Hints for Vector Quarks from Precision Electroweak Data?

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“Beautiful Mirrors and Precision EW Data”
D Choudhury, T Tait, and CEM Wagner,
PRD65, 053002 (2002); [hep-ph/0109097]

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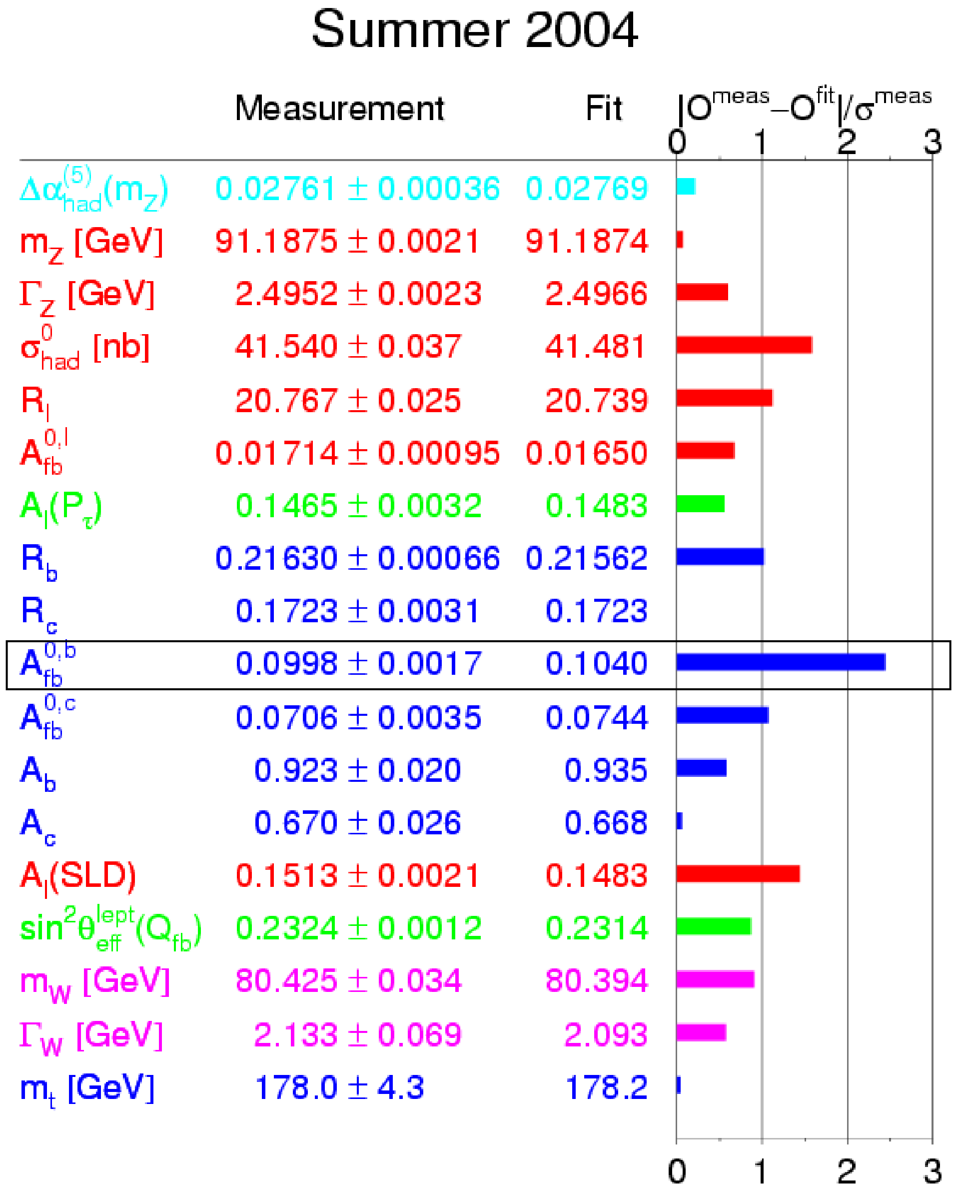
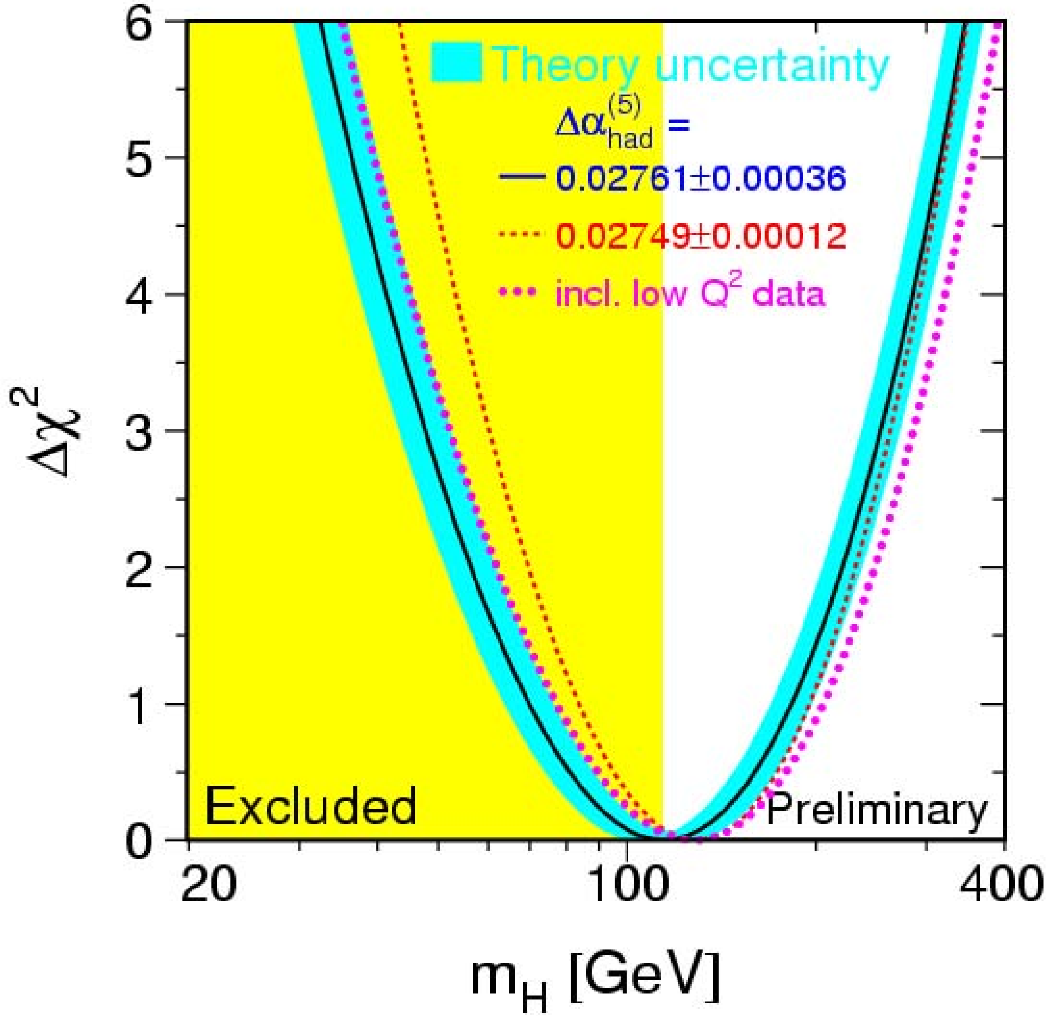
EW Fit

