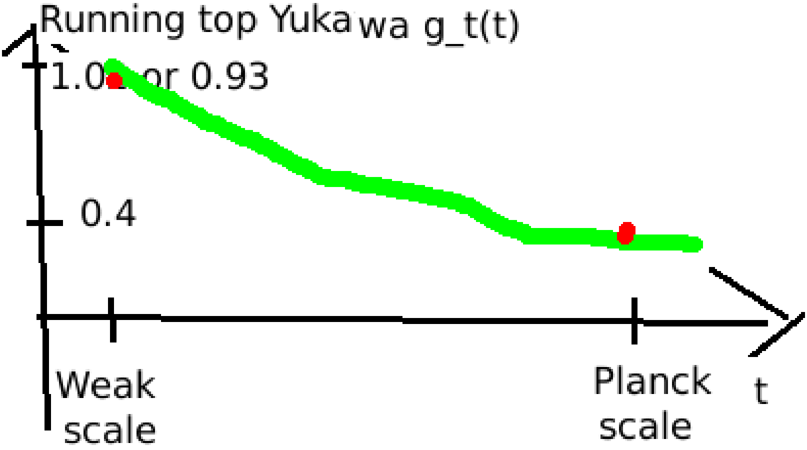
$$m_F = \frac{2}{3} * 6 m_t = 4 m_t = 173 GeV * 4 = 692 GeV \text{ agreeing well with } 710 GeV \tag{25}$$

Estimating How 6 Top + 6 Anto top Bind

Imganining that the top-Yukawa-coupling g_t were gradually screwed up, the Higgs field inside an ansatz bound state of 6 top + 6 anti tops at say the typical distance of the quarks themselves from the center, would gradually be lowered compared to the usual vacuum expectation value.

"Solve" Hierarchy problem

Having made a fine-tuning theory/model/rule we have at least the chance to have our fine-tuning theory MPP give the experimentally observed order of magnitude for the Higgs mass say. And indeed we predict the right order for the logarithm of the scale range over which μ has to run to get the running top-yukawa-coupling $g_{t\ run}(\mu)$ go from 0.4 at the 10^{18} GeV to the 0.935 needed at the weaak scale from the requirement of the "condensate vacuum " being degenerate with the 'present one".



Scale ratio of the Planck scale to weak scale must be so as to allow g_t to go from 1.0 to 0.4 !

Conclusion

The remarkable **coincidence**, that our three mass estimations coincide is an evindence in favour of the **truth of our model, with the Multiple Point Principle, and the bound state**!

Some Achievements of our Model MPP and Strongly Bound State of 6 Top + 6 Anti top, (in pure SM)

I must mention the following achievements most of which I did not have time for:

- Hierarchy problem The fine-tuning caused by our MPP requirements combined with the assumption, that the Higgs field in the "high field vacuum" is of the order of the Planck scale (or only a bit under) leads to the scale problem being solved in the sense, that the Higgs mass and weak scale get fixed to be *exponentially* much lower than the Planck scale, and that in fact very closely by the right size for the logarithm.

Achievements of Multiple Point Principle(=MPP)(in pure SM) Continued:

- g_t Froggatt and I estimated the value of the top-Yukawa-coupling g_t needed for MPP in the sense, that it represents a phase transition value between the "condensate vacuum" and the "present vacuum". We found the phase transition $g_{t\ phase\ transition} = 1.02 \pm 14\%$, agreeing with experiment $g_{t\ exp} = 0.93_5$.
- Stability Explaining the that the Higgs mass just puts our vacuum on the borderline of being meta-satble.
- Correction to Stability ...even very accurately, if we take seriously the very small correction due to the bound state by Laperashvili, Das, and myself.

Acievements Still in pure Standad Model of our MPP and boud sate:

- The “condensate vacuum” can be used for a model for dark matter as pearl size balls of the “condensate vacuum” surrounded necessarily by a skin - the transition surface - that is then pumped up by ordinary matter, carbon say, to a pressure of the order of that in a white dwarf star. Such pearls may be useful for
  - Dark matter
  - making supernovae explode so as to throw sufficient material out so that we can observe it.
  - Explaing the two bursts of neutrinoes observed with $\sim$ 5 hours time difference in SN1989A in the Big Maggelanic Cloud.
  - helps r-process fit ?
  - explain ratio of dark to normal matter being of order 6.

Achievements of MPP in Extended Models (i.e. not only SM):

- Value of Cosmological Constant With Roman Nevzorov we got values for the CC using "same version" of MPP and an almost supersymmetric vacuum state.
- Number of families Prior to having formulated MPP we fitted finstructure constants in an extension of the Standard Model "AntiGUT" in which each family of fermions has its own set of gauge bosons. We - including Brene and Don Bennett and me - **pre**dicted the number of families, which was not known yet at that time.

Encouridgement for Theoreticians to Calculate More Accurately This Bound State

At the end I would stress: **Since Our picture is PURE STANDARD MODEL, everything can in principle be CALCULATED!** So it is only a question of better techniques - Bethe Salpeter Equation ? - or better computers and use of them - lattice theory with Higgsfield on the lattice ? - to obtain more solid and accurate checks of MPP and calculation of the bound state mass than my crude estimates.

And this is just a work for the theoreticians (among the students say).

Then there should pop up some peaks - like the joke of Pich's - by themselves, when the experimentalists make the plots.

If not it would mean that Standard Model were not right also nonperturbatively.