- The Forward-backward Asymmetry of the b quark shows a deviation from the SM prediction, in disagreement at the 2.4σ level.
- It mars what is an otherwise perfect fit to the Z-pole data.
- 2.4σ is not very statistically significant, but what is perhaps more interesting is the effect it has on the fit as a whole.
- Recall that in the SM, the only parameter we don't know is m_h (which contributes to EW observables as $\log m_h/m_Z$).
- So any fit in the SM, is more or less a fit to the best value of m_h, and then we should see how well the fit works.



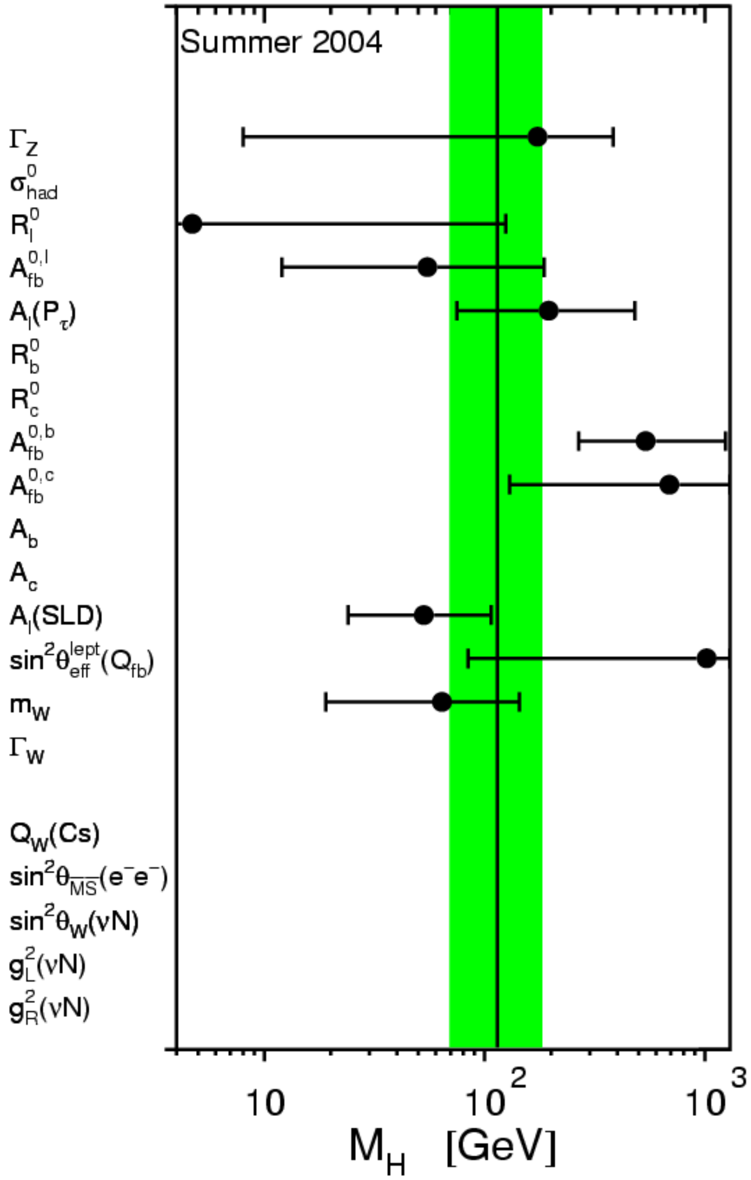
Fit to the Higgs Mass



- The global fits prefer a Higgs mass "right around the corner" – the minimum of the fit is right at the direct search bound of roughly 115 GeV.
- The over-all confidence level of the fit is low (mostly because A_{FB}^{b} doesn't agree well with the Higgs mass the rest of the data likes).
- We can see this explicitly by deriving a Higgs mass for every observable, and then seeing how they compare with one another, and with the global fit value.

What A^{FB}_b Really Wants

- A^{FB}_b would like the Higgs mass to be around 500 GeV.
- Clearly, now we see why it was unhappy with the central fit value around 115 GeV.
- The rest of the data would prefers m_h even lower.
- The other observables would average to something around 70 GeV or so – way below the direct search limit.
- What this suggests is that if we were to somehow re-measure A^{FB}_b at the SM value, we would do so that the price of a fit m_h below the direct limit.



"Lose-Lose for the SM!"

M Chanowitz **PRL87, 231802 (2001)**

- Mike Chanowitz has called this "Lose-lose for the SM"
  - Either we accept that there is a 2.4σ deviation which cannot be statistical (or systematic) in nature.
  - Or we must accept that the fit to the Higgs mass in the SM predicts a Higgs so light that it should have been discovered at LEP II!
- This situation can be understood as the fit calling out for physics beyond the SM.
- There are two different attitudes we can take:
  - A^{FB}_b IS a statistical (or systematic, or whatever…) deviation. There is something wrong with the SM fit to the Higgs mass because it is missing beyond the SM ingredients, which ultimately result in a Higgs mass consistent with the LEP II bound
  - A^{FB}_b is actually a manifestation of the new physics, and we should look for models which would lead to the deviation seen in the precision data.
  - I will follow the second line of reasoning in this talk.

Bottom Couplings

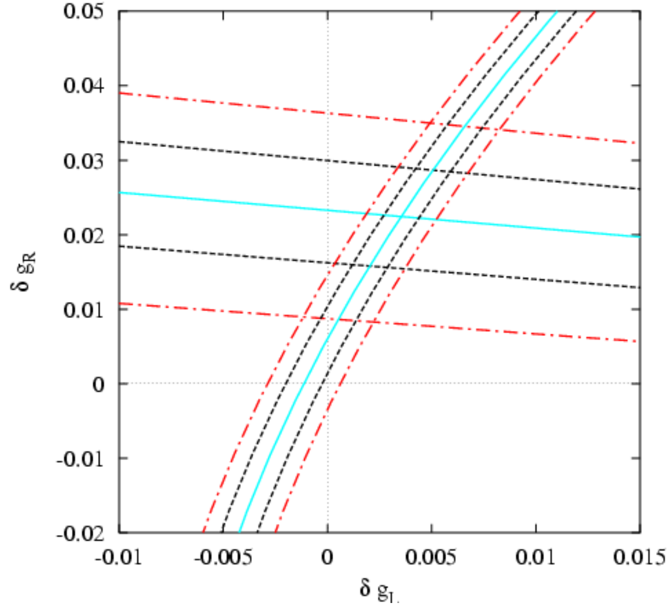
- A simple example of new physics which does what we want is something which modifies the way the b quark couples to the Z.
- In terms of left- and right-handed, R_b and $A_{FB}{}^b$ constrain the b couplings to Z in orthogonal ways:

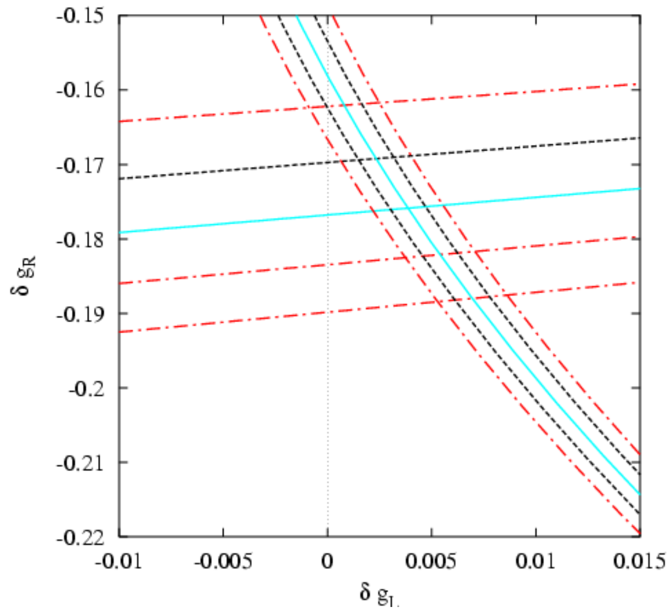
$$R_b = \frac{\left(g_L^b\right)^2 + \left(g_R^b\right)^2}{\sum_q \left[\left(g_L^q\right)^2 + \left(g_R^q\right)^2\right]}$$

$$A_b^{FB} = \frac{3}{4} A_e A_b$$

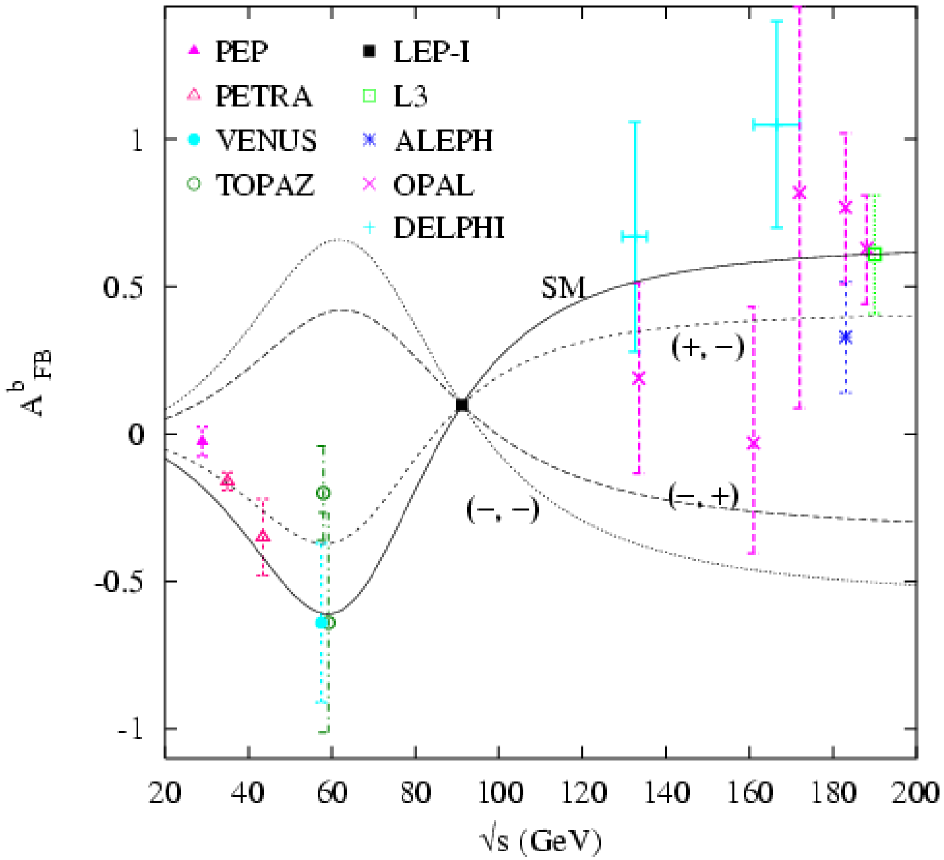
$$A_b = \frac{\left(g_L^b\right)^2 - \left(g_R^b\right)^2}{\left(g_L^b\right)^2 + \left(g_R^b\right)^2}$$

- The deviation is mostly RH, and too large (~26%) to be a loop effect.





Off the Z Peak



- On the Z peak, the solutions cannot tell the signs of the Z-b-b couplings.
- However, by going off peak, one can use the interference between the Z and the γ to learn about the signs of the couplings.
- If the LH coupling has the wrong sign, the data below the Z peak is in sharp disagreement.
- However, if the RH coupling has the wrong sign, the low energy data slightly prefers it to the SM.
- Not shown are two LEP I points around m_Z which slightly prefer the SM like case.

Vector Quarks

- In order to have a "large" (tree level) influence on the Z-b-b couplings, we introduce new quarks, with different EW quantum numbers (but the same electric charge) which mix with the bottom quark.
- We choose vector-like quarks (with equal R and L weak interactions) because they allow for reasonably small corrections to EW precision measurements such as the ρ parameter.
- It also guarantees that anomaly cancellation will work straight-forwardly.
- For example, consider:

$$\Psi_{L,R} = \begin{bmatrix} \chi \\ \omega \end{bmatrix}_{L,R} \qquad (3,2)_{1/6}$$

$$\xi_{L,R} \qquad (3,1)_{-1/3}$$

χ is "top-like"
ω and ζ are "bottom-like"

- Many theories predict such objects:
  - Cousins of the Top Seesaw theory of dynamical EW symmetry breaking
  - Extended EW symmetry theories (such as top flavor)
  - Little Higgs (partners of quarks)
  - Extra dimensional theories (KK modes of the bottom itself)
  - Large GUTs

Mixings and Masses

$$M_b = \begin{bmatrix} Y_1 v & Y_2 v & Y_3 v \\ Y_4 v & M_1 & Y_5 v \\ Y_6 v & Y_7 v & M_2 \end{bmatrix}$$

(β,ω,ζ) basis

- We assume that all EW symmetry breaking comes only from the usual SM Higgs boson (or copies).
- This is also important for, i.e. $\Delta\rho$.
- There are two gauge invariant mass parameters, plus seven Yukawa interactions which contribute to the mass matrix after EWSB.
- The eigenvalues are the masses and the mixing angles determine the couplings.
- We tune the RH mixing to be substantial, to explain A^{FB}_b, while data prefers a small LH mixing.
- Note that generically there are mixed **b-ω**, **b-ζ**, and ω–ζ Z couplings.

$$L^\dagger M_b R \rightarrow \mathrm{Diag}\left[m_b, m_\omega, m_\xi \right]$$

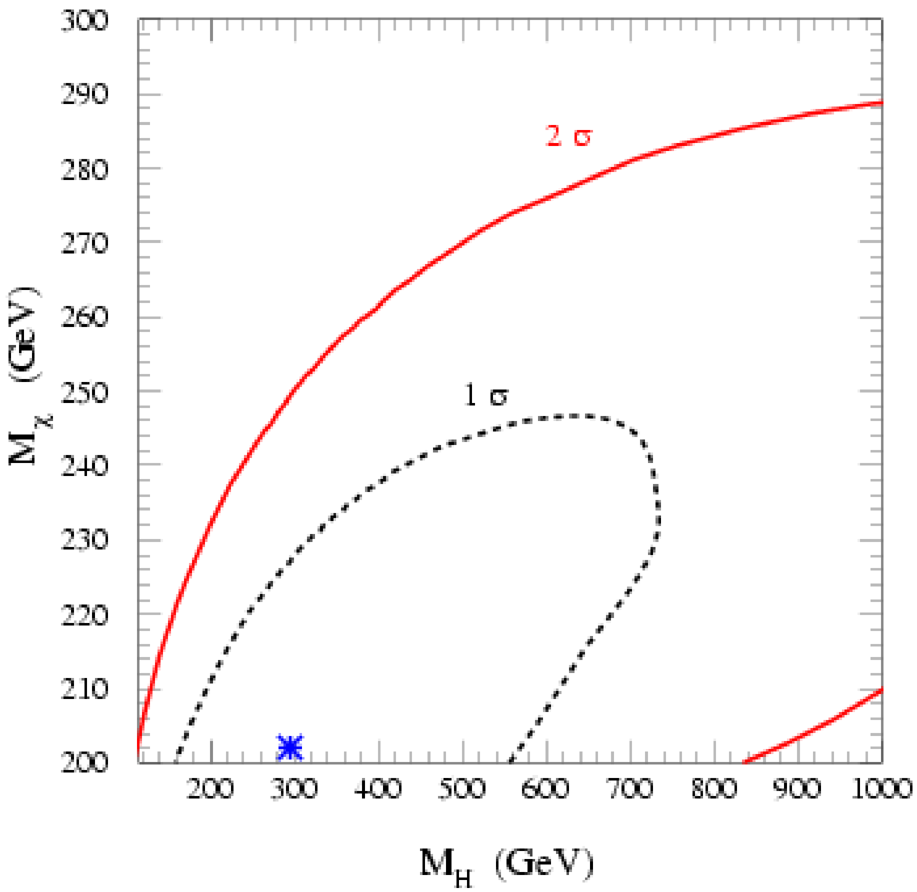
Z-b-b LH:

$$L^\dagger \begin{bmatrix} -\frac{1}{2} & 0 & 0 \\ 0 & -\frac{1}{2} & 0 \\ 0 & 0 & 0 \end{bmatrix} L$$

Z-b-b RH:

$$R^\dagger \begin{bmatrix} 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 \\ 0 & 0 & 0 \end{bmatrix} R$$

EW Fit

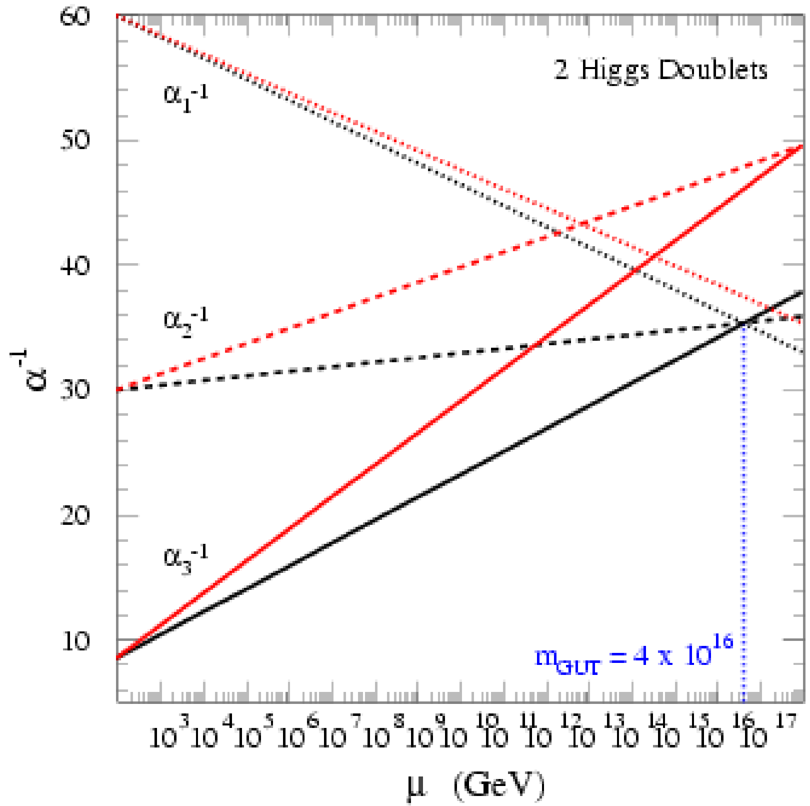


ζ mass is not very constrained by the fit.

- We do a global fit to the data.
- Since our ‘b coupling fix’ is non oblique we can’t use S,T, & U except to help organize some of the universal corrections.
- Clearly, Z-b-b both RH and LH couplings will deviate from the SM.
- Beyond that, dominant corrections come from the RH mixing which modifies the SM t-b contribution to the T ($\Delta\rho$) parameter.
- The fit prefers the exotic ω and χ quarks to be quite light; very close to the top mass.
- A (somewhat) heavier Higgs mass is favored – plus higher masses allowed.
- Overall χ^2 is improved, but what is more interesting is that we have relieved the tension in the fit to the Higgs mass.

Grand Unification?

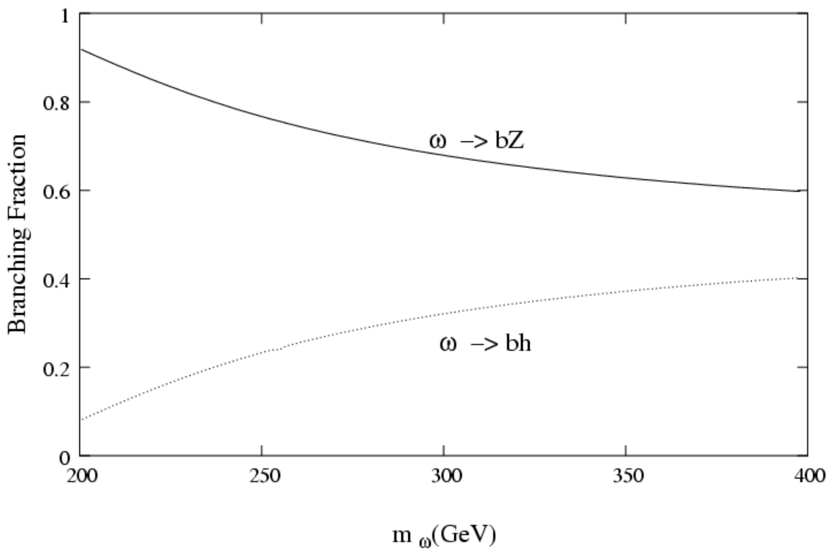
- Just for fun, let's see what these new ingredients imply for unification of couplings at high scales.
- In the SM, the couplings fail to meet at the 20% level.
- Amazingly enough, the ingredients in our vector quark model unify at the % level!
- Of course, this model has no explanation for the hierarchy problem.
- However, recent 'string landscape' arguments question how important that failing is.
- This model could be considered a realization of the landscape hinted at by experimental observations.

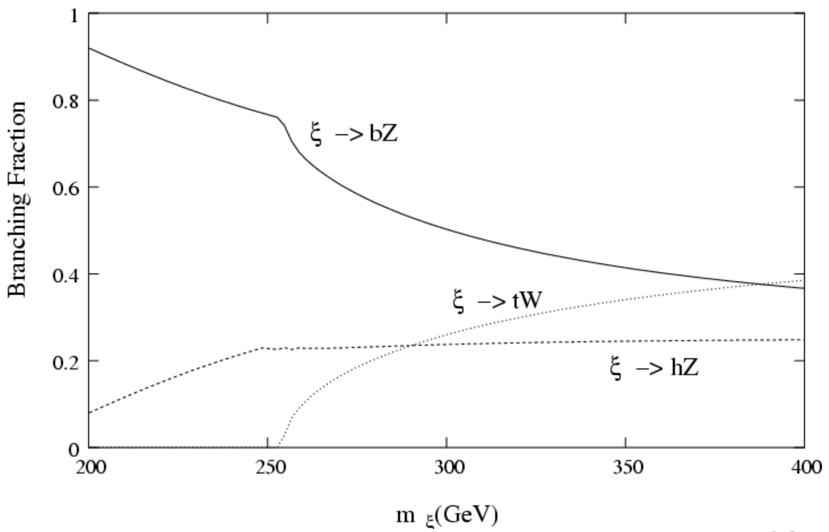


Selected Phenomenology

- Collider signatures for the exotic quarks: χ (top-like), and ω, and ζ (bottom-like).
- χ decays into b W, looks like t'. (Run II limits are close to m_t).
- ω usually is too close in mass for $W\chi$, but can decay into Zb and Hb (depending on m_h).
- ζ generally decays into Zb, Hb, or Wt.
- The low masses preferred can be hopefully done by the end of run II, or easily at LHC. LHC or LC may be needed to carefully measure parameters and verify the scenario.
- Higgs phenomenology is also interesting, and has many implications.
- For example, the bottom mass may arise mostly from the mixing, and thus the bottom Yukawa may be suppressed, allowing exotic H decays to compete more effectively for intermediate m_h.

D Morrissey, C Wagner **PRD69, 053001 (2004)**





Conclusions

- The precision EW data shows an interesting tension between A^{FB}_b and the rest of the observables. In the SM, since we don't know the Higgs mass today, this is realized as both observables preferring a different m_h.
- The deviations preferred if A^{FB}_b is a real effect are large and point to tree level effects such as the mixing between bottom and some exotic vector quarks.
- A global fit prefers light masses for the vector quarks, implying relevant phenomenology at Tevatron and LHC, and modifications of Higgs physics.
- Amazingly enough, these ingredients vastly improve the SM prediction for the (non-) unification of couplings at high scales.
- Many open questions remain:
  - Imbedding in a model already doing something else?
  - Electroweak symmetry breaking?
  - Expanded flavor including the vector quarks?
  - Hierarchy problem?
  - Other quark representations?